TASK 3B REPORT
WATER RESOURCES
CUMULATIVE IMPACT ASSESSMENT
WATER QUALITY AND CHANNEL STABILITY

Prepared in support of:

Powder River Basin Coal Review

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EXECUTIVE SUMMARY

The Task 3B component of the PRB Coal Review provides an assessment of the water resources cumulative impact associated with future levels of coal mining, coal mine dewatering, coal bed natural gas (CBNG) groundwater withdrawal and subsequent surface disposal of groundwater, surface disposal of groundwater by coal mines and conventional oil and gas wells. The information contained herein focuses on the cumulative impacts to surface water resources from surface discharge of groundwater by CBNG development and coal mine dewatering. Specifically, impacts related to water quality and channel stability are addressed. The study area and subwatersheds included in the surface water impact assessment are presented in **Figure ES. 1-1**.

Completion of the work associated with Task 3B relied on information and data provided in the PRB Coal Review Task 1 and Task 2 Reports. The Task 1 Report provides the basis for the resource-specific descriptions of current conditions within the study area. Past and present activities identified in the Task 1 Report are based on the most recent data available at the end of 2003. The Task 2 Report defines the past and present development actions within the study that have contributed to the current environmental and socioeconomic conditions in the PRB study area. The Task 2 Report also defines the Reasonably Foreseeable Development (RFD) scenarios in the Wyoming and Montana PRB for years 2010, 2015, and 2020. The RFD scenarios presented in the Task 2 Report provide the basis for the analysis of potential cumulative impacts to surface water resources in the Task 3 component of the PRB Coal Review.

ES.1 METHODOLOGY FOR WATER QUALITY EVALUATION

The cumulative impact assessment addresses current conditions (2003) and three future RFD scenarios for years 2010, 2015, and 2020. Based on the information developed in support of the assessment and documented in the Task 1B Report (ENSR, 2005a) and Task 2 Report (ENSR, 2005b), the impacts have been addressed on a subwatershed basis. The subwatersheds associated with the work effort are presented in **Figure ES.1-1.**

ES.1.1 Evaluation Parameters

Key water quality parameters for predicting the potential effects of CBNG development focused on the suitability of surface water for irrigated agriculture. Consequently, sodium adsorption ratio, or SAR, and salinity, measured by electrical conductivity or EC, were utilized for the prediction. Most restrictive and least restrictive regulatory standards for EC and SAR applicable to the subwatersheds were developed and utilized in the cumulative impact assessment. The

limits presented in **Table ES.1-1** were utilized during the comparison of EC and SAR values for resulting mixtures of existing streamflows and discharges from CBNG wells under various flow conditions and RFD projections for the years 2010, 2015 and 2020.

Table ES.1-1 Summary of Proposed Limits for SAR and EC

Subwatershed	Most Restrictive Proposed Limit (MRPL)		Least Restrictive Proposed Limit (LRPL)	
	SAR	EC (µS/cm)	SAR	EC (µS/cm)
Little Powder	5	2,000	9.75	2,500
Powder	5	2,000	9.75	2,500
Belle Fourche	6	2,000	10	2,500
Cheyenne, Antelope Creek	10	2,000	10	2,500

Source: Wyoming DEQ, Montana DEQ, and South Dakota Legislative Council.

The Ayers and Westcot (1985) irrigation suitability diagram was utilized to compare water quality before and after mixing with discharges from CBNG wells.

ES.1.2 Surface Water Quality Model

The surface water model utilized during the completion of the technical report (Greystone Environmental Consultants, Inc. and ALL Consulting; January 2003) in support of the Power River Basin Oil and Gas EIS (BLM, 2003a) was utilized for the cumulative impact assessment. This spreadsheet model employs a steady-state, mass-balance approach to estimate steady-state concentrations of EC and SAR after two or more inflows are mixed.

Input parameters to the spreadsheet model include the items listed below.

- Estimated CBNG Well Production Water (mmgpy)
- CBNG Well Production Water SAR
- CBNG Well Production Water EC (µS/cm)
- Channel Loss (%)
- Subwatershed Streamflow (acre-feet)
- Subwatershed Streamflow SAR
- Subwatershed Streamflow EC (µS/cm)

The operational aspects of the modeling procedure are itemized below.

1. Monthly estimates of CBNG groundwater discharged into the receiving channel are obtained from the data base.
2. The CBNG groundwater discharged to the receiving channel are reduced through conveyance losses to determine an estimate for the CBNG groundwater discharged to the receiving surface water source.
3. Monthly estimates of streamflow for the surface water source are obtained from the database. Two hydrologic conditions were evaluated; a dry year study period and a normal year study period. The dry year analysis was utilized to evaluate the maximum likely impacts to surface water quality, assuming limited flow in the receiving streams.
4. Water quality data (SAR and EC) for both the CBNG groundwater discharge and the receiving drainage are obtained from the data base.
5. A mixing analysis is completed using a simple flow-weighted mass balance equation with the input data associated with CBNG groundwater discharge and water quality data and streamflow and water quality data from the surface water source.
6. Monthly estimates of stream water quality before and after mixing with the CBNG groundwater are determined to support a comparative evaluation of EC and SAR and also plotted on the Ayers-Westcot diagram to ascertain the impact on water for irrigation.

ES.2 IMPACTS TO WATER QUALITY

The projected impacts to water quality from the discharge associated with CBNG development in each subwatershed were graphically evaluated with the data obtained from the surface water modeling results. The graphs depict the projected impact for the current conditions (2003) and each of three future RFD scenarios for years 2010, 2015, and 2020.

As indicated previously, the impacts to water quality on the receiving drainages assumed two hydrologic conditions; dry-year conditions and normal-year conditions. The impact analysis was conducted using monthly flows and comparatively evaluated the water quality parameters (SAR and EC) of the receiving drainage before and after mixing with discharge water generated by the CBNG wells within the watershed. In general, the water discharged from the CBNG wells reflected increased levels of SAR and reduced levels of EC compared to the water quality of the receiving drainages. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality also focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

The results of the water quality analyses are summarized in **Tables ES.2-1** and **Table ES.2-2**. Several observations can be made regarding the overall effects of mixing CBNG well production water with surface water within the study area. These general observations are discussed in the following paragraphs.

Table ES.2-1 Water Quality Results (Normal Year)

Item	Existing Condition (Before Mixing)	2003 (After Mixing)	2010 (After Mixing)	2015 (After Mixing)	2020 (After Mixing)
Antelope Creek					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increased	Increased	Increased	Increased
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Sept-Feb, June)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	Exceeds EC (Jan, Oct, Nov) Exceeds SAR (Aug-Jan)	EC OK (Except Jan) Exceeds SAR (Aug-Jan)	Exceeds EC (Oct-Jan) Exceeds SAR (Sep-Jan)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	Same (No CBNG Discharge)
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	≅ CBNG Discharge	Same	Same	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Except July-Sep, Dec)	Exceeds EC (Except Jul-Sep)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Upper Powder River					
EC	≅ CBNG Discharge	Slight Decrease	Slight Decrease	Slight Decrease	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slight Increase	Slight Increase	Slight Increase	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR (Except May-Jun)	Exceeds EC (Except May, Jun) Exceeds SAR (Except May, Jun)	Same (No CBNG Discharge)
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Same (No CBNG Discharge)
Little Powder River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Slight Increase	Slight Increase	Slight Increase	Slight Increase
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Except Mar, May) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar, May) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)
LRPL	Exceeds EC (Aug, Sept, Nov-Jan)	Exceeds EC (Jan, Aug)	Exceeds EC (Jan, Aug)	Exceeds EC (Aug, Sep, Nov, Dec, Jan)	Exceeds EC (Aug, Sep, Nov, Dec, Jan)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	OK	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)

1. Irrigation results reflect suitability of water for irrigation during the irrigation season

Table ES.2-2 Water Quality Results (Dry Year)

Item	Existing Condition (Before Mixing)	2003 (After Mixing)	2010 (After Mixing)	2015 (After Mixing)	2020 (After Mixing)
Antelope Creek					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increased	Increased	Increased	Increased
Irrigation (1)	Suitable	Suitable (Except June, Aug)	Suitable (Except June, Aug)	Suitable (Except June, Aug)	Suitable (Except June, Aug)
MRPL	Exceeds EC (Sept-Feb, June)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Same (No CBNG Discharge)
Irrigation (1)	Unsuitable (Aug-Oct)	Unsuitable (Sep, Oct)	Unsuitable (Aug-Oct)	Unsuitable (Oct)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	Exceeds SAR (Exc. Feb, Mar, May, July)	Exceeds SAR (Exc. Mar, July)	Exceeds SAR (Aug-Jan)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	Same (No CBNG Discharge
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	≅ CBNG Discharge	Slight Increase (July-Octt)	Slight Increase (July-Oct)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Suitable	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except July, Aug)	Exceeds EC (Except Aug)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Except Jul-Sep)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Upper Powder River					
EC	≅ CBNG Discharge	Same	Slightly Decreases	Slightly Decreases	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slight Increase	Increased	Increased	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR	Exceeds EC (Except May, Jun) Exceeds SAR	Exceeds EC (Except May, Jun) Exceeds SAR (Except May, Jun)	Same (No CBNG Discharge)
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Same (No CBNG Discharge
Little Powder River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increase	Increase	Increase	Increase
Irrigation (1)	Suitable	Suitable (Except Sept-Oct)	Suitable (Except Sept-Oct)	Suitable	Suitable
MRPL	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Feb, Apr, June, Aug) Exceeds SAR	Exceeds EC (Feb, Apr, June, Aug) Exceeds SAR	Exceeds EC (Except Mar, May, Jul, Sep, Oct) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)
LRPL	Exceeds EC (Aug, Sep, Nov-Jan)	Exceeds SAR (Sept)	Exceeds SAR (Sept)	Exceeds EC (Aug)	Exceeds EC (Jan, Aug, Nov, Dec)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	OK	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)

1. Irrigation results reflect suitability of water for irrigation during the irrigation season

ES.2.1 Current Surface Water Quality Conditions

With respect to the Most Restrictive Proposed Limit (MRPL) and the Least Restrictive Proposed Limit (LRPL) for the impact analysis, several of the surface water sources currently exceed the MRPL during many months of the years. Specific observations related to the water quality of the surface water sources are listed below.

- The surface water in the Upper Powder River exceeds the MRPL for both EC and SAR throughout the majority of the year. Levels of SAR are less than the LRPL while EC values generally exceed the LRPL the latter half of the year (July through December).
- The surface water in both Antelope Creek and the Dry Fork Cheyenne River exceeds the MRPL for EC during the low-flow months from September through February and also June. Levels of EC are typically less than the LRPL. The SAR values are relatively low and do not exceed the MRPL.
- The surface water in the Little Powder River exceeds the MRPL for EC and SAR throughout the majority of the year and exceeds the LRPL for EC during the low flow months of August, September and November through January. SAR levels remain below the LRPL throughout the year.
- The surface water in the Upper Cheyenne River exceeds the MRPL for EC for ten months of the year and exceeds the LRPL nine months of the year. The surface water does not exceed the MRPL for SAR.
- The surface water in the Upper Belle Fourche River exceeds the MRPL for EC during the low-flow months from September through January. Levels of EC are less than the LRPL with the exception of November through January. The SAR values are relatively low but tend to exceed the MRPL from November through January while meeting the LRPL throughout the year.

ES.2.2 Mixed Water Quality Conditions

Specific observations related to the MRPL and LRPL following mixing with CBNG well production water are provided below. The observations are related to the scenario that results in the highest contribution of CBNG well production water to the surface water source thereby maximizing the potential impact associated with the CBNG well production water. These conditions are typically reflected during the dry year; consequently, the observations discussed below reflect dry-year conditions.

- The surface water in the Upper Powder River demonstrates a minimal reduction in EC and a minor increase in SAR. These results reflect the relatively small

contribution of CBNG well production water to the much larger flows in Upper Powder River. EC values continue to exceed the MRPL throughout the majority of the year (July through April) and the LRPL from July through December. SAR values exceed the MRPL throughout the year while meeting the LRPL.

- The surface water in Antelope Creek reflect a reduction in EC that meets the MRPL throughout the year. Levels of SAR are increased but continue to meet the MRPL. This observation largely reflects the lack of surface water in these streams coupled with the relatively low values for EC and elevated SAR in the CBNG well production water.
- No CBNG well production water is contributed to the Dry Fork Cheyenne River. Consequently, the water quality in this surface water source remains the same as the current conditions (2003).
- The surface water in the Little Powder River reflects a reduction in EC but continues to exceed the MRPL four or more months of the year and exceed the LRPL from one (2003, 2010, 2015) to four (2020) months of the year. The SAR values reflect an increase and exceed the MRPL ten or more months of the year, and exceed the LRPL one (2003, 2010) month of the year.
- The surface water in the Upper Cheyenne River reflects a minor reduction in EC but continues to exceed the MRPL for ten or more months of the year and the LRPL for eight or more months of the year. A minimal increase in SAR is realized and the surface water continues to meet the MRPL.
- The surface water in the Upper Belle Fourche River reflects a reduction in EC that meets the MRPL throughout the year. The SAR values reflect a slight increase and tend to exceed the MRPL six or more months of the year while meeting the LRPL throughout the year.

ES.2.3 Observations Related to EC

The EC associated with the surface water sources is typically higher than the EC associated with the CBNG well production water. Consequently, the simple mixing approach utilized during the evaluation results in a reduction or improvement in EC after mixing with CBNG production water. In every instance, the most significant reduction in EC correlates to those scenarios (current conditions or RFD Scenarios) that involve the largest contribution of CBNG water to the receiving stream. This trend is amplified during time periods when surface water flows are reduced in the stream as confirmed by the results of the dry-year analysis. With the exception of the Upper Powder River, this observation was consistent for all surface water sources evaluated during this study. Within the Upper Powder River, the EC associated with the CBNG well production water was the most elevated and similar to the EC of the surface water.

ES.2.4 Observations Related to SAR

The SAR associated with the surface water sources is typically lower than the SAR associated with the CBNG well production water. Similar to the evaluation of EC, the simple mixing approach utilized during the evaluation will generally result in an increase in SAR after mixing with CBNG production water. The most significant increase in SAR correlates to those scenarios (current conditions or RFD Scenarios) that involve the largest contribution of CBNG water to the receiving stream. This trend is amplified during time periods when surface water flows are reduced in the stream as confirmed by the results of the dry-year analysis. With the exception of Upper Cheyenne River, this observation was consistent for all surface water sources evaluated during this study. Within the Upper Cheyenne River, the SAR associated with the CBNG well production water was similar to the SAR of the surface water.

ES.2.5 Observations Related to Irrigation Suitability

The suitability of the mixed water for irrigation purposes is also related to EC and SAR. The analysis for irrigation suitability relied solely on utilization of the Ayers Westcot Diagram. In general, the water most suitable for irrigation consists of a source with relatively low SAR and relatively high EC. Elevated SAR values may reduce permeability in clayey soils thereby reducing the rate of water infiltration. This relationship in EC and SAR is depicted in the Ayers Westcot Diagram in terms of the suitability of water sources for irrigation purposes. In those instances where the SAR is significantly increased and the EC is moderately low, the water source was considered unsuitable. This observation was specifically noted in the surface water sources associated with Antelope Creek, Little Power River and Upper Belle Fourche River. For these streams, the results demonstrated adequate suitability for irrigation during the normal year conditions and unsuitable water sources during a portion, or the entire irrigation season, during the dry-year conditions. These streams also demonstrated a reduced level of EC compared to the Upper Cheyenne River and the Upper Powder River. In general, the increased levels of SAR in the CBNG well production water directly relates to the reduction in the suitability of the water for irrigation purposes in streams receiving a large component of CBNG discharge. In general, this trend is amplified for all streams during periods when CBNG well production water represents the majority of the flows available for irrigation purposes.

ES.3 IMPACTS TO CHANNEL STABILITY

The cumulative impact assessment includes an evaluation of channel stability with respect to the surface water resources within the study area. In general, the impacts to channel stability largely

relate to the water quantity associated with the discharges from current or projected coal mining activities, CBNG wells or conventional oil and gas wells compared to the runoff characteristics of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages.

Given the limited data available to assess channel stability, quantification of the impacts becomes problematic. To the maximum extent possible, the impact to perennial drainages is addressed on a quantitative basis, at the subwatershed level, using regression equations related to discharge and channel width. To support this evaluation in consideration of the limited data, geomorphic relationships have been utilized to provide a qualitative assessment of the impacts associated with the production of CBNG discharge water. These relationships provided a qualitative assessment of the response of the receiving drainages to an increase in discharge provided by the introduction of CBNG well production water.

ES.3.1 Evaluation of Perennial Streams

Examination of United States Geological Survey (USGS) records for the Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500) and the Little Powder River above Dry Creek, near Weston, Wyoming (USGS Gage 06324970) provided the basis of the evaluation of perennial streams. For these two perennial streams, a hydraulic geometry relationship was developed that related channel width as a function of discharge. The hydraulic geometry relationships were developed from all data classified as good (G) by the USGS during the data collection efforts. Using the relationships developed, channel width in the range of the channel forming discharge was computed for the existing condition and for the maximum CBNG well production condition by adding the predicted CBNG discharge to the existing condition discharge **(Table ES.3-1)**. The estimated change in width for the Little Powder River was computed to be less than 0.3%, and was less than 0.2% for the Belle Fourche River. These results suggest that for the larger, perennial streams the effect of the CBNG well production water will be minimal.

From a qualitative standpoint, the geomorphic relationships also provide insight into the potential impacts of the CBNG production water on the mean annual discharge events. Applying the geomorphic relationships to the existing data resulted in the following observations:

- An increase in mean annual discharge may result in potential increases in channel width, depth, and meander wavelength while a decrease in channel gradient may occur.
- An increase in mean annual discharge may result in an increase in bed material transport or median particle size of the bed material.

Table ES.3-1 Impact of CBNG Production Water on Perennial Streams

Location	Channel Forming Discharge [1] (cfs)	CBNG Discharge		Estimated Width		Potential Impact [Increased Width]	
		(cfs)	(%)	Existing Conditions (ft)	Combined Discharge (ft)	(ft)	(%)
Little Powder River above Dry Creek near Weston, Wyoming (USGS Gage 06324970)	270 to 420	2.2	0.5% to 0.8%	47.3 to 56.3	47.4 to 56.4	0.15 to 0.12	0.3%
Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500)	652 to 789	3.9	0.5% to 0.6%	66.9 to 72.1	67.0 to 72.2	0.16 to 0.14	0.2%

[1] Discharge associated with the 1.5 to 2 year recurrence interval.

Given the relatively low increase in mean annual discharge, these trends predicted by the geomorphic relationships are considered to be imperceptible.

ES.3.2 Evaluation of Ephemeral Streams

Limited data on streamflows is available for the smaller, ephemeral drainage channels within the study area that may receive discharges from the CBNG wells. Furthermore, the data related to the predicted CBNG well production water is provided on a subwatershed basis. However, it is reasonable to assume that the CBNG well production water will represent a much higher percentage of the mean annual discharges in some of the ephemeral drainages within the study area. Consequently, the impacts to channel stability will be more readily apparent in ephemeral drainages and may be manifested by an increase in channel erosion, headcutting, and incision.

The discharge of CBNG well production water into the ephemeral drainages may initiate or exacerbate erosion within the conveyance channel. Should erosion be initiated, given the relatively minor flow compared to the typical gully section in the typical ephemeral drainage channel, it is anticipated that a small incision may occur. One must also consider that the sustained nature of the CBNB well production water may also generate and support an increase in diversity and density of the vegetation along the channel. The increase in vegetation may tend

to prevent channel erosion or partially stabilize existing erosion within the ephemeral drainage channel.

Similar to the perennial stream channels, the geomorphic relationships were utilized to provide insight into the potential impacts of the CBNG production water on the mean annual discharge events associated with the ephemeral drainages. Applying the geomorphic relationships to the ephemeral drainage systems provided the following observations:

- Given that the relative magnitude of the increase in mean annual discharge is more significant in the ephemeral drainage channel, it is likely that potential increases in channel width and depth will occur along with local reductions in channel slope.
- Again, an increase in mean annual discharge may reduce channel gradient or result in an increase in bed material transport or median particle size of the bed material.

Given the potentially significant increase in mean annual discharge, these trends predicted by the geomorphic relationships are more likely to occur, especially considering that the increases attributable to the CBNG production water are sustained discharges.

Due to the potential for erosion in the ephemeral drainages, it may be prudent to establish a monitoring and management plan on selected drainages prior to the discharge of CBNG production water. Where erosion is evident from the visual inspection and evaluation of the data, methods to mitigate the erosion should be considered. Mitigation measures may include placement of small grade control structures at locations of active erosion and headcutting.

Ephemeral drainage channels that are presently experiencing active headcutting and erosion should be identified. Monitoring of the erosion should be conducted as specified above. Where erosion of the channel is considered significant, mitigation measures should be implemented and the channel stabilized. Mitigation measures identified in the Draft EIS for the Seminoe Road Natural Gas Development Project (BLM, 2005) may be worthy of consideration and include grade control structures, check dams, impact basins, channel reconstruction, and other possible engineered erosion control measures.

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1.0 INTRODUCTION

The Powder River Basin (PRB) of Wyoming and Montana is a major energy development area with diverse environmental values. The PRB is the largest coal-producing region in the United States (U.S.); PRB coal is used to generate electricity both within and outside the region. The PRB also has and continues to produce large quantities of oil and natural gas resources. Within the last decade, this region has experienced nationally significant development of natural gas from coal seams.

This PRB Coal Review is a regional technical study to assess cumulative impacts associated with past, present, and reasonably foreseeable development (RFD) in the PRB. For purposes of this study, the Wyoming portion of the PRB study area (**Figure 1-1**) comprises all of Campbell County, all of Sheridan and Johnson counties less the Bighorn National Forest lands to the west of the PRB, and the northern portion of Converse County. It includes all of the area administered by the Bureau of Land Management (BLM) Buffalo Field Office, a portion of the area administered by the BLM Casper Field Office, and a portion of the Thunder Basin National Grasslands (TBNG), which is administered by the U.S. Department of Agriculture, Forest Service (FS) (**Figure 1-2**). The Montana portion of the PRB study area (**Figure 1-1**) comprises the area of relevant coal mines and the air quality study area and includes the lands administered by the BLM Miles City Field Office (**Figure 1-2**).

The Task 3B component of the PRB Coal Review provides an assessment of the water resources cumulative impact associated with future levels of coal mining, coal mine dewatering, coal bed natural gas (CBNG) groundwater withdrawal and subsequent surface disposal of groundwater, surface disposal of groundwater by coal mines and conventional oil and gas wells. This report focuses on the cumulative impacts to surface water resources from surface discharge of groundwater by CBNG development and coal mine dewatering. Specifically, impacts related to water quality and channel stability are addressed. The study area and subwatersheds included in the surface water impact assessment are presented in **Figure 1-3**. It should be noted that the database developed in support of this work was structured using 4th level sub-basins as a common denominator. However, the 4th level sub-basins are referred to as subwatersheds in this study for consistency with the PRB Oil and Gas Environmental Impact Statement (EIS) (BLM 2003a).

Completion of the work associated with Task 3B relied on information and data provided in the PRB Coal Review Task 1 and Task 2 reports. The Task 1 report provides the basis for the resource-specific descriptions of current conditions within the study area. Past and present activities identified in the Task 1 report are based on the most recent data available at the end of

2003. The Task 2 report defines the past and present development actions within the study that have contributed to the current environmental and socioeconomic conditions in the PRB study area. The Task 2 report also defines the RFD scenarios in the Wyoming and Montana PRB for years 2010, 2015, and 2020. The RFD scenarios presented in the Task 2 report provide the basis for the analysis of potential cumulative impacts to surface water resources in the Task 3 component of the PRB Coal Review.

The methodology used to assess the cumulative impact of current conditions and the RFD scenarios is summarized in Chapter 2.0. The projected impacts on water quality associated with future levels of coal mining, coal mine dewatering, coal bed natural gas groundwater withdrawal, and surface disposal of groundwater by coal mines is presented in Chapter 3.0. Chapter 4.0 presents projected impacts on channel stability. Documentation pertinent to the cumulative impact assessment is provided in technical appendices attached to the report.

2.0 METHODOLOGY FOR WATER QUALITY EVALUATION

2.1 General

The cumulative impact assessment addresses current conditions (2003) and three future RFD scenarios for years 2010, 2015, and 2020. Based on the information developed in support of the assessment and documented in the Task 1B Report (ENSR, 2005a) and Task 2 Report (ENSR, 2005b), the impacts have been addressed on a subwatershed basis. The subwatersheds associated with the work effort are presented in **Figure 1-3** and include:

- Antelope Creek
- Dry Fork Cheyenne River
- Little Powder River
- Upper Belle Fourche River
- Upper Cheyenne River
- Upper Powder River

As stated previously, the assessment focuses on the cumulative impacts to water quality and channel stability with respect to the surface water resources within the study area. In general, the impacts directly relate to the water quantity and quality associated with the discharges from current or projected coal mining activities, CBNG wells or conventional oil and gas wells compared to the water quantity and quality of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages. Based on a review of the data available in the Task 1 and Task 2 reports, it is assumed that the production water discharged directly to the receiving drainages is limited to CBNG wells. In general, the existing data reflects that water production from coal mining activities is largely consumed on site. Water production from conventional oil and gas wells typically requires treatment to meet water quality standards associated with the NPDES permitting requirements.

2.2 Water Quality

Potential impacts to surface water quality associated with proposed CBNG development were evaluated during completion of the Powder River Basin Oil & Gas EIS (BLM, 2003a) and

documented in a supporting technical report (Greystone Environmental Consultants, Inc. and ALL Consulting; January 2003). Key water quality parameters for predicting the potential effects of CBNG development focused on the suitability of surface water for irrigated agriculture. Consequently, sodium adsorption ratio, or SAR, and salinity, measured by electrical conductivity or EC, were utilized for the prediction. The impact assessment documented in this report utilizes the same water quality parameters and involves a similar evaluation.

2.2.1 Evaluation Criteria

Table 2.2-1 summarizes the most restrictive and least restrictive regulatory standards for EC and SAR applicable to the subwatersheds addressed in the cumulative impact assessment. This information was obtained from several sources including the Wyoming Department of Environmental Quality, Montana Department of Environmental Quality, and South Dakota Legislative Council. The limits presented in **Table 2.2-1** were utilized during the comparison of EC and SAR values for resulting mixtures of existing streamflows and discharges from CBNG wells under various flow conditions and RFD projections for the years 2010, 2015 and 2020.

Table 2.2-1 Summary of Proposed Limits for SAR and EC

Subwatershed	Most Restrictive Proposed Limit (MRPL)		Least Restrictive Proposed Limit (LRPL)	
	SAR	EC (µS/cm)	SAR	EC (µS/cm)
Little Powder	5	2,000	9.75	2,500
Powder	5	2,000	9.75	2,500
Belle Fourche	6	2,000	10	2,500
Cheyenne, Antelope Creek	10	2,000	10	2,500

Source: Wyoming DEQ Water Quality Rules and Regulations (2006), Montana DEQ Water Quality Standards of Classification (2006), and South Dakota Legislative Council Administrative Rules (2004).

With respect to the information provided in **Table 2.2-1**, the Wyoming Department of Environmental Quality (WDEQ) applies numeric water quality standards for EC and SAR that were adopted for water bodies downstream in South Dakota. Specifically, these standards apply to the Upper Belle Fourche River, Antelope Creek, Upper Cheyenne River, and Dry Fork Cheyenne River. In March of 2003, the Montana Board of Environmental Review adopted numeric standards for EC and SAR for surface water sources. These standards apply to the Little Powder River and Upper Powder River.

2.2.2 Irrigation Suitability Diagram

The Ayers and Westcot (1985) irrigation suitability diagram (also referred to as the "Hanson Diagram"; Hanson, Grattan, Fulton, 1999) was used to compare water quality before and after mixing with discharges from CBNG wells. The diagonal line on the diagram is used as the no-impact threshold for SAR and EC values of the water. Water quality would be expected to cause "no reduction in the rate of infiltration" as a result of dispersion of soils by SAR below and to the right of the irrigation threshold line (Ayers and Westcot, 1985). Alternatively, waters located to the left and above the threshold line for irrigation would be likely to cause slight to moderate reduction in the rate of infiltration (Ayers and Westcot, 1985).

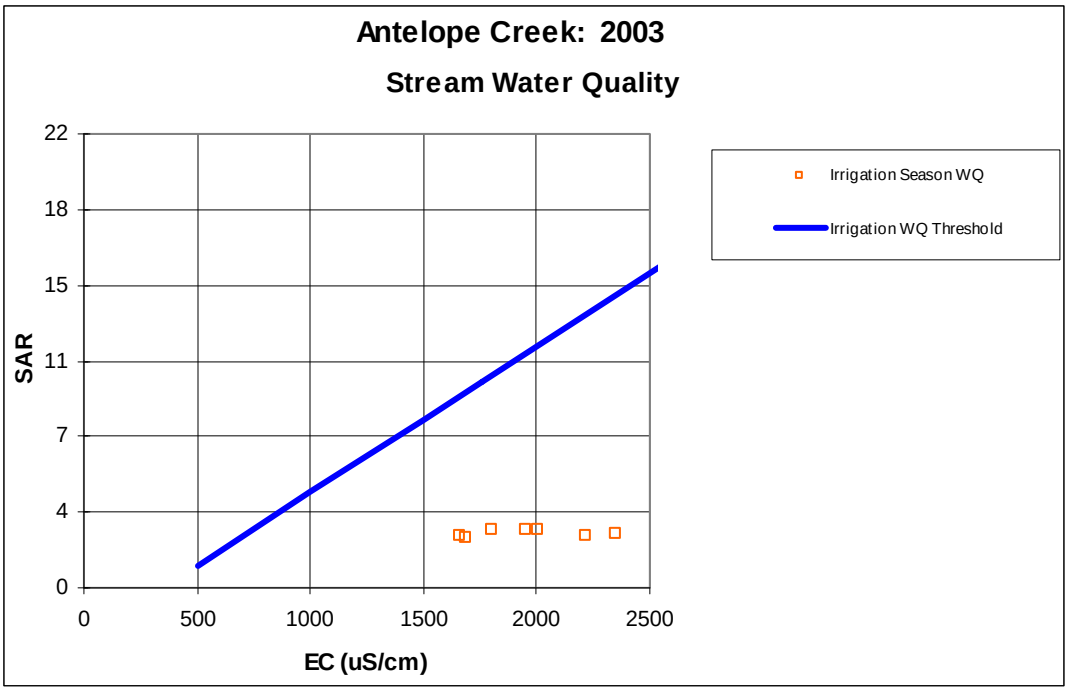
This EC/SAR relationship in the Ayers Westcot irrigation suitability diagram is utilized to determine the effect of irrigation waters on the infiltration capacity of soils. Elevated SAR values may reduce the permeability in clayey soils, consequently reducing the infiltration rate. It should be noted that the significance of the effects associated with a reduction in infiltration rate varies with soil type, and increases on clay and clay-loam soils. In addition, the EC/SAR relationship typically indicates that as salinity increases, the potential impacts of SAR decrease; however this relationship should not be applied without limits. The potential impact of rainfall on sodic soils can cause SAR problems by significantly lowering of the EC with little change in the SAR. An attempt to address this potential problem, along with the inherent variability in soils, is made through the application of an absolute maximum SAR during the analysis.

Figure 2.2-1 illustrates utilization of the Ayers and Westcot irrigation suitability diagram for the existing stream water quality (2003 current conditions) associated with Antelope Creek. As indicated in **Figure 2.2-1**, the existing water quality in Antelope Creek appears to be suitable for irrigation.

2.2.3 Surface Water Quality Model

The surface water model utilized during the completion of the technical report (Greystone Environmental Consultants, Inc. and ALL Consulting; January 2003) in support of the Power River Basin Oil and Gas EIS (BLM, 2003a) was utilized for the cumulative impact assessment. This spreadsheet model employs a steady-state, mass-balance approach to estimate steady-state concentrations of EC and SAR after two or more inflows are mixed.

Figure 2.2-1



Input parameters to the spreadsheet model are described below.

- Estimated CBNG Well Production Water (mmgpy)
- CBNG Well Production Water SAR
- CBNG Well Production Water EC (µS/cm)
- Channel Loss (%)
- Subwatershed Streamflow (acre-feet)
- Subwatershed Streamflow SAR
- Subwatershed Streamflow EC (µS/cm)

The mixing analysis integrated into the spreadsheet model is described in detail in **Appendix A**; this information was obtained from the technical report prepared by Greystone Environmental Consultants, Inc. and ALL Consulting (January 2003). A summary of the input data used during the impact analysis for surface water quality is presented in **Appendix B**. The results of the spreadsheet modeling are presented in **Appendix C**.

The operational aspects of the modeling procedure are itemized below.

1. Monthly estimates of CBNG groundwater discharged into the receiving channel are obtained from the data base.
2. The CBNG groundwater discharged to the receiving channel are reduced through conveyance losses to determine an estimate for the CBNG groundwater discharged to the receiving surface water source.
3. Monthly estimates of streamflow for the surface water source are obtained from the data base.
4. Water quality data (SAR and EC) for both the CBNG groundwater discharge and the receiving drainage are obtained from the data base.
5. A mixing analysis is completed using a simple flow-weighted mass balance equation with the input data associated with CBNG groundwater discharge and water quality data and streamflow and water quality data from the surface water source.
6. Monthly estimates of stream water quality before and after mixing with the CBNG groundwater are determined to support a comparative evaluation of EC and SAR and also plotted on the Ayers-Westcot diagram to ascertain the impact on the suitability of water for irrigation.

The following assumptions were incorporated into the approach to the water quality modeling. Many of these assumptions are similar to those described in the technical report prepared by Greystone Environmental Consultants, Inc. and ALL Consulting (January 2003) and are included herein:

- Assuming SAR behaves as a single constituent of water, mixed SAR was estimated using a simple flow-weighted mass balance equation. As indicated in Appendix A, this assumption results in an overestimation of SAR and, potentially, of impacts by a factor of 2.
- Impacts to the receiving streams were evaluated for hydrologic conditions associated with relatively dry years as well as normal or average years. The dry year analysis evaluated the maximum likely impacts to surface water quality.
- The model assumed complete mixing. Impacts to surface water quality may be greater than are predicted in the mixing zone near the points of discharge.
- A typical value of channel loss was used in the model. This value would under-predict the impacts to surface water quality if discharge were piped directly to the receiving stream or if the discharge point is very close to the receiving stream.

- Irrigation suitability was evaluated on the basis of the Ayers Westcot Diagram and was determined to be either suitable or unsuitable on the basis of the threshold diagonal line within the diagram. Numeric water quality standards were not utilized to determine irrigation suitability.

2.2.3.1 Stream Flow

Average monthly and annual flows at pertinent gauging stations for the major drainages within each subwatershed were obtained from the Powder/Tongue River Basin Water Plan (HKM Engineering, et al.; 2002a) and the Northeast Wyoming River Basins Water Plan (HKM Engineering, et al.; 2002b). The development of the streamflow data relied on historic streamflow gaging data to the maximum extent possible. The subwatersheds identified in this study, however, are characterized by a scarcity of historic streamflow records. Consequently, it was necessary to develop streamflow data at several locations within the study area. The methodology used to collect the historic records of streamflow, establish a study period, and to extend or fill-in the streamflow data where records are unavailable, has been summarized in the basin plans previously referenced (HKM Engineering, et. al.; 2002a and 2002b). **Appendix D** provides the technical memoranda describing the methodology and results of the surface water hydrology development utilized during this water quality assessment.

The documentation in **Appendix D** provides insight into the availability of existing streamflow data, synthesis of data and selection of the study period. For both basin plans, it was determined that a consistent approach should be utilized to develop streamflow data that reflects water availability at various locations within the watershed. The study period selected for the basin plans extended from 1970 to 1999. This study period contains extended periods of dry years including some of the driest years of record as well as periods of normal and wet hydrologic conditions. This period also has the greatest abundance of recorded streamflow data and ditch diversion data; consequently, less data synthesis was required. Based on the evaluation of the approach and information contained in the technical memoranda, it was determined that the most consistent streamflow data available to support the water quality evaluation was contained in the basin planning reports.

As described in the technical memoranda in **Appendix D**, surface water hydrology data was developed to represent dry year, normal year, and wet year hydrologic conditions. Consequently, the annual streamflows developed in the basin planning effort were ranked and divided into these three hydrologic categories. The years of the study period with non-exceedance probabilities of 20 percent or less (the driest 20 percent) were selected as dry years.

Similarly, the years with exceedance probabilities of 20 percent or less (the wettest 20 percent) were selected as wet years. The remaining 60 percent of the years represent normal years.

The impact analysis was conducted assuming two hydrologic conditions; a dry year study period and a normal year study period. The dry year analysis was utilized to evaluate the maximum likely impacts to surface water quality, assuming limited flow in the receiving streams.

2.2.3.2 Stream Water Quality

EC and SAR values for the streams within the study area were identical to the values used in the technical report (Greystone Environmental Consultants, Inc. and ALL Consulting; January 2003) in support of the Power River Basin Oil and Gas EIS (BLM, 2003a). It should be noted that limited data was available to characterize the water quality in the Dry Fork Cheyenne River. Consequently, the data available for the neighboring subwatershed, Antelope Creek, was utilized for the water quality impact analysis.

2.2.3.3 CBNG Well Production Water

Production water from existing and projected CBNG wells was obtained from the Task 2 Report for the Powder River Basin Coal Review (ENSR, October 2005). Sources for this data included, but were not limited to, an oil and gas production and well history database by IHS Energy Services (IHS, 2004) and a data provided by the Wyoming Oil and Gas Conservation Commission (WOGCC, 2004; 2005a; 2005b). This information is summarized in the data tables included in **Appendix B**.

2.2.3.4 CBNG Well Production Water Quality

EC and SAR values for the production water associated with the CBNG wells in the study area were documented in the technical report (Greystone Environmental Consultants, Inc. and ALL Consulting; January 2003) in support of the Power River Basin Oil and Gas EIS (BLM, 2003a). In addition, the Wyoming DEQ/WQD provided pertinent, and more recent water quality data from a Microsoft Access data base relevant to the effluent water quality from CBNG wells in all watersheds with the exception of Antelope Creek and Dry Fork Cheyenne River. The water quality data obtained from both of these sources was reviewed and utilized to describe the water quality associated with the CBNG well production water in this modeling effort. **Appendix B** presents the results of the analysis related to CBNG discharge water quality.

2.2.3.5 Managed Water Loss

The Powder River Basin Oil and Gas EIS (BLM, 2003a) assumed water produced from CBNG wells and managed through containment, land application disposal (LAD) and injection would not have direct effects on quality and quantity of surface water because none of the discharge water would reach drainages in the subwatersheds under these water handling options. The percentage of CBNG well production water managed through these options is referred to as Managed Water Loss (MWL). The percentage of CBNG production water included in the MWL varies between subwatersheds and is presented in **Table 2.2-2**. It should be noted that all CBNG water discharged directly into the drainages may ultimately be consumptively utilized by downstream water users. Based on the profile of water users within the subwatersheds, it is likely that this water will be utilized for irrigation purposes.

Table 2.2-2 Percent of Total Water Production from CBNG Wells per Discharge Method

Subwatershed	Untreated Discharge into Drainages	Passive Treatment	Active Treatment	Infiltration Impoundment	Containment Impoundment	LAD	Injection
Upper Powder River	35	0	10	40	5	5	5
Little Powder River	45	0	0	30	10	10	5
Antelope Creek	55	0	0	35	5	0	5
Upper Cheyenne River	55	0	0	35	5	0	5
Dry Fork Cheyenne River	55	0	0	35	5	0	5
Upper Belle Fourche River	45	0	0	40	5	0	10

Source: ENSR, October 2005

2.2.3.6 Conveyance Loss

Information contained in the Task 1 Report for the Powder River Basin Coal Review (ENSR, 2005) indicated the following:

"Studies conducted by the BLM (2003a) have shown that conveyance losses for direct discharge to drainages are approximately 70 to 90 percent, depending on the time of year. Evaporation losses, which are a large component of conveyance losses, can be 80 percent during the summer months in Wyoming. Thus, most CBNG discharge water either infiltrates or evaporates within a few miles of the discharge outfall and generally is not recorded at USGS stream gauging stations. Impacts to surface water flow and quality are thus limited to within a few miles of the discharge outfall and, as of 2002, have not been recorded by the network of USGS gauging stations."

Conveyance losses will vary by subwatershed as a function of the total CBNG water discharged to the channel, soils, slope of the channel, type of drainage (ephemeral versus perennial), cover/vegetation within the channel, time of year, etc. However, given the variability of these parameters within each subwatershed, a conveyance loss of 70 percent was selected for the water quality assessment and modeling effort. Based on the existing information, this estimate of conveyance loss is considered a conservative value that results in identification of the maximum impact of CBNG water on the water quality of the receiving drainages.

3.0 IMPACTS TO WATER QUALITY

The projected impacts to water quality from the discharge associated with CBNG development in each subwatershed are described in this chapter. Three graphs are utilized to depict the projected impact for the current conditions (2003) and each of three future RFD scenarios for years 2010, 2015, and 2020. These graphs include:

- illustration of EC for mean monthly flows before and after mixing with projected CBNG discharges;
- illustration of SAR for mean monthly flows before and after mixing with projected CBNG discharges; and an
- illustration of projected water quality (for irrigation purposes) for mean monthly flows for both EC and SAR in relation to the Ayers-Westcot EC-SAR threshold.

The first two graphs include lines depicting the LRPL and MRPL to facilitate evaluation of the impacts. With respect to the third graph, water quality that meets the proposed EC and SAR limits as well as the Ayers-Westcot threshold should fall to the left of the proposed EC limit, below the proposed SAR limit and below and to the right of the diagonal line on the graphs.

As indicated in Chapter 2, the impacts to water quality on the receiving drainages assumed two hydrologic conditions; dry-year conditions and normal-year conditions. The impact analysis was conducted using monthly flows and comparatively evaluated the water quality parameters (SAR and EC) of the receiving drainage before and after mixing with discharge water generated by the CBNG wells within the watershed. In general, the water discharged from the CBNG wells reflected increased levels of SAR and reduced levels of EC compared to the water quality of the receiving drainages. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions. Detailed results of the comparative evaluation all monthly flows associated with the dry-year and normal-year hydrologic conditions are presented in Appendix C.

3.1 Antelope Creek

Results of the impacts to water quality in the Antelope Creek subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.1-1**. **Table 3.1-1**

reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.1-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow for each RFD scenario. As noted above, impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

Table 3.1-1 Surface Water Impact Analysis of the Antelope Creek Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	10[1]	2000[1]	10[2]	2500[2]	0.31	2.79	2372	1.21	6.38	1299
2010	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.41	6.55	1247
2015	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.51	6.62	1226
2020	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.31	6.47	1271
Dry Year										
2003	10[1]	2000[1]	10[2]	2500[2]	0.13	2.79	2005	1.03	7.01	1065
2010	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.23	7.11	1043
2015	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.33	7.14	1035
2020	10[1]	2000[1]	10[2]	2500[2]	---	---	---	1.13	7.06	1053

[1] Wyoming DEQ

[2] South Dakota's Legislative Council

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The peak CBNG discharge in the watershed is realized for RFD Scenario 2015 when 1.20 cfs is conveyed into Antelope Creek. The quantity of water discharged into Antelope Creek would be less in the other RFD scenarios and would consequently result in a reduction in impacts to the existing water quality. For RFD Scenario 2015, the dry-year hydrologic conditions presented in **Table 3.1-1** illustrate the impacts associated with mixing 0.13 cfs of streamflow in Antelope Creek with 1.20 cfs of CBNG well discharge water on both SAR and EC. After the flows mix,

the resultant streamflow consists almost entirely of CBNG produced water. The resulting EC would decrease, whereas the SAR would increase compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 1.33 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to be adequate to meet the MRPL and LRPL for both SAR and EC.

3.1.1 Antelope Creek: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.1-1, 3.1-2, 3.1-3, 3.1-4, 3.1-5 and 3.1-6**. The information in these figures reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For the current conditions (2003), the observations presented below are based on the information presented in these figures.

- Before Mixing. Mean monthly EC values in Antelope Creek currently exceed the MRPL during low-flow conditions (September through February), and in June but are less than the LRPL for both the dry year and normal year. Mean monthly SAR values are currently less than the MRPL and LRPL for SAR under similar hydrologic conditions. The Ayers and Westcot diagram indicates that the water in Antelope Creek is suitable for irrigation during all months in both hydrologic conditions prior to mixing with the CBNG discharge water.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year. The resultant SAR values increase but continue to meet the LRPL and MRPL for SAR for both hydrologic conditions.
- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, primarily for the months of June and August during the irrigation season when the water becomes unsuitable for irrigation. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation.

3.1.2 Antelope Creek: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.1-1, 3.1-2, 3.1-3, 3.1-4, 3.1-5 and 3.1-6**. The information in these figures

reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For RFD Scenario 2010, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.1.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year. The resultant SAR values increase but continue to meet the LRPL and MRPL for SAR for both hydrologic conditions.
- Ayers and Westcot Diagram. For dry-year conditions, the data indicated a significant reduction in infiltration throughout the irrigation season following mixing with CBNG production water but remains suitable for irrigation except for June and August. Under normal-year conditions, a decrease in infiltration is realized following mixing with CBNG production water; overall, however, the data indicates that the mixed water is suitable for irrigation.

3.1.3 Antelope Creek: RFD Scenario 2015 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.1-1, 3.1-2, 3.1-3, 3.1-4, 3.1-5 and 3.1-6**. For RFD Scenario 2015, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.1.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year. The resultant SAR values increase but continue to meet the LRPL and MRPL for SAR for both hydrologic conditions.
- Ayers and Westcot Diagram. For dry-year conditions, the data continued to indicate a significant reduction in infiltration throughout the irrigation season following mixing with CBNG production water but remains suitable for irrigation except for June and August. Under normal-year conditions, a decrease in infiltration is realized following mixing with CBNG production water; overall, however, the data generally indicates that the mixed water remains suitable for irrigation during the irrigation season.

3.1.4 Antelope Creek: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.1-1, 3.1-2, 3.1-3 and 3.1-4, 3.1-5 and 3.1-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.1.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year. The resultant SAR values increase but continue to meet the LRPL and MRPL for SAR for both hydrologic conditions.
- Ayers and Westcot Diagram. For dry-year conditions, the data continued to indicate a significant reduction in infiltration throughout the irrigation season following mixing with CBNG production water but remains suitable for irrigation except for June and August. Under normal-year conditions, a decrease in infiltration is realized following mixing with CBNG production water; overall, however, the data generally indicates that the mixed water is suitable for irrigation.

3.2 Dry Fork Cheyenne River

Results of the impacts to water quality in the Dry Fork Cheyenne River subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.2-1**. **Table 3.2-1** reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year and normal-year hydrologic conditions. As stated previously, the information in **Table 3.2-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow in the Dry Fork Cheyenne River for each RFD scenario. As noted above, impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions. For the Dry Fork Cheyenne River, the minimum monthly flow for both hydrologic conditions is zero (0) cfs and occurs for several months of the year during the dry-year condition.

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a

decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

Table 3.2-1 Surface Water Impact Analysis of the Dry Fork Cheyenne River Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	0	---	---	0.00	---	---
2010	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---
2015	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---
2020	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---
Dry Year										
2003	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	0	---	---	0.00	---	---
2010	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---
2015	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---
2020	10[(1)]	2000[(1)]	10[(1)]	2500[(1)]	---	---	---	0.00	---	---

[(1)] Wyoming DEQ

There is no expected discharge of CBNG water to the Dry Fork Cheyenne River in the RFD Scenarios for 2010, 2015, and 2020. Thus, water quality is expected to be similar to the base year (2003) water quality.

3.2.1 Dry Fork Cheyenne River: Current and RFD Conditions (2003, 2010, 2015, 2020)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.2-1, 3.2-2, 3.2-3, 3.2-4, 3.2-5 and 3.2-6**. No CBNG production water is included in the evaluation of current conditions (2003) since no wells have been identified that discharge to the Dry Fork Cheyenne River. No CBNG discharge is expected in any of the RFD Scenarios (2010, 2015, 2020), thus no water quality impacts should be encountered beyond current conditions. Given the information in the referenced figures, the observations presented below represent the existing water quality and all RFD Scenarios in the river for both hydrologic conditions.

- Mean monthly EC values in the Dry Fork Cheyenne River currently exceed the MRPL, during the low flow months of June and from September through February. All mean monthly values meet the LRPL criteria for EC.

- Mean monthly SAR values are currently less than the MRPL and LRPL under similar flow conditions.
- The data obtained from the Ayers and Westcot Diagram for the current conditions indicates that the existing water in the Dry Fork Cheyenne River is suitable for irrigation.

3.3 Little Powder River

Results of the impacts to water quality in the Little Powder River subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.3-1**. **Table 3.3-1** reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year and normal-year hydrologic conditions. As stated previously, the information in **Table 3.3-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow in the Little Powder River for each RFD scenario. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

Table 3.3-1 Surface Water Impact Analysis of the Little Powder River Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	1.05	6.94	3300	2.7	9.08	2219
2010	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	2.5	8.97	2277
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	1.5	7.92	2806
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	1.2	7.25	3144
Dry Year										
2003	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	0.22	6.44	2810	1.8	10	1666
2010	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	1.6	9.94	1686
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	0.6	9.05	1971
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	0.3	7.71	2403

[(1)] Montana DEQ

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or

decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The peak CBNG discharge in the watershed is realized for the current condition (2003) when approximately 1.6 cfs is conveyed into the Little Powder River. The quantity of water discharged into the Little Powder River would be less in all RFD scenarios due to a reduction in CBNG development after 2003 and would consequently result in a reduction in impacts to the existing water quality. For current conditions (2003), the dry-year hydrologic conditions presented in **Table 3.3-1** illustrate the impacts associated with mixing 0.22 cfs (occurring in the month of September) of streamflow in the Little Powder River with 1.6 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resultant streamflow consists almost entirely of CBNG produced water. The resulting EC would decrease by over 1,000 uS/cm, whereas the SAR would increase by approximately 50 percent compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 1.8 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to meet the LRPL and MRPL for EC and exceeds the LRPL and MRPL for SAR.

3.3.1 Little Powder River: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.3-1, 3.3-2, 3.3-3, 3.3-4, 3.3-5 and 3.3-6**. The information in these figures reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For the current conditions (2003), the observations presented below are based on the information presented in these figures.

- Before Mixing. Mean monthly EC values in the Little Powder River currently exceed the MRPL for all months of the year except March, and exceed the LRPL during low-flow conditions in August, September and November through January for both the dry year and normal year. Mean monthly values currently exceed the MRPL for SAR with the exception of March and May and are less than the LRPL for both hydrologic conditions. The Ayers and Westcot diagram indicates that the water in Little Powder River is suitable for irrigation during all months in both hydrologic conditions prior to mixing with the CBNG discharge water.
- Following Mixing. For the normal year, the resultant EC values decrease but continue to exceed the MRPL for EC for all months except March and May and exceed the LRPL

during the low flow months of January and August. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the month of March and are less than the LRPL for the normal year. For the dry year, the EC values continue to decrease but exceed the MRPL during the months of February, April, June and August, and are less than the LRPL for all months. The resultant SAR values during dry years exceed the MRPL for all months and exceed the LRPL during the low flow conditions during the month of September.

- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, and marginal unsuitability for the months of September through October during the irrigation season. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.3.2 Little Powder River: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.3-1, 3.3-2, 3.3-3, 3.3-4, 3.3-5 and 3.3-6**. For RFD Scenario 2010, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.3.1.
- Following Mixing. For the normal year, the resultant EC values decrease but continue to exceed the MRPL for EC for all months except March and May and exceed the LRPL for the months of August and January. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the month of March and are less than the LRPL for the normal year. For the dry year, the EC values continue to decrease but exceed the MRPL during the months of February, April, June and August, and are less than the LRPL for all months. The resultant SAR values exceed the MRPL for all months and exceed the LRPL during the low flow conditions for the month of September .
- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, and the resulting water may be marginally unsuitable for the months of September through October during the irrigation season. Under normal-year conditions, only a minor decrease in infiltration is

realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.3.3 Little Powder River: RFD Scenario 2015 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.3-1, 3.3-2, 3.3-3, 3.3-4, 3.3-5 and 3.3-6**. For RFD Scenario 2015, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.3.1.
- Following Mixing. For the normal year, the resultant EC values decrease but continue to exceed the MRPL for EC for all months except March and exceed the LRPL for the months of August, September, and November through January. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the months of March and May and are less than the LRPL for the normal year. For the dry year, the EC values continue to decrease but exceed the MRPL with the exception of the months of March, May, July, September, and October, and are less than the LRPL for all months except August. The resultant SAR values exceed the MRPL for all months except March and are below the LRPL for all months.
- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, with the water remaining suitable for irrigation. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.3.4 Little Powder River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in Figures **3.3-1, 3.3-2, 3.3-3, 3.3-4, 3.3-5 and 3.3-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.3.1.

- Following Mixing. For the normal year, the resultant EC values decrease but continue to exceed the MRPL for EC for all months except March and exceed the LRPL for the months of August, September, and November through January. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the months of March and May and are less than the LRPL for the normal year. For the dry year, the EC values continue to decrease but exceed the MRPL during all months except March, and exceed the LRPL for January, August, November, and December. The resultant SAR values exceed the MRPL for all months except March and May and are less than the LRPL for the entire dry year.

- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, but continued suitability for irrigation. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.4 Upper Belle Fourche River

Results of the impacts to water quality in the Upper Belle Fourche River subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.4-1**. **Table 3.4-1** reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year and normal-year hydrologic conditions. As stated previously, the information in **Table 3.4-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow in the Upper Belle Fourche River for each RFD scenario. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

Table 3.4-1 Surface Water Impact Analysis of the Upper Belle Fourche River Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	6[1]	2000[2]	10[2]	2500[2]	3.31	6.77	2755	7.61	7.94	1825
2010	6[1]	2000[2]	10[2]	2500[2]	---	---	---	9.71	8.13	1671
2015	6[1]	2000[2]	10[2]	2500[2]	---	---	---	5.41	7.57	2116
2020	6[1]	2000[2]	10[2]	2500[2]	---	---	---	3.31	6.77	2755
Dry Year										
2003	6[1]	2000[2]	10[2]	2500[2]	0.42	5.75	2346	4.72	8.56	1220
2010	6[1]	2000[2]	10[2]	2500[2]	---	---	---	6.82	8.64	1186
2015	6[1]	2000[2]	10[2]	2500[2]	---	---	---	2.52	8.32	1316
2020	6[1]	2000[2]	10[2]	2500[2]	---	---	---	0.42	5.75	2346

[1] South Dakota's Legislative Council

[2] Wyoming DEQ

The peak CBNG discharge in the watershed is realized for year 2010 when 6.4 cfs is conveyed into the Upper Belle Fourche River. The quantity of water discharged into the Upper Belle Fourche River would be less in the other RFD scenarios and would consequently result in a reduction in impacts to the existing water quality. For 2010 conditions, the dry-year hydrologic conditions presented in **Table 3.4-1** illustrate the impacts associated with mixing 0.42 cfs (occurring in the month of October) of streamflow in the Upper Belle Fourche River with 6.40 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resultant streamflow consists almost entirely of CBNG produced water. The resulting EC would decrease, whereas the SAR would increase compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 6.82 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to meet the LRPL and the MRPL for EC while the SAR value exceeds the MRPL and meets the LRPL.

3.4.1 Upper Belle Fourche River: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.4-1, 3.4-2 3.4-3, 3.4-4, 3.4-5 and 3.4-6**. The information in these figures reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For the current conditions (2003), the observations presented below are based on the information presented in these figures.

- Before Mixing. Mean monthly EC values in the Upper Belle Fourche River currently exceed the MRPL from September through January, and exceed the LRPL during low-flow conditions during the months from November through January for both the dry year and normal year. Mean monthly values currently exceed the MRPL for SAR from November through January and are less than the LRPL for both hydrologic conditions. The Ayers and Westcot diagram indicates that the water in Upper Belle Fourche River is suitable for irrigation during all months in both hydrologic conditions prior to mixing with the CBNG discharge water.
- Following Mixing . The resultant EC values decrease sufficiently to meet both the LRPL and MRPL for dry-year conditions and exceed the MRPL during October, November and January for the normal year. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the months of February, March, May and July and are less than the LRPL for the dry year. For the normal year, the resultant SAR values exceed the MRPL from August through January and are less than the LRPL for all months.
- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, and is considered unsuitable for the months of September and October during the irrigation season. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.4.2 Upper Belle Fourche River: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.4-1, 3.4-2, 3.4-3, 3.4-4, 3.4-5 and 3.4-6**. For RFD Scenario 2010, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.4.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet both the LRPL and MRPL for dry-year conditions and exceed the MRPL during January for the normal year. The resultant SAR values increase and exceed the MRPL for SAR with the exception of the months of March and July and are less than the LRPL for the dry year. For the normal year, the resultant SAR values exceed the MRPL from August through January and are less than the LRPL for all months.

- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, and is considered unsuitable for the months of August, September and October during the irrigation season. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.4.3 Upper Belle Fourche River: RFD Scenario 2015 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.4-1, 3.4-2, 3.4-3, 3.4-4, 3.4-5 and 3.4-6**. For RFD Scenario 2015, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.4.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet both the LRPL and MRPL for dry-year conditions and exceed the MRPL during October, November, December, and January for the normal year. The resultant SAR values increase and exceed the MRPL for SAR for the months of August through January and are less than the LRPL for the dry year. For the normal year, the resultant SAR values exceed the MRPL from September through January and are less than the LRPL for all months.
- Ayers and Westcot Diagram. For the dry-year conditions, the data indicate a reduction in infiltration following mixing with CBNG production water, and may be marginally unsuitable for the month of October during the irrigation season. Under normal-year conditions, only a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicates that the mixed water is suitable for irrigation during a normal year.

3.4.4 Upper Belle Fourche River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in Figures **3.4-1, 3.4-2, 3.4-3, 3.4-4, 3.4-5 and 3.4-6**. For RFD scenario 2020, the observations based on the information presented in these figures indicate that no CBNG discharge is expected to reach the stream, thus no water quality impacts should be encountered beyond current conditions (2003; see Section 3.4.1).

3.5 Upper Cheyenne River

Results of the impacts to water quality in the Upper Cheyenne River subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.5-1**. **Table 3.5-1** reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year and normal-year hydrologic conditions. As stated previously, the information in **Table 3.5-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow in the Upper Cheyenne River for each RFD scenario. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

The peak CBNG discharge in the watershed is realized for the current conditions (i.e., 2003) when 0.80 cfs is conveyed into the Upper Cheyenne River. The quantity of water discharged into the Upper Cheyenne River would be less in the other RFD scenarios and would consequently result in a reduction in impacts to the existing water quality. For the dry-year hydrologic conditions for 2003, **Table 3.5-1** illustrates the impacts associated with mixing 0.82 cfs (occurring in the month of August) of streamflow in the Upper Cheyenne River with 0.80 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC would decrease, whereas the SAR would rise approximately 30 percent compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 1.62 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to meet the LRPL and the MRPL for both EC and SAR.

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs. It should be noted that the minimum mean monthly flow for the normal year is less than the minimum mean monthly flow for the dry year. As indicated in **Appendix B** and presented in the technical memorandum in **Appendix D**, the total flow in the Upper Cheyenne River is much less during the dry year, however, the minimum monthly flow during the dry year (occurring in August) is slightly larger than the minimum monthly flow of the normal year (occurring in December).

Table 3.5-1 Surface Water Impact Analysis of the Upper Cheyenne River Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	10[1]	2000[1]	10[1]	2500[1]	0.77	7.39	3405	1.57	7.50	2144
2010	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.07	7.45	2711
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.77	7.39	3405
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.77	7.39	3405
Dry Year										
2003	10[1]	2000[1]	10[1]	2500[1]	0.82	4.82	1972	1.62	6.20	1457
2010	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.12	5.57	1693
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.82	4.82	1972
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.82	4.82	1972

[1] Wyoming DEQ

3.5.1 Upper Cheyenne River: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.5-1, 3.5-2, 3.5-3, 3.5-4, 3.5-5 and 3.5-6**. The information in these figures reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For current conditions (2003), the observations presented below are based on the information presented in these figures.

- Before Mixing. Mean monthly EC values in the Upper Cheyenne River currently exceed the MRPL for all months with the exception of August and exceed the LRPL from October through June for both the dry year and normal year. Mean monthly values for SAR currently are less than the MRPL and LRPL for both hydrologic conditions. The Ayers and Westcot diagram indicates that the water in Upper Cheyenne River is suitable for irrigation during all months in both hydrologic conditions prior to mixing with the CBNG discharge.
- Following Mixing. The resultant EC values slightly decrease but continue to exceed the MRPL for all months with the exception of August in the normal year and both July and August in the dry year. EC values exceed the LRPL during all months except July through September and December for both the normal and the dry year. The resultant

SAR values are similar and remain less than the MRPL and LRPL for both hydrologic conditions.

- Ayers and Westcot Diagram. For both the normal-year and dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water. Overall, the data indicates that the mixed water is suitable for irrigation during both hydrologic conditions.

3.5.2 Upper Cheyenne River: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.5-1, 3.5-2, 3.5-3, 3.5-4, 3.5-5 and 3.5-6**. The observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.5.1.
- Following Mixing. EC exceeds the MRPL for all months except August and exceeds the LRPL for all months except July through September for both normal and dry hydrologic conditions. SAR for both hydrologic conditions is below the LRPL and MRPL.
- Ayers and Westcot Diagram. Both the normal and dry hydrologic conditions show a slight reduction in infiltration, but the mixed water is suitable for irrigation.

3.5.3 Upper Cheyenne River: RFD Scenarios 2015 and 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.5-1, 3.5-2, 3.5-3, 3.5-4, 3.5-5 and 3.5-6**. The observations are based on the information presented in these figures. No CBNG production water is discharged to the stream. Therefore, results are the same as the current conditions before mixing (2003) presented in Section 3.5.1.

3.6 Upper Powder River

Results of the impacts to water quality in the Upper Powder River subwatershed under the current condition and each of the three future RFD scenarios are presented in **Table 3.6-1**. **Table 3.6-1** reflects the results of the impact assessment at minimum mean monthly flow for both the dry-year and normal-year hydrologic conditions. As stated previously, the information

in **Table 3.6-1** is obtained from the results of the spreadsheet model documented in Appendix C and specifically evaluates the impact analysis for the minimum mean monthly flow in the Upper Powder River for each RFD scenario. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality initially focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

The peak CBNG discharge in the watershed is realized for the current conditions (i.e., 2003) when 2.3 cfs is conveyed into the Upper Powder River. The quantity of water discharged into the Upper Powder River would be less in the other RFD scenarios and would consequently result in a reduction in impacts to the existing water quality. For the dry-year hydrologic conditions for 2003, **Table 3.6-1** illustrates the impacts associated with mixing 38.57 cfs (occurring in the month of September) of streamflow in the Upper Powder River with 2.3 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC slightly decreases, whereas the SAR is slightly increased compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 40.87 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to exceed the LRPL and the MRPL for EC and the MRPL for SAR.

Table 3.6-1 Surface Water Impact Analysis of the Upper Powder River Subwatershed

Scenario	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow		
	SAR	EC (uS/cm)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
Normal Year										
2003	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	103.61	6.40	2482	105.91	6.75	2475
2010	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	105.71	6.72	2476
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	104.61	6.56	2479
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	103.61	6.40	2482
Dry Year										
2003	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	38.57	7.83	3400	40.87	8.66	3331
2010	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	40.67	8.59	3337
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	39.57	8.20	3369
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	38.57	7.83	3400

[(1)] Montana DEQ

The existing stream water quality data identify the minimum mean monthly flow (2003) and corresponding EC and SAR data for both the normal and dry years. Typically, the month in which the minimum flows occur varies from the normal and dry years, and generally reflects a

decrease in flow. The baseline (2003) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

3.6.1 Upper Powder River: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.6-1, 3.6-2, 3.6-3, 3.6-4, 3.6-5 and 3.6-6**. The information in these figures reflects the results of the impact assessment for all monthly flows for both the dry-year and normal-year hydrologic conditions. For the current conditions (2003), the observations presented below are based on the information presented in these figures.

- Before Mixing. Mean monthly EC values in the Upper Powder River currently exceed the MRPL for all months with the exception of May and June and exceed the LRPL from July through December for both the dry year and normal year. Mean monthly values for SAR currently exceed the MRPL for all months except May and June and meet the LRPL for both hydrologic conditions. The Ayers and Westcot diagram indicates that the water in Upper Powder River is suitable for irrigation during all months in both hydrologic conditions prior to mixing with the CBNG discharge water.
- Following Mixing. The resultant EC values slightly decrease but continue to exceed the MRPL for all months with the exception of May and June for both the normal year and dry year. EC values continue to exceed the LRPL from July through December for both the dry year and normal year. The resultant SAR values are increased and exceed the MRPL for all months for the dry year, and all months with the exception of May and June for the normal year. SAR values meet the LRPL for both hydrologic conditions.
- Ayers and Westcot Diagram. For both the normal-year and dry-year conditions, the data indicate a very slight reduction in infiltration following mixing with CBNG production water. Overall, the data indicates that the mixed water is suitable for irrigation during both hydrologic conditions.

3.6.2 Upper Powder River: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.6-1, 3.6-2, 3.6-3, 3.6-4, 3.6-5 and 3.6-6**. For RFD Scenario 2010, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.6.1.

- Following Mixing. The resultant EC values slightly decrease but continue to exceed the MRPL for all months with the exception of May and June for both the normal year and dry year. EC values continue to exceed the LRPL from July through December for both the dry year and normal year. The resultant SAR values are increased and exceed the MRPL for all months in the dry year and all except May and June in the normal year. SAR values are below the LRPL for all months in both the normal and dry years .

- Ayers and Westcot Diagram. For both the normal-year and dry-year conditions, the data indicate a slight reduction in infiltration following mixing with CBNG production water. Overall, the data indicate that the mixed water is suitable for irrigation during both hydrologic conditions.

3.6.3 Upper Powder River: RFD Scenario 2015 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.6-1, 3.6-2, 3.6-3, 3.6-4, 3.6-5 and 3.6-6**. For RFD Scenario 2015, the observations presented below are based on the information presented in these figures.

- Before Mixing. Same as the current conditions (2003) presented in Section 3.6.1.

- Following Mixing. The resultant EC values slightly decrease but continue to exceed the MRPL for all months with the exception of May and June for both the normal year and dry year. EC values continue to exceed the LRPL from July through December for both the dry year and normal year. The resultant SAR values are increased and exceed the MRPL for all months except May and June in the normal and dry years. SAR values meet the LRPL for both hydrologic conditions.

- Ayers and Westcot Diagram. For both the normal-year and dry-year conditions, the data indicate a slight reduction in infiltration following mixing with CBNG production water. Overall, the data indicates that the mixed water is suitable for irrigation during both hydrologic conditions.

3.6.4 Upper Powder River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.6-1, 3.6-2, 3.6-3, 3.6-4, 3.6-5 and 3.6-6**. The observations are based on the information presented in these figures. No CBNG production water is discharged to the stream. Therefore, results are the same as the current conditions before mixing (2003) presented in Section 3.6.1.

3.7 Sensitivity Analysis

A sensitivity analysis was conducted on the CBNG well discharge data (EC and SAR) provided by the Wyoming DEQ/WQD. The approach to the sensitivity analysis is described below.

- A statistical evaluation was conducted to determine the mean value and 95% confidence intervals associated with the monthly data for each EC and SAR data set.
- The spreadsheet model (water quality mixing) was utilized and iterated with the mean value and the upper and lower values associated within the 95% confidence interval for the CBNG discharge data to determine the mixed water quality.
- The difference (as a percentage) was computed between the mixed "mean" water quality and the water quality predicted for the upper and lower values within the 95% confidence interval.

The results of the sensitivity analysis are presented in Appendix C. In general, the results are summarized below.

- In the Dry Fork Cheyenne River, no CBNG production water occurs.
- In the Little Powder River, the maximum difference in the predicted values for EC was determined to be 0.82%. The maximum difference in predicted values for SAR was determined to be approximately 4.74%.
- In the Upper Cheyenne River, the maximum difference in the predicted values for EC was determined to be 0.71%. The maximum difference in predicted values for SAR was determined to be approximately 6.5%.

- In the Upper Powder River, the maximum difference in the predicted values for EC was determined to be 0.03%. The maximum difference in predicted values for SAR was determined to be approximately 0.62%.
- In the Upper Belle Fourche River, the maximum difference in the predicted values for EC was determined to be 0.60%. The maximum difference in predicted values for SAR was determined to be approximately 4.25%.
- In Antelope Creek, the maximum difference in the predicted values for EC was determined to be 1.82%. The maximum difference in predicted values for SAR was determined to be approximately 10.28%.

3.8 Summary

The impacts to water quality on the receiving drainages assumed two hydrologic conditions; dry-year conditions and normal-year conditions. The impact analysis was conducted using monthly flows and comparatively evaluated the water quality parameters (SAR and EC) of the receiving drainage before and after mixing with discharge water generated by the CBNG wells within the watershed. In general, the water discharged from the CBNG wells reflected increased levels of SAR and reduced levels of EC compared to the water quality of the receiving drainages. Impacts to water quality are likely to be maximized during the low flow months; consequently, the comparative evaluation of water quality also focused on the minimum monthly flow associated with the dry-year and normal-year conditions.

The results of the water quality analyses are summarized in **Table 3.8-1** and **Table 3.8-2**. Several observations can be made regarding the overall effects of mixing CBNG well production water with surface water within the study area. These general observations are discussed in the following paragraphs.

Table 3.8-1 Water Quality Results (Normal Year)

Item	Existing Condition (Before Mixing)	2003 (After Mixing)	2010 (After Mixing)	2015 (After Mixing)	2020 (After Mixing)
Antelope Creek					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increased	Increased	Increased	Increased
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Sept-Feb, June)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	Exceeds EC (Jan, Oct, Nov) Exceeds SAR (Aug-Jan)	EC OK (Except Jan) Exceeds SAR (Aug-Jan)	Exceeds EC (Oct-Jan) Exceeds SAR (Sep-Jan)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	Same (No CBNG Discharge)
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	≅ CBNG Discharge	Same	Same	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Jan-June, Oct)	Exceeds EC (Except Jul – Sep)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Upper Powder River					
EC	≅ CBNG Discharge	Slight Decrease	Slight Decrease	Slight Decrease	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slight Increase	Slight Increase	Slight Increase	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR (Except May-Jun)	Exceeds EC (Except May, Jun) Exceeds SAR (Except May, Jun)	Same (No CBNG Discharge)
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Same (No CBNG Discharge)
Little Powder River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Slight Increase	Slight Increase	Slight Increase	Slight Increase
Irrigation[1]	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Except Mar, May) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar, May) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)
LRPL	Exceeds EC (Aug, Sept, Nov-Jan)	Exceeds EC (Jan, Aug)	Exceeds EC (Jan, Aug)	Exceeds EC (Aug, Sep, Nov, Dec, Jan)	Exceeds EC (Aug, Sep, Nov, Dec, Jan)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation[1]	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	OK	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)

1. Irrigation results reflect suitability of water for irrigation during the irrigation season

Table 3.8-2 Water Quality Results (Dry Year)

Item	Existing Condition (Before Mixing)	2003 (After Mixing)	2010 (After Mixing)	2015 (After Mixing)	2020 (After Mixing)
Antelope Creek					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increased	Increased	Increased	Increased
Irrigation (1)	Suitable	Suitable (Except June, Aug)	Suitable (Except June, Aug)	Suitable (Except June, Aug)	Suitable (Except June, Aug)
MRPL	Exceeds EC (Sept-Feb, June)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Suitable Except (Sept, Oct)	Unsuitable (Aug-Oct)	Unsuitable (Oct)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	Exceeds SAR (Exc. Feb, Mar, May, July)	Exceeds SAR (Exc. Mar, July)	Exceeds SAR (Aug-Jan)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	Same (No CBNG Discharge
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	≅ CBNG Discharge	Slight Increase (July-Oct)	Slight Increase (July-Oct)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Suitable	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except July, Aug)	Exceeds EC (Except Aug)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Except Jul-Sep)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Upper Powder River					
EC	≅ CBNG Discharge	Slight Decrease	Slight Decrease	Slight Decreases	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Slight Increase	Increased	Slight Increase	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Suitable	Suitable	Suitable	Same (No CBNG Discharge)
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (Except May, Jun) Exceeds SAR	Exceeds EC (Except May, Jun) Exceeds SAR	Exceeds EC (Except May, Jun) Exceeds SAR (Except May, Jun)	Same (No CBNG Discharge)
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Same (No CBNG Discharge
Little Powder River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Increase	Increase	Increase	Increase
Irrigation (1)	Suitable	Suitable (Except Sept-Oct)	Suitable (Except Sept-Oct)	Suitable	Suitable
MRPL	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)	Exceeds EC (Feb, Apr, June, Aug) Exceeds SAR	Exceeds EC (Feb, Apr, June, Aug) Exceeds SAR	Exceeds EC (Except Mar, May, Jul, Sep, Oct) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar) Exceeds SAR (Except Mar, May)
LRPL	Exceeds EC (Aug, Sep, Nov-Jan)	Exceeds SAR (Sept)	Exceeds SAR (Sept)	Exceeds EC (Aug)	Exceeds EC (Jan, Aug, Nov, Dec)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
Irrigation (1)	Suitable	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)
LRPL	OK	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)	Same (No CBNG Discharge)

1. Irrigation results reflect suitability of water for irrigation during the irrigation season

3.8.1 Current Surface Water Quality Conditions

With respect to the Most Restrictive Proposed Limit (MRPL) and the Least Restrictive Proposed Limit (LRPL) for the impact analysis, several of the surface water sources currently (2003, prior to mixing) exceed the MRPL during many months of the years. Specific observations related to the water quality of the surface water sources are listed below.

- The surface water in the Upper Powder River exceeds the MRPL for both EC and SAR throughout the majority of the year. Levels of SAR are less than the LRPL while EC values generally exceed the LRPL the latter half of the year (July through December).
- The surface water in both Antelope Creek and the Dry Fork Cheyenne River exceeds the MRPL for EC during the low-flow months from September through February and also June. Levels of EC are typically less than the LRPL. The SAR values are relatively low and do not exceed the MRPL.
- The surface water in the Little Powder River exceeds the MRPL for EC and SAR throughout the majority of the year and exceeds the LRPL for EC during the low flow months of August, September and November through January. SAR levels remain below the LRPL throughout the year.
- The surface water in the Upper Cheyenne River exceeds the MRPL for EC for ten months of the year and exceeds the LRPL nine months of the year. The surface water does not exceed the MRPL for SAR.
- The surface water in the Upper Belle Fourche River exceeds the MRPL for EC during the low-flow months from September through January. Levels of EC are less than the LRPL with the exception of November through January. The SAR values are relatively low but tend to exceed the MRPL from November through January while meeting the LRPL throughout the year.

3.8.2 Mixed Water Quality Conditions

Specific observations related to the MRPL and LRPL *following mixing* with CBNG well production water are provided below. The observations are related to the scenario that results in the highest contribution of CBNG well production water to the surface water source thereby maximizing the potential impact associated with the CBNG well production water. These conditions are typically reflected during the dry year; consequently, the observations discussed below reflect dry-year conditions.

- The surface water in the Upper Powder River demonstrates a minimal reduction in EC and a minor increase in SAR. These results reflect the relatively small contribution of CBNG well production water to the much larger flows in Upper Powder River. EC values continue to exceed the MRPL throughout the majority of the year (July through April) and the LRPL from July through December. SAR values exceed the MRPL throughout the majority of the year while meeting the LRPL.
- The surface water in Antelope Creek reflects a reduction in EC that meets the MRPL throughout the year. Levels of SAR are increased but continue to meet the MRPL. This observation largely reflects the lack of surface water in these streams coupled with the relatively low values for EC and elevated SAR in the CBNG well production water.
- No CBNG well production water is contributed to the Dry Fork Cheyenne River. Consequently, the water quality in this surface water source remains the same as that described for the current conditions (2003).
- The surface water in the Little Powder River reflects a reduction in EC but continues to exceed the MRPL four or more months of the year and exceed the LRPL from one (2003, 2010, 2015) to four (2020) months of the year. The SAR values reflect an increase and exceed the MRPL ten or more months of the year, and exceed the LRPL one (2003, 2010) month of the year.
- The surface water in the Upper Cheyenne River reflects a minor reduction in EC but continues to exceed the MRPL for ten or more months of the year and the LRPL for eight or more months of the year. A minimal increase in SAR is realized and the surface water continues to meet the MRPL.
- The surface water in the Upper Belle Fourche River reflects a reduction in EC that meets the MRPL throughout the year. The SAR values reflect a slight increase and tend to exceed the MRPL six or more months of the year while meeting the LRPL throughout the year.

3.8.3 Observations Related to EC

The EC associated with the surface water sources is typically higher than the EC associated with the CBNG well production water. Consequently, the simple mixing approach utilized during the evaluation results in a reduction or improvement in EC after mixing with CBNG production water. In every instance, the most significant reduction in EC correlates to those scenarios

(current conditions or RFD Scenarios) that involve the largest contribution of CBNG water to the receiving stream. This trend is amplified during time periods when surface water flows are reduced in the stream as confirmed by the results of the dry-year analysis. With the exception of the Upper Powder River, this observation was consistent for all surface water sources evaluated during this study. Within the Upper Powder River, the EC associated with the CBNG well production water was the most elevated and similar to the EC of the surface water.

3.8.4 Observations Related to SAR

The SAR associated with the surface water sources is typically lower than the SAR associated with the CBNG well production water. Similar to the evaluation of EC, the simple mixing approach utilized during the evaluation will generally result in an increase in SAR after mixing with CBNG production water. The most significant increase in SAR correlates to those scenarios (current conditions or RFD Scenarios) that involve the largest contribution of CBNG water to the receiving stream. This trend is amplified during time periods when surface water flows are reduced in the stream as confirmed by the results of the dry-year analysis. With the exception of Upper Cheyenne River, this observation was consistent for all surface water sources evaluated during this study. Within the Upper Cheyenne River, the SAR associated with the CBNG well production water was similar to the SAR of the surface water.

3.8.5 Observations Related to Irrigation Suitability

The suitability of the mixed water for irrigation purposes is also related to EC and SAR. The analysis for irrigation suitability relied solely on utilization of the Ayers Westcot Diagram. In general, the water most suitable for irrigation consists of a source with relatively low SAR and relatively high EC. Elevated SAR values may reduce permeability in clayey soils thereby reducing the rate of water infiltration. This relationship in EC and SAR is depicted in the Ayers Westcot Diagram in terms of the suitability of water sources for irrigation purposes. In those instances where the SAR is significantly increased and the EC is moderately low, the water source was considered unsuitable. This observation was specifically noted in the surface water sources associated with Antelope Creek, Little Power River and Upper Belle Fourche River. For these streams, the results demonstrated adequate suitability for irrigation during the normal year conditions and unsuitable water sources during a portion, or the entire irrigation season, during the dry-year conditions. These streams also demonstrated a reduced level of EC compared to the Upper Cheyenne River and the Upper Powder River. In general, the increased levels of SAR in the CBNG well production water directly relates to the reduction in the suitability of the water for irrigation purposes in streams receiving a large component of CBNG discharge. In general,

this trend is amplified for all streams during periods when CBNG well production water represents the majority of the flows available for irrigation purposes.

4.0 CHANNEL STABILITY EVALUATION

4.1 General

The cumulative impact assessment includes an evaluation of channel stability with respect to the surface water resources within the study area. In general, the impacts to channel stability largely relate to the water quantity associated with the discharges from current or projected coal mining activities, CBNG wells or conventional oil and gas wells compared to the runoff characteristics of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages. As stated in Chapter 2, based on a review of the data available in the Task 1 and Task 2 reports, it is assumed that the production water discharged directly to the receiving drainages is limited to CBNG wells.

Conducting an evaluation for channel stability in relation to potential changes in the hydrologic regime is a difficult task, especially for semiarid and arid regions. For example, runoff from the tributary watersheds is typically considered the primary factor in channel development. In consideration of the smaller watersheds within the semiarid study area, this runoff may be infrequent and only in response to precipitation events. With respect to the study area, a USGS report (Martin, Naftz, Lowham, and Rankl; 1988) concluded that "the fluvial system currently (1987) is stable. Although some gullying and headcutting is occurring, the processes appear to be related to natural rejuvenation of the basins and generally are of a local nature". Consequently, it is likely that active erosion is occurring in some of the ephemeral drainages (in the form of gullying and headcutting).

Given the limited data available to assess channel stability, quantification of the impacts becomes problematic. To the maximum extent possible, the impact to perennial drainages is addressed on a quantitative basis, at the subwatershed level, using regression equations related to discharge and channel width. To support this evaluation in consideration of the limited data, geomorphic relationships have been utilized to provide a qualitative assessment of the impacts associated with the production of CBNG discharge water. These relationships include the following:

$$Q \sim (b, d, 8)/S \qquad \text{(Schumm, 1977)}$$

where Q represents mean annual discharge
b represents channel width
d represents depth

8 represents meander wavelength, and
S represents channel gradient.

$$Q_s d_{50} \sim Q S \qquad \text{(Lane, 1955)}$$

where Q_s represents bed material load
d_{50} represents median sediment size,
Q represents mean annual discharge, and
S represents channel gradient.

These relationships provided a qualitative assessment of the response of the receiving drainages to an increase in discharge provided by the introduction of CBNG well production water.

4.2 Evaluation of Perennial Streams

Examination of United States Geological Survey (USGS) records for the Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500) and the Little Powder River above Dry Creek, near Weston, Wyoming (USGS Gage 06324970) provided the basis of the evaluation of perennial streams. The daily discharge data for the Little Powder River indicated that zero discharge occurs less than 3% of the days of record, while the daily discharge data for the Belle Fourche River indicate that a zero discharge occurred about 23% of the days of record. Based on the CBNG discharge data presented in Appendix A, the annual streamflow in the Little Powder River and the Belle Fourche River will increase by a maximum of 2.2 cfs and 4.3 cfs, respectively and may essentially eliminate records of zero streamflow.

Figure 4.2-1 and Figure 4.2-2 provide estimates of peak annual discharge recurrence interval for the Little Powder River and Belle Fourche River, respectively. A common range for the channel forming discharge is between the 1.5-year and 2-year recurrence interval. Using this information, the Little Powder River channel forming discharge is estimated to be in the range of 270 to 420 cfs, and the Belle Fourche River channel forming discharge is estimated to be in the range of 652 to 789 cfs.

Figure 4.2-3 and Figure 4.2-4 present a hydraulic geometry relationship for channel width as a function of discharge for the Little Powder River and Belle Fourche River, respectively. The hydraulic geometry relationships were developed from all data classified as good (G) by the USGS during the data collection efforts. For each field measurement, the USGS crew will report a poor, fair, or good rating of the measurement conditions, which may vary depending on ice or

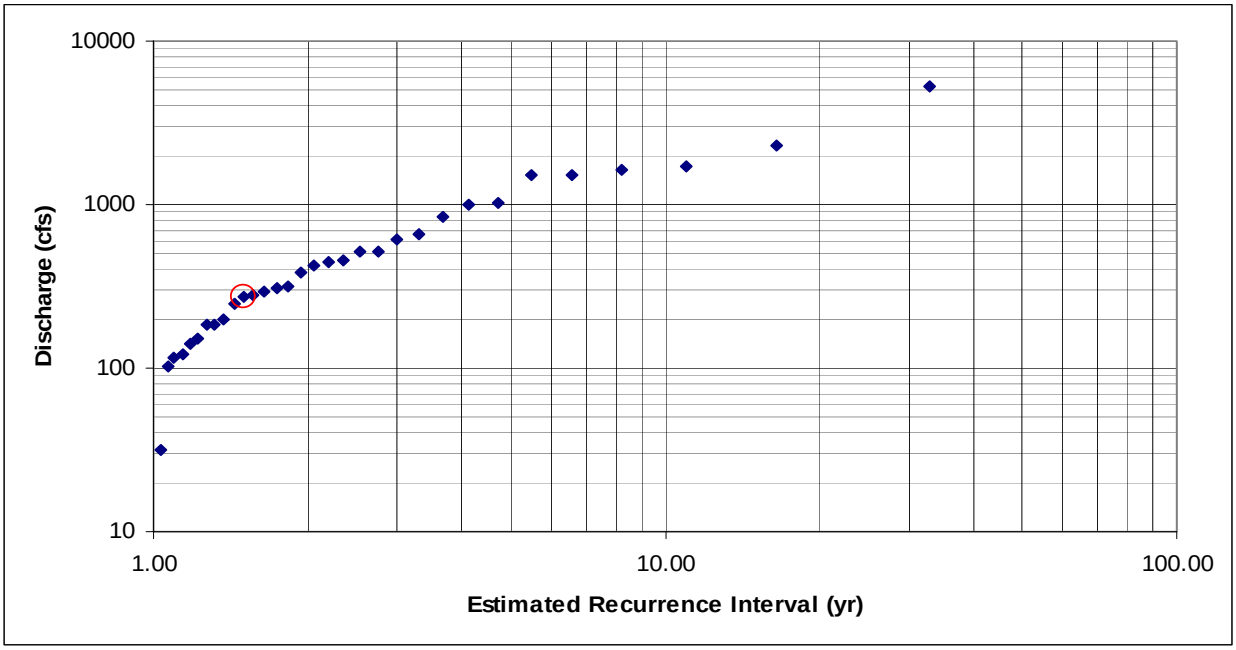


Figure 4.2-1 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Little Powder River.

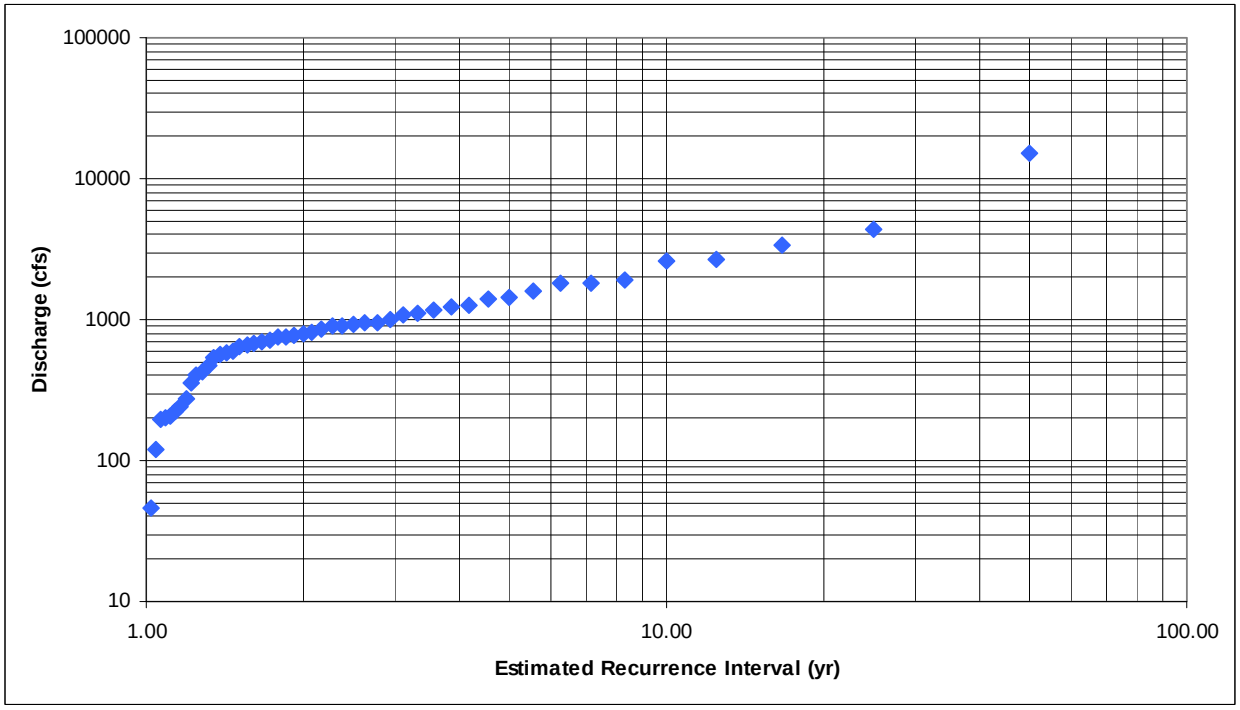


Figure 4.2-2 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Belle Fourche River.

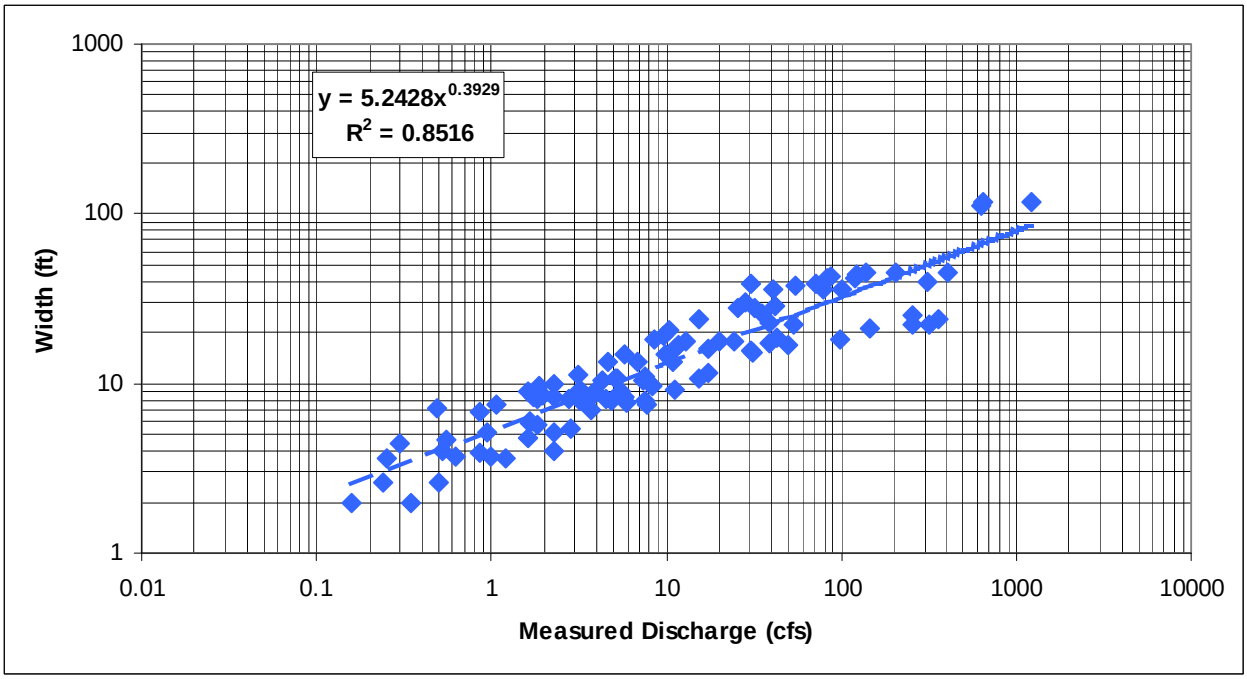


Figure 4.2-3 The Relationship Between Measured Discharge and Channel Width for the Little Powder River.

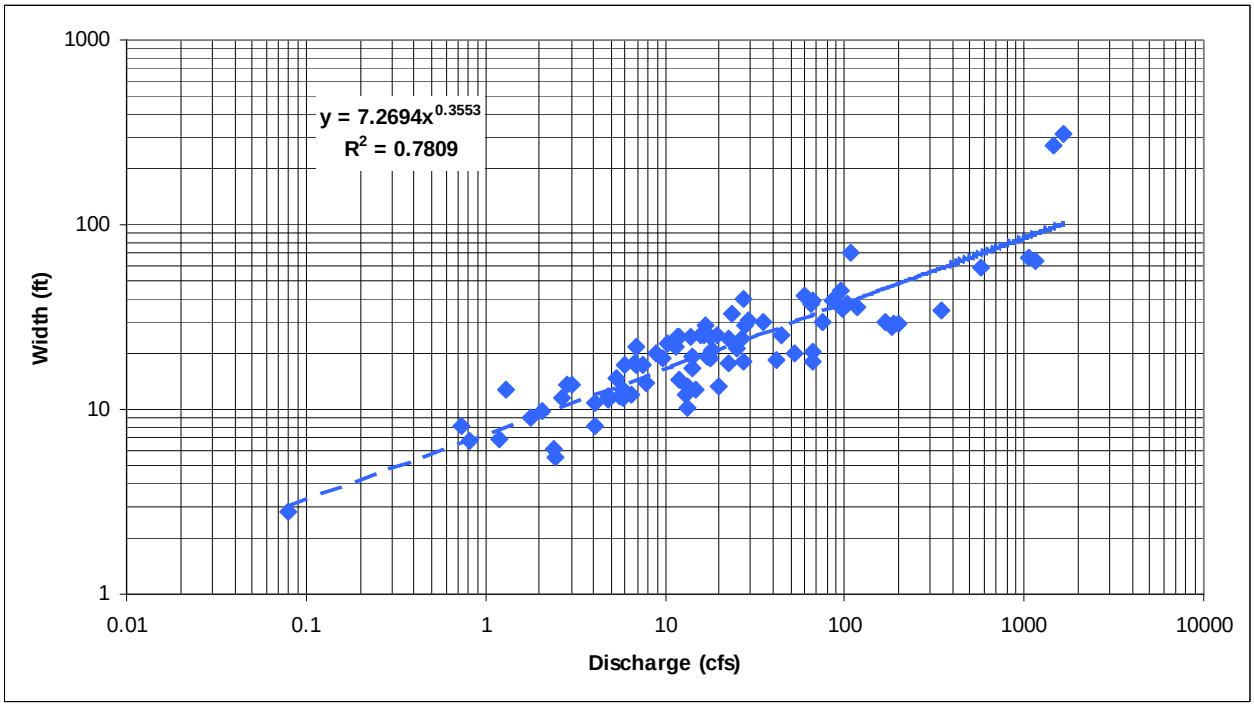


Figure 4.2-4 The Relationship Between Measured Discharge and Channel Width for the Belle Fourche River.

debris accumulation, rapidly changing water levels, or numerous other factors that are beyond control of the field crew. Using the relationships developed, channel width in the range of the channel forming discharge was computed for the existing condition and for the maximum CBNG well production condition by adding the predicted CBNG discharge to the existing condition discharge **(Table 4.2-1)**. The estimated change in width for the Little Powder River was computed to be less than 0.3%, and was less than 0.2% for the Belle Fourche River. These results suggest that for the larger, perennial streams the effect of the CBNG well production water will be minimal.

Table 4.2-1 Impact of CBNG Production Water on Perennial Streams

Location	Channel Forming Discharge [1] (cfs)	CBNG Discharge		Estimated Width		Potential Impact [Increased Width]	
		(cfs)	(%)	Existing Conditions (ft)	Combined Discharge (ft)	(ft)	(%)
Little Powder River above Dry Creek near Weston, Wyoming (USGS Gage 06324970)	270 to 420	2.2	0.5% to 0.8%	47.3 to 56.3	47.4 to 56.4	0.15 to 0.12	0.3%
Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500)	652 to 789	3.9	0.5% to 0.6%	66.9 to 72.1	67.0 to 72.2	0.16 to 0.14	0.2%

[1] Discharge associated with the 1.5 to 2 year recurrence interval.

From a qualitative standpoint, the geomorphic relationships also provide insight into the potential impacts of the CBNG production water on the mean annual discharge events. Increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

This means that an increase in mean annual discharge may result in potential increases in channel width, depth, and meander wavelength while a decrease in channel gradient may occur. With respect to the Lane relationship, increasing the discharge may result in:

$$Q_s^{+} d_{50}^{+} \sim Q^{+} S^{-}$$

The interpretation of this information reveals that an increase in mean annual discharge may reduce channel gradient or result in an increase in bed material transport or median particle size of the bed material. Given the relatively low increase in mean annual discharge, these trends predicted by the geomorphic relationships are considered to be imperceptible.

4.3 Evaluation of Ephemeral Streams

Limited data on streamflows is available for the smaller, ephemeral drainage channels within the study area that may receive discharges from the CBNG wells. Furthermore, the data related to the predicted CBNG well production water is provided on a subwatershed basis. However, it is reasonable to assume that the CBNG well production water will represent a much higher percentage of the mean annual discharges in some of the ephemeral drainages within the study area. Consequently, the impacts to channel stability will be more readily apparent and may be manifested by an increase in channel erosion, headcutting, and incision.

As stated previously, some of the ephemeral channels through which the CBNG production water will be conveyed are actively eroding. Numerous geomorphologic studies have used data developed from different locations to infer landform development through time, commonly employing a technique termed location-for-time substitution. This technique assumes that by observing channel form as one moves downstream along a channel, the effect of physical processes at one location through time can be predicted; that is, changing location is substituted for changing time. This technique was used to develop a Channel Evolution Model (CEM) for Oaklimeter Creek, an incised stream in northern Mississippi (Schumm *et al.* 1981, 1984). Simon and Hupp (1987) later developed a similar model of channel evolution based on Schumm *et al.* (1981, 1984).

The CEM consists of five channel-reach types **(Figure 4.3-1)**, which describe the evolutionary phases typically encountered in an incised channel. These evolutionary phases range from strong disequilibrium to a new state of quasi-equilibrium. Quasi-equilibrium implies that the system is not static and changes through time, but over a period of years the average condition is one of stability. The model is based on the assumption that moving downstream through the system is equivalent to remaining in place and monitoring changes due to the passage of time. The response at any given location in the channel can then be estimated from the morphology of downstream channel locations.

The channel reach types in the CEM are labeled Types I through V, and are assumed to occur consecutively in the downstream direction. The CEM assumes each channel type will occur in turn at a given location as the channel evolves. Type I reaches are located upstream of the actively degrading reach and have not yet experienced significant bed or bank instabilities. These reaches are generally characterized by U-shaped cross sections with little or no recently deposited sediment stored in the channel bed.

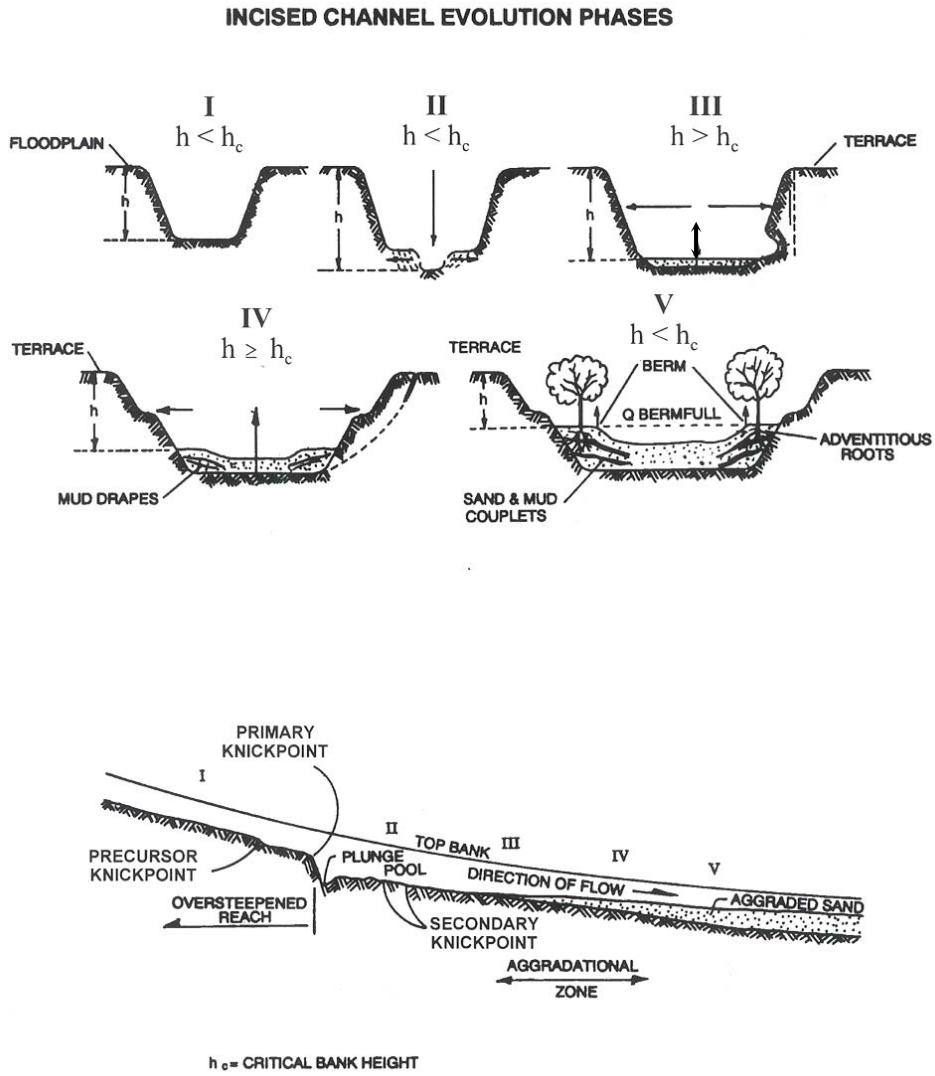


Figure 4.3-1 CEM Channel Types

Type II reaches are encountered immediately downstream of Type I reaches. Bed degradation is the dominant process in the Type II reach. Type II channels are over-steepened reaches where the sediment transport capacity exceeds the sediment supply. Although the channel is actively degrading in a Type II reach, the bank heights (h) do not exceed the critical bank height (h_c) and, therefore, reach-scale geotechnical bank instability is not encountered.

As bed degradation continues, the bank heights and angles continue to increase. When the bank heights exceed the critical bank height for stability in Type III reaches, mass failures

(geotechnical instability) begin. The dominant process in the Type III reach is channel widening. In places, the Type III reach may continue to be slightly degradational. However, the reduced sediment transport capacity resulting from the longitudinal channel slope decreasing combined with increased sediment supply from upstream due to instability and from bank failures within the reach often results in the initiation of sediment deposition on the channel

Type IV reaches are downstream of Type III reaches and represent the first manifestation of the incising channel returning to a new state of dynamic equilibrium. In the Type IV reach, geotechnical bank instabilities and channel widening may continue, but at a much reduced rate. The sediment supply from upstream (Type III) exceeds the sediment transport capacity, resulting in aggradation of the Type IV channel bed. The Type IV reach is also characterized by the development of berms, which are depositional features along margins of the over-widened channel. These berms represent the beginning of a new inner channel with dimensions adjusted to the flow and sediment regime.

Type V reaches represent a state of dynamic equilibrium with a balance between sediment transport capacity and sediment supply. Bank heights in the Type V channel are generally less than the critical bank height and, therefore, reach-scale geotechnical bank instability ceases. However, local bank failures can still exist as part of the meander process, or as the results of constrictions, obstructions, or other local factors. The berms, which were initiated in the Type IV reach have now become colonized by riparian vegetation forming a compound channel within the larger, incised channel. The equilibrium channel of Type V is of a compound shape, with a smaller inner channel bounded by a narrow floodplain. The original floodplain of the Type I channel is now a terrace.

The CEM addresses the channel stability status within a system context. Dynamic equilibrium in a Type V reach simply implies that system stability has been attained. A Type V reach may exhibit considerable erosion that is part of the natural meander process or some other local process, yet still be classified as being in dynamic equilibrium.

The primary value of the CEM sequence is to underpin identification of the evolutionary state of the channel from field reconnaissance. The morphometric characteristics of the channel reach types can also be correlated with hydraulic, geotechnical, and sediment transport parameters (Harvey and Watson 1986; Watson *et al.* 1988). The evolution sequence provides an understanding that while reaches of a stream may differ markedly in appearance, the channel form in one reach is associated with that in adjacent and remote reaches by an evolutionary process.

Fundamentally, the cause for incision (gully formation) is an imbalance between the sediment transport capacity and the sediment supply. For example, urbanization of the watershed increases runoff and increases sediment transport capacity. Urbanization can also decrease the sediment supply from the watershed to the stream, which can also upset the delicate balance. Downstream dredging or channelization decreases the base level and increases transport capacity. Stream sediment transport capacity can be abruptly increased through channelization, an increase in flow velocity or duration as a result of land-use change, or lowering base level. Sediment supplies may be abruptly reduced by sediment trapping in reservoirs, erosion control practices on uplands, and imperviousness. Natural causes such as uplift or subsidence, climate change, and lateral shifting of the stream can also cause the balance to be interrupted.

As stated previously, the discharge of CBNG well production water into the ephemeral drainages may initiate or exacerbate erosion within the conveyance channel. Should erosion be initiated, given the relatively minor flow compared to the typical gully section in the typical ephemeral drainage channel, it is anticipated that a small incision may occur, similar to the CEM Type II model. One must also consider that the sustained nature of the CBNB well production water may also generate and support an increase in diversity and density of the vegetation along the channel. The increase in vegetation may tend to prevent channel erosion or partially stabilize existing erosion within the ephemeral drainage channel.

Similar to the perennial stream channels, the geomorphic relationships were utilized to provide insight into the potential impacts of the CBNG production water on the mean annual discharge events associated with the ephemeral drainages. Increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

Given that the relative magnitude of the increase in mean annual discharge is more significant in the ephemeral drainage channel, it is likely that potential increases in channel width and depth will occur along with local reductions in channel slope. With respect to the Lane relationship (Lane 1955), increasing the discharge may result in the following:

$$Q_s^{+} d_{50}^{+} \sim Q^{+} S^{-}$$

Again, an increase in mean annual discharge may reduce channel gradient or result in an increase in bed material transport or median particle size of the bed material. Given the potentially significant increase in mean annual discharge, these trends predicted by the geomorphic

relationships are more likely to occur, especially considering that the increases attributable to the CBNG production water are sustained discharges.

Due to the potential for erosion in the ephemeral drainages, it may be prudent to establish a monitoring and management plan on selected drainages prior to the discharge of CBNG production water. Where an ephemeral drainage may be impacted, erosion monitoring pins can be installed into the bed and banks of the drainage channel at appropriate locations. The pins are typically driven 3 to 4 feet into the soil leaving about an inch exposed, and subsequent measurements are made of the length of exposed pin. Each erosion pin is located via a GPS; however no survey equipment is typically required. Seasonal measurements will yield a data set that quantifies estimated erosion at each point. Where erosion is evident from the visual inspection and evaluation of the data, methods to mitigate the erosion should be considered. Mitigation measures may include placement of small grade control structures at locations of active erosion and headcutting.

Ephemeral drainage channels that are presently experiencing active headcutting and erosion should be identified. Monitoring of the erosion should be conducted as specified above. Where erosion of the channel is considered significant, mitigation measures should be implemented and the channel stabilized. Mitigation measures identified in the Draft EIS for the Seminoe Road Natural Gas Development Project (BLM, 2005) may be worthy of consideration and include grade control structures, check dams, impact basins, channel reconstruction, and other possible engineered erosion control measures.

4.4 Evaluation of Caballo Creek near Belle Ayr Coal Mine

Following the assessment of the impact associated with CBNG well discharge on channel stability as discussed in the previous sections, the BLM and WDEQ requested an additional investigation be conducted with pertinent hydrologic data from an active coal mine in the Powder River Basin. Consequently, data available for Caballo Creek in the vicinity of the Belle Ayr Coal Mine was obtained, reviewed and utilized to complete the assessment of channel stability. The purpose of the channel stability assessment was to evaluate the impact of increased flows (associated with CBNG well discharge) in Caballo Creek on the existing and reclaimed channels as well as the diversion channels and structures constructed in accordance with the mine permit application.

4.4.1 Pertinent Information and Statistics

The Belle Ayr Coal Mine is located about 12 miles south of Gillette, Wyoming along State Highway 59. A USGS water quality sampling site (USGS 06425800-Caballo Creek near Gillette, Wyoming) is located near the crossing of Caballo Creek and the highway. Pertinent statistics associated with the sampling site include the drainage area of 122 square miles (estimated near the *western* mine permit boundary) and a gage datum that is 4520 feet above sea level NGVD29. At or very near the USGS sampling site is the first of two Caballo Creek stream gages associated with the Belle Ayr Coal Mine. The first stream gage, BA-6, is located near the upstream extent of the mine permit boundary. A second gage, BA-4, is located at the downstream extent of the mine permit boundary. North of Caballo Creek near the western boundary of the mine permit is Bone Pile Creek and Duck Nest Creek. Both of these streams are tributary to Caballo Creek. **Figure 4.4-1** presents a location map illustrating the mine permit boundary along with the existing streams and stream gages.

Information for this investigation was obtained from several documents pertinent to the Belle Ayr Coal Mine. Watershed data were obtained from relevant mine permit documents and specifically included a document entitled "***Reclamation Plan for Portions of Caballo Creek, Belle Ayr Mine, Campbell County, Wyoming"*** (Western Water Consultants, Inc. 1997). The watershed vertical relief is 740 feet from the headwaters to the confluence with the Belle Fouche River, with a mainstream channel length of 51 miles. The basin slope is 0.0056 and the average stream gradient is 0.0027, yielding a sinuosity of about 1.8. The 2-year recurrence interval storm was estimated to range from 400 to 441 cfs for the 200-square mile drainage area (estimated at the *eastern* mine permit boundary). An estimate of flow volume per year at the western mine boundary used by the mine is reported to be 1,300 ac-ft per year. The permit documents classified Caballo Creek as an intermittent stream.

4.4.2 Hydrologic Data

Figure 4.4-2 provides summary information related to gage data at BA-4 and BA-6 for the time period extending from 1984 to 2004. The data portrayed in the graph indicates that discharges in both gages began increasing in about 1992. Conversations with representatives of the Belle Ayr Mine, along with data provided in the Belle Ayr Mine annual reports, indicate that the increases in flow noted at that time were consistent with the production of CBNG well discharge water from wells located within the Caballo Creek, Bone Pile Creek and Duck Nest Creek watersheds. The location of the WYPDES discharge points associated with the CBNG wells and a listing of wells within Belle Ayr Mine permit area were documented in the annual reports.

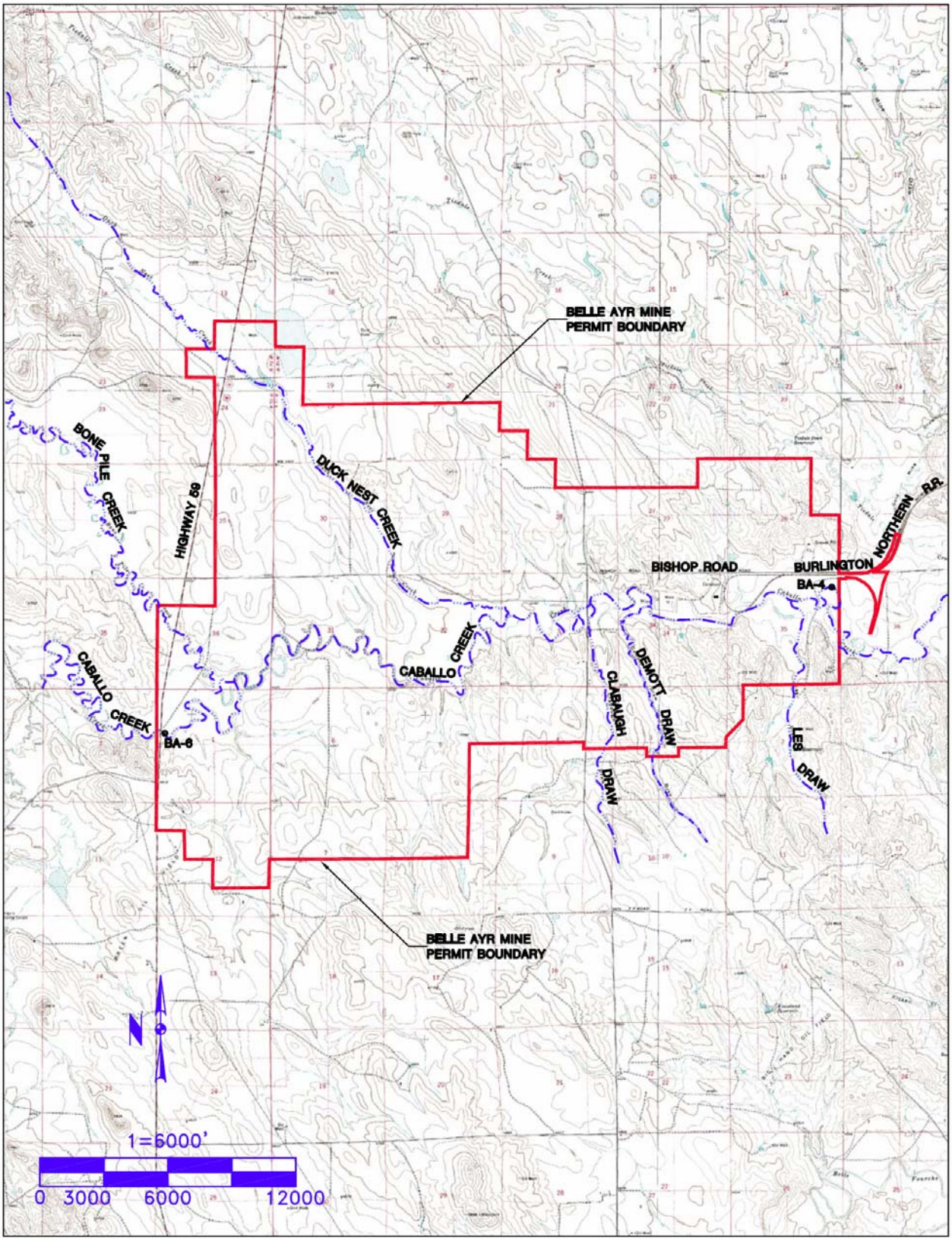


Figure 4.4-1 Vicinity Map

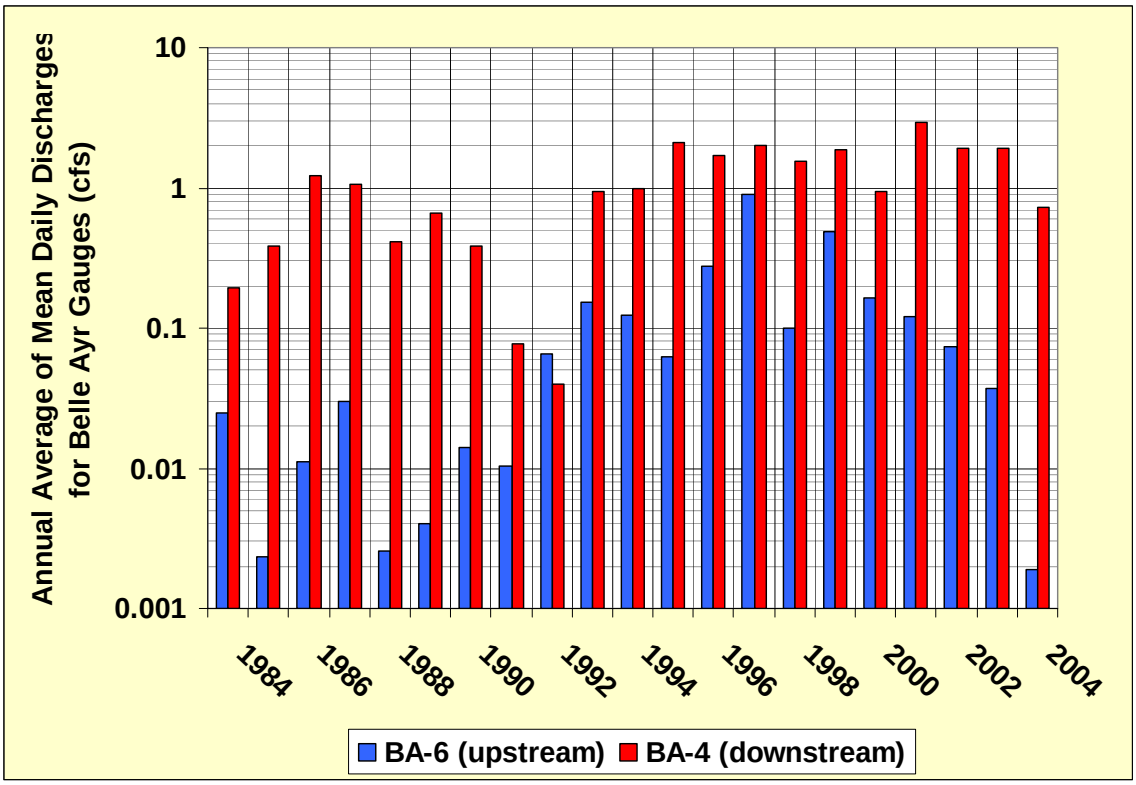


Figure 4.4-2 Hydrologic Data for Caballo Creek (1984-2004)

The information below is derived from a review of the data in **Figure 4.4-2.**

- Both gages may have received CBNG well discharge water for about 10 years.
- The average annual discharge for the BA-4 gage (downstream gage) increased from 0.5 cfs (from 1984 to 1992) to 1.6 cfs (from 1993 to 2004). This represents an increase of 1.1 cfs that is potentially attributable to the contribution of CBNG well discharge water.
- The average annual discharge for the BA-6 gage (upstream gage) increased from 0.02 cfs (from 1984 to 1992) to 0.21 cfs (from 1993 to 2004). This represents an increase of 0.19 cfs that is potentially attributable to the contribution of CBNG well discharge water.

It should be noted that the BA-6 gage is located upstream of the CBNG wells within the Bone Pile Creek and Duck Nest Creek watersheds, thereby reducing the contribution of CBNG well discharge water to this location compared to BA-4. Furthermore, the annual reports provided by the Belle Ayr Mine indicated that the majority of the CBNG well discharge water is contributed from the Bone Pile Creek and Duck Nest Creek watersheds. Consequently, the impact of the CBNG well discharge water will be more evident on the flow data reflected for the BA-4 gage.

The existence of Caballo Reservoir was investigated with respect to its impact on the flow records of Caballo Creek. Caballo Reservoir represented a premining impoundment formed by an earthen dam in the channel of Caballo Creek. Caballo Reservoir was located downstream of the confluence of Bone Pile Creek and Caballo Creek, thereby impacting the flows at the BA-4 gage. Following a period of flooding in 1978, the dam embankment for Caballo Reservoir was breached. Given the period of record chosen for this analysis (1984 to 2004), the existence of Caballo Reservoir did not impact the results illustrated in **Figure 4.4-2**.

During the field reconnaissance visit to the Belle Ayr Mine, areas of ponded water were apparent but no surface flow was evident in either Caballo Creek or Bone Pile Creek west of Highway 59. Reportedly, discharge collected from CBNG wells within the Duck Nest Creek watershed has been historically diverted into Bone Pile Creek. Evidence of historic diversions from Duck Nest Creek into Bone Pile Creek east of Highway 59 was observed during the field reconnaissance visit (see **Figure 4.4-7** and **Figure 4.4-8**). Minimal flow was observed at one of these locations. Since these historic diversions from Duck Nest Creek impact the flow in Bone Pile Creek (located downstream of the BA-6 gage), no impact on the records at the BA-6 gage on Caballo Creek are realized.

The data along with the field observations may reflect the limited precipitation and drought conditions that have existed since the turn of the century. An analysis of precipitation data was conducted to evaluate the impact of potential drought conditions on the hydrologic period of record chosen for this work effort. Data available for a precipitation gage near Gillette, Wyoming was utilized for the evaluation. The results of this work are illustrated in **Figure 4.4-3**. The precipitation data reflects the same general trend as the gage data. A general increase in average annual precipitation exists from a value of 14.36 inches (for the time period from 1984 to 1992) to 18.14 inches (for the time period form 1993 to 2004). This represents an increase of 3.78 inches or 19% in average annual precipitation. Based on a comparative evaluation of the gage data at BA-4, the increase in annual precipitation tends to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the gage.

A further evaluation of the impact of potential drought conditions was conducted through an evaluation of the Palmer Drought Index. The Palmer Drought Index, typically used as a measure of dryness, is based on a supply and demand model of soil moisture. The index has proven most effective in determining long-term drought. The methodology assigns 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is a moderate drought, minus 3 is a severe drought, and minus 4 is an extreme drought. For the Belle Fourche drainage basin in Wyoming, the index values (data limited to annual values prior to 2001) are presented in **Figure 4.4-4**. An evaluation of the data in **Figure 4.4-4** results in the following observations:

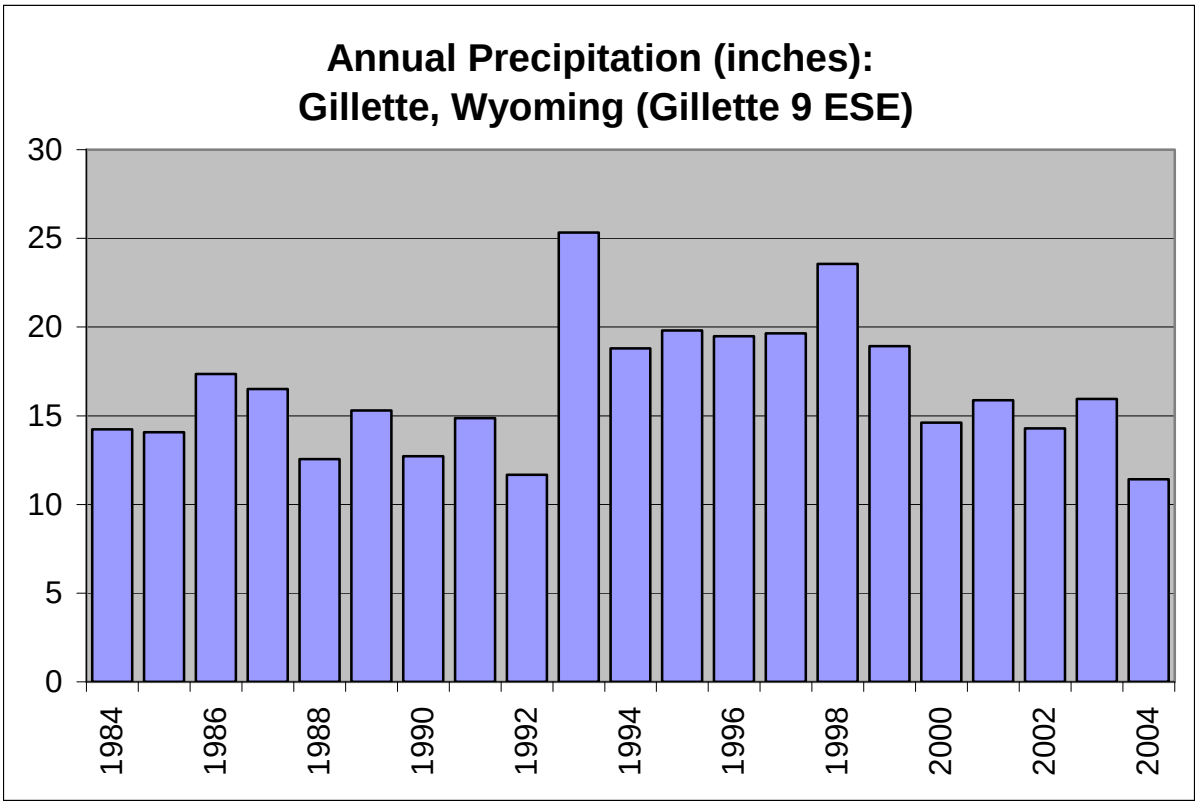


Figure 4.4-3 Average Annual Precipitation Data (1984-2004)

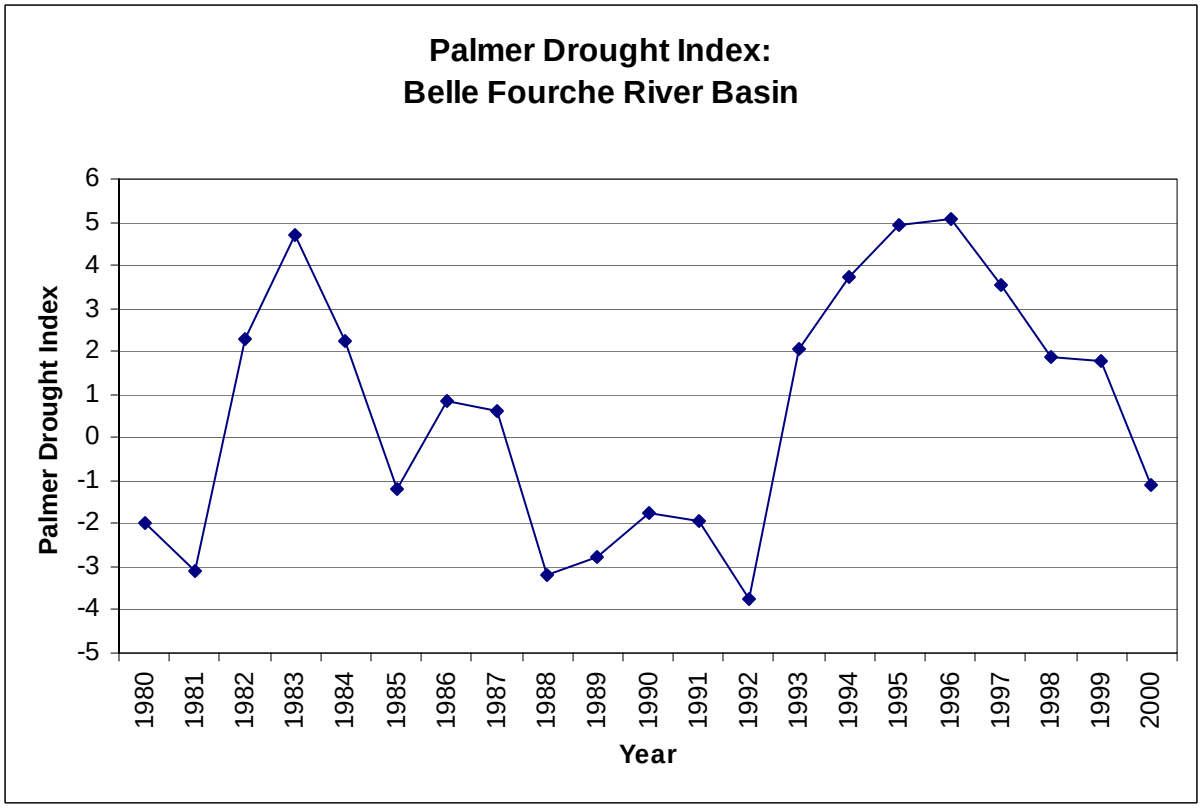


Figure 4.4-4 Palmer Drought Index Data (1980-2000)

- Drought conditions were present during the time period from 1984 to 1992 with noticeable improvement or absence of drought conditions beginning in 1993. Minor drought conditions are evident in 2000, the last year of the available data.

- As expected, there is a correlation between the index values and precipitation data. The increase in annual precipitation beginning in 1993 was manifested in an increase in the Palmer Drought Index and an absence of drought conditions from 1993 to 1999.

- The increase in the Palmer Drought index beginning in 1993 would support a corresponding increase in streamflow within the Belle Fourche drainage basin.

- With the addition of CBNG well discharge into Caballo Creek in 1992, the data for the Palmer Drought Index would tend to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the BA-4 gage.

4.4.3 Channel Stability

The concept of the dominant discharge or channel-forming discharge implies that the natural channel morphology (width, depth, slope and planform) adjusts to a discharge that is largely responsible for that geometry. As previously stated in Section 4.2, the dominant discharge is generally considered to be in the range of the 1.5-year to 2-year recurrence interval. The 2-year peak discharge for Caballo Creek at the eastern mine boundary was estimated to be about 400 cfs. The estimated contribution of CBNG well discharge water of 1.1 cfs represents less than 1% of the 2-year peak discharge. Therefore, it is unlikely that the modest increase in surface flows attributable to CBNG well discharge water would have a systematic effect on the channel morphology associated with the channel-forming discharge. Furthermore, given the relatively flat nature of the channel gradient coupled with the high sinuosity of the channel, a sustained discharge of this magnitude will likely promote an increase in diversity and density of the vegetation along the channel.

These results were confirmed by observations of the existing channels during the field reconnaissance visit. **Figures 4.4-5 to 4.4-12** are provided to document the increase in vegetation and lack of active erosion within the channels.

Figure 4.4-5 This view is looking downstream on Caballo Creek at the BA-6 v-notch weir gauging site.

Figure 4.4-6 This view is looking upstream on Caballo Creek at the BA-4 v-notch weir gauging site. No discernible flow was observed.

Figure 4.4-7 The view is looking upstream on Bone Pile Creek from a pipeline diversion associated with CBNG well production water from the Duck Nest Creek watershed.

Figure 4.4-8 This view illustrates Bone Pile Creek downstream of the location where CBNG well production water is introduced. Vegetation is very dense and no active erosion was noted.

Figure 4.4-9 This view presents a highly sinuous, deeper reach of Caballo Creek along the western permit boundary. Banks are well vegetated and no active erosion was noted.

Figure 4.4-10 This is a view of the confluence of Caballo Creek and Bone Pile Creek.

Figure 4.4-11 The view illustrates the diversion channel immediately downstream of the confluence of Caballo Creek and Bone Pile Creek.

Figure 4.4-12 The view displays Caballo Creek and Bone Pile Creek upstream of highway 59. Banks are stable with significant aquatic vegetation in the stream. No significant flow was observed in either channel.

Qualitatively, these results can also be confirmed by geomorphic relationships. As presented in Section 4.3, increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

Assuming the relative magnitude of the increase in mean annual discharge is more significant in the ephemeral drainage channel, it is likely that potential increases in channel width and depth will occur along with local reductions in channel slope. However, it should be noted that contribution of flow from the CBNG well discharges into Caballo Creek (characterized as an intermittent stream) is relatively small in comparison to the channel forming discharge. Furthermore, the existing slope and sinuosity (reported to be 0.0012 ft/ft and 1.81, respectively) of Caballo Creek would require a significant increase in discharge to manifest a noticeable decrease in slope or an increase in sinuosity. Consequently, it is unlikely that the minor contribution from CBNG well discharge to the flow in Caballo Creek will result in any active erosion to the channel.

4.4.4 Summary and Conclusions

Based on the channel stability assessment of Caballo Creek, the following information is provided:

- CBNG well production water has been historically and is presently discharged into Bone Pile Creek, Duck Nest Creek, and Caballo Creek. Based on the hydrologic data, the average annual discharge was estimated to increase from 0.5 cfs to 1.6 cfs (increase of 1.1 cfs) within Caballo Creek at the BA-4 gage. The estimated contribution of CBNG well production water of 1.1 cfs represents less than 1% of the 2-year peak discharge.

- The increase in the data related to average annual precipitation values and the Palmer Drought index beginning in 1993 support a corresponding increase in streamflow within the Belle Fourche drainage basin. With the addition of CBNG well discharge into Caballo Creek in 1992, the data related to average annual precipitation and the Palmer Drought Index would tend to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the BA-4 gage.

- No active erosion was evident within the natural channels associated with Caballo Creek, Bone Pile Creek or Duck Nest Creek. Furthermore, no active erosion was evident within the diversion channels or adjacent to the structures within the diversion channels.

- Field observations noted an increase in vegetation diversity and density within all drainage channels receiving CBNG well production water.

- Given the relative magnitude of the flow contribution from CBNG well production water, geomorphic relationships confirmed the conclusion that the minor contribution from CBNG well production to the flow in Caballo Creek will not likely result in any active erosion to the channel.

Based on the information provided on channel stability, a threshold may exist where the contribution of CBNG well production water may create erosion within the receiving drainage channel. Given the channel slope, sinuosity and watershed area, drainages such as Caballo Creek may not realize an increase in channel erosion and will more likely realize an increase in vegetation along the channel. Smaller drainages, such as Bone Pile Creek (drainage area of 44.4 square miles, slope of 0.0017 ft/ft, sinuosity of 2.14) or Duck Nest Creek (drainage area of 6.63 square miles, slope of 0.002 ft/ft, and sinuosity of 1.92) may be more likely to exhibit channel erosion depending on the magnitude of the flow contribution from CBNG well production compared to the channel forming discharge. However, field observations in these watersheds found similar increases in vegetation along the channels.

To have an impact on channel stability that is manifested in active channel erosion, CBNG well production water will likely have to represent a significant portion of the channel forming discharge in watersheds where the channel slope is steep enough and width/depth/sinuosity low enough to impact channel morphology. Given the magnitude of the discharges, the impact will more likely be evident in small ephemeral drainages that are characterized by steep channel gradients, lower sinuosity, and smaller widths and depths. Otherwise, as drainage area/basins increase, the channel slope typically decreases along with an increase in sinuosity thereby reducing the impact of CBNG well production water on channel stability.

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APPENDIX A

ANALYSIS OF SAR MIXING (GREYSTONE, 2003)

SURFACE WATER QUALITY ANALYSIS
TECHNICAL REPORT

SURFACE WATER MODELING OF WATER QUALITY IMPACTS ASSOCIATED WITH COAL BED METHANE DEVELOPMENT IN THE POWDER RIVER BASIN

Prepared in support of:

***Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project* for:**

Bureau of Land Management
Buffalo Field Office
Buffalo, Wyoming

and

***Statewide Oil and Gas Final Environmental Impact Statement and Amendment of the Powder River and Billings Resource Management Plans* for:**

Bureau of Land Management
Miles City Field Office
Billings Field Office
Billings, Montana

Prepared by:

Greystone Environmental Consultants, Inc.
Denver, Colorado

and

ALL Consulting
Tulsa, Oklahoma

January 2003

APPENDIX B

Analysis of SAR Mixing

APPENDIX B
ANALYSIS OF SAR MIXING

This appendix addresses the estimation of sodium adsorption ratio (SAR) in rivers of the Powder River Basin after mixing with discharge of coal bed methane (CBM) produced water. The following sections provide (1) a summary of the analysis, (2) the definition of SAR, (3) an explanation of ideal mixing in a river, (4) an evaluation of the ambient SAR at the three stateline river stations (Powder River at Moorhead, Little Powder River above Dry Creek, and Tongue River at Stateline) and the SAR of CBM produced-water discharge, and (5) an analysis of mixing approaches for estimating SAR in the river after discharge of CBM produced water.

A.1. Summary and Conclusions

This analysis concludes that a simple mixing approach to estimating SAR in a river after mixing with CBM discharge provides an acceptable, reasonably conservative estimate of the mixed SAR. In this approach, SAR is treated as a constituent of water and mixed using a simple flow-weighted mass balance equation. The mixed SAR calculated using this approach over-predicts SAR by a consistently conservative average factor of about 1.6 for the Powder River Basin. This error is relatively insignificant when compared to the variability in the other parameters used in modeling impacts of CBM discharge on water quality . Therefore, this method of calculating SAR is appropriate for use in this EIS.

When site-specific, synoptic water quality data are available for a particular project, or when determining TMDLs, the resultant mixed water quality should be determined by mixing the individual constituents in the SAR formula –Ca, Mg, and Na.

A.2. Definition of SAR

Sodium adsorption ratio (SAR) is used as an index of the potential for irrigation water to lessen the permeability of a soil subject to swelling if sodium exchanges for calcium and magnesium in soil particles. SAR is calculated as:

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}} \qquad [1]$$

where [Na], [Ca], and [Mg] represent the concentrations of sodium, calcium, and magnesium, respectively, expressed in milliequivalents per liter (meq/L) (USDA, 1954).

A.3. Ideal Mixing

Estimation of SAR in a river after mixing with CBM discharge ideally is calculated using a flow-weighted mass balance model to estimate mixed concentrations of the individual constituents—Ca, Mg, and Na. If complete mixing is assumed, the mixed concentration of each constituent can be calculated as (US EPA, 1995):

$$C_{mix} = \frac{Q_{river} C_{river} + Q_{discharge} C_{discharge}}{Q_{river} + Q_{discharge}} \qquad [2]$$

where

C_{mix}	=	concentration of constituent in the mixed zone,
Q_{river}	=	upstream (ambient) flow rate,
$Q_{discharge}$	=	discharge flow rate,
C_{river}	=	upstream (ambient) constituent concentration,
$C_{discharge}$	=	discharge constituent concentration,

This equation applies to any chemical constituent in the river and discharge that mixes conservatively (i.e., does not react upon mixing). Combining equations [1] and [2] yields the following equation for SAR mixing:

$$SAR_{mix} = \frac{\left\{\dfrac{(Q_{river} \times [Na]_{river}) + (Q_{CBM} \times [Na]_{CBM})}{(Q_{river} + Q_{CBM})}\right\}}{\sqrt{\dfrac{\left\{\dfrac{(Q_{river} \times Ca_{river}) + (Q_{CBM} \times Ca_{CBM})}{(Q_{river} + Q_{CBM})} + \dfrac{(Q_{river} \times Mg_{river}) + (Q_{CBM} \times Mg_{CBM})}{(Q_{river} + Q_{CBM})}\right\}}{2}}} \qquad [3]$$

In order to ensure that a representative mixed value is calculated, the upstream river and discharge samples should have been collected synoptically (concurrent sampling of the water in each inflow that will ultimately mix at the confluence of the two flows). If synoptic data are not available, application of equation [3] implies estimating representative values of [Na], [Ca], and [Mg] for the upstream river water and the CBM discharge.

A.4. Ambient River SAR and CBM Produced WaterSAR

This section analyzes different methods of calculating measures of central tendency (mean or median) to represent ambient river SAR and CBM produced water SAR. The mean and median SAR values calculated from individual samples are compared to the SAR values estimated from the mean and median values of Ca, Mg, and Na concentrations in individual samples. Because of the square root in the SAR formula, calculation of a mean SAR from sample SARs is not strictly correct. It is nevertheless

investigated in this analysis in order to evaluate the use of a simplified mixing model for SAR when synoptic water quality data are not available.

The data evaluated include data sets from three river stations (Powder River at Moorhead, Little Powder River above Dry Creek, and Tongue River at Stateline) as well as water quality data compiled for CBM produced-water discharge. The river data was obtained from the USGS NWIS database. The CBM data was obtained from a USGS study of the Powder River Basin (Rice et al., in press) and from data submitted to EPA by Fidelity for a UIC permit for the CX Ranch development.

Table A-1 and Figure A-1 compare the mean of sample SAR values to the SAR value estimated from mean values of Ca, Mg, and Na. As is shown in Table A-1 and Figure A-1, either way of estimating a representative SAR for the data yields equivalent results for the river station data. However, for the CBM data sets, estimating SAR from the mean values of Ca, Mg, and Na results in a significant under-prediction of the mean SAR value and, consequently from a regulatory standpoint, results in a less conservative and less acceptable estimate of SAR.

Table A-1
Comparison of (1) Mean Values of Sample SARs and (2) SARs Estimated from Mean Values of Sample Ca, Mg, and Na Concentrations

	(1)				(2)		
	Mean SAR	Mean Ca (mg/L)	Mean Mg (mg/L)	Mean Na (mg/L)	CaMgNa SAR	Ratio (1)/(2)	Ratio (2)/(1)
Powder River at Moorhead, MT	4.94	119	59	262	4.91	1.01	0.99
Little Powder River above Dry Creek, WY	6.24	141	96	404	6.43	0.97	1.03
Tongue River at State line near Decker, MT	0.68	55	33	27	0.71	0.95	1.05
Powder River Basin CBM Discharge	20.7	29	14	391	15.0	1.38	0.72
CX Ranch CBM Discharge	44.7	11	11	553	28.5	1.57	0.64
Fort Union Coal	14.5	161	192	401	5.1	2.86	0.35

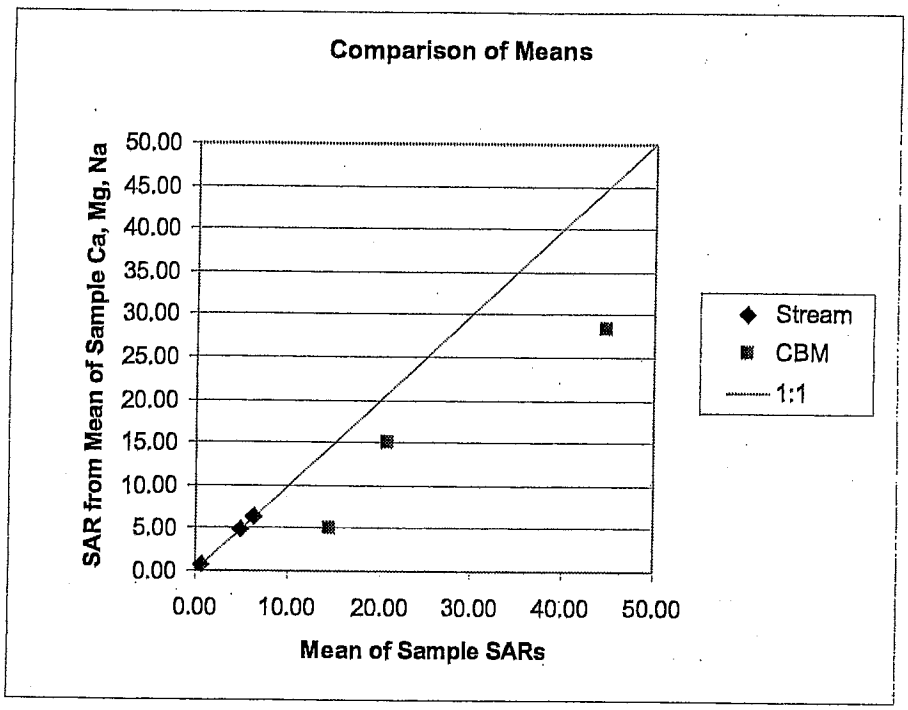

Figure A-1. Comparison of mean values of individual sample SARs and SARs estimated from mean values of sample Ca, Mg, and Na concentrations.

Similar information is presented in Table A-2 and Figure A-2 using median rather than mean values. For data from the river stations, either way of estimating a representative SAR yields equivalent results. This is the same result as was found when using mean values. For the CBM data sets, however, SAR estimated from the median values of Ca, Mg, and Na appears to over-predict SAR. The over-prediction in these examples is not as large as the under-prediction that results from using mean values as shown in Table A-1 and Figure A-1. From a regulatory standpoint, reasonable over-prediction is acceptable and, consequently, either method of calculating SAR using median values yields an acceptable estimate.

Table A-2
Comparison of (1) Median Values of Sample SARs and (2) SARs Estimated from Median Values of Sample Ca, Mg, and Na Concentrations

	(1)				(2)		
	Median SAR	Median Ca (mg/L)	Median Mg (mg/L)	Median Na (mg/L)	CaMgNa SAR	Ratio (1)/(2)	Ratio (2)/(1)
Powder River at Moorhead, MT	4.94	120	56	267	5.05	0.98	1.02
Little Powder River above Dry Creek, WY	6.61	150	108	438	6.66	0.99	1.01
Tongue River at State line near Decker, MT	0.66	59	36	26	0.66	1.00	1.00
Powder River Basin CBM Discharge	11.5	26	13	353	14.1	0.81	1.23
CX Ranch CBM Discharge	47.5	6	2	549	47.9	0.99	1.01
Fort Union Coal	4.6	109	102	329	5.4	0.85	1.18

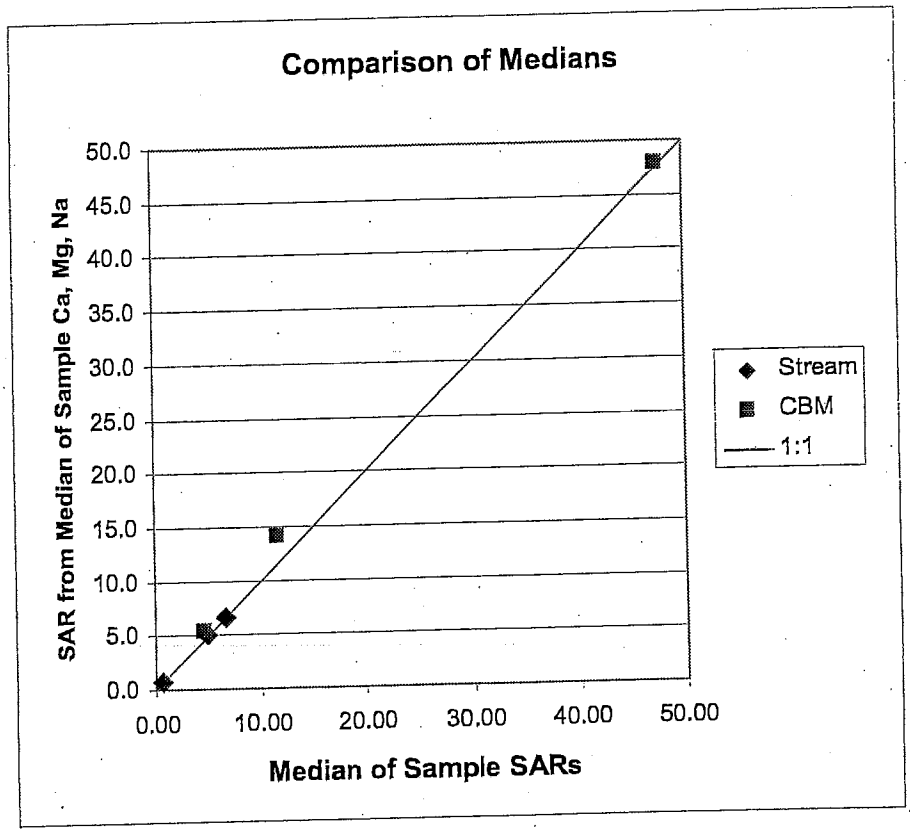

Figure A-2. Comparison of median values of sample SARs and SARs calculated from median values of sample Ca, Mg, and Na concentrations.

A. 5. SAR Mixing

As described above, estimation of SAR in a river after mixing with CBM discharge ideally is calculated using synoptic data and equation [3]. However, because synoptic data generally are not available for the streams or CBM discharges evaluated in the EIS, this section evaluates using the simple flow-weighted mass balance model, shown in equation [2], to estimate SAR after mixing. The corresponding simple mixing model for SAR is:

$$SAR_{simple\ mix} = \frac{(Q_{River} \times SAR_{River}) + (Q_{CBM} \times SAR_{CBM})}{(Q_{River} + Q_{CBM})} \qquad [4]$$

Two approaches are used to evaluate the use of equation [4] in place of equation [3]. One approach considers fractional mixing of stream water with CBM discharge using representative mean or median values of SAR, Ca, Mg, and Na for both the stream and CBM discharge. The other approach mixes CBM discharge characterized by representative mean values for water quality parameters with individual samples from each of the stateline stations.

A.5.1. Fractional Mixing Analysis

The fractional mixing analysis is illustrated in Figure A-3 using mean values of SAR, Ca, Mg, and Na from the Powder River at Moorhead station and CBM discharge in the Power River watershed. The figure compares the simple mix SAR values estimated using equation [4] to SAR values estimated using equation [3]. As shown, the simple SAR mixing approach overestimates SAR in the Powder River station at Moorhead by a factor ranging up to 1.33 at the reasonably foreseeable development (RFD) CBM discharge.

Table A-3 presents a summary of the results of the fractional mixing analysis for each of the stateline stations. This table shows that the simple mix approach—equation [4]—over-predicts SAR by a factor of at most 1.4 at the Powder River and Little Powder River stateline stations. At the Tongue River stateline station, the simple mix approach overestimates SAR by a factor of at most 1.6 using mean values and 2.7 using median values.

The over-prediction in SAR that results from using the simple mass balance approach is small when compared to the other uncertainties inherent in the impact analysis modeling. Consequently, this approach is considered appropriate for purposes of this EIS, as it yields a reasonably conservative estimate of SAR.

Powder River at Moorhead: Mean Values					
Flow	Sample SAR	Ca	Mg	Na	CaMgNa SAR
388	4.94	118	58	261	4.91

CBM Discharge: Mean Values					
Flow	Sample SAR	Ca	Mg	Na	CaMgNa SAR
206	20.7	29	14	540	20.7

Mix						
Frac	Simple SAR Mix (1)	Ca Mix	Mg Mix	Na Mix	CaMgNa Mix SAR (2)	Ratio (1):(2)
0	4.94	118	58	261	4.91	1.01
0.05	5.35	116	57	268	5.10	1.05
0.1	5.73	114	56	275	5.28	1.09
0.15	6.10	112	55	282	5.45	1.12
0.2	6.45	110	54	288	5.62	1.15
0.25	6.79	108	53	294	5.79	1.17
0.3	7.10	106	52	299	5.95	1.19
0.35	7.41	104	51	305	6.10	1.21
0.4	7.70	103	51	310	6.26	1.23
0.45	7.98	101	50	315	6.41	1.25
0.5	8.24	100	49	320	6.55	1.26
0.55	8.50	98	48	324	6.69	1.27
0.6	8.75	97	48	328	6.83	1.28
0.65	8.98	95	47	333	6.97	1.29
0.7	9.21	94	46	337	7.10	1.30
0.75	9.43	93	46	340	7.23	1.30
0.8	9.64	92	45	344	7.35	1.31
0.85	9.84	91	45	348	7.48	1.32
0.9	10.03	89	44	351	7.60	1.32
0.95	10.22	88	43	354	7.72	1.32
1	10.41	87	43	358	7.83	1.33

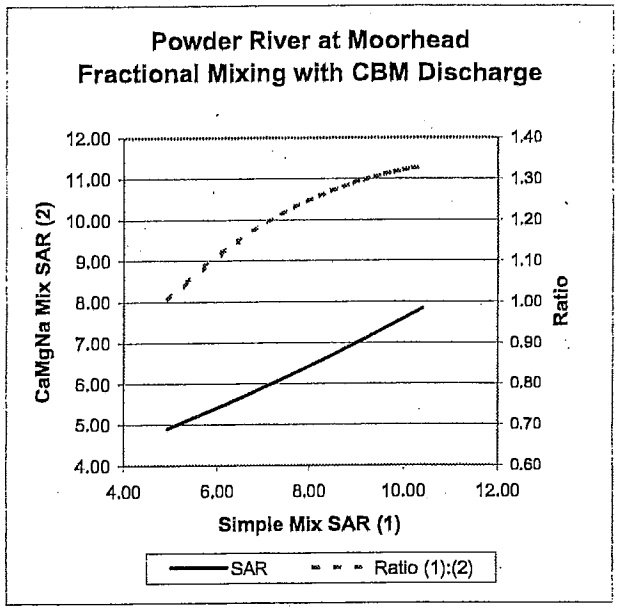

Figure A-3. Fractional mixing of stream water and CBM discharge. Comparison of SAR values calculated using (1) simple mixing as in equation [4] and (2) flow-weighted mixing of Ca, Mg, and Na as in equation [3].

Table A-3
Summary of Fractional Mixing Results. Comparison of SAR values calculated using simple mixing versus flow-weighted mixing of Ca, Mg, and Na.

Station	Statistic Used to Represent Water Quality	Average Ratio of Simple SAR Mix to Ca, Mg, Na Mixed SAR	Ratio of Simple SAR Mix to Ca, Mg, Na Mixed SAR at RFD CBM Discharge
Tongue River	Mean	1.40	1.60
Tongue River	Median	2.33	2.67
Powder River	Mean	1.23	1.33
Powder River	Median	1.12	1.20
Little Powder River	Mean	1.24	1.36
Little Powder River	Median	1.17	1.12

A.5.2. Distribution Mixing Analysis

Results similar to those obtained in the fractional mixing analysis are obtained by mixing individual samples of river water at the stateline stations (USGS data) with CBM discharge (mean values). The results are illustrated in Figures A-4 and A-5. These figures both indicate that the simple mix approach—equation [4]—over-predicts SAR by a factor of approximately 1.6 at both the Tongue River and Powder River stateline stations. As above, this over-prediction of SAR represents a conservative, yet reasonable estimate of SAR and, consequently, the simple mixing approach is the approach used in the analysis of impacts for the EIS.

References:

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U.S. EPA Region VIII, 1995, *Mixing Zones and Dilution Policy.*

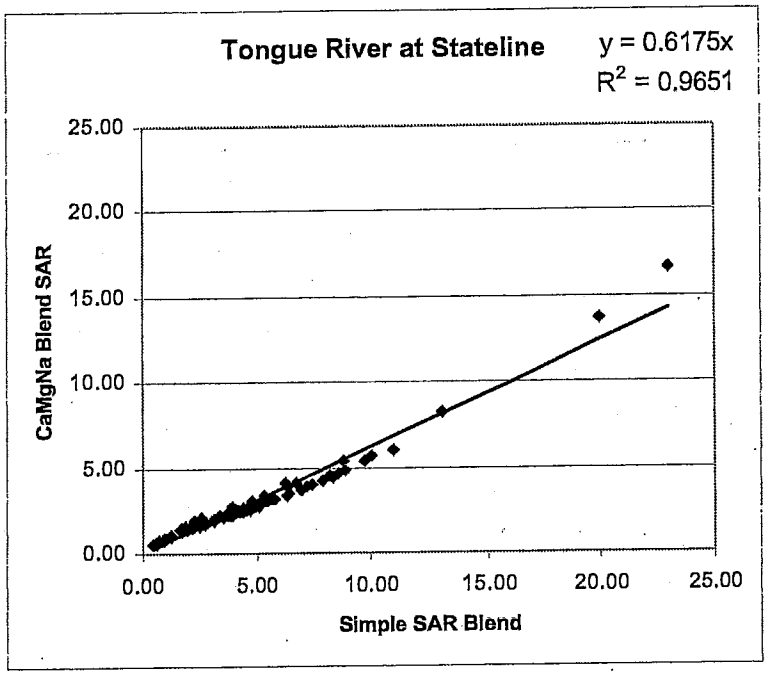


Figure 4. Tongue River at Stateline (USGS data) mixed with CX Ranch CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].

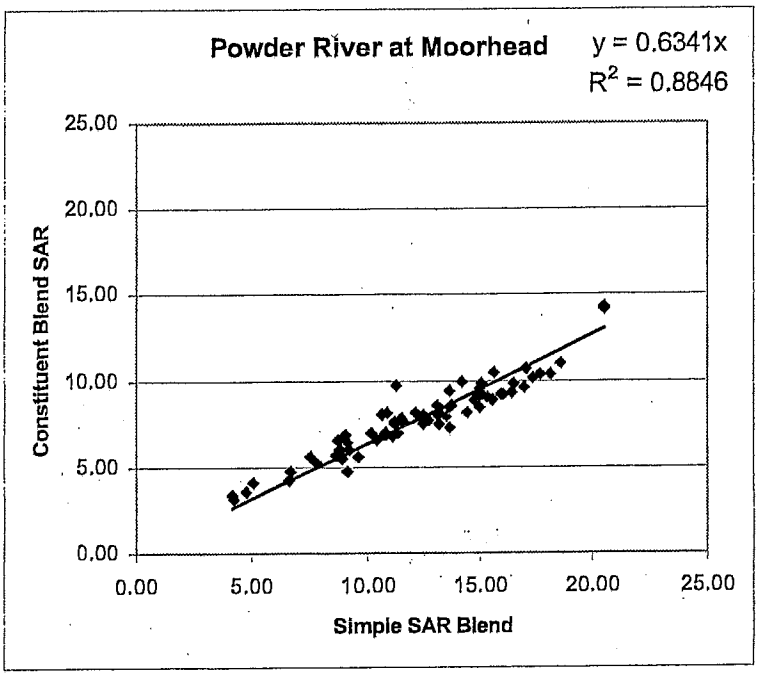


Figure 5. **Powder River at Moorhead (USGS data) mixed with Powder River Basin CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].**

APPENDIX B

SPREADSHEET MODEL INPUT DATA

APPENDIX B-1

NORMAL YEAR CONDITIONS

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Antelope Creek Near Teckla, Wyoming (Station 06364700)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	1.1	3.0	0.9	81.8%	10.9	3.3	300.0%	13.5	4.1	372.7%	12.9	3.9	354.5%
Nov	0.5	3.0	0.9	180.0%	10.9	3.3	660.0%	13.5	4.1	820.0%	12.9	3.9	780.0%
Dec	0.3	3.0	0.9	300.0%	10.9	3.3	1100.0%	13.5	4.1	1366.7%	12.9	3.9	1300.0%
Jan	0.3	3.0	0.9	300.0%	10.9	3.3	1100.0%	13.5	4.1	1366.7%	12.9	3.9	1300.0%
Feb	3.6	3.0	0.9	25.0%	10.9	3.3	91.7%	13.5	4.1	113.9%	12.9	3.9	108.3%
Mar	10.7	3.0	0.9	8.4%	10.9	3.3	30.8%	13.5	4.1	38.3%	12.9	3.9	36.4%
Apr	5.1	3.0	0.9	17.6%	10.9	3.3	64.7%	13.5	4.1	80.4%	12.9	3.9	76.5%
May	8.4	3.0	0.9	10.7%	10.9	3.3	39.3%	13.5	4.1	48.8%	12.9	3.9	46.4%
Jun	8.9	3.0	0.9	10.1%	10.9	3.3	37.1%	13.5	4.1	46.1%	12.9	3.9	43.8%
Jul	4.4	3.0	0.9	20.5%	10.9	3.3	75.0%	13.5	4.1	93.2%	12.9	3.9	88.6%
Aug	2.9	3.0	0.9	31.0%	10.9	3.3	113.8%	13.5	4.1	141.4%	12.9	3.9	134.5%
Sep	1.6	3.0	0.9	56.3%	10.9	3.3	206.3%	13.5	4.1	256.3%	12.9	3.9	243.8%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Little Powder River above Dry Creek Near Weston, Wyoming (Station 06324970)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	4.6	5.3	1.6	34.8%	7.3	2.2	47.8%	7.0	2.1	45.7%	6.0	1.8	39.1%
Nov	2.4	5.3	1.6	66.7%	7.3	2.2	91.7%	7.0	2.1	87.5%	6.0	1.8	75.0%
Dec	1.1	5.3	1.6	145.5%	7.3	2.2	200.0%	7.0	2.1	190.9%	6.0	1.8	163.6%
Jan	6.6	5.3	1.6	24.2%	7.3	2.2	33.3%	7.0	2.1	31.8%	6.0	1.8	27.3%
Feb	20.0	5.3	1.6	8.0%	7.3	2.2	11.0%	7.0	2.1	10.5%	6.0	1.8	9.0%
Mar	25.3	5.3	1.6	6.3%	7.3	2.2	8.7%	7.0	2.1	8.3%	6.0	1.8	7.1%
Apr	18.8	5.3	1.6	8.5%	7.3	2.2	11.7%	7.0	2.1	11.2%	6.0	1.8	9.6%
May	32.0	5.3	1.6	5.0%	7.3	2.2	6.9%	7.0	2.1	6.6%	6.0	1.8	5.6%
Jun	28.3	5.3	1.6	5.7%	7.3	2.2	7.8%	7.0	2.1	7.4%	6.0	1.8	6.4%
Jul	10.2	5.3	1.6	15.7%	7.3	2.2	21.6%	7.0	2.1	20.6%	6.0	1.8	17.6%
Aug	5.0	5.3	1.6	32.0%	7.3	2.2	44.0%	7.0	2.1	42.0%	6.0	1.8	36.0%
Sep	4.1	5.3	1.6	39.0%	7.3	2.2	53.7%	7.0	2.1	51.2%	6.0	1.8	43.9%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Belle Fourche River Below Moorcroft, Wyoming (Station 06426500)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	13.8	14.4	4.3	31.2%	13.1	3.9	28.3%	9.9	3.0	21.7%	7.3	2.2	15.9%
Nov	4.6	14.4	4.3	93.5%	13.1	3.9	84.8%	9.9	3.0	65.2%	7.3	2.2	47.8%
Dec	3.3	14.4	4.3	130.3%	13.1	3.9	118.2%	9.9	3.0	90.9%	7.3	2.2	66.7%
Jan	8.0	14.4	4.3	53.8%	13.1	3.9	48.8%	9.9	3.0	37.5%	7.3	2.2	27.5%
Feb	27.2	14.4	4.3	15.8%	13.1	3.9	14.3%	9.9	3.0	11.0%	7.3	2.2	8.1%
Mar	55.4	14.4	4.3	7.8%	13.1	3.9	7.0%	9.9	3.0	5.4%	7.3	2.2	4.0%
Apr	35.8	14.4	4.3	12.0%	13.1	3.9	10.9%	9.9	3.0	8.4%	7.3	2.2	6.1%
May	39.4	14.4	4.3	10.9%	13.1	3.9	9.9%	9.9	3.0	7.6%	7.3	2.2	5.6%
Jun	28.1	14.4	4.3	15.3%	13.1	3.9	13.9%	9.9	3.0	10.7%	7.3	2.2	7.8%
Jul	13.1	14.4	4.3	32.8%	13.1	3.9	29.8%	9.9	3.0	22.9%	7.3	2.2	16.8%
Aug	6.8	14.4	4.3	63.2%	13.1	3.9	57.4%	9.9	3.0	44.1%	7.3	2.2	32.4%
Sep	6.3	14.4	4.3	68.3%	13.1	3.9	61.9%	9.9	3.0	47.6%	7.3	2.2	34.9%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Cheyenne River Near Spencer, Wyoming (Station 06395000)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	3.0	2.5	0.8	26.7%	2.8	0.8	26.7%	2.4	0.7	23.3%	1.9	0.6	20.0%
Nov	2.7	2.5	0.8	29.6%	2.8	0.8	29.6%	2.4	0.7	25.9%	1.9	0.6	22.2%
Dec	0.8	2.5	0.8	100.0%	2.8	0.8	100.0%	2.4	0.7	87.5%	1.9	0.6	75.0%
Jan	11.3	2.5	0.8	7.1%	2.8	0.8	7.1%	2.4	0.7	6.2%	1.9	0.6	5.3%
Feb	21.5	2.5	0.8	3.7%	2.8	0.8	3.7%	2.4	0.7	3.3%	1.9	0.6	2.8%
Mar	12.2	2.5	0.8	6.6%	2.8	0.8	6.6%	2.4	0.7	5.7%	1.9	0.6	4.9%
Apr	25.8	2.5	0.8	3.1%	2.8	0.8	3.1%	2.4	0.7	2.7%	1.9	0.6	2.3%
May	240.6	2.5	0.8	0.3%	2.8	0.8	0.3%	2.4	0.7	0.3%	1.9	0.6	0.2%
Jun	115.8	2.5	0.8	0.7%	2.8	0.8	0.7%	2.4	0.7	0.6%	1.9	0.6	0.5%
Jul	31.5	2.5	0.8	2.5%	2.8	0.8	2.5%	2.4	0.7	2.2%	1.9	0.6	1.9%
Aug	8.3	2.5	0.8	9.6%	2.8	0.8	9.6%	2.4	0.7	8.4%	1.9	0.6	7.2%
Sep	55.9	2.5	0.8	1.4%	2.8	0.8	1.4%	2.4	0.7	1.3%	1.9	0.6	1.1%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Powder River at Arvada, Wyoming (Station 06317000)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	160.6	7.8	2.3	1.4%	26.6	8.0	5.0%	31.9	9.6	6.0%	30.0	9.0	5.6%
Nov	157.0	7.8	2.3	1.5%	26.6	8.0	5.1%	31.9	9.6	6.1%	30.0	9.0	5.7%
Dec	112.6	7.8	2.3	2.0%	26.6	8.0	7.1%	31.9	9.6	8.5%	30.0	9.0	8.0%
Jan	104.5	7.8	2.3	2.2%	26.6	8.0	7.7%	31.9	9.6	9.2%	30.0	9.0	8.6%
Feb	218.6	7.8	2.3	1.1%	26.6	8.0	3.7%	31.9	9.6	4.4%	30.0	9.0	4.1%
Mar	391.3	7.8	2.3	0.6%	26.6	8.0	2.0%	31.9	9.6	2.5%	30.0	9.0	2.3%
Apr	391.7	7.8	2.3	0.6%	26.6	8.0	2.0%	31.9	9.6	2.5%	30.0	9.0	2.3%
May	724.8	7.8	2.3	0.3%	26.6	8.0	1.1%	31.9	9.6	1.3%	30.0	9.0	1.2%
Jun	638.8	7.8	2.3	0.4%	26.6	8.0	1.3%	31.9	9.6	1.5%	30.0	9.0	1.4%
Jul	216.8	7.8	2.3	1.1%	26.6	8.0	3.7%	31.9	9.6	4.4%	30.0	9.0	4.2%
Aug	107.5	7.8	2.3	2.1%	26.6	8.0	7.4%	31.9	9.6	8.9%	30.0	9.0	8.4%
Sep	110.0	7.8	2.3	2.1%	26.6	8.0	7.3%	31.9	9.6	8.7%	30.0	9.0	8.2%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Dry Fork Cheyenne River Near Bill, Wyoming (Station 0634700)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	0.03	0.00	0.00	0.00	0.09	0.03	100.0%	0.15	0.04	133.3%	0.15	0.04	133.3%
Nov	0.08	0.00	0.00	0.00	0.09	0.03	37.5%	0.15	0.04	50.0%	0.15	0.04	50.0%
Dec	0.08	0.00	0.00	0.00	0.09	0.03	37.5%	0.15	0.04	50.0%	0.15	0.04	50.0%
Jan	0.03	0.00	0.00	0.00	0.09	0.03	100.0%	0.15	0.04	133.3%	0.15	0.04	133.3%
Feb	0.25	0.00	0.00	0.00	0.09	0.03	12.0%	0.15	0.04	16.0%	0.15	0.04	16.0%
Mar	0.49	0.00	0.00	0.00	0.09	0.03	6.1%	0.15	0.04	8.2%	0.15	0.04	8.2%
Apr	0.27	0.00	0.00	0.00	0.09	0.03	11.1%	0.15	0.04	14.8%	0.15	0.04	14.8%
May	1.51	0.00	0.00	0.00	0.09	0.03	2.0%	0.15	0.04	2.6%	0.15	0.04	2.6%
Jun	0.34	0.00	0.00	0.00	0.09	0.03	8.8%	0.15	0.04	11.8%	0.15	0.04	11.8%
Jul	0.23	0.00	0.00	0.00	0.09	0.03	13.0%	0.15	0.04	17.4%	0.15	0.04	17.4%
Aug	0.13	0.00	0.00	0.00	0.09	0.03	23.1%	0.15	0.04	30.8%	0.15	0.04	30.8%
Sep	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Normal Year Conditions

	Antelope Creek Near Teckla, Wyoming (1)	Little Powder River above Dry Creek Near Weston, Wyoming (2)	Belle Fourche River Below Moorcroft, Wyoming (1)	Cheyenne River Near Spencer, Wyoming (1)	Powder River at Arvada, Wyoming (2)	Dry Fork Cheyenne River Near Bill, Wyoming (1)
Station Number:	06364700	06324970	06426500	06386500	06317000	06365300
Month	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
Oct	69	283	846	186	9,874	2
Nov	27	144	276	159	9,343	5
Dec	19	65	205	48	6,922	5
Jan	21	405	494	695	6,424	2
Feb	199	1,109	1,513	1,196	12,141	14
Mar	658	1,553	3,406	748	24,059	30
Apr	302	1,119	2,128	1,534	23,309	16
May	519	1,970	2,420	14,793	44,564	93
Jun	531	1,683	1,675	6,889	38,014	20
Jul	268	625	804	1,938	13,330	14
Aug	179	309	418	511	6,608	8
Sep	94	246	376	3,325	6,543	0
Total	2,882	9,511	15,059	32,023	201,124	209

Note:

(1) HKM Engineering, Inc. 2002a. Northeast Wyoming River Basins Plan, Surface Water Hydrology, Tasks 3A and 3B Memorandum
(2) HKM Engineering, Inc. 2002b. Powder/Tongue River Basins Plan, Surface Water Hydrology, Tasks 3A and 3B Memorandum
(3) Average Streamflow for 1970-1999 in Acre-Feet

Spreadsheet Model Input Parameters- Normal Year Conditions

Summary of Annual Coal Bed Natural Gas-Related Disposal to Receiving Drainages

Sub-Basin	Annual CBNG-Related Disposal (mmgpy) [1]				Annual CBNG-Related Disposal (cfs)			
	2003	2010	2015	2020	2003	2010	2015	2020
Antelope Creek	710	2575	3185	3038	3.0	10.9	13.5	12.9
Dry Fork Cheryenne River	0	22	35	35	0.0	0.1	0.1	0.1
Little Powder River	1239	1716	1659	1421	5.3	7.3	7.0	6.0
Upper Belle Fourche River	3405	3085	2332	1713	14.4	13.1	9.9	7.3
Upper Cheyenne River	593	650	560	447	2.5	2.8	2.4	1.9
Upper Powder River	1833	6273	7532	7066	7.8	26.6	31.9	30.0
Total	7780	14321	15303	13720	33.0	60.7	64.9	58.2

Summary of Coal Bed Natural Gas-Related Discharge Water Quality (Source: WDEQ / WQD)

Sub-Basin	EC			SAR				Data used in Draft Report (12/2005)	
	95%lower	mean	95%upper	95%lower	mean	95%upper		EC	SAR
Antelope Creek	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927	See note	905	7.1
Dry Fork Cheyenne River	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927	See note	905	7.1
Little Powder River	1493.365	1508.912	1524.46	9.9514769	10.49116	11.03085		1271	11.1
Upper Belle Fourche River	1102.166	1109.774	1117.382	8.4426895	8.834127	9.225564		970	8.2
Upper Cheyenne River	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927		599	6.4
Upper Powder River	2160.573	2180.179	2199.786	21.615331	22.57612	23.53691		2163	19.5

note: no data were obtained specific to these sub-basins(antelope creek and dry fork cheyenne river)

Summary of Conveyance Losses

Sub-Basin	EC
Antelope Creek	0.7
Dry Fork Cheyenne River	0.7
Little Powder River	0.7
Upper Belle Fourche River	0.7
Upper Cheyenne River	0.7
Upper Powder River	0.7

Water Quality Standards

	Most Restrictive		Least Restrictive		
	EC	SAR	EC	SAR	
Antelope Creek	2,000	10	2,500	10	wdeq
Dry Fork Cheyenne River	2,000	10	2,500	10	wdeq
Little Powder River	2,000	5	2,500	9.75	montana deq standards
Upper Belle Fourche River	2,000	6	2,500	10	sar (6) from south dakota reg's
Upper Cheyenne River	2,000	10	2,500	10	wdeq
Upper Powder River	2,000	5	2,500	9.75	montana deq standards

Background Water Quality Data (Greystone, 2003)

	Antelope Creek		Upper Belle Fourche		Upper Cheyenne		Upper Powder		Little Powder		Dry Fork Cheyenne	
	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR
Jan	2335	2.74	2887	6.29	4229	8.58	2482	6.4	2953	6.33	2335	2.74
Feb	2251	2.71	1907	4.08	3911	8.01	2366	6.12	2477	5.57	2251	2.71
Mar	1782	2.52	1564	3.64	4127	8.66	2051	5.28	1785	4.44	1782	2.52
Apr	1949	2.77	1722	4.34	3630	7.87	2213	5.84	2457	5.55	1949	2.77
May	1800	2.82	1532	3.81	3155	6.88	1803	4.92	2013	4.81	1800	2.82
Jun	2005	2.8	1821	3.98	2895	5.93	1797	4.76	2333	5.29	2005	2.8
Jul	1661	2.48	1182	3.1	2250	5.69	2716	6.79	2174	5.29	1661	2.48
Aug	1684	2.47	1955	5.06	1972	4.82	2992	6.97	2860	6.57	1684	2.47
Sep	2214	2.52	2231	5.76	2271	5.63	3400	7.83	2810	6.44	2214	2.52
Oct	2354	2.6	2346	5.75	2916	6.46	2537	6.71	2289	5.73	2354	2.6
Nov	2460	2.74	2877	7.02	3565	7.22	2650	6.42	3044	6.7	2460	2.74
Dec	2372	2.79	2755	6.77	3405	7.39	2906	6.61	3300	6.94	2372	2.79

APPENDIX B-2

DRY YEAR CONDITIONS

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Antelope Creek Near Teckla, Wyoming (Station 06364700)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	0.4	3.0	0.9	225.0%	10.9	3.3	825.0%	13.5	4.1	1025.0%	12.9	3.9	975.0%
Nov	0.4	3.0	0.9	225.0%	10.9	3.3	825.0%	13.5	4.1	1025.0%	12.9	3.9	975.0%
Dec	0.1	3.0	0.9	900.0%	10.9	3.3	3300.0%	13.5	4.1	4100.0%	12.9	3.9	3900.0%
Jan	0.3	3.0	0.9	300.0%	10.9	3.3	1100.0%	13.5	4.1	1366.7%	12.9	3.9	1300.0%
Feb	0.7	3.0	0.9	128.6%	10.9	3.3	471.4%	13.5	4.1	585.7%	12.9	3.9	557.1%
Mar	2.6	3.0	0.9	34.6%	10.9	3.3	126.9%	13.5	4.1	157.7%	12.9	3.9	150.0%
Apr	1.2	3.0	0.9	75.0%	10.9	3.3	275.0%	13.5	4.1	341.7%	12.9	3.9	325.0%
May	0.6	3.0	0.9	150.0%	10.9	3.3	550.0%	13.5	4.1	683.3%	12.9	3.9	650.0%
Jun	0.1	3.0	0.9	900.0%	10.9	3.3	3300.0%	13.5	4.1	4100.0%	12.9	3.9	3900.0%
Jul	2.5	3.0	0.9	36.0%	10.9	3.3	132.0%	13.5	4.1	164.0%	12.9	3.9	156.0%
Aug	0.4	3.0	0.9	225.0%	10.9	3.3	825.0%	13.5	4.1	1025.0%	12.9	3.9	975.0%
Sep	2.2	3.0	0.9	40.9%	10.9	3.3	150.0%	13.5	4.1	186.4%	12.9	3.9	177.3%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Little Powder River above Dry Creek Near Weston, Wyoming (Station 06324970)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	0.3	5.3	1.6	533.3%	7.3	2.2	733.3%	7.0	2.1	700.0%	6.0	1.8	600.0%
Nov	0.4	5.3	1.6	400.0%	7.3	2.2	550.0%	7.0	2.1	525.0%	6.0	1.8	450.0%
Dec	0.5	5.3	1.6	320.0%	7.3	2.2	440.0%	7.0	2.1	420.0%	6.0	1.8	360.0%
Jan	0.4	5.3	1.6	400.0%	7.3	2.2	550.0%	7.0	2.1	525.0%	6.0	1.8	450.0%
Feb	5.7	5.3	1.6	28.1%	7.3	2.2	38.6%	7.0	2.1	36.8%	6.0	1.8	31.6%
Mar	6.5	5.3	1.6	24.6%	7.3	2.2	33.8%	7.0	2.1	32.3%	6.0	1.8	27.7%
Apr	4.8	5.3	1.6	33.3%	7.3	2.2	45.8%	7.0	2.1	43.8%	6.0	1.8	37.5%
May	7.7	5.3	1.6	20.8%	7.3	2.2	28.6%	7.0	2.1	27.3%	6.0	1.8	23.4%
Jun	3.7	5.3	1.6	43.2%	7.3	2.2	59.5%	7.0	2.1	56.8%	6.0	1.8	48.6%
Jul	1.0	5.3	1.6	160.0%	7.3	2.2	220.0%	7.0	2.1	210.0%	6.0	1.8	180.0%
Aug	2.7	5.3	1.6	59.3%	7.3	2.2	81.5%	7.0	2.1	77.8%	6.0	1.8	66.7%
Sep	0.2	5.3	1.6	800.0%	7.3	2.2	1100.0%	7.0	2.1	1050.0%	6.0	1.8	900.0%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Belle Fourche River Below Moorcroft, Wyoming (Station 06426500)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	0.4	14.4	4.3	1075.0%	13.1	3.9	975.0%	9.9	3.0	750.0%	7.3	2.2	550.0%
Nov	1.2	14.4	4.3	358.3%	13.1	3.9	325.0%	9.9	3.0	250.0%	7.3	2.2	183.3%
Dec	1.0	14.4	4.3	430.0%	13.1	3.9	390.0%	9.9	3.0	300.0%	7.3	2.2	220.0%
Jan	0.7	14.4	4.3	614.3%	13.1	3.9	557.1%	9.9	3.0	428.6%	7.3	2.2	314.3%
Feb	8.3	14.4	4.3	51.8%	13.1	3.9	47.0%	9.9	3.0	36.1%	7.3	2.2	26.5%
Mar	23.7	14.4	4.3	18.1%	13.1	3.9	16.5%	9.9	3.0	12.7%	7.3	2.2	9.3%
Apr	5.0	14.4	4.3	86.0%	13.1	3.9	78.0%	9.9	3.0	60.0%	7.3	2.2	44.0%
May	7.2	14.4	4.3	59.7%	13.1	3.9	54.2%	9.9	3.0	41.7%	7.3	2.2	30.6%
Jun	3.6	14.4	4.3	119.4%	13.1	3.9	108.3%	9.9	3.0	83.3%	7.3	2.2	61.1%
Jul	19.3	14.4	4.3	22.3%	13.1	3.9	20.2%	9.9	3.0	15.5%	7.3	2.2	11.4%
Aug	3.0	14.4	4.3	143.3%	13.1	3.9	130.0%	9.9	3.0	100.0%	7.3	2.2	73.3%
Sep	1.2	14.4	4.3	358.3%	13.1	3.9	325.0%	9.9	3.0	250.0%	7.3	2.2	183.3%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Cheyenne River Near Spencer, Wyoming (Station 06395000)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	4.2	2.5	0.8	19.0%	2.8	0.8	19.0%	2.4	0.7	16.7%	1.9	0.6	14.3%
Nov	3.6	2.5	0.8	22.2%	2.8	0.8	22.2%	2.4	0.7	19.4%	1.9	0.6	16.7%
Dec	1.1	2.5	0.8	72.7%	2.8	0.8	72.7%	2.4	0.7	63.6%	1.9	0.6	54.5%
Jan	15.5	2.5	0.8	5.2%	2.8	0.8	5.2%	2.4	0.7	4.5%	1.9	0.6	3.9%
Feb	7.7	2.5	0.8	10.4%	2.8	0.8	10.4%	2.4	0.7	9.1%	1.9	0.6	7.8%
Mar	4.6	2.5	0.8	17.4%	2.8	0.8	17.4%	2.4	0.7	15.2%	1.9	0.6	13.0%
Apr	7.9	2.5	0.8	10.1%	2.8	0.8	10.1%	2.4	0.7	8.9%	1.9	0.6	7.6%
May	28.2	2.5	0.8	2.8%	2.8	0.8	2.8%	2.4	0.7	2.5%	1.9	0.6	2.1%
Jun	12.8	2.5	0.8	6.3%	2.8	0.8	6.3%	2.4	0.7	5.5%	1.9	0.6	4.7%
Jul	3.0	2.5	0.8	26.7%	2.8	0.8	26.7%	2.4	0.7	23.3%	1.9	0.6	20.0%
Aug	0.8	2.5	0.8	100.0%	2.8	0.8	100.0%	2.4	0.7	87.5%	1.9	0.6	75.0%
Sep	4.7	2.5	0.8	17.0%	2.8	0.8	17.0%	2.4	0.7	14.9%	1.9	0.6	12.8%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

(Upper) Powder River at Arvada, Wyoming (Station 06317000)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	124.3	7.8	2.3	1.9%	26.6	8.0	6.4%	31.9	9.6	7.7%	30.0	9.0	7.2%
Nov	144.9	7.8	2.3	1.6%	26.6	8.0	5.5%	31.9	9.6	6.6%	30.0	9.0	6.2%
Dec	115.2	7.8	2.3	2.0%	26.6	8.0	6.9%	31.9	9.6	8.3%	30.0	9.0	7.8%
Jan	114.9	7.8	2.3	2.0%	26.6	8.0	7.0%	31.9	9.6	8.4%	30.0	9.0	7.8%
Feb	181.9	7.8	2.3	1.3%	26.6	8.0	4.4%	31.9	9.6	5.3%	30.0	9.0	4.9%
Mar	303.5	7.8	2.3	0.8%	26.6	8.0	2.6%	31.9	9.6	3.2%	30.0	9.0	3.0%
Apr	234.7	7.8	2.3	1.0%	26.6	8.0	3.4%	31.9	9.6	4.1%	30.0	9.0	3.8%
May	344.5	7.8	2.3	0.7%	26.6	8.0	2.3%	31.9	9.6	2.8%	30.0	9.0	2.6%
Jun	158.3	7.8	2.3	1.5%	26.6	8.0	5.1%	31.9	9.6	6.1%	30.0	9.0	5.7%
Jul	93.8	7.8	2.3	2.5%	26.6	8.0	8.5%	31.9	9.6	10.2%	30.0	9.0	9.6%
Aug	45.7	7.8	2.3	5.0%	26.6	8.0	17.5%	31.9	9.6	21.0%	30.0	9.0	19.7%
Sep	38.9	7.8	2.3	5.9%	26.6	8.0	20.6%	31.9	9.6	24.7%	30.0	9.0	23.1%

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Comparison of Coal Bed Natural Gas-Related Disposal to Receiving Drainage Hydrology Following 70% Conveyance Loss

Dry Fork Cheyenne River Near Bill, Wyoming (Station 0634700)													
Month	Receiving Drainage Streamflow (cfs)	**Alternative**											
		2003			2010			2015			2020		
		Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)	Annual CBNG Disposal (1)	Ultimate CBNG Flow (2)	Percent Increase (3)
		(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)	(cfs)	(cfs)	(%)
Oct	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!
Nov	0.02	0.00	0.00	0.00	0.09	0.03	150.0%	0.15	0.04	200.0%	0.15	0.04	200.0%
Dec	0.02	0.00	0.00	0.00	0.09	0.03	150.0%	0.15	0.04	200.0%	0.15	0.04	200.0%
Jan	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!
Feb	0.04	0.00	0.00	0.00	0.09	0.03	75.0%	0.15	0.04	100.0%	0.15	0.04	100.0%
Mar	0.08	0.00	0.00	0.00	0.09	0.03	37.5%	0.15	0.04	50.0%	0.15	0.04	50.0%
Apr	0.10	0.00	0.00	0.00	0.09	0.03	30.0%	0.15	0.04	40.0%	0.15	0.04	40.0%
May	0.07	0.00	0.00	0.00	0.09	0.03	42.9%	0.15	0.04	57.1%	0.15	0.04	57.1%
Jun	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!
Jul	0.18	0.00	0.00	0.00	0.09	0.03	16.7%	0.15	0.04	22.2%	0.15	0.04	22.2%
Aug	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!
Sep	0.00	0.00	0.00	#DIV/0!	0.09	0.03	#DIV/0!	0.15	0.04	#DIV/0!	0.15	0.04	#DIV/0!

(1) Source: ENSR, October 2005
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Dry Year Conditions

	Antelope Creek Near Teckla, Wyoming (1)	Little Powder River above Dry Creek Near Weston, Wyoming (2)	Belle Fourche River Below Moorcroft, Wyoming (1)	Cheyenne River Near Spencer, Wyoming (1)	Powder River at Arvada, Wyoming (2)	Dry Fork Cheyenne River Near Bill, Wyoming (1)
Station Number:	06364700	06324970	06426500	06386500	06317000	06365300
Month	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)	Streamflow (3)
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
Oct	22	19	26	259	7,643	0
Nov	24	26	70	216	8,622	1
Dec	9	30	61	67	7,085	1
Jan	18	24	41	953	7,065	0
Feb	38	319	464	430	10,102	2
Mar	161	399	1,460	283	18,663	5
Apr	69	284	299	473	13,967	6
May	39	474	443	1,734	21,182	4
Jun	8	220	212	762	9,420	0
Jul	153	64	1,189	187	5,767	11
Aug	27	169	183	51	2,810	0
Sep	130	13	71	280	2,314	0
Total	695	2,044	4,517	5,695	114,639	30

Note:

(1) HKM Engineering, Inc. 2002a. Northeast Wyoming River Basins Plan, Surface Water Hydrology, Tasks 3A and 3B Memorandum
(2) HKM Engineering, Inc. 2002b. Powder/Tongue River Basins Plan, Surface Water Hydrology, Tasks 3A and 3B Memorandum
(3) Average Streamflow for 1970-1999 in Acre-Feet

Summary of Annual Coal Bed Natural Gas-Related Disposal to Receiving Drainages

Sub-Basin	Annual CBNG-Related Disposal (mmgpy) [1]				Annual CBNG-Related Disposal (cfs)			
	2003	2010	2015	2020	2003	2010	2015	2020
Antelope Creek	710	2575	3185	3038	3.0	10.9	13.5	12.9
Dry Fork Cheyenne River	0	22	35	35	0.0	0.1	0.1	0.1
Little Powder River	1239	1716	1659	1421	5.3	7.3	7.0	6.0
Upper Belle Fourche River	3405	3085	2332	1713	14.4	13.1	9.9	7.3
Upper Cheyenne River	593	650	560	447	2.5	2.8	2.4	1.9
Upper Powder River	1833	6273	7532	7066	7.8	26.6	31.9	30.0
Total	7780	14321	15303	13720	33.0	60.7	64.9	58.2

Summary of Coal Bed Natural Gas-Related Discharge Water Quality

Sub-Basin	EC			SAR				Data used in Draft Report (12/2005)	
	95%lower	mean	95%upper	95%lower	mean	95%upper		EC	SAR
Antelope Creek	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927	See note	905	7.1
Dry Fork Cheyenne River	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927	See note	905	7.1
Little Powder River	1493.365	1508.912	1524.46	9.9514769	10.49116	11.03085		1271	11.1
Upper Belle Fourche River	1102.166	1109.774	1117.382	8.4426895	8.834127	9.225564		970	8.2
Upper Cheyenne River	908.5711	929.4581	950.3451	6.8012275	7.615577	8.429927		599	6.4
Upper Powder River	2160.573	2180.179	2199.786	21.615331	22.57612	23.53691		2163	19.5

note: no data were obtained specific to these sub-basins(antelope creek and dry fork cheyenne river)

Summary of Conveyance Losses

Sub-Basin	EC
Antelope Creek	0.7
Dry Fork Cheyenne River	0.7
Little Powder River	0.7
Upper Belle Fourche River	0.7
Upper Cheyenne River	0.7
Upper Powder River	0.7

Water Quality Standards

	Most Restrictive		Least Restrictive		
	EC	SAR	EC	SAR	
Antelope Creek	2,000	10	2,500	10	wdeq
Dry Fork Cheyenne River	2,000	10	2,500	10	wdeq
Little Powder River	2,000	5	2,500	9.75	montana deq standards
Upper Belle Fourche River	2,000	6	2,500	10	sar (6) from south dakota reg's
Upper Cheyenne River	2,000	10	2,500	10	wdeq
Upper Powder River	2,000	5	2,500	9.75	montana deq standards

Background Water Quality Data (Greystone, 2003)

	Antelope Creek		Upper Belle Fourche		Upper Cheyenne		Upper Powder		Little Powder		Dry Fork Cheyenne	
	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR
Jan	2335	2.74	2887	6.29	4229	8.58	2482	6.4	2953	6.33	2335	2.74
Feb	2251	2.71	1907	4.08	3911	8.01	2366	6.12	2477	5.57	2251	2.71
Mar	1782	2.52	1564	3.64	4127	8.66	2051	5.28	1785	4.44	1782	2.52
Apr	1949	2.77	1722	4.34	3630	7.87	2213	5.84	2457	5.55	1949	2.77
May	1800	2.82	1532	3.81	3155	6.88	1803	4.92	2013	4.81	1800	2.82
Jun	2005	2.8	1821	3.98	2895	5.93	1797	4.76	2333	5.29	2005	2.8
Jul	1661	2.48	1182	3.1	2250	5.69	2716	6.79	2174	5.29	1661	2.48
Aug	1684	2.47	1955	5.06	1972	4.82	2992	6.97	2860	6.57	1684	2.47
Sep	2214	2.52	2231	5.76	2271	5.63	3400	7.83	2810	6.44	2214	2.52
Oct	2354	2.6	2346	5.75	2916	6.46	2537	6.71	2289	5.73	2354	2.6
Nov	2460	2.74	2877	7.02	3565	7.22	2650	6.42	3044	6.7	2460	2.74
Dec	2372	2.79	2755	6.77	3405	7.39	2906	6.61	3300	6.94	2372	2.79

APPENDIX C

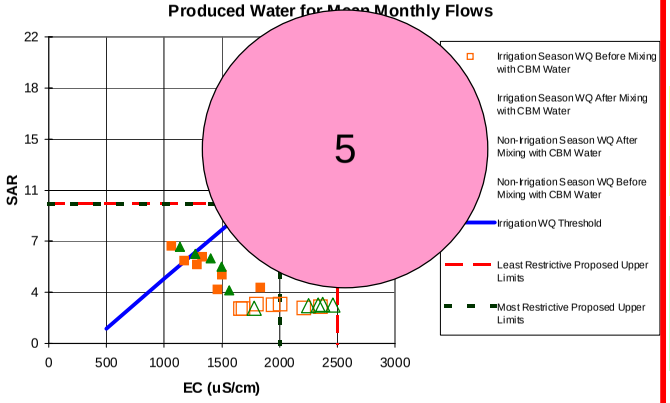
SPREADSHEET MODEL RESULTS

APPENDIX C-1

NORMAL YEAR CONDITIONS

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin



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		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	CBNG Discharge Quality EC (uS/cm) 95% Lower	EC (uS/cm) Mean	EC (uS/cm) 95% upper	SAR (--) 95% Lower	SAR (--) Mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)	
				909	929	950	6.80	7.62	8.43			
Non-Irrigation Season	Nov	0.9	0.40	1386				6.12	6.68	2460	2.74	Non-Irrigation Season
	Dec	0.9	0.15	1118				6.93	7.62	2372	2.79	
	Jan	0.9	0.29	1256				6.43	7.04	2335	2.74	
	Feb	0.9	0.68	1486				5.50	5.97	2251	2.71	
	Mar	0.9	2.60	1557				3.83	4.04	1782	2.52	
Irrigation Season	Apr	0.9	1.15	1492	150			4.90	5.25	1949	2.77	Irrigation Season
	May	0.9	0.63	1276	1288		16	5.64	6.12	1800	2.82	
	Jun	0.9	0.13	1047	1065		6.30	7.01	7.72	2005	2.8	
	Jul	0.9	2.47	1460	1466	1471	3.63	3.85	4.07	1661	2.48	
	Aug	0.9	0.44	1163	1177	1191	5.38	5.93	6.47	1684	2.47	
	Sep	0.9	2.17	1831	1837	1844	3.78	4.01	4.25	2214	2.52	
	Oct	0.9	0.35	1313	1328	1343	5.62	6.21	6.80	2354	2.6	

4

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and W

Drainage	Stream Gauge Location	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teck	0.7	0.9	0.9

3

Mean Monthly Discharge			
		Days	cfs
O		31	0.35
		30	0.40
		31	0.15
		31	0.29
		28	0.68
		31	2.60
		30	1.15
		31	0.63
		30	0.13
Ju		31	2.47
Aug		31	0.44
Sep	130	30	2.17

2

Plotting Position: Most and Least Restrictive Limits			
	EC	SAR	
	0		
Least Restrictiv	2500		
	2500		
	0		
Most Restrictiv	2000		
	2000		

Irrigation WQ Threshold Line	
500	1.07
1000	4.62
1500	8.17
2990	18.75

1

See following page for descriptions of chart sections

Descriptions of Chart Sections

1

Section 1: The values in this section are used to plot lines within the graph delineating themost restrictive, least restrictive, and the irrigation water quality threshold. The most restrictive and least restrictve limits data were obtained from the pertinent regulatory agency. They are tabulated in the spreadsheet table named "CBNG Discharge Parameters" and referenced herein.

2

Section 2: This section tabulates the mean monthly stream flow for each site. These data are referenced from the table located in Section 4 and used in the mixing calculations.

3

Section 3: This section computes the amount of CBM water which ultimately reaches the receiving waters following conveyance losses. The table is initially populated by reference to worksheet CBNG Discharge Parameters. Output from this table is then referenced by Section 4 where it is used in mixing computations

4

Section 4: This section is where the mixing calculations occur. CBM water with a given water quality is mixed with a background water with its own water quality. Using simple mixing computations described in the table, downstream water quality is estimated. Irrigation season is displayed in the area shaded green; non-irrigation season is shaded yellow.

5

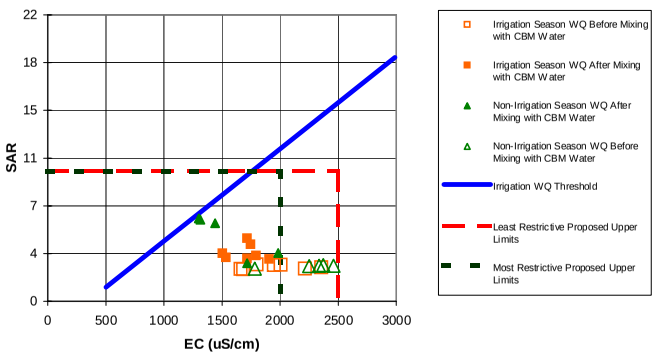
Section 5: This section presents the summary graph illustrating irrigation suitability and the water quality data relative to the "limits". The graph references "Limits" data from Section 1 and pertinent water quality data from section 4.

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality [1]						Background Water Quality	
		CBM Flow	StreamFlow	EC			SAR			EC	SAR
		(cfs)	(cfs)	(uS/cm)			(--)			(uS/cm)	(--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	0.9	0.45	1426	1440	1454	5.45	5.99	6.53	2460	2.74
	Dec	0.9	0.31	1283	1299	1315	5.77	6.38	6.98	2372	2.79
	Jan	0.9	0.34	1300	1315	1330	5.69	6.28	6.87	2335	2.74
	Feb	0.9	3.55	1979	1984	1988	3.54	3.70	3.87	2251	2.71
	Mar	0.9	10.61	1714	1715	1717	2.85	2.92	2.98	1782	2.52
Irrigation Season	Apr	0.9	5.03	1791	1794	1797	3.38	3.51	3.63	1949	2.77
	May	0.9	8.37	1713	1715	1718	3.21	3.29	3.36	1800	2.82
	Jun	0.9	8.85	1904	1906	1908	3.17	3.24	3.32	2005	2.8
	Jul	0.9	4.32	1531	1535	1538	3.23	3.37	3.51	1661	2.48
	Aug	0.9	2.89	1500	1505	1510	3.50	3.69	3.89	1684	2.47
	Sep	0.9	1.57	1738	1746	1754	4.08	4.38	4.67	2214	2.52
	Oct	0.9	1.11	1707	1716	1725	4.48	4.85	5.21	2354	2.6

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	3.0	0.7	0.9	0.9

Flow In Antelope Creek

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	69	31	1.11
Nov	27	30	0.45
Dec	19	31	0.31
Jan	21	31	0.34
Feb	199	28	3.55
Mar	658	31	10.61
Apr	302	30	5.03
May	519	31	8.37
Jun	531	30	8.85
Jul	268	31	4.32
Aug	179	31	2.89
Sep	94	30	1.57

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
	0	10
Most Restrictive	2000	10
	2000	0

Irrigation WQ Threshold Line

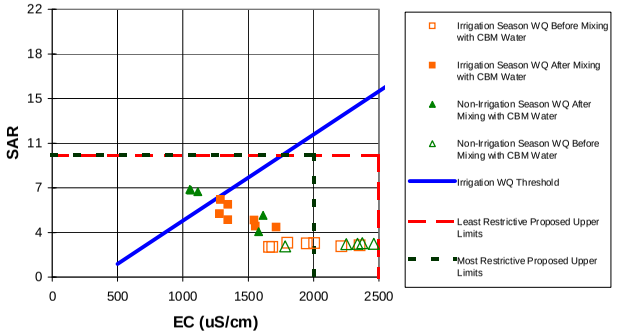
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% Lower	Mixed Water Quality EC (uS/cm) Mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% Lower	Mixed Water Quality SAR (--) Mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	3.3	0.45	1095	1113	1132	6.31	7.03	7.75	2460	2.74
	Dec	3.3	0.31	1034	1053	1072	6.46	7.20	7.95	2372	2.79
	Jan	3.3	0.34	1042	1061	1080	6.42	7.16	7.90	2335	2.74
	Feb	3.3	3.55	1604	1614	1624	4.68	5.07	5.47	2251	2.71
	Mar	3.3	10.61	1575	1580	1585	3.54	3.73	3.92	1782	2.52
Irrigation Season	Apr	3.3	5.03	1537	1545	1553	4.37	4.69	5.01	1949	2.77
	May	3.3	8.37	1548	1554	1560	3.95	4.18	4.41	1800	2.82
	Jun	3.3	8.85	1707	1713	1719	3.89	4.11	4.33	2005	2.8
	Jul	3.3	4.32	1335	1344	1353	4.35	4.70	5.06	1661	2.48
	Aug	3.3	2.89	1271	1282	1293	4.78	5.21	5.65	1684	2.47
	Sep	3.3	1.57	1329	1344	1358	5.42	5.97	6.52	2214	2.52
	Oct	3.3	1.11	1272	1288	1304	5.74	6.35	6.96	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	10.9	0.7	3.3	3.3

Flow In Antelope Creek

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	69	31	1.11
Nov	27	30	0.45
Dec	19	31	0.31
Jan	21	31	0.34
Feb	199	28	3.55
Mar	658	31	10.61
Apr	302	30	5.03
May	519	31	8.37
Jun	531	30	8.85
Jul	268	31	4.32
Aug	179	31	2.89
Sep	94	30	1.57

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

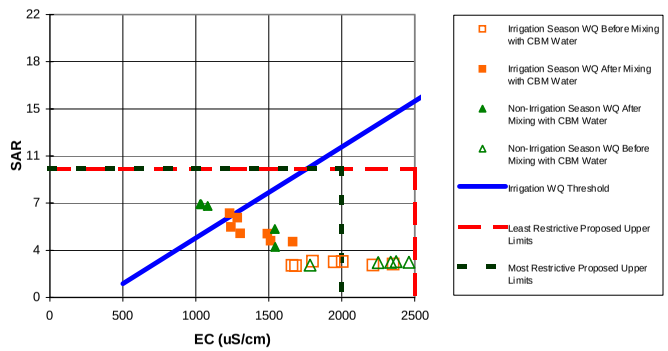
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	4.1	0.45	1062	1081	1100	6.40	7.13	7.87	2460	2.74
	Dec	4.1	0.31	1011	1031	1050	6.52	7.28	8.03	2372	2.79
	Jan	4.1	0.34	1018	1037	1056	6.49	7.24	7.99	2335	2.74
	Feb	4.1	3.55	1532	1543	1554	4.90	5.34	5.78	2251	2.71
	Mar	4.1	10.61	1539	1544	1550	3.71	3.94	4.17	1782	2.52
Irrigation Season	Apr	4.1	5.03	1482	1491	1501	4.58	4.95	5.31	1949	2.77
	May	4.1	8.37	1507	1514	1521	4.13	4.40	4.66	1800	2.82
	Jun	4.1	8.85	1658	1664	1671	4.07	4.32	4.58	2005	2.8
	Jul	4.1	4.32	1295	1305	1315	4.58	4.98	5.38	1661	2.48
	Aug	4.1	2.89	1229	1241	1254	5.01	5.49	5.97	1684	2.47
	Sep	4.1	1.57	1270	1285	1300	5.62	6.20	6.79	2214	2.52
	Oct	4.1	1.11	1217	1233	1249	5.91	6.55	7.19	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	13.5	0.7	4.1	4.1

Flow In Antelope Creek

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	69	31	1.11
Nov	27	30	0.45
Dec	19	31	0.31
Jan	21	31	0.34
Feb	199	28	3.55
Mar	658	31	10.61
Apr	302	30	5.03
May	519	31	8.37
Jun	531	30	8.85
Jul	268	31	4.32
Aug	179	31	2.89
Sep	94	30	1.57

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

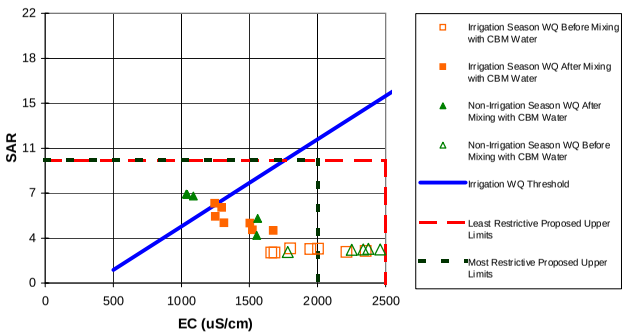
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2020
Stream Water Quality Before and After Mixing with CBM
Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% Lower	Mixed Water Quality EC (uS/cm) Mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% Lower	Mixed Water Quality SAR (--) Mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	3.9	0.45	1069	1088	1107	6.38	7.11	7.84	2460	2.74
	Dec	3.9	0.31	1016	1036	1055	6.51	7.26	8.01	2372	2.79
	Jan	3.9	0.34	1023	1042	1061	6.48	7.22	7.97	2335	2.74
	Feb	3.9	3.55	1548	1559	1570	4.85	5.28	5.70	2251	2.71
	Mar	3.9	10.61	1547	1553	1558	3.67	3.89	4.11	1782	2.52
Irrigation Season	Apr	3.9	5.03	1495	1504	1513	4.53	4.89	5.24	1949	2.77
	May	3.9	8.37	1517	1523	1530	4.09	4.34	4.60	1800	2.82
	Jun	3.9	8.85	1670	1676	1682	4.02	4.27	4.52	2005	2.8
	Jul	3.9	4.32	1304	1314	1324	4.53	4.92	5.30	1661	2.48
	Aug	3.9	2.89	1239	1251	1263	4.96	5.43	5.89	1684	2.47
	Sep	3.9	1.57	1283	1298	1313	5.57	6.15	6.73	2214	2.52
	Oct	3.9	1.11	1229	1245	1261	5.87	6.50	7.14	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	12.9	0.7	3.9	3.9

Flow In Antelope Creek

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	69	31	1.11
Nov	27	30	0.45
Dec	19	31	0.31
Jan	21	31	0.34
Feb	199	28	3.55
Mar	658	31	10.61
Apr	302	30	5.03
May	519	31	8.37
Jun	531	30	8.85
Jul	268	31	4.32
Aug	179	31	2.89
Sep	94	30	1.57

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

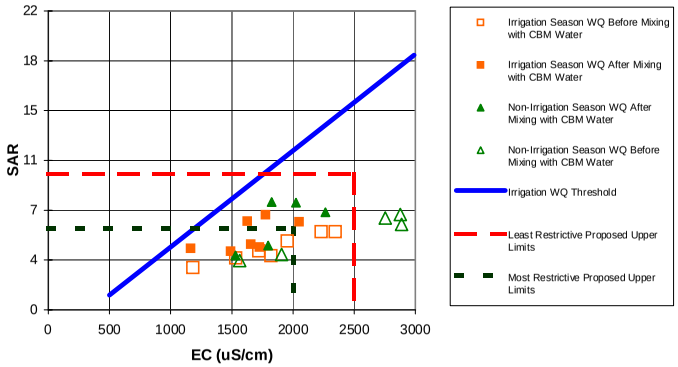
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
	EC (uS/cm)			SAR (--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	4.3	4.60	2019	2023	2027	7.71	7.90	8.09	2877	7.02
	Dec	4.3	3.31	1821	1825	1830	7.72	7.94	8.16	2755	6.77
	Jan	4.3	7.97	2262	2264	2267	7.04	7.18	7.32	2887	6.29
	Feb	4.3	27.02	1797	1798	1799	4.68	4.73	4.79	1907	4.08
	Mar	4.3	54.94	1530	1531	1532	3.99	4.02	4.05	1564	3.64
Irrigation Season	Apr	4.3	35.47	1655	1656	1657	4.78	4.83	4.87	1722	4.34
	May	4.3	39.03	1489	1490	1491	4.27	4.31	4.35	1532	3.81
	Jun	4.3	27.92	1725	1726	1727	4.58	4.63	4.68	1821	3.98
	Jul	4.3	12.97	1162	1164	1166	4.43	4.53	4.63	1182	3.1
	Aug	4.3	6.74	1623	1626	1629	6.38	6.53	6.68	1955	5.06
	Sep	4.3	6.27	1772	1775	1778	6.85	7.01	7.17	2231	5.76
	Oct	4.3	13.65	2048	2050	2052	6.40	6.49	6.58	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	14.4	0.7	4.3	4.3

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	846	31	13.65
Nov	276	30	4.60
Dec	205	31	3.31
Jan	494	31	7.97
Feb	1513	28	27.02
Mar	3406	31	54.94
Apr	2128	30	35.47
May	2420	31	39.03
Jun	1675	30	27.92
Jul	804	31	12.97
Aug	418	31	6.74
Sep	376	30	6.27

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

Irrigation WQ Threshold Line

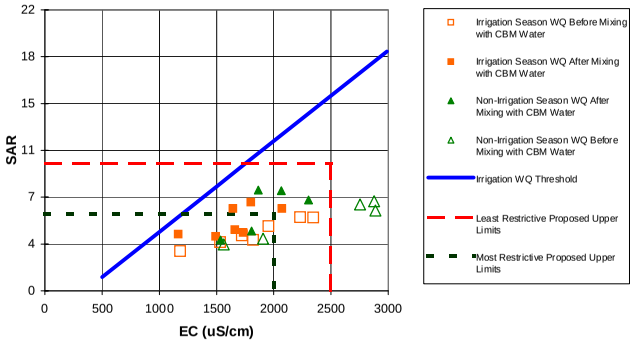
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
	EC (uS/cm)			SAR (--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	3.9	4.60	2063	2066	2070	7.67	7.85	8.03	2877	7.02
	Dec	3.9	3.31	1861	1865	1869	7.67	7.89	8.10	2755	6.77
	Jan	3.9	7.97	2301	2303	2306	7.00	7.13	7.25	2887	6.29
	Feb	3.9	27.02	1805	1806	1807	4.63	4.68	4.73	1907	4.08
	Mar	3.9	54.94	1533	1534	1534	3.96	3.98	4.01	1564	3.64
Irrigation Season	Apr	3.9	35.47	1661	1661	1662	4.75	4.79	4.82	1722	4.34
	May	3.9	39.03	1493	1494	1494	4.23	4.27	4.30	1532	3.81
	Jun	3.9	27.92	1733	1734	1735	4.53	4.57	4.62	1821	3.98
	Jul	3.9	12.97	1164	1165	1167	4.34	4.43	4.52	1182	3.1
	Aug	3.9	6.74	1642	1645	1648	6.30	6.44	6.59	1955	5.06
	Sep	3.9	6.27	1798	1801	1804	6.79	6.94	7.09	2231	5.76
	Oct	3.9	13.65	2070	2071	2073	6.35	6.44	6.52	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	13.1	0.7	3.9	3.9

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	846	31	13.65
Nov	276	30	4.60
Dec	205	31	3.31
Jan	494	31	7.97
Feb	1513	28	27.02
Mar	3406	31	54.94
Apr	2128	30	35.47
May	2420	31	39.03
Jun	1675	30	27.92
Jul	804	31	12.97
Aug	418	31	6.74
Sep	376	30	6.27

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

Irrigation WQ Threshold Line

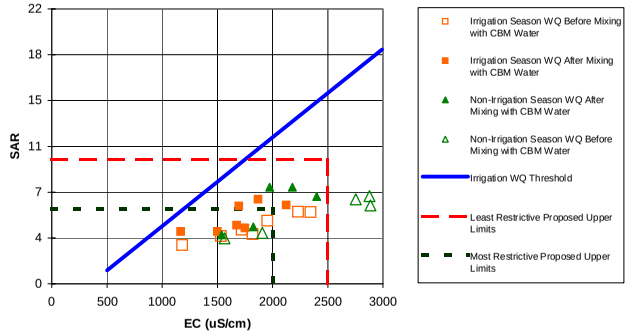
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
	EC (uS/cm)			SAR (--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	3.0	4.60	2176	2179	2182	7.58	7.74	7.89	2877	7.02
	Dec	3.0	3.31	1969	1973	1976	7.57	7.75	7.94	2755	6.77
	Jan	3.0	7.97	2399	2401	2403	6.88	6.99	7.09	2887	6.29
	Feb	3.0	27.02	1827	1827	1828	4.52	4.56	4.59	1907	4.08
	Mar	3.0	54.94	1540	1540	1541	3.89	3.91	3.93	1564	3.64
Irrigation Season	Apr	3.0	35.47	1674	1674	1675	4.66	4.69	4.72	1722	4.34
	May	3.0	39.03	1501	1502	1502	4.14	4.17	4.20	1532	3.81
	Jun	3.0	27.92	1751	1752	1753	4.41	4.45	4.49	1821	3.98
	Jul	3.0	12.97	1167	1168	1170	4.10	4.18	4.25	1182	3.1
	Aug	3.0	6.74	1692	1695	1697	6.10	6.22	6.34	1955	5.06
	Sep	3.0	6.27	1866	1868	1871	6.63	6.75	6.88	2231	5.76
	Oct	3.0	13.65	2122	2123	2125	6.24	6.31	6.38	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	9.9	0.7	3.0	3.0

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	846	31	13.65
Nov	276	30	4.60
Dec	205	31	3.31
Jan	494	31	7.97
Feb	1513	28	27.02
Mar	3406	31	54.94
Apr	2128	30	35.47
May	2420	31	39.03
Jun	1675	30	27.92
Jul	804	31	12.97
Aug	418	31	6.74
Sep	376	30	6.27

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
	0	6
Most Restrictive	2000	6
	2000	0

Irrigation WQ Threshold Line

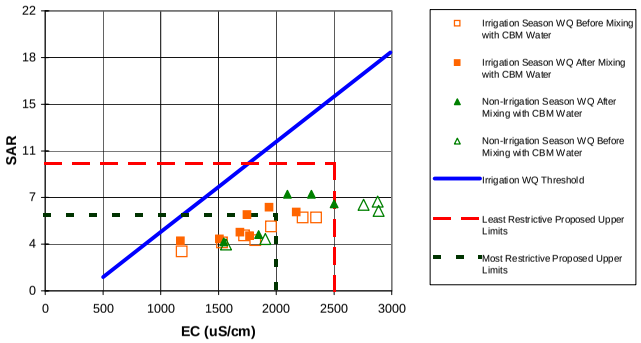
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
	EC (uS/cm)			SAR (--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	2.2	4.60	2303	2305	2308	7.48	7.61	7.73	2877	7.02
	Dec	2.2	3.31	2095	2098	2101	7.44	7.59	7.75	2755	6.77
	Jan	2.2	7.97	2501	2503	2504	6.76	6.84	6.93	2887	6.29
	Feb	2.2	27.02	1846	1847	1848	4.41	4.44	4.47	1907	4.08
	Mar	2.2	54.94	1546	1547	1547	3.82	3.84	3.86	1564	3.64
Irrigation Season	Apr	2.2	35.47	1686	1686	1687	4.58	4.60	4.63	1722	4.34
	May	2.2	39.03	1509	1509	1510	4.06	4.08	4.10	1532	3.81
	Jun	2.2	27.92	1768	1769	1770	4.31	4.33	4.36	1821	3.98
	Jul	2.2	12.97	1170	1172	1173	3.87	3.93	3.99	1182	3.1
	Aug	2.2	6.74	1745	1747	1749	5.89	5.99	6.09	1955	5.06
	Sep	2.2	6.27	1938	1940	1942	6.46	6.56	6.66	2231	5.76
	Oct	2.2	13.65	2173	2174	2175	6.12	6.18	6.23	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	7.3	0.7	2.2	2.2

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	846	31	13.65
Nov	276	30	4.60
Dec	205	31	3.31
Jan	494	31	7.97
Feb	1513	28	27.02
Mar	3406	31	54.94
Apr	2128	30	35.47
May	2420	31	39.03
Jun	1675	30	27.92
Jul	804	31	12.97
Aug	418	31	6.74
Sep	376	30	6.27

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

Irrigation WQ Threshold Line

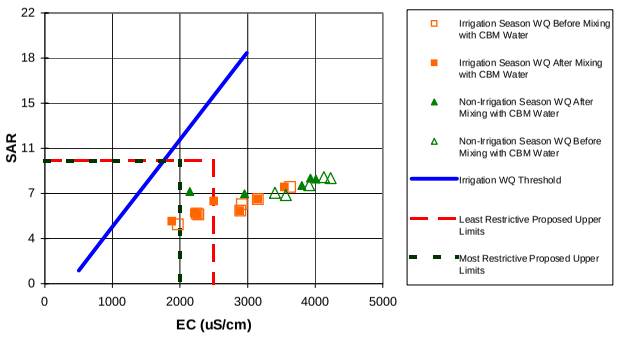
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.8	2.65	2949	2954	2959	7.12	7.31	7.50	3565	7.22
	Dec	0.8	0.77	2133	2144	2154	7.09	7.50	7.92	3405	7.39
	Jan	0.8	11.21	4008	4009	4011	8.46	8.52	8.57	4229	8.58
	Feb	0.8	21.36	3803	3803	3804	7.97	8.00	8.03	3911	8.01
	Mar	0.8	12.06	3927	3928	3929	8.54	8.60	8.65	4127	8.66
Irrigation Season	Apr	0.8	25.57	3547	3548	3549	7.84	7.86	7.89	3630	7.87
	May	0.8	238.60	3147	3148	3148	6.88	6.88	6.89	3155	6.88
	Jun	0.8	114.82	2881	2881	2882	5.94	5.94	5.95	2895	5.93
	Jul	0.8	31.26	2217	2217	2218	5.72	5.74	5.76	2250	5.69
	Aug	0.8	8.24	1878	1880	1882	5.00	5.07	5.14	1972	4.82
	Sep	0.8	55.42	2252	2252	2252	5.65	5.66	5.67	2271	5.63
	Oct	0.8	3.00	2493	2498	2502	6.53	6.70	6.87	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.5	0.7	0.8	0.8

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	186	31	3.00
Nov	159	30	2.65
Dec	48	31	0.77
Jan	695	31	11.21
Feb	1196	28	21.36
Mar	748	31	12.06
Apr	1534	30	25.57
May	14793	31	238.60
Jun	6889	30	114.82
Jul	1938	31	31.26
Aug	511	31	8.24
Sep	3325	30	55.42

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

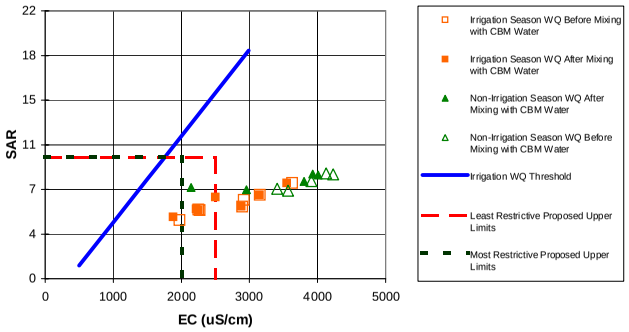
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.8	2.65	2949	2954	2959	7.12	7.31	7.50	3565	7.22
	Dec	0.8	0.77	2133	2144	2154	7.09	7.50	7.92	3405	7.39
	Jan	0.8	11.21	4008	4009	4011	8.46	8.52	8.57	4229	8.58
	Feb	0.8	21.36	3803	3803	3804	7.97	8.00	8.03	3911	8.01
	Mar	0.8	12.06	3927	3928	3929	8.54	8.60	8.65	4127	8.66
Irrigation Season	Apr	0.8	25.57	3547	3548	3549	7.84	7.86	7.89	3630	7.87
	May	0.8	238.60	3147	3148	3148	6.88	6.88	6.89	3155	6.88
	Jun	0.8	114.82	2881	2881	2882	5.94	5.94	5.95	2895	5.93
	Jul	0.8	31.26	2217	2217	2218	5.72	5.74	5.76	2250	5.69
	Aug	0.8	8.24	1878	1880	1882	5.00	5.07	5.14	1972	4.82
	Sep	0.8	55.42	2252	2252	2252	5.65	5.66	5.67	2271	5.63
	Oct	0.8	3.00	2493	2498	2502	6.53	6.70	6.87	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.8	0.7	0.8	0.8

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	186	31	3.00
Nov	159	30	2.65
Dec	48	31	0.77
Jan	695	31	11.21
Feb	1196	28	21.36
Mar	748	31	12.06
Apr	1534	30	25.57
May	14793	31	238.60
Jun	6889	30	114.82
Jul	1938	31	31.26
Aug	511	31	8.24
Sep	3325	30	55.42

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

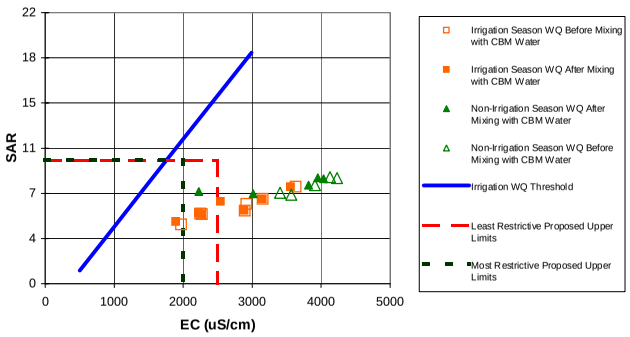
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	SAR (--)
Non-Irrigation Season	Nov	0.7	2.65	3010	3014	3019	7.13	7.30	7.47	3565	7.22
	Dec	0.7	0.77	2216	2226	2236	7.11	7.50	7.89	3405	7.39
	Jan	0.7	11.21	4034	4035	4036	8.48	8.52	8.57	4229	8.58
	Feb	0.7	21.36	3816	3816	3817	7.97	8.00	8.02	3911	8.01
	Mar	0.7	12.06	3950	3952	3953	8.56	8.60	8.65	4127	8.66
Irrigation Season	Apr	0.7	25.57	3557	3558	3559	7.84	7.86	7.88	3630	7.87
	May	0.7	238.60	3148	3148	3149	6.88	6.88	6.88	3155	6.88
	Jun	0.7	114.82	2883	2883	2883	5.94	5.94	5.95	2895	5.93
	Jul	0.7	31.26	2221	2221	2222	5.71	5.73	5.75	2250	5.69
	Aug	0.7	8.24	1889	1890	1892	4.98	5.04	5.10	1972	4.82
	Sep	0.7	55.42	2254	2254	2255	5.64	5.65	5.66	2271	5.63
	Oct	0.7	3.00	2536	2540	2544	6.52	6.68	6.83	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.4	0.7	0.7	0.7

Flow In Belle Fourche River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	186	31	3.00
Nov	159	30	2.65
Dec	48	31	0.77
Jan	695	31	11.21
Feb	1196	28	21.36
Mar	748	31	12.06
Apr	1534	30	25.57
May	14793	31	238.60
Jun	6889	30	114.82
Jul	1938	31	31.26
Aug	511	31	8.24
Sep	3325	30	55.42

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

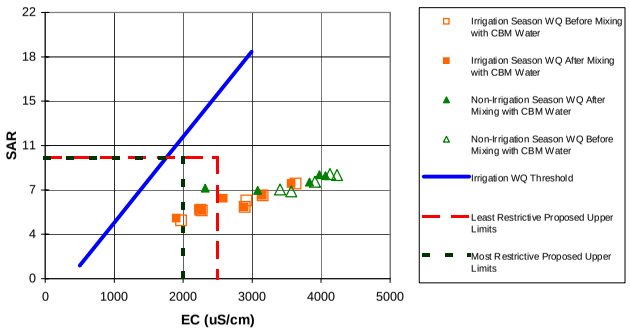
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.6	2.65	3075	3078	3082	7.14	7.29	7.44	3565	7.22
	Dec	0.6	0.77	2312	2321	2330	7.13	7.49	7.85	3405	7.39
	Jan	0.6	11.21	4060	4061	4062	8.49	8.53	8.57	4229	8.58
	Feb	0.6	21.36	3829	3830	3830	7.98	8.00	8.02	3911	8.01
	Mar	0.6	12.06	3974	3975	3976	8.57	8.61	8.65	4127	8.66
Irrigation Season	Apr	0.6	25.57	3568	3568	3569	7.85	7.86	7.88	3630	7.87
	May	0.6	238.60	3149	3149	3149	6.88	6.88	6.88	3155	6.88
	Jun	0.6	114.82	2885	2885	2885	5.93	5.94	5.94	2895	5.93
	Jul	0.6	31.26	2225	2225	2226	5.71	5.73	5.74	2250	5.69
	Aug	0.6	8.24	1900	1901	1903	4.95	5.01	5.07	1972	4.82
	Sep	0.6	55.42	2256	2257	2257	5.64	5.65	5.66	2271	5.63
	Oct	0.6	3.00	2581	2585	2588	6.52	6.65	6.79	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	1.9	0.7	0.6	0.6

Flow In Upper Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	186	31	3.00
Nov	159	30	2.65
Dec	48	31	0.77
Jan	695	31	11.21
Feb	1196	28	21.36
Mar	748	31	12.06
Apr	1534	30	25.57
May	14793	31	238.60
Jun	6889	30	114.82
Jul	1938	31	31.26
Aug	511	31	8.24
Sep	3325	30	55.42

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

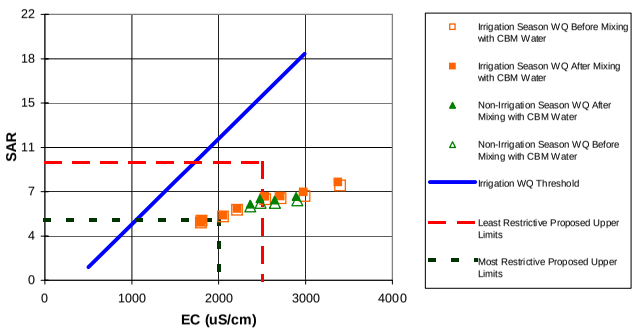
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54

Upper Powder River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	2.3	155.72	2643	2643	2643	6.64	6.66	6.67	2650	6.42
	Dec	2.3	111.65	2891	2891	2892	6.91	6.93	6.95	2906	6.61
	Jan	2.3	103.61	2475	2475	2476	6.73	6.75	6.77	2482	6.4
	Feb	2.3	216.80	2364	2364	2364	6.28	6.29	6.30	2366	6.12
Irrigation Season	Mar	2.3	388.05	2052	2052	2052	5.38	5.38	5.39	2051	5.28
	Apr	2.3	388.48	2213	2213	2213	5.93	5.94	5.94	2213	5.84
	May	2.3	718.77	1804	1804	1804	4.97	4.98	4.98	1803	4.92
	Jun	2.3	633.57	1798	1798	1798	4.82	4.82	4.83	1797	4.76
	Jul	2.3	215.00	2710	2710	2711	6.95	6.96	6.97	2716	6.79
	Aug	2.3	106.58	2974	2975	2975	7.28	7.30	7.32	2992	6.97
	Sep	2.3	109.05	3374	3375	3375	8.11	8.13	8.15	3400	7.83
	Oct	2.3	159.26	2532	2532	2532	6.92	6.94	6.95	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	7.8	0.7	2.3	2.3

Flow In Upper Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9874	31	159.26
Nov	9343	30	155.72
Dec	6922	31	111.65
Jan	6424	31	103.61
Feb	12141	28	216.80
Mar	24059	31	388.05
Apr	23309	30	388.48
May	44564	31	718.77
Jun	38014	30	633.57
Jul	13330	31	215.00
Aug	6608	31	106.58
Sep	6543	30	109.05

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

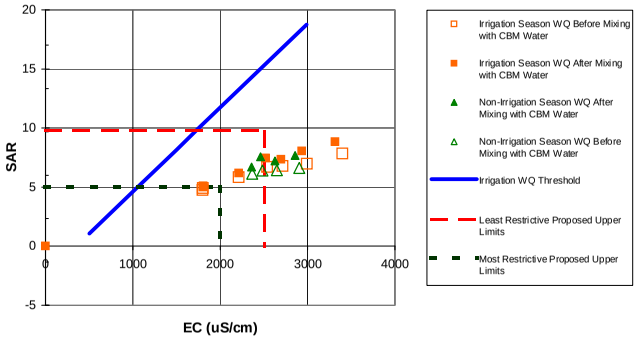
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54

Upper Powder River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	8.0	155.72	2626	2627	2628	7.16	7.21	7.26	2650	6.42
	Dec	8.0	111.65	2856	2857	2859	7.61	7.68	7.74	2906	6.61
	Jan	8.0	103.61	2459	2460	2462	7.49	7.56	7.63	2482	6.4
	Feb	8.0	216.80	2359	2359	2360	6.67	6.71	6.74	2366	6.12
Irrigation Season	Mar	0.0	-0.43	0	0	0	0.00	0.00	0.00	-162	-0.56
	Apr	8.0	388.48	2212	2212	2213	6.16	6.18	6.20	2213	5.84
	May	8.0	718.77	1807	1807	1807	5.10	5.11	5.12	1803	4.92
	Jun	8.0	633.57	1802	1802	1802	4.97	4.98	4.99	1797	4.76
	Jul	8.0	215.00	2696	2697	2697	7.32	7.36	7.39	2716	6.79
	Aug	8.0	106.58	2934	2935	2937	7.99	8.06	8.13	2992	6.97
	Sep	8.0	109.05	3315	3317	3318	8.77	8.84	8.90	3400	7.83
	Oct	8.0	159.26	2519	2520	2521	7.42	7.47	7.51	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	26.6	0.7	8.0	8.0

Flow In Upper Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9874	31	159.26
Nov	9343	30	155.72
Dec	6922	31	111.65
Jan	6424	31	103.61
Feb	12141	28	216.80
Mar	24059	31	388.05
Apr	23309	30	388.48
May	44564	31	718.77
Jun	38014	30	633.57
Jul	13330	31	215.00
Aug	6608	31	106.58
Sep	6543	30	109.05

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

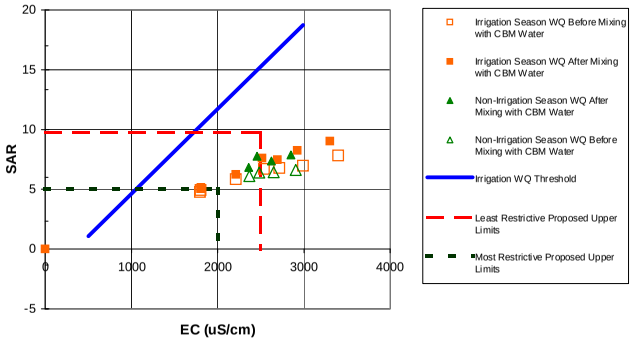
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54

Upper Powder River 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	9.6	155.72	2622	2623	2624	7.30	7.36	7.41	2650	6.42
	Dec	9.6	111.65	2847	2849	2850	7.80	7.87	7.95	2906	6.61
	Jan	9.6	103.61	2455	2456	2458	7.69	7.77	7.85	2482	6.4
	Feb	9.6	216.80	2357	2358	2359	6.78	6.82	6.86	2366	6.12
Irrigation Season	Mar	0.0	-0.43	0	0	0	0.00	0.00	0.00	-162	-0.56
	Apr	9.6	388.48	2212	2212	2213	6.22	6.24	6.27	2213	5.84
	May	9.6	718.77	1808	1808	1808	5.14	5.15	5.17	1803	4.92
	Jun	9.6	633.57	1802	1803	1803	5.01	5.03	5.04	1797	4.76
	Jul	9.6	215.00	2692	2693	2694	7.42	7.46	7.51	2716	6.79
	Aug	9.6	106.58	2923	2925	2927	8.18	8.26	8.34	2992	6.97
	Sep	9.6	109.05	3300	3301	3303	8.95	9.02	9.10	3400	7.83
	Oct	9.6	159.26	2516	2517	2518	7.56	7.61	7.67	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	31.9	0.7	9.6	9.6

Flow In Upper Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9874	31	159.26
Nov	9343	30	155.72
Dec	6922	31	111.65
Jan	6424	31	103.61
Feb	12141	28	216.80
Mar	24059	31	388.05
Apr	23309	30	388.48
May	44564	31	718.77
Jun	38014	30	633.57
Jul	13330	31	215.00
Aug	6608	31	106.58
Sep	6543	30	109.05

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

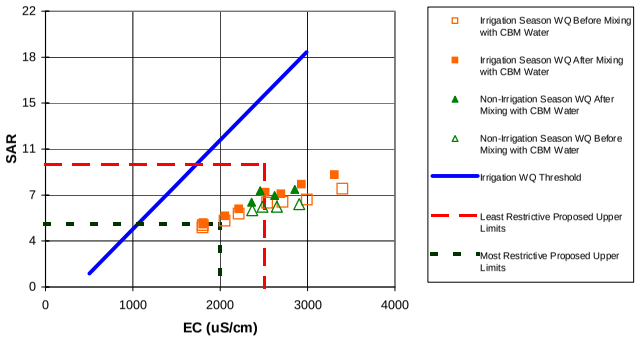
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54

Upper Powder River 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC (uS/cm) mean	EC (uS/cm) 95% upper	SAR (--) 95% lower	SAR (--) mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	9.0	155.72	2623	2624	2625	7.25	7.30	7.36	2650	6.42
	Dec	9.0	111.65	2850	2852	2853	7.73	7.80	7.87	2906	6.61
	Jan	9.0	103.61	2456	2458	2459	7.62	7.69	7.77	2482	6.4
	Feb	9.0	216.80	2358	2359	2359	6.74	6.78	6.81	2366	6.12
Irrigation Season	Mar	9.0	388.05	2053	2054	2054	5.65	5.67	5.69	2051	5.28
	Apr	9.0	388.48	2212	2212	2213	6.20	6.22	6.24	2213	5.84
	May	9.0	718.77	1807	1808	1808	5.13	5.14	5.15	1803	4.92
	Jun	9.0	633.57	1802	1802	1803	5.00	5.01	5.02	1797	4.76
	Jul	9.0	215.00	2694	2694	2695	7.39	7.42	7.46	2716	6.79
	Aug	9.0	106.58	2927	2929	2930	8.11	8.19	8.26	2992	6.97
	Sep	9.0	109.05	3306	3307	3308	8.88	8.95	9.03	3400	7.83
	Oct	9.0	159.26	2517	2518	2519	7.51	7.56	7.61	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	30.0	0.7	9.0	9.0

Flow In Upper Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9874	31	159.26
Nov	9343	30	155.72
Dec	6922	31	111.65
Jan	6424	31	103.61
Feb	12141	28	216.80
Mar	24059	31	388.05
Apr	23309	30	388.48
May	44564	31	718.77
Jun	38014	30	633.57
Jul	13330	31	215.00
Aug	6608	31	106.58
Sep	6543	30	109.05

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

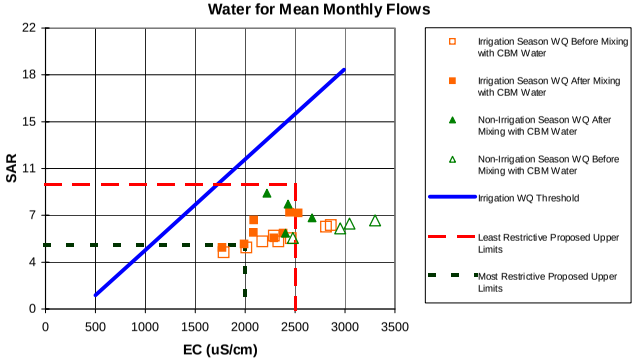
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC (uS/cm) mean	EC (uS/cm) 95% upper	SAR (--) 95% lower	SAR (--) mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	1.6	2.40	2424	2430	2436	8.00	8.22	8.43	3044	6.7
	Dec	1.6	1.05	2209	2219	2228	8.76	9.08	9.41	3300	6.94
	Jan	1.6	6.53	2666	2669	2672	7.04	7.15	7.26	2953	6.33
	Feb	1.6	19.80	2403	2405	2406	5.90	5.94	5.98	2477	5.57
Irrigation Season	Mar	1.6	25.05	1767	1768	1769	4.77	4.80	4.84	1785	4.44
	Apr	1.6	18.65	2381	2382	2383	5.90	5.94	5.98	2457	5.55
	May	1.6	31.77	1988	1989	1990	5.06	5.08	5.11	2013	4.81
	Jun	1.6	28.05	2288	2289	2289	5.54	5.57	5.60	2333	5.29
	Jul	1.6	10.08	2081	2083	2085	5.93	6.00	6.08	2174	5.29
	Aug	1.6	4.98	2528	2531	2535	7.39	7.52	7.65	2860	6.57
	Sep	1.6	4.10	2440	2445	2449	7.43	7.58	7.73	2810	6.44
	Oct	1.6	4.56	2082	2086	2090	6.83	6.97	7.11	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	5.3	0.7	1.6	1.6

Flow In Little Powder River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	283	31	4.56
Nov	144	30	2.40
Dec	65	31	1.05
Jan	405	31	6.53
Feb	1109	28	19.80
Mar	1553	31	25.05
Apr	1119	30	18.65
May	1970	31	31.77
Jun	1683	30	28.05
Jul	625	31	10.08
Aug	309	31	4.98
Sep	246	30	4.10

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

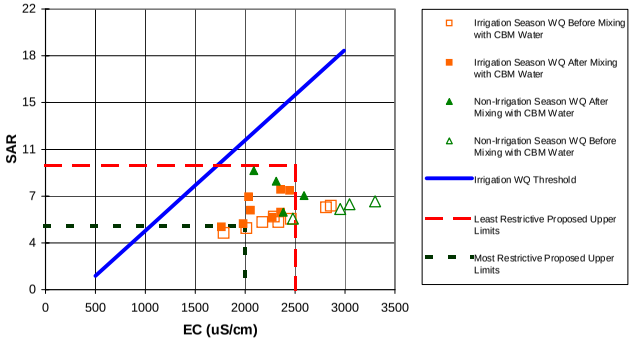
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC (uS/cm) mean	EC (uS/cm) 95% upper	SAR (--) 95% lower	SAR (--) mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	2.2	2.40	2302	2310	2317	8.26	8.51	8.77	3044	6.7
	Dec	2.2	1.05	2077	2088	2098	8.98	9.34	9.71	3300	6.94
	Jan	2.2	6.53	2585	2589	2593	7.24	7.38	7.51	2953	6.33
	Feb	2.2	19.80	2379	2380	2382	6.01	6.06	6.12	2477	5.57
Irrigation Season	Mar	2.2	25.05	1761	1763	1764	4.88	4.93	4.97	1785	4.44
	Apr	2.2	18.65	2355	2357	2359	6.01	6.07	6.13	2457	5.55
	May	2.2	31.77	1979	1980	1981	5.14	5.18	5.21	2013	4.81
	Jun	2.2	28.05	2272	2273	2274	5.63	5.67	5.71	2333	5.29
	Jul	2.2	10.08	2052	2055	2058	6.13	6.22	6.32	2174	5.29
	Aug	2.2	4.98	2441	2446	2451	7.61	7.77	7.94	2860	6.57
	Sep	2.2	4.10	2350	2356	2361	7.67	7.85	8.04	2810	6.44
	Oct	2.2	4.56	2030	2035	2040	7.10	7.28	7.46	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	7.3	0.7	2.2	2.2

Flow In Little Powder River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	283	31	4.56
Nov	144	30	2.40
Dec	65	31	1.05
Jan	405	31	6.53
Feb	1109	28	19.80
Mar	1553	31	25.05
Apr	1119	30	18.65
May	1970	31	31.77
Jun	1683	30	28.05
Jul	625	31	10.08
Aug	309	31	4.98
Sep	246	30	4.10

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

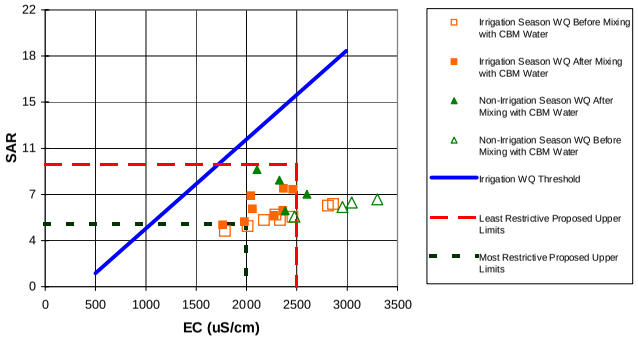
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% lower	mean	95% upper	95% lower	mean	95% upper		
Non-Irrigation Season	Nov	2.1	2.40	2320	2328	2335	8.22	8.47	8.72	3044	6.7
	Dec	2.1	1.05	2096	2106	2116	8.95	9.31	9.67	3300	6.94
	Jan	2.1	6.53	2598	2602	2605	7.21	7.34	7.47	2953	6.33
	Feb	2.1	19.80	2383	2384	2386	5.99	6.04	6.09	2477	5.57
Irrigation Season	Mar	2.1	25.05	1762	1764	1765	4.87	4.91	4.95	1785	4.44
	Apr	2.1	18.65	2359	2361	2363	6.00	6.05	6.10	2457	5.55
	May	2.1	31.77	1981	1982	1983	5.13	5.16	5.20	2013	4.81
	Jun	2.1	28.05	2275	2276	2277	5.61	5.65	5.69	2333	5.29
	Jul	2.1	10.08	2057	2059	2062	6.09	6.19	6.28	2174	5.29
	Aug	2.1	4.98	2455	2459	2464	7.57	7.73	7.89	2860	6.57
	Sep	2.1	4.10	2364	2369	2375	7.63	7.81	7.99	2810	6.44
	Oct	2.1	4.56	2038	2043	2048	7.06	7.23	7.40	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	7.0	0.7	2.1	2.1

Flow In Little Powder River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	283	31	4.56
Nov	144	30	2.40
Dec	65	31	1.05
Jan	405	31	6.53
Feb	1109	28	19.80
Mar	1553	31	25.05
Apr	1119	30	18.65
May	1970	31	31.77
Jun	1683	30	28.05
Jul	625	31	10.08
Aug	309	31	4.98
Sep	246	30	4.10

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

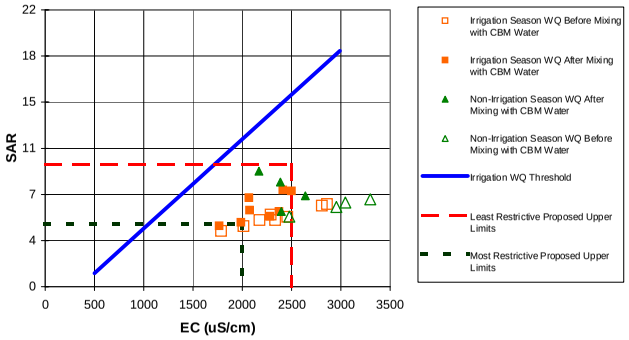
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	1.8	2.40	2379	2386	2393	8.09	8.32	8.56	3044	6.7
	Dec	1.8	1.05	2159	2169	2179	8.84	9.18	9.52	3300	6.94
	Jan	1.8	6.53	2638	2641	2644	7.11	7.23	7.35	2953	6.33
	Feb	1.8	19.80	2395	2396	2398	5.94	5.98	6.03	2477	5.57
Irrigation Season	Mar	1.8	25.05	1765	1766	1768	4.81	4.85	4.88	1785	4.44
	Apr	1.8	18.65	2372	2374	2375	5.94	5.98	6.03	2457	5.55
	May	1.8	31.77	1985	1986	1987	5.09	5.11	5.14	2013	4.81
	Jun	1.8	28.05	2282	2283	2284	5.57	5.60	5.64	2333	5.29
	Jul	1.8	10.08	2071	2073	2076	6.00	6.08	6.16	2174	5.29
	Aug	1.8	4.98	2497	2501	2505	7.47	7.61	7.75	2860	6.57
	Sep	1.8	4.10	2408	2413	2418	7.51	7.68	7.84	2810	6.44
	Oct	1.8	4.56	2064	2068	2073	6.92	7.08	7.23	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	6.0	0.7	1.8	1.8

Flow In Little Powder River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	283	31	4.56
Nov	144	30	2.40
Dec	65	31	1.05
Jan	405	31	6.53
Feb	1109	28	19.80
Mar	1553	31	25.05
Apr	1119	30	18.65
May	1970	31	31.77
Jun	1683	30	28.05
Jul	625	31	10.08
Aug	309	31	4.98
Sep	246	30	4.10

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line

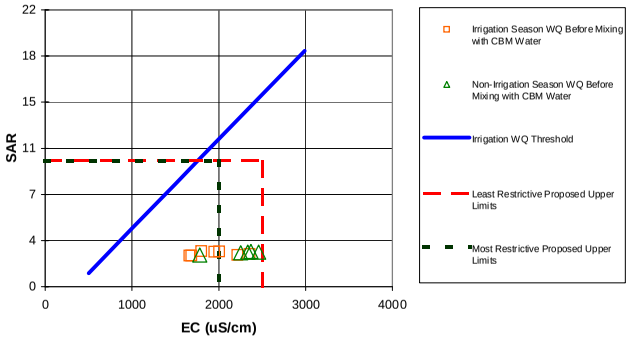
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2003
Stream Water Quality Before Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC (uS/cm) mean	EC (uS/cm) 95% upper	SAR (--) 95% lower	SAR (--) mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.00	0.08	2460	2460	2460	2.74	2.74	2.74	2460	2.74
	Dec	0.00	0.08	2372	2372	2372	2.79	2.79	2.79	2372	2.79
	Jan	0.00	0.03	2335	2335	2335	2.74	2.74	2.74	2335	2.74
	Feb	0.00	0.25	2251	2251	2251	2.71	2.71	2.71	2251	2.71
	Mar	0.00	0.48	1782	1782	1782	2.52	2.52	2.52	1782	2.52
Irrigation Season	Apr	0.00	0.27	1949	1949	1949	2.77	2.77	2.77	1949	2.77
	May	0.00	1.50	1800	1800	1800	2.82	2.82	2.82	1800	2.82
	Jun	0.00	0.33	2005	2005	2005	2.80	2.80	2.80	2005	2.8
	Jul	0.00	0.23	1661	1661	1661	2.48	2.48	2.48	1661	2.48
	Aug	0.00	0.13	1684	1684	1684	2.47	2.47	2.47	1684	2.47
	Sep	0.00	0.00							2214	2.52
	Oct	0.00	0.03	2354	2354	2354	2.60	2.60	2.60	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.0	0.7	0.0	0.0

Flow In Dry Fork Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2	31	0.03
Nov	5	30	0.08
Dec	5	31	0.08
Jan	2	31	0.03
Feb	14	28	0.25
Mar	30	31	0.48
Apr	16	30	0.27
May	93	31	1.50
Jun	20	30	0.33
Jul	14	31	0.23
Aug	8	31	0.13
Sep	0	30	0.00

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

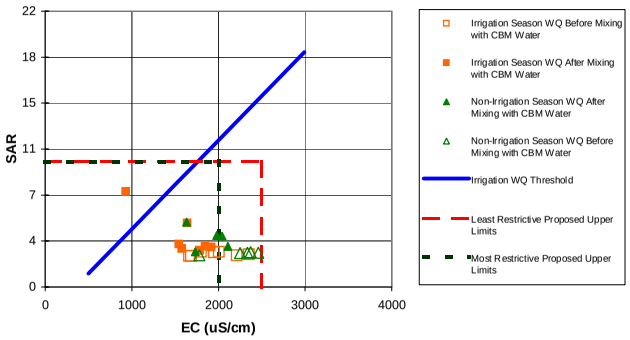
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.03	0.08	2037	2043	2048	3.85	4.07	4.29	2460	2.74
	Dec	0.03	0.08	1973	1979	1984	3.88	4.11	4.33	2372	2.79
	Jan	0.03	0.03	1622	1632	1643	4.77	5.18	5.58	2335	2.74
	Feb	0.03	0.25	2107	2109	2112	3.15	3.24	3.32	2251	2.71
	Mar	0.03	0.48	1731	1732	1733	2.77	2.82	2.87	1782	2.52
Irrigation Season	Apr	0.03	0.27	1845	1847	1849	3.17	3.25	3.34	1949	2.77
	May	0.03	1.50	1783	1783	1783	2.90	2.91	2.93	1800	2.82
	Jun	0.03	0.33	1914	1915	1917	3.13	3.20	3.27	2005	2.8
	Jul	0.03	0.23	1574	1577	1579	2.98	3.07	3.17	1661	2.48
	Aug	0.03	0.13	1539	1543	1546	3.28	3.43	3.59	1684	2.47
	Sep	0.03	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.03	0.03	1631	1642	1652	4.70	5.11	5.51	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.0	0.0

Flow In Dry Fork Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2	31	0.03
Nov	5	30	0.08
Dec	5	31	0.08
Jan	2	31	0.03
Feb	14	28	0.25
Mar	30	31	0.48
Apr	16	30	0.27
May	93	31	1.50
Jun	20	30	0.33
Jul	14	31	0.23
Aug	8	31	0.13
Sep	0	30	0.00

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

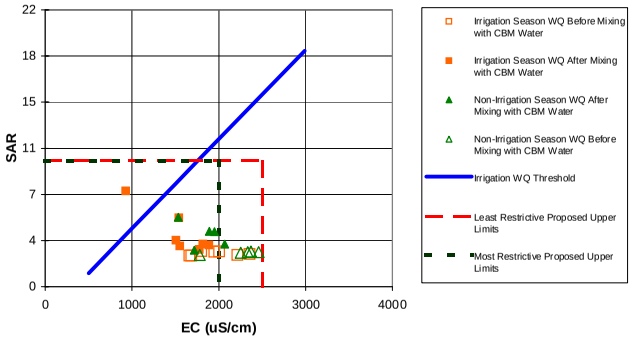
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.04	0.08	1943	1950	1957	4.09	4.37	4.64	2460	2.74
	Dec	0.04	0.08	1884	1891	1898	4.13	4.40	4.67	2372	2.79
	Jan	0.04	0.03	1520	1532	1544	5.06	5.53	5.99	2335	2.74
	Feb	0.04	0.25	2066	2069	2072	3.27	3.39	3.50	2251	2.71
	Mar	0.04	0.48	1715	1716	1718	2.85	2.91	2.97	1782	2.52
Irrigation Season	Apr	0.04	0.27	1815	1817	1820	3.29	3.40	3.50	1949	2.77
	May	0.04	1.50	1777	1777	1778	2.92	2.94	2.97	1800	2.82
	Jun	0.04	0.33	1886	1889	1891	3.23	3.32	3.41	2005	2.8
	Jul	0.04	0.23	1550	1553	1556	3.12	3.24	3.36	1661	2.48
	Aug	0.04	0.13	1502	1506	1511	3.49	3.68	3.87	1684	2.47
	Sep	0.04	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.04	0.03	1528	1540	1552	5.00	5.47	5.93	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.04	0.0

Flow In Dry Fork Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2	31	0.03
Nov	5	30	0.08
Dec	5	31	0.08
Jan	2	31	0.03
Feb	14	28	0.25
Mar	30	31	0.48
Apr	16	30	0.27
May	93	31	1.50
Jun	20	30	0.33
Jul	14	31	0.23
Aug	8	31	0.13
Sep	0	30	0.00

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

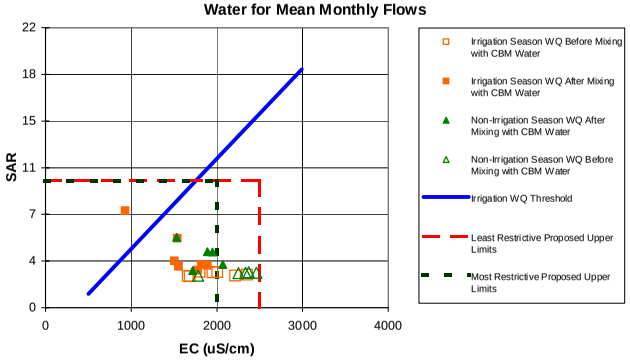
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Normal Year Conditions					
CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.04	0.08	1943	1950	1957	4.09	4.37	4.64	2460	2.74
	Dec	0.04	0.08	1884	1891	1898	4.13	4.40	4.67	2372	2.79
	Jan	0.04	0.03	1520	1532	1544	5.06	5.53	5.99	2335	2.74
	Feb	0.04	0.25	2066	2069	2072	3.27	3.39	3.50	2251	2.71
	Mar	0.04	0.48	1715	1716	1718	2.85	2.91	2.97	1782	2.52
Irrigation Season	Apr	0.04	0.27	1815	1817	1820	3.29	3.40	3.50	1949	2.77
	May	0.04	1.50	1777	1777	1778	2.92	2.94	2.97	1800	2.82
	Jun	0.04	0.33	1886	1889	1891	3.23	3.32	3.41	2005	2.8
	Jul	0.04	0.23	1550	1553	1556	3.12	3.24	3.36	1661	2.48
	Aug	0.04	0.13	1502	1506	1511	3.49	3.68	3.87	1684	2.47
	Sep	0.04	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.04	0.03	1528	1540	1552	5.00	5.47	5.93	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.04	0.0

Flow In Dry Fork Cheyenne River

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2	31	0.03
Nov	5	30	0.08
Dec	5	31	0.08
Jan	2	31	0.03
Feb	14	28	0.25
Mar	30	31	0.48
Apr	16	30	0.27
May	93	31	1.50
Jun	20	30	0.33
Jul	14	31	0.23
Aug	8	31	0.13
Sep	0	30	0.00

Plotting Position: Most and Least Restrictive Limits

	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line

EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Fork Cheyenne Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Dry Fork Cheyenne River	Nov	2460	2.7	909	929	950	6.8	7.6	8.4	2460	2460	2460	2.7	2.7	2.7	2037	2043	2048	3.8	4.1	4.3	1943	1950	1957	4.1	4.4	4.6	1943	1950	1957	4.1	4.4	4.6
	Dec	2372	2.8	909	929	950	6.8	7.6	8.4	2372	2372	2372	2.8	2.8	2.8	1973	1979	1984	3.9	4.1	4.3	1884	1891	1898	4.1	4.4	4.7	1884	1891	1898	4.1	4.4	4.7
	Jan	2335	2.7	909	929	950	6.8	7.6	8.4	2335	2335	2335	2.7	2.7	2.7	1622	1632	1643	4.8	5.2	5.6	1520	1532	1544	5.1	5.5	6.0	1520	1532	1544	5.1	5.5	6.0
	Feb	2251	2.7	909	929	950	6.8	7.6	8.4	2251	2251	2251	2.7	2.7	2.7	2107	2109	2112	3.1	3.2	3.3	2066	2069	2072	3.3	3.4	3.5	2066	2069	2072	3.3	3.4	3.5
	Mar	1782	2.5	909	929	950	6.8	7.6	8.4	1782	1782	1782	2.5	2.5	2.5	1731	1732	1733	2.8	2.8	2.9	1715	1716	1718	2.8	2.9	3.0	1715	1716	1718	2.8	2.9	3.0
	Apr	1949	2.8	909	929	950	6.8	7.6	8.4	1949	1949	1949	2.8	2.8	2.8	1845	1847	1849	3.2	3.3	3.3	1815	1817	1820	3.3	3.4	3.5	1815	1817	1820	3.3	3.4	3.5
	May	1800	2.8	909	929	950	6.8	7.6	8.4	1800	1800	1800	2.8	2.8	2.8	1783	1783	1783	2.9	2.9	2.9	1777	1777	1778	2.9	2.9	3.0	1777	1777	1778	2.9	2.9	3.0
	Jun	2005	2.8	909	929	950	6.8	7.6	8.4	2005	2005	2005	2.8	2.8	2.8	1914	1915	1917	3.1	3.2	3.3	1886	1889	1891	3.2	3.3	3.4	1886	1889	1891	3.2	3.3	3.4
	Jul	1661	2.5	909	929	950	6.8	7.6	8.4	1661	1661	1661	2.5	2.5	2.5	1574	1577	1579	3.0	3.1	3.2	1550	1553	1556	3.1	3.2	3.4	1550	1553	1556	3.1	3.2	3.4
	Aug	1684	2.5	909	929	950	6.8	7.6	8.4	1684	1684	1684	2.5	2.5	2.5	1539	1543	1546	3.3	3.4	3.6	1502	1506	1511	3.5	3.7	3.9	1502	1506	1511	3.5	3.7	3.9
	Sep	2214	2.5	909	929	950	6.8	7.6	8.4	Not Applicable						Not Applicable						Not Applicable						Not Applicable					
	Oct	2354	2.6	909	929	950	6.8	7.6	8.4	2354	2354	2354	2.6	2.6	2.6	1631	1642	1652	4.7	5.1	5.5	1528	1540	1552	5.0	5.5	5.9	1528	1540	1552	5.0	5.5	5.9

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Dry Fork Cheyenne River	0.00%	0.0%		0.00%	0.0%		0.28%	-17.0%		5.46%	48.5%		0.36%	-20.7%		6.22%	59.3%		0.36%	-20.7%		6.22%	59.3%	
Dec		0.00%	0.0%		0.00%	0.0%		0.29%	-16.6%		5.41%	47.2%		0.37%	-20.3%		6.17%	57.7%		0.37%	-20.3%		6.17%	57.7%	
Jan		0.00%	0.0%		0.00%	0.0%		0.64%	-30.1%		7.86%	89.0%		0.78%	-34.4%		8.42%	101.7%		0.78%	-34.4%		8.42%	101.7%	
Feb		0.00%	0.0%		0.00%	0.0%		0.11%	-6.3%		2.70%	19.4%		0.14%	-8.1%		3.32%	25.0%		0.14%	-8.1%		3.32%	25.0%	
Mar		0.00%	0.0%		0.00%	0.0%		0.07%	-2.8%		1.70%	11.9%		0.09%	-3.7%		2.15%	15.6%		0.09%	-3.7%		2.15%	15.6%	
Apr		0.00%	0.0%		0.00%	0.0%		0.11%	-5.2%		2.50%	17.5%		0.15%	-6.7%		3.09%	22.6%		0.15%	-6.7%		3.09%	22.6%	
May		0.00%	0.0%		0.00%	0.0%		0.02%	-0.9%		0.55%	3.3%		0.03%	-1.3%		0.72%	4.4%		0.03%	-1.3%		0.72%	4.4%	
Jun		0.00%	0.0%		0.00%	0.0%		0.09%	-4.5%		2.12%	14.3%		0.12%	-5.8%		2.65%	18.6%		0.12%	-5.8%		2.65%	18.6%	
Jul		0.00%	0.0%		0.00%	0.0%		0.15%	-5.1%		3.06%	23.9%		0.20%	-6.5%		3.72%	30.7%		0.20%	-6.5%		3.72%	30.7%	
Aug		0.00%	0.0%		0.00%	0.0%		0.25%	-8.4%		4.45%	39.1%		0.33%	-10.5%		5.21%	49.0%		0.33%	-10.5%		5.21%	49.0%	
Sep		Not Applicable						Not Applicable						Not Applicable						Not Applicable					
Oct		0.00%	0.0%		0.00%	0.0%		0.64%	-30.3%		7.97%	96.5%		0.78%	-34.6%		8.51%	110.2%		0.78%	-34.6%		8.51%	110.2%	
	Max	0.00%	0.00%		0.00%	0.00%		0.64%	-30.26%		7.97%	96.45%		0.78%	-34.58%		8.51%	110.23%		0.78%	-34.58%		8.51%	110.23%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Little Powder River Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
				EC			SAR			EC			SAR			EC			SAR			EC			SAR			EC			SAR		
				(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)		
		EC	SAR	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Little Powder River	Nov	3044	6.7	1493	1509	1524	10.0	10.5	11.0	2424	2430	2436	8.0	8.2	8.4	2302	2310	2317	8.3	8.5	8.8	2320	2328	2335	8.2	8.5	8.7	2379	2386	2393	8.1	8.3	8.6
	Dec	3300	6.9	1493	1509	1524	10.0	10.5	11.0	2209	2219	2228	8.8	9.1	9.4	2077	2088	2098	9.0	9.3	9.7	2096	2106	2116	8.9	9.3	9.7	2159	2169	2179	8.8	9.2	9.5
	Jan	2953	6.3	1493	1509	1524	10.0	10.5	11.0	2666	2669	2672	7.0	7.1	7.3	2585	2589	2593	7.2	7.4	7.5	2598	2602	2605	7.2	7.3	7.5	2638	2641	2644	7.1	7.2	7.3
	Feb	2477	5.6	1493	1509	1524	10.0	10.5	11.0	2403	2405	2406	5.9	5.9	6.0	2379	2380	2382	6.0	6.1	6.1	2383	2384	2386	6.0	6.0	6.1	2395	2396	2398	5.9	6.0	6.0
	Mar	1785	4.4	1493	1509	1524	10.0	10.5	11.0	1767	1768	1769	4.8	4.8	4.8	1761	1763	1764	4.9	4.9	5.0	1762	1764	1765	4.9	4.9	4.9	1765	1766	1768	4.8	4.8	4.9
	Apr	2457	5.6	1493	1509	1524	10.0	10.5	11.0	2381	2382	2383	5.9	5.9	6.0	2355	2357	2359	6.0	6.1	6.1	2359	2361	2363	6.0	6.1	6.1	2372	2374	2375	5.9	6.0	6.0
	May	2013	4.8	1493	1509	1524	10.0	10.5	11.0	1988	1989	1990	5.1	5.1	5.1	1979	1980	1981	5.1	5.2	5.2	1981	1982	1983	5.1	5.2	5.2	1985	1986	1987	5.1	5.1	5.1
	Jun	2333	5.3	1493	1509	1524	10.0	10.5	11.0	2288	2289	2289	5.5	5.6	5.6	2272	2273	2274	5.6	5.7	5.7	2275	2276	2277	5.6	5.7	5.7	2282	2283	2284	5.6	5.6	5.6
	Jul	2174	5.3	1493	1509	1524	10.0	10.5	11.0	2081	2083	2085	5.9	6.0	6.1	2052	2055	2058	6.1	6.2	6.3	2057	2059	2062	6.1	6.2	6.3	2071	2073	2076	6.0	6.1	6.2
	Aug	2860	6.6	1493	1509	1524	10.0	10.5	11.0	2528	2531	2535	7.4	7.5	7.7	2441	2446	2451	7.6	7.8	7.9	2455	2459	2464	7.6	7.7	7.9	2497	2501	2505	7.5	7.6	7.8
	Sep	2810	6.4	1493	1509	1524	10.0	10.5	11.0	2440	2445	2449	7.4	7.6	7.7	2350	2356	2361	7.7	7.9	8.0	2364	2369	2375	7.6	7.8	8.0	2408	2413	2418	7.5	7.7	7.8
	Oct	2289	5.7	1493	1509	1524	10.0	10.5	11.0	2082	2086	2090	6.8	7.0	7.1	2030	2035	2040	7.1	7.3	7.5	2038	2043	2048	7.1	7.2	7.4	2064	2068	2073	6.9	7.1	7.2

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Little Powder River	0.26%	-20.2%		2.63%	22.6%		0.32%	-24.1%		3.03%	27.1%		0.31%	-23.5%		2.97%	26.4%		0.28%	-21.6%		2.78%	24.3%	
Dec		0.42%	-32.8%		3.59%	30.9%		0.50%	-36.7%		3.91%	34.6%		0.49%	-36.2%		3.87%	34.1%		0.45%	-34.3%		3.71%	32.3%	
Jan		0.11%	-9.6%		1.49%	12.9%		0.15%	-12.3%		1.84%	16.6%		0.15%	-11.9%		1.79%	16.0%		0.13%	-10.6%		1.61%	14.2%	
Feb		0.05%	-2.9%		0.68%	6.6%		0.07%	-3.9%		0.89%	8.8%		0.06%	-3.7%		0.86%	8.5%		0.05%	-3.3%		0.75%	7.4%	
Mar		0.05%	-0.9%		0.67%	8.2%		0.07%	-1.2%		0.88%	11.0%		0.07%	-1.2%		0.85%	10.5%		0.06%	-1.0%		0.75%	9.1%	
Apr		0.05%	-3.0%		0.72%	7.0%		0.07%	-4.1%		0.94%	9.4%		0.07%	-3.9%		0.90%	9.0%		0.06%	-3.4%		0.79%	7.8%	
May		0.04%	-1.2%		0.51%	5.7%		0.05%	-1.6%		0.68%	7.6%		0.05%	-1.6%		0.65%	7.3%		0.04%	-1.3%		0.57%	6.3%	
Jun		0.04%	-1.9%		0.52%	5.3%		0.05%	-2.6%		0.69%	7.2%		0.05%	-2.5%		0.67%	6.8%		0.04%	-2.1%		0.58%	5.9%	
Jul		0.10%	-4.2%		1.23%	13.5%		0.14%	-5.5%		1.55%	17.6%		0.13%	-5.3%		1.50%	17.0%		0.11%	-4.6%		1.35%	14.9%	
Aug		0.15%	-11.5%		1.74%	14.5%		0.19%	-14.5%		2.13%	18.3%		0.19%	-14.0%		2.07%	17.7%		0.17%	-12.5%		1.88%	15.8%	
Sep		0.18%	-13.0%		2.00%	17.7%		0.23%	-16.2%		2.40%	22.0%		0.22%	-15.7%		2.34%	21.3%		0.20%	-14.1%		2.15%	19.2%	
Oct		0.19%	-8.9%		2.01%	21.6%		0.25%	-11.1%		2.41%	27.0%		0.24%	-10.7%		2.35%	26.2%		0.21%	-9.6%		2.16%	23.5%	
	Max	0.42%	-32.77%		3.59%	30.89%		0.50%	-36.74%		3.91%	34.64%		0.49%	-36.18%		3.87%	34.11%		0.45%	-34.28%		3.71%	32.32%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Upper Powder River Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Upper Powder River	Nov	2650	6.4	2161	2180	2200	21.6	22.6	23.5	2643	2643	2643	6.6	6.7	6.7	2626	2627	2628	7.2	7.2	7.3	2622	2623	2624	7.3	7.4	7.4	2623	2624	2625	7.3	7.3	7.4
	Dec	2906	6.6	2161	2180	2200	21.6	22.6	23.5	2891	2891	2892	6.9	6.9	7.0	2856	2857	2859	7.6	7.7	7.7	2847	2849	2850	7.8	7.9	8.0	2850	2852	2853	7.7	7.8	7.9
	Jan	2482	6.4	2161	2180	2200	21.6	22.6	23.5	2475	2475	2476	6.7	6.8	6.8	2459	2460	2462	7.5	7.6	7.6	2455	2456	2458	7.7	7.8	7.9	2456	2458	2459	7.6	7.7	7.8
	Feb	2366	6.1	2161	2180	2200	21.6	22.6	23.5	2364	2364	2364	6.3	6.3	6.3	2359	2359	2360	6.7	6.7	6.7	2357	2358	2359	6.8	6.8	6.9	2358	2359	2359	6.7	6.8	6.8
	Mar	2051	5.3	2161	2180	2200	21.6	22.6	23.5	2052	2052	2052	5.4	5.4	5.4	0	0	0	0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	2053	2054	2054	5.7	5.7	5.7
	Apr	2213	5.8	2161	2180	2200	21.6	22.6	23.5	2213	2213	2213	5.9	5.9	5.9	2212	2212	2213	6.2	6.2	6.2	2212	2212	2213	6.2	6.2	6.3	2212	2212	2213	6.2	6.2	6.2
	May	1803	4.9	2161	2180	2200	21.6	22.6	23.5	1804	1804	1804	5.0	5.0	5.0	1807	1807	1807	5.1	5.1	5.1	1808	1808	1808	5.1	5.2	5.2	1807	1808	1808	5.1	5.1	5.2
	Jun	1797	4.8	2161	2180	2200	21.6	22.6	23.5	1798	1798	1798	4.8	4.8	4.8	1802	1802	1802	5.0	5.0	5.0	1802	1803	1803	5.0	5.0	5.0	1802	1802	1803	5.0	5.0	5.0
	Jul	2716	6.8	2161	2180	2200	21.6	22.6	23.5	2710	2710	2711	6.9	7.0	7.0	2696	2697	2697	7.3	7.4	7.4	2692	2693	2694	7.4	7.5	7.5	2694	2694	2695	7.4	7.4	7.5
	Aug	2992	7.0	2161	2180	2200	21.6	22.6	23.5	2974	2975	2975	7.3	7.3	7.3	2934	2935	2937	8.0	8.1	8.1	2923	2925	2927	8.2	8.3	8.3	2927	2929	2930	8.1	8.2	8.3
	Sep	3400	7.8	2161	2180	2200	21.6	22.6	23.5	3374	3375	3375	8.1	8.1	8.2	3315	3317	3318	8.8	8.8	8.9	3300	3301	3303	8.9	9.0	9.1	3306	3307	3308	8.9	9.0	9.0
	Oct	2537	6.7	2161	2180	2200	21.6	22.6	23.5	2532	2532	2532	6.9	6.9	6.9	2519	2520	2521	7.4	7.5	7.5	2516	2517	2518	7.6	7.6	7.7	2517	2518	2519	7.5	7.6	7.6

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Upper Powder River	0.01%	-0.3%		0.21%	3.7%		0.04%	-0.9%		0.65%	12.3%		0.04%	-1.0%		0.76%	14.6%		0.04%	-1.0%		0.72%	13.7%	
Dec		0.01%	-0.5%		0.28%	4.9%		0.05%	-1.7%		0.84%	16.2%		0.05%	-2.0%		0.97%	19.1%		0.05%	-1.9%		0.92%	18.0%	
Jan		0.02%	-0.3%		0.31%	5.5%		0.06%	-0.9%		0.91%	18.1%		0.07%	-1.0%		1.05%	21.4%		0.06%	-1.0%		1.00%	20.2%	
Feb		0.01%	-0.1%		0.16%	2.8%		0.03%	-0.3%		0.51%	9.6%		0.04%	-0.3%		0.60%	11.4%		0.03%	-0.3%		0.57%	10.7%	
Mar		0.01%	0.0%		0.11%	1.9%		#DIV/0!	-100.0%		#DIV/0!	-100.0%		#DIV/0!	-100.0%		#DIV/0!	-100.0%		0.02%	0.1%		0.38%	7.4%	
Apr		0.01%	0.0%		0.10%	1.7%		0.02%	0.0%		0.31%	5.8%		0.02%	0.0%		0.37%	6.9%		0.02%	0.0%		0.35%	6.5%	
May		0.00%	0.1%		0.06%	1.1%		0.01%	0.2%		0.21%	4.0%		0.01%	0.3%		0.25%	4.7%		0.01%	0.3%		0.23%	4.4%	
Jun		0.00%	0.1%		0.07%	1.4%		0.01%	0.3%		0.24%	4.7%		0.02%	0.3%		0.29%	5.6%		0.02%	0.3%		0.27%	5.2%	
Jul		0.01%	-0.2%		0.15%	2.5%		0.03%	-0.7%		0.47%	8.3%		0.03%	-0.8%		0.55%	9.9%		0.03%	-0.8%		0.52%	9.3%	
Aug		0.01%	-0.6%		0.28%	4.7%		0.05%	-1.9%		0.83%	15.6%		0.06%	-2.2%		0.96%	18.5%		0.05%	-2.1%		0.91%	17.4%	
Sep		0.01%	-0.7%		0.24%	3.9%		0.04%	-2.5%		0.74%	12.9%		0.05%	-2.9%		0.86%	15.2%		0.05%	-2.7%		0.82%	14.4%	
Oct		0.01%	-0.2%		0.20%	3.4%		0.04%	-0.7%		0.62%	11.3%		0.04%	-0.8%		0.72%	13.4%		0.04%	-0.8%		0.68%	12.6%	
	Max	0.02%	-0.74%		0.31%	5.49%		#DIV/0!	-100.00%		#DIV/0!	18.12%		#DIV/0!	-100.00%		#DIV/0!	21.43%		0.06%	-2.74%		1.00%	20.20%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Upper Cheyenne Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Upper cheyenne River	Nov	3565	7.2	909	929	950	6.8	7.6	0.0	2949	2954	2959	7.1	7.3	7.5	2949	2954	2959	7.1	7.3	7.5	3010	3014	3019	7.1	7.3	7.5	3075	3078	3082	7.1	7.3	7.4
	Dec	3405	7.4	909	929	950	6.8	7.6	0.0	2133	2144	2154	7.1	7.5	7.9	2133	2144	2154	7.1	7.5	7.9	2216	2226	2236	7.1	7.5	7.9	2312	2321	2330	7.1	7.5	7.8
	Jan	4229	8.6	909	929	950	6.8	7.6	0.0	4008	4009	4011	8.5	8.5	8.6	4008	4009	4011	8.5	8.5	8.6	4034	4035	4036	8.5	8.5	8.6	4060	4061	4062	8.5	8.5	8.6
	Feb	3911	8.0	909	929	950	6.8	7.6	0.0	3803	3803	3804	8.0	8.0	8.0	3803	3803	3804	8.0	8.0	8.0	3816	3816	3817	8.0	8.0	8.0	3829	3830	3830	8.0	8.0	8.0
	Mar	4127	8.7	909	929	950	6.8	7.6	0.0	3927	3928	3929	8.5	8.6	8.6	3927	3928	3929	8.5	8.6	8.6	3950	3952	3953	8.6	8.6	8.6	3974	3975	3976	8.6	8.6	8.6
	Apr	3630	7.9	909	929	950	6.8	7.6	0.0	3547	3548	3549	7.8	7.9	7.9	3547	3548	3549	7.8	7.9	7.9	3557	3558	3559	7.8	7.9	7.9	3568	3568	3569	7.8	7.9	7.9
	May	3155	6.9	909	929	950	6.8	7.6	0.0	3147	3148	3148	6.9	6.9	6.9	3147	3148	3148	6.9	6.9	6.9	3148	3148	3149	6.9	6.9	6.9	3149	3149	3149	6.9	6.9	6.9
	Jun	2895	5.9	909	929	950	6.8	7.6	0.0	2881	2881	2882	5.9	5.9	5.9	2881	2881	2882	5.9	5.9	5.9	2883	2883	2883	5.9	5.9	5.9	2885	2885	2885	5.9	5.9	5.9
	Jul	2250	5.7	909	929	950	6.8	7.6	0.0	2217	2217	2218	5.7	5.7	5.8	2217	2217	2218	5.7	5.7	5.8	2221	2221	2222	5.7	5.7	5.8	2225	2225	2226	5.7	5.7	5.7
	Aug	1972	4.8	909	929	950	6.8	7.6	0.0	1878	1880	1882	5.0	5.1	5.1	1878	1880	1882	5.0	5.1	5.1	1889	1890	1892	5.0	5.0	5.1	1900	1901	1903	5.0	5.0	5.1
	Sep	2271	5.6	909	929	950	6.8	7.6	0.0	2252	2252	2252	5.6	5.7	5.7	2252	2252	2252	5.6	5.7	5.7	2254	2254	2255	5.6	5.7	5.7	2256	2257	2257	5.6	5.7	5.7
	Oct	2916	6.5	909	929	950	6.8	7.6	0.0	2493	2498	2502	6.5	6.7	6.9	2493	2498	2502	6.5	6.7	6.9	2536	2540	2544	6.5	6.7	6.8	2581	2585	2588	6.5	6.7	6.8

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Upper cheyenne River	0.16%	-17.1%		2.58%	1.3%		0.16%	-17.1%		2.58%	1.3%		0.14%	-15.4%		2.33%	1.1%		0.13%	-13.6%		2.06%	1.0%	
Dec		0.50%	-37.0%		5.53%	1.6%		0.50%	-37.0%		5.53%	1.6%		0.45%	-34.6%		5.17%	1.5%		0.39%	-31.8%		4.76%	1.3%	
Jan		0.03%	-5.2%		0.64%	-0.7%		0.03%	-5.2%		0.64%	-0.7%		0.03%	-4.6%		0.56%	-0.7%		0.03%	-4.0%		0.48%	-0.6%	
Feb		0.02%	-2.8%		0.37%	-0.2%		0.02%	-2.8%		0.37%	-0.2%		0.02%	-2.4%		0.32%	-0.2%		0.01%	-2.1%		0.28%	-0.1%	
Mar		0.03%	-4.8%		0.59%	-0.8%		0.03%	-4.8%		0.59%	-0.8%		0.03%	-4.3%		0.52%	-0.7%		0.02%	-3.7%		0.45%	-0.6%	
Apr		0.02%	-2.3%		0.31%	-0.1%		0.02%	-2.3%		0.31%	-0.1%		0.02%	-2.0%		0.28%	-0.1%		0.01%	-1.7%		0.24%	-0.1%	
May		0.00%	-0.2%		0.04%	0.0%		0.00%	-0.2%		0.04%	0.0%		0.00%	-0.2%		0.03%	0.0%		0.00%	-0.2%		0.03%	0.0%	
Jun		0.01%	-0.5%		0.09%	0.2%		0.01%	-0.5%		0.09%	0.2%		0.00%	-0.4%		0.08%	0.2%		0.00%	-0.4%		0.07%	0.1%	
Jul		0.02%	-1.5%		0.35%	0.8%		0.02%	-1.5%		0.35%	0.8%		0.02%	-1.3%		0.31%	0.7%		0.02%	-1.1%		0.27%	0.6%	
Aug		0.10%	-4.7%		1.42%	5.1%		0.10%	-4.7%		1.42%	5.1%		0.09%	-4.1%		1.27%	4.5%		0.07%	-3.6%		1.10%	3.9%	
Sep		0.01%	-0.8%		0.20%	0.5%		0.01%	-0.8%		0.20%	0.5%		0.01%	-0.7%		0.18%	0.4%		0.01%	-0.6%		0.15%	0.4%	
Oct		0.18%	-14.3%		2.56%	3.8%		0.18%	-14.3%		2.56%	3.8%		0.16%	-12.9%		2.31%	3.4%		0.13%	-11.4%		2.04%	3.0%	
	Max	0.50%	-37.05%		5.53%	5.13%		0.50%	-37.05%		5.53%	5.13%		0.45%	-34.62%		5.17%	4.54%		0.39%	-31.84%		4.76%	3.94%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Belle Fourche Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Belle Fourche River	Nov	2877	7.0	1102	1110	1117	8.4	8.8	9.2	2019	2023	2027	7.7	7.9	8.1	2063	2066	2070	7.7	7.9	8.0	2176	2179	2182	7.6	7.7	7.9	2303	2305	2308	7.5	7.6	7.7
	Dec	2755	6.8	1102	1110	1117	8.4	8.8	9.2	1821	1825	1830	7.7	7.9	8.2	1861	1865	1869	7.7	7.9	8.1	1969	1973	1976	7.6	7.8	7.9	2095	2098	2101	7.4	7.6	7.8
	Jan	2887	6.3	1102	1110	1117	8.4	8.8	9.2	2262	2264	2267	7.0	7.2	7.3	2301	2303	2306	7.0	7.1	7.3	2399	2401	2403	6.9	7.0	7.1	2501	2503	2504	6.8	6.8	6.9
	Feb	1907	4.1	1102	1110	1117	8.4	8.8	9.2	1797	1798	1799	4.7	4.7	4.8	1805	1806	1807	4.6	4.7	4.7	1827	1827	1828	4.5	4.6	4.6	1846	1847	1848	4.4	4.4	4.5
	Mar	1564	3.6	1102	1110	1117	8.4	8.8	9.2	1530	1531	1532	4.0	4.0	4.0	1533	1534	1534	4.0	4.0	4.0	1540	1540	1541	3.9	3.9	3.9	1546	1547	1547	3.8	3.8	3.9
	Apr	1722	4.3	1102	1110	1117	8.4	8.8	9.2	1655	1656	1657	4.8	4.8	4.9	1661	1661	1662	4.7	4.8	4.8	1674	1674	1675	4.7	4.7	4.7	1686	1686	1687	4.6	4.6	4.6
	May	1532	3.8	1102	1110	1117	8.4	8.8	9.2	1489	1490	1491	4.3	4.3	4.3	1493	1494	1494	4.2	4.3	4.3	1501	1502	1502	4.1	4.2	4.2	1509	1509	1510	4.1	4.1	4.1
	Jun	1821	4.0	1102	1110	1117	8.4	8.8	9.2	1725	1726	1727	4.6	4.6	4.7	1733	1734	1735	4.5	4.6	4.6	1751	1752	1753	4.4	4.5	4.5	1768	1769	1770	4.3	4.3	4.4
	Jul	1182	3.1	1102	1110	1117	8.4	8.8	9.2	1162	1164	1166	4.4	4.5	4.6	1164	1165	1167	4.3	4.4	4.5	1167	1168	1170	4.1	4.2	4.3	1170	1172	1173	3.9	3.9	4.0
	Aug	1955	5.1	1102	1110	1117	8.4	8.8	9.2	1623	1626	1629	6.4	6.5	6.7	1642	1645	1648	6.3	6.4	6.6	1692	1695	1697	6.1	6.2	6.3	1745	1747	1749	5.9	6.0	6.1
	Sep	2231	5.8	1102	1110	1117	8.4	8.8	9.2	1772	1775	1778	6.9	7.0	7.2	1798	1801	1804	6.8	6.9	7.1	1866	1868	1871	6.6	6.8	6.9	1938	1940	1942	6.5	6.6	6.7
	Oct	2346	5.8	1102	1110	1117	8.4	8.8	9.2	2048	2050	2052	6.4	6.5	6.6	2070	2071	2073	6.3	6.4	6.5	2122	2123	2125	6.2	6.3	6.4	2173	2174	2175	6.1	6.2	6.2

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Belle Fourche River	0.18%	-29.7%		2.40%	12.5%		0.17%	-28.2%		2.29%	11.9%		0.14%	-24.2%		2.00%	10.2%		0.11%	-19.9%		1.66%	8.4%	
Dec		0.24%	-33.7%		2.79%	17.2%		0.22%	-32.3%		2.68%	16.5%		0.18%	-28.4%		2.40%	14.5%		0.14%	-23.8%		2.06%	12.2%	
Jan		0.12%	-21.6%		1.91%	14.2%		0.11%	-20.2%		1.80%	13.3%		0.09%	-16.8%		1.53%	11.1%		0.07%	-13.3%		1.24%	8.7%	
Feb		0.06%	-5.7%		1.14%	16.0%		0.05%	-5.3%		1.06%	14.7%		0.04%	-4.2%		0.86%	11.6%		0.03%	-3.1%		0.66%	8.8%	
Mar		0.04%	-2.1%		0.71%	10.4%		0.03%	-1.9%		0.65%	9.5%		0.03%	-1.5%		0.52%	7.4%		0.02%	-1.1%		0.39%	5.5%	
Apr		0.05%	-3.8%		0.88%	11.2%		0.05%	-3.5%		0.81%	10.3%		0.04%	-2.8%		0.65%	8.1%		0.03%	-2.1%		0.50%	6.0%	
May		0.05%	-2.7%		0.90%	13.1%		0.05%	-2.5%		0.83%	12.0%		0.04%	-2.0%		0.67%	9.4%		0.03%	-1.5%		0.51%	7.0%	
Jun		0.06%	-5.2%		1.13%	16.3%		0.05%	-4.8%		1.05%	14.9%		0.04%	-3.8%		0.85%	11.8%		0.03%	-2.9%		0.66%	8.9%	
Jul		0.16%	-1.5%		2.15%	46.1%		0.15%	-1.4%		2.04%	42.8%		0.12%	-1.1%		1.76%	34.7%		0.09%	-0.9%		1.44%	26.8%	
Aug		0.18%	-16.8%		2.33%	29.1%		0.17%	-15.8%		2.23%	27.3%		0.14%	-13.3%		1.94%	23.0%		0.11%	-10.6%		1.61%	18.4%	
Sep		0.17%	-20.4%		2.27%	21.7%		0.16%	-19.3%		2.16%	20.5%		0.13%	-16.3%		1.88%	17.3%		0.10%	-13.1%		1.55%	13.9%	
Oct		0.09%	-12.6%		1.45%	12.8%		0.08%	-11.7%		1.35%	11.9%		0.06%	-9.5%		1.12%	9.7%		0.05%	-7.3%		0.88%	7.4%	
	Max	0.24%	-33.74%		2.79%	46.06%		0.22%	-32.30%		2.68%	42.76%		0.18%	-28.39%		2.40%	34.75%		0.14%	-23.84%		2.06%	26.83%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Antelope Creek Sensitivity Analysis
Normal Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Antelope Creek	Nov	2460	2.7	909	929	950	6.8	7.6	8.4	1426	1440	1454	5.4	6.0	6.5	1095	1113	1132	6.3	7.0	7.7	1062	1081	1100	6.4	7.1	7.9	1069	1088	1107	6.4	7.1	7.8
	Dec	2372	2.8	909	929	950	6.8	7.6	8.4	1283	1299	1315	5.8	6.4	7.0	1034	1053	1072	6.5	7.2	7.9	1011	1031	1050	6.5	7.3	8.0	1016	1036	1055	6.5	7.3	8.0
	Jan	2335	2.7	909	929	950	6.8	7.6	8.4	1300	1315	1330	5.7	6.3	6.9	1042	1061	1080	6.4	7.2	7.9	1018	1037	1056	6.5	7.2	8.0	1023	1042	1061	6.5	7.2	8.0
	Feb	2251	2.7	909	929	950	6.8	7.6	8.4	1979	1984	1988	3.5	3.7	3.9	1604	1614	1624	4.7	5.1	5.5	1532	1543	1554	4.9	5.3	5.8	1548	1559	1570	4.9	5.3	5.7
	Mar	1782	2.5	909	929	950	6.8	7.6	8.4	1714	1715	1717	2.9	2.9	3.0	1575	1580	1585	3.5	3.7	3.9	1539	1544	1550	3.7	3.9	4.2	1547	1553	1558	3.7	3.9	4.1
	Apr	1949	2.8	909	929	950	6.8	7.6	8.4	1791	1794	1797	3.4	3.5	3.6	1537	1545	1553	4.4	4.7	5.0	1482	1491	1501	4.6	4.9	5.3	1495	1504	1513	4.5	4.9	5.2
	May	1800	2.8	909	929	950	6.8	7.6	8.4	1713	1715	1718	3.2	3.3	3.4	1548	1554	1560	3.9	4.2	4.4	1507	1514	1521	4.1	4.4	4.7	1517	1523	1530	4.1	4.3	4.6
	Jun	2005	2.8	909	929	950	6.8	7.6	8.4	1904	1906	1908	3.2	3.2	3.3	1707	1713	1719	3.9	4.1	4.3	1658	1664	1671	4.1	4.3	4.6	1670	1676	1682	4.0	4.3	4.5
	Jul	1661	2.5	909	929	950	6.8	7.6	8.4	1531	1535	1538	3.2	3.4	3.5	1335	1344	1353	4.4	4.7	5.1	1295	1305	1315	4.6	5.0	5.4	1304	1314	1324	4.5	4.9	5.3
	Aug	1684	2.5	909	929	950	6.8	7.6	8.4	1500	1505	1510	3.5	3.7	3.9	1271	1282	1293	4.8	5.2	5.6	1229	1241	1254	5.0	5.5	6.0	1239	1251	1263	5.0	5.4	5.9
	Sep	2214	2.5	909	929	950	6.8	7.6	8.4	1738	1746	1754	4.1	4.4	4.7	1329	1344	1358	5.4	6.0	6.5	1270	1285	1300	5.6	6.2	6.8	1283	1298	1313	5.6	6.2	6.7
	Oct	2354	2.6	909	929	950	6.8	7.6	8.4	1707	1716	1725	4.5	4.8	5.2	1272	1288	1304	5.7	6.4	7.0	1217	1233	1249	5.9	6.5	7.2	1229	1245	1261	5.9	6.5	7.1

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Antelope Creek	0.97%	-41.5%		9.06%	118.6%		1.65%	-54.8%		10.19%	156.6%		1.74%	-56.1%		10.29%	160.3%		1.72%	-55.8%		10.27%	159.5%	
Dec		1.20%	-45.2%		9.50%	128.6%		1.81%	-55.6%		10.34%	158.1%		1.88%	-56.5%		10.40%	160.8%		1.87%	-56.3%		10.39%	160.2%	
Jan		1.15%	-43.7%		9.41%	129.2%		1.79%	-54.6%		10.31%	161.3%		1.86%	-55.6%		10.38%	164.3%		1.84%	-55.4%		10.37%	163.7%	
Feb		0.21%	-11.9%		4.45%	36.6%		0.62%	-28.3%		7.73%	87.2%		0.73%	-31.5%		8.17%	97.0%		0.70%	-30.7%		8.08%	94.8%	
Mar		0.10%	-3.7%		2.18%	15.8%		0.31%	-11.3%		5.18%	48.0%		0.38%	-13.3%		5.76%	56.4%		0.36%	-12.9%		5.63%	54.3%	
Apr		0.18%	-7.9%		3.53%	26.5%		0.54%	-20.7%		6.88%	69.3%		0.63%	-23.5%		7.39%	78.6%		0.61%	-22.8%		7.28%	76.4%	
May		0.12%	-4.7%		2.41%	16.5%		0.38%	-13.7%		5.51%	48.1%		0.45%	-15.9%		6.09%	55.9%		0.44%	-15.4%		5.96%	54.1%	
Jun		0.10%	-5.0%		2.32%	15.9%		0.33%	-14.6%		5.38%	46.7%		0.40%	-17.0%		5.96%	54.5%		0.38%	-16.4%		5.83%	52.6%	
Jul		0.23%	-7.6%		4.17%	35.7%		0.67%	-19.1%		7.50%	89.7%		0.78%	-21.4%		7.96%	100.8%		0.75%	-20.9%		7.86%	98.2%	
Aug		0.33%	-10.6%		5.24%	49.5%		0.87%	-23.9%		8.33%	111.1%		0.99%	-26.3%		8.70%	122.2%		0.96%	-25.7%		8.62%	119.7%	
Sep		0.44%	-21.1%		6.78%	73.7%		1.05%	-39.3%		9.24%	137.0%		1.18%	-42.0%		9.49%	146.2%		1.15%	-41.4%		9.44%	144.2%	
Oct		0.54%	-27.1%		7.52%	86.4%		1.21%	-45.3%		9.59%	144.4%		1.33%	-47.6%		9.79%	151.8%		1.31%	-47.1%		9.75%	150.2%	
	Max	1.20%	-3.74%		9.50%	129.15%		1.81%	-11.35%		10.34%	161.32%		1.88%	-13.33%		10.40%	164.31%		1.87%	-12.86%		10.39%	163.67%	

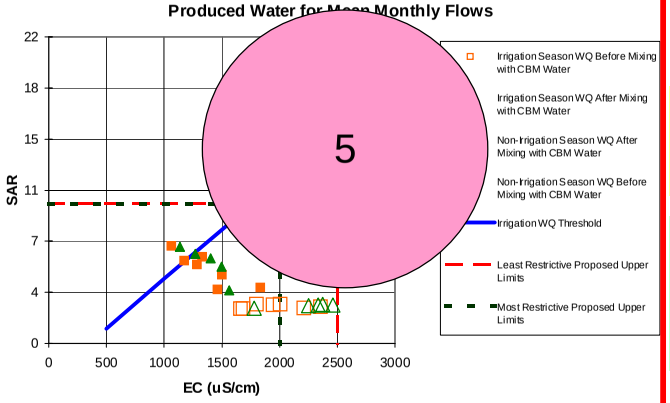
(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

APPENDIX C-2

DRY YEAR CONDITIONS

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin



5

		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	CBNG Discharge Quality EC (uS/cm) 95% Lower	EC (uS/cm) Mean	EC (uS/cm) 95% upper	SAR (--) 95% Lower	SAR (--) Mean	SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)	
				909	929	950	6.80	7.62	8.43			
Non-Irrigation Season	Nov	0.9	0.40	1386				6.12	6.68	2460	2.74	Non-Irrigation Season
	Dec	0.9	0.15	1118				6.93	7.62	2372	2.79	
	Jan	0.9	0.29	1256				6.43	7.04	2335	2.74	
	Feb	0.9	0.68	1486				5.50	5.97	2251	2.71	
	Mar	0.9	2.60	1557				3.83	4.04	1782	2.52	
Irrigation Season	Apr	0.9	1.15	1492	150			4.90	5.25	1949	2.77	Irrigation Season
	May	0.9	0.63	1276	1288		16	5.64	6.12	1800	2.82	
	Jun	0.9	0.13	1047	1065		6.30	7.01	7.72	2005	2.8	
	Jul	0.9	2.47	1460	1466	1471	3.63	3.85	4.07	1661	2.48	
	Aug	0.9	0.44	1163	1177	1191	5.38	5.93	6.47	1684	2.47	
	Sep	0.9	2.17	1831	1837	1844	3.78	4.01	4.25	2214	2.52	
	Oct	0.9	0.35	1313	1328	1343	5.62	6.21	6.80	2354	2.6	

4

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and W

Drainage	Stream Gauge Location	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teck	0.7	0.9	0.9

3

Mean Monthly Discharge			
		Days	cfs
O		31	0.35
		30	0.40
		31	0.15
		31	0.29
		28	0.68
		31	2.60
		30	1.15
		31	0.63
		30	0.13
Ju		31	2.47
Aug		31	0.44
Sep	130	30	2.17

2

Plotting Position: Most and Least Restrictive Limits			
	EC	SAR	
	0		
Least Restrictiv	2500		
	2500		
	0		
Most Restrictiv	2000		
	2000		

Irrigation WQ Threshold Line	
500	1.07
1000	4.62
1500	8.17
2990	18.75

1

See following page for descriptions of chart sections

Descriptions of Chart Sections

1

Section 1: The values in this section are used to plot lines within the graph delineating themost restrictive, least restrictive, and the irrigation water quality threshold. The most restrictive and least restrictve limits data were obtained from the pertinent regulatory agency. They are tabulated in the spreadsheet table named "CBNG Discharge Parameters" and referenced herein.

2

Section 2: This section tabulates the mean monthly stream flow for each site. These data are referenced from the table located in Section 4 and used in the mixing calculations.

3

Section 3: This section computes the amount of CBM water which ultimately reaches the receiving waters following conveyance losses. The table is initially populated by reference to worksheet CBNG Discharge Parameters. Output from this table is then referenced by Section 4 where it is used in mixing computations

4

Section 4: This section is where the mixing calculations occur. CBM water with a given water quality is mixed with a background water with its own water quality. Using simple mixing computations described in the table, downstream water quality is estimated. Irrigation season is displayed in the area shaded green; non-irrigation season is shaded yellow.

5

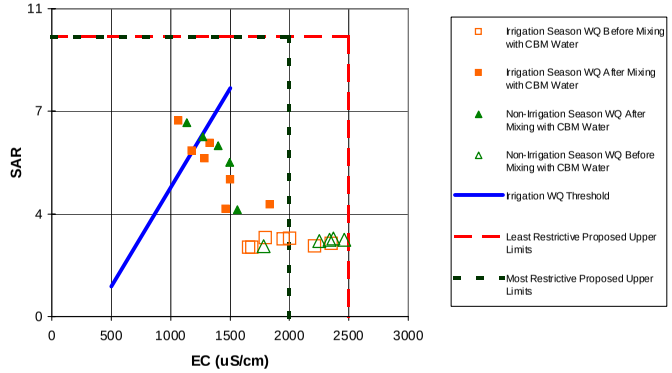
Section 5: This section presents the summary graph illustrating irrigation suitability and the water quality data relative to the "limits". The graph references "Limits" data from Section 1 and pertinent water quality data from section 4.

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality [1] EC (uS/cm) 95% Lower	EC Mean	EC 95% upper	SAR (--) 95% Lower	SAR Mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.9	0.40	1386	1400	1415	5.55	6.12	6.68	2460	2.74
	Dec	0.9	0.15	1118	1136	1153	6.23	6.93	7.62	2372	2.79
	Jan	0.9	0.29	1256	1272	1288	5.81	6.43	7.04	2335	2.74
	Feb	0.9	0.68	1486	1498	1510	5.04	5.50	5.97	2251	2.71
	Mar	0.9	2.60	1557	1563	1568	3.62	3.83	4.04	1782	2.52
Irrigation Season	Apr	0.9	1.15	1492	1501	1511	4.54	4.90	5.25	1949	2.77
	May	0.9	0.63	1276	1288	1300	5.16	5.64	6.12	1800	2.82
	Jun	0.9	0.13	1047	1065	1083	6.30	7.01	7.72	2005	2.8
	Jul	0.9	2.47	1460	1466	1471	3.63	3.85	4.07	1661	2.48
	Aug	0.9	0.44	1163	1177	1191	5.38	5.93	6.47	1684	2.47
	Sep	0.9	2.17	1831	1837	1844	3.78	4.01	4.25	2214	2.52
	Oct	0.9	0.35	1313	1328	1343	5.62	6.21	6.80	2354	2.6

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	3.0	0.7	0.9	0.9

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	22	31	0.35
Nov	24	30	0.40
Dec	9	31	0.15
Jan	18	31	0.29
Feb	38	28	0.68
Mar	161	31	2.60
Apr	69	30	1.15
May	39	31	0.63
Jun	8	30	0.13
Jul	153	31	2.47
Aug	27	31	0.44
Sep	130	30	2.17

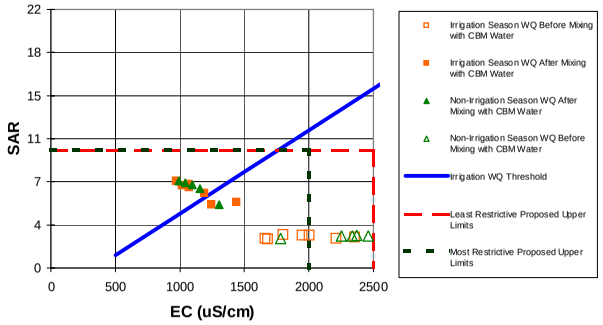
Plotting Position: Most and Least Restrictive Limits			
	EC	SAR	
	0	10	
Least Restrictiv	2500	10	
	2500	0	
	0	10	
Most Restrictiv	2000	10	
	2000	0	

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Antelope Creek: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	3.3	0.40	1076	1095	1114	6.36	7.09	7.81	2460	2.74
	Dec	3.3	0.15	972	992	1012	6.63	7.41	8.18	2372	2.79
	Jan	3.3	0.29	1024	1043	1062	6.47	7.22	7.97	2335	2.74
	Feb	3.3	0.68	1138	1155	1173	6.10	6.78	7.45	2251	2.71
	Mar	3.3	2.60	1293	1305	1317	4.91	5.37	5.83	1782	2.52
Irrigation Season	Apr	3.3	1.15	1177	1193	1208	5.76	6.36	6.97	1949	2.77
	May	3.3	0.63	1051	1069	1087	6.16	6.85	7.53	1800	2.82
	Jun	3.3	0.13	950	970	990	6.65	7.43	8.22	2005	2.8
	Jul	3.3	2.47	1231	1243	1255	4.95	5.42	5.88	1661	2.48
	Aug	3.3	0.44	1000	1018	1037	6.29	7.01	7.73	1684	2.47
	Sep	3.3	2.17	1426	1439	1452	5.10	5.59	6.09	2214	2.52
	Oct	3.3	0.35	1047	1066	1085	6.40	7.13	7.87	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	10.9	0.7	3.3	3.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	22	31	0.35
Nov	24	30	0.40
Dec	9	31	0.15
Jan	18	31	0.29
Feb	38	28	0.68
Mar	161	31	2.60
Apr	69	30	1.15
May	39	31	0.63
Jun	8	30	0.13
Jul	153	31	2.47
Aug	27	31	0.44
Sep	130	30	2.17

Table of Plotting Positions for graph

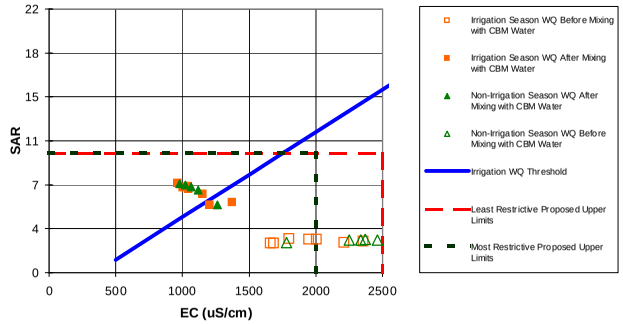
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Antelope Creek: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% Lower	Mean	95% upper	Mixed Water Quality SAR (--) 95% Lower	Mean	95% upper	Background Water Quality EC (uS/cm)	SAR (--)
Non-Irrigation Season	Nov	4.1	0.40	1046	1066	1085	6.44	7.18	7.92	2460	2.74
	Dec	4.1	0.15	960	980	1001	6.66	7.45	8.23	2372	2.79
	Jan	4.1	0.29	1003	1022	1042	6.53	7.29	8.05	2335	2.74
	Feb	4.1	0.68	1100	1117	1135	6.22	6.92	7.62	2251	2.71
	Mar	4.1	2.60	1248	1260	1273	5.14	5.64	6.14	1782	2.52
Irrigation Season	Apr	4.1	1.15	1136	1153	1169	5.92	6.55	7.19	1949	2.77
	May	4.1	0.63	1027	1045	1064	6.27	6.98	7.68	1800	2.82
	Jun	4.1	0.13	942	963	983	6.68	7.47	8.26	2005	2.8
	Jul	4.1	2.47	1191	1204	1218	5.18	5.68	6.19	1661	2.48
	Aug	4.1	0.44	984	1003	1021	6.38	7.12	7.85	1684	2.47
	Sep	4.1	2.17	1360	1374	1388	5.32	5.85	6.38	2214	2.52
	Oct	4.1	0.35	1022	1042	1061	6.47	7.22	7.97	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	13.5	0.7	4.1	4.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	22	31	0.35
Nov	24	30	0.40
Dec	9	31	0.15
Jan	18	31	0.29
Feb	38	28	0.68
Mar	161	31	2.60
Apr	69	30	1.15
May	39	31	0.63
Jun	8	30	0.13
Jul	153	31	2.47
Aug	27	31	0.44
Sep	130	30	2.17

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

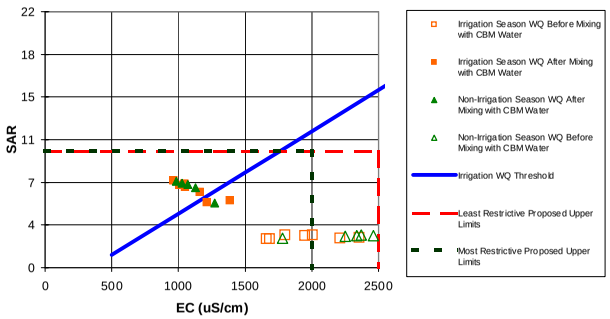
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Antelope Creek: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% Lower	Mixed Water Quality EC (uS/cm) Mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% Lower	Mixed Water Quality SAR (--) Mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	3.9	0.40	1053	1072	1091	6.42	7.16	7.90	2460	2.74
	Dec	3.9	0.15	963	983	1003	6.65	7.44	8.22	2372	2.79
	Jan	3.9	0.29	1007	1027	1046	6.52	7.28	8.04	2335	2.74
	Feb	3.9	0.68	1108	1126	1143	6.19	6.89	7.58	2251	2.71
	Mar	3.9	2.60	1258	1270	1283	5.09	5.58	6.07	1782	2.52
Irrigation Season	Apr	3.9	1.15	1146	1162	1178	5.88	6.51	7.14	1949	2.77
	May	3.9	0.63	1033	1051	1069	6.25	6.95	7.65	1800	2.82
	Jun	3.9	0.13	944	964	984	6.67	7.46	8.25	2005	2.8
	Jul	3.9	2.47	1200	1213	1226	5.13	5.62	6.12	1661	2.48
	Aug	3.9	0.44	987	1006	1025	6.36	7.09	7.83	1684	2.47
	Sep	3.9	2.17	1375	1389	1402	5.27	5.79	6.32	2214	2.52
	Oct	3.9	0.35	1028	1047	1066	6.46	7.20	7.95	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Antelope	Antelope Creek near Teckla, WY	12.9	0.7	3.9	3.9

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	22	31	0.35
Nov	24	30	0.40
Dec	9	31	0.15
Jan	18	31	0.29
Feb	38	28	0.68
Mar	161	31	2.60
Apr	69	30	1.15
May	39	31	0.63
Jun	8	30	0.13
Jul	153	31	2.47
Aug	27	31	0.44
Sep	130	30	2.17

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restric	2500	10
	2500	0
Most Restric	0	10
	2000	10
	2000	0

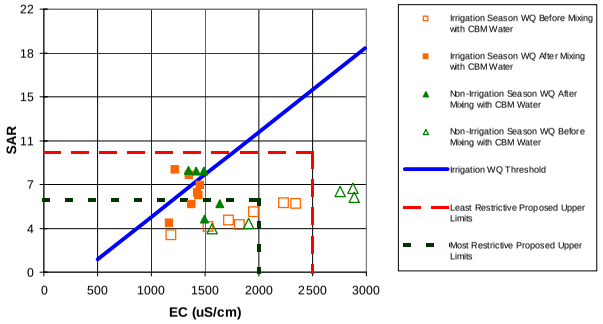
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
	EC			SAR	
	(uS/cm)			(--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow	StreamFlow	EC			SAR			EC	SAR
		(cfs)	(cfs)	(uS/cm)			(--)			(uS/cm)	(--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	4.3	1.16	1479	1485	1491	8.14	8.45	8.76	2877	7.02
	Dec	4.3	0.98	1409	1415	1421	8.13	8.45	8.77	2755	6.77
	Jan	4.3	0.65	1337	1343	1350	8.16	8.50	8.84	2887	6.29
	Feb	4.3	8.28	1632	1634	1637	5.57	5.71	5.84	1907	4.08
	Mar	4.3	23.54	1493	1494	1495	4.38	4.44	4.50	1564	3.64
Irrigation Season	Apr	4.3	4.98	1435	1438	1442	6.24	6.42	6.60	1722	4.34
	May	4.3	7.15	1371	1373	1376	5.55	5.70	5.84	1532	3.81
	Jun	4.3	3.53	1426	1430	1435	6.43	6.65	6.86	1821	3.98
	Jul	4.3	19.18	1167	1169	1170	4.08	4.15	4.22	1182	3.1
	Aug	4.3	2.94	1448	1453	1458	7.07	7.30	7.53	1955	5.06
	Sep	4.3	1.19	1347	1353	1359	7.86	8.17	8.47	2231	5.76
	Oct	4.3	0.42	1213	1220	1227	8.20	8.56	8.92	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	14.4	0.7	4.3	4.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	25.78333333	31	0.42
Nov	69.75937	30	1.16
Dec	60.83333333	31	0.98
Jan	40.5	31	0.65
Feb	463.7034167	28	8.28
Mar	1459.54671	31	23.54
Apr	298.7534767	30	4.98
May	443.4144467	31	7.15
Jun	211.5	30	3.53
Jul	1189.381403	31	19.18
Aug	182.5	31	2.94
Sep	71.17809667	30	1.19

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

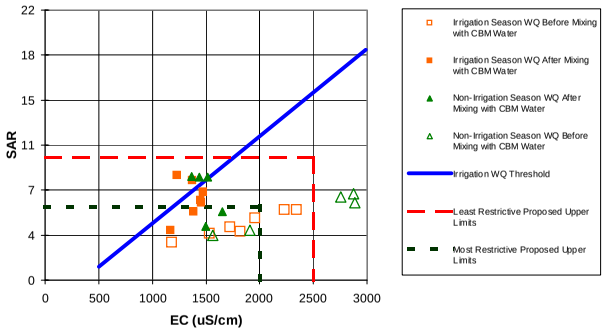
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
	EC			SAR	
	(uS/cm)			(--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow	StreamFlow	EC			SAR			EC	SAR
		(cfs)	(cfs)	(uS/cm)			(--)			(uS/cm)	(--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	3.9	1.16	1509	1515	1521	8.12	8.42	8.72	2877	7.02
	Dec	3.9	0.98	1434	1440	1446	8.11	8.42	8.73	2755	6.77
	Jan	3.9	0.65	1357	1364	1370	8.14	8.47	8.81	2887	6.29
	Feb	3.9	8.28	1649	1652	1654	5.48	5.60	5.73	1907	4.08
	Mar	3.9	23.54	1498	1499	1501	4.32	4.38	4.43	1564	3.64
Irrigation Season	Apr	3.9	4.98	1450	1453	1456	6.14	6.31	6.49	1722	4.34
	May	3.9	7.15	1380	1383	1386	5.45	5.58	5.72	1532	3.81
	Jun	3.9	3.53	1444	1448	1452	6.32	6.53	6.73	1821	3.98
	Jul	3.9	19.18	1169	1170	1171	4.00	4.07	4.14	1182	3.1
	Aug	3.9	2.94	1469	1473	1477	6.99	7.21	7.44	1955	5.06
	Sep	3.9	1.19	1366	1372	1378	7.82	8.12	8.42	2231	5.76
	Oct	3.9	0.42	1223	1230	1237	8.18	8.53	8.89	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	13.1	0.7	3.9	3.9

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	25.78333333	31	0.42
Nov	69.75937	30	1.16
Dec	60.83333333	31	0.98
Jan	40.5	31	0.65
Feb	463.7034167	28	8.28
Mar	1459.54671	31	23.54
Apr	298.7534767	30	4.98
May	443.4144467	31	7.15
Jun	211.5	30	3.53
Jul	1189.381403	31	19.18
Aug	182.5	31	2.94
Sep	71.17809667	30	1.19

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

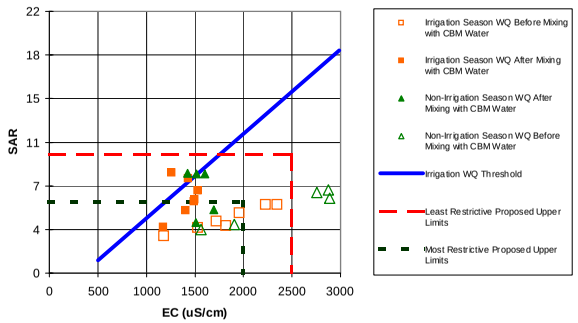
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
	EC			SAR	
	(uS/cm)			(--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow	StreamFlow	EC			SAR			EC	SAR
		(cfs)	(cfs)	(uS/cm)			(--)			(uS/cm)	(--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	3.0	1.16	1597	1603	1608	8.05	8.33	8.61	2877	7.02
	Dec	3.0	0.98	1509	1515	1521	8.03	8.33	8.62	2755	6.77
	Jan	3.0	0.65	1420	1426	1433	8.06	8.38	8.70	2887	6.29
	Feb	3.0	8.28	1693	1695	1697	5.24	5.34	5.45	1907	4.08
	Mar	3.0	23.54	1512	1513	1514	4.18	4.23	4.27	1564	3.64
Irrigation Season	Apr	3.0	4.98	1489	1492	1495	5.88	6.03	6.18	1722	4.34
	May	3.0	7.15	1405	1407	1409	5.18	5.29	5.41	1532	3.81
	Jun	3.0	3.53	1491	1494	1498	6.03	6.21	6.39	1821	3.98
	Jul	3.0	19.18	1171	1172	1173	3.82	3.88	3.93	1182	3.1
	Aug	3.0	2.94	1524	1528	1532	6.77	6.97	7.16	1955	5.06
	Sep	3.0	1.19	1423	1428	1434	7.68	7.96	8.24	2231	5.76
	Oct	3.0	0.42	1255	1262	1268	8.11	8.46	8.80	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	9.9	0.7	3.0	3.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	25.78333333	31	0.42
Nov	69.75937	30	1.16
Dec	60.83333333	31	0.98
Jan	40.5	31	0.65
Feb	463.7034167	28	8.28
Mar	1459.54671	31	23.54
Apr	298.7534767	30	4.98
May	443.4144467	31	7.15
Jun	211.5	30	3.53
Jul	1189.381403	31	19.18
Aug	182.5	31	2.94
Sep	71.17809667	30	1.19

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
	0	6
Most Restrictive	2000	6
	2000	0

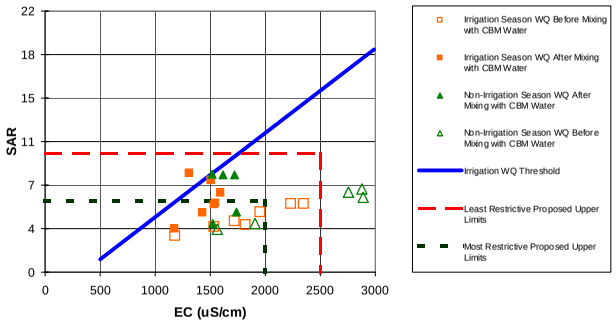
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
	EC			SAR	
	(uS/cm)			(--)	
1102	1110	1117	8.4	8.8	9.2

Upper Belle Fourche River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean		Mixed Water Quality						Background Water Quality	
		CBM Flow	StreamFlow	EC			SAR			EC	SAR
		(cfs)	(cfs)	(uS/cm)			(--)			(uS/cm)	(--)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper		
Non-Irrigation Season	Nov	2.2	1.16	1715	1720	1725	7.95	8.21	8.46	2877	7.02
	Dec	2.2	0.98	1612	1617	1622	7.93	8.20	8.47	2755	6.77
	Jan	2.2	0.65	1509	1515	1521	7.95	8.25	8.56	2887	6.29
	Feb	2.2	8.28	1738	1740	1741	5.00	5.08	5.16	1907	4.08
	Mar	2.2	23.54	1525	1525	1526	4.05	4.08	4.12	1564	3.64
Irrigation Season	Apr	2.2	4.98	1532	1534	1537	5.60	5.72	5.84	1722	4.34
	May	2.2	7.15	1431	1433	1434	4.90	4.99	5.08	1532	3.81
	Jun	2.2	3.53	1545	1548	1551	5.69	5.84	5.99	1821	3.98
	Jul	2.2	19.18	1174	1175	1175	3.65	3.69	3.73	1182	3.1
	Aug	2.2	2.94	1590	1593	1596	6.51	6.68	6.84	1955	5.06
	Sep	2.2	1.19	1498	1503	1508	7.50	7.76	8.01	2231	5.76
	Oct	2.2	0.42	1302	1308	1314	8.01	8.34	8.67	2346	5.75

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Belle Fourche	Upper Belle Fourche River	7.3	0.7	2.2	2.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	25.78333333	31	0.42
Nov	69.75937	30	1.16
Dec	60.83333333	31	0.98
Jan	40.5	31	0.65
Feb	463.7034167	28	8.28
Mar	1459.54671	31	23.54
Apr	298.7534767	30	4.98
May	443.4144467	31	7.15
Jun	211.5	30	3.53
Jul	1189.381403	31	19.18
Aug	182.5	31	2.94
Sep	71.17809667	30	1.19

Table of Plotting Positions for graph

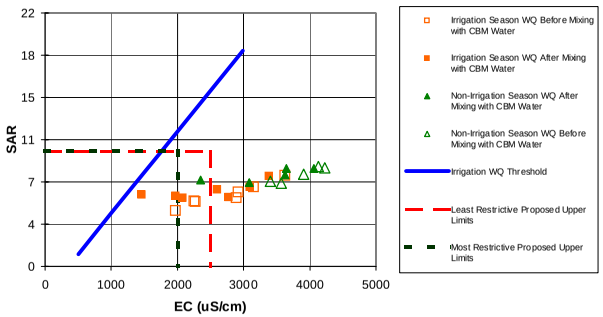
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.8	3.60	3082	3086	3090	7.14	7.29	7.44	3565	7.22
	Dec	0.8	1.08	2343	2352	2360	7.14	7.49	7.83	3405	7.39
	Jan	0.8	15.37	4065	4066	4067	8.49	8.53	8.57	4229	8.58
	Feb	0.8	7.68	3628	3630	3632	7.90	7.97	8.05	3911	8.01
	Mar	0.8	4.56	3647	3650	3653	8.38	8.50	8.63	4127	8.66
Irrigation Season	Apr	0.8	7.88	3379	3381	3383	7.77	7.85	7.92	3630	7.87
	May	0.8	27.97	3093	3093	3094	6.88	6.90	6.92	3155	6.88
	Jun	0.8	12.70	2777	2779	2780	5.98	6.03	6.08	2895	5.93
	Jul	0.8	3.02	1969	1973	1978	5.92	6.09	6.26	2250	5.69
	Aug	0.8	0.82	1447	1457	1467	5.80	6.20	6.60	1972	4.82
	Sep	0.8	4.67	2072	2075	2078	5.80	5.92	6.04	2271	5.63
	Oct	0.8	4.18	2594	2597	2600	6.51	6.65	6.78	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.5	0.7	0.8	0.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	259	31	4.18
Nov	216	30	3.60
Dec	67	31	1.08
Jan	953	31	15.37
Feb	430	28	7.68
Mar	283	31	4.56
Apr	473	30	7.88
May	1734	31	27.97
Jun	762	30	12.70
Jul	187	31	3.02
Aug	51	31	0.82
Sep	280	30	4.67

Table of Plotting Positions for graph

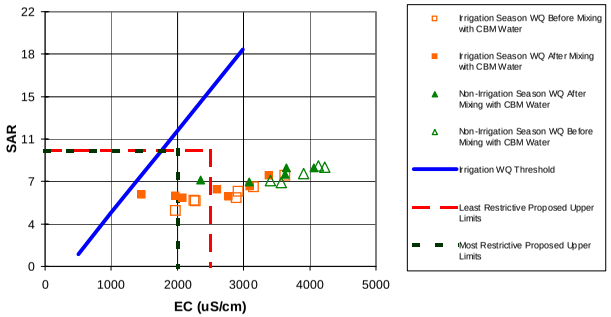
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.8	3.60	3082	3086	3090	7.14	7.29	7.44	3565	7.22
	Dec	0.8	1.08	2343	2352	2360	7.14	7.49	7.83	3405	7.39
	Jan	0.8	15.37	4065	4066	4067	8.49	8.53	8.57	4229	8.58
	Feb	0.8	7.68	3628	3630	3632	7.90	7.97	8.05	3911	8.01
	Mar	0.8	4.56	3647	3650	3653	8.38	8.50	8.63	4127	8.66
Irrigation Season	Apr	0.8	7.88	3379	3381	3383	7.77	7.85	7.92	3630	7.87
	May	0.8	27.97	3093	3093	3094	6.88	6.90	6.92	3155	6.88
	Jun	0.8	12.70	2777	2779	2780	5.98	6.03	6.08	2895	5.93
	Jul	0.8	3.02	1969	1973	1978	5.92	6.09	6.26	2250	5.69
	Aug	0.8	0.82	1447	1457	1467	5.80	6.20	6.60	1972	4.82
	Sep	0.8	4.67	2072	2075	2078	5.80	5.92	6.04	2271	5.63
	Oct	0.8	4.18	2594	2597	2600	6.51	6.65	6.78	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.8	0.7	0.8	0.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	259	31	4.18
Nov	216	30	3.60
Dec	67	31	1.08
Jan	953	31	15.37
Feb	430	28	7.68
Mar	283	31	4.56
Apr	473	30	7.88
May	1734	31	27.97
Jun	762	30	12.70
Jul	187	31	3.02
Aug	51	31	0.82
Sep	280	30	4.67

Table of Plotting Positions for graph

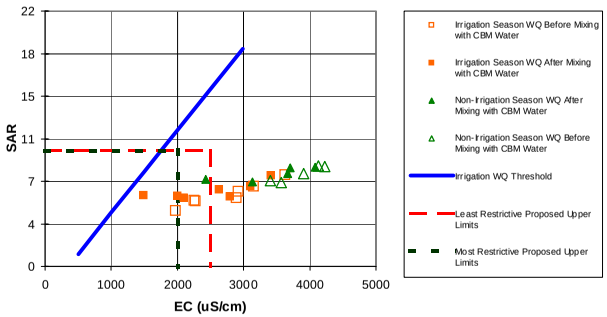
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.7	3.60	3133	3136	3139	7.15	7.28	7.42	3565	7.22
	Dec	0.7	1.08	2423	2431	2440	7.16	7.48	7.80	3405	7.39
	Jan	0.7	15.37	4084	4085	4086	8.50	8.54	8.57	4229	8.58
	Feb	0.7	7.68	3660	3662	3664	7.91	7.98	8.05	3911	8.01
	Mar	0.7	4.56	3699	3701	3704	8.41	8.52	8.63	4127	8.66
Irrigation Season	Apr	0.7	7.88	3408	3410	3411	7.78	7.85	7.92	3630	7.87
	May	0.7	27.97	3100	3101	3101	6.88	6.90	6.92	3155	6.88
	Jun	0.7	12.70	2791	2792	2793	5.98	6.02	6.06	2895	5.93
	Jul	0.7	3.02	1998	2002	2005	5.90	6.05	6.21	2250	5.69
	Aug	0.7	0.82	1482	1492	1502	5.73	6.11	6.48	1972	4.82
	Sep	0.7	4.67	2093	2096	2099	5.78	5.89	5.99	2271	5.63
	Oct	0.7	4.18	2628	2631	2634	6.51	6.63	6.74	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	2.4	0.7	0.7	0.7

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	259	31	4.18
Nov	216	30	3.60
Dec	67	31	1.08
Jan	953	31	15.37
Feb	430	28	7.68
Mar	283	31	4.56
Apr	473	30	7.88
May	1734	31	27.97
Jun	762	30	12.70
Jul	187	31	3.02
Aug	51	31	0.82
Sep	280	30	4.67

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

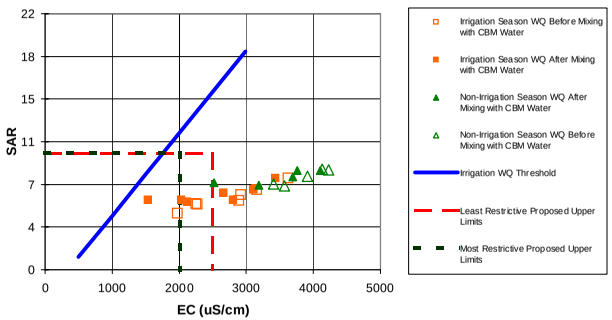
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Upper Cheyenne River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.6	3.60	3186	3188	3191	7.16	7.28	7.39	3565	7.22
	Dec	0.6	1.08	2513	2521	2528	7.18	7.47	7.76	3405	7.39
	Jan	0.6	15.37	4104	4105	4106	8.51	8.54	8.57	4229	8.58
	Feb	0.6	7.68	3693	3695	3696	7.92	7.98	8.04	3911	8.01
	Mar	0.6	4.56	3753	3755	3758	8.44	8.54	8.63	4127	8.66
Irrigation Season	Apr	0.6	7.88	3437	3439	3440	7.79	7.85	7.91	3630	7.87
	May	0.6	27.97	3108	3108	3109	6.88	6.90	6.91	3155	6.88
	Jun	0.6	12.70	2805	2806	2807	5.97	6.01	6.04	2895	5.93
	Jul	0.6	3.02	2028	2031	2035	5.87	6.01	6.14	2250	5.69
	Aug	0.6	0.82	1523	1531	1540	5.66	6.00	6.35	1972	4.82
	Sep	0.6	4.67	2116	2118	2121	5.76	5.86	5.95	2271	5.63
	Oct	0.6	4.18	2664	2667	2669	6.50	6.61	6.71	2916	6.46

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Cheyenne	Upper Cheyenne River	1.9	0.7	0.6	0.6

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	259	31	4.18
Nov	216	30	3.60
Dec	67	31	1.08
Jan	953	31	15.37
Feb	430	28	7.68
Mar	283	31	4.56
Apr	473	30	7.88
May	1734	31	27.97
Jun	762	30	12.70
Jul	187	31	3.02
Aug	51	31	0.82
Sep	280	30	4.67

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

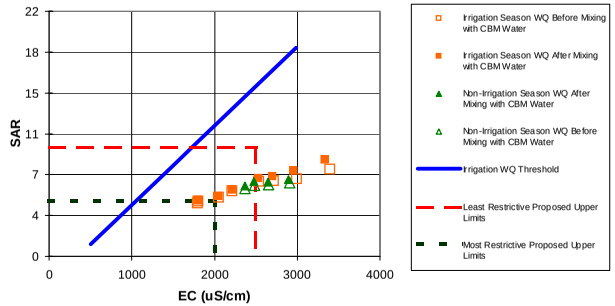
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54

Upper Powder River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	2.3	143.70	2642	2643	2643	6.66	6.67	6.69	2650	6.42
	Dec	2.3	114.27	2891	2892	2892	6.91	6.93	6.94	2906	6.61
	Jan	2.3	113.95	2476	2476	2476	6.70	6.72	6.74	2482	6.4
	Feb	2.3	180.39	2363	2364	2364	6.32	6.33	6.34	2366	6.12
	Mar	2.3	301.02	2052	2052	2052	5.40	5.41	5.42	2051	5.28
Irrigation Season	Apr	2.3	232.78	2212	2213	2213	5.99	6.00	6.01	2213	5.84
	May	2.3	341.65	1805	1806	1806	5.03	5.04	5.04	1803	4.92
	Jun	2.3	157.00	1802	1803	1803	5.00	5.02	5.03	1797	4.76
	Jul	2.3	93.02	2703	2703	2704	7.15	7.17	7.19	2716	6.79
	Aug	2.3	45.32	2952	2953	2954	7.68	7.72	7.77	2992	6.97
	Sep	2.3	38.57	3330	3331	3332	8.61	8.66	8.71	3400	7.83
	Oct	2.3	123.27	2530	2530	2531	6.98	7.00	7.02	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	7.8	0.7	2.3	2.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	7643	31	123.27
Nov	8622	30	143.70
Dec	7085	31	114.27
Jan	7065	31	113.95
Feb	10102	28	180.39
Mar	18663	31	301.02
Apr	13967	30	232.78
May	21182	31	341.65
Jun	9420	30	157.00
Jul	5767	31	93.02
Aug	2810	31	45.32
Sep	2314	30	38.57

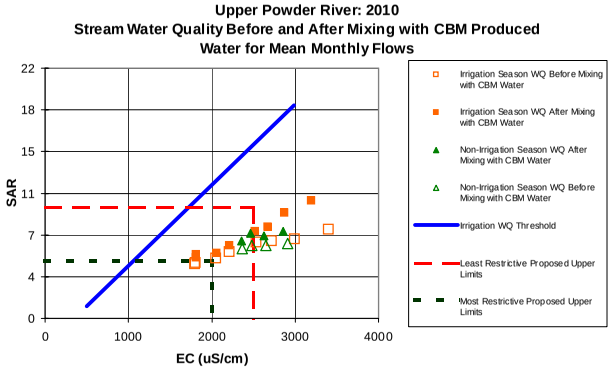
Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line	
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	8.0	143.70	2624	2625	2626	7.22	7.27	7.32	2650	6.42
	Dec	8.0	114.27	2857	2859	2860	7.59	7.65	7.72	2906	6.61
	Jan	8.0	113.95	2461	2462	2463	7.40	7.46	7.52	2482	6.4
	Feb	8.0	180.39	2357	2358	2359	6.78	6.82	6.86	2366	6.12
	Mar	8.0	301.02	2054	2054	2055	5.70	5.73	5.75	2051	5.28
Irrigation Season	Apr	8.0	232.78	2211	2212	2213	6.36	6.40	6.43	2213	5.84
	May	8.0	341.65	1811	1812	1812	5.30	5.32	5.35	1803	4.92
	Jun	8.0	157.00	1815	1816	1817	5.58	5.62	5.67	1797	4.76
	Jul	8.0	93.02	2672	2674	2675	7.96	8.04	8.12	2716	6.79
	Aug	8.0	45.32	2867	2870	2873	9.17	9.31	9.46	2992	6.97
	Sep	8.0	38.57	3187	3190	3194	10.20	10.36	10.53	3400	7.83
	Oct	8.0	123.27	2514	2515	2516	7.62	7.68	7.74	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	26.6	0.7	8.0	8.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	7643	31	123.27
Nov	8622	30	143.70
Dec	7085	31	114.27
Jan	7065	31	113.95
Feb	10102	28	180.39
Mar	18663	31	301.02
Apr	13967	30	232.78
May	21182	31	341.65
Jun	9420	30	157.00
Jul	5767	31	93.02
Aug	2810	31	45.32
Sep	2314	30	38.57

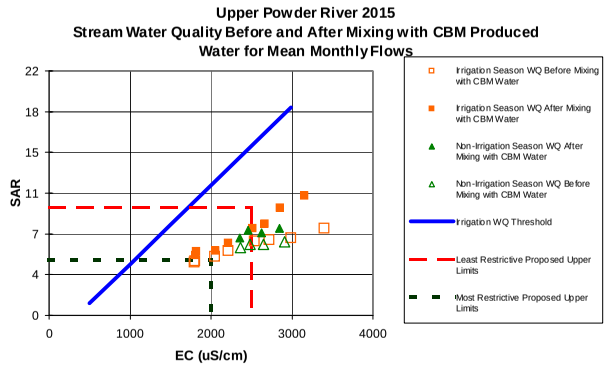
Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	9.75
Least Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	9.6	143.70	2619	2621	2622	7.37	7.43	7.49	2650	6.42
	Dec	9.6	114.27	2848	2850	2851	7.77	7.85	7.92	2906	6.61
	Jan	9.6	113.95	2457	2459	2460	7.58	7.66	7.73	2482	6.4
	Feb	9.6	180.39	2356	2357	2358	6.90	6.95	7.00	2366	6.12
	Mar	9.6	301.02	2054	2055	2056	5.78	5.81	5.84	2051	5.28
Irrigation Season	Apr	9.6	232.78	2211	2212	2212	6.46	6.50	6.54	2213	5.84
	May	9.6	341.65	1813	1813	1814	5.38	5.40	5.43	1803	4.92
	Jun	9.6	157.00	1818	1819	1820	5.73	5.79	5.84	1797	4.76
	Jul	9.6	93.02	2664	2666	2668	8.18	8.27	8.36	2716	6.79
	Aug	9.6	45.32	2847	2850	2854	9.53	9.70	9.87	2992	6.97
	Sep	9.6	38.57	3153	3157	3161	10.58	10.77	10.96	3400	7.83
	Oct	9.6	123.27	2510	2511	2513	7.79	7.86	7.93	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	31.9	0.7	9.6	9.6

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	7643	31	123.27
Nov	8622	30	143.70
Dec	7085	31	114.27
Jan	7065	31	113.95
Feb	10102	28	180.39
Mar	18663	31	301.02
Apr	13967	30	232.78
May	21182	31	341.65
Jun	9420	30	157.00
Jul	5767	31	93.02
Aug	2810	31	45.32
Sep	2314	30	38.57

Table of Plotting Positions for graph

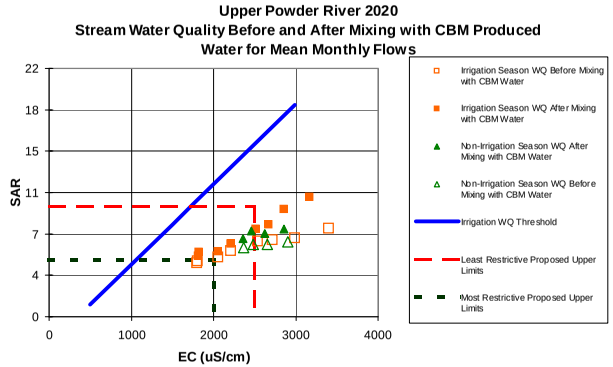
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	9.75
Least Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
2161	2180	2200	21.62	22.58	23.54



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	9.0	143.70	2621	2622	2623	7.32	7.37	7.43	2650	6.42
	Dec	9.0	114.27	2852	2853	2854	7.71	7.78	7.85	2906	6.61
	Jan	9.0	113.95	2458	2460	2461	7.51	7.58	7.65	2482	6.4
	Feb	9.0	180.39	2356	2357	2358	6.86	6.90	6.95	2366	6.12
Irrigation Season	Mar	9.0	301.02	2054	2055	2055	5.75	5.78	5.81	2051	5.28
	Apr	9.0	232.78	2211	2212	2213	6.43	6.46	6.50	2213	5.84
	May	9.0	341.65	1812	1813	1813	5.35	5.37	5.40	1803	4.92
	Jun	9.0	157.00	1817	1818	1819	5.67	5.73	5.78	1797	4.76
	Jul	9.0	93.02	2667	2669	2670	8.10	8.18	8.27	2716	6.79
	Aug	9.0	45.32	2854	2857	2861	9.40	9.56	9.71	2992	6.97
	Sep	9.0	38.57	3166	3169	3173	10.44	10.62	10.80	3400	7.83
	Oct	9.0	123.27	2511	2513	2514	7.72	7.79	7.85	2537	6.71

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Upper Powder	Upper Powder River	30.0	0.7	9.0	9.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	7643	31	123.27
Nov	8622	30	143.70
Dec	7085	31	114.27
Jan	7065	31	113.95
Feb	10102	28	180.39
Mar	18663	31	301.02
Apr	13967	30	232.78
May	21182	31	341.65
Jun	9420	30	157.00
Jul	5767	31	93.02
Aug	2810	31	45.32
Sep	2314	30	38.57

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

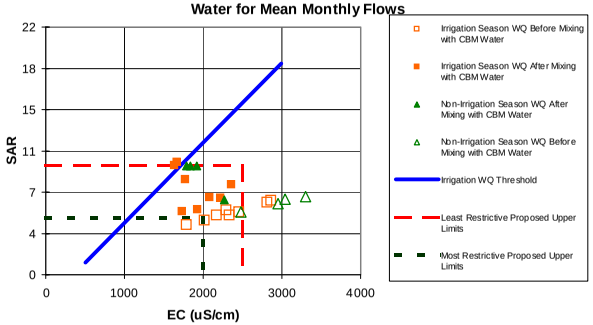
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2003
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	1.6	0.43	1822	1834	1846	9.26	9.69	10.11	3044	6.7
	Dec	1.6	0.48	1910	1922	1934	9.26	9.67	10.09	3300	6.94
	Jan	1.6	0.39	1779	1792	1804	9.24	9.68	10.11	2953	6.33
	Feb	1.6	5.70	2261	2265	2268	6.53	6.65	6.77	2477	5.57
	Mar	1.6	6.44	1727	1730	1733	5.54	5.64	5.75	1785	4.44
Irrigation Season	Apr	1.6	4.73	2213	2217	2221	6.66	6.80	6.94	2457	5.55
	May	1.6	7.65	1923	1926	1928	5.70	5.79	5.89	2013	4.81
	Jun	1.6	3.67	2078	2083	2088	6.71	6.87	7.03	2333	5.29
	Jul	1.6	1.03	1760	1769	1779	8.13	8.45	8.78	2174	5.29
	Aug	1.6	2.73	2355	2361	2366	7.82	8.02	8.22	2860	6.57
	Sep	1.6	0.22	1653	1666	1680	9.53	10.00	10.48	2810	6.44
	Oct	1.6	0.31	1622	1636	1649	9.27	9.72	10.17	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	5.3	0.7	1.6	1.6

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	19	31	0.31
Nov	26	30	0.43
Dec	30	31	0.48
Jan	24	31	0.39
Feb	319	28	5.70
Mar	399	31	6.44
Apr	284	30	4.73
May	474	31	7.65
Jun	220	30	3.67
Jul	64	31	1.03
Aug	169	31	2.73
Sep	13	30	0.22

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

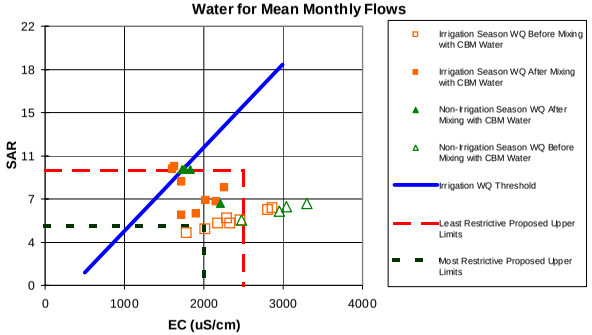
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	2.2	0.43	1747	1760	1773	9.42	9.87	10.32	3044	6.7
	Dec	2.2	0.48	1817	1830	1842	9.41	9.86	10.30	3300	6.94
	Jan	2.2	0.39	1713	1726	1740	9.41	9.86	10.32	2953	6.33
	Feb	2.2	5.70	2203	2207	2212	6.79	6.94	7.09	2477	5.57
	Mar	2.2	6.44	1711	1715	1719	5.84	5.98	6.12	1785	4.44
Irrigation Season	Apr	2.2	4.73	2151	2156	2161	6.95	7.12	7.29	2457	5.55
	May	2.2	7.65	1897	1900	1904	5.96	6.08	6.20	2013	4.81
	Jun	2.2	3.67	2018	2024	2030	7.04	7.24	7.44	2333	5.29
	Jul	2.2	1.03	1710	1721	1732	8.46	8.83	9.20	2174	5.29
	Aug	2.2	2.73	2250	2257	2264	8.08	8.32	8.56	2860	6.57
	Sep	2.2	0.22	1613	1627	1641	9.63	10.12	10.61	2810	6.44
	Oct	2.2	0.31	1592	1605	1619	9.43	9.90	10.38	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	7.3	0.7	2.2	2.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	19	31	0.31
Nov	26	30	0.43
Dec	30	31	0.48
Jan	24	31	0.39
Feb	319	28	5.70
Mar	399	31	6.44
Apr	284	30	4.73
May	474	31	7.65
Jun	220	30	3.67
Jul	64	31	1.03
Aug	169	31	2.73
Sep	13	30	0.22

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

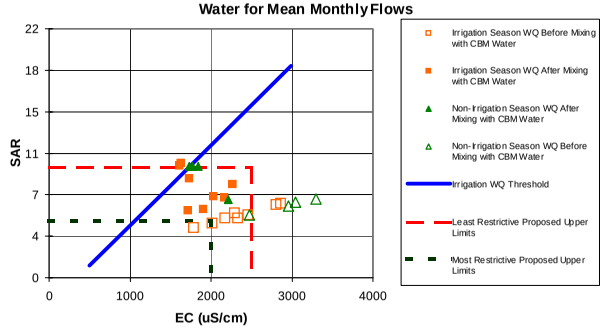
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	2.1	0.43	1757	1770	1783	9.40	9.85	10.29	3044	6.7
	Dec	2.1	0.48	1829	1842	1855	9.39	9.83	10.27	3300	6.94
	Jan	2.1	0.39	1722	1735	1748	9.38	9.84	10.29	2953	6.33
	Feb	2.1	5.70	2212	2216	2221	6.75	6.89	7.04	2477	5.57
	Mar	2.1	6.44	1713	1717	1721	5.80	5.93	6.06	1785	4.44
Irrigation Season	Apr	2.1	4.73	2161	2165	2170	6.90	7.07	7.24	2457	5.55
	May	2.1	7.65	1901	1904	1908	5.92	6.03	6.15	2013	4.81
	Jun	2.1	3.67	2027	2033	2039	6.99	7.18	7.38	2333	5.29
	Jul	2.1	1.03	1717	1728	1738	8.42	8.78	9.14	2174	5.29
	Aug	2.1	2.73	2266	2273	2279	8.04	8.27	8.51	2860	6.57
	Sep	2.1	0.22	1618	1632	1646	9.62	10.11	10.60	2810	6.44
	Oct	2.1	0.31	1596	1609	1623	9.41	9.88	10.35	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	7.0	0.7	2.1	2.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	19	31	0.31
Nov	26	30	0.43
Dec	30	31	0.48
Jan	24	31	0.39
Feb	319	28	5.70
Mar	399	31	6.44
Apr	284	30	4.73
May	474	31	7.65
Jun	220	30	3.67
Jul	64	31	1.03
Aug	169	31	2.73
Sep	13	30	0.22

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

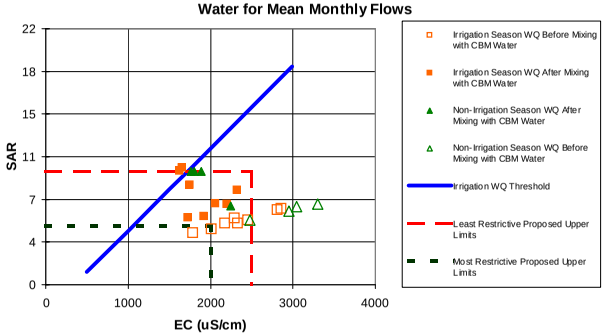
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1493	1509	1524	9.95	10.49	11.03

Little Powder River: 2020
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	1.8	0.43	1792	1805	1817	9.32	9.76	10.20	3044	6.7
	Dec	1.8	0.48	1874	1886	1898	9.32	9.74	10.17	3300	6.94
	Jan	1.8	0.39	1753	1766	1779	9.31	9.75	10.19	2953	6.33
	Feb	1.8	5.70	2241	2245	2248	6.62	6.75	6.88	2477	5.57
	Mar	1.8	6.44	1721	1725	1728	5.64	5.76	5.88	1785	4.44
Irrigation Season	Apr	1.8	4.73	2191	2196	2200	6.76	6.91	7.06	2457	5.55
	May	1.8	7.65	1914	1917	1920	5.79	5.89	5.99	2013	4.81
	Jun	1.8	3.67	2057	2062	2067	6.82	7.00	7.18	2333	5.29
	Jul	1.8	1.03	1741	1751	1761	8.25	8.60	8.94	2174	5.29
	Aug	1.8	2.73	2317	2323	2329	7.91	8.13	8.34	2860	6.57
	Sep	1.8	0.22	1637	1651	1664	9.57	10.05	10.53	2810	6.44
	Oct	1.8	0.31	1610	1624	1637	9.33	9.79	10.25	2289	5.73

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Little Powder	Little Powder River	6.0	0.7	1.8	1.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	19	31	0.31
Nov	26	30	0.43
Dec	30	31	0.48
Jan	24	31	0.39
Feb	319	28	5.70
Mar	399	31	6.44
Apr	284	30	4.73
May	474	31	7.65
Jun	220	30	3.67
Jul	64	31	1.03
Aug	169	31	2.73
Sep	13	30	0.22

Table of Plotting Positions for graph

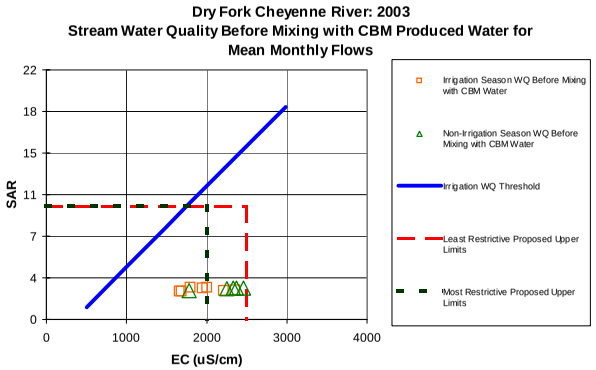
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictive	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	mean	95% upper	SAR (--)			Background Water Quality EC (uS/cm)	SAR (--)
							Not Applicable				
Non-Irrigation Season	Nov	0.00	0.02	2460	2460	2460	2.74	2.74	2.74	2460	2.74
	Dec	0.00	0.02	2372	2372	2372	2.79	2.79	2.79	2372	2.79
	Jan	0.00	0.00		Not Applicable			Not Applicable		2335	2.74
	Feb	0.00	0.04	2251	2251	2251	2.71	2.71	2.71	2251	2.71
	Mar	0.00	0.08	1782	1782	1782	2.52	2.52	2.52	1782	2.52
Irrigation Season	Apr	0.00	0.10	1949	1949	1949	2.77	2.77	2.77	1949	2.77
	May	0.00	0.06	1800	1800	1800	2.82	2.82	2.82	1800	2.82
	Jun	0.00	0.00		Not Applicable			Not Applicable		2005	2.8
	Jul	0.00	0.18	1661	1661	1661	2.48	2.48	2.48	1661	2.48
	Aug	0.00	0.00		Not Applicable			Not Applicable		1684	2.47
	Sep	0.00	0.00		Not Applicable			Not Applicable		2214	2.52
	Oct	0.00	0.00		Not Applicable			Not Applicable		2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.0	0.7	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	0	31	0.00
Nov	1	30	0.02
Dec	1	31	0.02
Jan	0	31	0.00
Feb	2	28	0.04
Mar	5	31	0.08
Apr	6	30	0.10
May	4	31	0.06
Jun	0	30	0.00
Jul	11	31	0.18
Aug	0	31	0.00
Sep	0	30	0.00

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

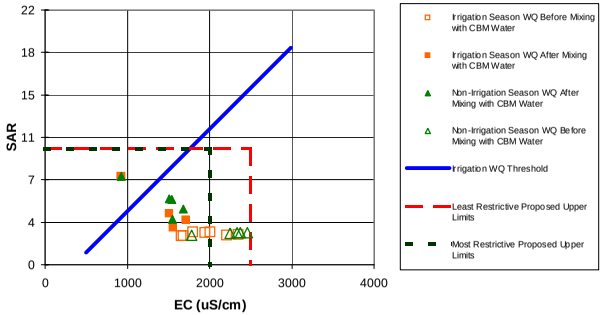
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2010
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	EC mean	EC 95% upper	SAR (--) 95% lower	SAR mean	SAR 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.03	0.02	1529	1542	1554	5.18	5.67	6.15	2460	2.74
	Dec	0.03	0.02	1494	1506	1519	5.20	5.69	6.17	2372	2.79
	Jan	0.03	0.00	909	929	950	6.80	7.62	8.43	2335	2.74
	Feb	0.03	0.04	1676	1685	1694	4.46	4.81	5.16	2251	2.71
	Mar	0.03	0.08	1544	1549	1555	3.69	3.91	4.13	1782	2.52
Irrigation Season	Apr	0.03	0.10	1709	1714	1719	3.70	3.89	4.08	1949	2.77
	May	0.03	0.06	1503	1510	1517	4.15	4.42	4.69	1800	2.82
	Jun	0.03	0.00	909	929	950	6.80	7.62	8.43	2005	2.8
	Jul	0.03	0.18	1554	1556	1559	3.10	3.21	3.33	1661	2.48
	Aug	0.03	0.00	909	929	950	6.80	7.62	8.43	1684	2.47
	Sep	0.03	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.03	0.00	909	929	950	6.80	7.62	8.43	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	0	31	0.00
Nov	1	30	0.02
Dec	1	31	0.02
Jan	0	31	0.00
Feb	2	28	0.04
Mar	5	31	0.08
Apr	6	30	0.10
May	4	31	0.06
Jun	0	30	0.00
Jul	11	31	0.18
Aug	0	31	0.00
Sep	0	30	0.00

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

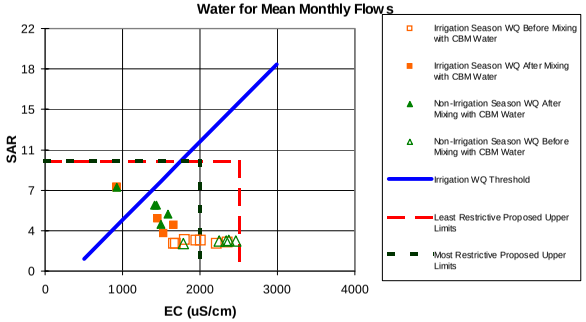
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43

Dry Fork Cheyenne River: 2015
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.04	0.02	1426	1440	1454	5.45	5.99	6.53	2460	2.74
	Dec	0.04	0.02	1396	1410	1424	5.46	6.01	6.55	2372	2.79
	Jan	0.04	0.00	909	929	950	6.80	7.62	8.43	2335	2.74
	Feb	0.04	0.04	1580	1590	1601	4.76	5.16	5.57	2251	2.71
	Mar	0.04	0.08	1491	1498	1505	3.95	4.22	4.49	1782	2.52
Irrigation Season	Apr	0.04	0.10	1652	1658	1664	3.92	4.15	4.39	1949	2.77
	May	0.04	0.06	1443	1452	1460	4.41	4.74	5.06	1800	2.82
	Jun	0.04	0.00	909	929	950	6.80	7.62	8.43	2005	2.8
	Jul	0.04	0.18	1524	1528	1532	3.27	3.41	3.56	1661	2.48
	Aug	0.04	0.00	909	929	950	6.80	7.62	8.43	1684	2.47
	Sep	0.04	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.04	0.00	909	929	950	6.80	7.62	8.43	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.04	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	0	31	0.00
Nov	1	30	0.02
Dec	1	31	0.02
Jan	0	31	0.00
Feb	2	28	0.04
Mar	5	31	0.08
Apr	6	30	0.10
May	4	31	0.06
Jun	0	30	0.00
Jul	11	31	0.18
Aug	0	31	0.00
Sep	0	30	0.00

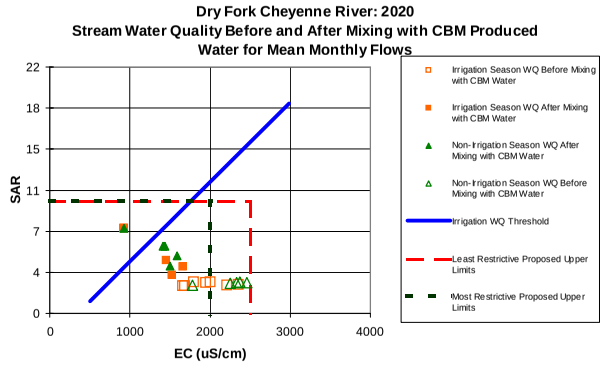
Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions
Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
909	929	950	6.80	7.62	8.43



		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	Mixed Water Quality EC (uS/cm) 95% lower	Mixed Water Quality EC (uS/cm) mean	Mixed Water Quality EC (uS/cm) 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed Water Quality SAR (--) mean	Mixed Water Quality SAR (--) 95% upper	Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)
Non-Irrigation Season	Nov	0.04	0.02	1426	1440	1454	5.45	5.99	6.53	2460	2.74
	Dec	0.04	0.02	1396	1410	1424	5.46	6.01	6.55	2372	2.79
	Jan	0.04	0.00	909	929	950	6.80	7.62	8.43	2335	2.74
	Feb	0.04	0.04	1580	1590	1601	4.76	5.16	5.57	2251	2.71
	Mar	0.04	0.08	1491	1498	1505	3.95	4.22	4.49	1782	2.52
Irrigation Season	Apr	0.04	0.10	1652	1658	1664	3.92	4.15	4.39	1949	2.77
	May	0.04	0.06	1443	1452	1460	4.41	4.74	5.06	1800	2.82
	Jun	0.04	0.00	909	929	950	6.80	7.62	8.43	2005	2.8
	Jul	0.04	0.18	1524	1528	1532	3.27	3.41	3.56	1661	2.48
	Aug	0.04	0.00	909	929	950	6.80	7.62	8.43	1684	2.47
	Sep	0.04	0.00	909	929	950	6.80	7.62	8.43	2214	2.52
	Oct	0.04	0.00	909	929	950	6.80	7.62	8.43	2354	2.6

[1] Note:

Mixed water quality =
{(Q1 x C1) + (Q2 x C2)} / (Q1 + Q2)

Where:
Q1 = CBM Flow (cfs)
Q2 = Streamflow (cfs)
C1 = CBM EC or SAR
C2 = Background EC or SAR

Calculated Effective CBM Surface Discharge and Water Quality

Drainage	Stream Gauge Location	Estimated CBM Water Production (cfs)	Conveyance Losses (%)	Estimated CBM Discharge to River (cfs)	Cumulative Estimated CBM Discharge to River (cfs)
Dry Fork Cheyenne	Dry Fork Cheyenne River	0.1	0.7	0.04	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	0	31	0.00
Nov	1	30	0.02
Dec	1	31	0.02
Jan	0	31	0.00
Feb	2	28	0.04
Mar	5	31	0.08
Apr	6	30	0.10
May	4	31	0.06
Jun	0	30	0.00
Jul	11	31	0.18
Aug	0	31	0.00
Sep	0	30	0.00

Table of Plotting Positions for graph

Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Fork Cheyenne Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
				EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		EC	SAR	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork	95% Lower	Mean	95% Dry Fork
Dry Fork Cheyenne River	Nov	2460	2.7	909	929	950	6.8	7.6	8.4	2460	2460	2460	2.7	2.7	2.7	1529	1542	1554	5.2	5.7	6.2	1426	1440	1454	5.4	6.0	6.5	1426	1440	1454	5.4	6.0	6.5
	Dec	2372	2.8	909	929	950	6.8	7.6	8.4	2372	2372	2372	2.8	2.8	2.8	1494	1506	1519	5.2	5.7	6.2	1396	1410	1424	5.5	6.0	6.5	1396	1410	1424	5.5	6.0	6.5
	Jan	2335	2.7	909	929	950	6.8	7.6	8.4	Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
	Feb	2251	2.7	909	929	950	6.8	7.6	8.4	2251	2251	2251	2.7	2.7	2.7	1676	1685	1694	4.5	4.8	5.2	1580	1590	1601	4.8	5.2	5.6	1580	1590	1601	4.8	5.2	5.6
	Mar	1782	2.5	909	929	950	6.8	7.6	8.4	1782	1782	1782	2.5	2.5	2.5	1544	1549	1555	3.7	3.9	4.1	1491	1498	1505	3.9	4.2	4.5	1491	1498	1505	3.9	4.2	4.5
	Apr	1949	2.8	909	929	950	6.8	7.6	8.4	1949	1949	1949	2.8	2.8	2.8	1709	1714	1719	3.7	3.9	4.1	1652	1658	1664	3.9	4.2	4.4	1652	1658	1664	3.9	4.2	4.4
	May	1800	2.8	909	929	950	6.8	7.6	8.4	1800	1800	1800	2.8	2.8	2.8	1503	1510	1517	4.1	4.4	4.7	1443	1452	1460	4.4	4.7	5.1	1443	1452	1460	4.4	4.7	5.1
	Jun	2005	2.8	909	929	950	6.8	7.6	8.4	Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
	Jul	1661	2.5	909	929	950	6.8	7.6	8.4	1661	1661	1661	2.5	2.5	2.5	1554	1556	1559	3.1	3.2	3.3	1524	1528	1532	3.3	3.4	3.6	1524	1528	1532	3.3	3.4	3.6
	Aug	1684	2.5	909	929	950	6.8	7.6	8.4	Not Applicable			Not Applicable			909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4
	Sep	2214	2.5	909	929	950	6.8	7.6	8.4	Not Applicable						909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4
	Oct	2354	2.6	909	929	950	6.8	7.6	8.4	Not Applicable			Not Applicable			909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4	909	929	950	6.8	7.6	8.4

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Dry Fork Cheyenne River	0.00%	0.0%		0.00%	0.0%		0.81%	-37.3%		8.62%	106.8%		0.97%	-41.5%		9.06%	118.6%		0.97%	-41.5%		9.06%	118.6%	
Dec		0.00%	0.0%		0.00%	0.0%		0.83%	-36.5%		8.59%	103.8%		0.99%	-40.5%		9.04%	115.3%		0.99%	-40.5%		9.04%	115.3%	
Jan		Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
Feb		0.00%	0.0%		0.00%	0.0%		0.53%	-25.2%		7.25%	77.6%		0.66%	-29.4%		7.89%	90.5%		0.66%	-29.4%		7.89%	90.5%	
Mar		0.00%	0.0%		0.00%	0.0%		0.37%	-13.0%		5.68%	55.1%		0.46%	-15.9%		6.43%	67.4%		0.46%	-15.9%		6.43%	67.4%	
Apr		0.00%	0.0%		0.00%	0.0%		0.28%	-12.1%		4.83%	40.4%		0.36%	-14.9%		5.60%	50.0%		0.36%	-14.9%		5.60%	50.0%	
May		0.00%	0.0%		0.00%	0.0%		0.46%	-16.1%		6.14%	56.7%		0.58%	-19.3%		6.87%	68.0%		0.58%	-19.3%		6.87%	68.0%	
Jun		Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
Jul		0.00%	0.0%		0.00%	0.0%		0.19%	-6.3%		3.62%	29.6%		0.25%	-8.0%		4.34%	37.7%		0.25%	-8.0%		4.34%	37.7%	
Aug		Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
Sep		Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
Oct		Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable			Not Applicable		
	Max	0.00%	0.00%		0.00%	0.00%		0.83%	-37.33%		8.62%	106.76%		0.99%	-41.48%		9.06%	118.63%		0.99%	-41.48%		9.06%	118.63%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Little Powder River Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little	95% Lower	Mean	95% Little
Little Powder River	Nov	3044	6.7	1493	1509	1524	10.0	10.5	11.0	1822	1834	1846	9.3	9.7	10.1	1747	1760	1773	9.4	9.9	10.3	1757	1770	1783	9.4	9.8	10.3	1792	1805	1817	9.3	9.8	10.2
	Dec	3300	6.9	1493	1509	1524	10.0	10.5	11.0	1910	1922	1934	9.3	9.7	10.1	1817	1830	1842	9.4	9.9	10.3	1829	1842	1855	9.4	9.8	10.3	1874	1886	1898	9.3	9.7	10.2
	Jan	2953	6.3	1493	1509	1524	10.0	10.5	11.0	1779	1792	1804	9.2	9.7	10.1	1713	1726	1740	9.4	9.9	10.3	1722	1735	1748	9.4	9.8	10.3	1753	1766	1779	9.3	9.8	10.2
	Feb	2477	5.6	1493	1509	1524	10.0	10.5	11.0	2261	2265	2268	6.5	6.6	6.8	2203	2207	2212	6.8	6.9	7.1	2212	2216	2221	6.7	6.9	7.0	2241	2245	2248	6.6	6.8	6.9
	Mar	1785	4.4	1493	1509	1524	10.0	10.5	11.0	1727	1730	1733	5.5	5.6	5.8	1711	1715	1719	5.8	6.0	6.1	1713	1717	1721	5.8	5.9	6.1	1721	1725	1728	5.6	5.8	5.9
	Apr	2457	5.6	1493	1509	1524	10.0	10.5	11.0	2213	2217	2221	6.7	6.8	6.9	2151	2156	2161	6.9	7.1	7.3	2161	2165	2170	6.9	7.1	7.2	2191	2196	2200	6.8	6.9	7.1
	May	2013	4.8	1493	1509	1524	10.0	10.5	11.0	1923	1926	1928	5.7	5.8	5.9	1897	1900	1904	6.0	6.1	6.2	1901	1904	1908	5.9	6.0	6.1	1914	1917	1920	5.8	5.9	6.0
	Jun	2333	5.3	1493	1509	1524	10.0	10.5	11.0	2078	2083	2088	6.7	6.9	7.0	2018	2024	2030	7.0	7.2	7.4	2027	2033	2039	7.0	7.2	7.4	2057	2062	2067	6.8	7.0	7.2
	Jul	2174	5.3	1493	1509	1524	10.0	10.5	11.0	1760	1769	1779	8.1	8.5	8.8	1710	1721	1732	8.5	8.8	9.2	1717	1728	1738	8.4	8.8	9.1	1741	1751	1761	8.3	8.6	8.9
	Aug	2860	6.6	1493	1509	1524	10.0	10.5	11.0	2355	2361	2366	7.8	8.0	8.2	2250	2257	2264	8.1	8.3	8.6	2266	2273	2279	8.0	8.3	8.5	2317	2323	2329	7.9	8.1	8.3
	Sep	2810	6.4	1493	1509	1524	10.0	10.5	11.0	1653	1666	1680	9.5	10.0	10.5	1613	1627	1641	9.6	10.1	10.6	1618	1632	1646	9.6	10.1	10.6	1637	1651	1664	9.6	10.0	10.5
	Oct	2289	5.7	1493	1509	1524	10.0	10.5	11.0	1622	1636	1649	9.3	9.7	10.2	1592	1605	1619	9.4	9.9	10.4	1596	1609	1623	9.4	9.9	10.3	1610	1624	1637	9.3	9.8	10.3

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Little Powder River	0.67%	-39.7%		4.39%	44.6%		0.74%	-42.2%		4.57%	47.3%		0.73%	-41.9%		4.55%	47.0%		0.70%	-40.7%		4.46%	45.7%	
Dec		0.62%	-41.8%		4.29%	39.4%		0.70%	-44.6%		4.50%	42.0%		0.69%	-44.2%		4.47%	41.6%		0.65%	-42.8%		4.37%	40.4%	
Jan		0.70%	-39.3%		4.48%	52.9%		0.76%	-41.5%		4.65%	55.8%		0.76%	-41.2%		4.63%	55.4%		0.72%	-40.2%		4.55%	54.0%	
Feb		0.15%	-8.6%		1.78%	19.4%		0.20%	-10.9%		2.17%	24.6%		0.19%	-10.5%		2.11%	23.8%		0.17%	-9.4%		1.92%	21.2%	
Mar		0.18%	-3.1%		1.90%	27.1%		0.23%	-3.9%		2.30%	34.7%		0.22%	-3.8%		2.24%	33.5%		0.20%	-3.4%		2.05%	29.8%	
Apr		0.18%	-9.8%		2.01%	22.5%		0.23%	-12.2%		2.41%	28.3%		0.22%	-11.9%		2.35%	27.4%		0.20%	-10.6%		2.15%	24.5%	
May		0.14%	-4.3%		1.61%	20.4%		0.18%	-5.6%		1.98%	26.4%		0.18%	-5.4%		1.93%	25.4%		0.15%	-4.8%		1.74%	22.5%	
Jun		0.23%	-10.7%		2.39%	29.9%		0.29%	-13.2%		2.79%	36.8%		0.28%	-12.9%		2.73%	35.8%		0.25%	-11.6%		2.54%	32.4%	
Jul		0.53%	-18.6%		3.88%	59.8%		0.62%	-20.8%		4.16%	67.0%		0.60%	-20.5%		4.12%	66.0%		0.56%	-19.5%		3.99%	62.5%	
Aug		0.24%	-17.5%		2.49%	22.1%		0.31%	-21.1%		2.89%	26.6%		0.30%	-20.5%		2.84%	25.9%		0.27%	-18.8%		2.64%	23.7%	
Sep		0.82%	-40.7%		4.74%	55.3%		0.87%	-42.1%		4.85%	57.2%		0.86%	-41.9%		4.83%	56.9%		0.84%	-41.3%		4.79%	56.1%	
Oct		0.80%	-28.5%		4.65%	69.6%		0.85%	-29.9%		4.78%	72.8%		0.84%	-29.7%		4.76%	72.4%		0.82%	-29.1%		4.70%	70.9%	
	Max	0.82%	-41.75%		4.74%	69.61%		0.87%	-44.55%		4.85%	72.83%		0.86%	-44.18%		4.83%	72.40%		0.84%	-42.85%		4.79%	70.88%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Upper Powder River Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Upper Powder River	Nov	2650	6.4	2161	2180	2200	21.6	22.6	23.5	2642	2643	2643	6.7	6.7	6.7	2624	2625	2626	7.2	7.3	7.3	2619	2621	2622	7.4	7.4	7.5	2621	2622	2623	7.3	7.4	7.4
	Dec	2906	6.6	2161	2180	2200	21.6	22.6	23.5	2891	2892	2892	6.9	6.9	6.9	2857	2859	2860	7.6	7.7	7.7	2848	2850	2851	7.8	7.8	7.9	2852	2853	2854	7.7	7.8	7.8
	Jan	2482	6.4	2161	2180	2200	21.6	22.6	23.5	2476	2476	2476	6.7	6.7	6.7	2461	2462	2463	7.4	7.5	7.5	2457	2459	2460	7.6	7.7	7.7	2458	2460	2461	7.5	7.6	7.7
	Feb	2366	6.1	2161	2180	2200	21.6	22.6	23.5	2363	2364	2364	6.3	6.3	6.3	2357	2358	2359	6.8	6.8	6.9	2356	2357	2358	6.9	7.0	7.0	2356	2357	2358	6.9	6.9	6.9
	Mar	2051	5.3	2161	2180	2200	21.6	22.6	23.5	2052	2052	2052	5.4	5.4	5.4	2054	2054	2055	5.7	5.7	5.8	2054	2055	2056	5.8	5.8	5.8	2054	2055	2055	5.8	5.8	5.8
	Apr	2213	5.8	2161	2180	2200	21.6	22.6	23.5	2212	2213	2213	6.0	6.0	6.0	2211	2212	2213	6.4	6.4	6.4	2211	2212	2212	6.5	6.5	6.5	2211	2212	2213	6.4	6.5	6.5
	May	1803	4.9	2161	2180	2200	21.6	22.6	23.5	1805	1806	1806	5.0	5.0	5.0	1811	1812	1812	5.3	5.3	5.3	1813	1813	1814	5.4	5.4	5.4	1812	1813	1813	5.3	5.4	5.4
	Jun	1797	4.8	2161	2180	2200	21.6	22.6	23.5	1802	1803	1803	5.0	5.0	5.0	1815	1816	1817	5.6	5.6	5.7	1818	1819	1820	5.7	5.8	5.8	1817	1818	1819	5.7	5.7	5.8
	Jul	2716	6.8	2161	2180	2200	21.6	22.6	23.5	2703	2703	2704	7.1	7.2	7.2	2672	2674	2675	8.0	8.0	8.1	2664	2666	2668	8.2	8.3	8.4	2667	2669	2670	8.1	8.2	8.3
	Aug	2992	7.0	2161	2180	2200	21.6	22.6	23.5	2952	2953	2954	7.7	7.7	7.8	2867	2870	2873	9.2	9.3	9.5	2847	2850	2854	9.5	9.7	9.9	2854	2857	2861	9.4	9.6	9.7
	Sep	3400	7.8	2161	2180	2200	21.6	22.6	23.5	3330	3331	3332	8.6	8.7	8.7	3187	3190	3194	10.2	10.4	10.5	3153	3157	3161	10.6	10.8	11.0	3166	3169	3173	10.4	10.6	10.8
	Oct	2537	6.7	2161	2180	2200	21.6	22.6	23.5	2530	2530	2531	7.0	7.0	7.0	2514	2515	2516	7.6	7.7	7.7	2510	2511	2513	7.8	7.9	7.9	2511	2513	2514	7.7	7.8	7.9

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Upper Powder River	0.01%	-0.3%		0.23%	4.0%		0.04%	-0.9%		0.70%	13.3%		0.05%	-1.1%		0.81%	15.8%		0.04%	-1.0%		0.77%	14.8%	
Dec		0.01%	-0.5%		0.27%	4.8%		0.04%	-1.6%		0.82%	15.8%		0.05%	-1.9%		0.95%	18.7%		0.05%	-1.8%		0.90%	17.6%	
Jan		0.02%	-0.2%		0.28%	5.0%		0.05%	-0.8%		0.84%	16.6%		0.06%	-0.9%		0.97%	19.6%		0.06%	-0.9%		0.93%	18.5%	
Feb		0.01%	-0.1%		0.19%	3.4%		0.04%	-0.3%		0.60%	11.4%		0.04%	-0.4%		0.70%	13.6%		0.04%	-0.4%		0.66%	12.8%	
Mar		0.01%	0.0%		0.13%	2.5%		0.02%	0.2%		0.43%	8.5%		0.03%	0.2%		0.51%	10.1%		0.03%	0.2%		0.48%	9.5%	
Apr		0.01%	0.0%		0.16%	2.8%		0.03%	0.0%		0.50%	9.5%		0.04%	-0.1%		0.59%	11.4%		0.03%	-0.1%		0.55%	10.7%	
May		0.01%	0.1%		0.13%	2.4%		0.02%	0.5%		0.41%	8.2%		0.03%	0.6%		0.49%	9.8%		0.03%	0.5%		0.46%	9.2%	
Jun		0.02%	0.3%		0.28%	5.4%		0.05%	1.0%		0.83%	18.1%		0.06%	1.2%		0.96%	21.6%		0.06%	1.2%		0.91%	20.3%	
Jul		0.02%	-0.5%		0.32%	5.6%		0.06%	-1.6%		0.95%	18.4%		0.07%	-1.8%		1.09%	21.7%		0.06%	-1.7%		1.04%	20.5%	
Aug		0.03%	-1.3%		0.60%	10.8%		0.10%	-4.1%		1.55%	33.6%		0.12%	-4.7%		1.73%	39.1%		0.11%	-4.5%		1.67%	37.1%	
Sep		0.03%	-2.0%		0.62%	10.6%		0.11%	-6.2%		1.59%	32.4%		0.12%	-7.2%		1.78%	37.5%		0.12%	-6.8%		1.71%	35.6%	
Oct		0.01%	-0.3%		0.25%	4.3%		0.05%	-0.9%		0.76%	14.4%		0.06%	-1.0%		0.88%	17.1%		0.05%	-1.0%		0.84%	16.1%	
	Max	0.03%	-2.02%		0.62%	10.81%		0.11%	-6.16%		1.59%	33.59%		0.12%	-7.15%		1.78%	39.14%		0.12%	-6.79%		1.71%	37.10%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Upper Cheyenne Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Upper cheyenne River	Nov	3565	7.2	909	929	950	6.8	7.6	8.4	3082	3086	3090	7.1	7.3	7.4	3082	3086	3090	7.1	7.3	7.4	3133	3136	3139	7.2	7.3	7.4	3186	3188	3191	7.2	7.3	7.4
	Dec	3405	7.4	909	929	950	6.8	7.6	8.4	2343	2352	2360	7.1	7.5	7.8	2343	2352	2360	7.1	7.5	7.8	2423	2431	2440	7.2	7.5	7.8	2513	2521	2528	7.2	7.5	7.8
	Jan	4229	8.6	909	929	950	6.8	7.6	8.4	4065	4066	4067	8.5	8.5	8.6	4065	4066	4067	8.5	8.5	8.6	4084	4085	4086	8.5	8.5	8.6	4104	4105	4106	8.5	8.5	8.6
	Feb	3911	8.0	909	929	950	6.8	7.6	8.4	3628	3630	3632	7.9	8.0	8.0	3628	3630	3632	7.9	8.0	8.0	3660	3662	3664	7.9	8.0	8.0	3693	3695	3696	7.9	8.0	8.0
	Mar	4127	8.7	909	929	950	6.8	7.6	8.4	3647	3650	3653	8.4	8.5	8.6	3647	3650	3653	8.4	8.5	8.6	3699	3701	3704	8.4	8.5	8.6	3753	3755	3758	8.4	8.5	8.6
	Apr	3630	7.9	909	929	950	6.8	7.6	8.4	3379	3381	3383	7.8	7.8	7.9	3379	3381	3383	7.8	7.8	7.9	3408	3410	3411	7.8	7.8	7.9	3437	3439	3440	7.8	7.9	7.9
	May	3155	6.9	909	929	950	6.8	7.6	8.4	3093	3093	3094	6.9	6.9	6.9	3093	3093	3094	6.9	6.9	6.9	3100	3101	3101	6.9	6.9	6.9	3108	3108	3109	6.9	6.9	6.9
	Jun	2895	5.9	909	929	950	6.8	7.6	8.4	2777	2779	2780	6.0	6.0	6.1	2777	2779	2780	6.0	6.0	6.1	2791	2792	2793	6.0	6.0	6.1	2805	2806	2807	6.0	6.0	6.0
	Jul	2250	5.7	909	929	950	6.8	7.6	8.4	1969	1973	1978	5.9	6.1	6.3	1969	1973	1978	5.9	6.1	6.3	1998	2002	2005	5.9	6.1	6.2	2028	2031	2035	5.9	6.0	6.1
	Aug	1972	4.8	909	929	950	6.8	7.6	8.4	1447	1457	1467	5.8	6.2	6.6	1447	1457	1467	5.8	6.2	6.6	1482	1492	1502	5.7	6.1	6.5	1523	1531	1540	5.7	6.0	6.3
	Sep	2271	5.6	909	929	950	6.8	7.6	8.4	2072	2075	2078	5.8	5.9	6.0	2072	2075	2078	5.8	5.9	6.0	2093	2096	2099	5.8	5.9	6.0	2116	2118	2121	5.8	5.9	5.9
	Oct	2916	6.5	909	929	950	6.8	7.6	8.4	2594	2597	2600	6.5	6.6	6.8	2594	2597	2600	6.5	6.6	6.8	2628	2631	2634	6.5	6.6	6.7	2664	2667	2669	6.5	6.6	6.7

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Upper cheyenne River	0.12%	-13.4%		2.03%	1.0%		0.12%	-13.4%		2.03%	1.0%		0.11%	-12.0%		1.82%	0.9%		0.09%	-10.6%		1.60%	0.8%	
Dec		0.38%	-30.9%		4.63%	1.3%		0.38%	-30.9%		4.63%	1.3%		0.34%	-28.6%		4.28%	1.2%		0.30%	-26.0%		3.89%	1.1%	
Jan		0.03%	-3.9%		0.47%	-0.6%		0.03%	-3.9%		0.47%	-0.6%		0.02%	-3.4%		0.42%	-0.5%		0.02%	-2.9%		0.36%	-0.4%	
Feb		0.05%	-7.2%		0.96%	-0.5%		0.05%	-7.2%		0.96%	-0.5%		0.05%	-6.4%		0.85%	-0.4%		0.04%	-5.5%		0.74%	-0.4%	
Mar		0.09%	-11.6%		1.43%	-1.8%		0.09%	-11.6%		1.43%	-1.8%		0.08%	-10.3%		1.27%	-1.6%		0.06%	-9.0%		1.11%	-1.4%	
Apr		0.06%	-6.9%		0.96%	-0.3%		0.06%	-6.9%		0.96%	-0.3%		0.05%	-6.1%		0.85%	-0.3%		0.04%	-5.3%		0.73%	-0.2%	
May		0.02%	-2.0%		0.33%	0.3%		0.02%	-2.0%		0.33%	0.3%		0.02%	-1.7%		0.29%	0.3%		0.01%	-1.5%		0.25%	0.2%	
Jun		0.04%	-4.0%		0.80%	1.7%		0.04%	-4.0%		0.80%	1.7%		0.04%	-3.5%		0.71%	1.5%		0.03%	-3.1%		0.61%	1.3%	
Jul		0.22%	-12.3%		2.80%	7.1%		0.22%	-12.3%		2.80%	7.1%		0.20%	-11.0%		2.53%	6.4%		0.17%	-9.7%		2.25%	5.6%	
Aug		0.71%	-26.1%		6.49%	28.6%		0.71%	-26.1%		6.49%	28.6%		0.64%	-24.3%		6.14%	26.7%		0.58%	-22.3%		5.73%	24.5%	
Sep		0.15%	-8.6%		2.01%	5.2%		0.15%	-8.6%		2.01%	5.2%		0.13%	-7.7%		1.80%	4.6%		0.11%	-6.7%		1.58%	4.0%	
Oct		0.13%	-10.9%		1.97%	2.9%		0.13%	-10.9%		1.97%	2.9%		0.11%	-9.8%		1.76%	2.6%		0.10%	-8.6%		1.55%	2.2%	
	Max	0.71%	-30.94%		6.49%	28.64%		0.71%	-30.94%		6.49%	28.64%		0.64%	-28.59%		6.14%	26.71%		0.58%	-25.97%		5.73%	24.51%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Belle Fourche Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC	SAR	EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Belle Fourche River	Nov	2877	7.0	1102	1110	1117	8.4	8.8	9.2	1479	1485	1491	8.1	8.4	8.8	1509	1515	1521	8.1	8.4	8.7	1597	1603	1608	8.0	8.3	8.6	1715	1720	1725	8.0	8.2	8.5
	Dec	2755	6.8	1102	1110	1117	8.4	8.8	9.2	1409	1415	1421	8.1	8.5	8.8	1434	1440	1446	8.1	8.4	8.7	1509	1515	1521	8.0	8.3	8.6	1612	1617	1622	7.9	8.2	8.5
	Jan	2887	6.3	1102	1110	1117	8.4	8.8	9.2	1337	1343	1350	8.2	8.5	8.8	1357	1364	1370	8.1	8.5	8.8	1420	1426	1433	8.1	8.4	8.7	1509	1515	1521	8.0	8.3	8.6
	Feb	1907	4.1	1102	1110	1117	8.4	8.8	9.2	1632	1634	1637	5.6	5.7	5.8	1649	1652	1654	5.5	5.6	5.7	1693	1695	1697	5.2	5.3	5.4	1738	1740	1741	5.0	5.1	5.2
	Mar	1564	3.6	1102	1110	1117	8.4	8.8	9.2	1493	1494	1495	4.4	4.4	4.5	1498	1499	1501	4.3	4.4	4.4	1512	1513	1514	4.2	4.2	4.3	1525	1525	1526	4.1	4.1	4.1
	Apr	1722	4.3	1102	1110	1117	8.4	8.8	9.2	1435	1438	1442	6.2	6.4	6.6	1450	1453	1456	6.1	6.3	6.5	1489	1492	1495	5.9	6.0	6.2	1532	1534	1537	5.6	5.7	5.8
	May	1532	3.8	1102	1110	1117	8.4	8.8	9.2	1371	1373	1376	5.5	5.7	5.8	1380	1383	1386	5.4	5.6	5.7	1405	1407	1409	5.2	5.3	5.4	1431	1433	1434	4.9	5.0	5.1
	Jun	1821	4.0	1102	1110	1117	8.4	8.8	9.2	1426	1430	1435	6.4	6.6	6.9	1444	1448	1452	6.3	6.5	6.7	1491	1494	1498	6.0	6.2	6.4	1545	1548	1551	5.7	5.8	6.0
	Jul	1182	3.1	1102	1110	1117	8.4	8.8	9.2	1167	1169	1170	4.1	4.2	4.2	1169	1170	1171	4.0	4.1	4.1	1171	1172	1173	3.8	3.9	3.9	1174	1175	1175	3.6	3.7	3.7
	Aug	1955	5.1	1102	1110	1117	8.4	8.8	9.2	1448	1453	1458	7.1	7.3	7.5	1469	1473	1477	7.0	7.2	7.4	1524	1528	1532	6.8	7.0	7.2	1590	1593	1596	6.5	6.7	6.8
	Sep	2231	5.8	1102	1110	1117	8.4	8.8	9.2	1347	1353	1359	7.9	8.2	8.5	1366	1372	1378	7.8	8.1	8.4	1423	1428	1434	7.7	8.0	8.2	1498	1503	1508	7.5	7.8	8.0
	Oct	2346	5.8	1102	1110	1117	8.4	8.8	9.2	1213	1220	1227	8.2	8.6	8.9	1223	1230	1237	8.2	8.5	8.9	1255	1262	1268	8.1	8.5	8.8	1302	1308	1314	8.0	8.3	8.7

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Belle Fourche River	0.40%	-48.4%		3.65%	20.4%		0.39%	-47.3%		3.58%	19.9%		0.34%	-44.3%		3.39%	18.6%		0.29%	-40.2%		3.12%	16.9%	
Dec		0.44%	-48.6%		3.77%	24.8%		0.42%	-47.7%		3.72%	24.4%		0.38%	-45.0%		3.54%	23.0%		0.33%	-41.3%		3.30%	21.1%	
Jan		0.49%	-53.5%		4.00%	35.1%		0.48%	-52.8%		3.96%	34.7%		0.44%	-50.6%		3.84%	33.2%		0.39%	-47.5%		3.66%	31.2%	
Feb		0.16%	-14.3%		2.35%	39.8%		0.15%	-13.4%		2.24%	37.3%		0.12%	-11.1%		1.95%	31.0%		0.09%	-8.8%		1.62%	24.5%	
Mar		0.08%	-4.5%		1.36%	22.0%		0.07%	-4.1%		1.27%	20.3%		0.06%	-3.3%		1.05%	16.1%		0.04%	-2.5%		0.82%	12.2%	
Apr		0.25%	-16.5%		2.82%	48.0%		0.23%	-15.6%		2.72%	45.5%		0.19%	-13.4%		2.44%	38.9%		0.15%	-10.9%		2.10%	31.7%	
May		0.21%	-10.4%		2.58%	49.5%		0.19%	-9.7%		2.47%	46.5%		0.16%	-8.1%		2.19%	39.0%		0.12%	-6.5%		1.84%	31.0%	
Jun		0.29%	-21.4%		3.23%	67.0%		0.28%	-20.5%		3.15%	64.0%		0.23%	-17.9%		2.90%	56.0%		0.19%	-15.0%		2.57%	46.8%	
Jul		0.12%	-1.1%		1.73%	33.9%		0.11%	-1.0%		1.63%	31.3%		0.09%	-0.8%		1.37%	25.0%		0.07%	-0.6%		1.09%	19.0%	
Aug		0.31%	-25.7%		3.18%	44.3%		0.29%	-24.7%		3.09%	42.5%		0.25%	-21.8%		2.84%	37.7%		0.20%	-18.5%		2.51%	31.9%	
Sep		0.44%	-39.4%		3.75%	41.8%		0.42%	-38.5%		3.70%	40.9%		0.38%	-36.0%		3.52%	38.2%		0.33%	-32.6%		3.28%	34.6%	
Oct		0.57%	-48.0%		4.17%	48.9%		0.56%	-47.6%		4.14%	48.4%		0.53%	-46.2%		4.06%	47.0%		0.49%	-44.2%		3.94%	45.0%	
	Max	0.57%	-53.48%		4.17%	66.98%		0.56%	-52.77%		4.14%	64.02%		0.53%	-50.60%		4.06%	56.03%		0.49%	-47.52%		3.94%	46.83%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

Antelope Creek Sensitivity Analysis
Dry Year Conditions

River	Month	Background		CBNG Discharge Quality						Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
				EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		EC	SAR	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper
Antelope Creek	Nov	2460	2.7	909	929	950	6.8	7.6	8.4	1386	1400	1415	5.6	6.1	6.7	1076	1095	1114	6.4	7.1	7.8	1046	1066	1085	6.4	7.2	7.9	1053	1072	1091	6.4	7.2	7.9
	Dec	2372	2.8	909	929	950	6.8	7.6	8.4	1118	1136	1153	6.2	6.9	7.6	972	992	1012	6.6	7.4	8.2	960	980	1001	6.7	7.4	8.2	963	983	1003	6.7	7.4	8.2
	Jan	2335	2.7	909	929	950	6.8	7.6	8.4	1256	1272	1288	5.8	6.4	7.0	1024	1043	1062	6.5	7.2	8.0	1003	1022	1042	6.5	7.3	8.1	1007	1027	1046	6.5	7.3	8.0
	Feb	2251	2.7	909	929	950	6.8	7.6	8.4	1486	1498	1510	5.0	5.5	6.0	1138	1155	1173	6.1	6.8	7.5	1100	1117	1135	6.2	6.9	7.6	1108	1126	1143	6.2	6.9	7.6
	Mar	1782	2.5	909	929	950	6.8	7.6	8.4	1557	1563	1568	3.6	3.8	4.0	1293	1305	1317	4.9	5.4	5.8	1248	1260	1273	5.1	5.6	6.1	1258	1270	1283	5.1	5.6	6.1
	Apr	1949	2.8	909	929	950	6.8	7.6	8.4	1492	1501	1511	4.5	4.9	5.3	1177	1193	1208	5.8	6.4	7.0	1136	1153	1169	5.9	6.6	7.2	1146	1162	1178	5.9	6.5	7.1
	May	1800	2.8	909	929	950	6.8	7.6	8.4	1276	1288	1300	5.2	5.6	6.1	1051	1069	1087	6.2	6.8	7.5	1027	1045	1064	6.3	7.0	7.7	1033	1051	1069	6.2	6.9	7.6
	Jun	2005	2.8	909	929	950	6.8	7.6	8.4	1047	1065	1083	6.3	7.0	7.7	950	970	990	6.6	7.4	8.2	942	963	983	6.7	7.5	8.3	944	964	984	6.7	7.5	8.2
	Jul	1661	2.5	909	929	950	6.8	7.6	8.4	1460	1466	1471	3.6	3.9	4.1	1231	1243	1255	5.0	5.4	5.9	1191	1204	1218	5.2	5.7	6.2	1200	1213	1226	5.1	5.6	6.1
	Aug	1684	2.5	909	929	950	6.8	7.6	8.4	1163	1177	1191	5.4	5.9	6.5	1000	1018	1037	6.3	7.0	7.7	984	1003	1021	6.4	7.1	7.9	987	1006	1025	6.4	7.1	7.8
	Sep	2214	2.5	909	929	950	6.8	7.6	8.4	1831	1837	1844	3.8	4.0	4.3	1426	1439	1452	5.1	5.6	6.1	1360	1374	1388	5.3	5.9	6.4	1375	1389	1402	5.3	5.8	6.3
	Oct	2354	2.6	909	929	950	6.8	7.6	8.4	1313	1328	1343	5.6	6.2	6.8	1047	1066	1085	6.4	7.1	7.9	1022	1042	1061	6.5	7.2	8.0	1028	1047	1066	6.5	7.2	7.9

Upper portion of spreadsheet collects data from previous worksheets and summarizes here

Month	River	Mixed Water Quality 2003						Mixed Water Quality 2010						Mixed Water Quality - 2015						Mixed Water Quality - 2020					
		EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)			EC (uS/cm)			SAR (--)		
		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)		95% Confidence (plus or minus) (2)	Mean (1)	
Nov	Antelope Creek	1.03%	-43.1%		9.22%	123.2%		1.70%	-55.5%		10.25%	158.7%		1.79%	-56.7%		10.33%	162.1%		1.77%	-56.4%		10.31%	161.4%	
Dec		1.58%	-52.1%		10.08%	148.3%		2.01%	-58.2%		10.52%	165.4%		2.06%	-58.7%		10.55%	166.9%		2.05%	-58.6%		10.54%	166.6%	
Jan		1.24%	-45.5%		9.58%	134.6%		1.84%	-55.3%		10.37%	163.6%		1.91%	-56.2%		10.43%	166.2%		1.89%	-56.0%		10.41%	165.6%	
Feb		0.79%	-33.4%		8.43%	103.1%		1.50%	-48.7%		9.96%	150.1%		1.60%	-50.4%		10.10%	155.3%		1.58%	-50.0%		10.07%	154.1%	
Mar		0.34%	-12.3%		5.47%	52.0%		0.90%	-26.8%		8.48%	113.1%		1.01%	-29.3%		8.84%	123.7%		0.99%	-28.7%		8.76%	121.3%	
Apr		0.61%	-23.0%		7.30%	76.8%		1.30%	-38.8%		9.49%	129.7%		1.41%	-40.9%		9.70%	136.6%		1.39%	-40.4%		9.66%	135.1%	
May		0.95%	-28.4%		8.49%	100.0%		1.64%	-40.6%		9.99%	142.8%		1.73%	-41.9%		10.12%	147.4%		1.71%	-41.6%		10.09%	146.4%	
Jun		1.71%	-46.9%		10.15%	150.3%		2.07%	-51.6%		10.54%	165.5%		2.10%	-52.0%		10.57%	166.7%		2.10%	-51.9%		10.56%	166.4%	
Jul		0.38%	-11.8%		5.65%	55.3%		0.96%	-25.2%		8.60%	118.4%		1.08%	-27.5%		8.94%	129.2%		1.05%	-27.0%		8.86%	126.8%	
Aug		1.19%	-30.1%		9.23%	139.9%		1.81%	-39.5%		10.25%	183.8%		1.88%	-40.5%		10.33%	188.1%		1.87%	-40.3%		10.32%	187.2%	
Sep		0.33%	-17.0%		5.95%	59.3%		0.88%	-35.0%		8.78%	122.0%		0.99%	-37.9%		9.10%	132.2%		0.97%	-37.3%		9.03%	129.9%	
Oct		1.13%	-43.6%		9.44%	138.9%		1.77%	-54.7%		10.32%	174.4%		1.85%	-55.8%		10.39%	177.7%		1.83%	-55.5%		10.38%	177.0%	
	Max	1.71%	-52.13%		10.15%	150.28%		2.07%	-58.17%		10.54%	183.81%		2.10%	-58.67%		10.57%	188.13%		2.10%	-58.56%		10.56%	187.20%	

(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

APPENDIX D

WYOMING WATER DEVELOPMENT COMMISSION BASIN PLAN TECHNICAL MEMORANDA

APPENDIX D-1

SURFACE WATER HYDROLOGY: POWDER / TONGUE RIVER BASIN PLAN

APPENDIX D-2

SURFACE WATER HYDROLOGY: NORTHEAST WYOMING BASINS PLAN