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

Prepared in support of:

Powder River Basin Coal Review

Prepared for:

ENSR International
1601 Prospect Parkway
Fort Collins, CO 80525-9769

Prepared by:

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Fort Collins, CO 80525
(ACE Project No. WYENSR01)

August 2006
(Revised February 2008)

ANDERSON CONSULTING ENGINEERS, INC.
Civil • Water Resources • Environmental

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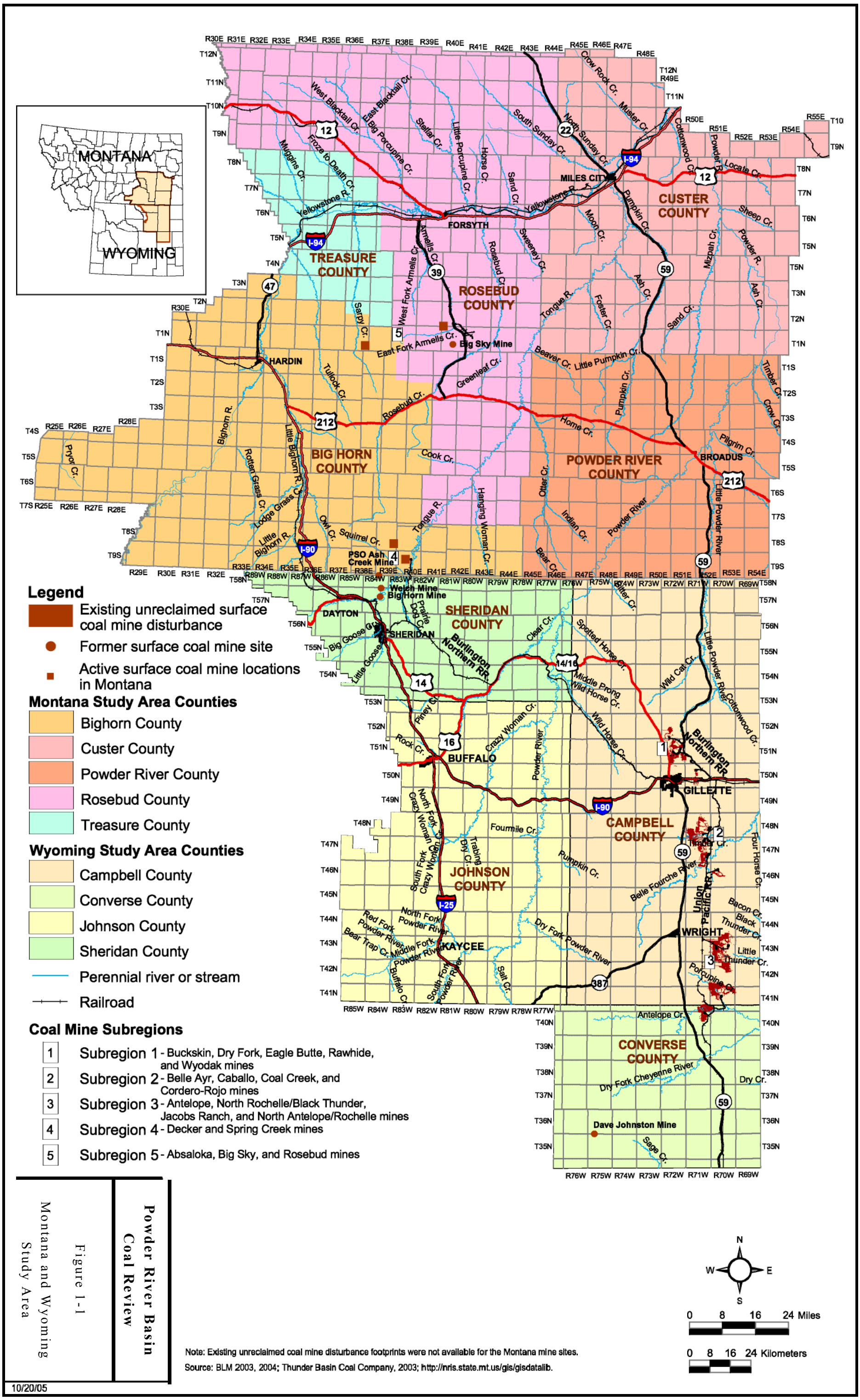
1.0 INTRODUCTION

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



Note: Existing unreclaimed coal mine disturbance footprints were not available for the Montana mine sites.

Source: BLM 2003, 2004; Thunder Basin Coal Company, 2003; http://nris.state.mt.us/gis/gisdatalib.

Powder River Basin Coal Review

Figure 1-1

Montana and Wyoming Study Area

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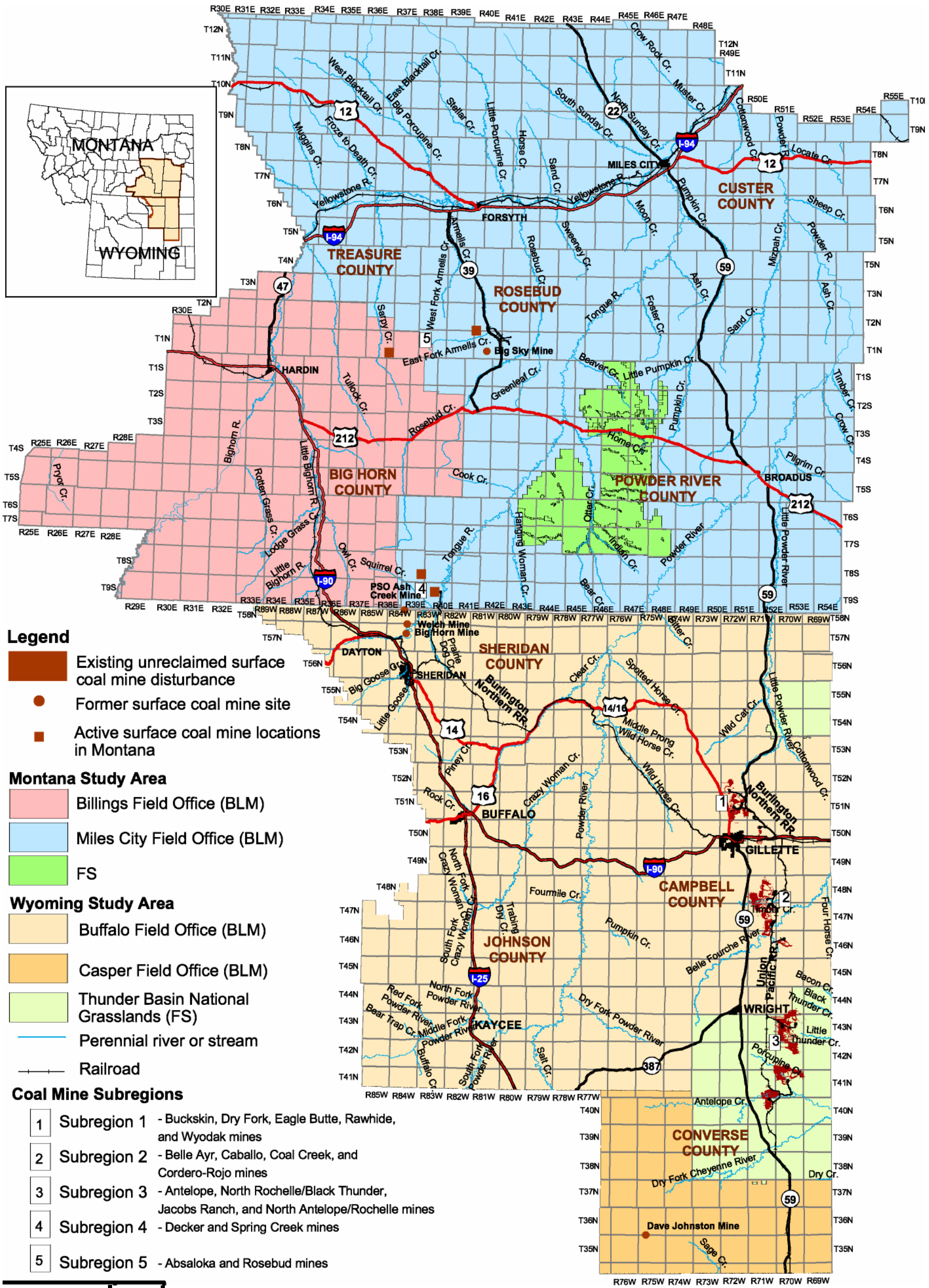


Note: Existing unreclaimed coal mine disturbance footprints were not available for the Montana mine sites.

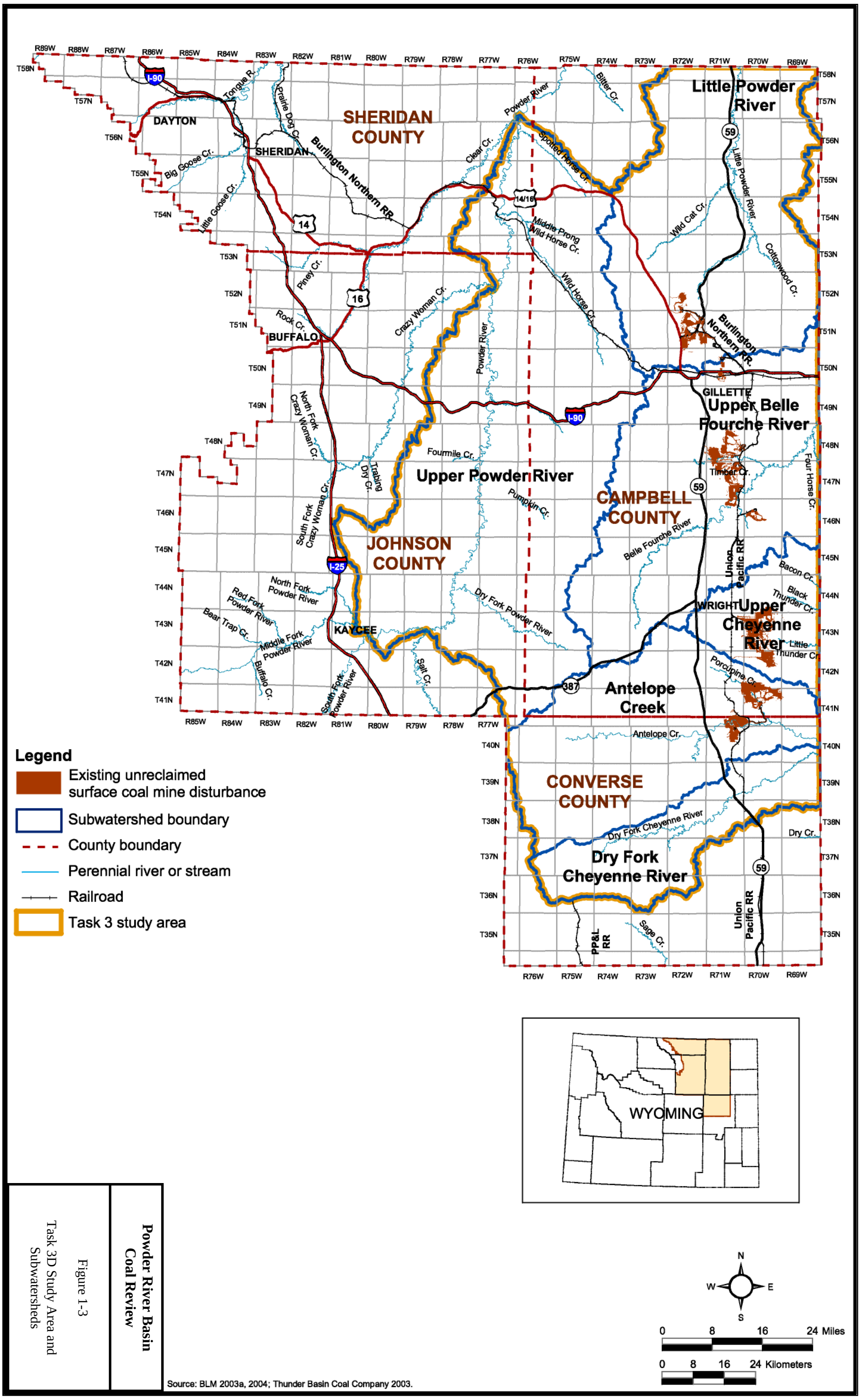
Source: BLM 2003, 2004; Thunder Basin Coal Company, 2003; http://nris.state.mt.us/gis/gisdatalib.

Powder River Basin Coal Review

Figure 1-2

Federal Land Management

10/20/05



Source: BLM 2003a, 2004; Thunder Basin Coal Company 2003.

Powder River Basin Coal Review

Figure 1-3
Task 3D Study Area and Subwatersheds

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).

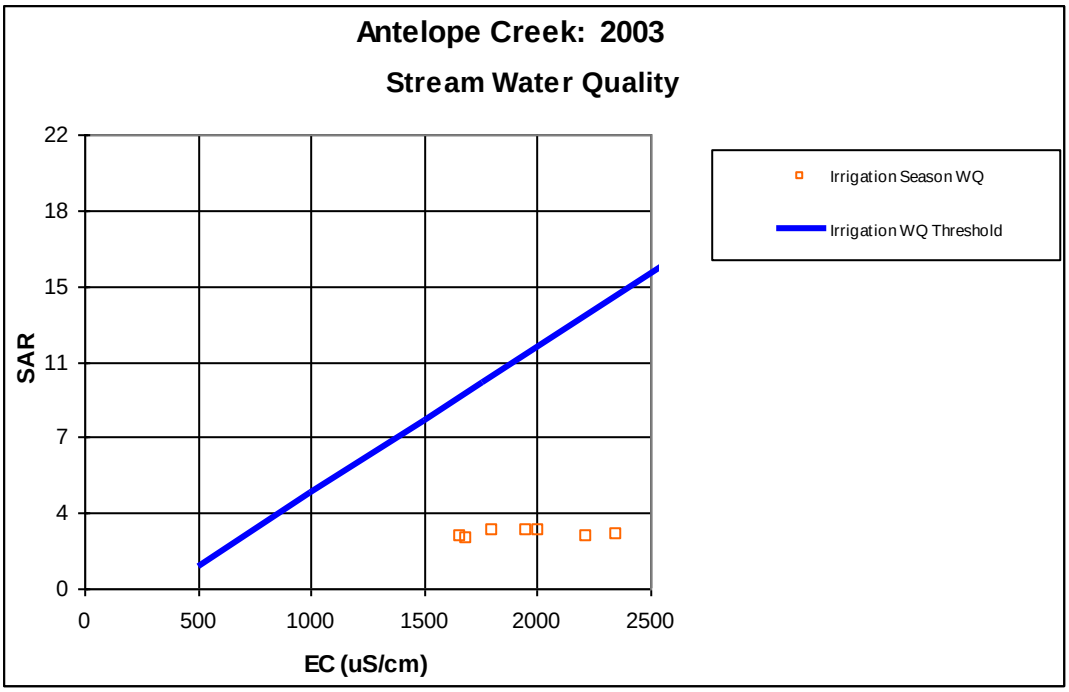
This EC/SAR relationship in the Ayers Westcot irrigation suitability diagram is utilized to determine the effect of irrigation waters on the infiltration capacity of soils. Elevated SAR values may reduce the permeability in clayey soils, consequently reducing the infiltration rate. It should be noted 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 (:S/cm)
- Channel Loss (%)
- Subwatershed Streamflow (acre-feet)
- Subwatershed Streamflow SAR
- Subwatershed Streamflow EC (:S/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.

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 3.1-1 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)]	---	---	---	3.61	7.20	1053
2015	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	---	---	---	4.41	7.28	1031
2020	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	---	---	---	4.21	1.26	1036
Dry Year										
2003	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	0.10	2.79	2005	1.03	7.01	1065
2010	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	---	---	---	3.43	7.43	970
2015	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	---	---	---	4.23	7.47	963
2020	10[(1)]	2000[(1)]	10[(2)]	2500[(2)]	---	---	---	4.03	7.46	964

[(1)] Wyoming DEQ

[(2)] South Dakota's Legislative Council

The peak CBNG discharge in the watershed is realized for RFD Scenario 2015 when 4.1 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 4.1 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 4.2

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), 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.
- 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. 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.

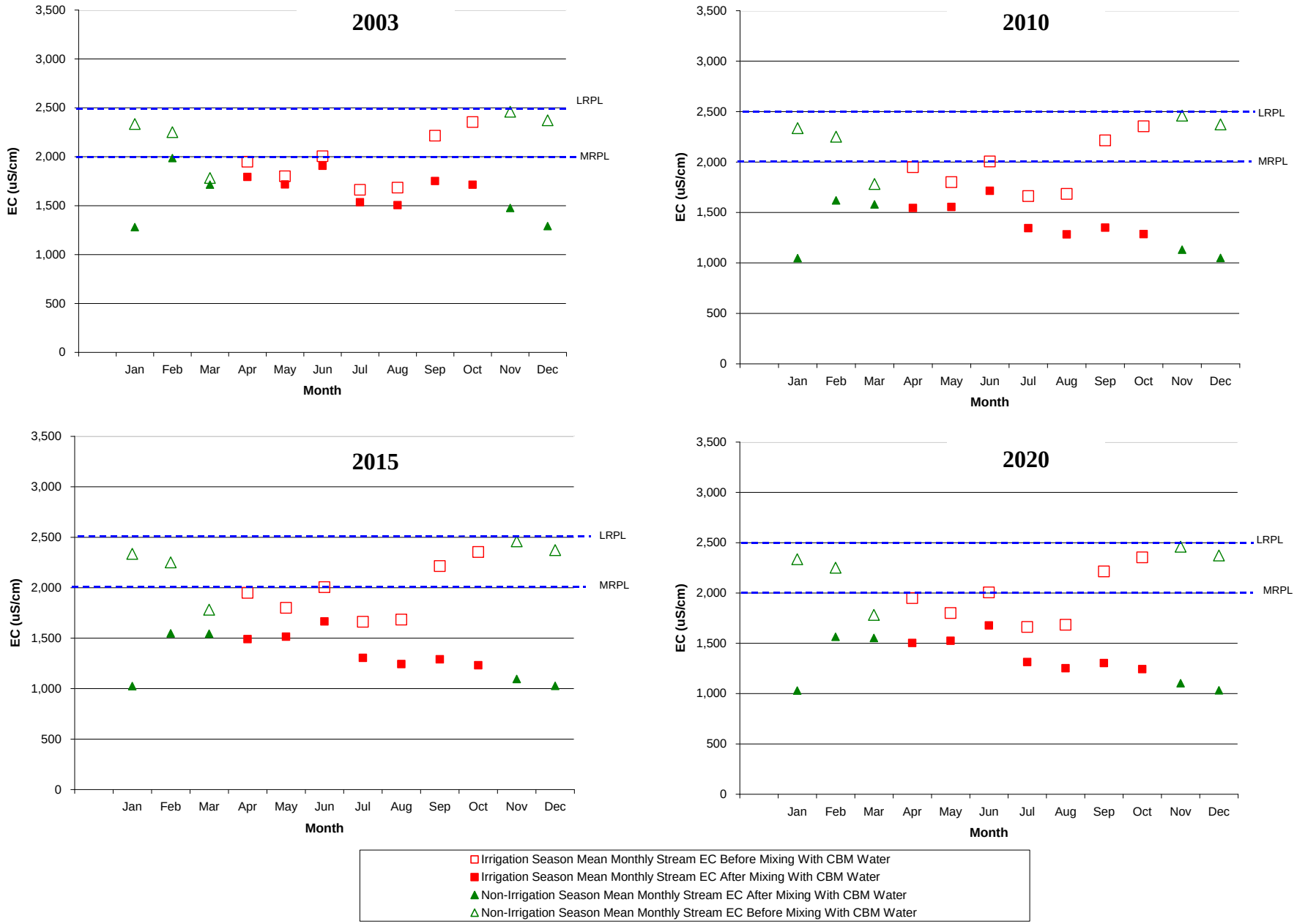


Figure 3.1-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Antelope Creek near Teckla, WY (06364700)

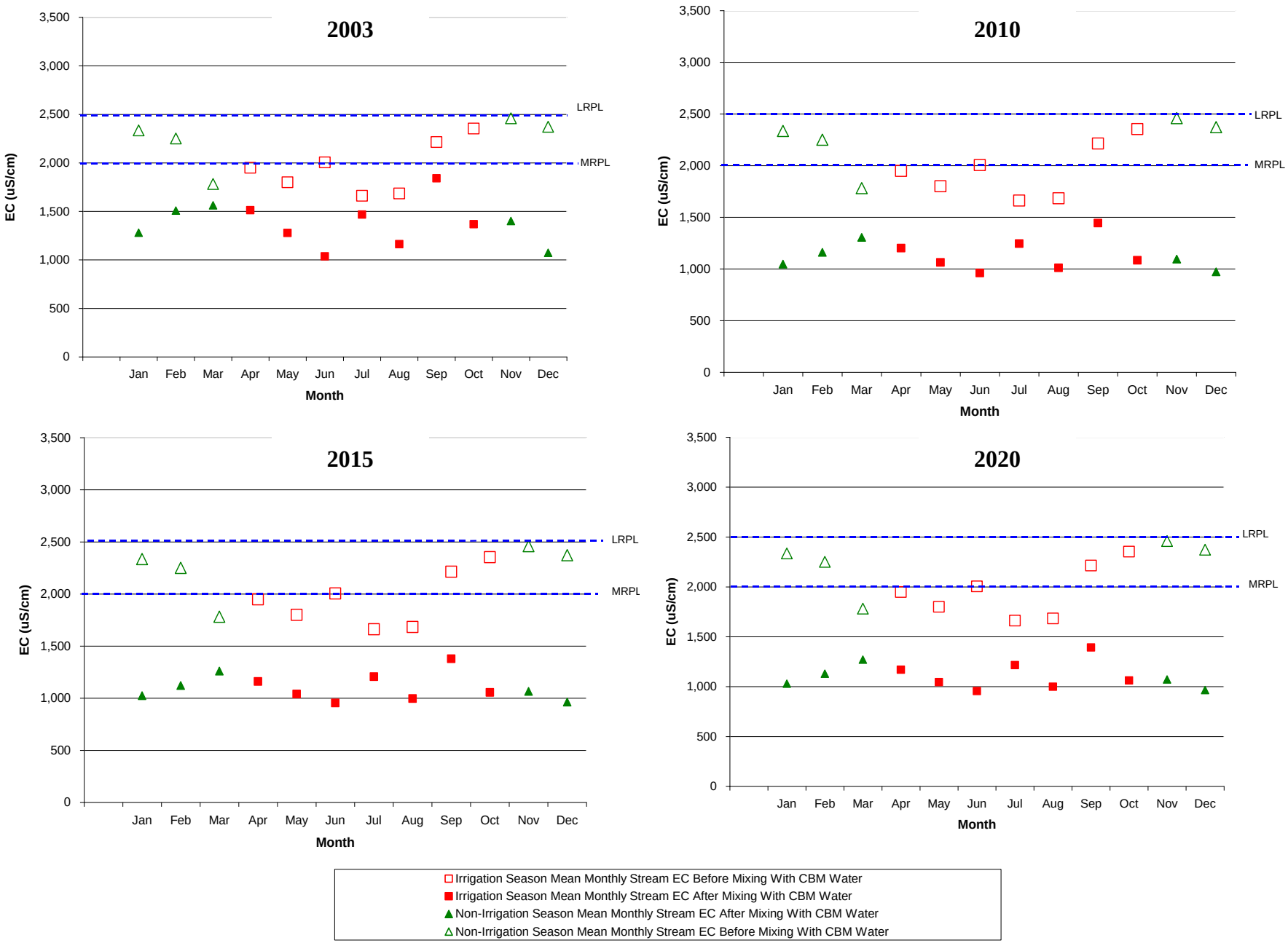


Figure 3.1-2
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows- Dry Year Hydrology
Antelope Creek near Teckla, WY (06364700)

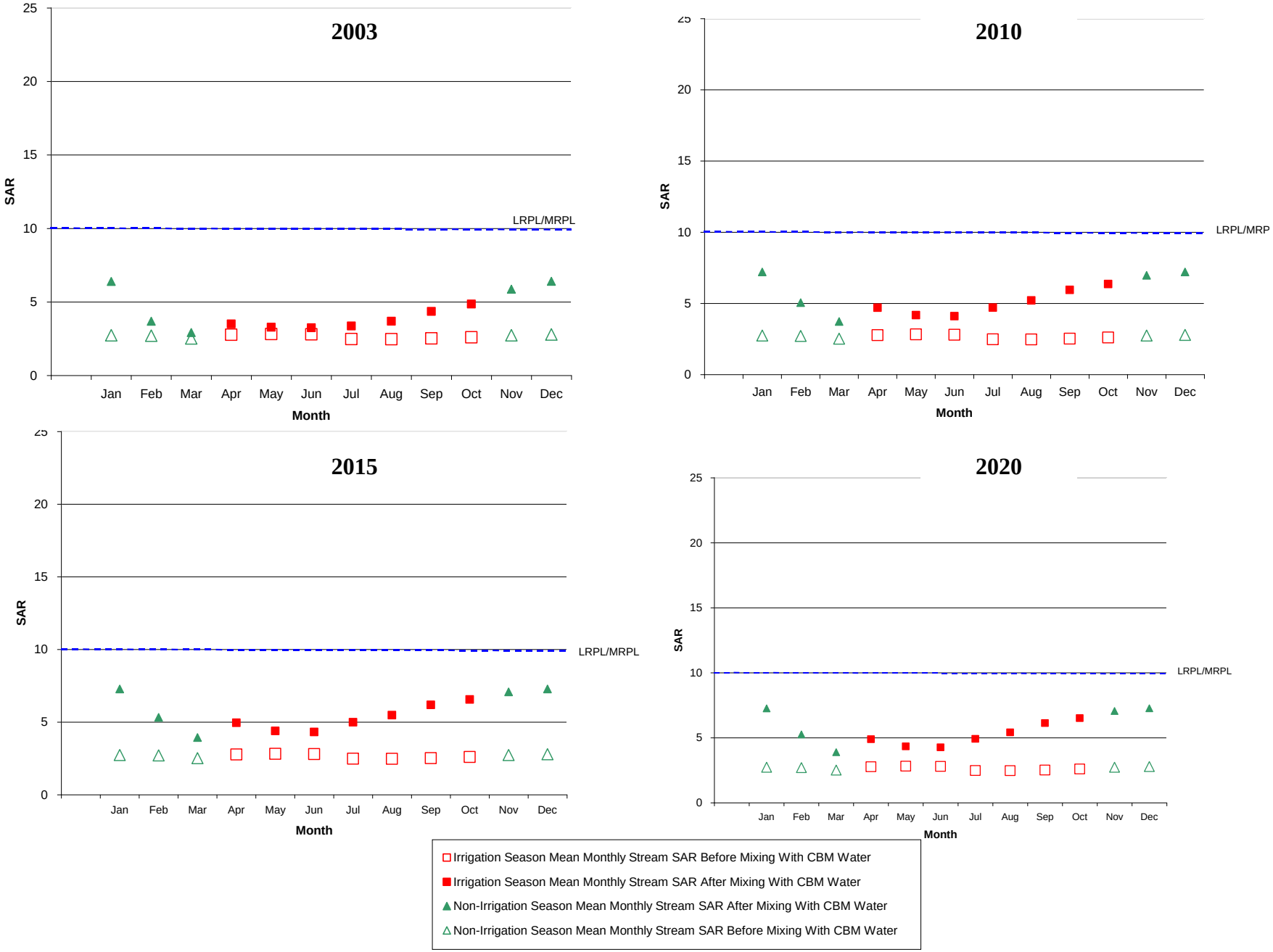


Figure 3.1-3
Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows – Normal Year Hydrology Antelope Creek near Teckla, WY (06364700)

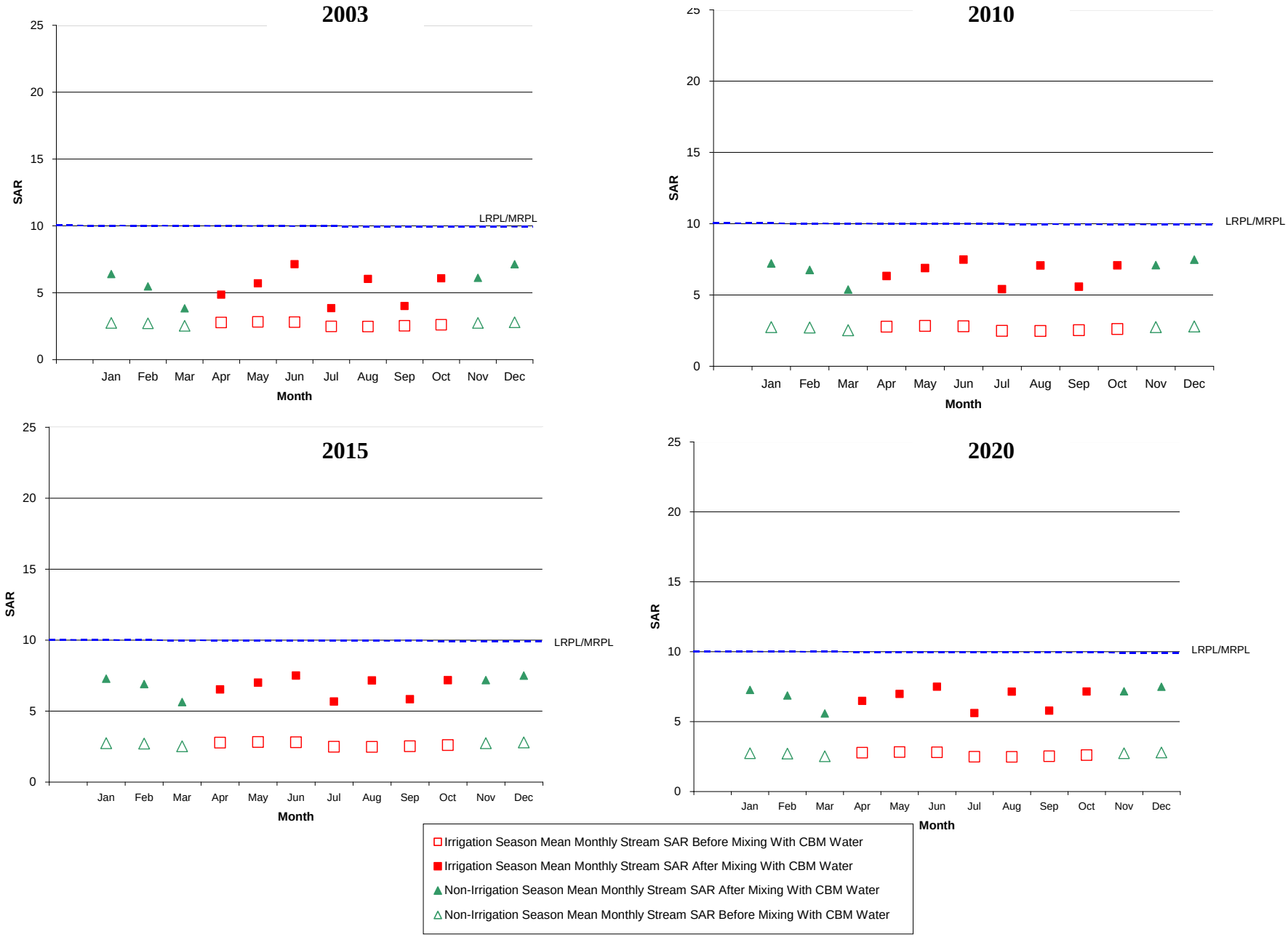


Figure 3.1-4
Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows – Dry Year Hydrology Antelope Creek near Teckla, WY (06364700)

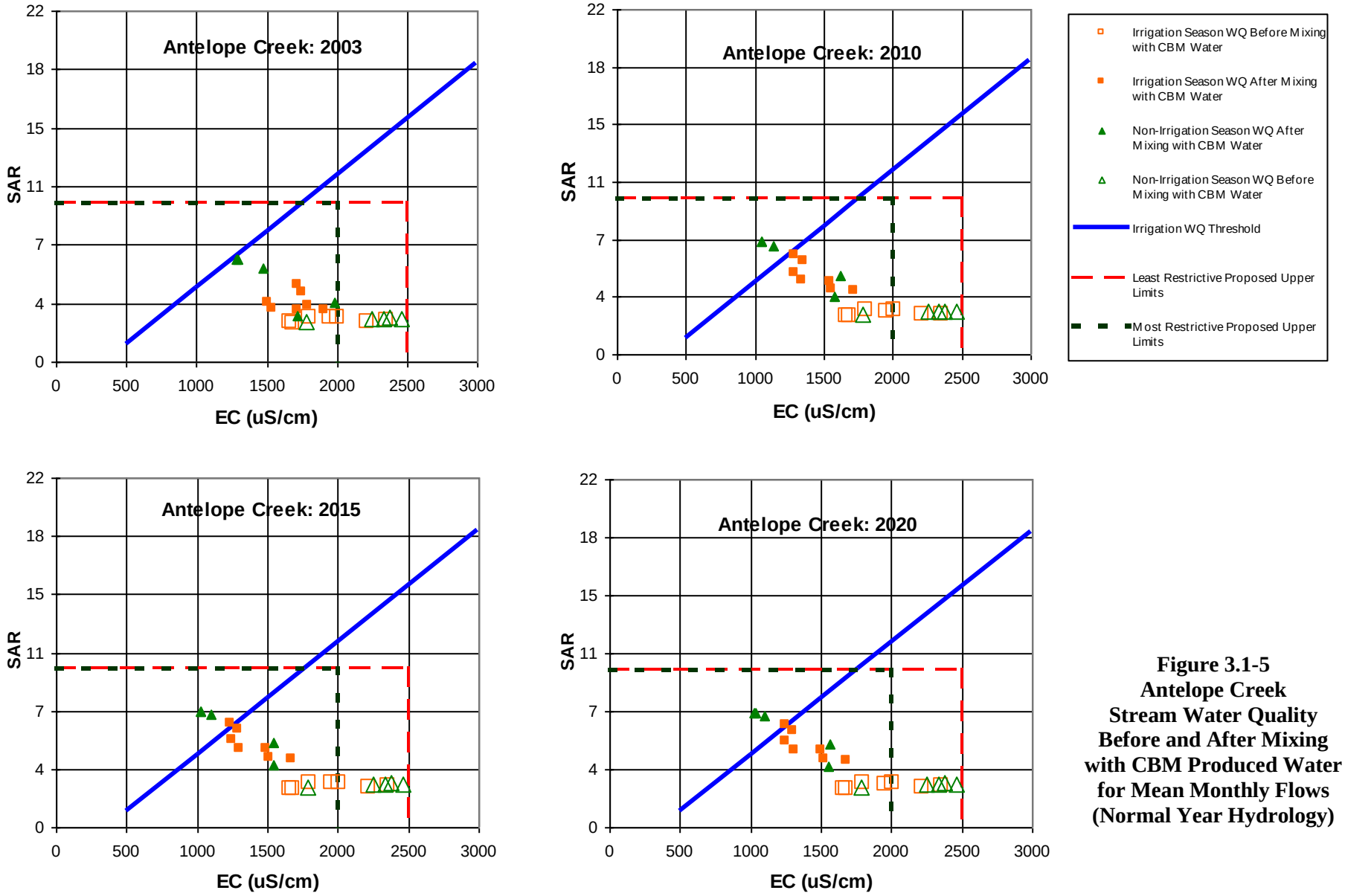


Figure 3.1-5
Antelope Creek
Stream Water Quality
Before and After Mixing
with CBM Produced Water
for Mean Monthly Flows
(Normal Year Hydrology)

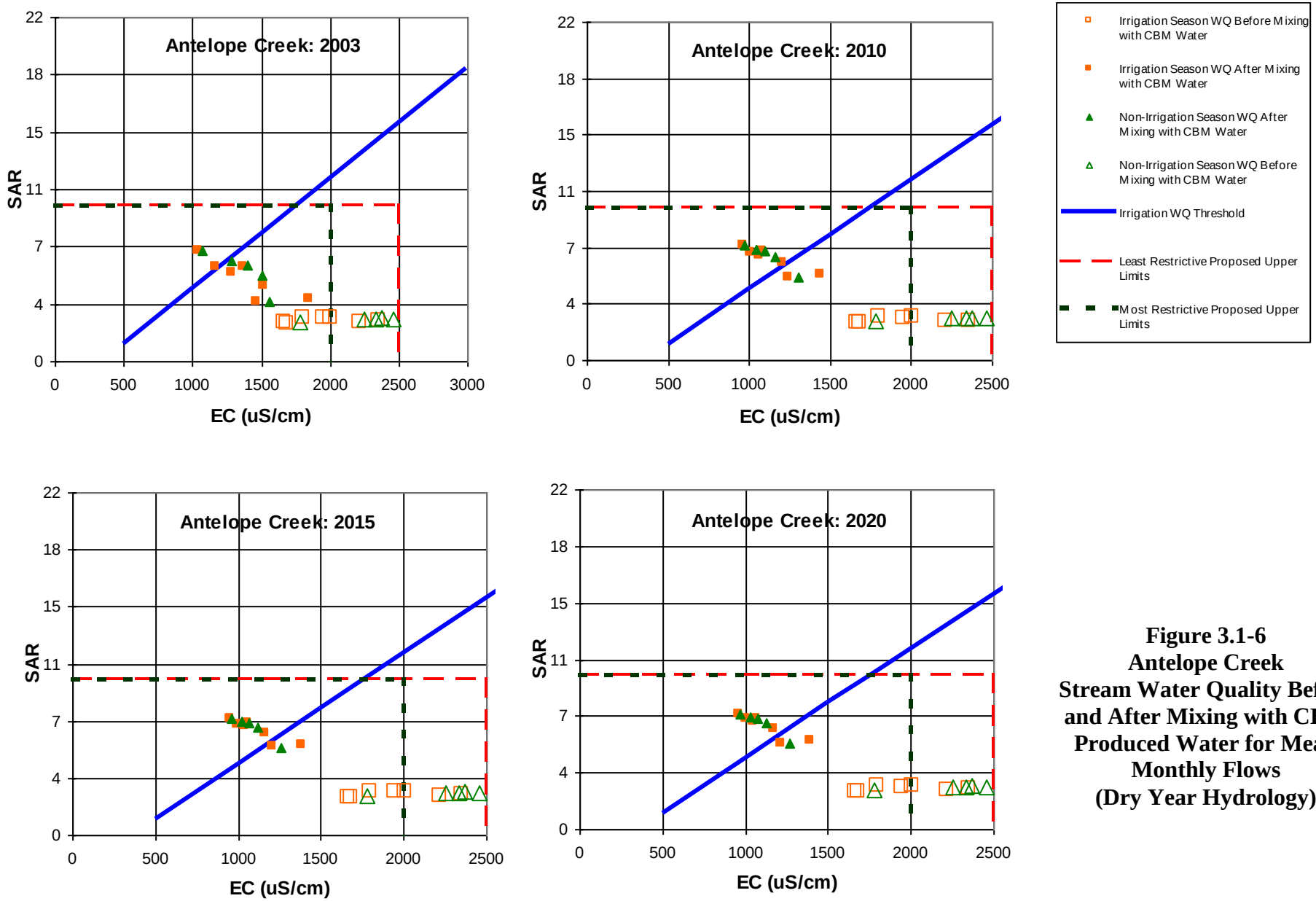


Figure 3.1-6
Antelope Creek
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

- 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 and is unsuitable for irrigation except for July and September. 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 and is unsuitable for irrigation except for July and September. 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 with the exception of October..

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 and is unsuitable for irrigation except for July and September. 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 with the exception of October.

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]	---	---	---	0.03	7.62	929
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.04	7.62	929
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.04	7.62	929
Dry Year										
2003	10[1]	2000[1]	10[1]	2500[1]	0	---	---	0.00	---	---
2010	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.03	7.62	929
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.04	7.62	929
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	0.04	7.62	929

[1] Wyoming DEQ

The peak CBNG discharge in the watershed is similar for RFD Scenarios 2015 and 2020 and reflects approximately 0.04 cfs conveyed into the Dry Fork Cheyenne River. The quantity of water discharged into the Dry Fork Cheyenne River would be less in the other RFD scenarios but results in similar impacts to the existing water quality since no flow is available under either hydrologic condition. For RFD Scenario 2120, the dry-year hydrologic conditions presented in **Table 3.2-1** illustrate the impacts associated with mixing 0 cfs of streamflow in the Dry Fork Cheyenne River with 0.04 cfs of CBNG well discharge water on both SAR and EC. Consequently, the resultant streamflow consists entirely of CBNG produced water. Compared to typical values when streamflow is available in the river (see water quality input data in Appendix B), the resulting EC would decrease, whereas the SAR would increase. The combined streamflow of approximately 0.04 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.

3.2.1 Dry Fork Cheyenne River: Current Conditions (2003)

The results of the water quality impact assessment under current conditions and all RFD Scenarios are presented in **Figures 3.2-1, 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. Given the information in the referenced figures, the observations presented below represent the existing water quality in the river for both hydrologic conditions.

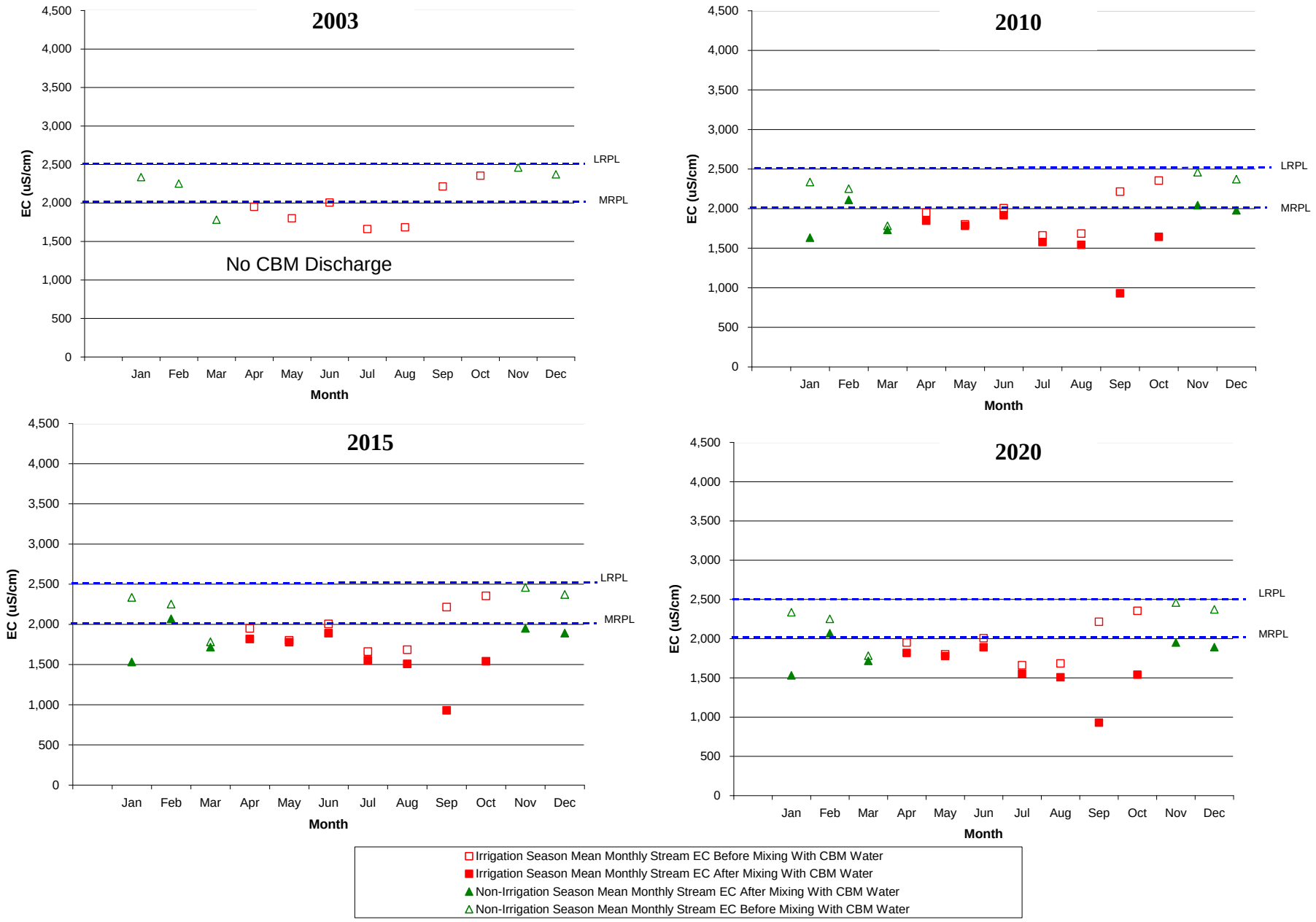


Figure 3.2-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Dry Fork Cheyenne River Near Bill, Wyoming (0634700)

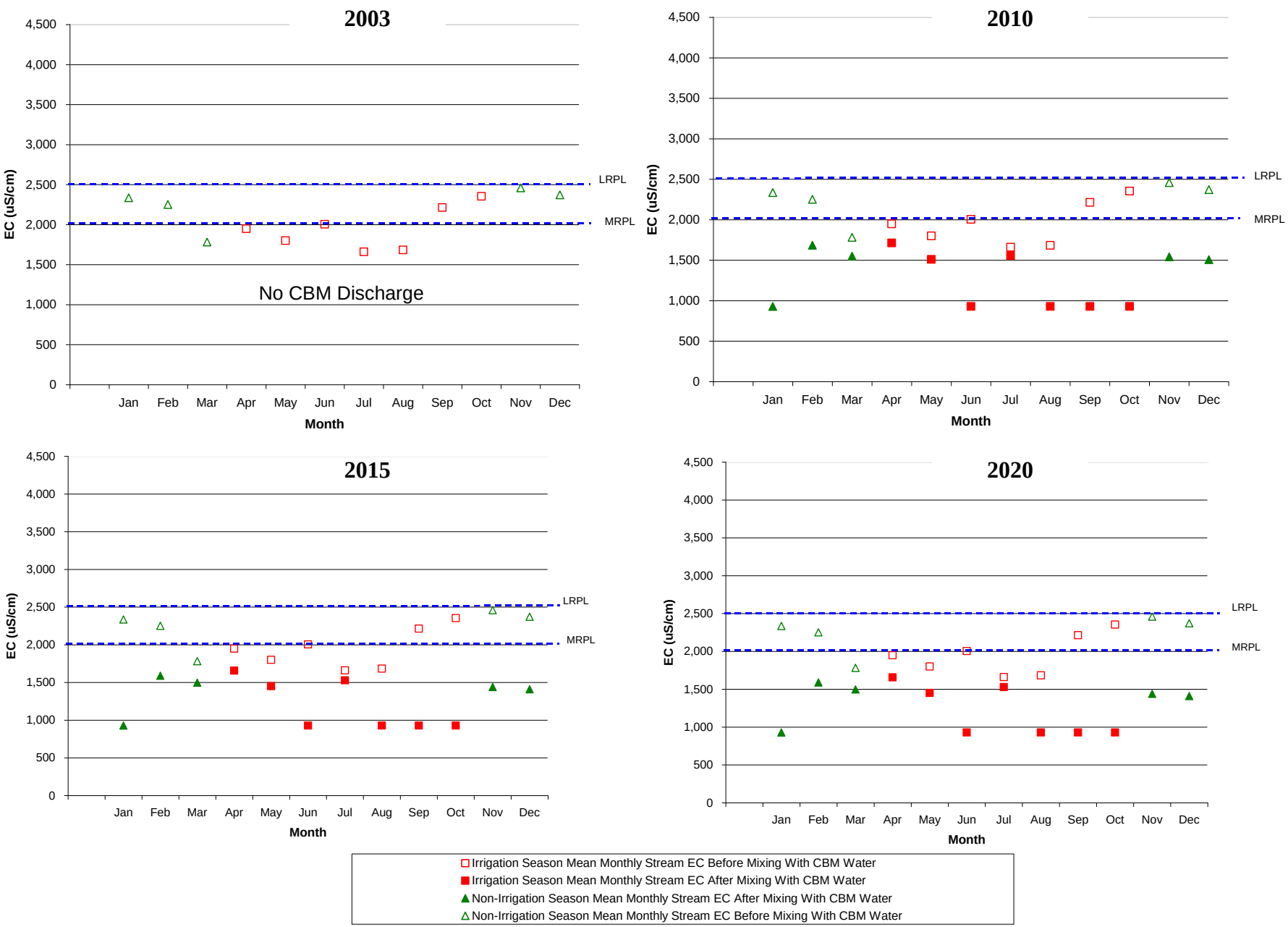


Figure 3.2-2
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Dry Fork Cheyenne River Near Bill, Wyoming (0634700)

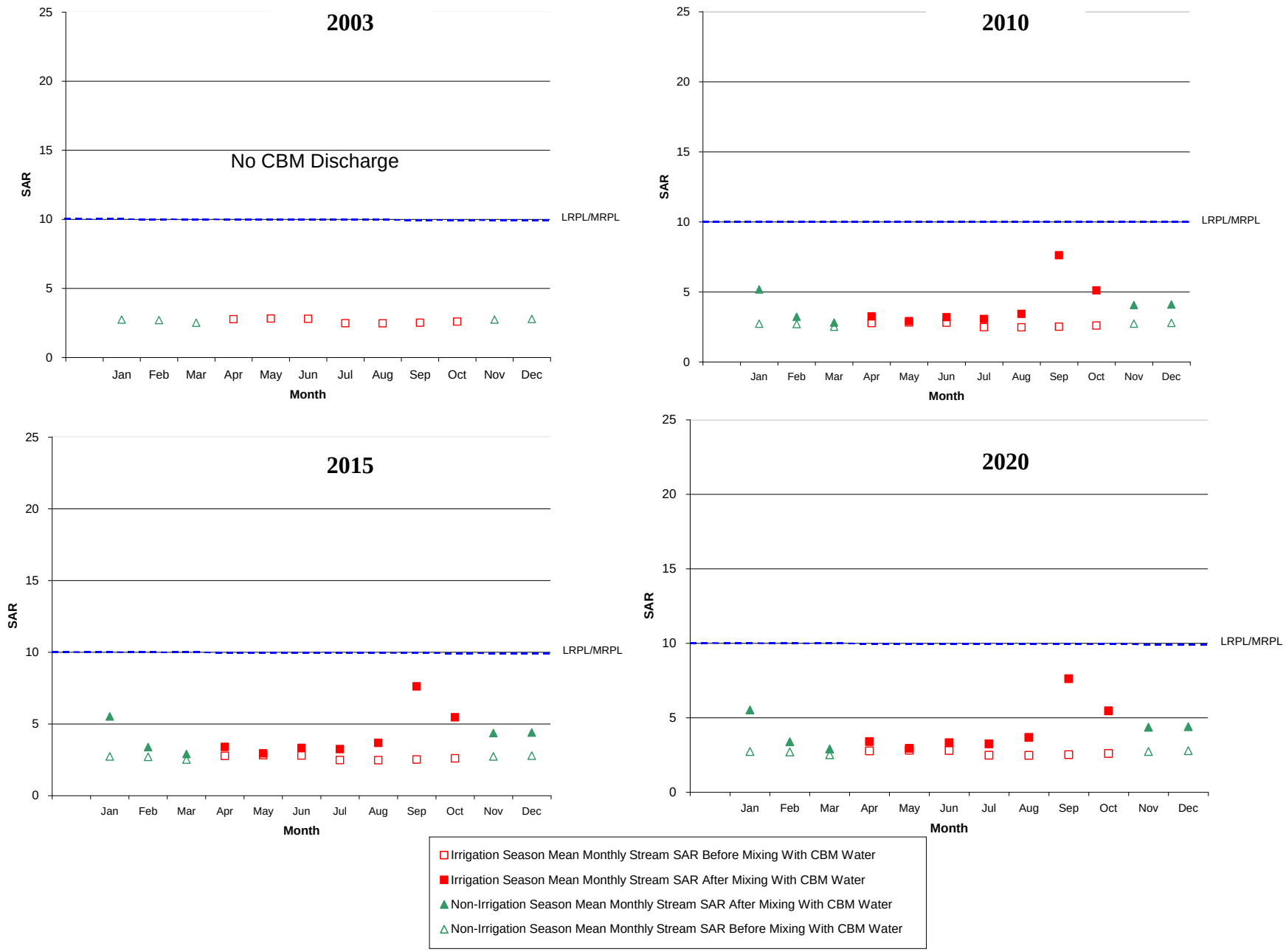


Figure 3.2-3
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Dry Fork Cheyenne River Near Bill, Wyoming (0634700)

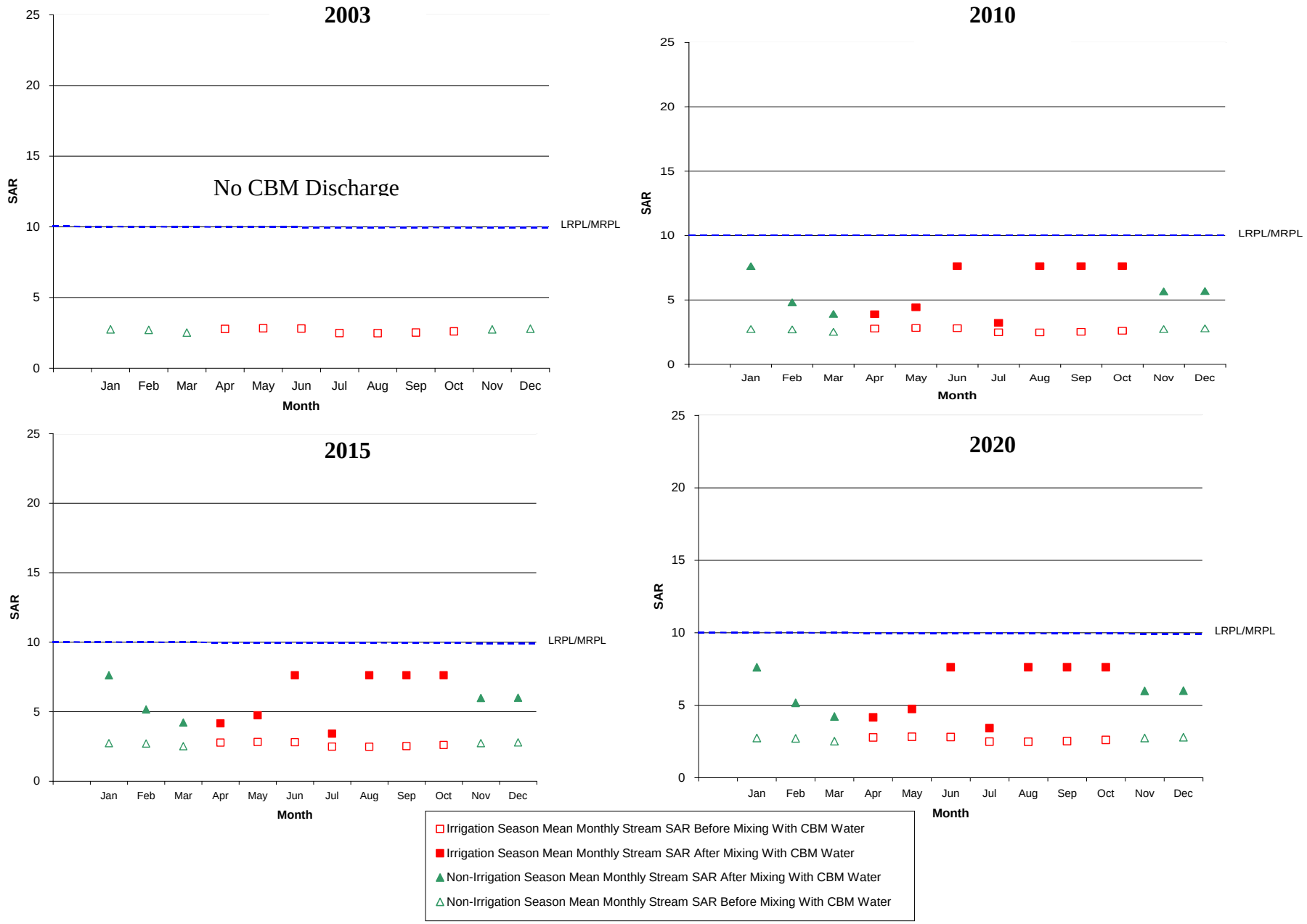


Figure 3.2-4
Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows – Dry Year Hydrology
Dry Fork Cheyenne River Near Bill, Wyoming (0634700)

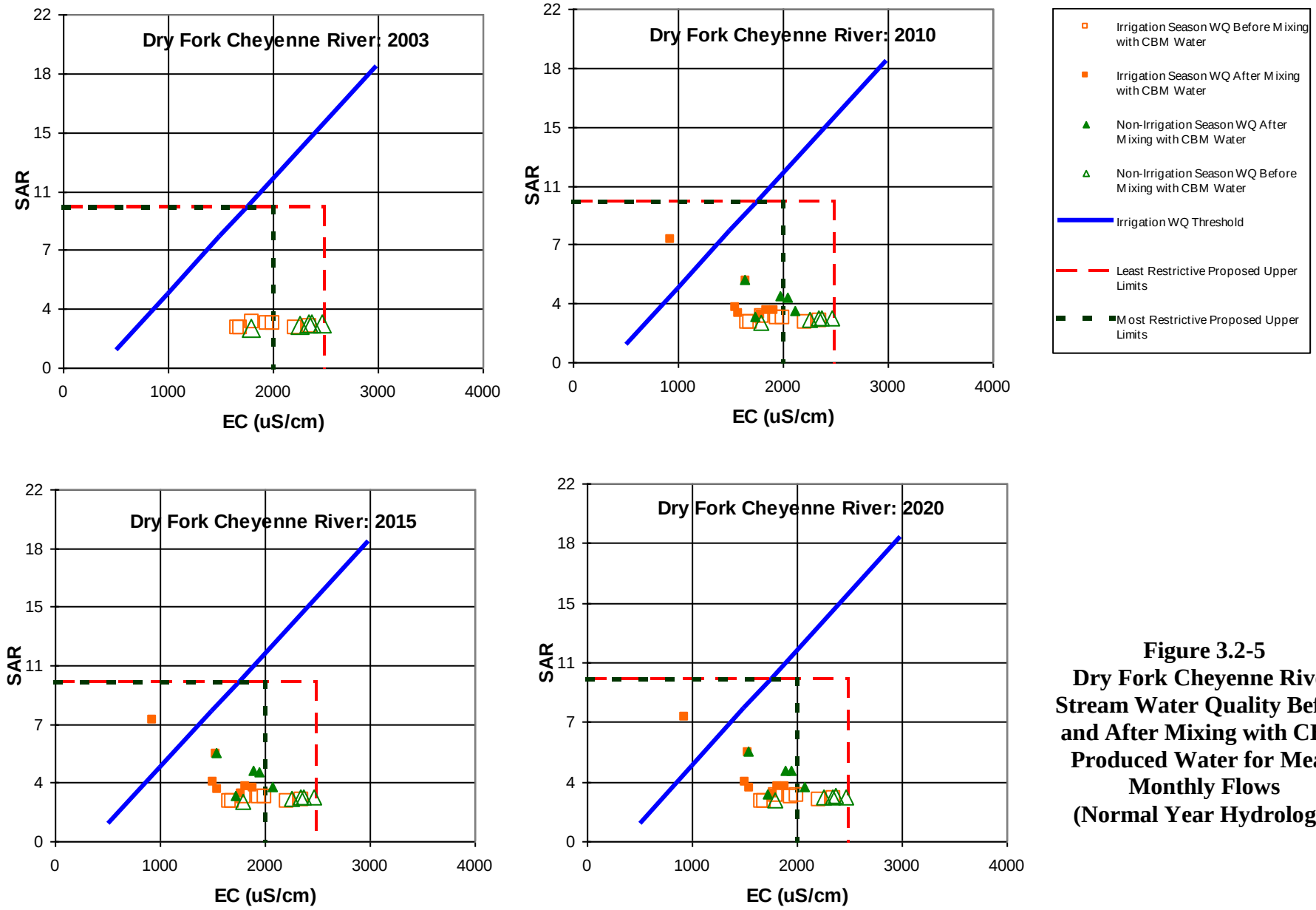


Figure 3.2-5
Dry Fork Cheyenne River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

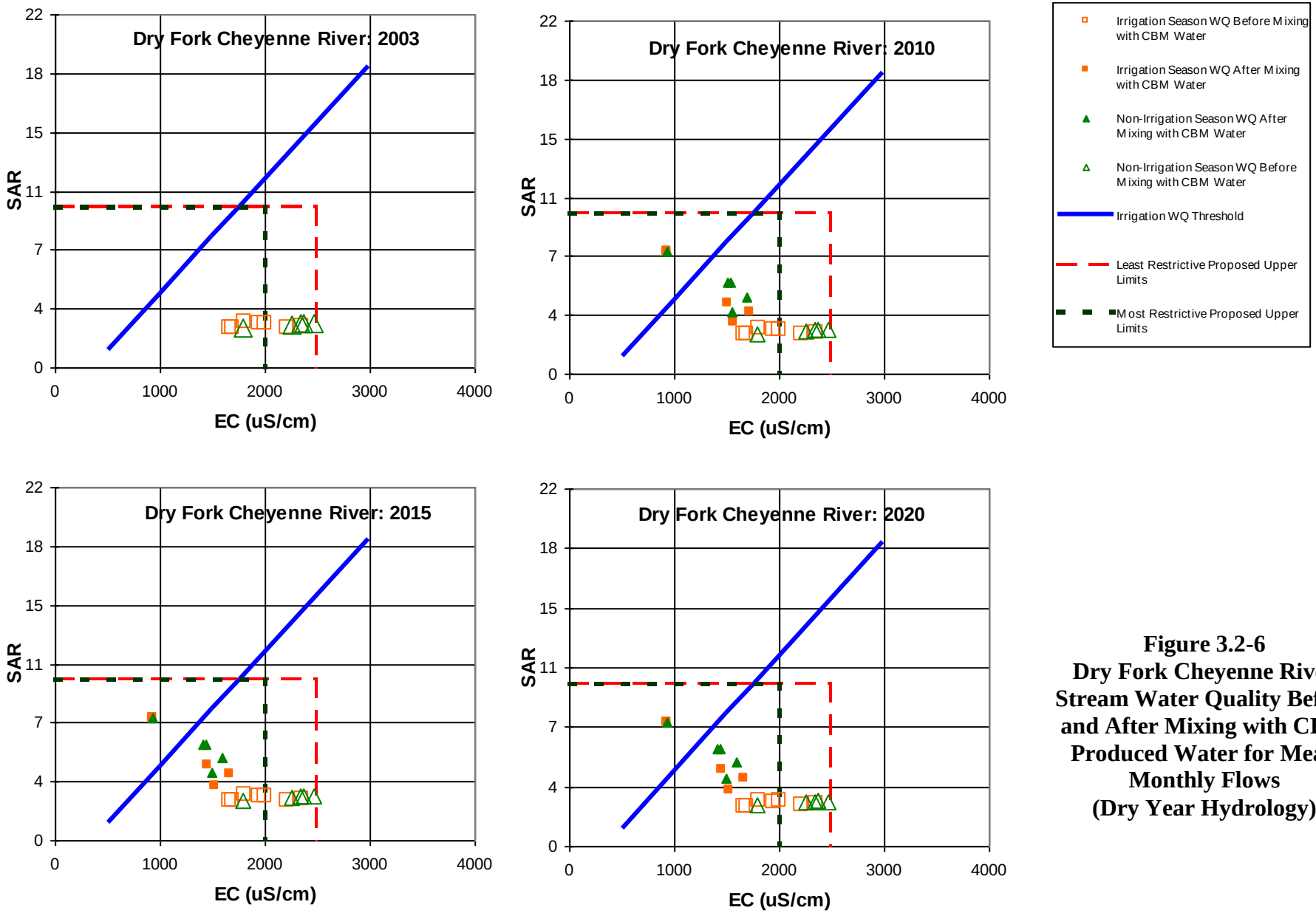


Figure 3.2-6
Dry Fork Cheyenne River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)

- Mean monthly EC values in the Dry Fork Cheyenne River currently exceed the MRPL, during the low flow months 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.

3.2.2 Dry Fork Cheyenne River: RFD Scenario 2010 Conditions

The results of the water quality impact assessment under RFD Scenario 2010 conditions are also presented in **Figures 3.2-1, 3.2-2, 3.2-3, 3.2-4, 3.2-5 and 3.2-6**. 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 3.2.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year (with the exception of February and November). 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 flow in the river is entirely or largely composed of CBNG production water. Given the water quality of the CBNG production water, a significant reduction in infiltration is noted throughout the irrigation season and the mixed water is considered unsuitable for irrigation (June, August through September); the unsuitable nature of the water is largely attributed to the elevated levels of SAR. Under normal-year conditions, a minor decrease in infiltration is realized following mixing with CBNG production water; overall, however, the data indicates that the mixed water is suitable for irrigation with the exception of the month of September.

3.2.3 Dry Fork Cheyenne River: RFD Scenario 2015 Conditions

The results of the water quality impact assessment under RFD Scenario 2015 conditions are also presented in **Figures 3.2-1, 3.2-2, 3.2-3, 3.2-4, 3.2-5 and 3.2-6**. 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 3.2.1.
- Following Mixing. The resultant EC values decrease sufficiently to meet the LRPL and MRPL for EC for both the dry year and normal year (with the exception of February). 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 flow in the river is entirely or largely composed of CBNG production water. Given the water quality of the CBNG production water, a significant reduction in infiltration is noted throughout the irrigation season and the mixed water is considered unsuitable for irrigation (June, August through September); the unsuitable nature of the water is largely attributed to the elevated levels of SAR. Under normal-year conditions, a minor decrease in infiltration is realized following mixing with CBNG production water; overall, however, the data indicates that the mixed water is suitable for irrigation with the exception of the month of September.

3.2.4 Dry Fork Cheyenne River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in Figures **3.2-1, 3.2-2, 3.2-3, 3.2-4, 3.2-5 and 3.2-6**. The observations presented for RFD Scenario 2015 are identical for RFD Scenario 2020 given the CBNG production water remains constant for both scenarios.

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.

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 3.3-1 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)]	---	---	---	3.3	9.34	2088
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	2.2	9.31	2106
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	2.9	9.18	2169
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)]	---	---	---	2.4	10.12	1627
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	2.3	10.11	1632
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	2.0	10.05	1651

[(1)] Montana DEQ

The peak CBNG discharge in the watershed is realized for RFD Scenario 2010 when 2.2 cfs is conveyed into the Little Powder River. The quantity of water discharged into the Little 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 RFD Scenario 2010, 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 2.2 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 2.4 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.
- 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 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 may be 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.

3.3.2 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.

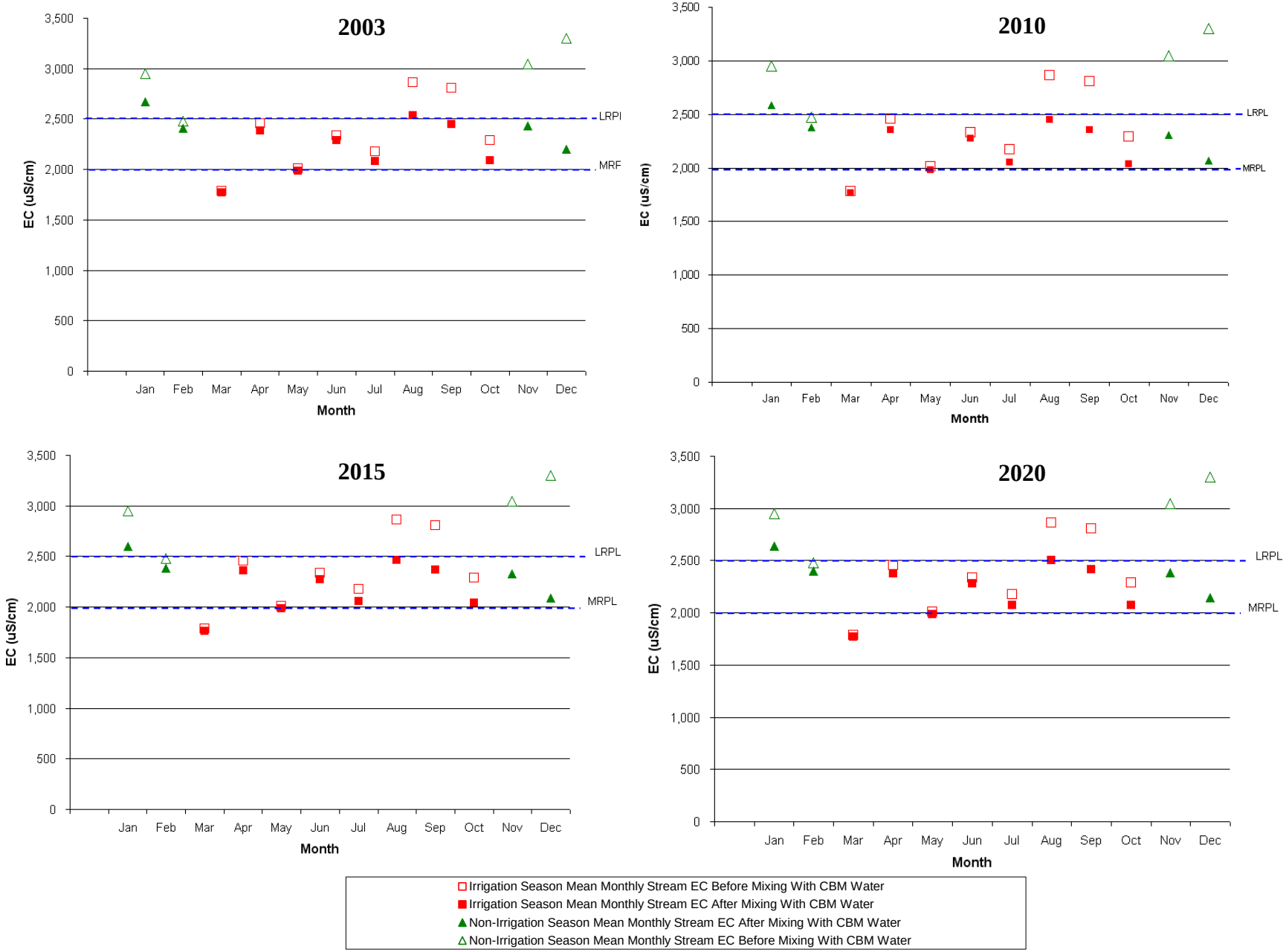


Figure 3.3-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Little Powder River near Weston, WY (06324970)

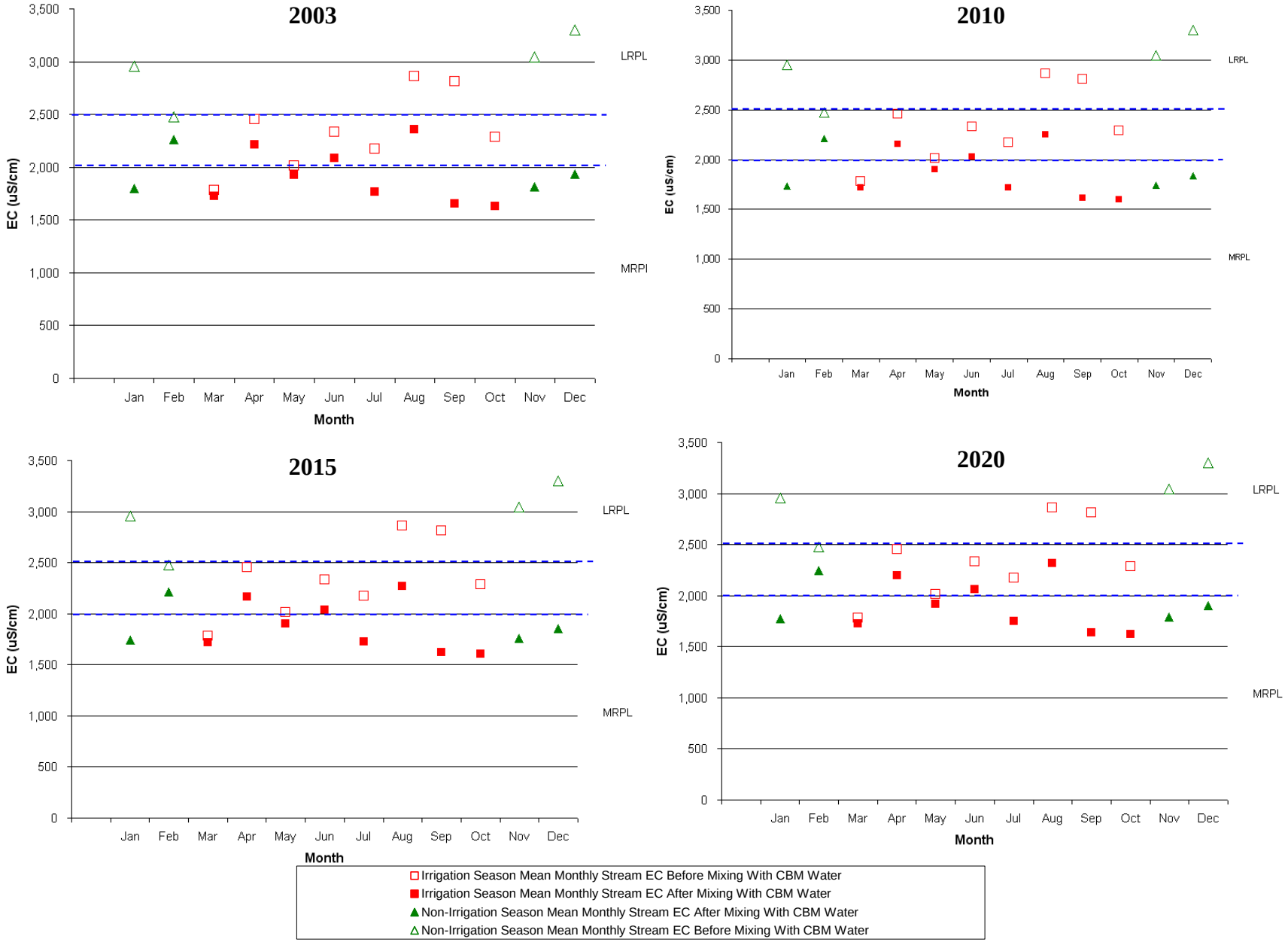


Figure 3.3-2
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Little Powder River near Weston, WY (06324970)

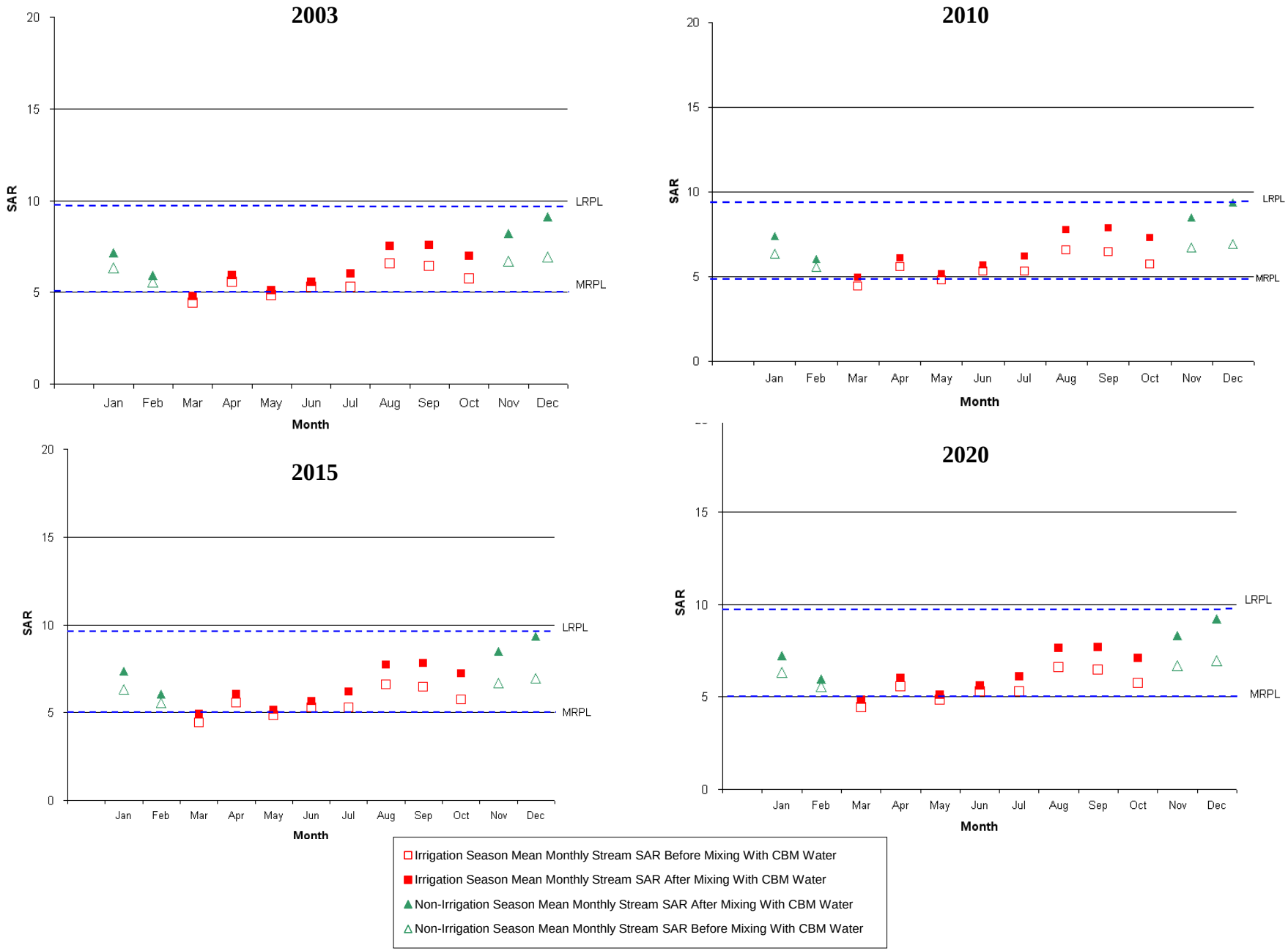


Figure 3.3-3
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Little Powder River near Weston, WY (06324970)

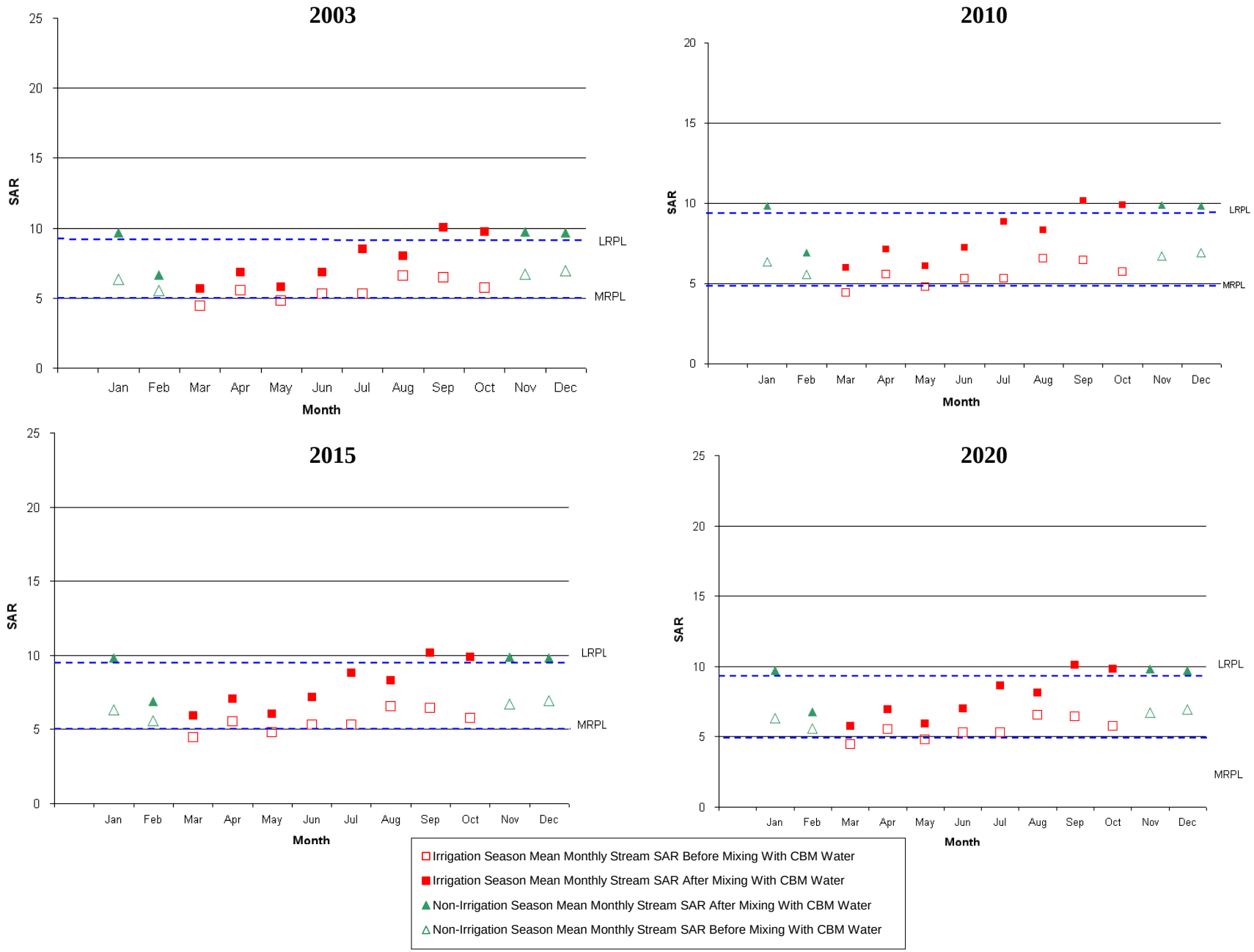


Figure 3.3-4
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Little Powder River near Weston, WY (06324970)

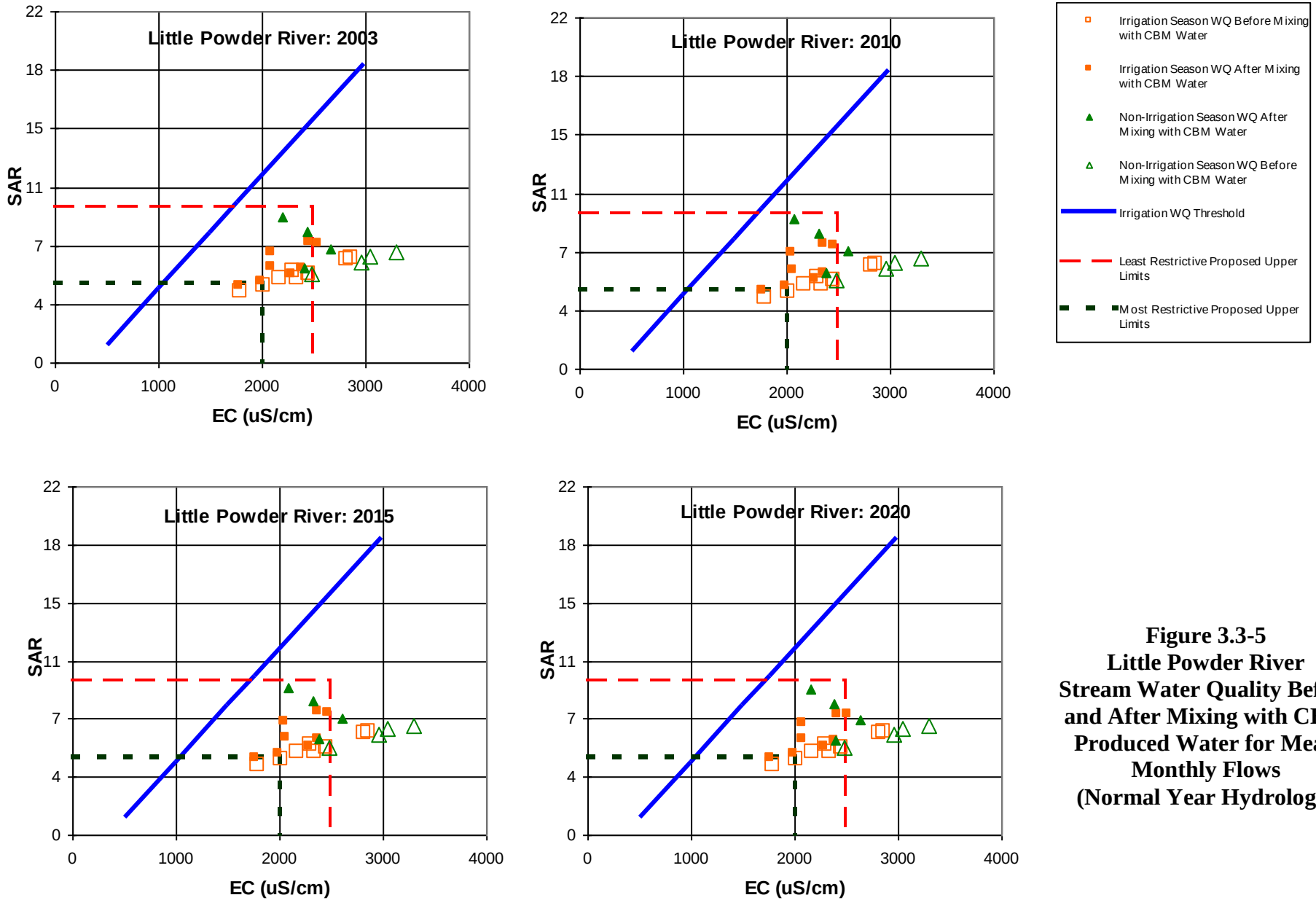


Figure 3.3-5
Little Powder River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

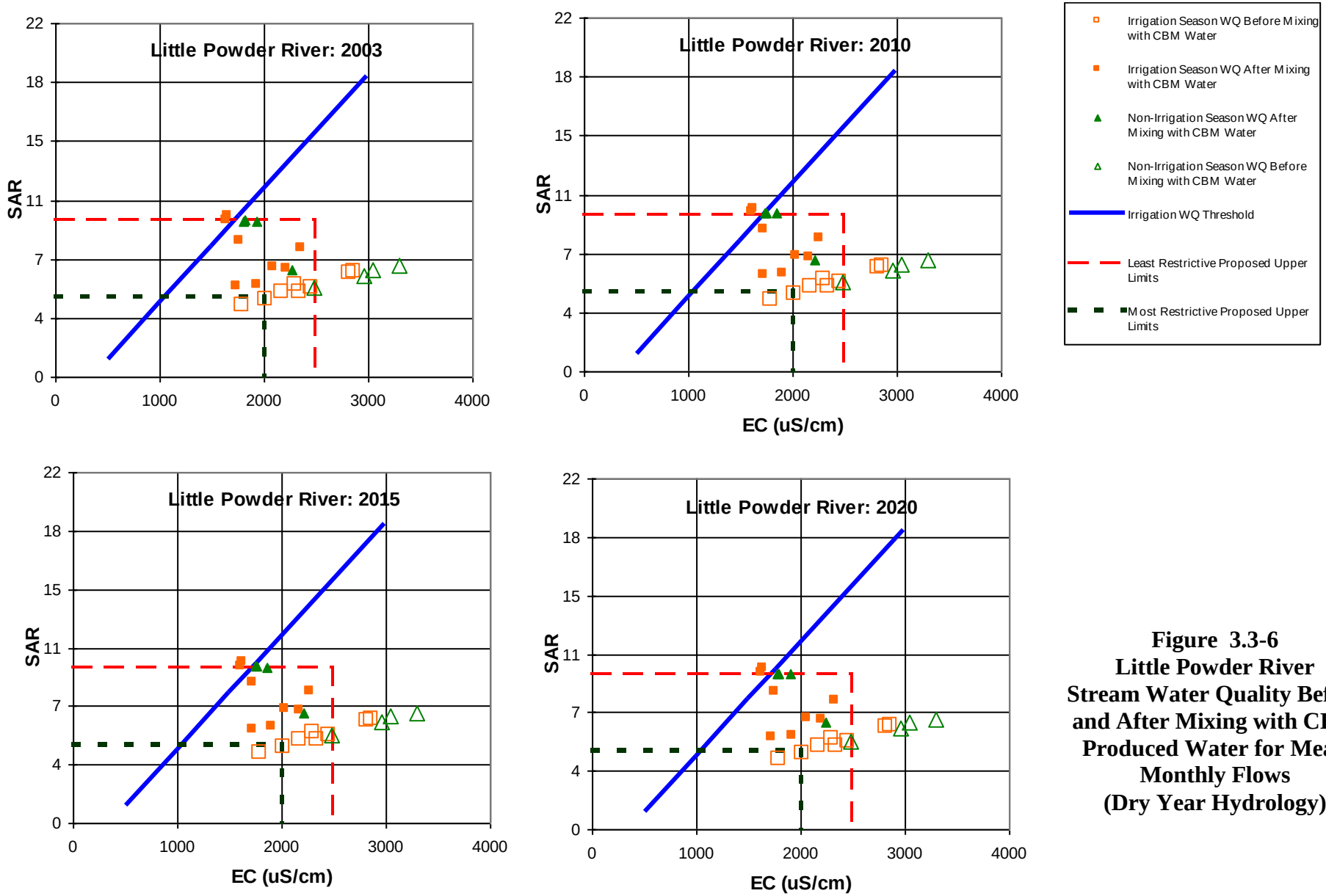


Figure 3.3-6
Little Powder River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)

- 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 during the low flow month of 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 during the months of September through January.

- 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 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 May and exceed the LRPL during the low flow month of 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 during the months of September through January.

- 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 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.

3.3.4 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 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 exceed the MRPL for all months and exceed the LRPL during the low flow conditions during the months of September through November.
- 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 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.

3.4 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)]	---	---	---	7.21	7.89	1865
2015	6[(1)]	2000[(2)]	10[(2)]	2500[(2)]	---	---	---	6.31	7.75	1973
2020	6[(1)]	2000[(2)]	10[(2)]	2500[(2)]	---	---	---	5.51	7.59	2098
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)]	---	---	---	1.32	8.53	1230
2015	6[(1)]	2000[(2)]	10[(2)]	2500[(2)]	---	---	---	3.42	8.46	1262
2020	6[(1)]	2000[(2)]	10[(2)]	2500[(2)]	---	---	---	2.62	8.34	1308

[(1)] South Dakota's Legislative Council

[(2)] Wyoming DEQ

The peak CBNG discharge in the watershed is realized for the current conditions (i.e., 2003) when 4.3 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 RFD scenarios and would consequently result in a reduction in impacts to the existing water quality. For the current 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 4.3 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 4.7 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.
- 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 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.

3.4.2 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.

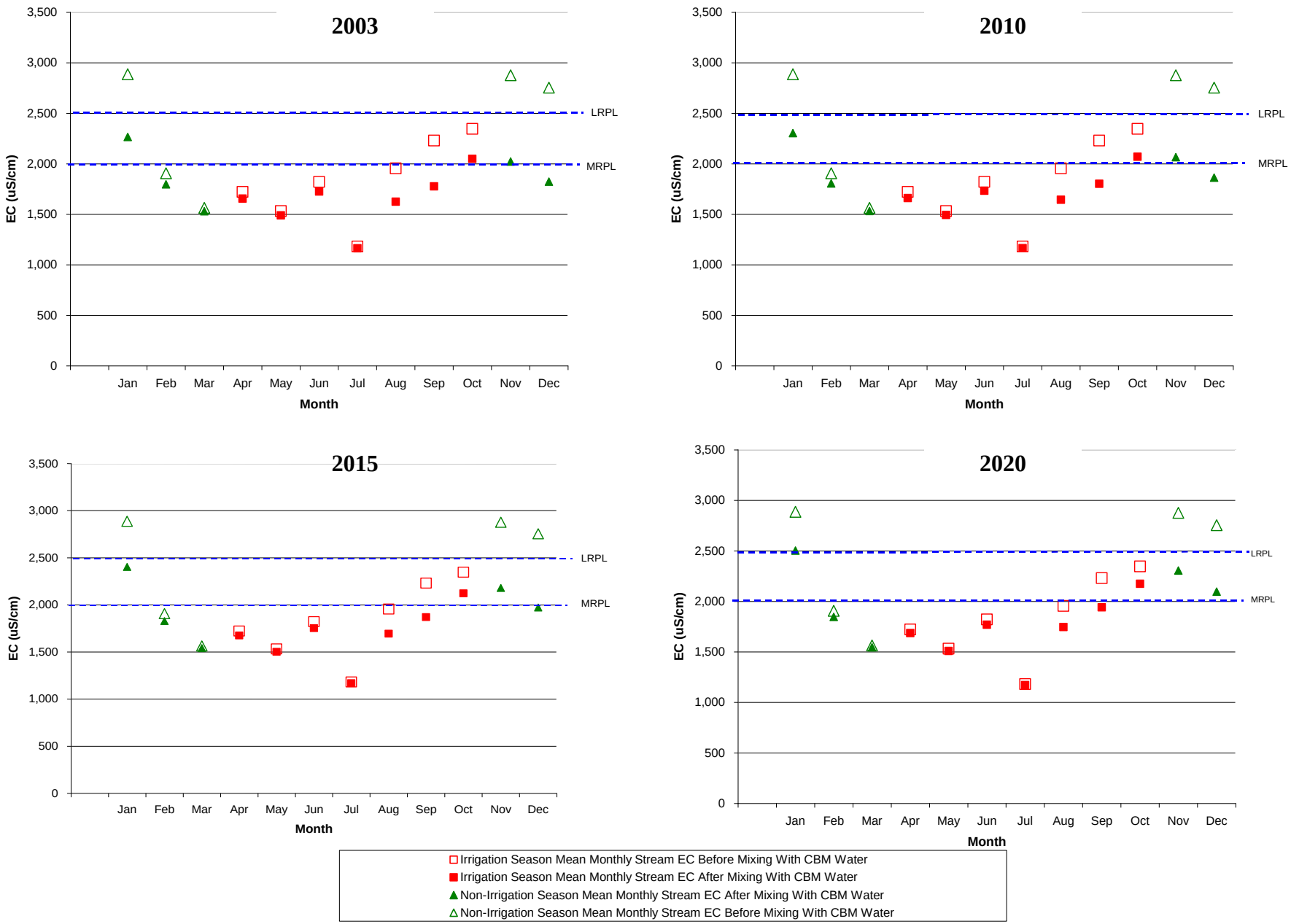


Figure 3.4-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

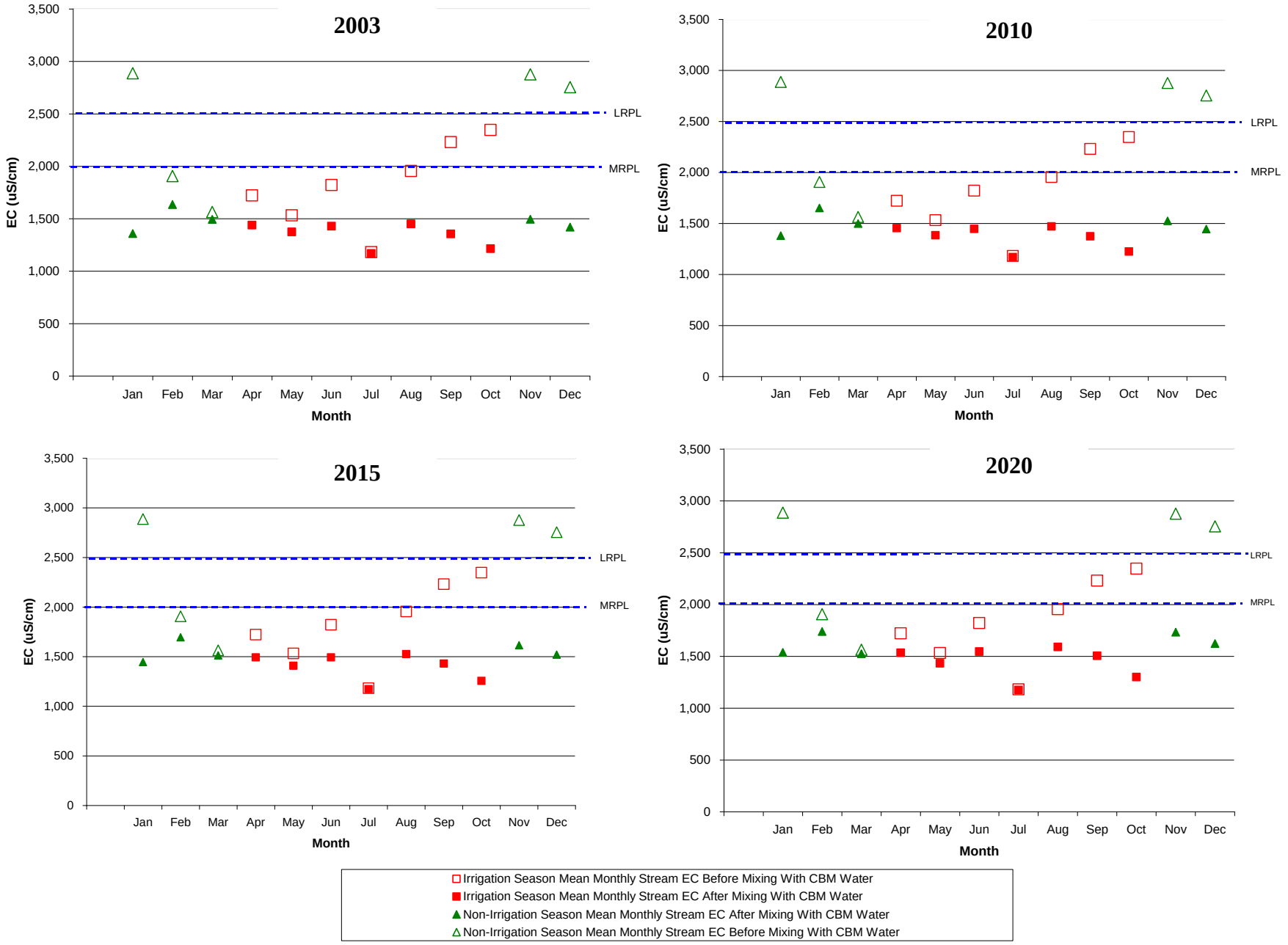


Figure 3.4-2
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

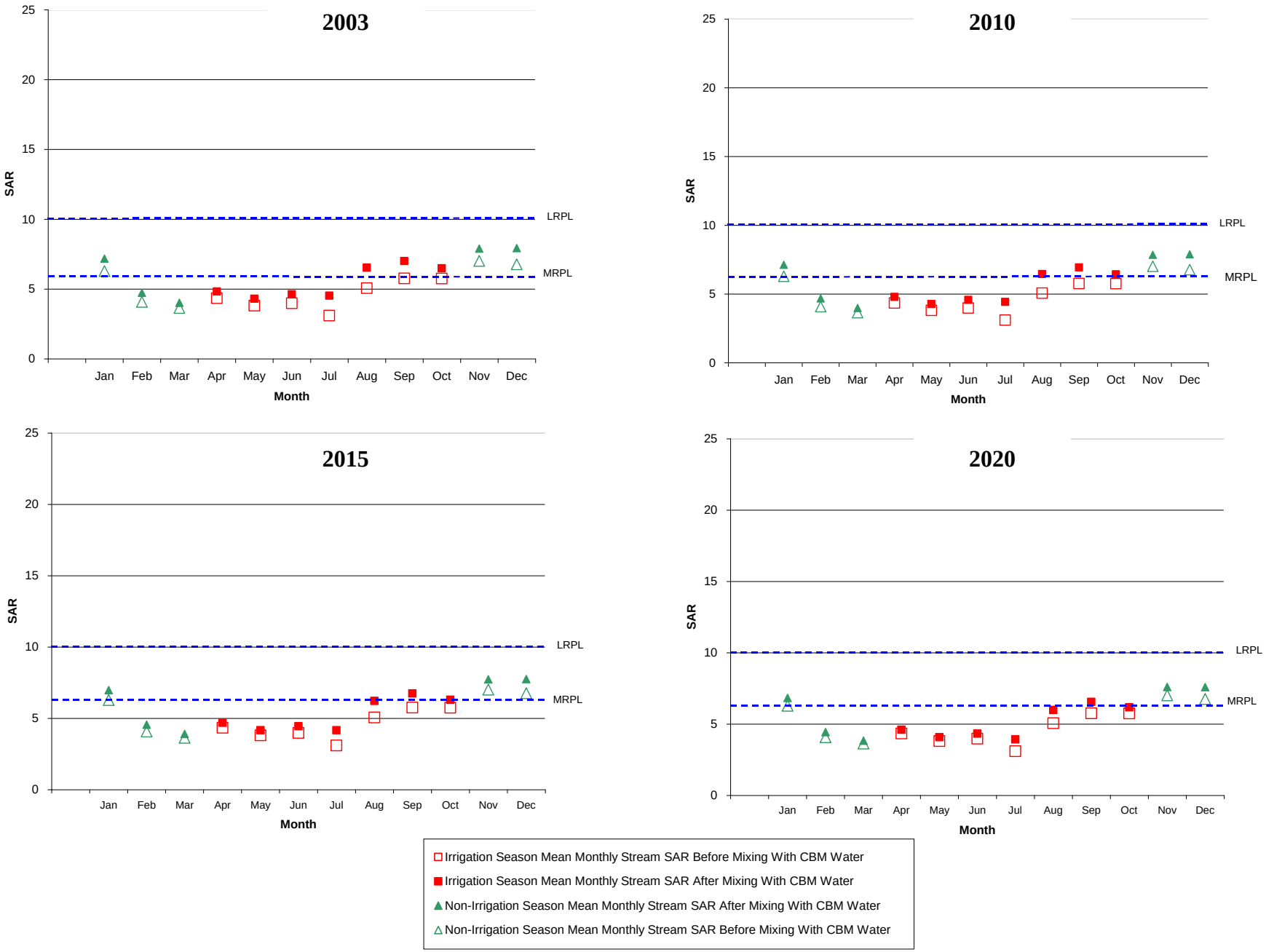


Figure 3.4-3
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

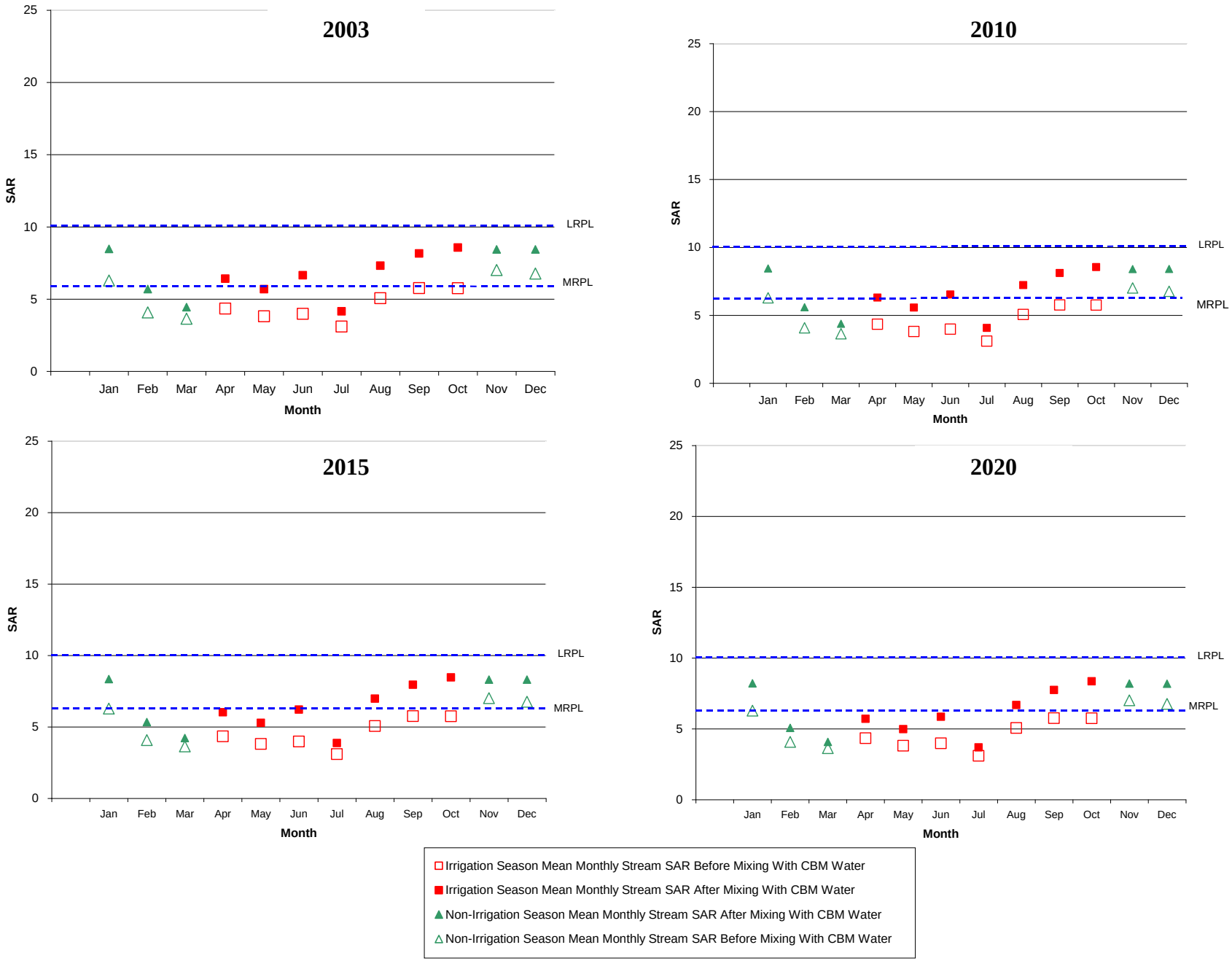


Figure 3.4-4
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

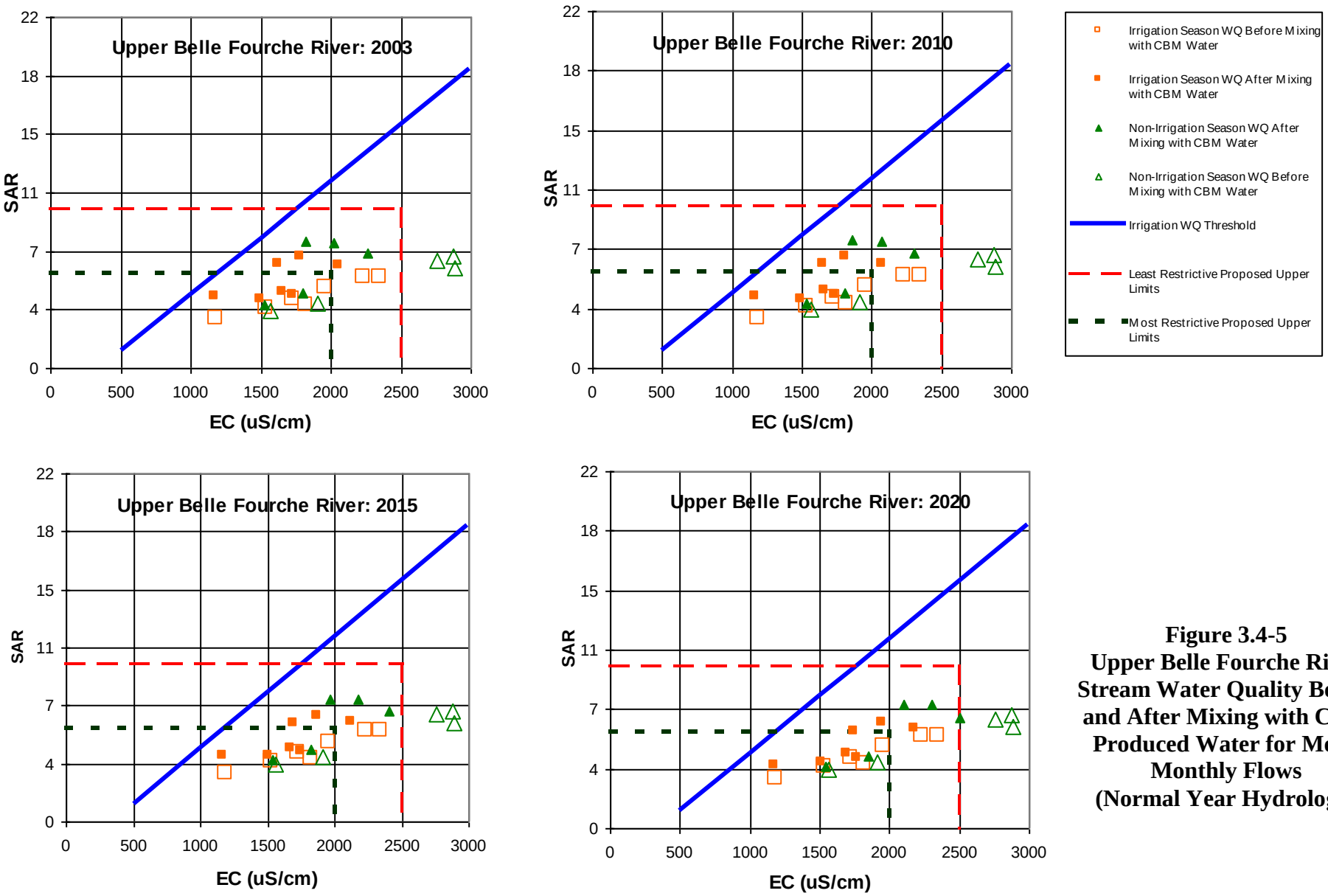


Figure 3.4-5
Upper Belle Fourche River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

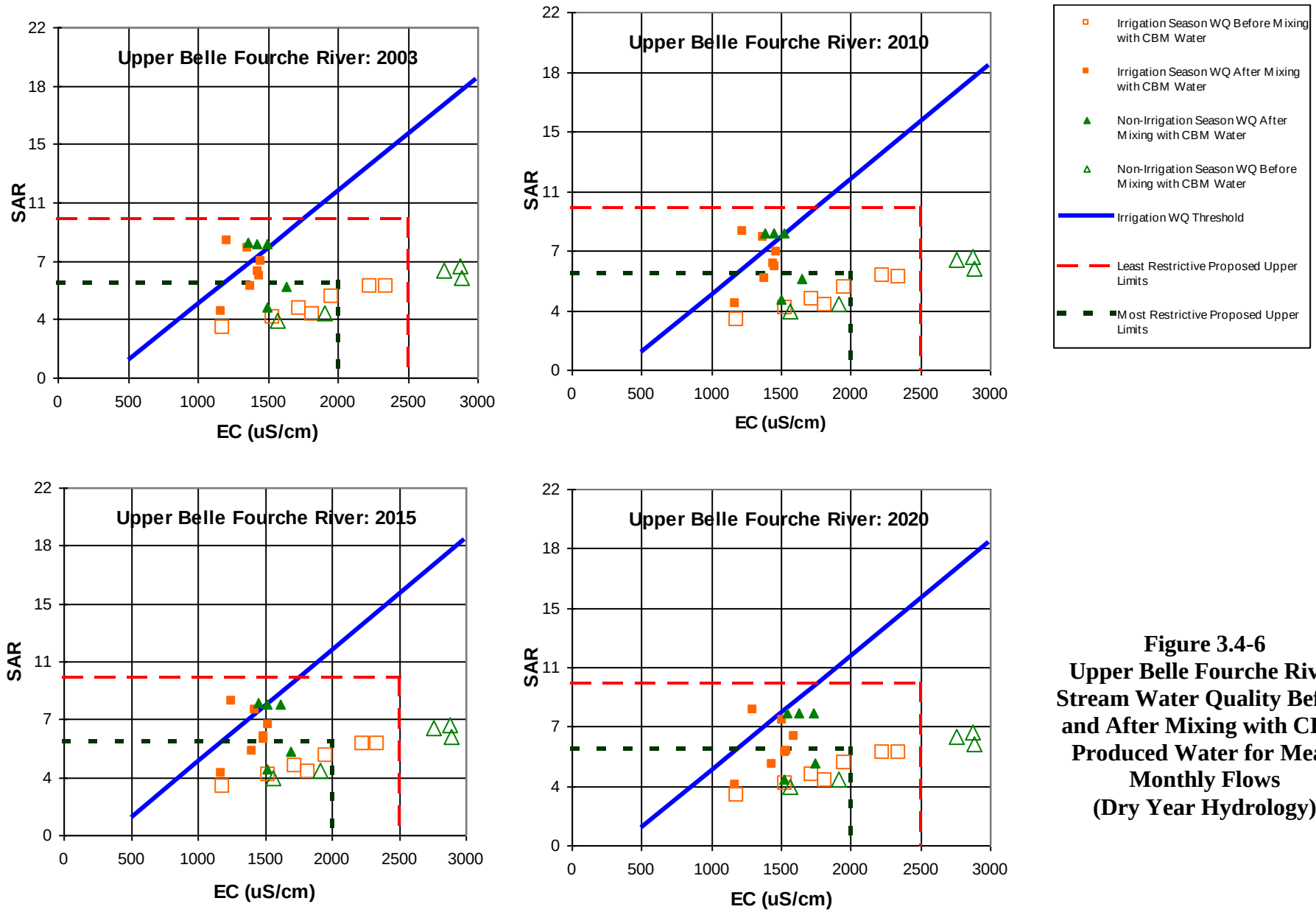


Figure 3.4-6
Upper Belle Fourche River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)

- 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 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 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 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, April, 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 may be 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.

3.4.4 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 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 from October through January for the normal year. The resultant SAR values increase and exceed the MRPL for SAR from 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 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.

3.5 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) and RFD Scenario 2010 when 0.84 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 RFD Scenario 2010, **Table 3.5-1** illustrates the impacts associated with mixing 0.8 cfs (occurring in the month of August) of streamflow in the Upper Cheyenne River with 0.84 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC would decrease, whereas the SAR is similar compared to existing stream water quality conditions (see water quality input data in Appendix B). The combined streamflow of approximately 1.6 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 exceeds 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 (occurring in August) during the dry year is slightly larger than the minimum monthly flow (occurring in December) of the normal year.

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]	---	---	---	1.57	7.50	2144
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.47	7.50	2226
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.37	7.49	2321
Dry Year										
2003	10[1]	2000[1]	10[1]	2500[1]	0.82	4.80	2271	1.62	6.20	1457
2010	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.62	6.20	1457
2015	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.52	6.11	1492
2020	10[1]	2000[1]	10[1]	2500[1]	---	---	---	1.42	6.00	1531

[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.
- 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 November and January through June for the normal year along with October for 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 . The contribution of CBNG production water in RFD Scenario 2010 is the same as the current conditions (2003). Consequently, the results are the same as those presented in Section 3.5.1.

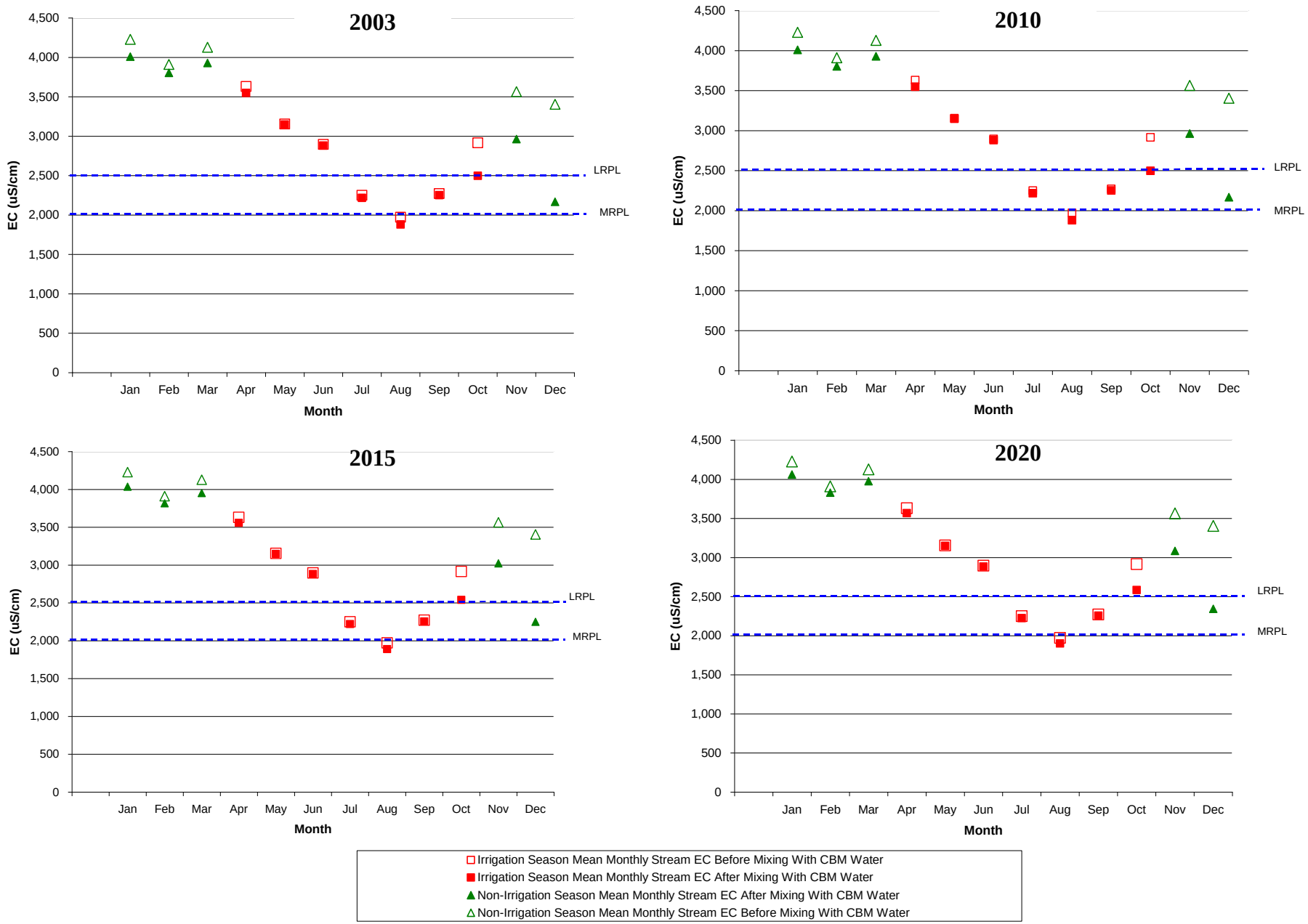


Figure 3.5-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Cheyenne River near Spencer, WY (06386500)

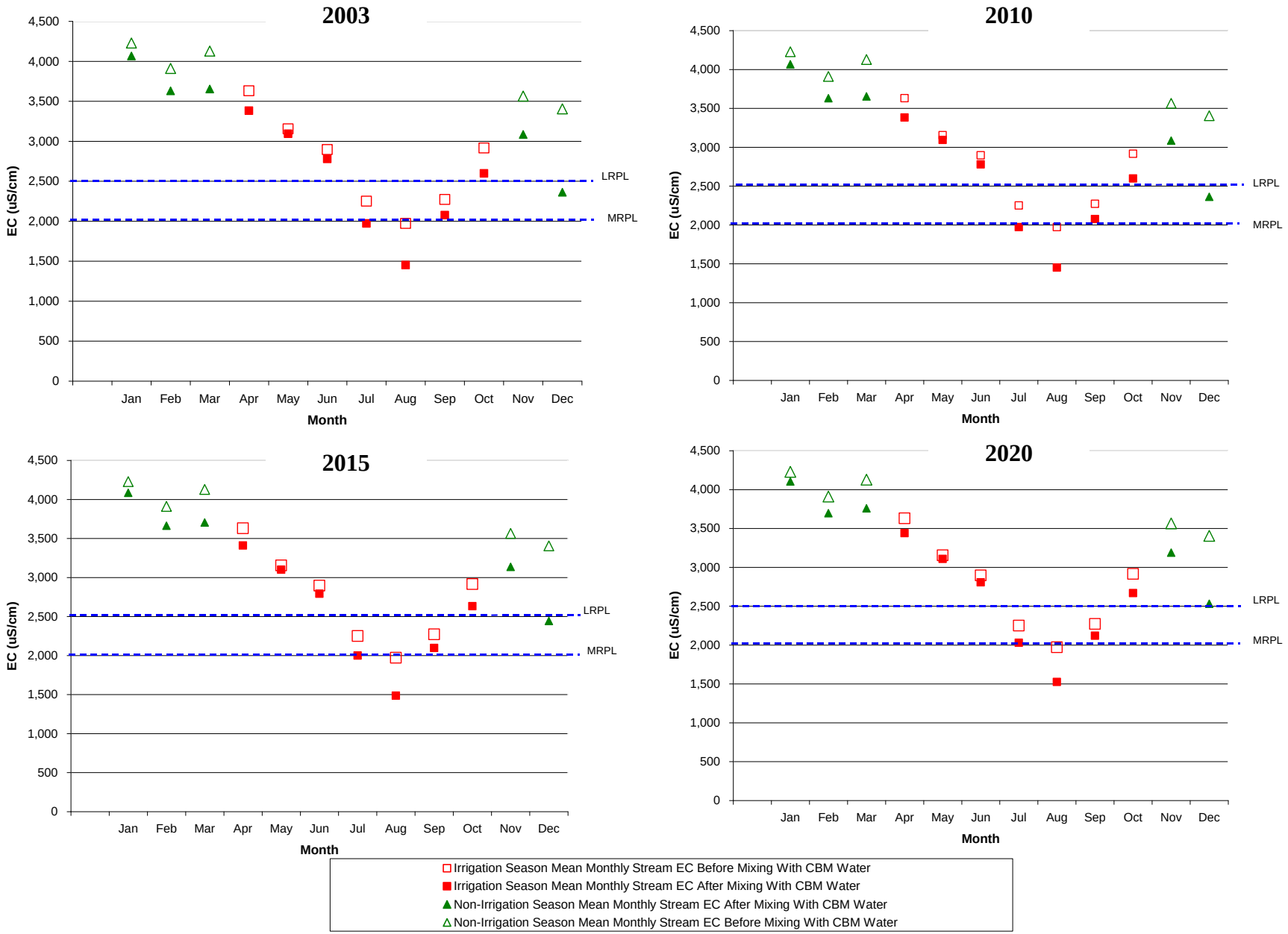


Figure 3.5-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows – Dry Year Hydrology Cheyenne River near Spencer, WY (06386500)

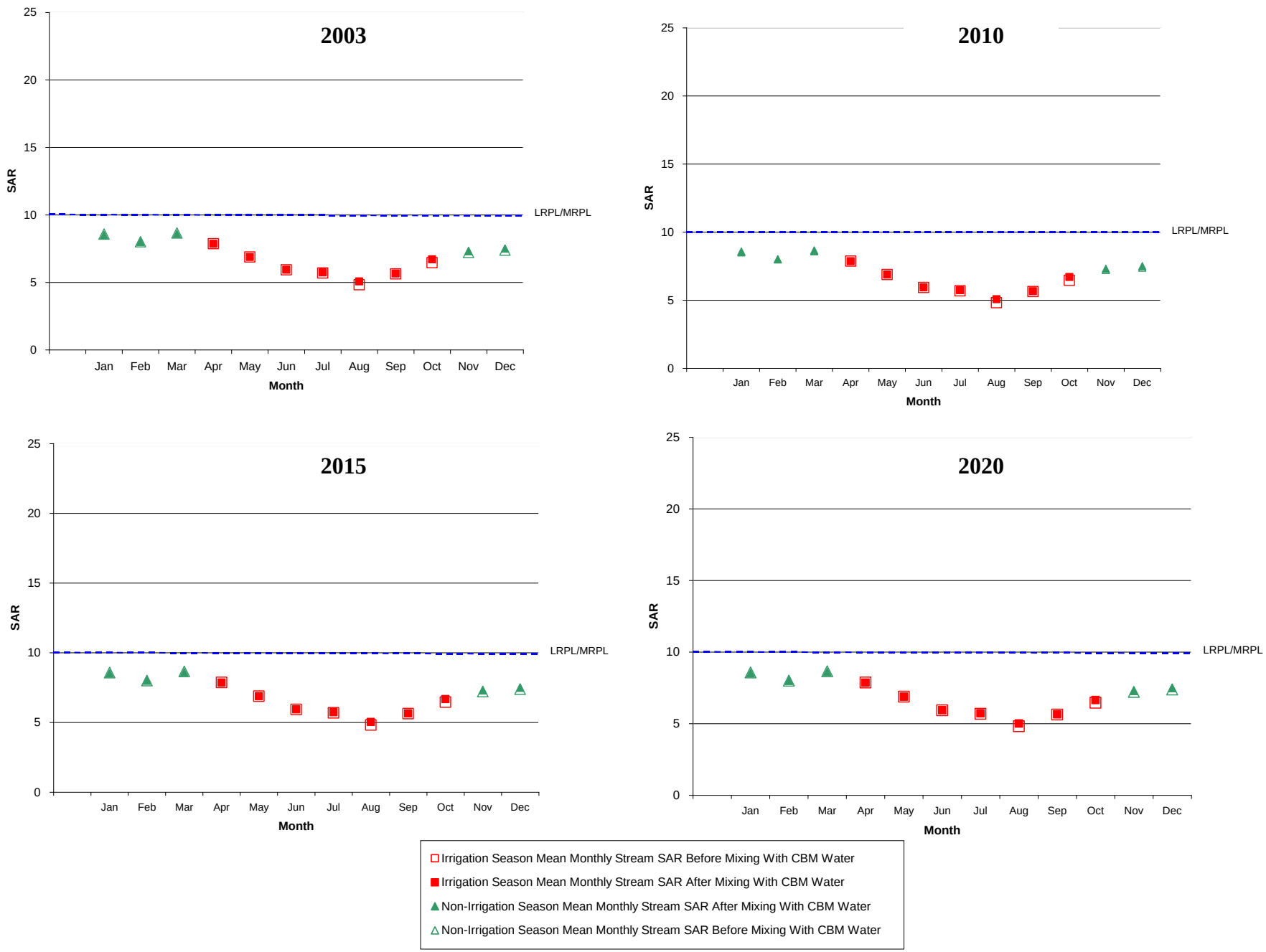


Figure 3.5-3
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Cheyenne River near Spencer, WY (06386500)

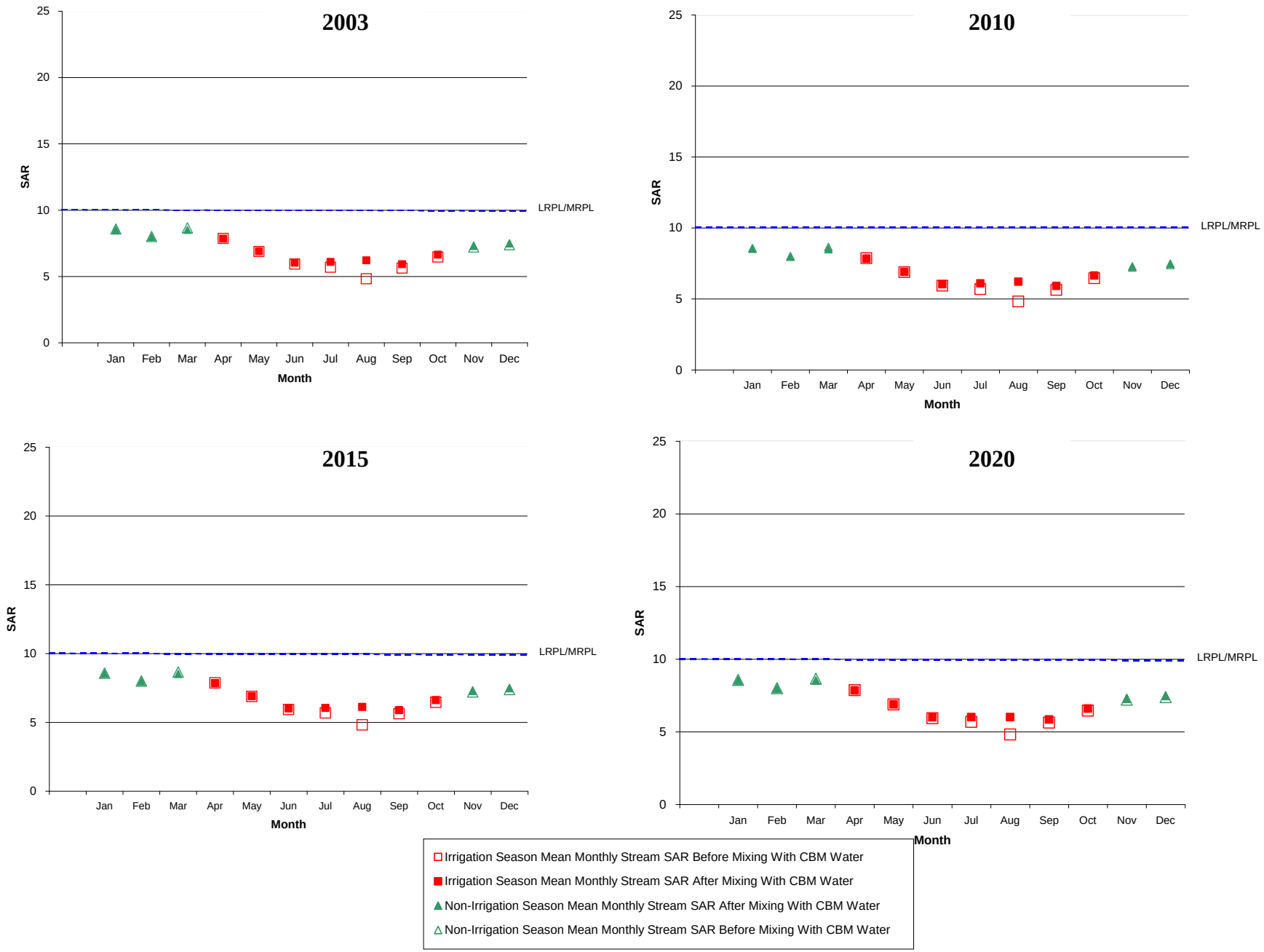


Figure 3.5-4
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Cheyenne River near Spencer, WY (06386500)

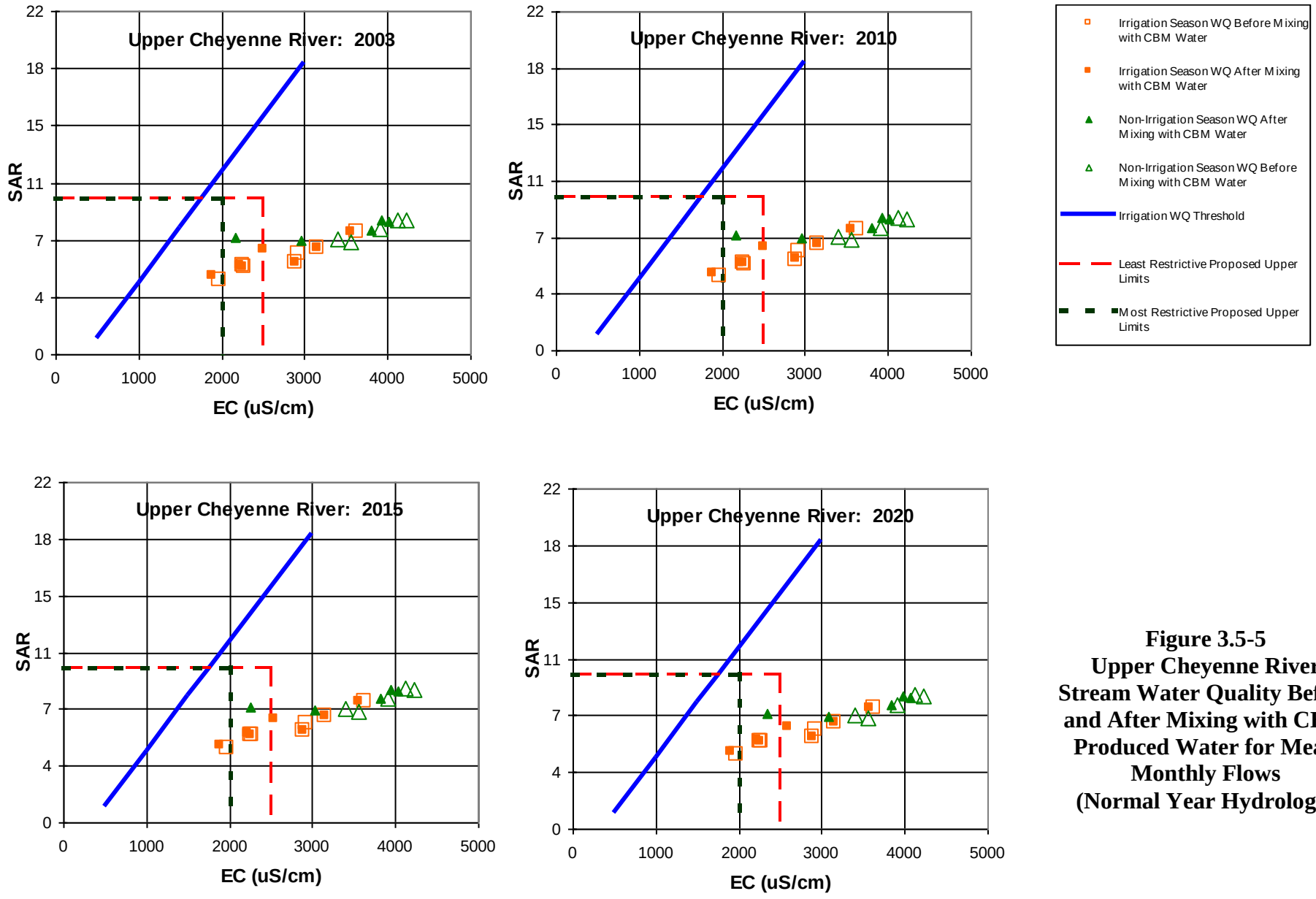


Figure 3.5-5
Upper Cheyenne River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

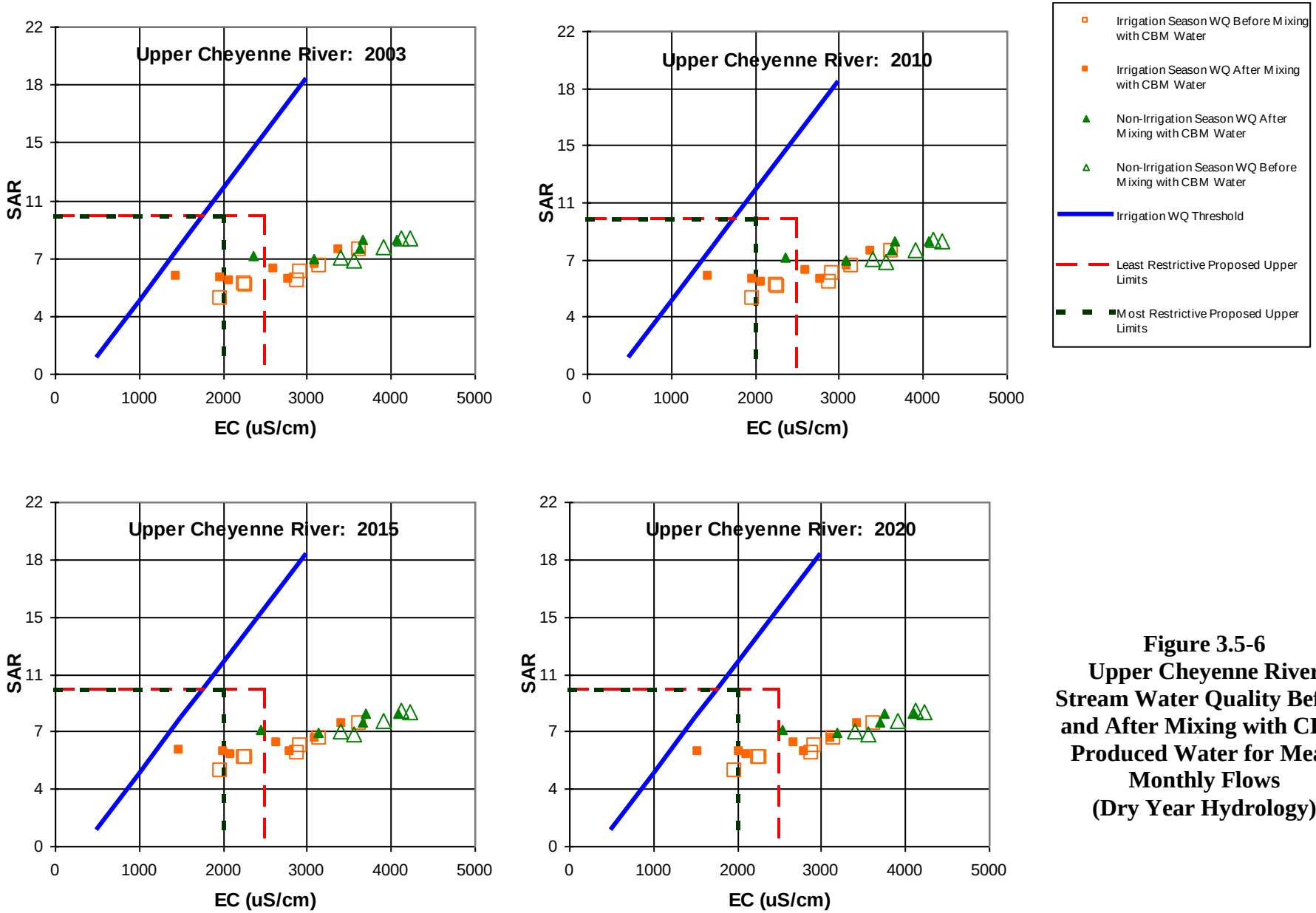


Figure 3.5-6
Upper Cheyenne River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)

- Ayers and Westcot Diagram. The contribution of CBNG production water in RFD Scenario 2010 is the same as the current conditions (2003). Consequently, the results are the same as those presented in Section 3.5.1.

3.5.3 Upper Cheyenne River: RFD Scenario 2015 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 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 . 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 October, November and January through June for both the dry year and normal 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.

3.5.4 Upper Cheyenne River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are 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 . 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 dry year. EC values exceed the LRPL during October, November and January through June for the normal year along with December for 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.

3.6 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) and RFD Scenario 2015 when 9.6 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 RFD Scenario 2015, **Table 3.6-1** illustrates the impacts associated with mixing 38.5 cfs (occurring in the month of September) of streamflow in the Upper Powder River with 9.6 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 48.2 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to exceed 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.

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)]	---	---	---	111.61	7.56	2460
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	113.21	7.77	2456
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	112.61	7.69	2458
Dry Year										
2003	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	38.51	7.83	3400	40.87	8.66	3331
2010	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	46.57	10.36	3190
2015	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	48.17	10.77	3157
2020	5[(1)]	2000[(1)]	9.75[(1)]	2500[(1)]	---	---	---	47.57	10.62	3169

[(1)] Montana DEQ

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.
- 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.

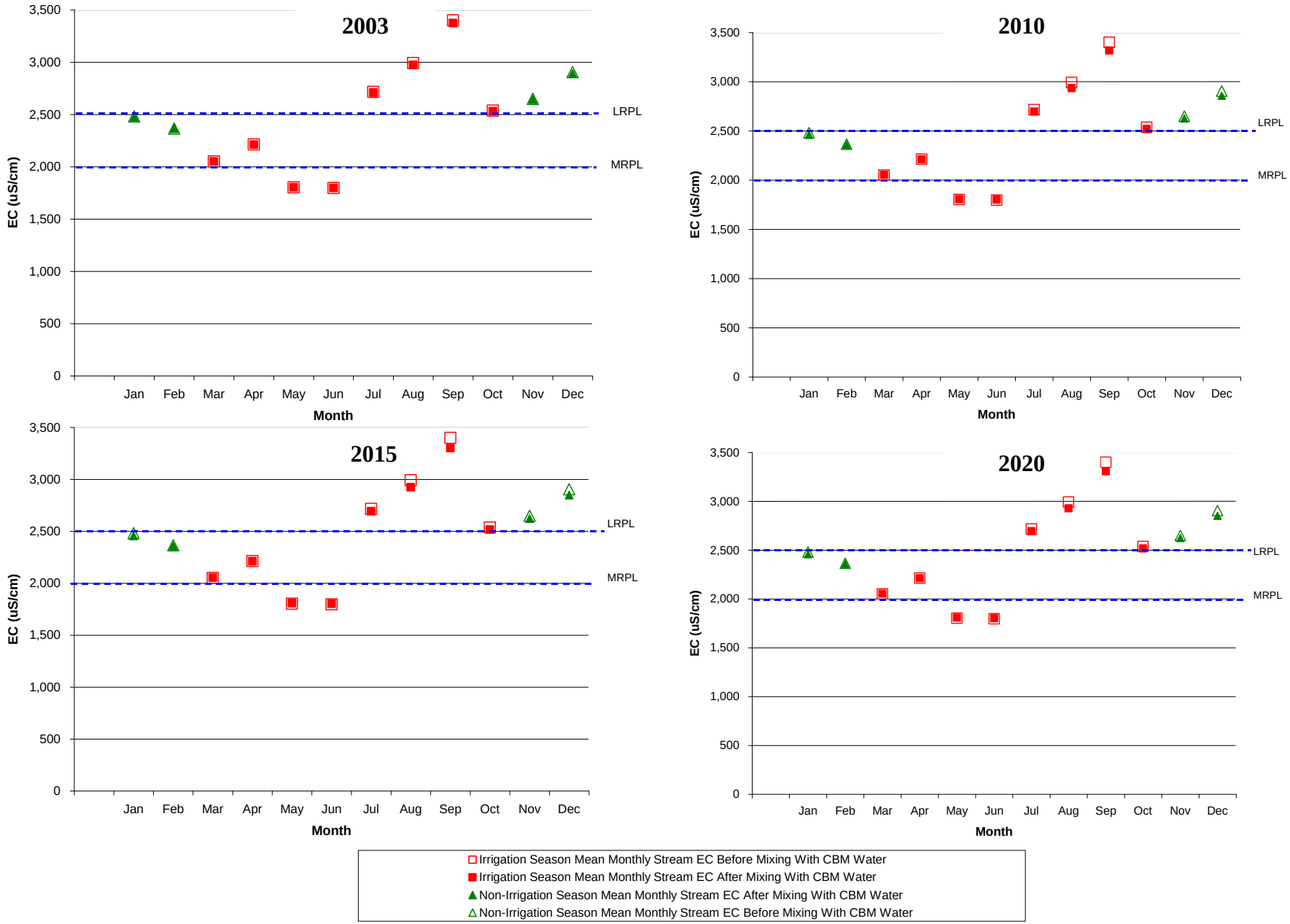


Figure 3.6-1
Stream EC Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Upper Powder River at Arvada, WY (06317000)

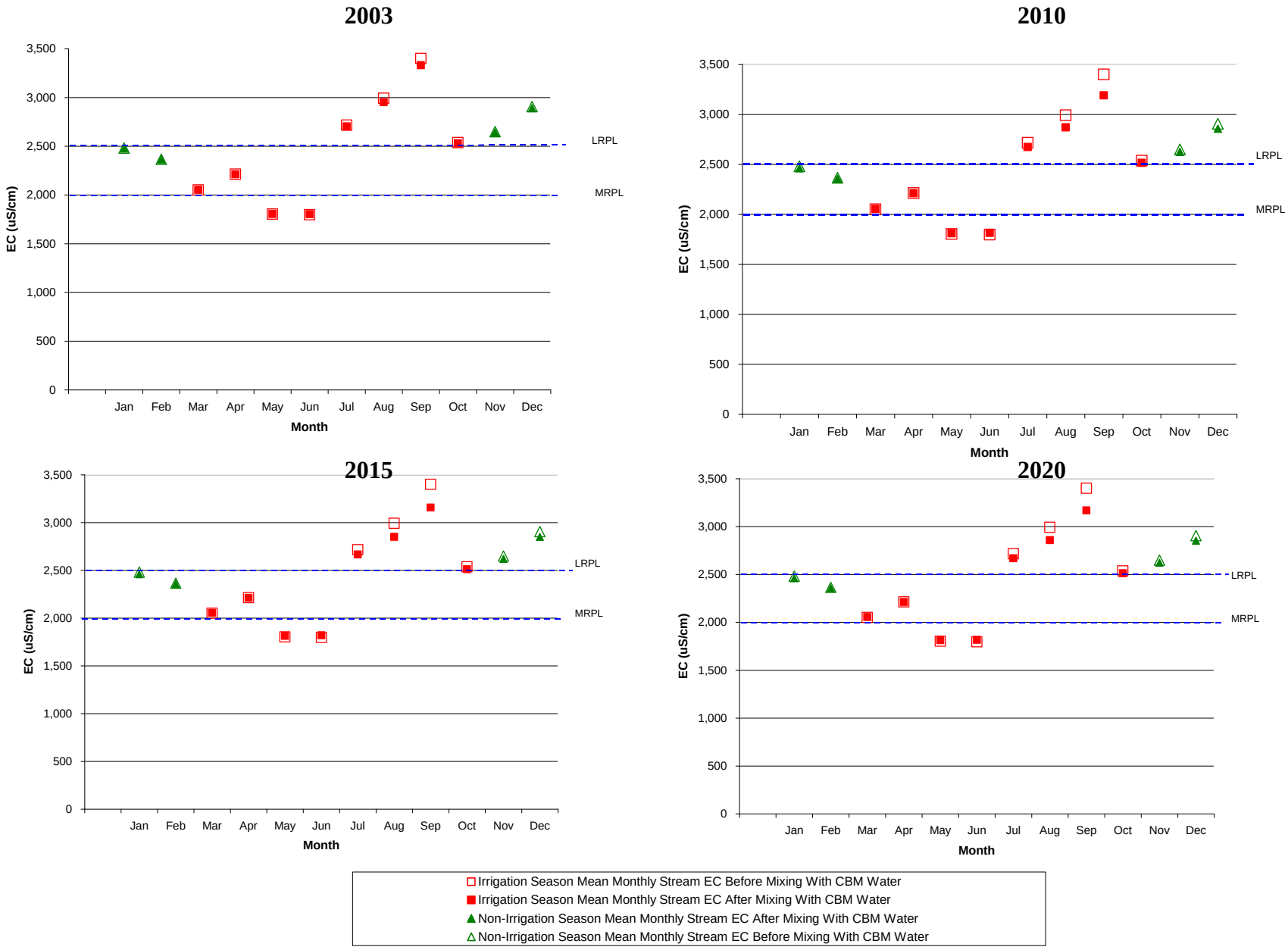


Figure 3.6-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows – Dry Year Hydrology Upper Powder River at Arvada, WY (06317000)

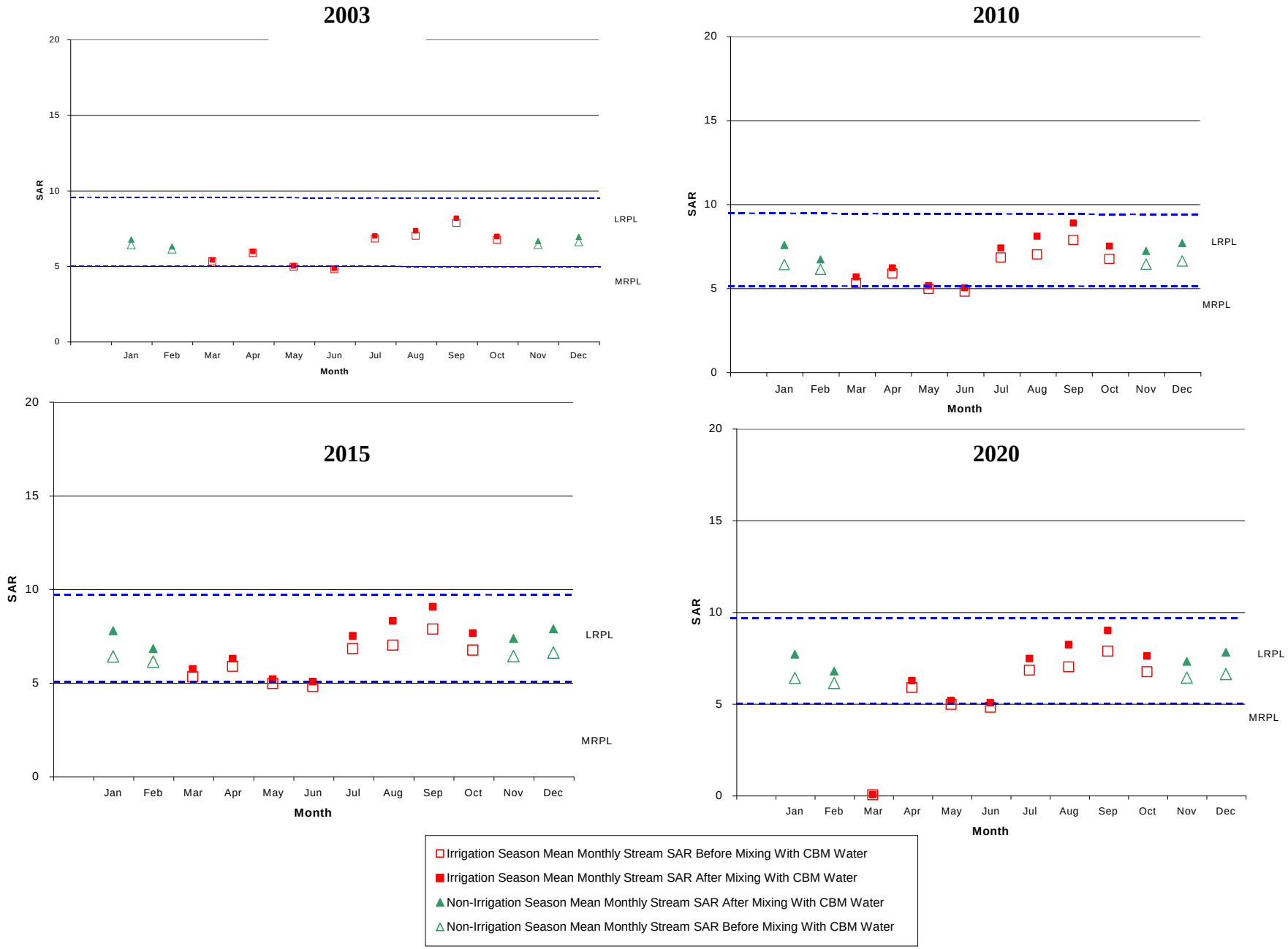


Figure 3.6-3
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Normal Year Hydrology
Upper Powder River at Arvada, WY (06317000)

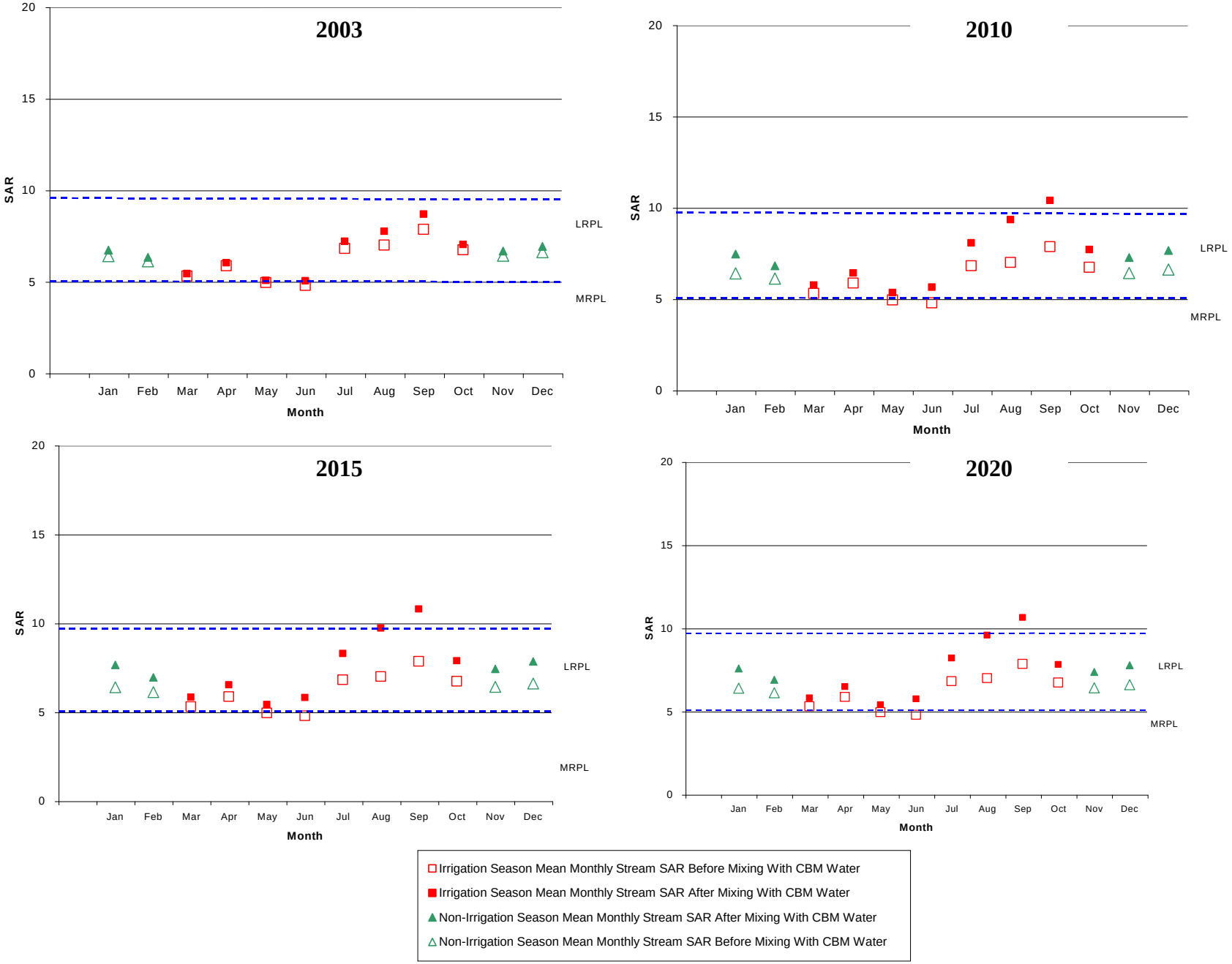


Figure 3.6-4
Stream SAR Before and After Mixing with CBM Produced Water
for Mean Monthly Flows – Dry Year Hydrology
Upper Powder River at Arvada, WY (06317000)

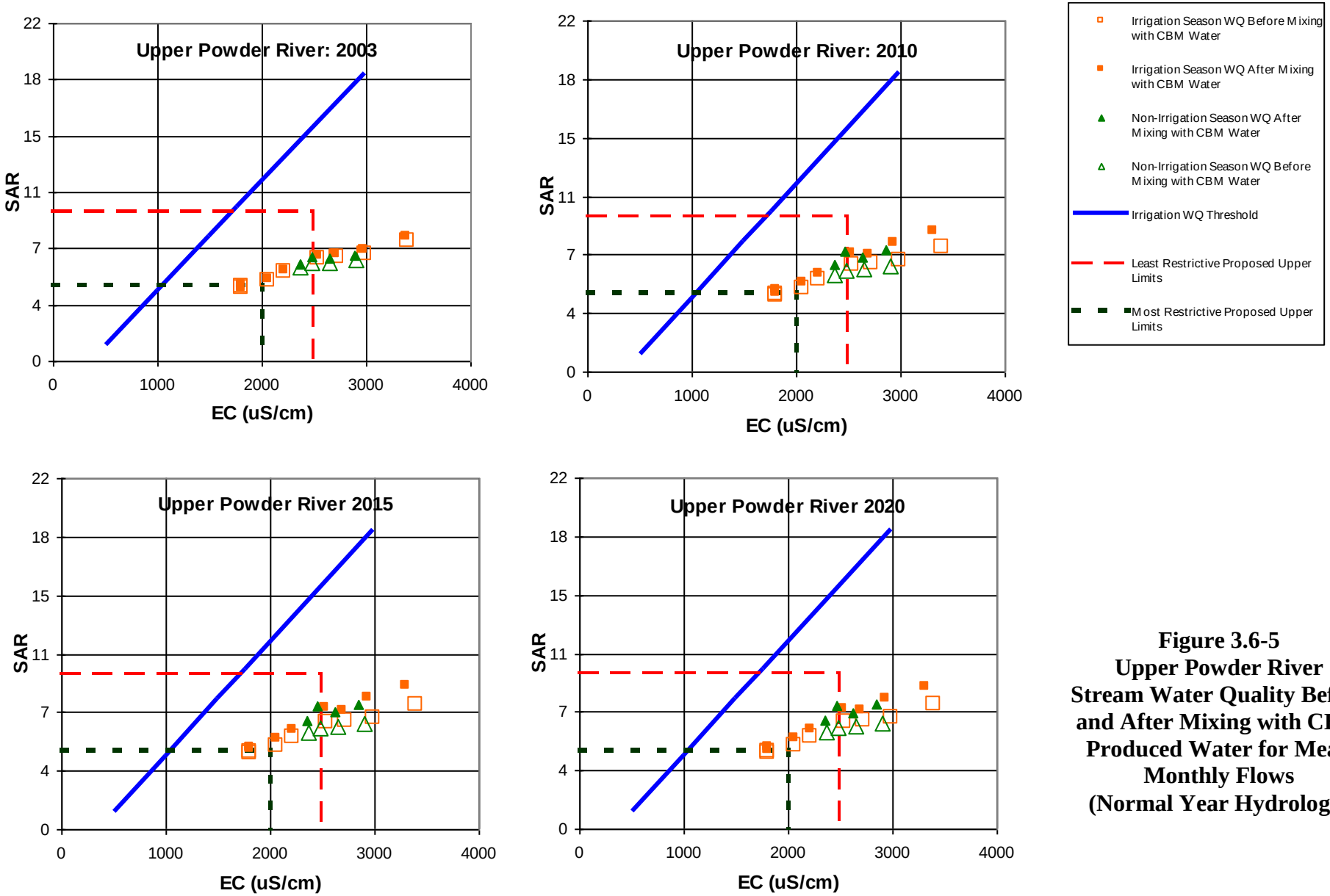


Figure 3.6-5
Upper Powder River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

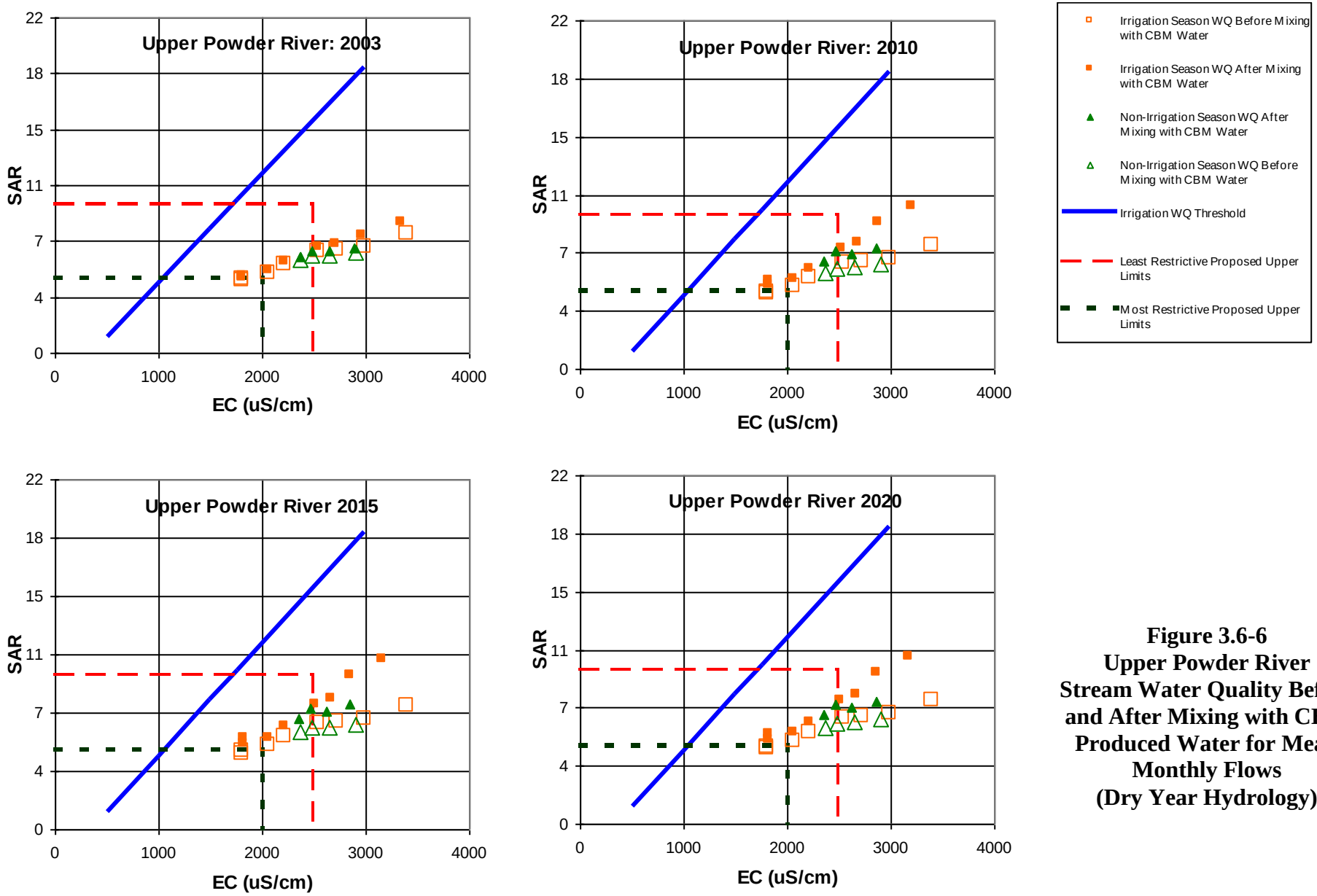


Figure 3.6-6
Upper Powder River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)

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 for the dry year, and all months with the exception of June for the normal year. SAR values meet the LRPL with the exception of the month of September for the dry-year condition.
- 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.

3.6.3 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 for the dry year, and all months with the exception of June for the normal year. SAR values meet the LRPL with the exception of the month of September for the dry-year condition.

- 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**. 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 3.6.1.
- 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 for both the dry and normal year. SAR values meet the LRPL with the exception of the month of September for the dry-year condition.
- 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.

3.7 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, the maximum difference in the predicted values for EC was determined to be 0.99%. The maximum difference in predicted values for SAR was determined to be approximately 9.1%.
- In the Little Powder River, the maximum difference in the predicted values for EC was determined to be 0.87%. The maximum difference in predicted values for SAR was determined to be approximately 4.9%.
- 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 0.12%. The maximum difference in predicted values for SAR was determined to be approximately 1.8%.
- In the Upper Belle Fourche River, the maximum difference in the predicted values for EC was determined to be 0.57%. The maximum difference in predicted values for SAR was determined to be approximately 4.2%.
- In Antelope Creek, the maximum difference in the predicted values for EC was determined to be 2.1%. The maximum difference in predicted values for SAR was determined to be approximately 10.6%.

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.

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. 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 eleven 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.

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 (Except Oct)	Suitable (Except Oct)
MRPL	Exceeds EC (Sept-Feb)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Slightly Increased
Irrigation(1)	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	Exceeds EC (Jan, Oct, Nov) Exceeds SAR (Aug-Jan)	Exceeds EC (Jan, Oct, Nov) Exceeds SAR (Aug-Jan)	Exceeds EC (Jan, Oct, Nov) Exceeds SAR (Aug-Jan)	Exceeds EC (Oct-Jan) Exceeds SAR (Sept-Jan)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	OK
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	≅ CBNG Discharge	Same	Same	Same	Same
Irrigation(1)	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)	Exceeds EC (Except Aug)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Jan-June, Nov)	Exceeds EC (Jan-June, Nov)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Jan-June, Oct, Nov)
Upper Powder River					
EC	≅ CBNG Discharge	Slight Decrease	Slight Decrease	Slight Decrease	Slight Decrease
SAR	< CBNG Discharge	Slight Increase	Slight Increase	Slight Increase	Slight Increase
Irrigation(1)	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (July-Apr) Exceeds SAR (Exc. June)	Exceeds EC (July-Apr) Exceeds SAR (Exc. June)	Exceeds EC (July-Apr) Exceeds SAR (All Year)
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)
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, May) Exceeds SAR (Except Mar)	Exceeds EC (Except Mar, May) Exceeds SAR (Except Mar)
LRPL	Exceeds EC (Aug, Sept, Nov-Jan)	Exceeds EC (Jan, Aug)	Exceeds EC (Jan)	Exceeds EC (Jan)	Exceeds EC (Jan, Aug)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Slight Increase	Slight Increase	Slight Increase
Irrigation(1)	Suitable	Same (No CBNG Discharge)	Suitable (Except Sept)	Suitable (Except Sept)	Suitable (Except Sept)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	Exceeds EC (Feb, Nov)	Exceeds EC (Feb)	Exceeds EC (Feb)
LRPL	OK	OK	OK	OK	OK

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)	Unsuitable (Except July, Sep)	Unsuitable (Except July, Sep)	Unsuitable (Except July, Sep)
MRPL	Exceeds EC (Sept-Feb)	OK	OK	OK	OK
LRPL	OK	OK	OK	OK	OK
Upper Belle Fourche River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Slightly Increased	Slightly Increased	Slightly Increased	Slightly Increased
Irrigation (1)	Unsuitable (Aug-Oct)	Unsuitable (Aug-Oct)	Unsuitable (Aug-Oct)	Unsuitable (Sep-Oct)	Unsuitable (Oct)
MRPL	Exceeds EC (Sept-Jan) Exceeds SAR (Nov-Jan)	OK Exceeds SAR (Exc. Feb, Mar, May, July)	OK Exceeds SAR (Exc. Feb, Mar, May, July)	OK Exceeds SAR (Exc. Feb, Mar-May, July)	OK Exceeds SAR (Aug-Jan)
LRPL	Exceeds EC (Nov-Jan)	OK	OK	OK	OK
Upper Cheyenne River					
EC	> CBNG Discharge	Reduced	Reduced	Reduced	Reduced
SAR	≅ CBNG Discharge	Slight Increase (July-Sept)	Slight Increase (July-Sept)	Slight Increase (July-Sept)	Slight Increase (July-Sept)
Irrigation (1)	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (Except Aug)	Exceeds EC (Except July, Aug)	Exceeds EC (Except July, Aug)	Exceeds EC (Except July, Aug)	Exceeds EC (Except Aug)
LRPL	Exceeds EC (Oct-June)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Jan-June, Oct, Nov)	Exceeds EC (Oct-June)
Upper Powder River					
EC	≅ CBNG Discharge	Same	Slightly Decreases (Aug, Sept)	Slightly Decreases (Aug, Sept)	Slightly Decreases (Aug, Sept)
SAR	< CBNG Discharge	Slight Increase	Increased	Increased	Increased
Irrigation (1)	Suitable	Suitable	Suitable	Suitable	Suitable
MRPL	Exceeds EC (July-Apr) Exceeds SAR (July-Apr)	Exceeds EC (July-Apr) Exceeds SAR	Exceeds EC (July-Apr) Exceeds SAR	Exceeds EC (July-Apr) Exceeds SAR	Exceeds EC (July-Apr) Exceeds SAR
LRPL	Exceeds EC (July-Dec)	Exceeds EC (July-Dec)	Exceeds EC (July-Dec) Exceeds SAR (Sept)	Exceeds EC (July-Dec) Exceeds SAR (Sept)	Exceeds EC (July-Dec) Exceeds SAR (Sept)
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 (Except Sept-Oct)	Suitable (Except Sept-Oct)
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 (Feb, Apr, June, Aug) Exceeds SAR	Exceeds EC (Feb, Apr, June, Aug) Exceeds SAR
LRPL	Exceeds EC (Aug, Sep, Nov-Jan)	Exceeds SAR (Sept)	Exceeds SAR (Sept-Jan)	Exceeds SAR (Sept-Jan)	Exceeds SAR (Sept-Nov)
Dry Fork Cheyenne River					
EC	> CBNG Discharge	Same (No CBNG Discharge)	Reduced	Reduced	Reduced
SAR	< CBNG Discharge	Same (No CBNG Discharge)	Increase	Increase	Increase
Irrigation (1)	Suitable	Same (No CBNG Discharge)	Unsuitable (June, Aug-Sep)	Unsuitable (June, Aug-Sep)	Unsuitable (June, Aug-Sep)
MRPL	Exceeds EC (June, Sept-Feb)	Same (No CBNG Discharge)	OK	OK	OK
LRPL	OK	OK	OK	OK	OK

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

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 year while meeting the LRPL.
- The surface water in both Antelope Creek and the Dry Fork Cheyenne River 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 SAR in the CBNG well production water.
- The surface water in the Little Powder River reflects a reduction in EC but continues to exceed the MRPL for four months of the year while meeting the LRPL throughout the year. The SAR values reflect an increase and exceed the MRPL throughout the year, and exceed the LRPL from one (2003) to five (2010, 2015) months 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 six 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, Dry Fork Cheyenne River, 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. It should be noted that the unsuitable nature of the water quality in the Dry Fork Cheyenne River is largely attributable to the lack of surface water flow in the river; consequently 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 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

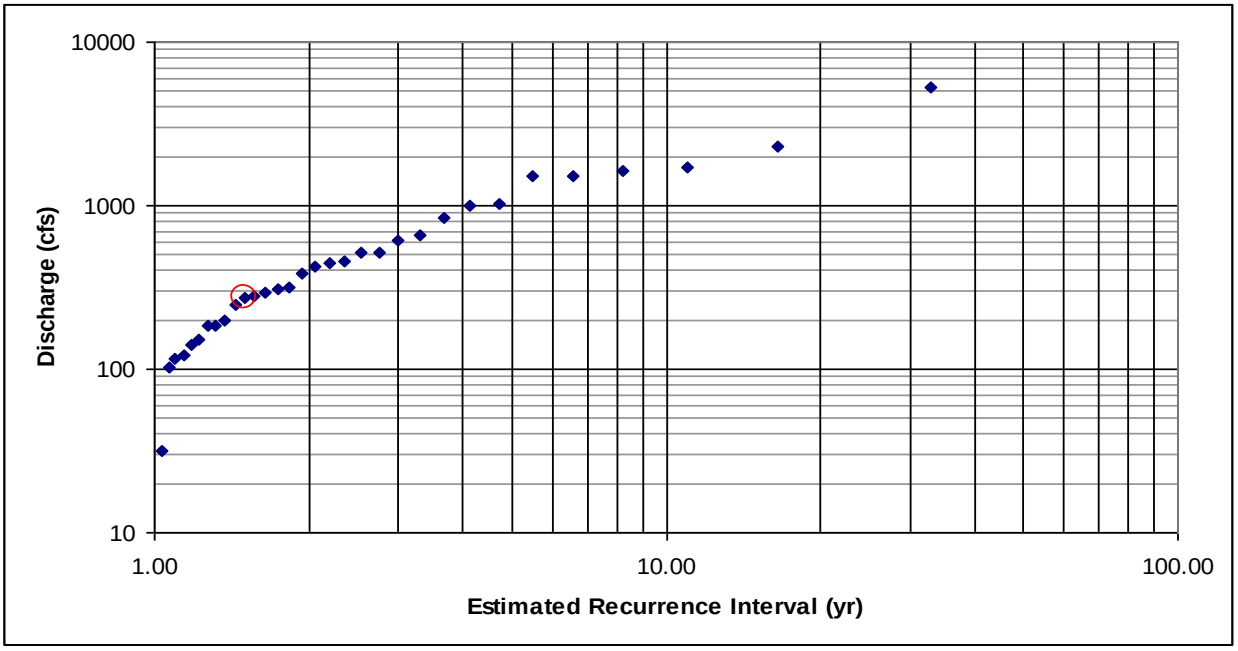


Figure 4.2-1 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Little Powder River.

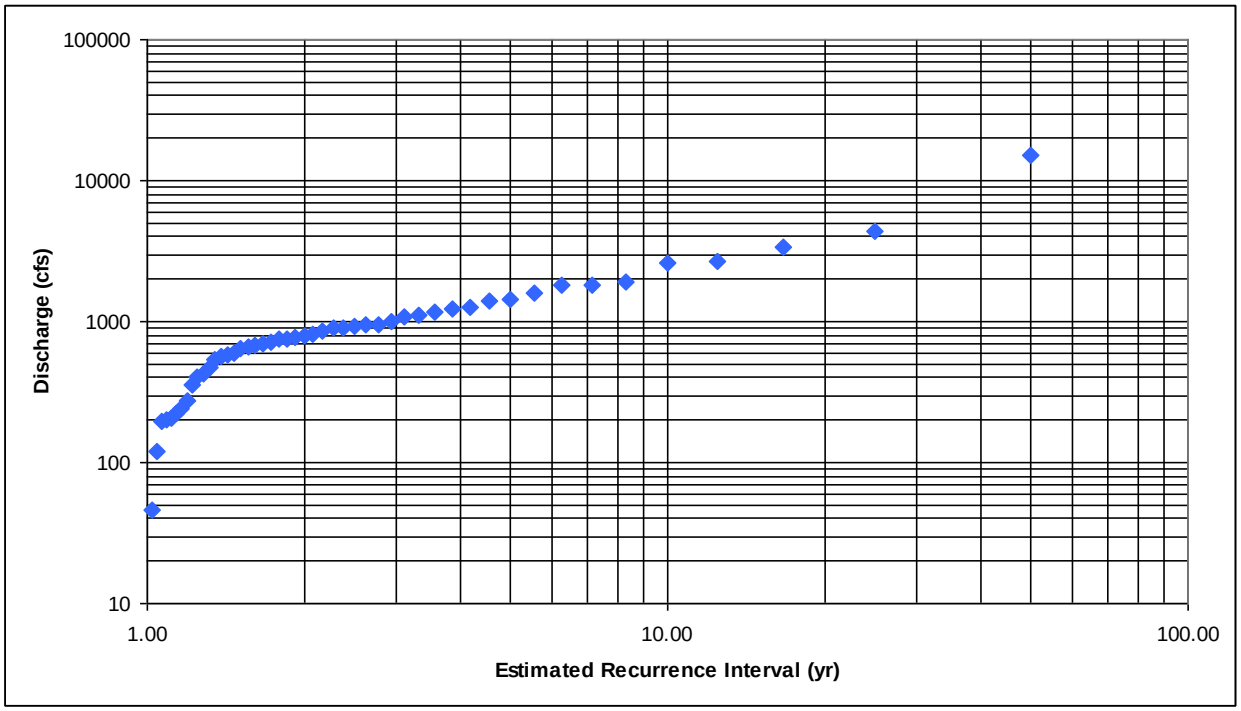


Figure 4.2-2 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Belle Fourche River.

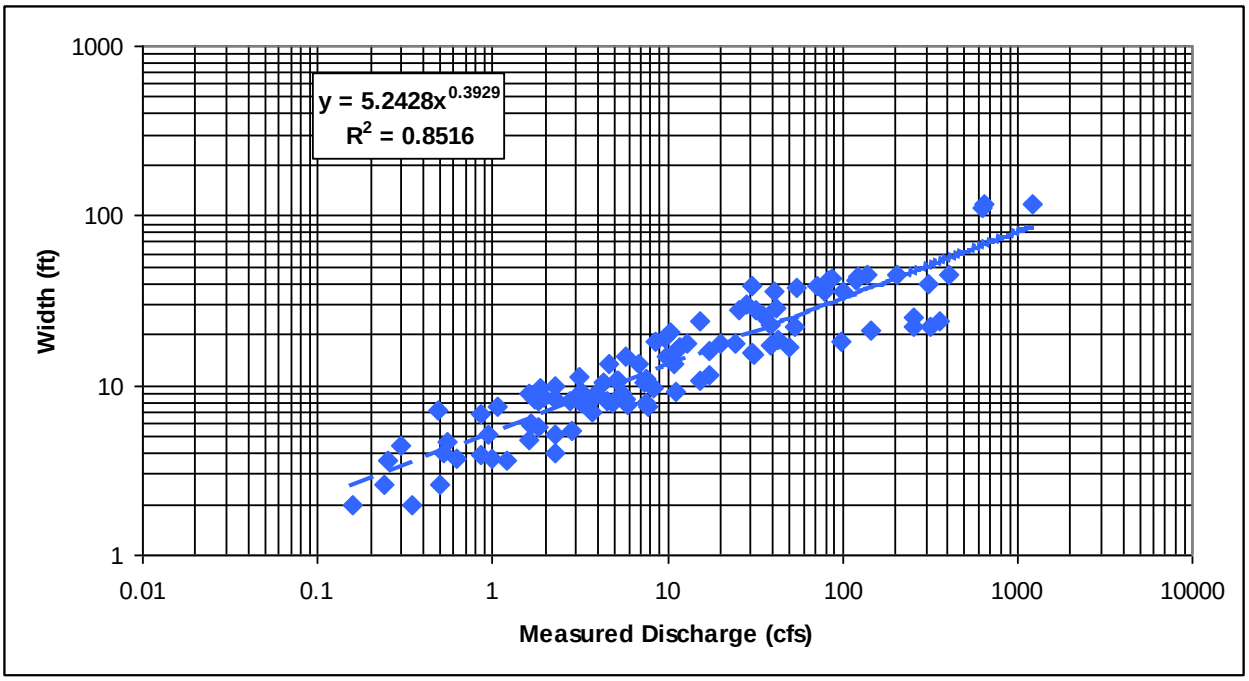


Figure 4.2-3 The Relationship Between Measured Discharge and Channel Width for the Little Powder River.

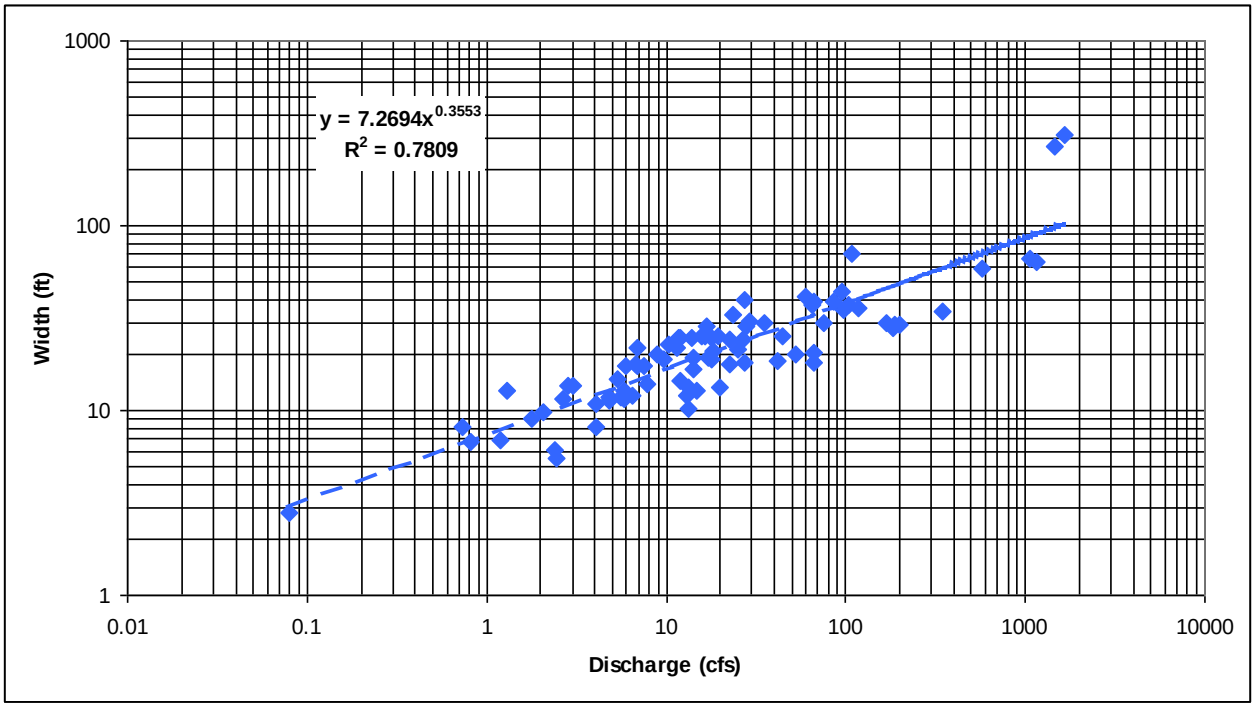


Figure 4.2-4 The Relationship Between Measured Discharge and Channel Width for the Belle Fourche River.

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.

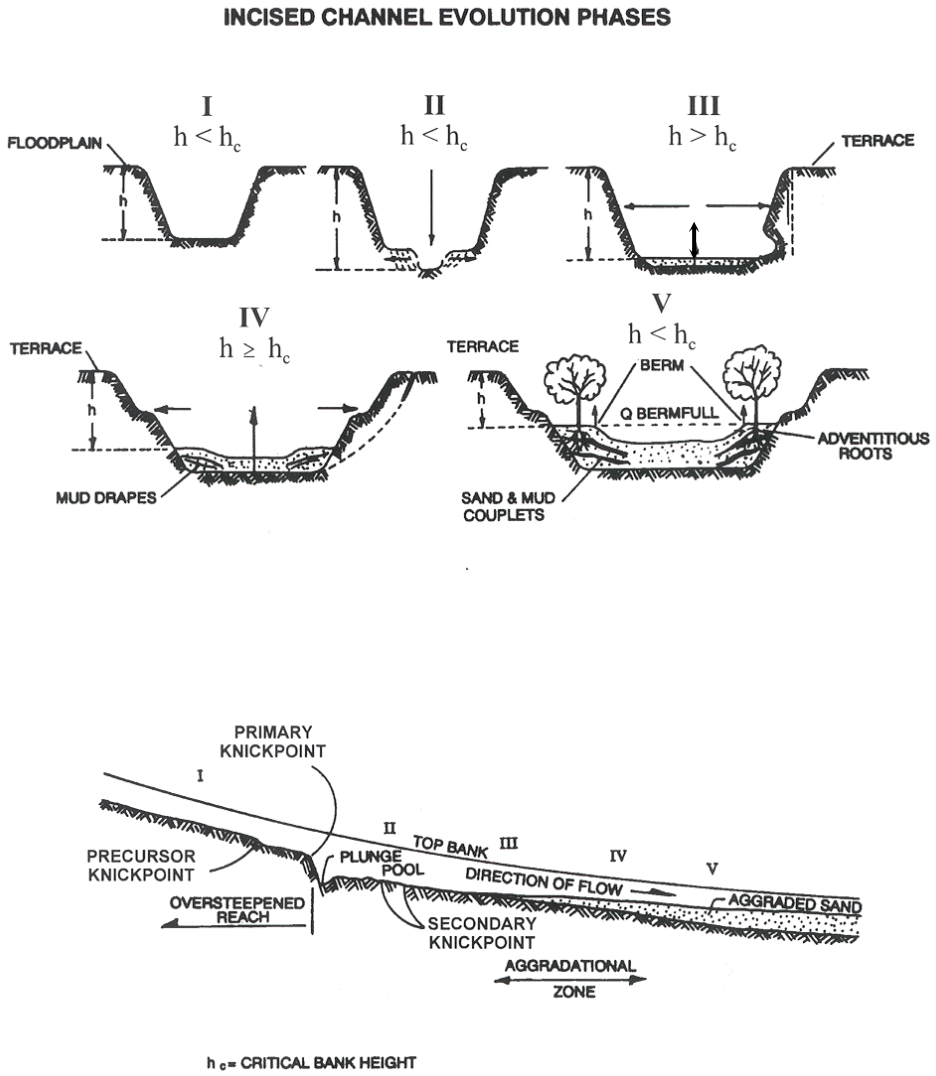


Figure 4.3-1 CEM Channel Types

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.

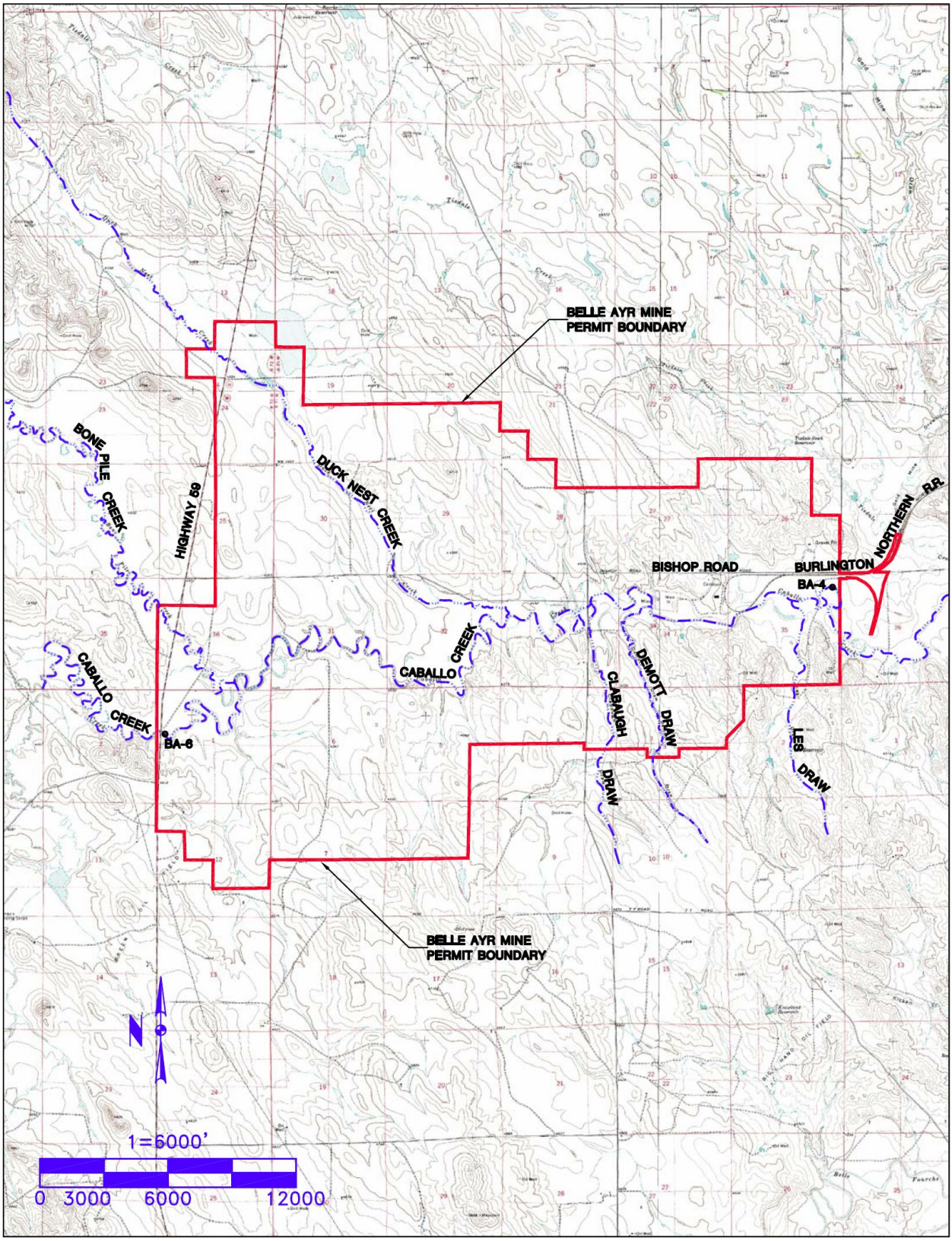


Figure 4.4-1 Vicinity Map

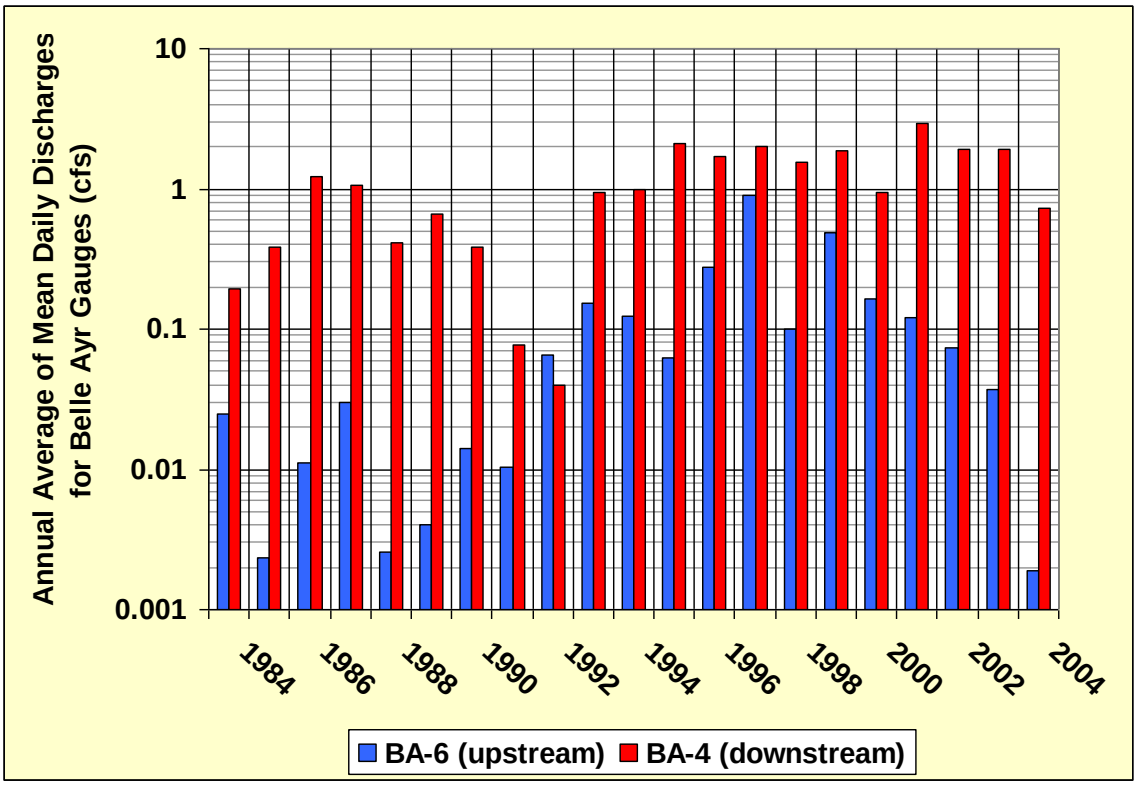


Figure 4.4-2 Hydrologic Data for Caballo Creek (1984-2004)

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:

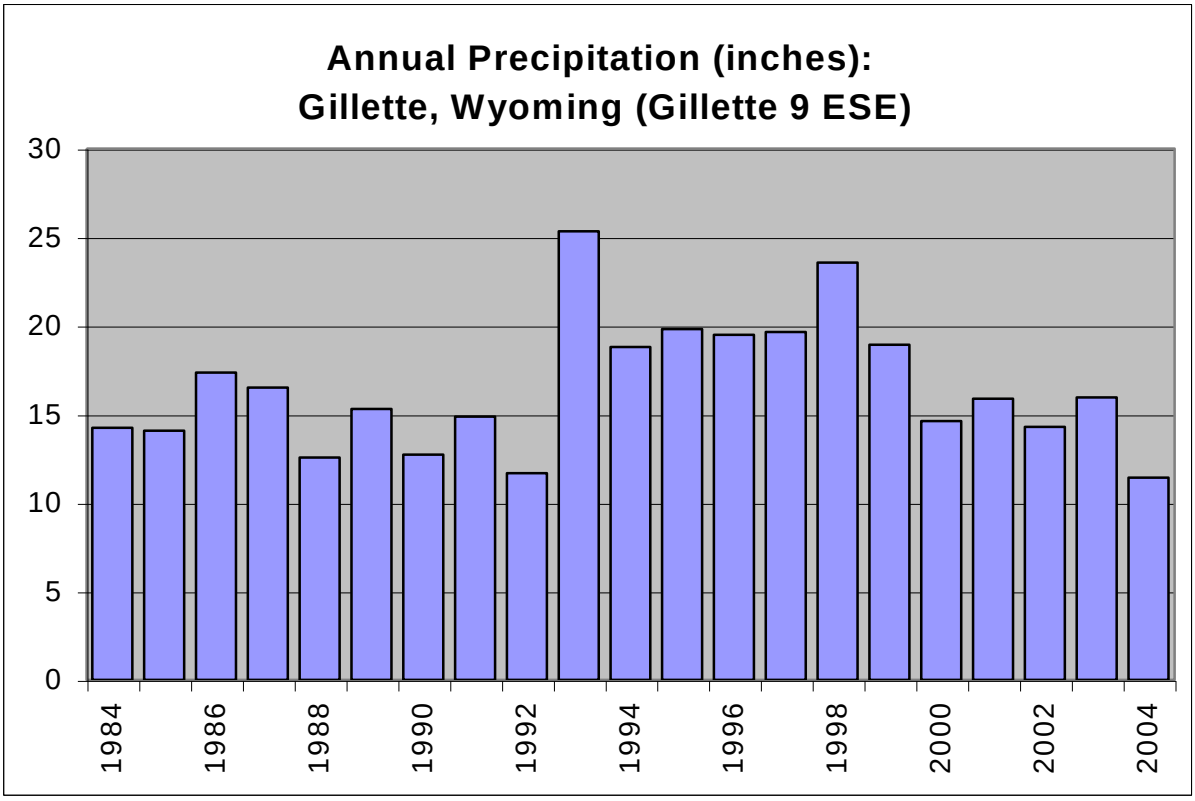


Figure 4.4-3 Average Annual Precipitation Data (1984-2004)

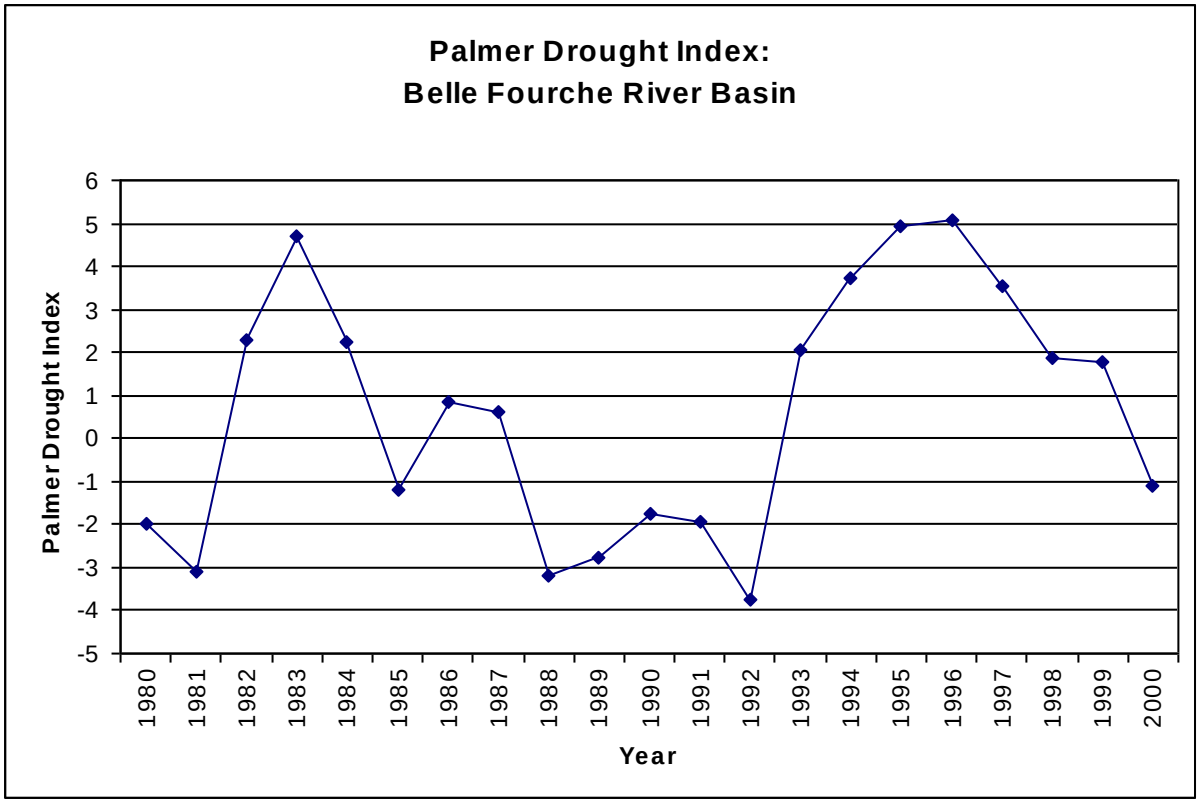


Figure 4.4-4 Palmer Drought Index Data (1980-2000)

- 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

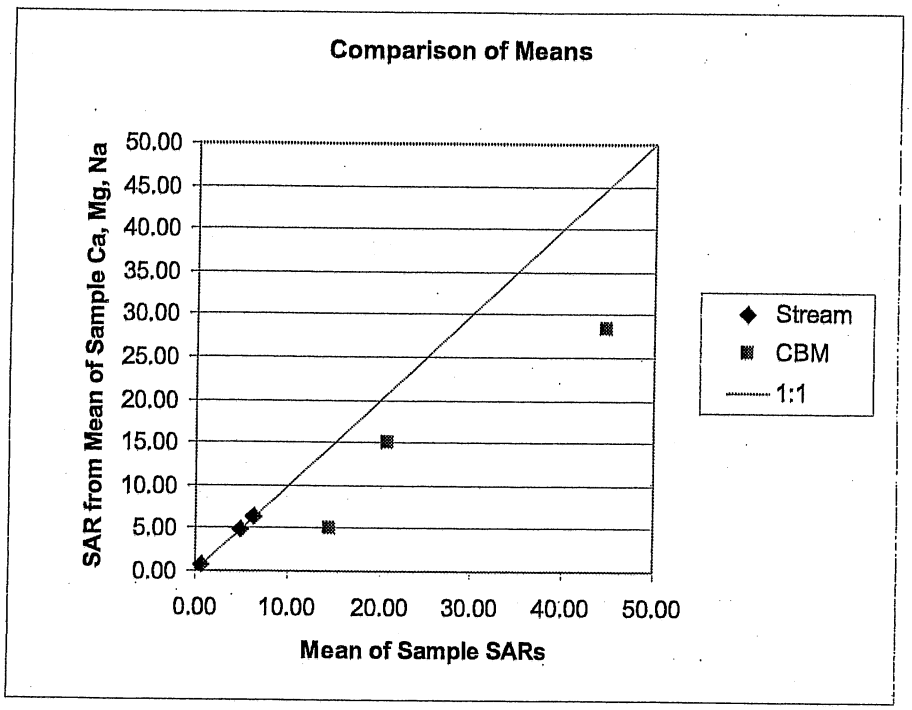


Figure A-1. Comparison of mean values of individual sample SARs and SARs estimated from mean values of sample Ca, Mg, and Na concentrations.

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

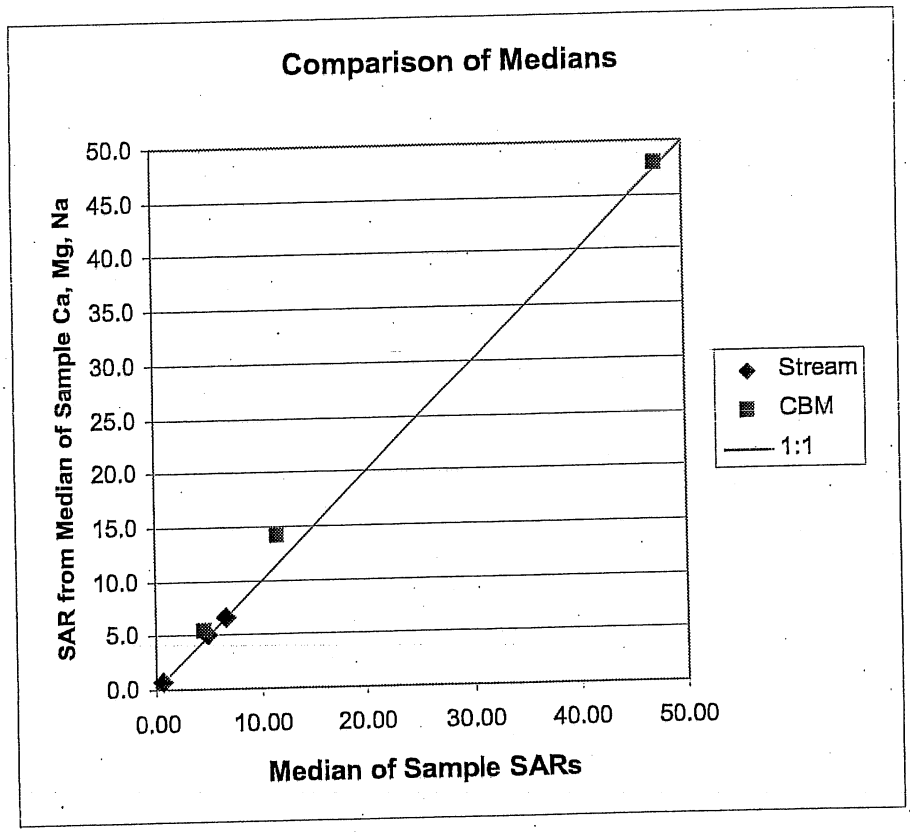


Figure A-2. Comparison of median values of sample SARs and SARs calculated from median values of sample Ca, Mg, and Na concentrations.

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

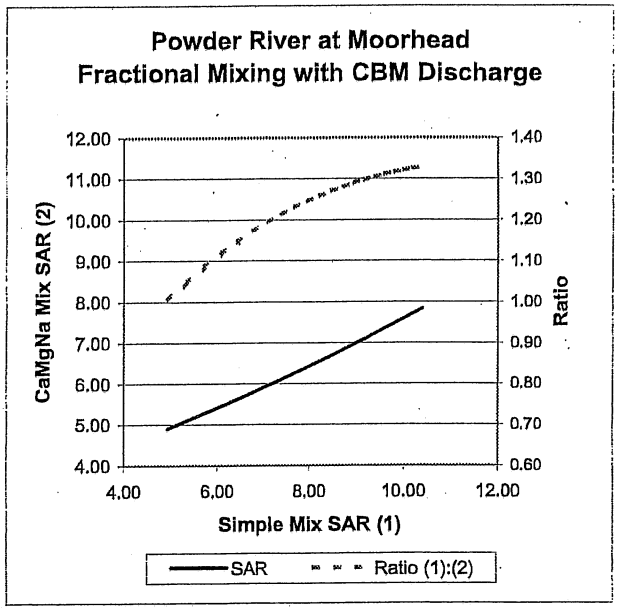


Figure A-3. Fractional mixing of stream water and CBM discharge. Comparison of SAR values calculated using (1) simple mixing as in equation [4] and (2) flow-weighted mixing of Ca, Mg, and Na as in equation [3].

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:

U.S. Dept. of Agriculture (USDA), 1954, *Agriculture Handbook 60.* www.ussl.ars.usda.gov/hb60/hb60requ.htm

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

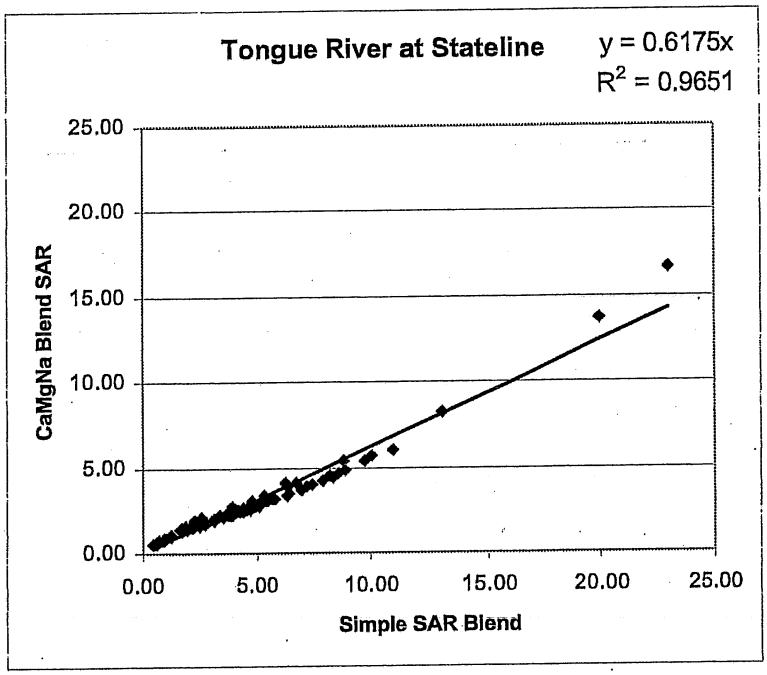


Figure 4. Tongue River at Stateline (USGS data) mixed with CX Ranch CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].

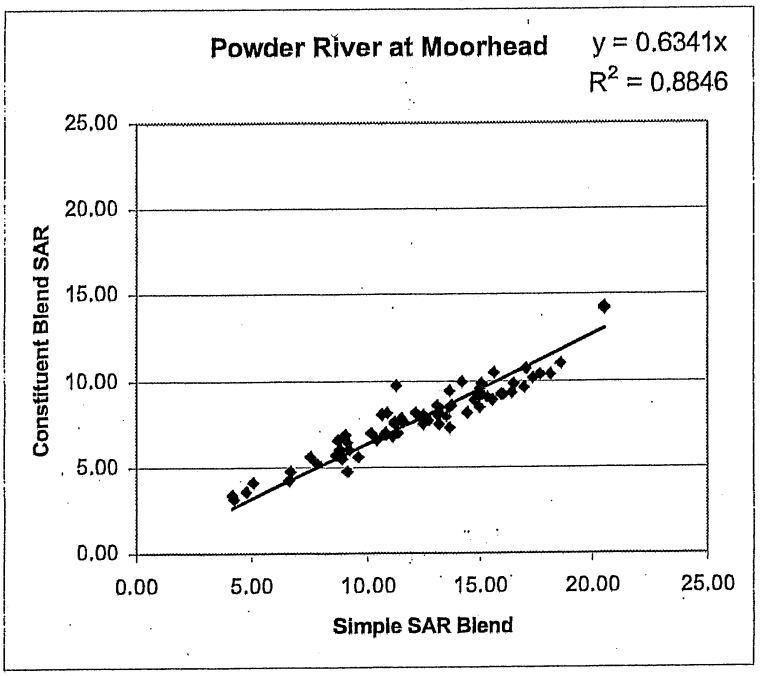


Figure 5. **Powder River at Moorhead (USGS data) mixed with Powder River Basin CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].**

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)													
		Alternative											
		2003			2010			2015			2020		
Month	Receiving Drainage Streamflow (cfs)	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)													
		Alternative											
		2003			2010			2015			2020		
Month	Receiving Drainage Streamflow (cfs)	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

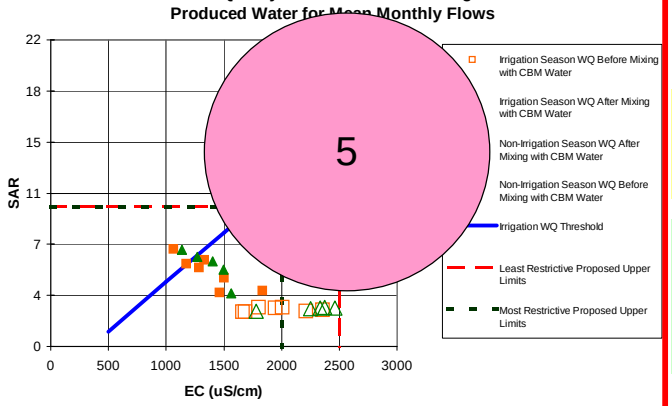
SPREADSHEET MODEL RESULTS

APPENDIX C-1

NORMAL YEAR CONDITIONS

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin



5

		Monthly Mean CBM Flow (cfs)	Monthly Mean StreamFlow (cfs)	CBNG Discharge 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 (--)	
				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

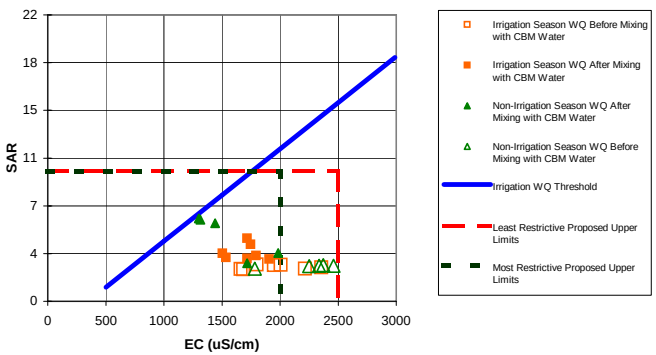
Section 5: This section presents the summary graph illustrating irrigation suitability and the water quality data relative to the "limits". The graph references "Limits" data from Section 1 and pertinent water quality data from section 4.

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

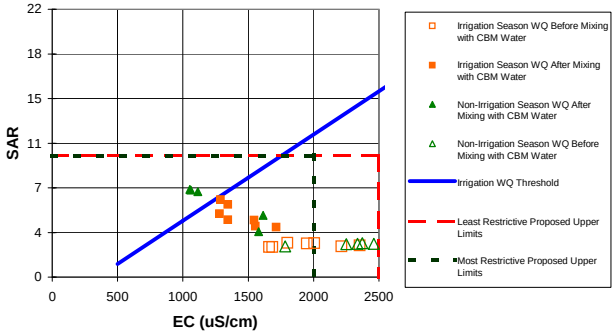
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

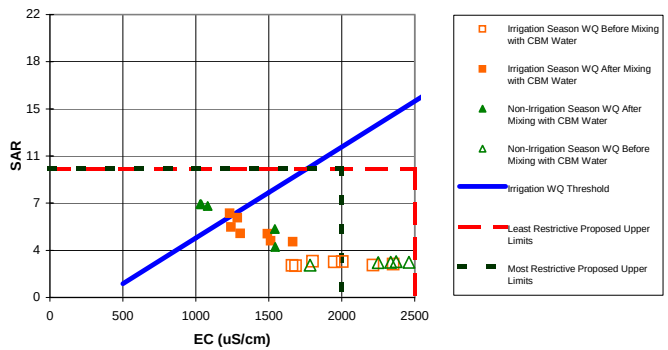
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

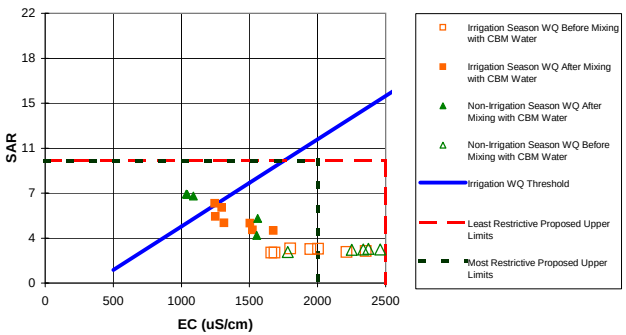
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

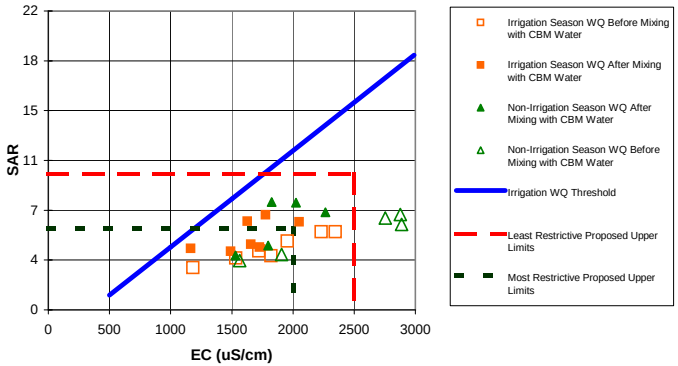
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

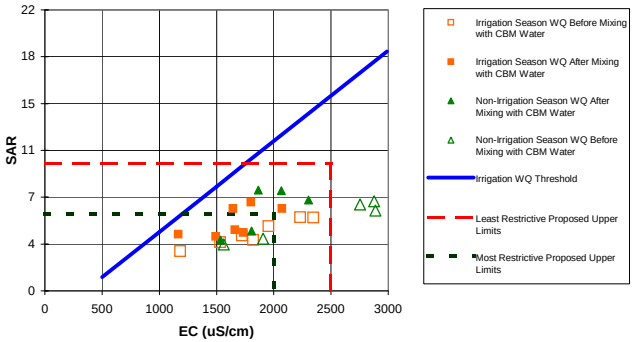
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

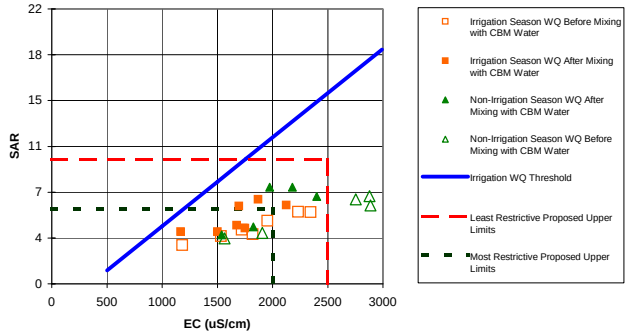
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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 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	3.0	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

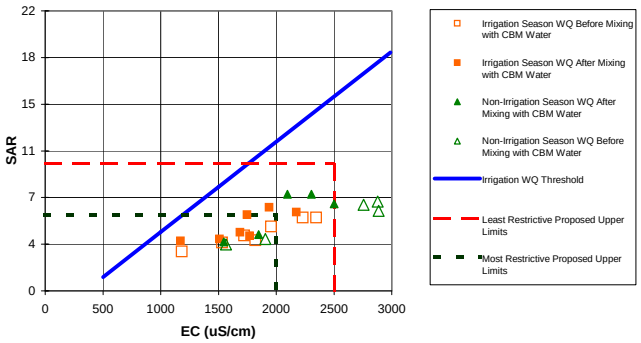
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

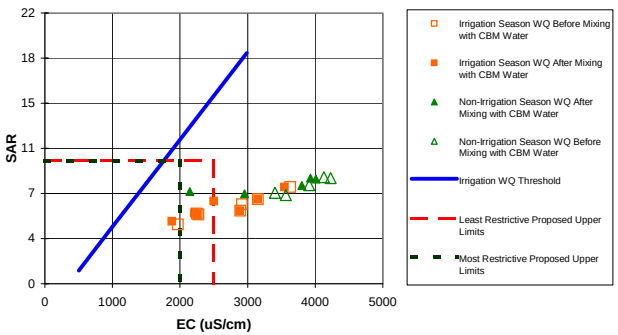
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

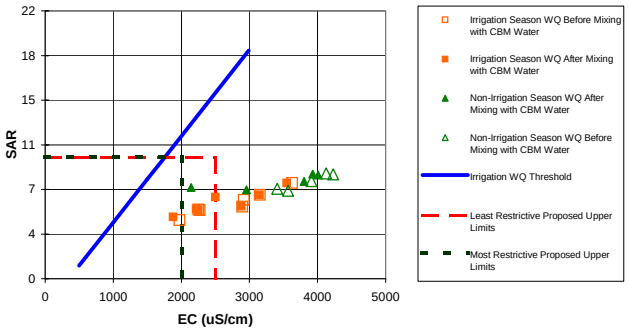
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

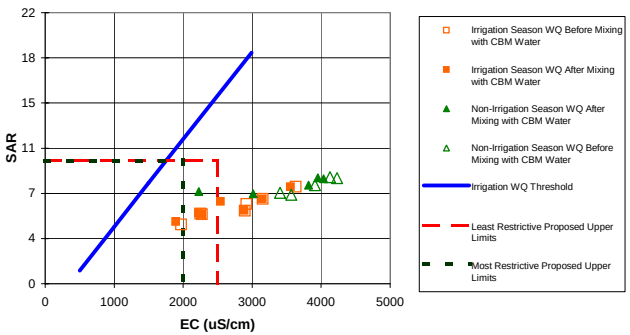
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

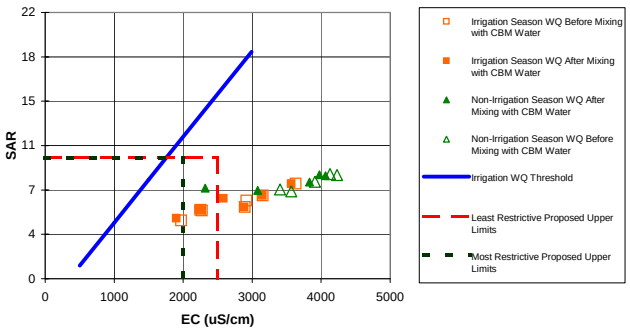
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

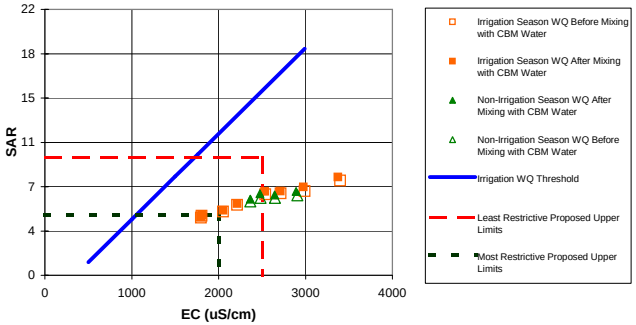
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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	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	2.3	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

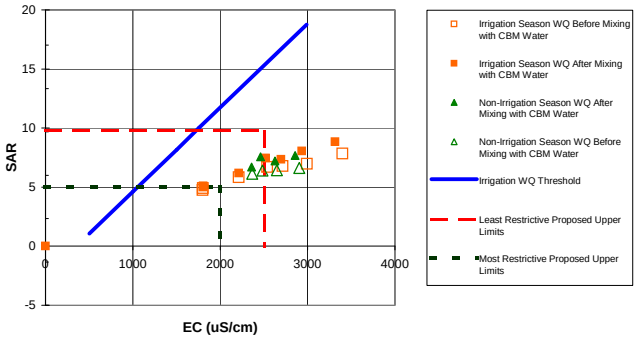
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

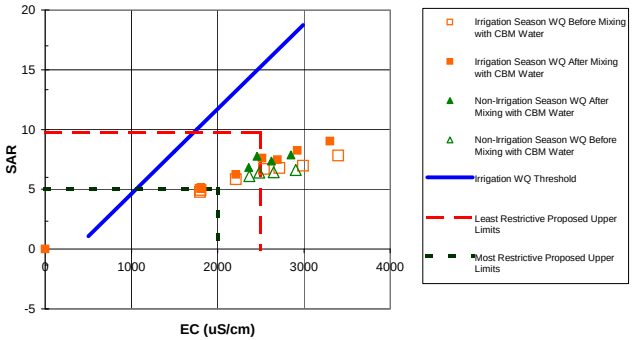
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

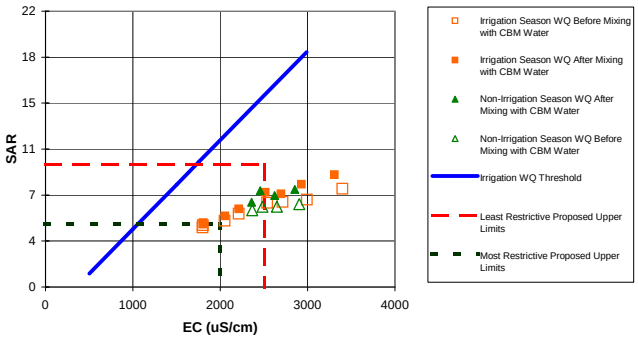
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

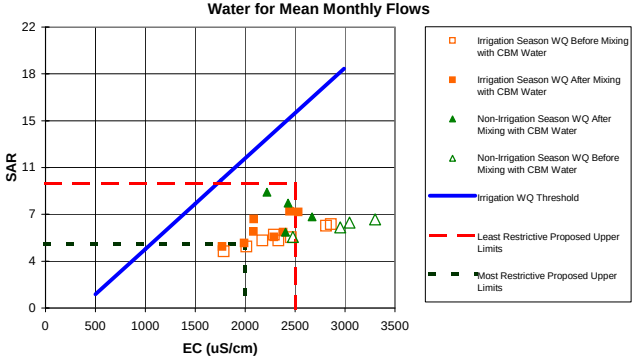
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

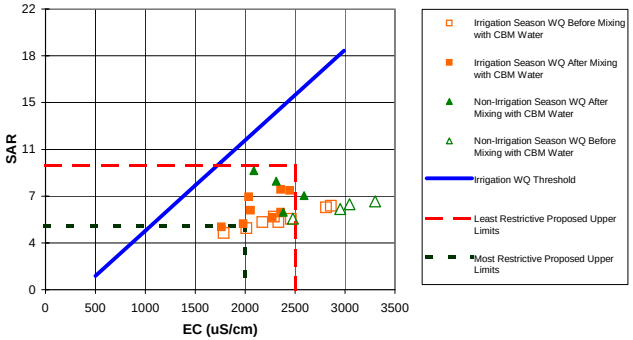
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

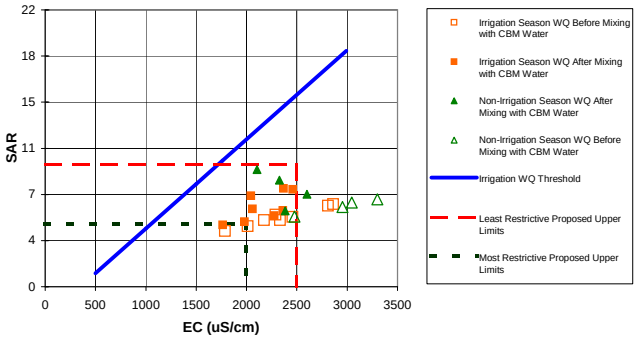
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

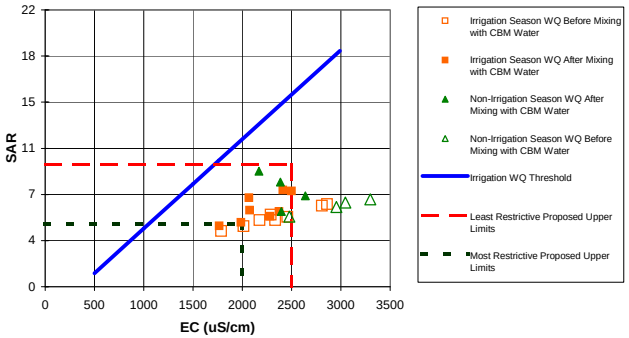
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

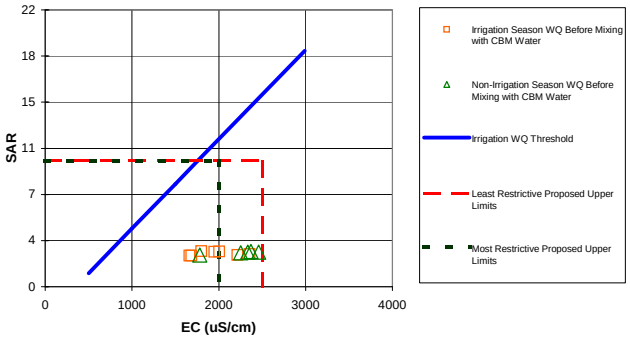
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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	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	0.00	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

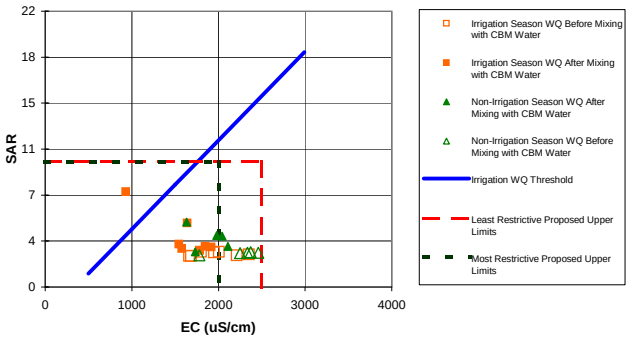
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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		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	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

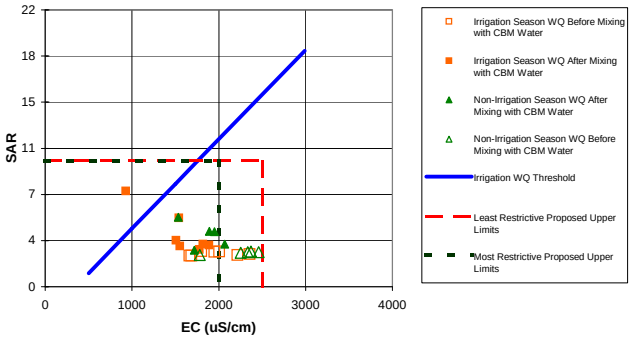
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

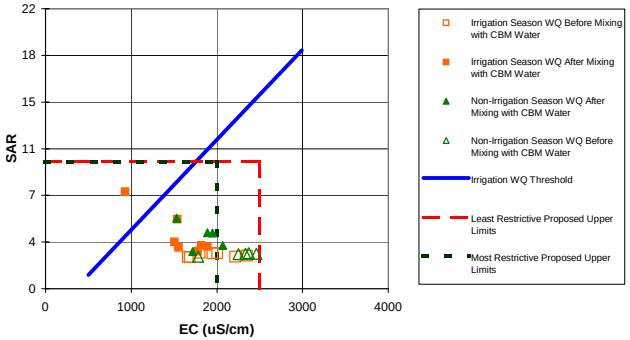
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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 EC mean	Mixed EC 95% upper	Mixed Water Quality SAR (--) 95% lower	Mixed SAR mean	Mixed SAR 95% upper	Background Water Quality EC (uS/cm)	Background 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			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
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			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
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			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
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			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
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%	

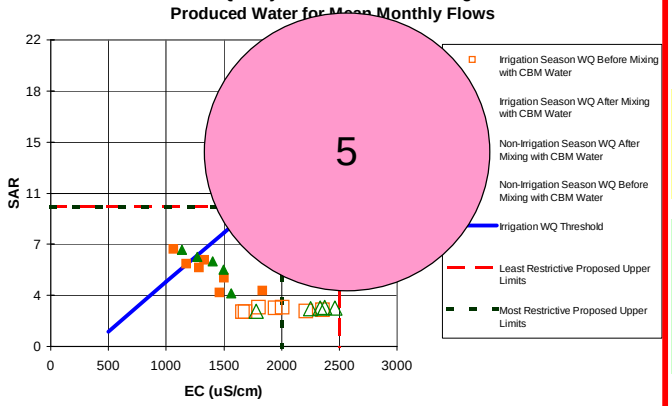
(1) Computed difference between mixed water and background water quality
(2) Computed difference (as a percentage) between mixed mean water quality and upper or lower 95% confidence limit

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 Mean	EC 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

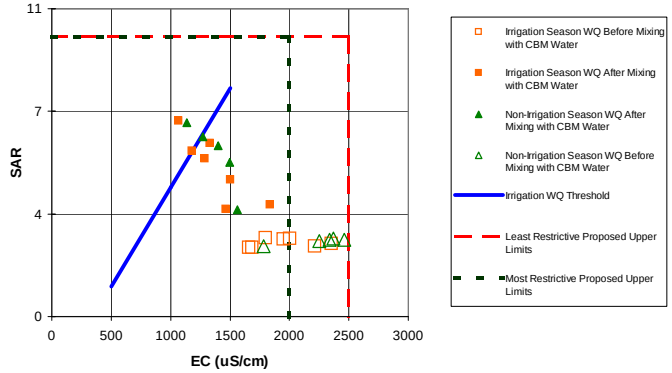
Section 5: This section presents the summary graph illustrating irrigation suitability and the water quality data relative to the "limits". The graph references "Limits" data from Section 1 and pertinent water quality data from section 4.

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	

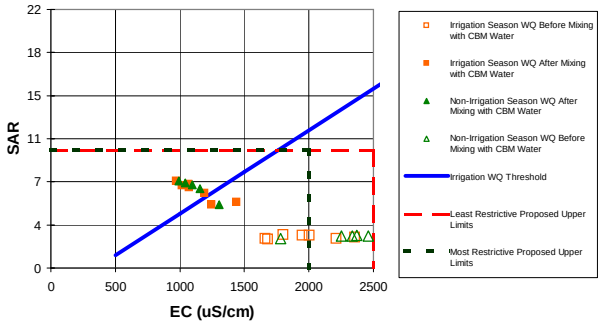
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

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		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 Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

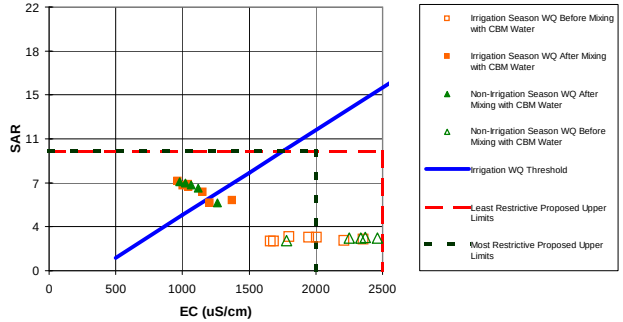
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17

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: 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	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 Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

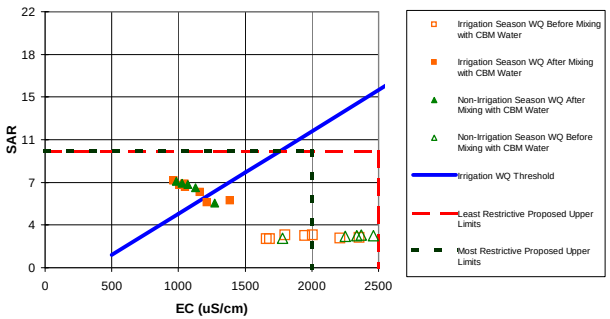
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

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

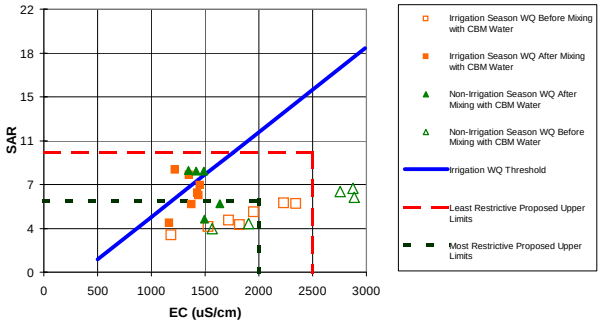
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

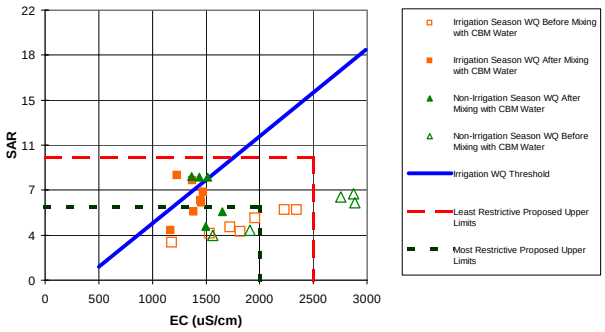
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

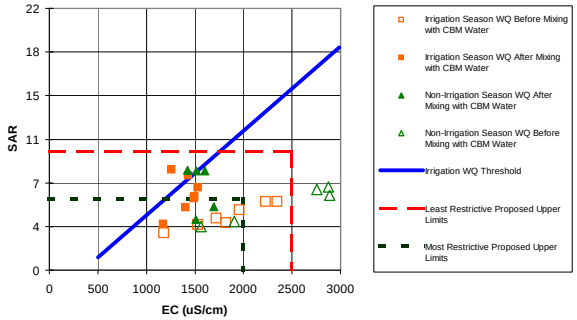
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

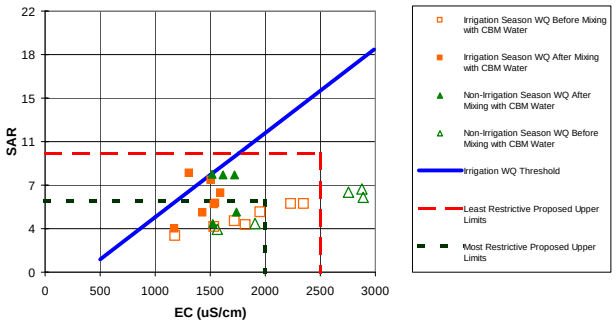
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

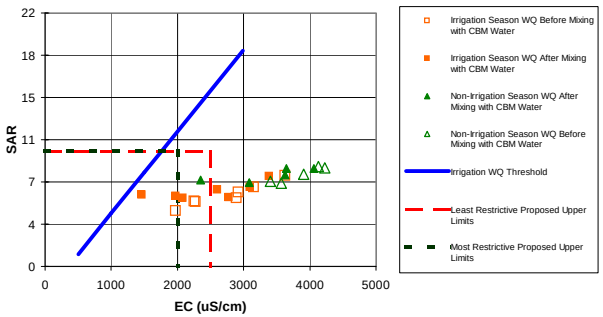
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	6
	2000	6
	2000	0

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		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	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

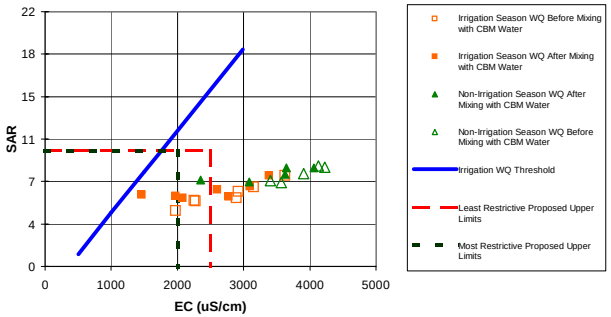
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

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

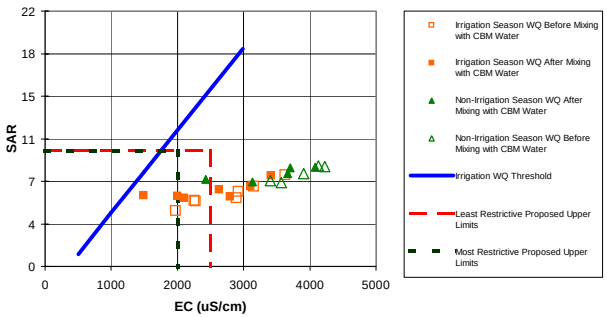
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

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 (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	0.7	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

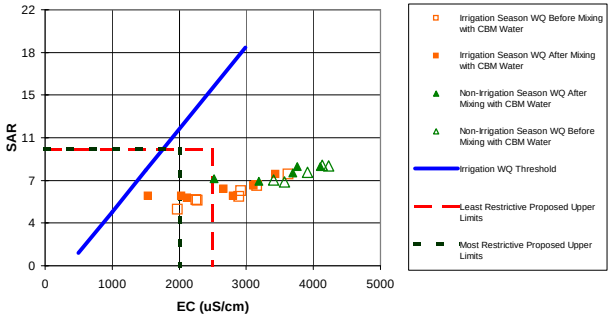
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

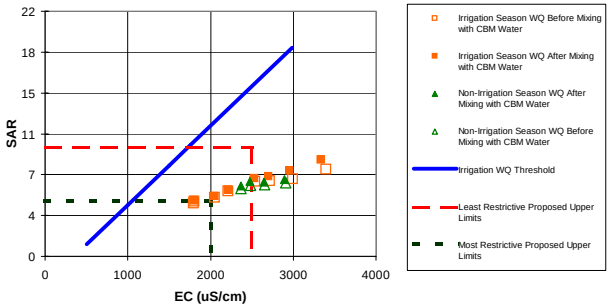
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

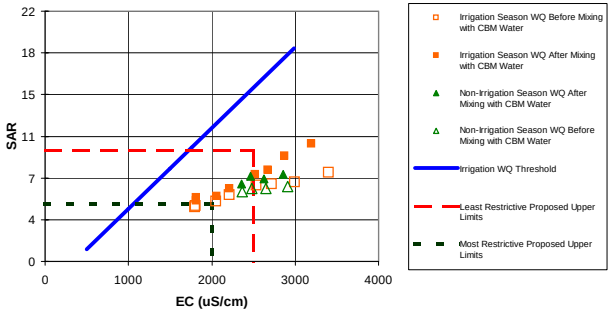
Plotting Position: Most and Least Restrictive Limits		
	EC	SAR
	0	9.75
Least Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

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

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	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

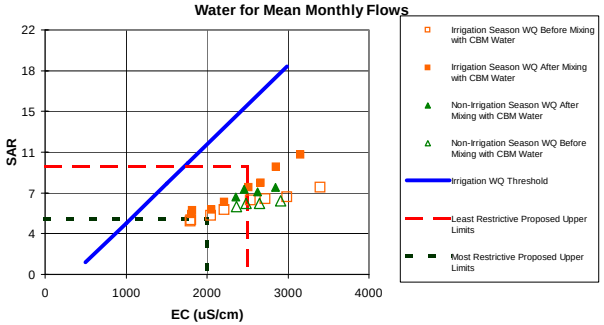
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	9.75
Least Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

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

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	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

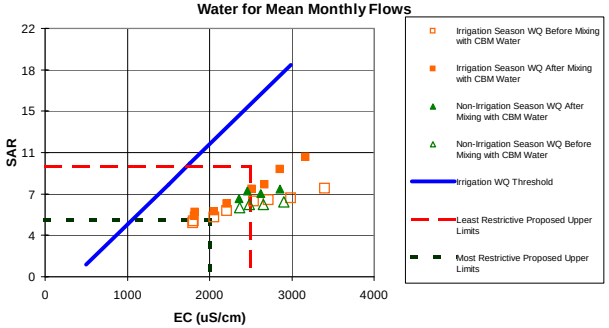
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

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	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	9.0	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
	Mar	9.0	301.02	2054	2055	2055	5.75	5.78	5.81	2051	5.28
Irrigation Season	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 Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

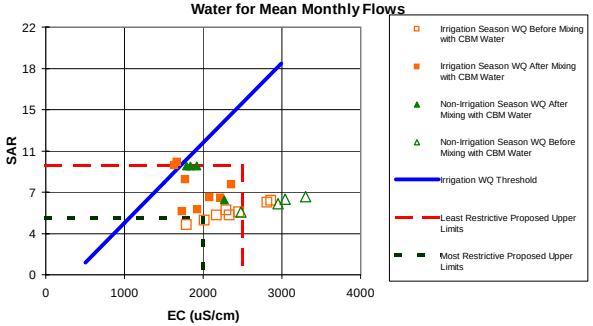
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
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

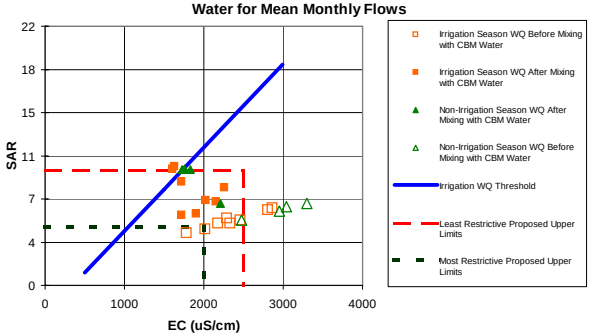
Plotting Position: Most and Least Restrictive Limits			Irrigation WQ Threshold Line	
	EC	SAR	EC	SAR
			500	1.07
	0	9.75	1000	4.62
Least Restrictive	2500	9.75	1500	8.17
	2500	0	2990	18.75
Most Restrictive	0	5		
	2000	5		
	2000	0		

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	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	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

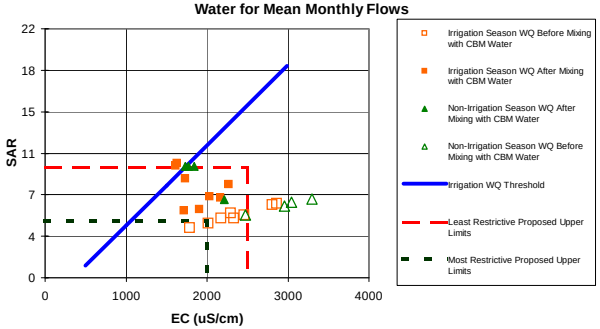
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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

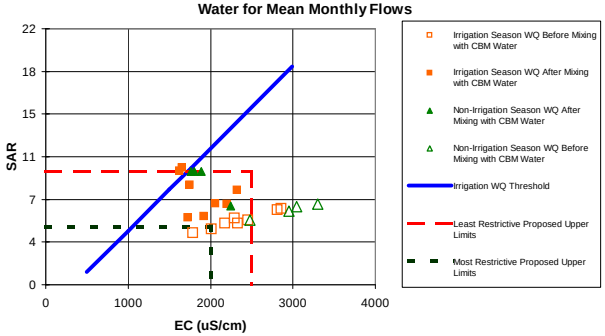
Plotting Position: Most and Least Restrictive Limits			Irrigation WQ Threshold Line	
	EC	SAR	EC	SAR
			500	1.07
	0	9.75	1000	4.62
Least Restrictive	2500	9.75	1500	8.17
	2500	0	2990	18.75
Most Restrictive	0	5		
	2000	5		
	2000	0		

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	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	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 Restrictiv	2500	9.75
	2500	0
Most Restrictive	0	5
	2000	5
	2000	0

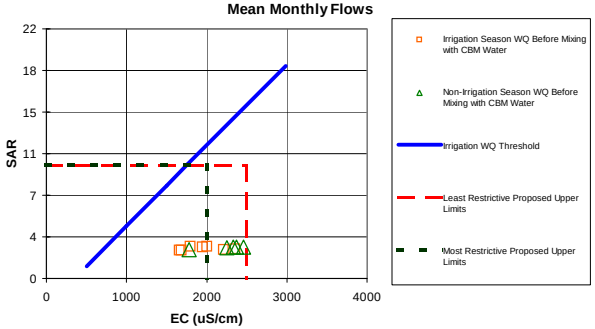
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

Dry Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
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	0.02	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

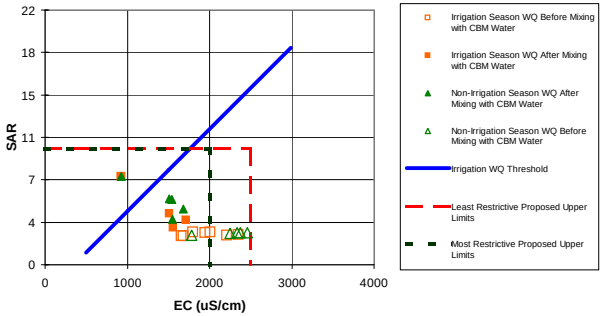
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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 Restrictive	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

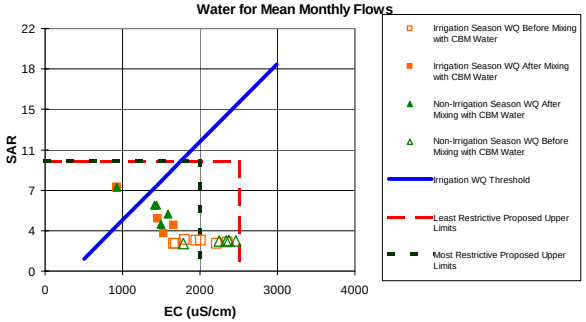
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

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: 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

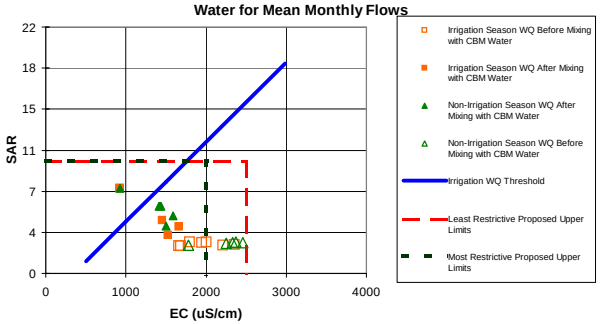
Plotting Position: Most and Least Restrictive Limits	EC	SAR
	0	10
Least Restrictiv	2500	10
	2500	0
Most Restrictive	0	10
	2000	10
	2000	0

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: 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	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			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% 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			SAR			EC			SAR			EC			SAR			EC			SAR		
		(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)		
		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			SAR			EC			SAR			EC			SAR			EC			SAR		
				(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)		
		EC	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			SAR			EC			SAR			EC			SAR			EC			SAR		
		(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)		
		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			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
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			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
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			SAR			EC			SAR			EC			SAR			EC			SAR		
		(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)			(uS/cm)			(--)		
		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	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	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

Subject: **Powder/Tongue River Basin Plan**
Surface Water Hydrology
Tasks 3A and 3B

Date: February 2002

Prepared by: HKM Engineering Inc.

INTRODUCTION

Water availability models are to be developed to represent dry year, normal year, and wet year hydrologic conditions throughout the Powder/Tongue River Basin Planning area. Several key inputs are necessary to model the water availability including the current irrigated land base, crop water requirements, municipal and industrial surface water demands, and regulation by reservoir storage facilities. This information was developed through the Task 2 work effort. Schematic representations of the water availability models have been developed identifying the appropriate location of model nodes in relation to the various surface water demands, return flows, and storage regulation. Model nodes are located, in large part, at historic streamflow gaging stations in order to take advantage of the historic records of streamflow at these locations. Additionally, it is necessary to locate model nodes at locations with no record of streamflow, to appropriately simulate water use in the various drainages. This memorandum summarizes the methodology used to collect the historic records of streamflow, establish a study period for modeling, and to extend or fill-in the streamflow data where records are unavailable. The methodology used to estimate natural (virgin) streamflow at ungaged model nodes is also discussed in this memorandum.

HISTORIC STREAMFLOW RECORDS

HKM inventoried the available records of streamflow in the Powder/Tongue River Basin. Data from the following four sources were used for this study:

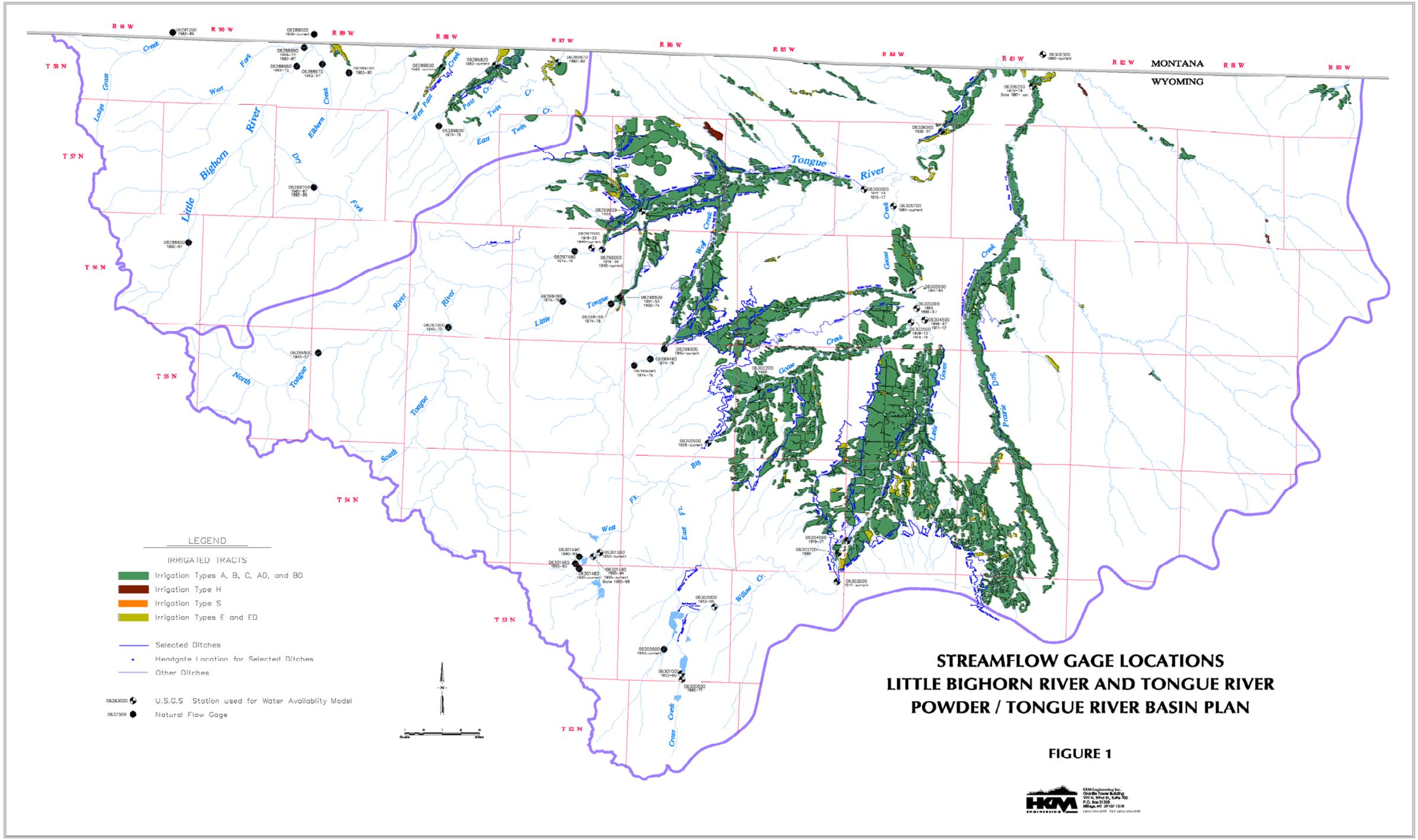
1. Wyoming USGS digital database in Cheyenne
2. USGS Water Resources Data Books for Wyoming
3. Records from State Engineers Office Hydrographers Annual Reports as compiled by HKM
4. Water Resources Data System (WRDS) database

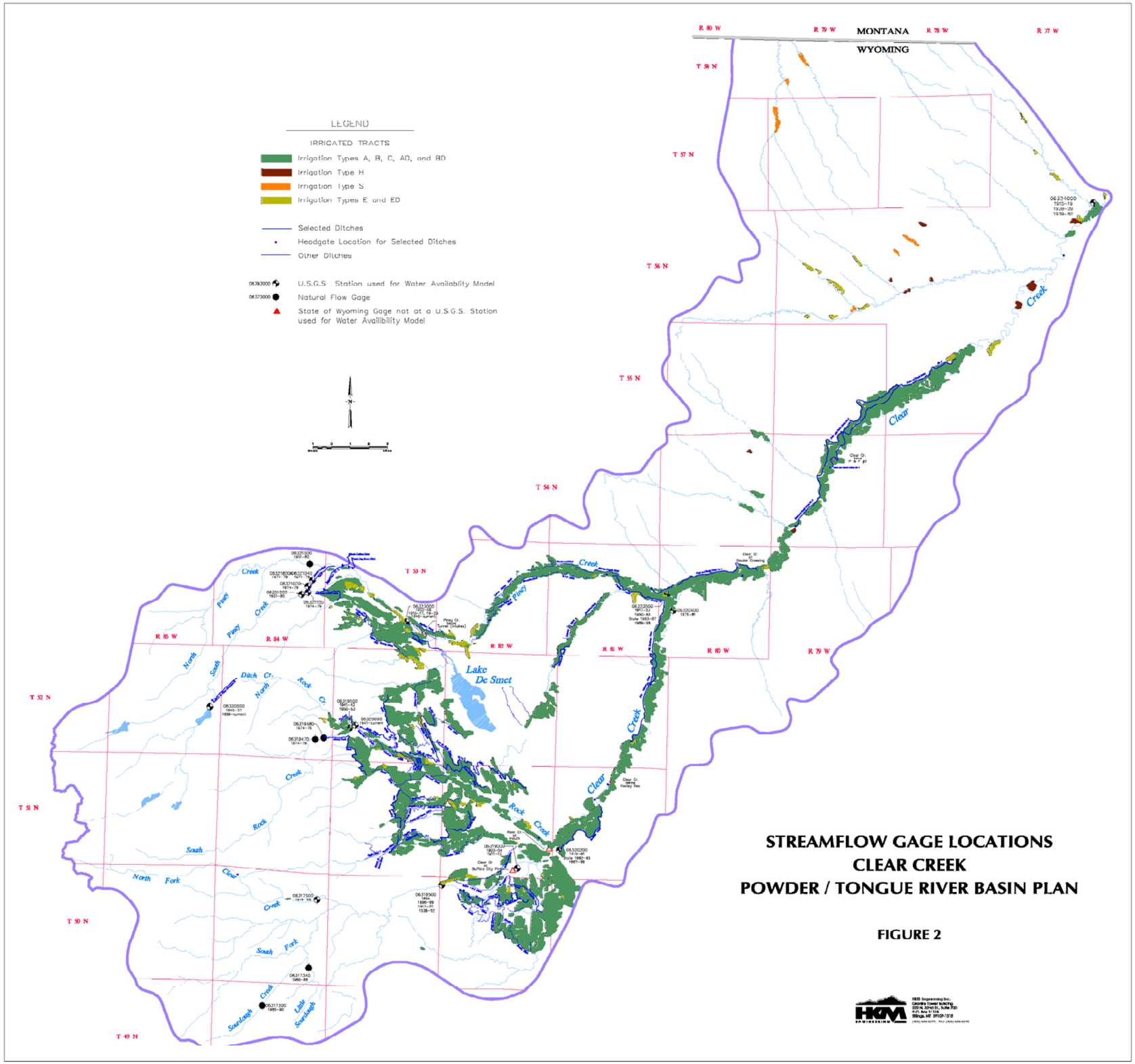
The order of priority for use of data available from multiple sources was as numbered above.

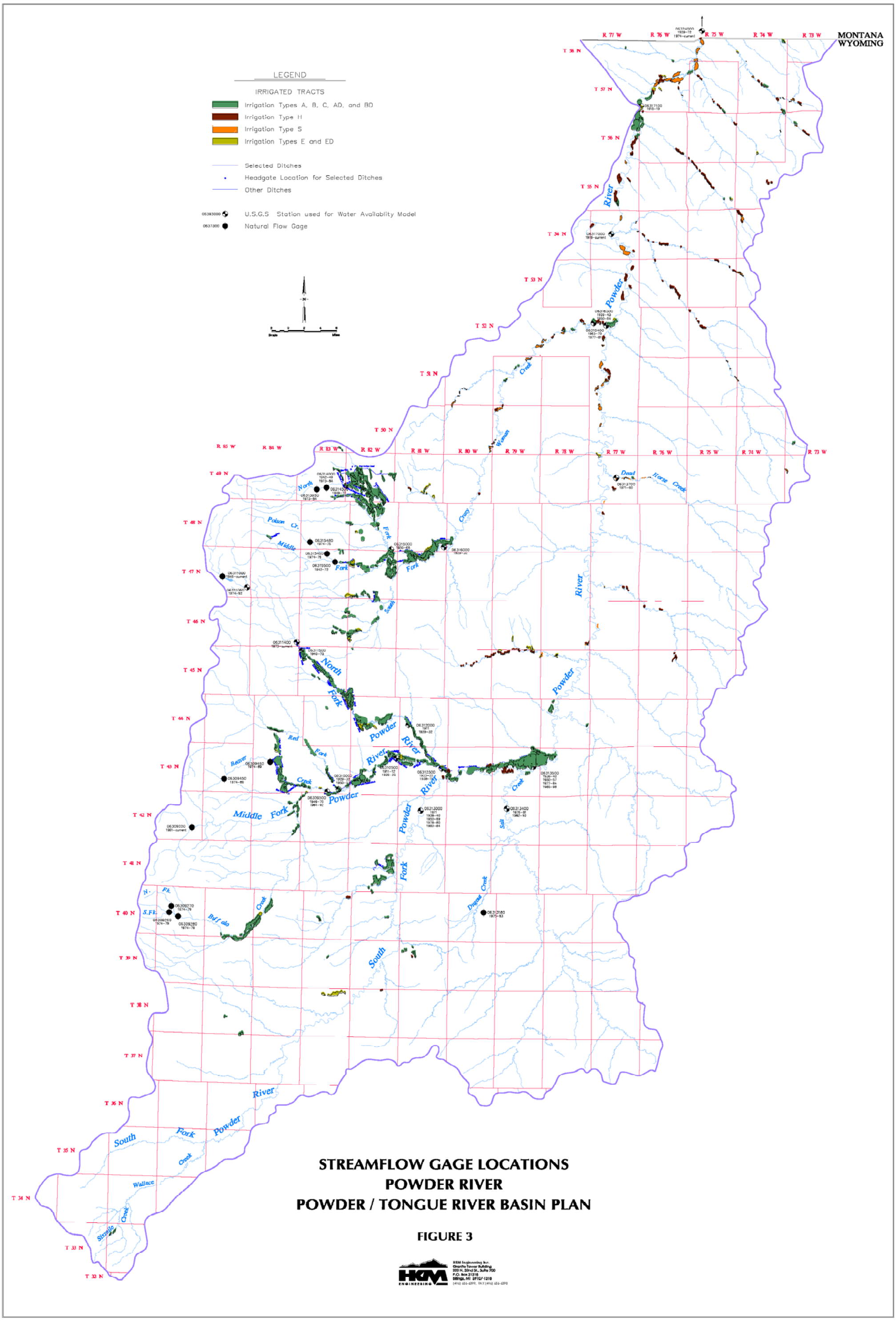
The location of the various streamflow gaging stations are plotted in relation to the significant storage reservoirs and the irrigated lands mapped by HKM (Figures 1 through 4). The streamflow gages that are relatively free from the influence of depletions or storage regulations are characterized as natural flow stations. Where reasonably possible, those gages that are impacted by upstream irrigation depletions were adjusted to remove these effects. The list of streamflow gages inventoried for this study is provided in Table 1.

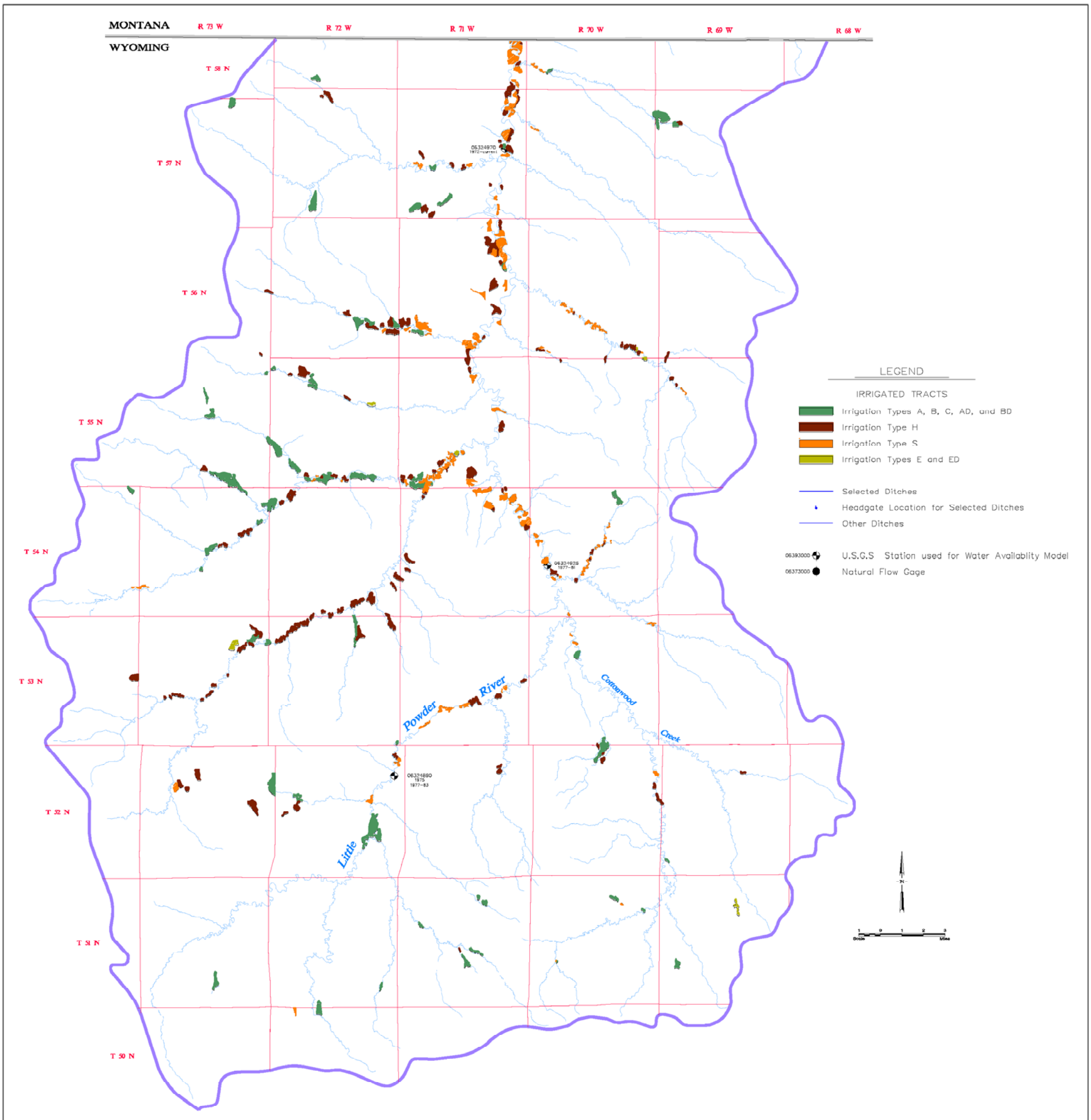
Figure 5 illustrates the period of record for all of the natural flow stations available in the basins. Figure 6 shows the period of record for the non-natural flow stations at model nodes. Figure 7 summarizes the records available for stations not selected for use in the water availability models. These records were typically excluded either because the stations were discontinued many years ago or because records for stations on the same stream at more appropriate locations are available.

As shown in Figures 5 and 6, records from 40 to 50 streamflow gaging stations are available beginning in the 1970s and 1980s in addition to those existing prior to that time.


MONTANA
WYOMING
R 91 W
R 90 W
R 89 W
R 88 W
R 87 W
R 86 W
R 85 W
R 84 W
R 83 W
R 82 W
R 81 W
R 80 W
T 58 N
T 57 N
T 56 N
T 55 N
T 54 N
T 53 N
T 52 N
Little Bighorn River
Tongue River
LEGEND
IRRIGATED TRACTS
Irrigation Types A, B, C, AD, and BD
Irrigation Type H
Irrigation Type S
Irrigation Types E and ED
Selected Ditches
Headgate Location for Selected Ditches
Other Ditches
06393000 U.S.G.S Station used for Water Availablity Model
0637300 Natural Flow Gage
STREAMFLOW GAGE LOCATIONS
LITTLE BIGHORN RIVER AND TONGUE RIVER
POWDER / TONGUE RIVER BASIN PLAN
FIGURE 1
HKM ENGINEERING
HKM Engineering Inc.
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31316
Billings, MT 59107-1316
(406) 656-6200 FAX (406) 656-6298


MONTANA
WYOMING
LEGEND
IRRIGATED TRACTS
Irrigation Types A, B, C, AD, and BD
Irrigation Type H
Irrigation Type S
Irrigation Types E and ED
Selected Ditches
Headgate Location for Selected Ditches
Other Ditches
U.S.G.S Station used for Water Availability Model
Natural Flow Gage
State of Wyoming Gage not at a U.S.G.S. Station used for Water Availibility Model
Lake De Smet
Clear Creek
Piney Creek
North Fork
South Fork
Rock Creek
Ditch Cr.
Soarlash Creek
Little Soarlash
STREAMFLOW GAGE LOCATIONS
CLEAR CREEK
POWDER / TONGUE RIVER BASIN PLAN
FIGURE 2


LEGEND
IRRIGATED TRACTS
Irrigation Types A, B, C, AD, and BD
Irrigation Type H
Irrigation Type S
Irrigation Types E and ED
Selected Ditches
Headgate Location for Selected Ditches
Other Ditches
U.S.G.S Station used for Water Availablity Model
Natural Flow Gage
MONTANA
WYOMING
Powder River
Middle Fork Powder River
North Fork Powder River
South Fork Powder River
Red Fork
Beaver Creek
Poison Cr.
Crazy Woman Creek
Dead Horse Creek
Salt Creek
Dugout Creek
Buffalo Creek
Wallace Creek
Sterrett Creek
STREAMFLOW GAGE LOCATIONS
POWDER RIVER
POWDER / TONGUE RIVER BASIN PLAN
FIGURE 3
HGM ENGINEERING



STREAMFLOW GAGE LOCATIONS
LITTLE POWDER RIVER
POWDER / TONGUE RIVER BASIN PLAN

FIGURE 4

HKM ENGINEERING
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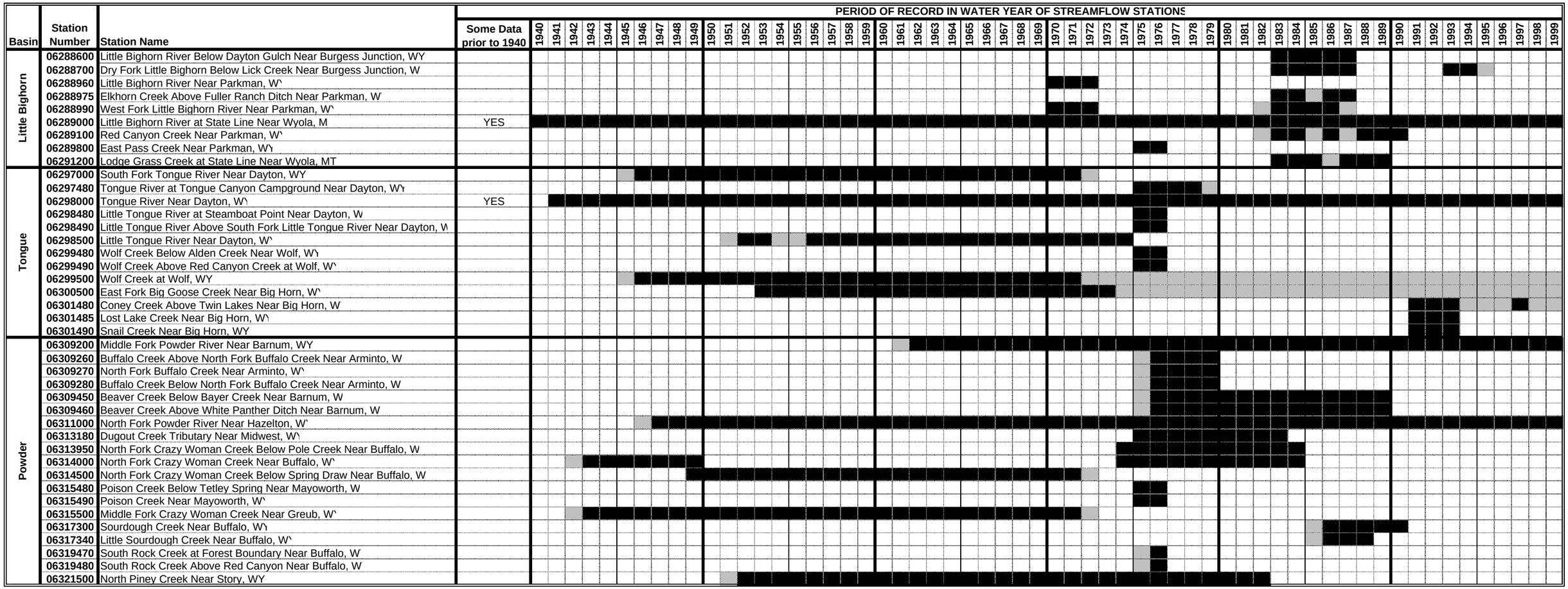
TABLE 1

STREAMFLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	Natural Flow	Period of Record in Water Years **	Note
Little Bighorn	06288600	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	YES	1983-1987	
	06288700	Dry Fork Little Bighorn Below Lick Creek Near Burgess Junction, WY	YES	1983-1987, 1993-1995	
	06288960	Little Bighorn River Near Parkman, WY	YES	1970-1972	
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	YES	1983-1987	No winter records in 1985
	06288990	West Fork Little Bighorn River Near Parkman, WY	YES	1970-72, 1983-1987	No winter records in 1987
	06289000	Little Bighorn River at State Line Near Wyola, MT	YES	1939-current	
	06289100	Red Canyon Creek Near Parkman, WY	YES	1982-1990	No winter records in 1985, 1987
	06289500	Little Bighorn River Near Wyola, MT	NO	1912-1924	No winter records; Abt. 7 mi. into MT
	06289600	West Pass Creek Near Parkman, WY	NO	1983-current	No winter records 1985-1987
	06289800	East Pass Creek Near Parkman, WY	YES	1975-1976	
	06289820	East Pass Creek Near Dayton, WY	NO	1983-current	
	06289870	Twin Creek Near Parkman, WY	NO	1983-1990	No winter records 1985-1987
	06290000	Pass Creek Near Wyola, MT	NO	1939-1975	Winter records incomplete before 1939; Abt. 4 mi. into MT
	06290500	Little Bighorn River Below Pass Creek Near Wyola, MT	NO	1939-1975	Abt. 13 mi. into MT
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	YES	1982-1989	No winter records 1986
Tongue	06296500	North Fork Tongue River Near Dayton, WY	YES	1945-1958	No winter records before 1950
	06297000	South Fork Tongue River Near Dayton, WY	YES	1945-1972	
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY	YES	1975-1979	
	06298000	Tongue River Near Dayton, WY	YES	1919-1929, 1941-current	Adjusted using Highline Ditch Near Dayton, WY (06297500) as published
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY	YES	1975-1976	
	06298490	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY	YES	1975-1976	
	06298500	Little Tongue River Near Dayton, WY	YES	1951-1974	
	06299000	Tongue River at Dayton, WY	NO	1903-1904	Seasonal (May 1903 to Oct. 1904)
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY	YES	1975-1976	
	06299490	Wolf Creek Above Red Canyon Creek at Wolf, WY	YES	1975-1976	
	06299500	Wolf Creek at Wolf, WY	YES	1945-current	No winter records after 1971
	06300000	Tongue River at Carneyville, WY	NO	1911-1917	Seasonal only
	06300500	East Fork Big Goose Creek Near Big Horn, WY	YES	1954-current	No winter records after 1973
	06300900	Cross Creek Above Big Horn Reservoir Near Big Horn, WY	NO	1961-1971	
	06301000	Cross Creek Near Big Horn, WY	NO	1954-1960	
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY	YES	1991-current	No winter records 1993, 1996, 1998, 1999
	06301485	Lost Lake Creek Near Big Horn, WY	YES	1991-1993	
	06301490	Snail Creek Near Big Horn, WY	YES	1991-1993	
	06301495	Coney Creek Below Twin Lakes Near Big Horn, WY	NO	1991-1994, 1996-current	No winter records some years
	06301500	West Fork Big Goose Creek Near Big Horn, WY	NO	1954-current	No winter records after 1971
	06302000	Big Goose Creek Near Sheridan, WY	NO	1929-current	No winter records after 1971; Adjusted for diversions using PK Ditch & Sheridan City Intake Ditch
	06302200	Big Goose Creek Above Park Creek Near Sheridan, WY	NO	1999-current	Jul. - Sep. 1999
	06302500	Goose Creek at Sheridan, WY	NO	1909-1916	No winter records
	06303000	Willow Creek Near Big Horn, WY	NO	1954-1955	
	06303500	Little Goose Creek in Canyon Near Big Horn, WY	NO	1941-current	No winter records after 1971
	06303700	Little Goose Creek Above Davis Creek Near Big Horn, WY	NO	1999-current	Jul. - Sep. 1999
	06304000	Little Goose Creek Near Big Horn, WY	NO	1919-1922	No winter records 1919
	06304500	Little Goose Creek at Sheridan, WY	NO	1896-1897, 1911-1913	No winter records
	06305000	Goose Creek Below Little Goose Creek at Sheridan, WY	NO	1896-1897	No winter records
	06305500	Goose Creek Below Sheridan, WY	NO	1942-1984	
	06305700	Goose Creek Near Acme, WY	NO	1984-current	
	06306000	Tongue River Near Acme, WY	NO	1939-1957	
	06306100	Squirrel Creek Near Decker, MT	NO	1975-1986	Abt. 3.5 mi. into MT
	06306250	Prairie Dog Creek Near Acme, WY	NO	WRDS: 1965-1970; USGS: 1971-1980; SEO: 1981-1999	State data seasonal only
	06306300	Tongue River at State Line Near Decker, MT	NO	1960-current	
Powder	06309200	Middle Fork Powder River Near Barnum, WY	YES	1961-current	
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY	YES	1975-1979	
	06309270	North Fork Buffalo Creek Near Arminto, WY	YES	1975-1979	
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY	YES	1975-1979	
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY	YES	1975-1989	
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	YES	1975-1989	
	06309500	Middle Fork Powder River Above Kaycee, WY	NO	1949-1970, 1984-1992	
	06310000	Red Fork Powder River Near Barnum, WY	NO	1929-1932, 1950-1954	
	06310500	Middle Fork Powder River at Kaycee, WY	NO	1911-1913, 1929-1932	
	06311000	North Fork Powder River Near Hazelton, WY	YES	1946-current	
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	YES	1975-1992	
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	NO	1974-current	
	06311500	North Fork Powder River Near Mayoworth, WY	NO	1941-1973	
	06312000	North Fork Powder River Near Kaycee, WY	NO	1911-1912, 1929-1932	
	06312500	Powder River Near Kaycee, WY	NO	1934-1935, 1938-1971, 1979-1980	
	06313000	South Fork Powder River Near Kaycee, WY	NO	1911-1912, 1938-1940, 1950-1969, 1979-1980, 1983-1984	
	06313180	Dugout Creek Tributary Near Midwest, WY	YES	1975-1983	
	06313400	Salt Creek Near Sussex, WY	NO	1976-1981, 1983-1993	
	06313500	Powder River at Sussex, WY	NO	1938-1940, 1950-1957, 1978-1999	
	06313700	Dead Horse Creek Near Buffalo, WY	NO	1972-1990	
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY	YES	1974-1984	
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	YES	1942-1949, 1974-1984	
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY	YES	1949-1972	
	06315000	North Fork Crazy Woman Near Greub, WY	NO	1950-1968	
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY	YES	1975-1976	
	06315490	Poison Creek Near Mayoworth, WY	YES	1975-1976	
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY	YES	1942-1972	No winter records 1972
	06316000	Crazy Woman Creek Near Buffalo, WY	NO	1929-1932	No winter records some years
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY	NO	SEO: 1982-current	Seasonal data only
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY	NO	1963-1970, 1978-1981	
	06316500	Crazy Woman Creek Near Arvada, WY	NO	1940-1944, 1950-1964	
	06317000	Powder River at Arvada, WY	NO	1919-current	No winter records 1919-1930, 1934
	06317100	Powder River Near Arvada, WY	NO	1915-1919	No winter records
	06317300	Sourdough Creek Near Buffalo, WY	YES	1985-1990	
	06317340	Little Sourdough Creek Near Buffalo, WY	YES	1985-1988	
	06317500	North Fork Clear Creek Near Buffalo, WY	NO	1950-1968	
	06318500	Clear Creek Near Buffalo, WY	NO	1894, 1896, 1897-1900, 1917-1928, 1938-1992	Records after Oct. 1987 not equivalent due to diversion by City of Buffalo; Adjusted for diversions using 100 acres of irrigated lands upstream and 6 cfs diversion by Buffalo
	SEO Gage	Clear Creek in Buffalo City Park Buffalo, WY	NO	WRDS: 1971-1978; SEO: 1987-1999	Seasonal data only
	06319000	Clear Creek at Buffalo, WY	NO	1903-1905, 1911-1912	No winter records
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY	YES	1975-1976	
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY	YES	1975-1976	
	06319500	South Fork Rock Creek Near Buffalo, WY	NO	1941-1943, 1950-1954	No winter records 1941-1943
	06320000	Rock Creek Near Buffalo, WY	NO	1941-current	No winter records after 1971; Adjusted for irrigation using Mowry Basin Ditch
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY	NO	WRDS: 1971-1975, 1977-1978; SEO: 1980-1981, 1983, 1985-1988, 1990-1999	Seasonal data only
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY	NO	USGS: 1976-1981; SEO: 1982-1985, 1987-1999	State data mostly seasonal
	06320400	Clear Creek at Ucross, WY	NO	1976-1981	
	SEO Gage	Clear Creek Below Healy Reservoir Near Buffalo, WY	NO	1977-1999	State data mostly seasonal
	06320500	South Piney Creek at Willow Park Reservoir, WY	NO	1945-1957, 1960-current	No winter records before 1948 and after 1971
	06321000	South Piney Creek Near Story, WY	NO	1951-1980	No winter records 1972-1974
	06321100	South Piney Creek Below Mead-Coffeen Ditch Near Story, WY	NO	1975-1979	
	06321500	North Piney Creek Near Story, WY	YES	1951-1982	
	06321800	Spring Creek Near Story, WY	NO	1975-1979	
	06323000	Piney Creek at Kearney, WY	NO	1902-1906, 1910-1917, 1919-1923, 1941-current	No winter records some years
	SEO Gage	Little Piney Creek, WY	NO	SEO: 1981, 1983, 1985-1986, 1988, 1991-1999	Seasonal data only; from spot measurements
	SEO Gage	Piney Creek Below Lake DeSmet Tunnel Intake Near Story, WY	NO	WRDS: 1971-1973, 1977, 1979; SEO: 1980-1984, 1986-1996	Mostly seasonal data
	06323500	Piney Creek at Ucross, WY	NO	USGS: 1917-1923, 1980-1982; SEO: 1983-1987, 1989-1998	No winter records 1917-1923; State data seasonal only
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY	NO	WRDS: 1973-1978; SEO: 1980-1996, 1998-1999	Seasonal data only
	SEO Gage	Clear Creek Below P&F#3 Ditch Near Clearmont, WY	NO	WRDS: 1978; SEO: 1980-1999	Seasonal data only
	06324000	Clear Creek Near Arvada, WY	NO	1915-1919, 1928-1929, 1940-1982	No winter records before 1929
	06324500	Powder River at Moorhead, MT	NO	1929-1972, 1975-current	Abt. 4 mi. into MT
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	NO	1978-1981	
	06324925	Little Powder River Near Weston, WY	NO	1977-1981	
	06324970	Little Powder River Above Dry Creek Near Weston, WY	NO	1973-current	
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	NO	1943-1970, 1976-1983, 1986-1987, 1991-current	

** Unless otherwise noted, records were obtained from the USGS.

FIGURE 5
NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS



LEGEND
Monthly Flow Reported for Entire Year
Monthly Flow Reported for Some Months

FIGURE 6
NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS — SELECTED FOR MODELING

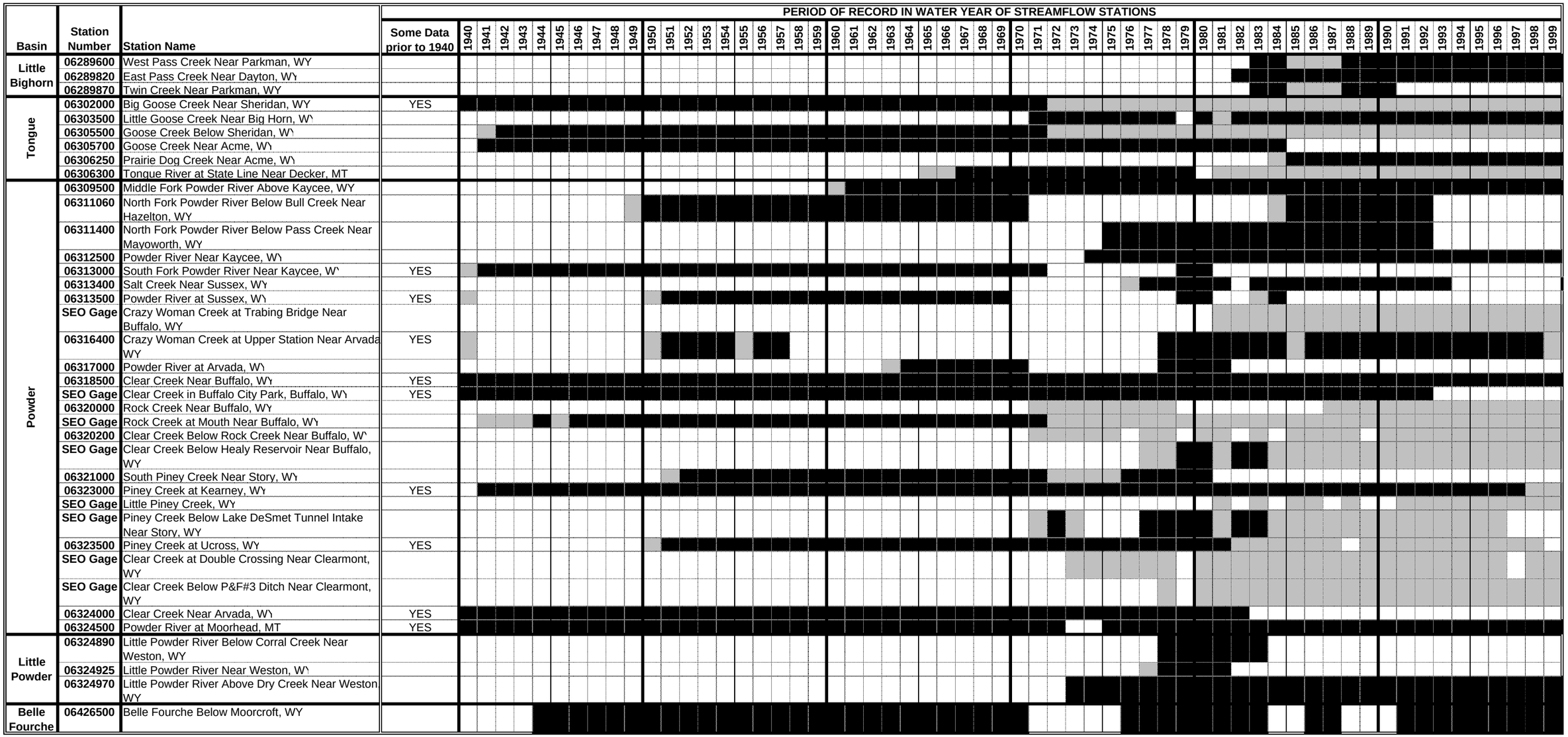
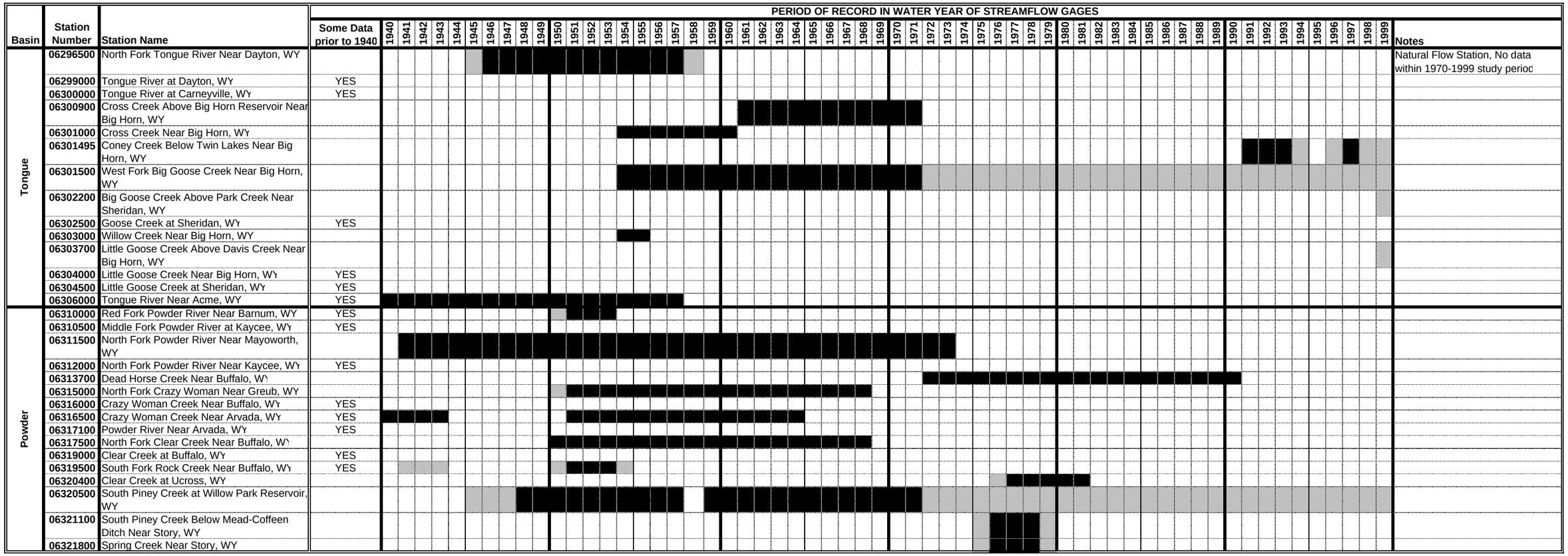


FIGURE 7

STATIONS IN THE POWDER-TONGUE RIVER BASINS NOT SELECTED FOR MODELING



STUDY PERIOD

It is important in any water availability evaluation to select a study period that is long enough to include a variety of hydrologic conditions including an extended period of dry years as well as wet years and normal years. At the same time, it is also important not to select a study period so long that many streamflows must be synthesized to fill-in missing data.

The USGS has maintained a streamflow station on the Tongue River near Dayton (#06298000) since 1919 and continuous records are available from 1941 to present (Table 1). This station is impacted by diversions to the Highline Ditch just upstream of the gage. Natural flow at this station is therefore determined by adding these recorded diversions to the recorded streamflow. The 59-year period of continuous record for this station (1941 through 1999) is selected as the best single representation of long term natural hydrologic conditions in the basin. Figure 8 is a Cumulative Surplus/Deficit plot for the Tongue River near Dayton and represents a running total of the annual deviations from the long-term mean annual streamflow. Downward sloping lines (left to right) represent periods of time during which annual streamflow is less than the long-term mean. Conversely, upward sloping lines represent years which are wetter than average. As shown on Figure 8, the periods from 1941 through 1947 and from 1962 through 1978 can be generally characterized as wet periods, whereas the periods from 1948 through 1961 and from 1979 through 1989 can be generally characterized as dry periods. The period from 1990 through 1999 can generally be characterized as near average. Exceptions to each of these generalities exist within each period. By way of example, 1966 is a dry year within a generally wet period of years and 1984 is a wet year within a generally dry period. Based on an evaluation of the long-term hydrologic conditions on the Tongue River, together with the an understanding of the availability of historic streamflow records, the 30-year period 1970 through 1999 is selected as a candidate study period. Selection of this potential study period is also influenced by the fact that ditch diversion records are available predominantly for the period after 1970. Both streamflow records and ditch diversions records will be needed to develop water availability models that accurately simulate existing water use in the basin. As shown on Figure 8, the average annual flow of the Tongue River near Dayton, for the period 1970 – 1999, is essentially equal to the long-term (1941 – 1999) average annual flow (133,175 AF vs. 133,210 AF).

The representativeness of the potential 1970 to 1999 study period is further evaluated by reviewing long-term natural flow gages that more completely represent the entire Powder/Tongue River Basin, including the Little Bighorn River, the Tongue River, and the Powder River. Three gages with relatively long periods of record are selected for this purpose: 1) Little Bighorn River at State Line (#06289000); 2) Tongue River near Dayton (#06298000); and North Fork Powder River near Hazelton (#06311000). The recorded streamflow at each of these sites either reflects or is adjusted to reflect natural flow, without the influence of man. The annual streamflow at each of these stations for the longest concurrent period of record (1947 – 1999) are summarized in Table 2.

The average annual flow for the period 1970 to 1999 is relatively close to the average annual flow for the longer-term period (1% to 4% wetter) for the three stations. Surplus / Deficit plots for each of these three stations for the 1947 to 1999 period are shown on Figures 9, 10, and 11.

On the Little Bighorn River, the period 1970 to 1999 includes the extended dry periods from 1979 through 1983 and 1985 through 1994 as well as the wet period from 1971 through 1978. This period also contains three out of six of the driest years of the 1947 – 1999 records including 1985, 1987, and 1989. The period also contains three out of six of the wettest years of record in 1970, 1975, and 1978. The driest and wettest years are defined here as those with exceedance or non-exceedance probabilities of less than approximately 10 percent.

On the Tongue River, the period 1970 to 1999 includes the extended dry periods 1979 to 1982 and 1985 to 1989 as well as the wet period from 1971 to 1978. Similar to the Little Bighorn, this period contains three out of six of the driest years of the 1947 – 1999 records for the Tongue River including 1985, 1987, and 1989. The period also contains three out of six of the wettest years of record in 1970, 1975, and 1978.

FIGURE 8

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

TONGUE RIVER NEAR DAYTON, WY (Station 06298000) — 1941 TO 1999

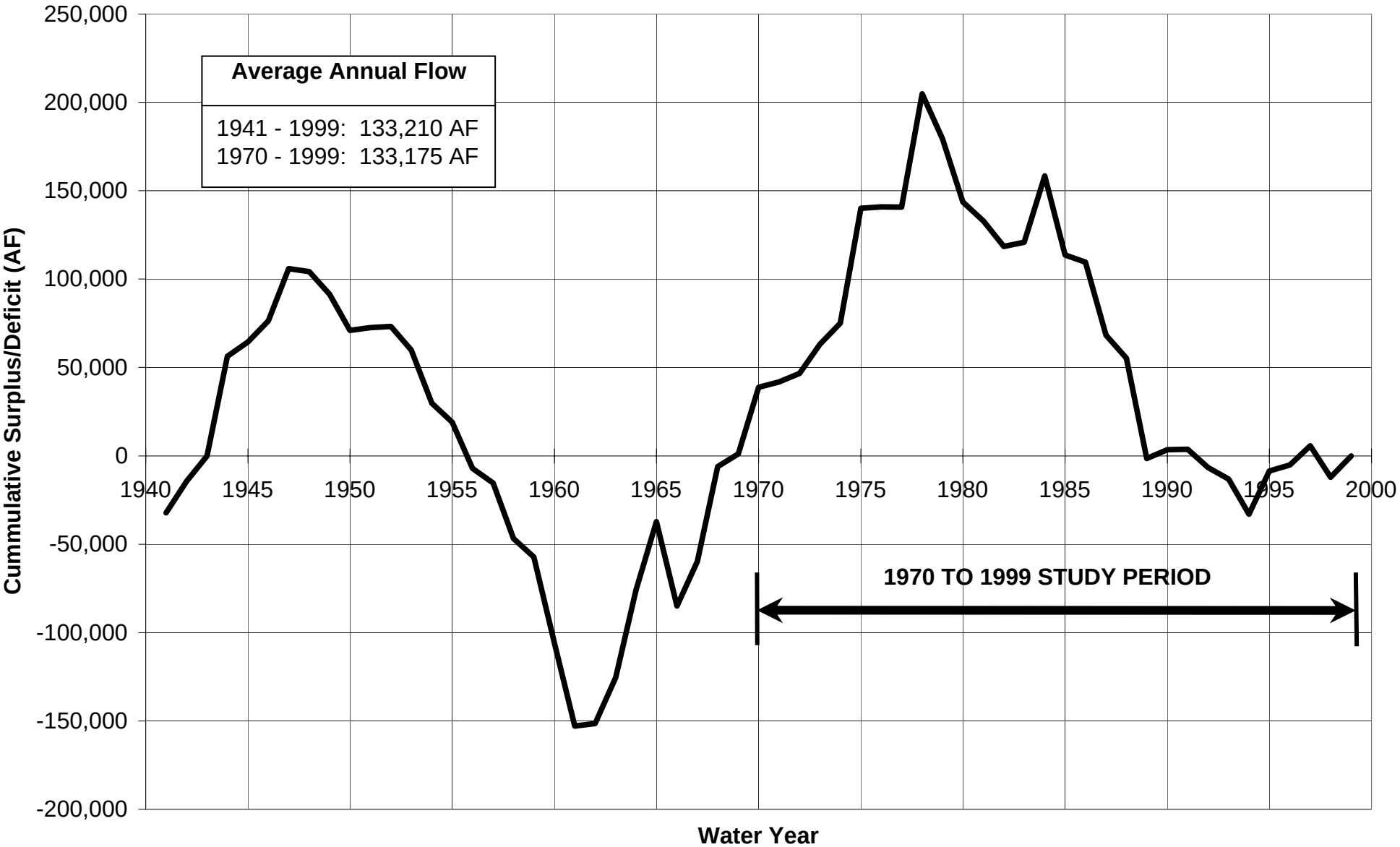


TABLE 2

AVERAGE ANNUAL FLOW COMPARISON TO 1970-1999 STUDY PERIOD AVERAGE

	Annual Flow in Acre-Feet		
YEAR	Little Bighorn River at State Line Near Wyola, MT **06289000**	Tongue Near Dayton **06298000**	North Fork Powder Near Hazelton **06311000**
1947	132,030	162,878	13,906
1948	102,260	131,476	9,462
1949	93,250	120,409	10,017
1950	78,340	112,752	8,873
1951	94,970	134,751	7,763
1952	98,470	133,919	11,231
1953	92,550	119,860	9,382
1954	88,230	103,095	5,178
1955	98,040	122,448	10,253
1956	80,480	107,076	8,116
1957	114,990	124,900	11,243
1958	87,300	101,807	9,414
1959	104,190	122,788	9,191
1960	71,260	84,561	5,812
1961	65,400	86,151	5,006
1962	95,040	134,761	15,031
1963	126,220	159,248	12,706
1964	157,060	182,715	13,592
1965	146,190	171,865	13,469
1966	83,510	85,379	5,694
1967	133,180	158,525	19,339
1968	142,730	186,786	15,748
1969	118,280	140,406	10,297
1970	159,600	170,984	10,137
1971	121,810	136,242	11,584
1972	111,430	138,031	8,818
1973	133,310	149,701	9,131
1974	130,710	145,021	8,001
1975	182,880	198,294	15,883
1976	123,370	134,000	12,204
1977	115,910	133,134	8,882
1978	170,730	197,249	18,963
1979	93,400	107,713	10,405
1980	81,830	97,481	7,931
1981	95,510	122,507	7,608
1982	97,200	118,780	13,633
1983	106,830	135,628	13,118
1984	136,970	170,772	14,335
1985	72,360	88,393	6,974
1986	101,170	129,213	10,860
1987	77,020	91,860	9,735
1988	93,900	120,159	7,889
1989	68,060	76,527	8,693
1990	103,430	138,184	9,213
1991	110,400	133,469	12,926
1992	90,470	122,866	12,580
1993	96,740	126,667	13,847
1994	98,000	113,240	8,105
1995	126,540	157,750	15,254
1996	113,090	136,583	13,603
1997	121,120	144,068	15,384
1998	107,010	115,427	12,443
1999	127,190	145,292	17,182
Avg 47-99	108,905	131,770	11,057
Avg 70-99	112,266	133,175	11,511

FIGURE 9

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

LITTLE BIGHORN RIVER AT STATE LINE NEAR WYOLA, MT (Station 06289000)

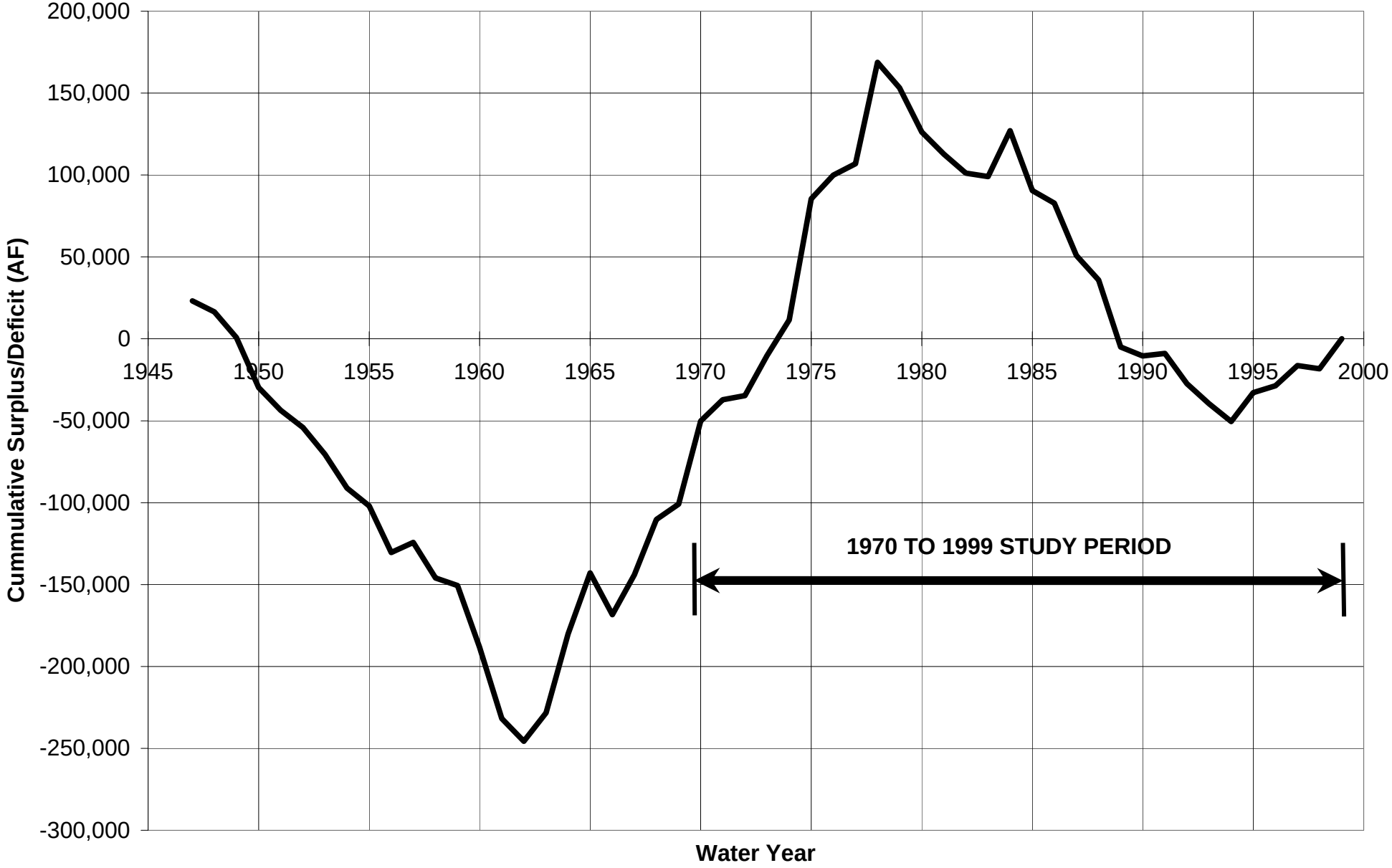


FIGURE 10

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

TONGUE RIVER NEAR DAYTON, WY (Station 06298000)

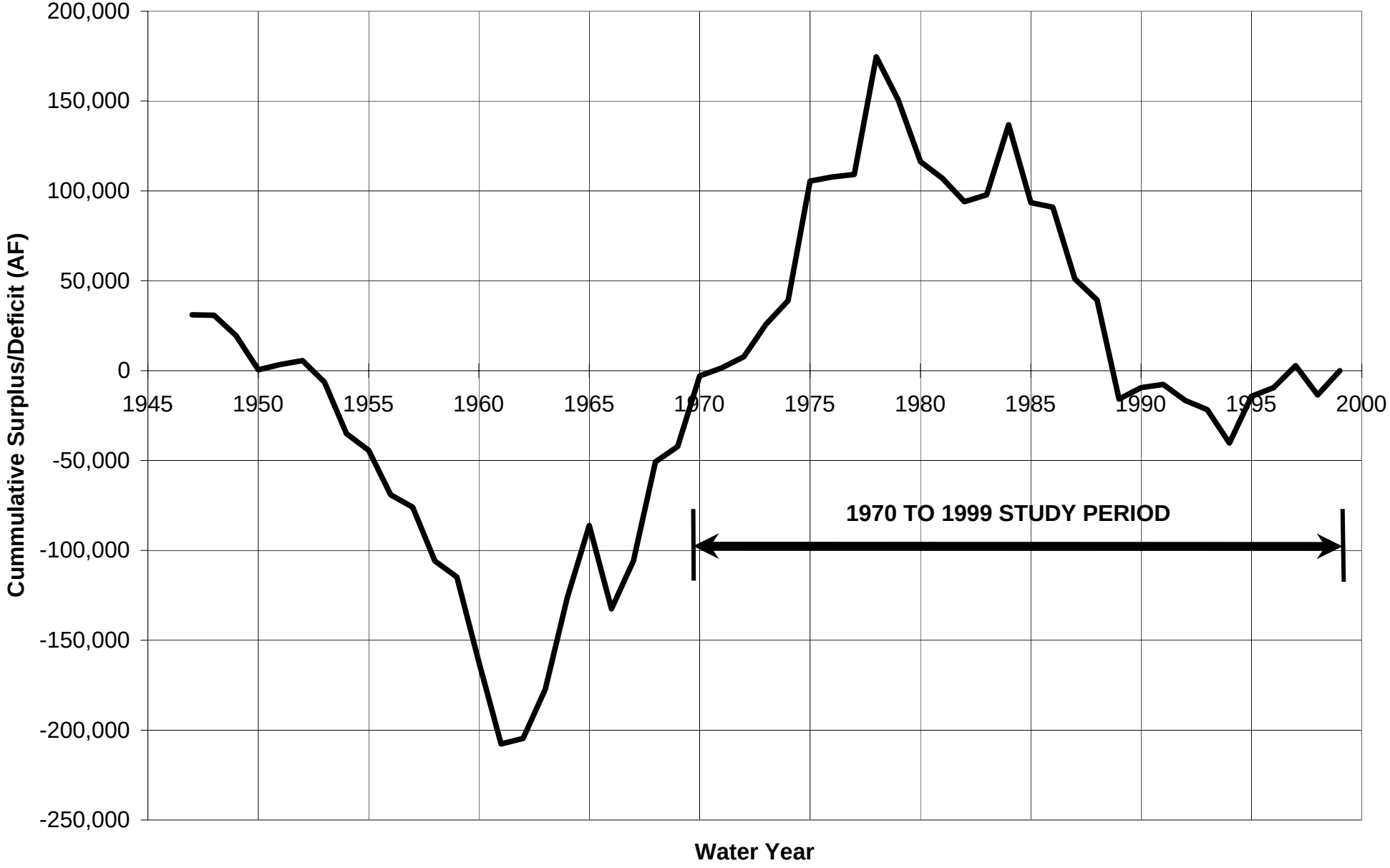
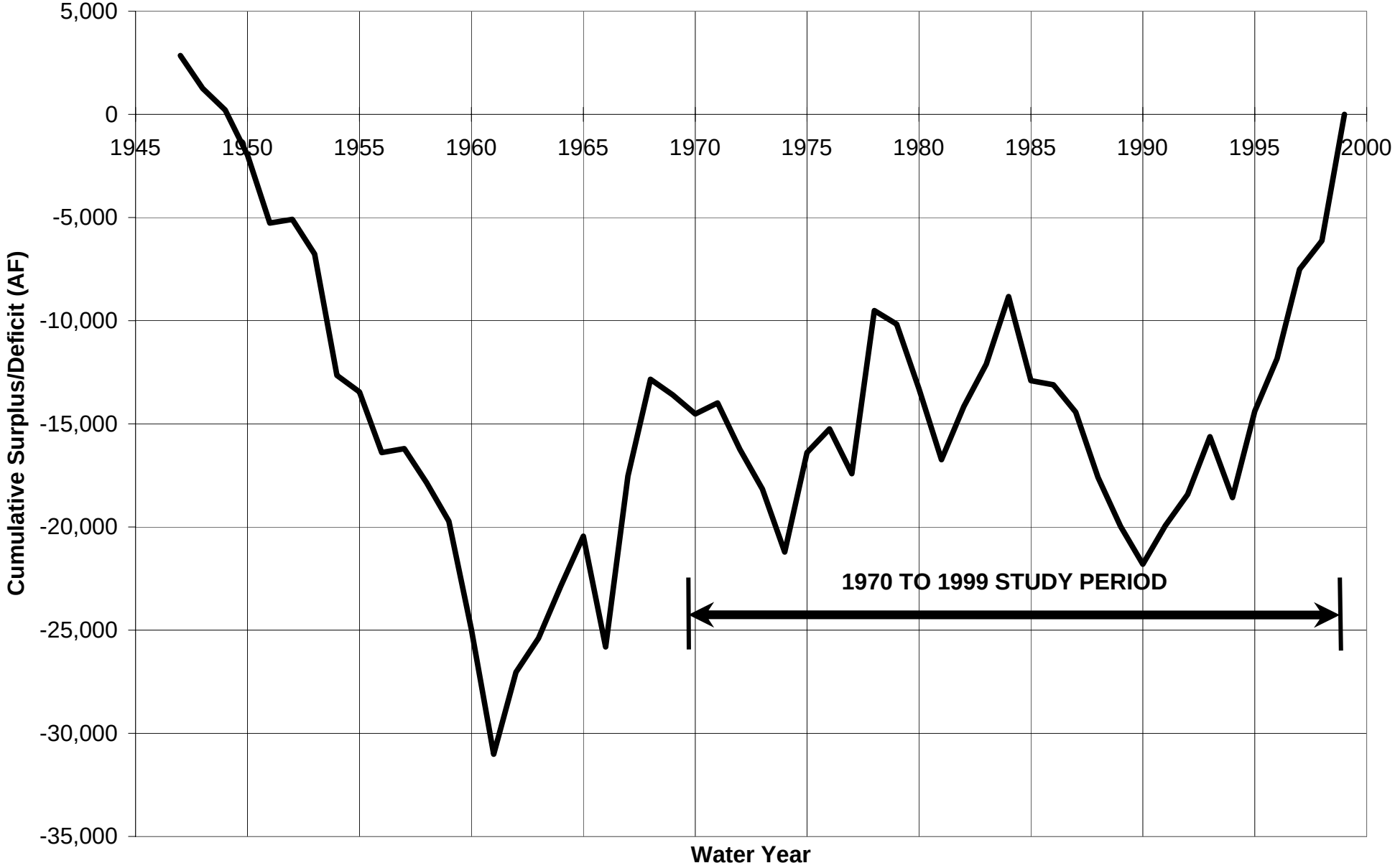


FIGURE 11

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

NORTH FORK POWDER RIVER NEAR HAZELTON, WY (Station 06311000)



The 1970 to 1999 period on the North Fork Powder River contains the dry periods from 1972 through 1974, 1979 through 1981 and 1985 through 1990 as well as the wet period 1995 through 1999. This period also contains two of the six driest years of the 1947 – 1999 records in 1981 and 1985 and 4 of the six wettest years of record in 1975, 1978, 1997, and 1999.

In summary, the period 1970 through 1999 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 and therefore requires less data synthesis. A study period of 1970 through 1999 is therefore appropriate for purposes of water availability modeling for the Powder/Tongue River Basin Plan.

The remainder of this memorandum describes the methodologies used to determine the typical dry year, normal year, and wet year monthly flows required at each of the model nodes.

DATA EXTENSION

The spreadsheet modeling approach used for the Basin Plan relies on both records of natural flow as well as records from stations impacted by upstream diversions or regulation. Natural flow is supplied to the model, where available, at the headwater nodes and non-natural flow records at downstream gaging stations are used to calibrate the model to historic conditions. Monthly streamflows must therefore be estimated for both categories of gaging stations for those months, during the study period, with no recorded streamflow data.

The monthly record extension approach used in this study follows the procedure used by the USGS in recent studies in Montana (USGS WRI 89-4165, 1989: USGS WRI 89-4082, 1989). This mixed-station procedure uses the best base station from among all available base stations to fill in each month of missing data for a given gage. It is therefore possible that several different base stations may be used to fill in different months of missing data for a given station. The base station producing the smallest standard error of prediction is used for each particular month. The monthly record extension procedure also offers the option of using cyclic or noncyclic equations to fill in missing records. If the cyclic option is selected, an extension equation is computed for each month using only concurrent streamflows for the month. If the noncyclic option is selected, a single extension equation is computed using all concurrent streamflows. The smallest standard error criterion is used to select between the cyclic or noncyclic option for each month of missing record. For this study, the cyclic option is used only if the base station and the short record station have at least five concurrent monthly streamflows. The noncyclic option is used in all other cases. The technique used to estimate missing values in this study was developed by Hirsch and is referred to as MOVE.1 (Maintenance of Variance Extension, Type 1). This technique offers the advantage over ordinary least-squares regression of preserving the variance of the unextended records (Alley and Burns, 1983). The MOVE.1 technique differs from ordinary least-squares regression in that ordinary regression minimizes the squared vertical deviations of the response variable from the regression line, whereas the MOVE.1 technique minimizes the areas of the right triangles formed by the horizontal and vertical deviations from the regression line (USGS WRI 89-4165, 1989). This procedure is carried out using a computer program developed by the USGS.

The USGS and SEO streamflow stations are first divided into natural flow stations and non-natural flow stations. The stations are then further divided into hydrologically similar groups with each group having at least one gage with sufficient data to develop relationships based on concurrent streamflow for the entire study period. The monthly flow extension procedure is performed for each of these groupings of monthly streamflow data. There is a certain amount of overlap in hydrologic similarity among the various groupings. Some streamflow stations are therefore included in multiple groups. Records from the long-term natural flow stations are also included with some of the non-natural flow groupings where appropriate to provide adequate data for extending the records through the entire study period. The station groupings and the resulting coefficients of determination (R^2) are provided in Table 3 and Table 4 respectively for the natural flow stations and the non-natural flow stations. The coefficient of determination is defined as the proportion of variation in the independent variable that can be explained by variation in the dependent variable (DeVore, 1987). The higher the value of R^2, the stronger the

TABLE 3

CORRELATION RESULTS BASED ON MONTHLY DATA

NATURAL FLOW STATIONS IN THE POWDER-TONGUE BASIN

Basin	Station Number	Station Name	USGS MOVE.1 EXTENSION GROUPINGS											Wtd. Avg. R^2 Value	Notes
			LBIGNAT7	LBIENAT7	LBIDNAT7	TONANAT7	TONBNAT7	POWANAT7	POWDNAT7	CRAANAT7	CRABNAT7	CLEANAT7	CLERNAT7		
Little Bighorn	06288600	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	■	▒	▒									0.95	
	06288700	Dry Fork Little Bighorn Below Lick Creek Near Burgess Junction, WY	▒	■	▒									0.98	
	06288960	Little Bighorn River Near Parkman, WY	▒	■	▒									0.99	
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	■	▒	▒									0.83	
	06288990	West Fork Little Bighorn River Near Parkman, WY	▒	■										0.96	
	06289000	Little Bighorn River at State Line Near Wyola, MT	▒	▒										N/A	Records available for entire study period
	06289100	Red Canyon Creek Near Parkman, WY	▒	▒	▒									No Correlation	See Table 5
	06289800	East Pass Creek Near Parkman, WY	▒	▒	■									0.88	
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	▒	▒	■									0.96	
Tongue	06297000	South Fork Tongue River Near Dayton, WY				■	▒							0.96	
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY				■	▒							0.99	
	06298000	Tongue River Near Dayton, WY	▒	▒	▒	▒	▒							N/A	Records available for entire study period
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY				■	▒							0.97	
	06298480	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY				■	▒							0.98	
	06298500	Little Tongue River Near Dayton, WY				▒	■							0.95	
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY				■	▒							0.99	
	06299490	Wolf Creek Above Red Canyon Creek at Wolf, WY				■	▒							0.99	
	06299500	Wolf Creek at Wolf, WY				■	▒							0.97	
	06300500	East Fork Big Goose Creek Near Big Horn, WY				▒	■							0.88	
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY				■	▒							0.94	
Powder	06309200	Middle Fork Powder River Near Barnum, WY						▒	▒			▒	▒	N/A	Records available for entire study period
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY						■	▒					0.98	
	06309270	North Fork Buffalo Creek Near Arminto, WY						■	▒					0.96	
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY						▒	■					0.85	
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY						■	▒					0.88	
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY						■	▒					0.83	
	06311000	North Fork Powder River Near Hazelton, WY						▒	▒			▒	▒	N/A	Records available for entire study period
	06313180	Dugout Creek Tributary Near Midwest, WY						▒	▒					No Correlation	See Table 5
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY								■	▒			0.94	
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY								■	▒			0.94	
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY								▒	■			0.92	
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY								▒	■			0.80	
	06315490	Poison Creek Near Mayoworth, WY								▒	■			0.82	
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY								▒	■			0.86	
	06317300	Sourdough Creek Near Buffalo, WY										■	▒	0.85	
	06317340	Little Sourdough Creek Near Buffalo, WY										▒	▒	No Correlation	See Table 5
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY										▒	■	0.98	
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY										▒	■	0.98	
	06321500	North Piney Creek Near Story, WY										■	▒	0.90	

LEGEND	
■	USGS MOVE.1 Group resulting in best R^2 value
▒	Station included in USGS MOVE.1 group

TABLE 4

CORRELATION RESULTS BASED ON MONTHLY DATA

NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE BASIN

Basin	Station Number	Station Name	USGS MOVE.1 EXTENSION GROUPINGS												Wtd. Avg. R^2 Value	Notes
			TONDNON7	TONBNON7	NONTONC7	POWCNON7	POWANON7	CLEBNON7	CLEANON7	PINANON7	NONPOWC7	NONPOWH7	NONPOWB7	BELBNON7		
Little Bighorn	06289600	West Pass Creek Near Parkman, WY	■	▒											0.83	
	06289000	Little Bighorn River at State Line Near Wyola, MT			▒						▒	▒			N/A	Natural Flow Station; Records available for entire study period
	06289820	East Pass Creek Near Dayton, WY	■	▒											0.88	
	06289870	Twin Creek Near Parkman, WY	▒	▒	▒										No Correlation	See Table 5
Tongue	06298000	Tongue River Near Dayton, WY			▒						▒	▒			N/A	Natural Flow Station; Records available for entire study period
	06302000	Big Goose Creek Near Sheridan, WY	▒	▒	■										0.90	
	06303500	Little Goose Creek Near Big Horn, WY	▒	▒											0.76	
	06305500	Goose Creek Below Sheridan, WY	▒	■											0.99	
	06305700	Goose Creek Near Acme, WY	▒												0.99	
	06306250	Prairie Dog Creek Near Acme, WY	▒	▒	▒										No Correlation	See Table 5
	06306300	Tongue River at State Line Near Decker, MT											▒		N/A	Records available for entire study period
Powder	06309200	Middle Fork Powder River Near Barnum, WY			▒	▒	▒				▒	▒			N/A	Natural Flow Station; Records available for entire study period
	06309500	Middle Fork Powder River Above Kaycee, WY				▒	▒					■			0.88	
	06311000	North Fork Powder River Near Hazelton, WY			▒	▒	▒					▒			N/A	Natural Flow Station; Records available for entire study period
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY				▒	▒					▒			No Correlation	See Table 5
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY				▒	▒					▒			No Correlation	See Table 5
	06313500	Powder River at Sussex, WY				■	▒								0.85	
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY				■	▒					▒			0.78	
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY				▒	■								0.83	
	06317000	Powder River at Arvada, WY	▒	▒		▒	▒	▒	▒						N/A	Records available for entire study period
	06318500	Clear Creek Near Buffalo, WY						▒	▒						No Correlation	See Table 5
	06318550	Clear Creek in Buffalo City Park, Buffalo, WY						■	▒						0.84	
	06320000	Rock Creek Near Buffalo, WY						▒	▒		■		▒		0.81	
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY						▒	■						0.73	
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY						▒	▒		▒		■		0.85	
	SEO Gage	Clear Creek Below Healy Reservoir Near Buffalo, WY						■	▒						0.72	
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY						▒	■						0.76	
	SEO Gage	Clear Creek Below P&F#3 Ditch Near Clearmont, WY						▒	▒	■					0.89	
	06324000	Clear Creek Near Arvada, WY						▒	▒	■					0.77	
	06321000	South Piney Creek Near Story, WY										▒			No Correlation	See Table 5
	06323000	Piney Creek at Kearney, WY								▒	▒		■		0.81	
	SEO Gage	Little Piney Creek, WY								■					0.78	
	SEO Gage	Piney Creek Below Lake DeSmet Tunnel Intake Near Story, WY								▒	▒		▒		No Correlation	See Table 5
	06323500	Piney Creek at Ucross, WY								▒	▒		▒		No Correlation	See Table 5
	06324500	Powder River at Moorhead, MT				■	▒			▒					0.86	
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY				▒	▒							▒	No Correlation	See Table 5
	06324925	Little Powder River Near Weston, WY				▒	▒							■	0.80	
	06324970	Little Powder River Above Dry Creek Near Weston, WY				▒	▒							▒	No Correlation	See Table 5
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY											▒	▒	N/A	See Table 5

LEGEND	
■	USGS MOVE.1 Group resulting in best R^2 value
▒	Station included in USGS MOVE.1 group

relationship between the two variables. A perfect relationship would have an $R^2 = 1.0$. Regression of hydrologic data resulting in $R^2 > 0.7$ is typically considered strong enough for data estimating. This criterion was used in evaluating the results of the regression analyses. The results of the MOVE.1 analyses are provided in Appendix A.

As shown in Tables 3 and 4, in some instances no significant correlation ($R^2<0.7$) could be found using concurrent monthly streamflows between any base station and the short record station. Annual flow regression rather than monthly flow regression was performed in these instances to fill-in the missing streamflow data. The results of this analysis including the base station record used to fill-in the missing data at the short record station, the regression equation, and the resulting coefficient of determination (R^2) are summarized in Table 5. The supporting computations and graphic displays of the results of the annual flow regression analyses are provided in Appendix B. As noted in Table 5, in a few cases, no significant correlation ($R^2<0.7$) could be found using the annual flow regression either. These stations were dropped from the study. The monthly streamflows for the years of missing data were estimated by applying the average monthly distribution for the period of recorded streamflow to the estimated total annual flow. For those instances when records for some months are available, the recorded streamflows are used and subtracted from the estimated annual total. The remaining months of missing data are then filled-in using the average monthly distribution for these months applied to the total remaining streamflow for the partial year.

The average monthly and annual streamflows for the 1970 to 1999 study period, for the natural flow streamflow stations and the non-natural flow streamflow stations are summarized in Table 6 and Table 7 respectively. The recorded and extended monthly streamflows for each year of the 1970 to 1999 study period are provided in Appendix C for each gaging station selected for use in the water availability models.

NATURAL FLOW AT UNGAGED MODEL NODES

Records of streamflow are used to the extent available to represent natural flow at model nodes. However, to fully represent water use in the various drainages, estimates of natural flow are also required at several model nodes where records from USGS or SEO streamflow stations are unavailable. HKM evaluated several alternatives for estimating natural flow at these locations including:

1. Use the recorded streamflow at a downstream streamflow station, adjusting for depletions and storage regulation as well as for the smaller drainage area to estimate natural flow at an upstream location.

2. Develop a regression equation based on recorded and extended natural flow for 1970 to 1999 developed through this study (Table 6), relating drainage area and average annual precipitation or mean basin elevation to natural flow.

3. Use the regression equations developed by the USGS in WRIR 88-4045 relating drainage area and either average annual precipitation or mean basin elevation to natural flow.

The downstream streamflow stations are typically highly influenced by irrigation depletions, transbasin diversions, and storage regulation. To develop natural flows using Alternative 1, the records for the downstream station would first need to be adjusted to remove these influences. Insufficient transbasin diversion and reservoir operation data is, typically, available to make these adjustments. It is also questionable, in many cases, whether the downstream gages, which represent runoff from a much larger area, are representative of the unit runoff rates from the smaller and higher elevation drainages of the ungaged model nodes. It is therefore concluded that the first alternative does not yield reliable estimates of natural flow in most cases. The two exceptions are Prairie Dog Creek in the Tongue River basin and Little Piney Creek in the Powder River basin. Alternative 1 yielded the most reasonable estimates of natural flow for these two locations as evaluated during the calibration of the water availability models. Natural flow at the upstream location is estimated as natural flow at the downstream location multiplied by the proportion of the upstream drainage area to the downstream drainage area. The depletions

TABLE 5
CORRELATION RESULTS BASED ON ANNUAL DATA
STATIONS IN THE POWDER-TONGUE BASIN

Basin	Station Number	Station Name	Natural Flow	Station Used in Regression	R^2 Value	Regression Equation	Notes
Little Bighorn	06289100	Red Canyon Creek Near Parkman, WY	YES	Little Bighorn River at State Line, Near Wyola, MT (Station 06289000)	0.90	Y = 0.025398X - 1391.2	
	06289870	Twin Creek Near Parkman, WY	NO	Little Bighorn River at State Line, Near Wyola, MT (Station 06289000)	0.74	Y = 0.11280X - 7152.9	
Tongue	06301485	Lost Lake Creek Near Big Horn, WY	YES		No Correlation		Unable to find significant correlation with any available station
	06301490	Snail Creek Near Big Horn, WY	YES		No Correlation		Unable to find significant correlation with any available station
	06306250	Prairie Dog Creek Near Acme, WY	NO	Powder River at Arvada, WY (Station 06317000)	0.87	Y = 0.072738X + 15381	
Powder	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	NO	North Fork Powder River Near Hazelton, WY (Station 06311000)	0.83	Y = 0.95976X + 2154.2	
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	NO	North Fork Powder River Near Hazelton, WY (Station 06311000)	0.79	Y = 1.4351X + 9453.4	
	06312500	Powder River Near Kaycee, WY	NO	Middle Fork Powder River Near Barnum, WY (Station 06309200)	0.87	Y = 2.6695X + 36671	
	06313000	South Fork Powder River Near Kaycee, WY	NO	Powder River at Arvada, WY (Station 06317000)	0.91	Y = 0.13407X + 307.34	
	06313180	Dugout Creek Tributary Near Midwest, WY	YES		No Correlation		Unable to find significant correlation with any available station
	06313400	Salt Creek Near Sussex, WY	NO	Powder River at Sussex, WY (Station 06313500)	0.75	Y = 0.14172X + 10815	
	06317340	Little Sourdough Creek Near Buffalo, WY	YES	Powder River at Arvada, WY (Station 06317000)	0.99	Y = 0.0047854X - 207.81	
	06318500	Clear Creek Near Buffalo, WY	NO	Clear Creek in Buffalo City Park, Buffalo, WY (SEO Gage)	0.80	Y = 0.73548X + 24886	
	06321000	South Piney Creek Near Story, WY	NO	North Fork Powder River Near Hazelton, WY (Station 06311000)	0.84	Y = 2.8480X + 28319	
	SEO Gage	Piney Creek Below Lake DeSmet Tunnel Intake Near Story, WY	NO	Piney Creek at Kearney, WY (Station 06323000)	0.88	Y = 0.97670X - 10655	Irrigation Season Regression
	06323500	Piney Creek at Ucross, WY	NO	Piney Creek at Kearney, WY (Station 06323000)	0.78	Y = 1.0792X - 3636.2	Irrigation Season Regression
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.99	Y = 0.18483X - 463.92	
	06324970	Little Powder River Above Dry Creek Near Weston, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.80	Y = 0.90409X+ 475.71	
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	NO	Inflow to Keyhole Reservoir (USBR Gage)	0.87	Y = 0.57098X - 386.15	Applied to Monthly Values

TABLE 6

SUMMARY OF AVERAGE MONTHLY AND ANNUAL FLOWS (1970 TO 1999)

NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	**06288600**	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	414	301	268	238	195	215	358	3,600	6,008	1,685	779	463	**14,524**
	06288700	Dry Fork Little Bighorn River Below Lick Creek Near Burgess Junction, WY	1,855	1,599	1,498	1,383	1,223	1,326	1,709	6,248	9,433	4,505	2,644	2,029	**35,452**
	06288960	Little Bighorn River near Parkman, WY	4,011	3,353	3,098	2,864	2,479	2,777	3,771	17,119	27,107	11,347	6,045	4,433	**88,404**
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	114	100	92	86	75	88	141	486	618	202	135	124	**2,261**
	06288990	West Fork Little Bighorn River Near Parkman, WY	939	794	734	672	593	671	896	3,868	5,800	2,421	1,355	1,040	**19,783**
	06289000	Little Bighorn River at State Line Near Wyola, MT	5,420	4,574	4,258	3,958	3,479	3,880	5,154	21,093	32,321	14,270	7,902	5,957	**112,266**
	06289100	Red Canyon Creek Near Parkman, WY	35	32	26	28	23	42	216	561	242	65	32	28	**1,330**
	06289800	East Pass Creek Near Parkman, WY	469	389	366	338	303	328	547	1,899	2,298	1,062	638	508	**9,145**
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	464	352	316	288	242	271	558	3,619	5,268	1,760	780	531	**14,449**
Tongue	**06297000**	South Fork Tongue River Near Dayton, WY	1,424	1,033	942	803	652	741	1,839	14,823	22,367	6,444	2,527	1,656	**55,251**
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY	5,064	3,935	3,623	3,295	2,824	3,107	6,129	31,109	42,528	15,621	7,855	5,653	**130,743**
	06298000	Tongue River Near Dayton, WY	5,130	3,954	3,642	3,315	2,825	3,117	6,186	31,983	43,180	16,162	7,951	5,730	**133,175**
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY	134	94	83	72	58	69	249	2,165	3,088	726	274	167	**7,179**
	06298490	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY	98	67	58	50	40	46	139	1,641	2,643	591	200	118	**5,691**
	06298500	Little Tongue River Near Dayton, WY	225	158	139	124	105	118	402	3,299	4,503	1,144	427	268	**10,912**
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY	471	341	304	267	219	255	784	6,063	8,521	2,214	855	537	**20,831**
	06299490	Wolf Creek Above Red Canyon Creek Near Wolf, WY	536	404	364	329	276	308	784	5,804	8,126	2,169	849	540	**20,489**
	06299500	Wolf Creek at Wolf, WY	539	399	356	317	271	298	854	5,767	7,980	2,237	926	603	**20,547**
	06300500	East Fork Big Goose Creek Near Big Horn, WY	426	284	220	204	154	171	557	5,296	10,978	3,740	1,096	698	**23,824**
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY	30	18	14	10	8	9	49	1,091	1,781	534	83	48	**3,675**
Powder	**06309200**	Middle Fork Powder River Near Barnum, WY	457	416	370	331	295	424	2,125	9,807	5,212	1,061	527	433	**21,457**
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY	31	28	23	20	17	28	218	1,350	649	101	38	28	**2,531**
	06309270	North Fork Buffalo Creek Near Arminto, WY	86	79	70	62	55	79	370	1,639	915	200	103	84	**3,742**
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY	0	0	0	0	0	0	34	1,918	950	51	2	1	**2,956**
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY	185	166	143	126	111	156	519	1,787	1,141	429	247	192	**5,202**
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	612	568	546	518	476	561	997	2,211	1,674	911	695	610	**10,379**
	06311000	North Fork Powder River Near Hazelton, WY	294	220	180	144	120	142	603	3,864	4,037	1,111	471	325	**11,511**
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY	629	474	387	307	257	301	1,142	5,582	5,774	1,983	918	645	**18,399**
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	640	481	395	316	265	307	1,152	5,490	5,637	1,987	924	655	**18,249**
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY	558	412	337	264	217	269	1,184	7,726	8,139	2,222	917	624	**22,869**
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY	214	175	150	127	112	126	346	1,172	1,155	490	279	218	**4,564**
	06315490	Poison Creek Near Mayoworth, WY	246	202	176	150	132	151	387	1,232	1,220	542	320	251	**5,009**
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY	707	551	470	391	334	411	1,290	5,891	6,016	2,072	1,031	759	**19,923**
	06317300	Sourdough Creek Near Buffalo, WY	70	52	44	34	28	34	107	775	905	265	112	78	**2,504**
	06317340	Little Sourdough Creek Near Buffalo, WY	37	22	7	3	2	5	206	214	139	36	16	25	**712**
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY	447	341	280	227	187	217	900	5,431	5,744	1,722	714	491	**16,701**
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY	426	325	264	213	177	205	870	5,367	5,703	1,675	689	471	**16,385**
	06321500	North Piney Creek Near Story, WY	800	626	511	423	354	439	1,817	10,506	10,318	2,733	1,139	842	**30,508**

TABLE 7
SUMMARY OF AVERAGE MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06289600	West Pass Creek Near Parkman, WY	522	476	441	419	407	497	770	2,023	2,007	810	488	495	**9,355**
	06289820	East Pass Creek Near Dayton, WY	621	575	543	531	519	629	958	2,666	2,800	905	469	530	**11,746**
	06289870	Twin Creek Near Parkman, WY	108	92	119	328	236	741	847	1,656	349	154	115	87	**4,833**
Tongue	06302000	Big Goose Creek Near Sheridan, WY	2,307	1,727	1,576	1,427	1,199	1,336	2,247	13,175	27,034	8,560	4,642	3,625	**68,855**
	06303500	Little Goose Creek in Canyon Near Big Horn, WY	1,855	1,396	1,274	1,147	968	1,076	2,082	10,835	14,826	6,582	5,236	3,425	**50,702**
	06305500	Goose Creek Below Sheridan, WY	6,692	5,855	5,109	4,570	4,971	6,223	8,284	26,807	40,099	10,115	4,047	5,595	**128,367**
	06305700	Goose Creek Near Acme, WY	6,848	5,984	5,215	4,660	5,076	6,364	8,494	27,713	41,776	10,431	4,120	5,725	**132,406**
	06306250	Prairie Dog Creek Near Acme, WY	2,785	2,192	1,835	1,286	2,567	5,705	2,784	3,701	2,327	1,416	1,730	2,350	**30,678**
	06306300	Tongue River at State Line Near Decker, MT	16,187	13,719	11,317	11,134	13,110	19,427	21,867	73,969	98,409	29,613	11,756	13,340	**333,850**
Powder	06309500	Middle Fork Powder River Above Kaycee, WY	2,812	2,642	2,490	2,387	2,235	2,693	5,676	14,882	9,586	3,978	2,759	2,581	**54,721**
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	240	169	159	129	119	143	367	3,188	4,121	2,014	1,524	1,028	**13,202**
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	1,326	1,138	1,139	1,110	994	1,089	1,613	4,891	5,510	2,835	2,410	1,917	**25,972**
	06312500	Powder River Near Kaycee, WY	5,062	6,385	6,481	5,606	6,441	8,416	8,944	27,066	15,875	1,006	888	1,783	**93,950**
	06313000	South Fork Powder River Near Kaycee, WY	172	237	163	190	1,350	7,672	5,987	9,131	2,072	602	1,729	11	**29,316**
	06313400	Salt Creek Near Sussex, WY	2,257	1,820	1,706	1,849	2,577	4,243	3,003	5,395	4,120	3,062	1,940	1,853	**33,825**
	06313500	Powder River at Sussex, WY	10,088	8,646	7,430	7,200	10,592	17,746	17,475	38,478	26,121	9,211	4,476	4,899	**162,362**
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY	329	223	218	196	150	189	1,697	8,924	13,287	3,211	1,242	978	**30,644**
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY	1,688	1,356	1,036	885	1,627	2,517	3,386	9,747	8,975	2,196	1,151	769	**35,333**
	06317000	Powder River at Arvada, WY	11,144	9,646	7,235	6,773	11,517	23,619	21,176	52,067	42,800	14,235	6,162	5,400	**211,773**
	06318500	Clear Creek Near Buffalo, WY	2,253	1,583	1,220	909	759	1,009	2,710	12,305	17,834	8,639	3,929	2,749	**55,899**
	SEO Gage	Clear Creek in Buffalo City Park, Buffalo, WY	1,886	1,397	1,138	947	1,277	1,972	2,407	9,746	14,070	4,659	1,414	1,254	**42,167**
	06320000	Rock Creek Near Buffalo, WY	894	653	587	525	437	490	993	7,108	9,142	3,800	2,729	1,558	**28,916**
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY	1,572	1,322	1,026	927	1,272	2,245	1,360	5,460	7,121	1,755	929	918	**25,907**
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY	3,672	3,132	2,571	2,386	2,774	4,084	5,349	17,212	23,059	7,586	3,034	3,074	**77,933**
	SEO Gage	Clear Creek below Healy Reservoir Near Buffalo, WY	2,601	1,730	1,299	1,079	1,454	2,483	3,739	14,926	20,747	7,964	3,380	2,772	**64,174**
	06321000	South Piney Creek Near Story, WY	2,068	1,539	1,514	1,257	961	1,032	1,555	5,964	20,205	12,621	9,042	5,535	**63,293**
	06323000	Piney Creek at Kearney, WY	1,886	2,307	2,059	1,875	1,607	2,038	4,072	15,796	23,765	6,122	2,061	1,265	**64,853**
	SEO Gage	Little Piney Creek, WY	784	751	591	583	709	964	945	1,620	1,489	881	602	689	**10,608**
	SEO Gage	Piney Creek below Lake DeSmet Tunnel Intake Near Story, WY	1,524	1,056	741	664	613	864	1,953	10,657	20,258	5,591	2,118	1,431	**47,470**
	06323500	Piney Creek at Ucross, WY	3,450	3,413	2,641	2,362	1,632	2,969	3,928	12,580	20,834	7,887	5,206	3,718	**70,620**
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY	8,484	7,580	6,042	5,208	5,866	9,456	9,217	27,303	42,211	14,623	7,589	6,807	**150,386**
	SEO Gage	Clear Creek below P&F#3 Ditch Near Clearmont, WY	6,464	5,750	3,619	3,474	5,276	9,697	8,968	24,292	38,482	10,460	4,558	4,444	**125,484**
	06324000	Clear Creek Near Arvada, WY	7,050	6,494	4,356	4,151	5,773	9,919	10,332	25,700	38,174	11,742	5,498	5,462	**134,651**
	06324500	Powder River at Moorhead, MT	18,021	16,072	10,330	10,928	18,963	36,118	29,810	73,536	79,314	27,131	11,758	10,494	**342,475**
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	8	16	23	57	182	1,022	138	1,239	103	267	38	0	**3,093**
	06324925	Little Powder River Near Weston, WY	637	128	74	360	2,640	4,275	1,982	3,093	1,600	463	275	161	**15,688**
	06324970	Little Powder River Above Dry Creek Near Weston, WY	823	260	174	580	2,501	4,299	1,602	4,205	1,992	748	404	284	**17,873**
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	682	203	149	420	1,761	4,664	2,268	5,169	2,134	997	515	281	**19,243**

(diversions minus return flows) used to make the adjustments to the downstream gage records are based on three representative hydrologic conditions (wet, normal, and dry years) and are taken from the water availability modeling work. The natural flow estimates for these two locations are therefore provided for these three representative hydrologic conditions only. This is in contrast to the estimates of natural flow at the other ungaged node locations for which natural flow estimates are provided for each month and each year within the 1970 to 1999 study period. The selection of the years used to represent wet, normal, and dry conditions are discussed in the next section. The derivation of natural flow at these two locations is provided in Appendix D.

Monthly natural flows have been developed through this study at 40 streamflow stations in the Powder/Tongue River Basin. A second alternative is therefore to utilize this data to develop a localized regression equation for estimating natural flow at the ungaged sites. Unfortunately the mean basin elevation for these natural flow stations are typically greater than 7,000 feet. Whereas, the majority of the drainages contributing to the ungaged model nodes have mean basin elevations less than 7,000 feet. A regression equation developed from the recorded natural flow data set would not be applicable to the sites where natural flow estimates are required. Alternative 2 was therefore not selected.

The USGS is currently updating the work originally developed by Lowham in the report "Streamflows in Wyoming" (USGS, 1988). Unfortunately, at the time of this writing, that work is several months away from completion. The 1988 USGS report however presents regression equations, which rely on drainage area and average annual precipitation or mean basin elevation to estimate mean annual flow. The equation for the mountainous region is applicable for drainages with mean basin elevations from 5,000 to 10,800 feet. Only one ungaged model node has a mean basin elevation less than 5,000 feet (Prairie Dog Creek with a MBE of 4550). The USGS regression equation for the mountainous region is selected as the most appropriate alternative for estimating natural flow at most of the ungaged model nodes. The regression equation is as follows:

$$Q_a = 0.0015\ A^{1.01}\ (ELEV/1{,}000)^{2.88}$$

Where: Q_a is mean annual flow in cubic feet per second,
A is contributing drainage area in square miles, and
ELEV is mean basin elevation in feet.

The reasonableness of the estimates of average annual flow are evaluated by comparing the estimated unit runoff (acre-feet per square mile) to the recorded unit runoff at the nearest natural flow station during the 1970 to 1999 study period. The average annual natural flow is, in some instances, adjusted based on this comparison. The estimated average annual flow and the comparison to unit runoff at the nearest natural flow station are summarized in Table 8 for the ungaged model nodes. The locations of these nodes are shown on Figure 12.

In addition to average annual natural flow at the ungaged model nodes, it is necessary to generate sequential monthly flows at these sites for all years of the study period. This is accomplished by selecting a natural flow gaging station having similar hydrologic characteristics and multiplying the sequential monthly flows at the gaged location by the ratio of the ungaged average annual natural flow to the gaged average annual natural flow. The time distribution of monthly flows at the ungaged sites is, therefore, represented by the streamflow at similar gaged sites. The average monthly and annual streamflows for the 1970 to 1999 study period, for the ungaged model nodes are summarized in Table 9. The estimated monthly natural flows for each year of the 1970 to 1999 study period are provided in Appendix E for each ungaged model node.

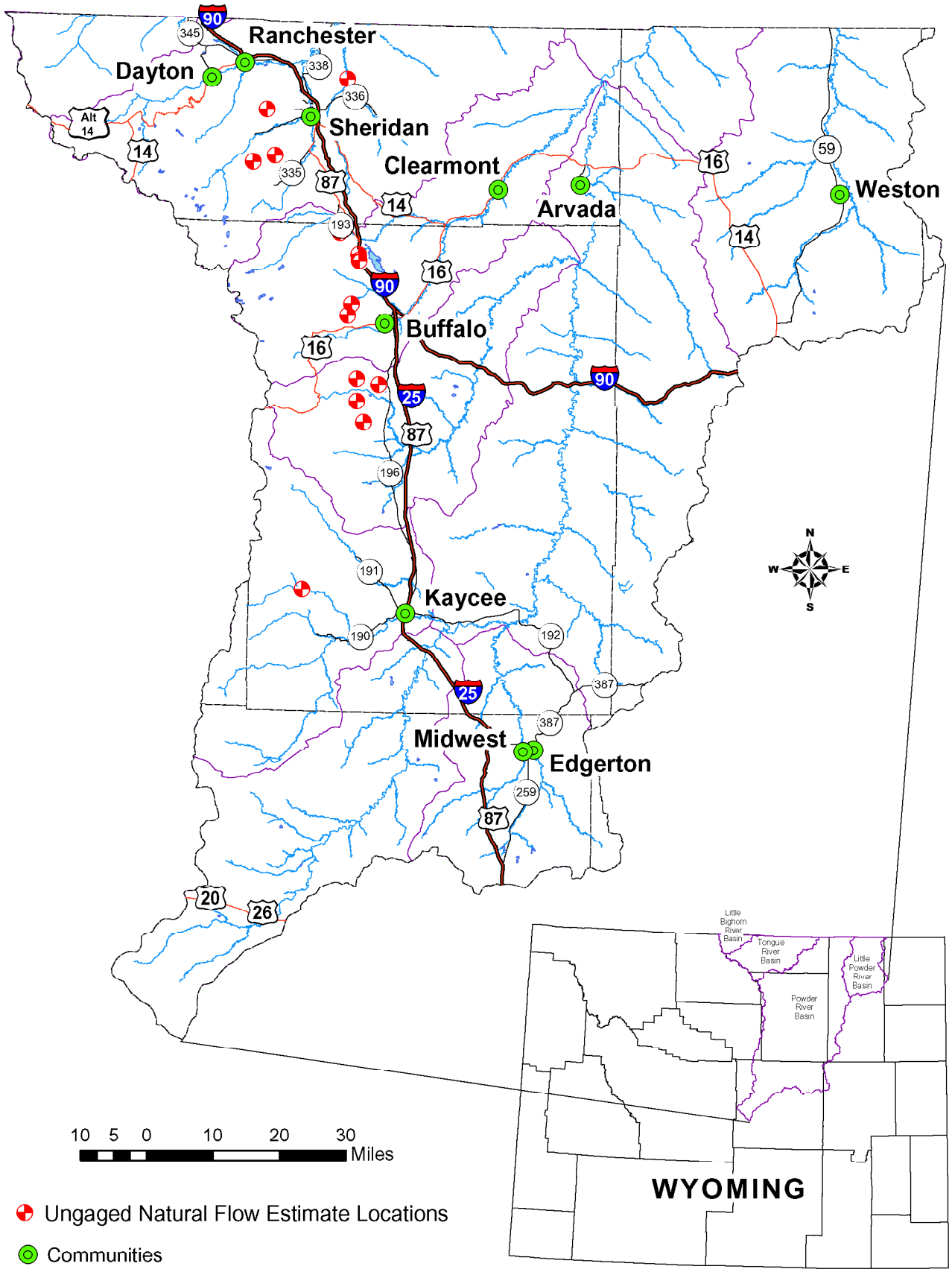
WET, DRY, AND NORMAL YEARS

Water availability models are to be developed to represent dry year, normal year, and wet year hydrologic conditions throughout the Powder/Tongue River Basin. To this end, the annual streamflows for the 1970 to 1999 study period developed through the surface water hydrology work are ranked and divided into these three hydrologic categories. Indicator gages are selected for this purpose, to represent hydrologic

TABLE 8
ESTIMATED AVERAGE ANNUAL NATURAL FLOW AT UNGAGED MODEL NODES

Basin	Site	Stream Type	Drainage Area (sq. mi.)	Mean Basin Elevation (ft)	Estimated Average Annual Runoff		1970-1999 Average Annual Flow at Nearest Natural Flow Gage			Note	Selected Average Annual AF
					Annual AF	AF/sq. mi.	Gage #	MBE	Runoff/ sq. mi.		
Tongue	Rapid Creek Just Below Little Rapid Creek in Section 32, T55N, R85W	Perennial	13.9	6720	3742	269	06299500	7700	544	Flow from USGS equation seems reasonable	3,742
	Beaver Creek at Bottom of Section 26, T55N, R85W	Perennial	8.26	5160	1034	125	06299500	7700	544	Flow from USGS equation seems reasonable	1,034
	Soldier Creek at Right Edge of Section 28, T56N, R85W	Perennial	18.7	5100	2281	122	06299500	7700	544	Flow from USGS equation seems reasonable	2,281
	Prairie Dog Creek Just Above Dutch Creek in Section 34, T57N, R83W	Perennial	122.7	NA	20,332[4]	166[4]	06306250[3]	NA	166[4]	Flow transferred from naturalized USGS Station 06306250	20,332[4]
Powder	Red Fork Powder River Just Below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	Perennial	114	7670	45866	402	06309460	7180	429	Flow from USGS equation seems reasonable	45,866
	Kelly Creek at Top of Section 21, T49N, R82W	Perennial	10.9	5980	2092	192	06314000	8440	406	Flow from USGS equation seems reasonable	2,092
	Little North Fork Crazy Woman Creek Just Below Grossett Canyon in Section 14, T49N, R83W	Perennial	12.5	7570	4737	379	06314000	8440	406	Flow from USGS equation seems reasonable	4,737
	Muddy Creek at Diversion Near East Side of Section 35, T49N, R83W	Perennial	11.8	7500	4351	369	06314000	8440	406	Flow from USGS equation seems reasonable	4,351
	Billy Creek at Diversion to O'Malley Draw in Section 13, T48N, R83W	Perennial	9.64	7410	3426	355	06315490	7820 est	203	Flow from USGS equation too high — use 203 AF/sq. mi. from upstream gage 06315490	1,957
	Little Piney Creek Just Below Bear Gulch in Section 28, T53N, R83W	Perennial	14.8	NA	7,336[4]	496[4]	SEO Gage[3]	NA	496[4]	Flow transferred from naturalized SEO Station on Little Piney Creek	7,336[4]
	North & South Forks Shell Creek (Combined), at Confluence of Little North Fork Shell Creek and North Fork Shell Creek in Section 11, and Confluence of Unnamed Tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	Perennial	15.4	5340	2141	139	06319480	9200 est	405	Flow from USGS equation seems reasonable	2,141
	Johnson Creek at Top of Section 22, T51N, R83W	Perennial	7.26	6850	2052	283	06319480	9200 est	405	Flow from USGS equation seems reasonable	2,052
	French Creek at Penrose Ditch Diversion in Section 27, T51N, R83W	Perennial	13.4	7490	4928	368	06319480	9200 est	405	Flow from USGS equation seems reasonable	4,928

Notes: 1. USGS equation for average annual flow, from WRIR 88-4045 = $0.0015A^{1.01}(MBE/1000)^{2.88}$.
2. Average annual flow at USGS natural flow gages based on recorded and/or filled in data for 1970-99 study period.
3. Naturalized gage flow based on recorded and filled in data for the 1970-99 sudy period.
4. These values use the average of the dry, normal, and wet year values.



Ungaged Natural Flow Estimate Locations

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Figure 12

TABLE 9
SUMMARY OF AVERAGE MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
UNGAGED NATURAL FLOW NODES IN THE POWDER-TONGUE RIVER BASINS

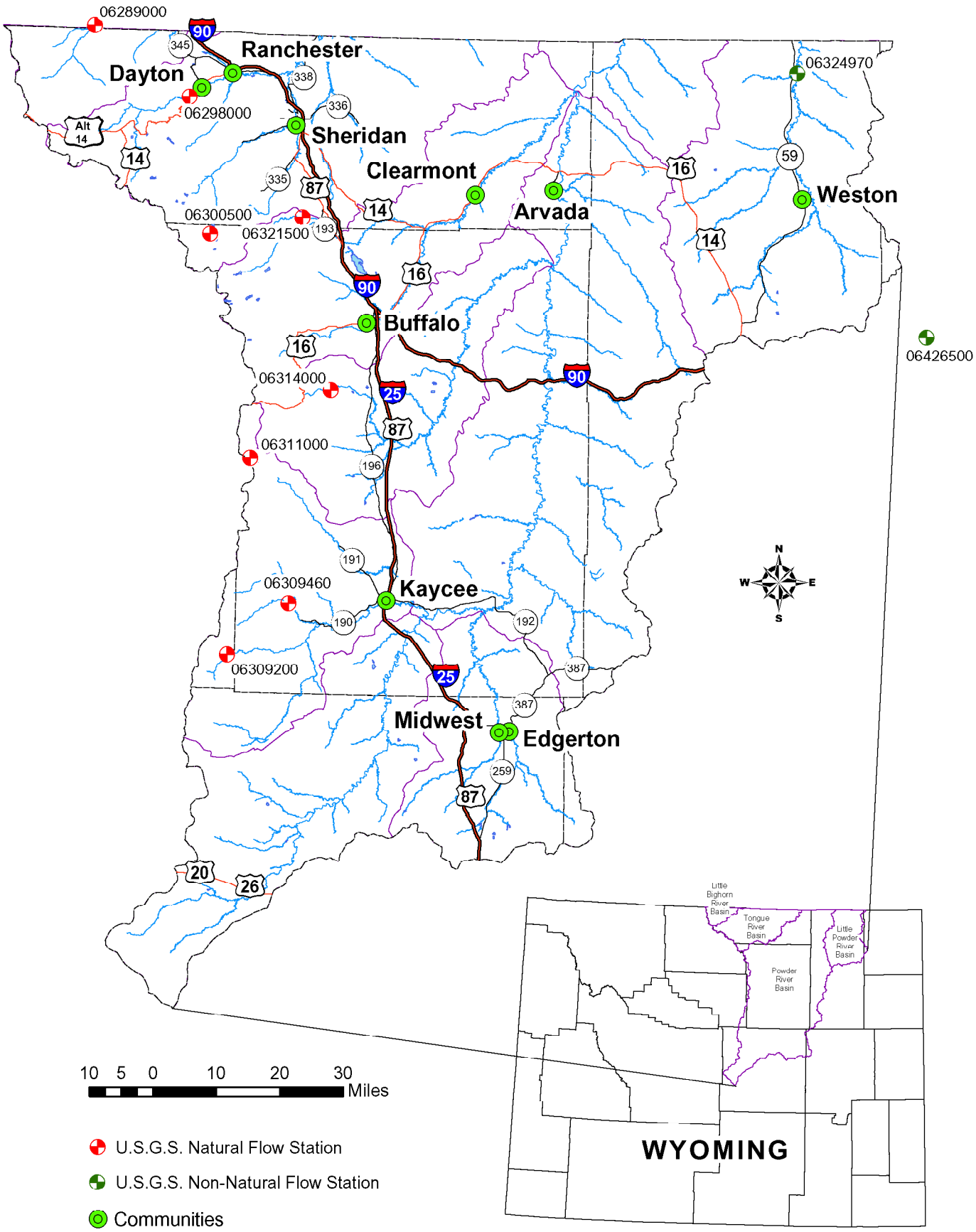
Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Tongue	Rapid Creek Just Below Little Rapid Creek in Section 32, T55N, R85W	98	73	65	58	49	54	156	1,050	1,453	407	169	110	**3,742**
	Beaver Creek at Bottom of Section 26, T55N, R85W	27	20	18	16	14	15	43	290	402	113	47	30	**1,034**
	Soldier Creek at Right Edge of Section 28, T56N, R85W	60	44	39	35	30	33	95	640	886	248	103	67	**2,281**
	Prairie Dog Creek Just Above Dutch Creek in Section 34, T57N, R83W	487	1,314	3,453	2,229	3,493	2,296	1,963	1,560	1,253	886	725	673	**20,332**[1]
Powder	Red Fork Powder River Just Below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	2,706	2,511	2,415	2,290	2,104	2,477	4,405	9,771	7,396	4,024	3,071	2,695	**45,866**
	Kelly Creek at Top of Section 21, T49N, R82W	73	55	45	36	30	35	132	629	646	228	106	75	**2,092**
	Little North Fork Crazy Woman Creek Just Below Grossett Canyon in Section 14, T49N, R83W	166	125	103	82	69	80	299	1,425	1,463	516	240	170	**4,737**
	Muddy Creek at Diversion Near East Side of Section 35, T49N, R83W	153	115	94	75	63	73	275	1,309	1,344	474	220	156	**4,351**
	Billy Creek at Diversion to O'Malley Draw in Section 13, T48N, R83W	96	79	69	59	52	59	151	481	477	212	125	98	**1,957**
	Little Piney Creek Just Below Bear Gulch in Section 28, T53N, R83W	324	421	625	676	1,295	1,250	811	544	470	309	338	273	**7,336**[1]
	North & South Forks Shell Creek (Combined), at Confluence of Little North Fork Shell Creek and North Fork Shell Creek in Section 11, and Confluence of Unnamed Tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	56	42	35	28	23	27	114	701	745	219	90	62	**2,141**
	Johnson Creek at Top of Section 22, T51N, R83W	53	41	33	27	22	26	109	672	714	210	86	59	**2,052**
	French Creek at Penrose Ditch Diversion in Section 27, T51N, R83W	128	98	80	64	53	62	262	1,614	1,715	504	207	142	**4,928**

Note: 1. The monthly and annual flows for Prairie Dog Creek and Little Piney Creek are the average of the dry, normal, and wet year monthly and annual flows.

conditions for the entire geographic area of the Powder/Tongue River Basin. To the extent possible, natural flow stations, free from transbasin diversion, irrigation depletions, or storage regulation are selected. One exception, Little Powder River above Dry Creek (#06324970) which is impacted by irrigation depletions was selected to represent hydrologic conditions in the Little Powder drainage. The nine indicator gages are shown on Figure 13. The years 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 dry years, normal years, and wet years for the indicator gages are illustrated on Figure 14. As can be seen, the hydrologic conditions from year to year vary from location to location (i.e. dry years, wet years, and normal years do not occur at all locations simultaneously). Some general conclusions are however evident. For example, 1980, 1985, 1988, and 1989 are dry years at most locations. Whereas, 1975 1978, 1984, and 1995 are wet years at most locations.

Water use in the Tongue River and Powder River are interrelated through transbasin diversions including the Mead Coffeen Ditch, Piney Cruse Ditch, and the Prairie Dog Ditch. Because of this interrelationship, the years selected to represent the various hydrologic conditions must be consistent for all locations within each of these two river basins. Water use in the Little Bighorn River is essentially independent of water use in the other river basins. Similarly, water use in the Little Powder River drainage is also independent of water use in the other drainages. The driest 20 percent and wettest 20 percent of the years at each of the indicator gages are listed in Figure 15. The years selected to represent dry years, wet years, and normal years for the Little Bighorn River basin, the Tongue and Powder River basins, and the Little Powder River basin are also summarized in Figure 15.

The average monthly and annual streamflow for the natural flow stations for dry years, normal years, and wet years are provided in Tables 10, 11, and 12 respectively. The average monthly and annual streamflow for the non-natural flow stations for dry years, normal years, and wet years are provided in Tables 13, 14, and 15 respectively. Finally, the average monthly and annual streamflow for the ungaged model nodes for dry years, normal years, and wet years are provided in Tables 16, 17, and 18 respectively.



Indicator Gages for Selection of Dry, Normal, & Wet Years

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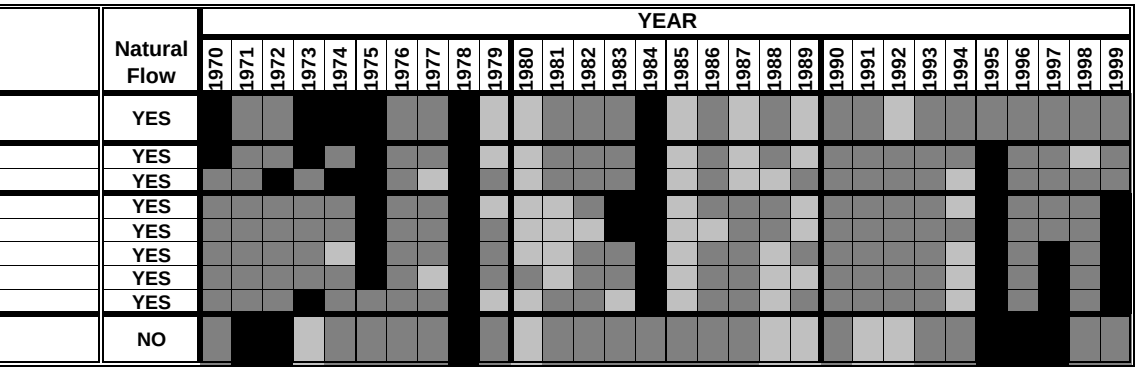
Figure 13

FIGURE 14

WET, DRY AND NORMAL YEARS FOR INDICATOR STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	Natural Flow
Little Bighorn	06289000	Little Bighorn River at State Line Near Wyola, MT	YES
Tongue	06298000	Tongue River Near Dayton, WY	YES
	06300500	East Fork Big Goose Creek Near Big Horn, WY	YES
Powder	06309200	Middle Fork Powder River Near Barnum, WY	YES
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	YES
	06311000	North Fork Powder River Near Hazelton, WY	YES
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	YES
	06321500	North Piney Creek Near Story, WY	YES
Little Powder	06324970	Little Powder River Above Dry Creek Near Weston, WY	NO



LEGEND	
Wet	
Normal	
Dry	

FIGURE 15
SELECTION OF WET, DRY, AND NORMAL YEARS FOR MODELING
INDICATOR STATIONS FOR THE POWDER-TONGUE RIVER BASINS

		Little Bighorn	
		Little Bighorn River at State Line, Near Wyola, MT	
Rank	Weibull Plotting Position	Year	06289000
1	3.23%	1989	68,060
2	6.45%	1985	72,360
3	9.68%	1987	77,020
4	12.90%	1980	81,830
5	16.13%	1992	90,470
6	19.35%	1979	93,400
7	22.58%	1988	93,900
8	25.81%	1981	95,510
9	29.03%	1993	96,740
10	32.26%	1982	97,200
11	35.48%	1994	98,000
12	38.71%	1986	101,170
13	41.94%	1990	103,430
14	45.16%	1983	106,830
15	48.39%	1998	107,010
16	51.61%	1991	110,400
17	54.84%	1972	111,430
18	58.06%	1996	113,090
19	61.29%	1977	115,910
20	64.52%	1997	121,120
21	67.74%	1971	121,810
22	70.97%	1976	123,370
23	74.19%	1995	126,540
24	77.42%	1999	127,190
25	80.65%	1974	130,710
26	83.87%	1973	133,310
27	87.10%	1984	136,970
28	90.32%	1970	159,600
29	93.55%	1978	170,730
30	96.77%	1975	182,880

		Tongue River Basin				Powder River Basin									
		Tongue River Near Dayton, WY		East Fork Big Goose Creek Near Big Horn, WY		Middle Fork Powder River Near Barnum, WY		Beaver Creek Above White Panther Ditch, Near Barnum, WY		North Fork Powder River Near Hazelton, WY		North Fork Crazy Woman Creek Near Buffalo, WY		North Piney Creek Near Story, WY	
Rank	Weibull Plotting Position	Year	06298000	Year	06300500	Year	06309200	Year	06309460	Year	06311000	Year	06314000	Year	06321500
1	3.23%	1989	76,527	1985	15,754	1989	9,469	1989	6,634	1985	6,974	1977	10,122	1985	18,786
2	6.45%	1985	88,393	1988	17,616	1985	10,915	1981	7,204	1981	7,608	1981	11,608	1980	19,694
3	9.68%	1987	91,860	1994	17,717	1980	11,564	1980	7,893	1988	7,889	1985	12,404	1988	21,032
4	12.90%	1980	97,481	1987	18,242	1981	12,890	1985	8,016	1980	7,931	1988	13,511	1994	21,652
5	16.13%	1979	107,713	1977	18,318	1994	13,243	1982	8,040	1974	8,001	1994	13,978	1979	21,655
6	19.35%	1994	113,240	1980	18,340	1979	13,665	1986	8,325	1994	8,105	1989	14,551	1982	22,230
7	22.58%	1998	115,427	1989	18,387	1992	13,731	1988	8,506	1989	8,693	1974	14,671	1989	23,038
8	25.81%	1982	118,780	1991	19,455	1982	15,847	1987	8,963	1972	8,818	1972	14,752	1981	24,199
9	29.03%	1988	120,159	1981	20,437	1974	16,281	1994	9,036	1977	8,882	1973	15,375	1990	24,437
10	32.26%	1981	122,507	1998	20,660	1976	16,609	1974	9,387	1973	9,131	1990	15,464	1987	25,989
11	35.48%	1992	122,866	1979	20,850	1987	16,928	1992	9,635	1990	9,213	1982	15,982	1976	26,899
12	38.71%	1993	126,667	1982	21,839	1988	18,445	1991	9,722	1987	9,735	1970	16,319	1972	27,025
13	41.94%	1986	129,213	1993	22,222	1990	20,436	1990	10,269	1970	10,137	1980	16,411	1971	27,648
14	45.16%	1977	133,134	1983	22,330	1991	20,530	1976	10,299	1979	10,405	1979	16,564	1986	28,593
15	48.39%	1991	133,469	1970	23,062	1986	20,626	1979	10,329	1986	10,860	1987	16,707	1977	29,148
16	51.61%	1976	134,000	1996	23,340	1998	20,860	1998	10,491	1971	11,584	1986	17,730	1974	31,480
17	54.84%	1983	135,628	1990	23,717	1996	20,941	1996	10,511	1976	12,204	1971	18,160	1998	32,568
18	58.06%	1971	136,242	1992	24,316	1972	21,715	1971	10,558	1998	12,443	1998	19,877	1992	33,073
19	61.29%	1996	136,583	1971	24,586	1993	22,499	1972	10,609	1992	12,580	1991	20,064	1991	33,574
20	64.52%	1972	138,031	1997	24,639	1971	22,626	1993	10,710	1991	12,926	1976	20,131	1983	34,423
21	67.74%	1990	138,184	1976	24,826	1997	23,239	1997	10,875	1983	13,118	1992	20,391	1996	35,321
22	70.97%	1997	144,068	1986	24,899	1977	24,757	1973	10,877	1996	13,603	1996	21,093	1993	36,058
23	74.19%	1974	145,021	1973	25,555	1973	26,807	1977	11,016	1982	13,633	1983	21,296	1970	36,073
24	77.42%	1999	145,292	1999	25,853	1970	29,218	1970	11,042	1993	13,847	1993	21,679	1975	36,325
25	80.65%	1973	149,701	1972	27,268	1975	29,477	1983	11,976	1984	14,335	1995	23,013	1984	37,158
26	83.87%	1995	157,750	1974	28,147	1983	30,407	1975	12,565	1995	15,254	1975	23,229	1973	37,710
27	87.10%	1984	170,772	1978	28,491	1984	30,471	1995	12,975	1997	15,384	1997	23,681	1995	39,315
28	90.32%	1970	170,984	1975	30,620	1978	35,430	1999	13,206	1975	15,883	1984	24,218	1997	39,885
29	93.55%	1978	197,249	1995	38,229	1995	36,855	1984	13,707	1999	17,182	1999	25,986	1999	44,332
30	96.77%	1975	198,294	1984	44,963	1999	37,229	1978	17,984	1978	18,963	1978	28,477	1978	45,924

		Little Powder	
		Little Powder River Above Dry Creek, Near Weston, WY	
Rank	Weibull Plotting Position	Year	06324970
1	3.23%	1992	1,084
2	6.45%	1991	2,905
3	9.68%	1989	2,924
4	12.90%	1988	4,005
5	16.13%	1973	4,062
6	19.35%	1980	4,155
7	22.58%	1981	4,414
8	25.81%	1977	6,511
9	29.03%	1985	6,953
10	32.26%	1998	7,776
11	35.48%	1979	7,949
12	38.71%	1976	9,241
13	41.94%	1990	10,057
14	45.16%	1970	10,277
15	48.39%	1975	10,586
16	51.61%	1974	11,634
17	54.84%	1987	11,882
18	58.06%	1983	13,608
19	61.29%	1986	13,884
20	64.52%	1993	17,653
21	67.74%	1982	19,220
22	70.97%	1999	19,251
23	74.19%	1994	21,031
24	77.42%	1984	24,547
25	80.65%	1971	37,031
26	83.87%	1997	39,292
27	87.10%	1972	40,495
28	90.32%	1996	40,534
29	93.55%	1995	41,091
30	96.77%	1978	92,138

LEGEND	
	WET
	DRY

SELECTION OF WET, DRY, & NORMAL YEARS			
	MODEL AREA		
Hydrologic Condition	Little Bighorn Model	Tongue & Powder Models	Little Powder Model
WET	1970, 1973, 1974, 1975, 1978, 1984	1975, 1978, 1984, 1995, 1997, 1999	1971, 1972, 1978, 1995, 1996, 1997
DRY	1979, 1980, 1985, 1987, 1989, 1992	1980, 1981, 1985, 1988, 1989, 1994	1973, 1980, 1988, 1989, 1991, 1992
AVERAGE	All Other Years Between 1970 and 1999	All Other Years Between 1970 and 1999	All Other Years Between 1970 and 1999

TABLE 10
SUMMARY OF DRY YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06288600	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	383	293	270	230	186	199	396	2,737	2,400	1,220	631	406	**9,348**
	06288700	Dry Fork Little Bighorn River Below Lick Creek Near Burgess Junction, WY	1,781	1,540	1,467	1,330	1,157	1,254	1,685	4,567	4,393	2,990	2,106	1,666	**25,935**
	06288960	Little Bighorn River near Parkman, WY	3,804	3,159	2,990	2,746	2,375	2,648	3,934	12,923	11,513	6,948	4,513	3,536	**61,087**
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	104	97	90	81	70	83	145	327	258	145	119	101	**1,621**
	06288990	West Fork Little Bighorn River Near Parkman, WY	911	765	710	645	563	627	872	2,647	2,377	1,526	1,041	824	**13,505**
	06289000	Little Bighorn River at State Line Near Wyola, MT	5,168	4,347	4,130	3,815	3,330	3,687	5,332	16,225	14,538	9,057	6,063	4,832	**80,523**
	06289100	Red Canyon Creek Near Parkman, WY	23	24	19	21	16	23	126	260	103	34	20	21	**689**
	06289800	East Pass Creek Near Parkman, WY	450	377	359	329	293	315	616	1,506	1,362	863	587	468	**7,524**
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	445	356	322	284	238	262	607	2,835	2,606	1,242	690	464	**10,349**
Tongue	06297000	South Fork Tongue River Near Dayton, WY	1,253	926	859	714	604	671	2,638	15,853	9,285	2,993	1,616	1,228	**38,639**
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY	4,618	3,659	3,455	2,989	2,624	2,850	8,122	32,437	20,874	8,460	5,619	4,552	**100,258**
	06298000	Tongue River Near Dayton, WY	4,654	3,681	3,473	3,002	2,633	2,862	8,224	33,196	21,910	9,160	5,672	4,587	**103,051**
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY	119	85	79	65	54	60	335	2,105	1,413	441	190	128	**5,073**
	06298490	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY	85	59	54	44	36	41	209	1,748	926	239	115	83	**3,639**
	06298500	Little Tongue River Near Dayton, WY	200	143	132	108	90	101	528	3,159	2,144	692	306	208	**7,811**
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY	423	313	291	241	205	227	1,036	5,941	4,067	1,352	610	419	**15,122**
	06299490	Wolf Creek Above Red Canyon Creek Near Wolf, WY	499	380	355	300	258	284	1,025	5,696	3,926	1,334	610	423	**15,089**
	06299500	Wolf Creek at Wolf, WY	496	370	344	287	244	270	1,106	5,662	3,972	1,426	678	478	**15,331**
	06300500	East Fork Big Goose Creek Near Big Horn, WY	355	243	221	176	143	163	918	6,291	6,407	1,855	700	573	**18,042**
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY	25	15	13	10	8	9	88	1,282	1,059	153	46	38	**2,746**
Powder	06309200	Middle Fork Powder River Near Barnum, WY	366	344	335	299	259	320	2,163	5,973	1,485	523	351	336	**12,754**
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY	23	22	21	18	15	20	211	755	132	36	22	21	**1,294**
	06309270	North Fork Buffalo Creek Near Arminto, WY	70	65	64	57	50	61	387	1,033	269	98	67	64	**2,284**
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY	0	0	0	0	0	0	10	932	123	3	0	0	**1,067**
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY	167	145	128	110	89	119	461	804	454	252	180	153	**3,060**
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	600	544	538	521	456	513	889	1,247	860	647	558	508	**7,882**
	06311000	North Fork Powder River Near Hazelton, WY	271	200	155	121	97	116	961	2,983	1,847	587	305	226	**7,867**
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY	596	463	368	276	227	260	1,652	4,799	3,037	1,122	596	451	**13,847**
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	599	475	373	285	232	264	1,648	4,661	3,031	1,127	598	451	**13,744**
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY	510	374	287	222	177	212	1,878	6,015	3,677	1,130	577	423	**15,483**
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY	209	173	145	117	100	111	453	1,024	717	339	209	169	**3,766**
	06315490	Poison Creek Near Mayoworth, WY	241	202	171	139	120	133	502	1,091	777	382	242	197	**4,195**
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY	659	513	416	339	282	327	1,881	4,814	3,223	1,256	730	569	**15,009**
	06317300	Sourdough Creek Near Buffalo, WY	64	45	36	25	22	28	153	457	433	152	75	56	**1,545**
	06317340	Little Sourdough Creek Near Buffalo, WY	16	11	3	1	1	2	106	95	55	12	5	8	**314**
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY	414	308	240	189	152	181	1,425	4,299	2,691	882	466	347	**11,594**
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY	395	293	227	178	143	170	1,383	4,239	2,637	850	445	330	**11,288**
	06321500	North Piney Creek Near Story, WY	751	587	459	371	295	342	2,571	8,859	4,307	1,475	776	606	**21,400**

TABLE 11
SUMMARY OF NORMAL YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06288600	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	422	303	267	237	196	220	361	3,862	6,199	1,629	778	463	**14,937**
	06288700	Dry Fork Little Bighorn River Below Lick Creek Near Burgess Junction, WY	1,854	1,591	1,477	1,379	1,227	1,329	1,722	6,442	9,677	4,367	2,630	2,024	**35,720**
	06288960	Little Bighorn River near Parkman, WY	4,002	3,337	3,079	2,837	2,458	2,766	3,732	17,480	27,873	10,893	6,005	4,414	**88,877**
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	116	101	92	86	75	88	139	470	602	186	136	123	**2,213**
	06288990	West Fork Little Bighorn River Near Parkman, WY	932	790	731	671	589	675	901	3,871	5,812	2,315	1,355	1,037	**19,677**
	06289000	Little Bighorn River at State Line Near Wyola, MT	5,412	4,543	4,226	3,927	3,465	3,879	5,112	21,438	33,132	13,750	7,872	5,948	**112,704**
	06289100	Red Canyon Creek Near Parkman, WY	35	31	25	27	23	42	214	545	241	64	31	27	**1,304**
	06289800	East Pass Creek Near Parkman, WY	474	391	365	339	303	331	552	1,928	2,318	1,057	644	510	**9,211**
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	466	351	310	282	238	273	581	3,838	5,310	1,658	784	529	**14,620**
Tongue	06297000	South Fork Tongue River Near Dayton, WY	1,462	1,069	976	816	655	749	1,756	14,632	20,914	5,932	2,554	1,700	**53,216**
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY	5,140	3,987	3,650	3,349	2,827	3,124	5,922	31,052	40,989	14,721	7,889	5,768	**128,419**
	06298000	Tongue River Near Dayton, WY	5,232	4,031	3,687	3,369	2,853	3,163	6,003	31,944	41,798	15,382	8,019	5,825	**131,306**
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY	137	96	85	74	59	71	239	2,024	2,889	689	280	176	**6,819**
	06298490	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY	102	70	60	52	40	47	133	1,615	2,453	532	202	121	**5,427**
	06298500	Little Tongue River Near Dayton, WY	228	162	140	127	111	124	392	3,153	4,156	1,074	427	278	**10,372**
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY	481	347	306	269	221	261	757	5,691	8,097	2,060	859	561	**19,909**
	06299490	Wolf Creek Above Red Canyon Creek Near Wolf, WY	537	404	362	330	272	308	753	5,442	7,717	2,019	857	564	**19,565**
	06299500	Wolf Creek at Wolf, WY	543	405	355	321	281	301	827	5,443	7,591	2,118	934	627	**19,746**
	06300500	East Fork Big Goose Creek Near Big Horn, WY	434	279	208	210	153	169	516	4,890	10,683	3,453	1,208	777	**22,980**
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY	31	19	13	10	7	9	46	1,069	1,782	423	84	55	**3,548**
Powder	06309200	Middle Fork Powder River Near Barnum, WY	458	392	362	328	296	434	2,192	9,883	4,450	1,052	528	430	**20,805**
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY	31	26	23	20	18	29	229	1,337	562	91	37	28	**2,429**
	06309270	North Fork Buffalo Creek Near Arminto, WY	87	74	68	61	55	81	383	1,674	775	195	102	83	**3,639**
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY	0	0	0	0	0	0	51	1,904	700	41	3	1	**2,700**
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY	183	160	144	127	117	163	545	1,824	1,026	395	238	186	**5,106**
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	603	555	539	513	479	566	1,040	2,191	1,524	876	673	595	**10,154**
	06311000	North Fork Powder River Near Hazelton, WY	305	230	190	148	127	143	546	3,946	3,634	1,076	481	347	**11,173**
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY	670	487	403	316	261	305	1,062	5,365	5,452	1,909	946	698	**17,873**
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	681	494	412	327	273	313	1,079	5,238	5,249	1,878	934	700	**17,577**
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY	581	430	358	268	229	273	1,081	7,809	7,212	2,176	946	671	**22,032**
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY	224	179	155	129	114	128	321	1,133	1,112	490	290	233	**4,508**
	06315490	Poison Creek Near Mayoworth, WY	256	207	181	153	134	152	362	1,195	1,174	541	331	268	**4,954**
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY	728	568	492	398	350	426	1,222	5,982	5,545	2,015	1,045	796	**19,565**
	06317300	Sourdough Creek Near Buffalo, WY	73	56	47	36	30	33	96	822	847	265	115	84	**2,504**
	06317340	Little Sourdough Creek Near Buffalo, WY	34	20	7	3	2	5	188	201	133	35	16	25	**668**
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY	461	353	296	234	199	220	818	5,550	5,256	1,631	730	520	**16,268**
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY	439	336	278	216	186	208	790	5,473	5,219	1,595	706	502	**15,949**
	06321500	North Piney Creek Near Story, WY	829	650	535	441	374	472	1,688	10,668	9,908	2,619	1,137	897	**30,217**

TABLE 12
SUMMARY OF WET YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06288600	Little Bighorn River Below Dayton Gulch Near Burgess Junction, WY	406	293	265	246	199	212	299	3,733	10,128	2,551	981	538	**19,851**
	06288700	Dry Fork Little Bighorn River Below Lick Creek Near Burgess Junction, WY	1,921	1,678	1,583	1,455	1,301	1,407	1,696	7,747	15,057	7,010	3,406	2,525	**46,785**
	06288960	Little Bighorn River near Parkman, WY	4,222	3,588	3,245	3,076	2,707	2,977	3,723	21,474	45,028	18,889	8,210	5,703	**122,841**
	06288975	Elkhorn Creek Above Fuller Ranch Ditch Near Parkman, WY	118	102	95	89	81	92	136	715	1,125	327	159	157	**3,196**
	06288990	West Fork Little Bighorn River Near Parkman, WY	984	836	764	707	647	710	901	5,327	10,134	4,021	1,785	1,335	**28,152**
	06289000	Little Bighorn River at State Line Near Wyola, MT	5,667	4,890	4,467	4,217	3,748	4,120	5,097	26,348	52,728	23,118	10,465	7,502	**152,367**
	06289100	Red Canyon Creek Near Parkman, WY	55	48	40	44	36	66	346	1,002	424	109	51	42	**2,263**
	06289800	East Pass Creek Near Parkman, WY	464	387	372	344	313	330	455	2,223	3,454	1,392	706	557	**10,995**
	06291200	Lodge Grass Creek at State Line Near Wyola, MT	466	344	322	308	257	270	427	3,807	8,850	2,869	913	624	**19,456**
Tongue	06297000	South Fork Tongue River Near Dayton, WY	1,479	1,030	923	856	690	786	1,288	14,366	39,809	11,430	3,358	1,954	**77,970**
	06297480	Tongue River at Tongue Canyon Campground Near Dayton, WY	5,280	4,056	3,710	3,440	3,012	3,311	4,758	29,952	68,799	25,483	9,988	6,407	**168,195**
	06298000	Tongue River Near Dayton, WY	5,301	3,998	3,673	3,465	2,930	3,237	4,697	30,887	68,594	25,504	10,027	6,591	**168,904**
	06298480	Little Tongue River at Steamboat Point Near Dayton, WY	139	97	84	74	62	72	194	2,648	5,358	1,124	339	177	**10,367**
	06298490	Little Tongue River Above South Fork Little Tongue River Near Dayton, WY	98	65	56	52	41	49	90	1,614	4,929	1,122	280	141	**8,538**
	06298500	Little Tongue River Near Dayton, WY	240	161	143	132	104	120	303	3,874	7,901	1,805	548	296	**15,626**
	06299480	Wolf Creek Below Alden Creek Near Wolf, WY	488	351	314	284	228	267	617	7,299	14,248	3,542	1,089	585	**29,311**
	06299490	Wolf Creek Above Red Canyon Creek Near Wolf, WY	568	429	380	357	304	332	636	6,999	13,552	3,453	1,068	586	**28,664**
	06299500	Wolf Creek at Wolf, WY	568	412	369	336	272	317	683	6,843	13,155	3,405	1,153	657	**28,171**
	06300500	East Fork Big Goose Creek Near Big Horn, WY	471	342	254	217	169	187	320	5,517	16,433	6,483	1,155	587	**32,133**
	06301480	Coney Creek Above Twin Lakes Near Big Horn, WY	33	19	15	12	9	11	21	965	2,498	1,252	116	37	**4,987**
Powder	06309200	Middle Fork Powder River Near Barnum, WY	543	561	427	373	329	497	1,886	13,410	11,223	1,624	703	542	**32,117**
	06309260	Buffalo Creek Above North Fork Buffalo Creek Near Arminto, WY	38	40	27	22	19	33	194	1,984	1,426	194	58	36	**4,070**
	06309270	North Fork Buffalo Creek Near Arminto, WY	102	109	81	70	60	91	313	2,141	1,981	317	143	111	**5,518**
	06309280	Buffalo Creek Below North Fork Buffalo Creek Near Arminto, WY	0	0	0	0	0	0	7	2,947	2,525	133	1	0	**5,612**
	06309450	Beaver Creek Below Bayer Creek Near Barnum, WY	209	204	155	138	118	174	499	2,662	2,173	708	343	251	**7,634**
	06309460	Beaver Creek Above White Panther Ditch Near Barnum, WY	652	633	577	531	487	593	975	3,236	2,937	1,278	898	756	**13,553**
	06311000	North Fork Powder River Near Hazelton, WY	286	213	174	157	120	169	415	4,497	7,433	1,738	607	360	**16,167**
	06313950	North Fork Crazy Woman Creek Below Pole Creek Near Buffalo, WY	542	449	359	315	272	329	874	7,018	9,478	3,068	1,159	683	**24,544**
	06314000	North Fork Crazy Woman Creek Near Buffalo, WY	557	448	366	314	275	331	875	7,077	9,409	3,174	1,220	724	**24,767**
	06314500	North Fork Crazy Woman Creek Below Spring Draw Near Buffalo, WY	539	398	324	291	221	314	798	9,188	15,384	3,455	1,171	684	**32,766**
	06315480	Poison Creek Below Tetley Spring Near Mayoworth, WY	192	165	140	130	116	136	314	1,436	1,721	642	318	222	**5,530**
	06315490	Poison Creek Near Mayoworth, WY	222	191	167	153	139	165	350	1,485	1,805	704	365	253	**5,997**
	06315500	Middle Fork Crazy Woman Creek Near Greub, WY	692	540	460	422	338	447	903	6,697	10,221	3,060	1,289	838	**25,906**
	06317300	Sourdough Creek Near Buffalo, WY	66	50	41	37	29	40	94	953	1,555	379	137	83	**3,462**
	06317340	Little Sourdough Creek Near Buffalo, WY	65	39	13	5	3	9	359	373	242	62	28	43	**1,242**
	06319470	South Rock Creek at Forest Boundary Near Buffalo, WY	437	337	274	244	187	244	621	6,203	10,264	2,837	914	545	**23,106**
	06319480	South Rock Creek Above Red Canyon Near Buffalo, WY	417	325	262	238	180	232	599	6,175	10,222	2,742	882	516	**22,788**
	06321500	North Piney Creek Near Story, WY	763	595	490	422	353	437	1,450	11,665	17,560	4,334	1,506	916	**40,490**

TABLE 13
SUMMARY OF DRY YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06289600	West Pass Creek Near Parkman, WY	522	485	460	421	377	469	647	1,126	1,038	584	406	415	**6,949**
	06289820	East Pass Creek Near Dayton, WY	620	578	551	506	458	592	790	1,407	1,317	673	398	475	**8,364**
	06289870	Twin Creek Near Parkman, WY	71	64	81	213	155	472	573	664	160	93	70	59	**2,676**
Tongue	06302000	Big Goose Creek Near Sheridan, WY	2,116	1,637	1,536	1,310	1,136	1,244	2,545	14,220	14,547	5,167	3,833	2,937	**52,227**
	06303500	Little Goose Creek in Canyon Near Big Horn, WY	1,738	1,352	1,271	1,087	945	1,033	2,160	9,517	7,440	5,127	3,802	2,395	**37,866**
	06305500	Goose Creek Below Sheridan, WY	6,048	5,421	4,763	4,009	3,664	6,136	6,965	20,947	16,605	3,094	2,118	2,882	**82,651**
	06305700	Goose Creek Near Acme, WY	6,185	5,536	4,858	4,084	3,730	6,277	7,133	21,677	17,157	3,147	2,146	2,927	**84,857**
	06306250	Prairie Dog Creek Near Acme, WY	2,437	1,924	1,611	1,129	2,253	5,008	2,043	1,678	1,279	878	1,552	1,928	**23,719**
	06306300	Tongue River at State Line Near Decker, MT	14,045	12,138	8,888	8,018	8,497	16,247	19,902	61,280	43,982	10,638	6,433	7,775	**217,843**
Powder	06309500	Middle Fork Powder River Above Kaycee, WY	2,616	2,537	2,419	2,362	2,125	2,471	5,738	10,427	4,480	2,483	2,065	2,177	**41,898**
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	238	137	131	117	104	134	415	2,289	2,342	2,011	1,313	719	**9,949**
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	1,348	1,128	1,160	1,145	1,008	1,105	1,672	3,450	2,843	2,598	2,122	1,548	**21,128**
	06312500	Powder River Near Kaycee, WY	3,984	5,116	5,210	4,358	5,231	6,568	7,052	18,405	10,431	643	850	1,268	**69,116**
	06313000	South Fork Powder River Near Kaycee, WY	86	118	116	102	1,136	3,680	2,856	5,383	1,170	269	1,000	6	**15,923**
	06313400	Salt Creek Near Sussex, WY	1,962	1,848	1,795	1,885	2,721	2,888	2,282	2,930	2,355	2,618	1,773	1,885	**26,941**
	06313500	Powder River at Sussex, WY	6,572	7,446	7,294	6,924	9,824	12,733	11,749	17,875	6,632	5,191	3,572	2,639	**98,450**
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY	330	204	221	210	153	193	1,013	1,442	1,788	852	607	293	**7,307**
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY	1,073	1,174	1,125	1,024	1,198	1,904	2,181	3,773	2,521	792	423	278	**17,466**
	06317000	Powder River at Arvada, WY	7,643	8,622	7,085	7,065	10,102	18,663	13,967	21,182	9,420	5,767	2,810	2,314	**114,639**
	06318500	Clear Creek Near Buffalo, WY	1,806	1,397	1,062	778	621	912	2,633	9,770	11,330	5,321	2,680	1,977	**40,287**
	SEO Gage	Clear Creek in Buffalo City Park, Buffalo, WY	1,168	1,174	1,195	949	1,419	1,700	2,507	6,059	5,297	1,360	525	600	**23,951**
	06320000	Rock Creek Near Buffalo, WY	826	623	581	489	419	461	1,248	5,991	4,429	2,886	2,113	990	**21,055**
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY	1,054	1,042	961	822	1,067	1,851	1,141	3,790	1,495	616	506	708	**15,052**
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY	3,157	2,766	2,312	1,853	2,020	3,282	4,667	9,945	7,571	2,407	1,211	1,518	**42,708**
	SEO Gage	Clear Creek below Healy Reservoir Near Buffalo, WY	1,647	1,448	1,248	1,052	1,480	2,101	3,662	8,955	6,790	3,071	1,722	1,527	**34,703**
	06321000	South Piney Creek Near Story, WY	1,735	1,225	1,214	1,033	803	895	1,370	4,880	16,184	9,925	7,096	4,360	**50,719**
	06323000	Piney Creek at Kearney, WY	1,401	1,985	1,785	1,713	1,514	1,740	4,029	12,630	8,558	2,033	784	497	**38,670**
	SEO Gage	Little Piney Creek, WY	766	760	636	627	589	941	809	1,082	623	660	538	586	**8,616**
	SEO Gage	Piney Creek below Lake DeSmet Tunnel Intake Near Story, WY	974	552	422	387	356	458	2,180	8,305	6,194	2,871	1,073	1,094	**24,865**
	06323500	Piney Creek at Ucross, WY	3,235	3,416	3,367	3,181	1,307	1,717	3,657	7,110	8,503	7,061	4,634	3,715	**50,904**
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY	7,063	7,196	6,881	6,323	5,321	6,584	7,413	15,042	12,668	8,499	6,054	5,085	**94,127**
	SEO Gage	Clear Creek below P&F#3 Ditch Near Clearmont, WY	10,045	7,190	3,181	3,300	7,712	9,831	10,268	38,389	61,603	13,948	5,051	4,132	**174,649**
	06324000	Clear Creek Near Arvada, WY	6,687	6,744	5,449	5,313	4,172	8,956	8,859	13,104	9,400	4,922	3,449	3,796	**80,849**
	06324500	Powder River at Moorhead, MT	15,447	16,172	10,265	11,567	13,510	27,822	22,040	33,420	20,735	10,368	6,822	5,603	**193,770**
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	2	12	16	22	89	278	41	296	39	63	9	0	**868**
	06324925	Little Powder River Near Weston, WY	19	26	30	24	319	399	284	474	220	64	169	13	**2,041**
	06324970	Little Powder River Above Dry Creek Near Weston, WY	41	54	69	60	481	630	480	737	383	127	111	17	**3,189**
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	26	70	61	41	464	1,460	299	443	212	1,189	183	71	**4,517**

TABLE 14
SUMMARY OF NORMAL YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06289600	West Pass Creek Near Parkman, WY	504	467	437	411	417	498	799	2,160	2,006	825	529	501	**9,554**
	06289820	East Pass Creek Near Dayton, WY	596	562	544	528	542	635	982	2,882	2,855	883	494	512	**12,016**
	06289870	Twin Creek Near Parkman, WY	124	105	137	370	270	783	909	1,820	398	173	129	98	**5,316**
Tongue	06302000	Big Goose Creek Near Sheridan, WY	2,326	1,735	1,570	1,430	1,194	1,339	2,282	12,149	25,660	7,537	4,754	3,721	**65,698**
	06303500	Little Goose Creek in Canyon Near Big Horn, WY	1,847	1,384	1,250	1,126	945	1,057	2,189	10,298	14,356	6,323	5,629	3,521	**49,924**
	06305500	Goose Creek Below Sheridan, WY	6,814	5,975	5,231	4,636	5,507	5,947	8,728	23,311	37,384	8,686	4,240	6,047	**122,506**
	06305700	Goose Creek Near Acme, WY	6,974	6,107	5,341	4,729	5,627	6,080	8,953	24,129	38,842	8,919	4,325	6,185	**126,210**
	06306250	Prairie Dog Creek Near Acme, WY	2,839	2,208	1,848	1,309	2,689	5,514	2,968	2,928	2,289	1,335	1,630	2,521	**30,078**
	06306300	Tongue River at State Line Near Decker, MT	16,788	14,097	12,116	12,437	15,372	19,950	22,686	66,751	92,276	27,317	11,874	14,461	**326,123**
Powder	06309500	Middle Fork Powder River Above Kaycee, WY	2,833	2,582	2,475	2,381	2,258	2,727	5,709	15,043	9,203	3,998	2,751	2,576	**54,536**
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	240	178	167	130	119	141	363	3,099	3,867	1,850	1,470	1,096	**12,720**
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	1,303	1,116	1,119	1,084	971	1,069	1,688	4,781	5,035	2,692	2,343	1,915	**25,116**
	06312500	Powder River Near Kaycee, WY	4,911	6,163	6,250	5,456	6,193	8,182	8,671	27,220	16,087	1,025	811	1,775	**92,743**
	06313000	South Fork Powder River Near Kaycee, WY	159	215	149	166	1,198	7,158	5,540	8,230	1,974	608	1,676	11	**27,086**
	06313400	Salt Creek Near Sussex, WY	2,235	1,706	1,580	1,726	2,412	3,985	3,012	4,564	4,661	2,916	1,876	1,750	**32,423**
	06313500	Powder River at Sussex, WY	8,804	8,411	7,030	6,999	11,096	18,936	19,424	33,736	24,225	8,661	4,715	5,703	**157,741**
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY	324	221	215	186	144	182	1,589	8,734	10,816	2,724	959	1,084	**27,177**
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY	1,419	1,319	961	811	1,793	2,626	3,724	8,073	7,100	2,075	1,083	974	**31,956**
	06317000	Powder River at Arvada, WY	9,874	9,343	6,922	6,424	12,141	24,059	23,302	44,564	38,014	13,330	6,608	6,543	**201,124**
	06318500	Clear Creek Near Buffalo, WY	2,258	1,534	1,184	881	742	970	2,622	11,564	17,291	7,889	3,941	2,840	**53,714**
	SEO Gage	Clear Creek in Buffalo City Park, Buffalo, WY	1,413	1,131	871	736	924	1,738	2,159	9,095	13,292	4,229	1,565	1,501	**38,653**
	06320000	Rock Creek Near Buffalo, WY	893	651	578	519	431	485	946	6,726	8,800	3,682	2,774	1,684	**28,169**
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY	1,401	1,292	952	870	1,214	2,267	1,322	4,706	6,204	1,592	957	925	**23,702**
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY	3,910	3,267	2,698	2,618	3,170	4,190	5,369	16,040	22,192	7,063	3,307	3,584	**77,409**
	SEO Gage	Clear Creek below Healy Reservoir Near Buffalo, WY	1,916	1,373	996	831	1,044	2,262	3,532	13,057	19,113	7,319	3,615	3,025	**58,083**
	06321000	South Piney Creek Near Story, WY	2,011	1,524	1,491	1,217	908	968	1,493	5,891	19,901	11,386	8,790	5,621	**61,201**
	06323000	Piney Creek at Kearney, WY	1,866	2,259	2,118	1,854	1,603	2,138	4,087	15,123	22,767	4,996	1,897	1,497	**62,203**
	SEO Gage	Little Piney Creek, WY	744	722	580	549	707	950	954	1,428	1,428	803	584	718	**10,166**
	SEO Gage	Piney Creek below Lake DeSmet Tunnel Intake Near Story, WY	1,463	1,057	713	642	595	861	1,678	9,173	18,866	4,704	2,047	1,432	**43,231**
	06323500	Piney Creek at Ucross, WY	3,045	3,150	2,126	1,851	1,543	2,979	3,926	12,380	17,789	5,885	4,958	3,896	**63,527**
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY	7,147	6,939	5,087	4,263	5,128	9,624	9,332	24,775	37,299	11,948	7,645	7,449	**136,634**
	SEO Gage	Clear Creek below P&F#3 Ditch Near Clearmont, WY	6,599	5,483	4,320	4,630	6,173	10,641	7,800	19,529	38,577	12,655	6,281	5,376	**128,064**
	06324000	Clear Creek Near Arvada, WY	6,461	6,176	4,147	3,680	5,852	10,041	10,320	23,374	34,407	9,106	5,364	6,169	**125,097**
	06324500	Powder River at Moorhead, MT	16,672	14,954	10,739	10,319	20,648	36,869	31,922	62,461	71,190	23,837	11,879	12,535	**324,023**
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	8	14	21	60	187	713	138	837	84	296	41	0	**2,399**
	06324925	Little Powder River Near Weston, WY	283	144	65	405	1,109	1,553	1,119	1,970	1,683	625	309	246	**9,511**
	06324970	Little Powder River Above Dry Creek Near Weston, WY	450	254	142	548	1,493	2,209	1,519	2,318	2,026	812	453	360	**12,582**
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	846	276	205	494	1,513	3,406	2,128	2,920	1,675	804	418	376	**15,059**

TABLE 15
SUMMARY OF WET YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)
NON-NATURAL FLOW STATIONS IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Number	Station Name	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
			OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Little Bighorn	06289600	West Pass Creek Near Parkman, WY	580	489	427	437	397	554	790	2,821	3,336	1,121	468	608	**12,027**
	06289820	East Pass Creek Near Dayton, WY	710	600	520	549	484	684	1,035	3,727	4,598	1,411	517	721	**15,555**
	06289870	Twin Creek Near Parkman, WY	201	171	218	631	444	1,621	1,779	3,801	735	309	233	170	**10,314**
Tongue	06302000	Big Goose Creek Near Sheridan, WY	2,438	1,792	1,633	1,532	1,276	1,423	1,844	15,206	43,642	15,021	5,115	4,027	**94,948**
	06303500	Little Goose Creek in Canyon Near Big Horn, WY	1,998	1,477	1,349	1,267	1,059	1,178	1,681	13,765	23,622	8,813	5,493	4,168	**65,872**
	06305500	Goose Creek Below Sheridan, WY	6,969	5,930	5,088	4,932	4,673	7,138	8,270	43,156	71,740	21,424	5,397	6,955	**191,672**
	06305700	Goose Creek Near Acme, WY	7,133	6,062	5,193	5,033	4,767	7,306	8,477	44,499	75,198	22,253	5,480	7,142	**198,542**
	06306250	Prairie Dog Creek Near Acme, WY	3,018	2,448	2,050	1,394	2,556	7,069	3,027	8,112	3,531	2,223	2,239	2,303	**39,972**
	06306300	Tongue River at State Line Near Decker, MT	16,527	14,165	11,352	10,340	10,940	21,038	21,378	108,313	171,233	55,478	16,727	15,543	**473,035**
Powder	06309500	Middle Fork Powder River Above Kaycee, WY	2,946	2,927	2,605	2,432	2,273	2,817	5,514	18,856	15,840	5,414	3,479	3,002	**68,105**
	06311060	North Fork Powder River Below Bull Creek Near Hazelton, WY	241	175	161	139	133	159	332	4,356	6,662	2,508	1,899	1,134	**17,899**
	06311400	North Fork Powder River Below Pass Creek Near Mayoworth, WY	1,370	1,215	1,178	1,153	1,048	1,133	1,330	6,663	9,603	3,500	2,898	2,293	**33,386**
	06312500	Powder River Near Kaycee, WY	6,596	8,318	8,443	7,304	8,391	10,965	11,653	35,264	20,683	1,310	1,157	2,323	**122,407**
	06313000	South Fork Powder River Near Kaycee, WY	277	394	234	331	1,879	12,398	9,830	14,619	3,052	854	2,431	15	**46,315**
	06313400	Salt Creek Near Sussex, WY	2,618	2,134	1,994	2,179	2,928	6,372	3,697	10,353	4,264	3,944	2,299	2,130	**44,913**
	06313500	Powder River at Sussex, WY	17,455	10,548	8,768	8,082	9,846	19,191	17,354	73,310	51,299	14,882	4,663	4,747	**240,144**
	SEO Gage	Crazy Woman Creek at Trabing Bridge Near Buffalo, WY	342	248	227	213	167	205	2,705	16,980	32,197	7,031	2,723	1,346	**64,382**
	06316400	Crazy Woman Creek at Upper Station Near Arvada, WY	3,113	1,647	1,174	970	1,556	2,802	3,577	20,742	21,055	3,967	2,082	646	**63,330**
	06317000	Powder River at Arvada, WY	18,455	11,577	8,322	7,527	11,060	27,253	22,005	105,460	90,540	25,422	8,175	5,057	**340,852**
	06318500	Clear Creek Near Buffalo, WY	2,683	1,917	1,485	1,122	948	1,224	3,052	17,066	25,968	14,208	5,142	3,249	**78,065**
	SEO Gage	Clear Creek in Buffalo City Park, Buffalo, WY	4,025	2,420	1,881	1,577	2,194	2,946	3,054	15,386	25,177	9,248	1,853	1,168	**70,930**
	06320000	Rock Creek Near Buffalo, WY	964	688	622	579	474	535	878	9,368	14,881	5,068	3,209	1,747	**39,012**
	SEO Gage	Rock Creek at Mouth Near Buffalo, WY	2,602	1,694	1,311	1,205	1,650	2,571	1,691	9,391	15,501	3,386	1,269	1,104	**43,372**
	06320200	Clear Creek Below Rock Creek Near Buffalo, WY	3,474	3,091	2,449	2,224	2,341	4,567	5,969	27,998	41,149	14,336	4,037	3,100	**114,733**
	SEO Gage	Clear Creek below Healy Reservoir Near Buffalo, WY	5,612	3,084	2,263	1,852	2,658	3,530	4,435	26,501	39,607	14,794	4,335	3,255	**111,926**
	06321000	South Piney Creek Near Story, WY	2,333	1,720	1,708	1,457	1,168	1,244	1,749	6,581	22,873	17,609	10,733	5,829	**75,004**
	06323000	Piney Creek at Kearney, WY	2,432	2,775	2,159	2,103	1,710	2,037	4,070	20,980	41,967	13,590	3,830	1,340	**98,991**
	SEO Gage	Little Piney Creek, WY	925	830	582	642	833	1,030	1,054	2,734	2,540	1,336	722	707	**13,933**
	SEO Gage	Piney Creek below Lake DeSmet Tunnel Intake Near Story, WY	2,259	1,558	1,144	1,004	927	1,280	2,549	17,464	38,497	10,973	3,374	1,762	**82,791**
	06323500	Piney Creek at Ucross, WY	4,880	4,201	3,459	3,078	2,221	4,190	4,203	18,650	42,300	14,719	6,525	3,190	**111,616**
	SEO Gage	Clear Creek at Double Crossing Near Clearmont, WY	13,916	9,888	8,067	6,929	8,629	11,825	10,678	47,150	86,491	28,773	8,955	6,602	**247,901**
	SEO Gage	Clear Creek below P&F#3 Ditch Near Clearmont, WY	5,842	5,553	2,924	2,797	4,373	12,829	12,513	17,547	3,355	2,034	589	1,452	**71,807**
	06324000	Clear Creek Near Arvada, WY	9,179	7,200	3,891	4,404	7,135	10,514	11,838	45,277	78,252	26,470	7,949	5,007	**217,115**
	06324500	Powder River at Moorhead, MT	24,643	19,325	9,172	12,118	19,360	42,163	31,243	146,877	162,267	53,775	16,330	9,263	**546,537**
Little Powder	06324890	Little Powder River Below Corral Creek Near Weston, WY	11	27	37	83	261	2,693	233	3,385	225	387	58	1	**7,400**
	06324925	Little Powder River Near Weston, WY	2,316	180	143	562	9,553	16,317	6,268	9,079	2,733	377	279	53	**47,860**
	06324970	Little Powder River Above Dry Creek Near Weston, WY	2,722	485	375	1,195	7,548	14,241	2,977	13,336	3,498	1,177	553	323	**48,430**
Belle Fourche	06426500	Belle Fourche River Below Moorcroft, WY	850	118	70	577	3,802	11,643	4,656	16,641	5,432	1,384	1,138	208	**46,519**

TABLE 16

SUMMARY OF DRY YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)

UNGAGED NATURAL FLOW NODES IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Tongue	Rapid Creek Just Below Little Rapid Creek in Section 32, T55N, R85W	90	67	63	52	44	49	201	1,031	723	260	123	87	**2,792**
	Beaver Creek at Bottom of Section 26, T55N, R85W	25	19	17	14	12	14	56	285	200	72	34	24	**771**
	Soldier Creek at Right Edge of Section 28, T56N, R85W	55	41	38	32	27	30	123	628	441	158	75	53	**1,702**
	Prairie Dog Creek Just Above Dutch Creek in Section 34, T57N, R83W	462	1,322	3,269	2,125	1,827	1,432	1,401	1,314	1,134	748	612	610	**16,255**
Powder	Red Fork Powder River Just Below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	24	24	19	20	15	23	118	335	105	33	18	17	**752**
	Kelly Creek at Top of Section 21, T49N, R82W	49	37	28	22	18	21	173	531	330	106	56	41	**1,414**
	Little North Fork Crazy Woman Creek Just Below Grossett Canyon in Section 14, T49N, R83W	156	123	97	74	60	68	428	1,210	787	292	155	117	**3,568**
	Muddy Creek at Diversion Near East Side of Section 35, T49N, R83W	143	113	89	68	55	63	393	1,111	723	269	143	108	**3,277**
	Billy Creek at Diversion to O'Malley Draw in Section 13, T48N, R83W	2,116	1,637	1,536	1,310	1,136	1,244	2,545	14,220	14,547	5,167	3,833	2,937	**52,227**
	Little Piney Creek Just Below Bear Gulch in Section 28, T53N, R83W	332	336	601	616	820	626	564	407	341	245	309	282	**5,480**
	North & South Forks Shell Creek (Combined), at Confluence of Little North Fork Shell Creek & North Fork Shell Creek in Section 11, and Confluence of Unnamed Tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	52	38	30	23	19	22	181	554	345	111	58	43	**1,475**
	Johnson Creek at Top of Section 22, T51N, R83W	49	37	28	22	18	21	173	531	330	106	56	41	**1,414**
	French Creek at Penrose Ditch Diversion in Section 27, T51N, R83W	119	88	68	53	43	51	416	1,275	793	256	134	99	**3,395**

TABLE 17

SUMMARY OF NORMAL YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)

UNGAGED NATURAL FLOW NODES IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Tongue	Rapid Creek Just Below Little Rapid Creek in Section 32, T55N, R85W	99	74	65	58	51	55	151	991	1,382	386	170	114	**3,596**
	Beaver Creek at Bottom of Section 26, T55N, R85W	27	20	18	16	14	15	42	274	382	107	47	32	**994**
	Soldier Creek at Right Edge of Section 28, T56N, R85W	60	45	39	36	31	33	92	604	843	235	104	70	**2,192**
	Prairie Dog Creek Just Above Dutch Creek in Section 34, T57N, R83W	559	1,529	3,372	2,321	2,368	2,074	1,852	1,470	1,202	1,066	830	752	**19,396**
Powder	Red Fork Powder River Just Below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	34	31	25	27	23	41	215	515	238	64	32	28	**1,272**
	Kelly Creek at Top of Section 21, T49N, R82W	55	42	35	27	23	26	99	685	654	200	88	63	**1,998**
	Little North Fork Crazy Woman Creek Just Below Grossett Canyon in Section 14, T49N, R83W	177	128	107	85	71	81	280	1,360	1,363	488	243	182	**4,563**
	Muddy Creek at Diversion Near East Side of Section 35, T49N, R83W	162	118	98	78	65	75	257	1,249	1,252	448	223	167	**4,191**
	Billy Creek at Diversion to O'Malley Draw in Section 13, T48N, R83W	2,326	1,735	1,570	1,430	1,194	1,339	2,282	12,149	25,660	7,537	4,754	3,721	**65,698**
	Little Piney Creek Just Below Bear Gulch in Section 28, T53N, R83W	289	422	610	672	1,086	1,143	678	483	465	271	309	264	**6,691**
	North & South Forks Shell Creek (Combined), at Confluence of Little North Fork Shell Creek & North Fork Shell Creek in Section 11, and Confluence of Unnamed Tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	57	44	36	28	24	27	103	715	682	208	92	66	**2,084**
	Johnson Creek at Top of Section 22, T51N, R83W	55	42	35	27	23	26	99	685	654	200	88	63	**1,998**
	French Creek at Penrose Ditch Diversion in Section 27, T51N, R83W	132	101	84	65	56	63	237	1,646	1,570	480	212	151	**4,797**

TABLE 18

SUMMARY OF WET YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999)

UNGAGED NATURAL FLOW NODES IN THE POWDER-TONGUE RIVER BASINS

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Tongue	Rapid Creek Just Below Little Rapid Creek in Section 32, T55N, R85W	103	75	67	61	50	58	124	1,246	2,396	620	210	120	**5,130**
	Beaver Creek at Bottom of Section 26, T55N, R85W	29	21	19	17	14	16	34	344	662	171	58	33	**1,418**
	Soldier Creek at Right Edge of Section 28, T56N, R85W	63	46	41	37	30	35	76	760	1,460	378	128	73	**3,127**
	Prairie Dog Creek Just Above Dutch Creek in Section 34, T57N, R83W	439	1,090	3,718	2,241	6,284	3,382	2,637	1,896	1,423	845	733	657	**25,344**
Powder	Red Fork Powder River Just Below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	50	44	36	41	33	60	316	925	390	100	46	39	**2,081**
	Kelly Creek at Top of Section 21, T49N, R82W	52	41	33	30	23	29	75	773	1,280	343	110	65	**2,854**
	Little North Fork Crazy Woman Creek Just Below Grossett Canyon in Section 14, T49N, R83W	145	116	95	81	71	86	227	1,837	2,442	824	317	188	**6,429**
	Muddy Creek at Diversion Near East Side of Section 35, T49N, R83W	133	107	87	75	66	79	209	1,687	2,243	757	291	173	**5,905**
	Billy Creek at Diversion to O'Malley Draw in Section 13, T48N, R83W	2,438	1,792	1,633	1,532	1,276	1,423	1,844	15,206	43,642	15,021	5,115	4,027	**94,948**
	Little Piney Creek Just Below Bear Gulch in Section 28, T53N, R83W	351	505	664	740	1,979	1,982	1,190	741	604	411	397	271	**9,837**
	North & South Forks Shell Creek (Combined), at Confluence of Little North Fork Shell Creek & North Fork Shell Creek in Section 11, and Confluence of Unnamed Tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	54	42	34	31	24	30	78	807	1,336	358	115	67	**2,978**
	Johnson Creek at Top of Section 22, T51N, R83W	52	41	33	30	23	29	75	773	1,280	343	110	65	**2,854**
	French Creek at Penrose Ditch Diversion in Section 27, T51N, R83W	125	98	79	71	54	70	180	1,857	3,074	825	265	155	**6,854**

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APPENDIX D-2

SURFACE WATER HYDROLOGY: NORTHEAST WYOMING BASINS PLAN

Subject: **Northeast Wyoming River Basins Plan**
Surface Water Hydrology
Tasks 3A and 3B

Date: February 2002

Prepared by: HKM Engineering Inc.

INTRODUCTION

Water availability models are to be developed to represent dry year, normal year, and wet year hydrologic conditions throughout the Northeast Wyoming River Basins planning area. Several key inputs are necessary to model the water availability including the current irrigated land base, crop water requirements, municipal and industrial surface water demands, and regulation by reservoir storage facilities. This information was developed through the Task 2 work effort. Schematic representations of the water availability models have been developed identifying the appropriate location of model nodes in relation to the various surface water demands, return flows, and storage regulation. Model nodes are located, to the extent possible, at historic streamflow gaging stations in order to take advantage of the historic records of streamflow at these locations. The Northeast Wyoming River Basins, however, are characterized by a scarcity of historic streamflow records. It is therefore necessary to locate model nodes at many locations with no record of streamflow, to appropriately simulate water use in the various drainages. This memorandum summarizes the methodology used to collect the historic records of streamflow, establish a study period for modeling, and to extend or fill-in the streamflow data where records are unavailable. The methodology used to estimate natural (virgin) streamflow at ungaged model nodes is also discussed in this memorandum.

HISTORIC STREAMFLOW RECORDS

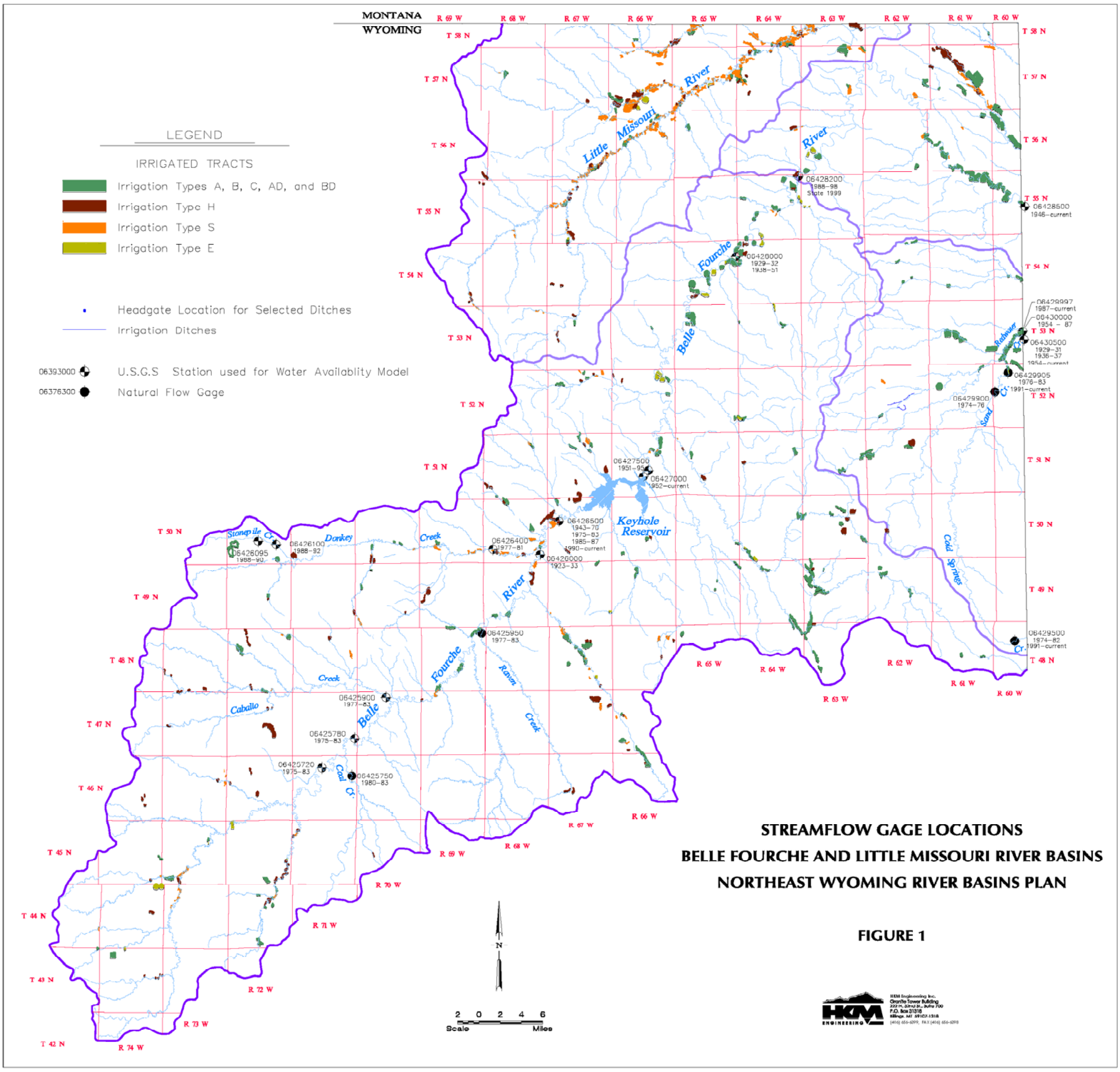
HKM inventoried the available records of streamflow in the Northeast Wyoming River Basins. Data from the following four sources were used for this study:

1. Wyoming USGS digital database in Cheyenne
2. USGS Water Resources Data Books for Wyoming
3. Records from State Engineers Office Hydrographers Annual Reports as compiled by HKM
4. Water Resources Data System (WRDS) database

The order of priority for use of data available from multiple sources was as numbered above.

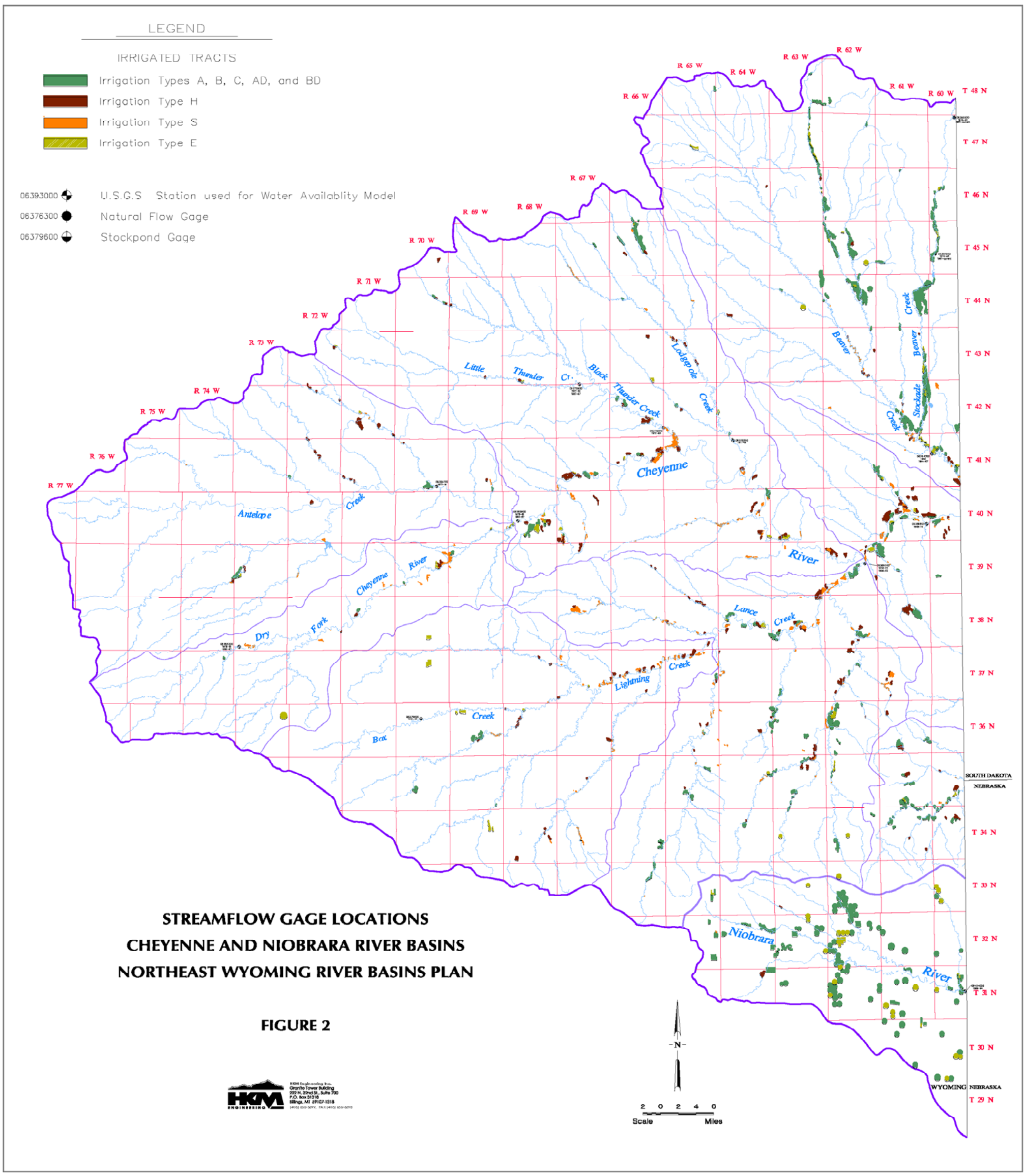
The location of the various streamflow gaging stations are plotted in relation to the significant storage reservoirs and the irrigated lands mapped by HKM (Figures 1 and 2). The streamflow gages that are relatively free from the influence of depletions or storage regulations are characterized as natural flow stations. Where reasonably possible, those gages that are impacted by upstream depletions were adjusted to remove these effects. The list of streamflow gages inventoried for this study is provided in Table 1. Figure 3 illustrates the period of record for all of the streamflow stations available in the basins.

As shown in Figure 3, prior to 1970, there were only 13 streamflow gages in operation in the Northeast Wyoming River Basins. Beginning in the 1970s and 1980s, with the installation of an additional 18 streamflow gages, records for a total of 31 streamflow stations became available.



STREAMFLOW GAGE LOCATIONS
BELLE FOURCHE AND LITTLE MISSOURI RIVER BASINS
NORTHEAST WYOMING RIVER BASINS PLAN

FIGURE 1



STREAMFLOW GAGE LOCATIONS
CHEYENNE AND NIOBRARA RIVER BASINS
NORTHEAST WYOMING RIVER BASINS PLAN

FIGURE 2

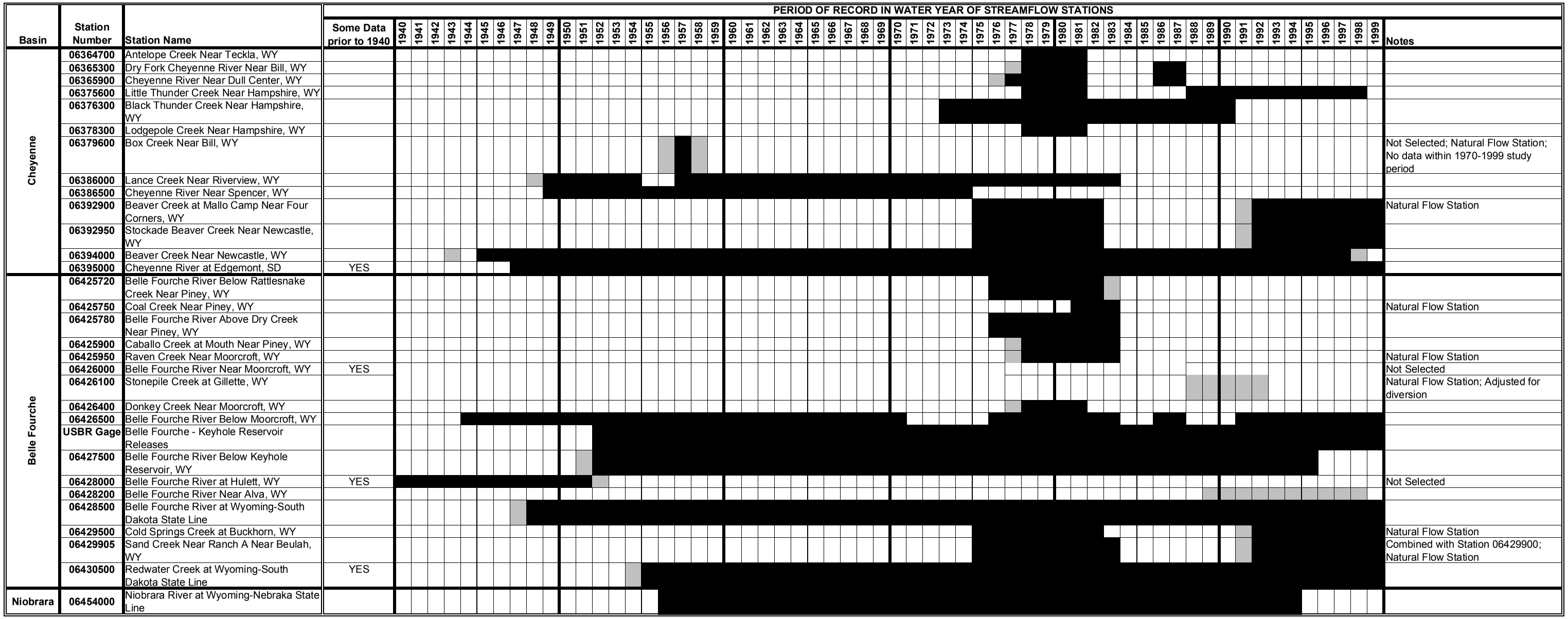
TABLE 1
STREAMFLOW STATIONS IN THE NORTHEAST WYOMING RIVER BASINS

Basin	Station Number	Station Name	Natural Flow	Period of Record in Water Years **	Note
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO	1978-1981	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO	1977-1981, 1986-1987	
	06365900	Cheyenne River Near Dull Center, WY	NO	1976-1981, 1986-1987	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	1978-1981, 1988-1998	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	1973-1990	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	1978-1981	
	06379600	Box Creek Near Bill, WY	YES	1956-1958	
	06386000	Lance Creek Near Riverview, WY	NO	1948-1954, 1956-1983	
	06386500	Cheyenne River Near Spencer, WY	NO	1949-1974	
	06392900	Beaver Creek at Mallo Camp, Near Four Corners, WY	YES	1975-1982, 1991-current	
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO	1975-1982, 1991-current	
	06394000	Beaver Creek Near Newcastle, WY	NO	1945-1998	
	06394500	Beaver Creek Near Burdock, SD	NO	1905-1907, 1929-1932	Abt. 2 mi. into SD
	06395000	Cheyenne River at Edgemont, SD	NO	1903-1907, 1928-1933, 1947-current	Several miles into SD; No winter records 1903-1906
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek, Near Piney, WY	NO	1976-1983	
	06425750	Coal Creek Near Piney, WY	YES	1981-1983	
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO	1976-1983	
	06425900	Caballo Creek at Mouth Near Piney, WY	NO	1977-1983	
	06425950	Raven Creek Near Moorcroft, WY	YES	1977-1983	
	06426000	Belle Fourche River Near Moorcroft, WY	NO	1923-1933	
	06426100	Stonepile Creek at Gillette, WY	YES	1988-1992	No winter records; Adjusted for diversions using Burlington Lake Ditch
	06426400	Donkey Creek Near Moorcroft, WY	NO	1977-1981	
	06426500	Belle Fourche River Below Moorcroft, WY	NO	1943-1970, 1976-1983, 1986-1987, 1991-current	
	USBR Gage	Inflow to Keyhole Reservoir	NO	USBR: 1952-current	Adjusted for evaporation
	USBR Gage	Belle Fourche - Keyhole Reservoir Releases	NO	USBR: 1952-current	
	06427500	Belle Fourche River Below Keyhole Reservoir, WY	NO	1951-1995	
	06428000	Belle Fourche River at Hulett, WY	NO	1929-1933, 1938-1952	
	06428200	Belle Fourche River Near Alva, WY	NO	1989-1998	No winter records
	06428500	Belle Fourche River at Wyoming-South Dakota State Line	NO	1947-current	
	06429500	Cold Springs Creek at Buckhorn, WY	YES	1975-1982, 1991-current	
	06429900	Sand Creek at Ranch A Near Beulah, WY	YES	1975-1976	Combined with Station 06429905
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES	1976-1983, 1991-current	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO	1929-1931, 1936-1937, 1954-current	Adjusted for diversions using Murrey Ditch
Niobrara	06454000	Niobrara River at Wyoming-Nebraka State Line	NO	1956-1994	

** Unless otherwise noted, records were obtained from the USGS.

FIGURE 3

STREAMFLOW STATIONS IN THE NORTHEAST WYOMING RIVER BASINS



STUDY PERIOD

It is important in any water availability evaluation to select a study period that is long enough to include a variety of hydrologic conditions including an extended period of dry years as well as wet years and normal years. At the same time, it is also important not to select a study period so long that many streamflows must be synthesized to fill-in missing data.

It is desirable in evaluating long-term hydrologic conditions to utilize streamflow records for a station that has a long period of continuous records and that reflects natural (virgin) flow, unaffected by upstream depletions or storage regulation. Unfortunately, no such streamflow gaging station exists in, or in near vicinity to, the Northeast Wyoming River Basins. The USGS has, however, maintained streamflow stations on Beaver Creek near Newcastle (#06394000) and the Cheyenne River at Edgemont, South Dakota (#06395000) since the mid 1940s (Table 1). The Beaver Creek gage was discontinued in 1998. The records for these gages are impacted by upstream irrigation depletions and storage, primarily in the form of stock ponds. The change in carryover storage from year to year is however expected to be relatively minor and the amount of irrigation depletion in relation to the total streamflow is not expected to vary greatly from year to year. The records for these stations although non-natural can therefore be used as a reasonable representation of annual hydrologic conditions. The USGS has also maintained a streamflow station on the Belle Fourche River below Moorcroft (#06426500) since 1944 with some gaps in the record in the 1970s and 1980s (Table 1). Similar to stations on Beaver Creek and the Cheyenne River, the streamflow at this gage is impacted by upstream irrigation depletion and stock pond storage. The record for this station can however be used to represent hydrologic conditions in the Belle Fourche drainage. The USBR maintains records of computed inflows into Keyhole Reservoir downstream from the Moorcroft gage (#06426500). HKM utilized this information to develop a regression relationship between streamflows at the upstream Moorcroft gage and inflows to Keyhole Reservoir to fill-in the missing records in the 1970s and 1980s. The relationship is shown below:

$$Q_{06426500} = 0.671 * Q_{\text{Keyhole Inflow}} - 386.2$$

Where: $Q_{06426500}$ is monthly streamflow at Gage #06426500 in acre-feet and
$Q_{\text{Keyhole Inflow}}$ is computed inflow to Keyhole Reservoir from USBR in acre-feet.

The coefficient of determination (R^2) for this relationship is 0.87. The coefficient of determination is defined as the proportion of variation in the independent variable that can be explained by variation in the dependent variable (DeVore, 1987). The higher the value of R^2, the stronger the relationship between the two variables. A perfect relationship would have an $R^2 = 1.0$. Regression of hydrologic data resulting in $R^2>0.7$ is typically considered strong enough for data estimating. The regression analysis and the resulting monthly streamflows for this station are provided in Appendix A.

The recorded and estimated streamflow records from the gages on Beaver Creek (#06394000), the Cheyenne River (#06395000), and the Belle Fourche River (#06426500) are selected as representative of the hydrologic conditions throughout the Northeast Wyoming River basins.

Figures 4, 5, and 6 are Cumulative Surplus/Deficit plots for Beaver Creek, the Cheyenne River, and the Belle Fourche River respectively for the longest concurrent period of record (1947 to 1997 or 1999). A Cumulative Surplus/Deficit plot represents a running total of the annual deviations from the long-term mean annual streamflow. Downward sloping lines (left to right) represent periods of time during which annual streamflow is less than the long-term mean (dry periods). Conversely, upward sloping lines represent years, which are wetter than average (wet periods). As can be seen from these plots, the hydrologic conditions can vary considerably throughout the Northeast Wyoming River Basins in any given period of years. By way of example, the period 1964 to 1970 is generally a wet period on Beaver Creek. Whereas, on the Cheyenne River, this same period is generally average, and on the Belle Fourche River, 1964 to 1970 is generally a dry period. Some similarities do however exist throughout the study area. The periods 1959 to 1961, 1979 to 1985, and 1988 to 1990 are generally dry periods at all locations. The years 1962 and 1978 are also extreme wet years at all locations.

FIGURE 4

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

BEAVER CREEK NEAR NEWCASTLE, WY (Station 06394000)

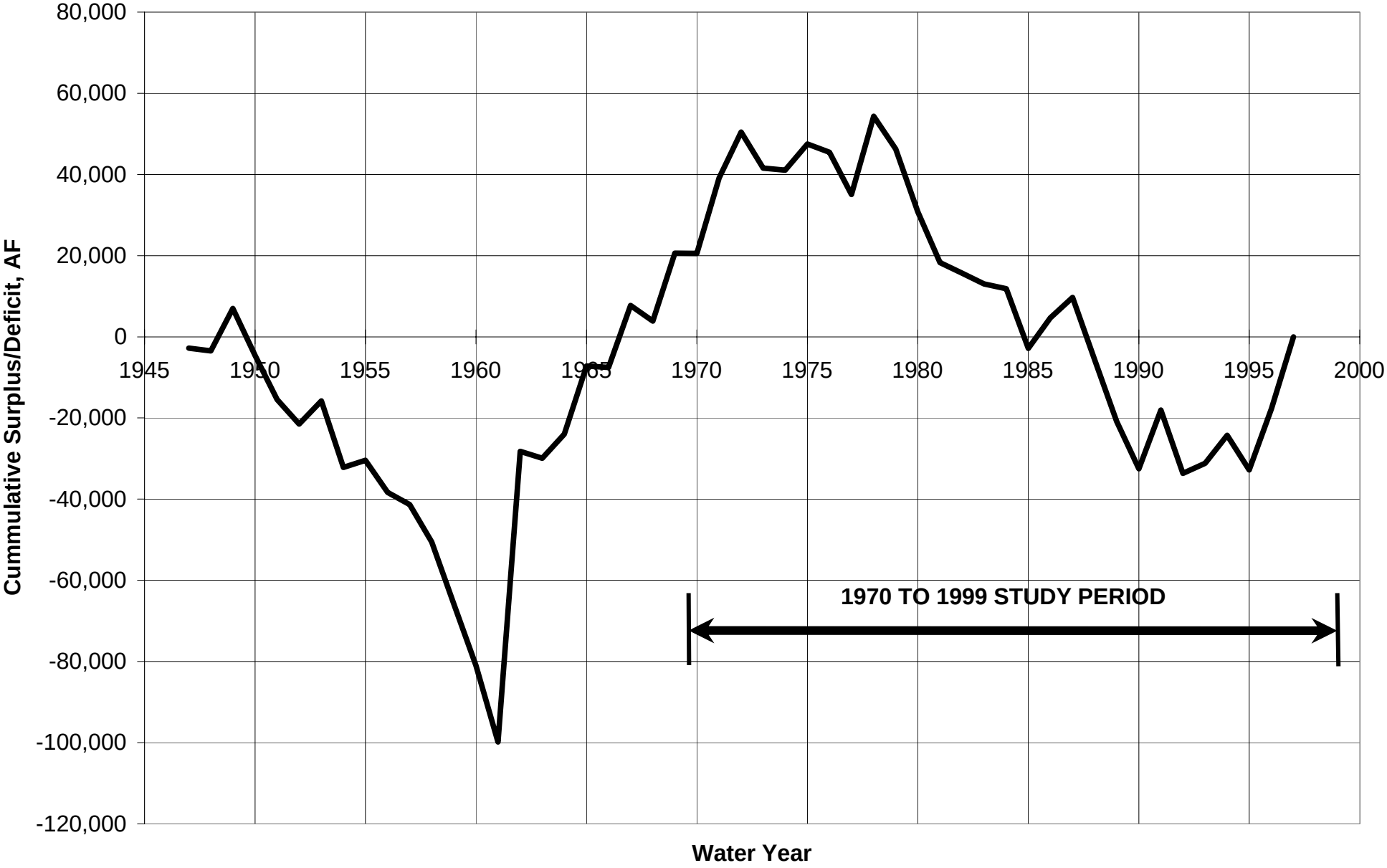


FIGURE 5

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

CHEYENNE RIVER AT EDGEMONT, SD (Station 06395000)

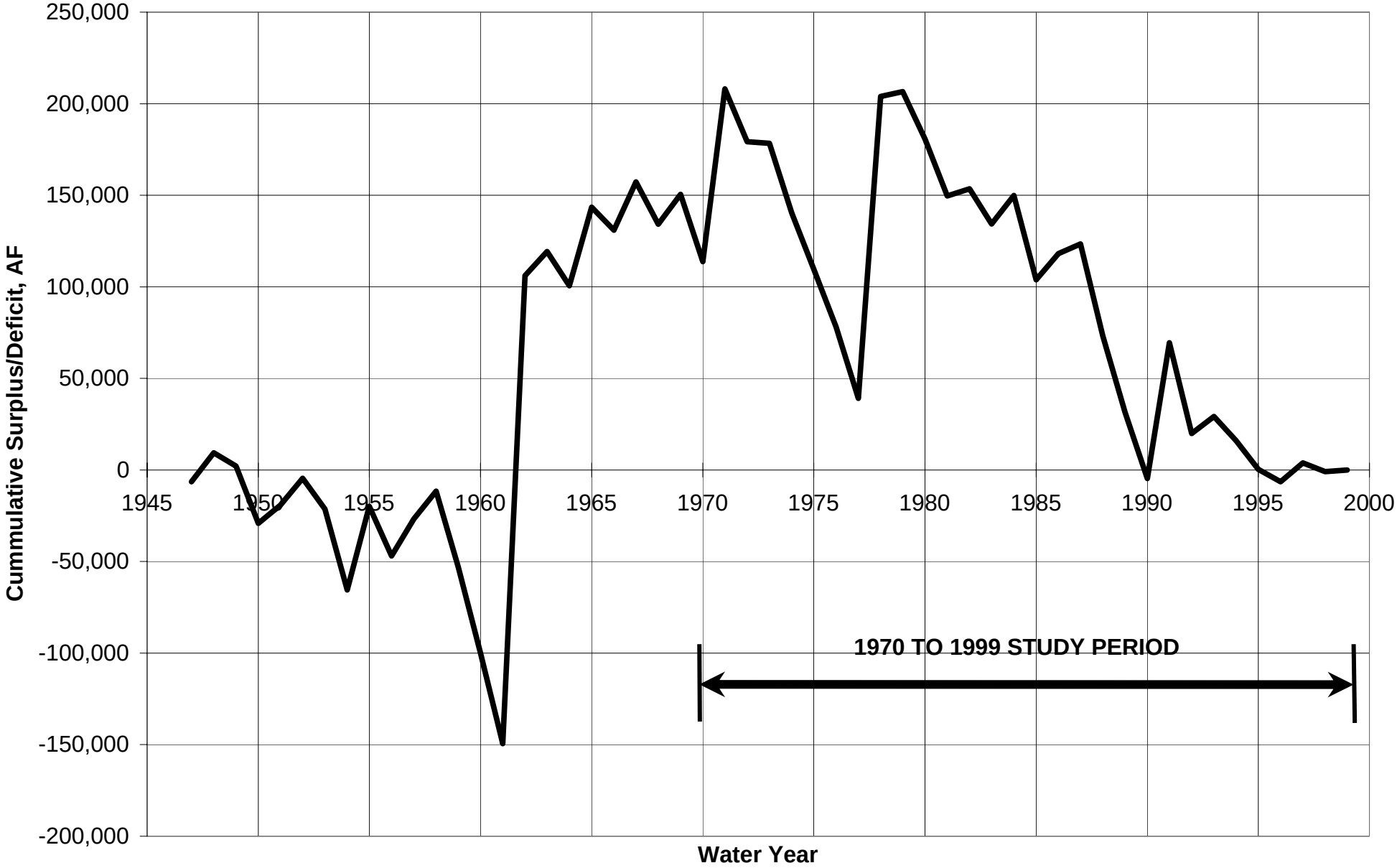


FIGURE 6

CUMULATIVE SURPLUS/DEFICIT OF ANNUAL HISTORIC FLOWS

BELLE FOURCHE RIVER BELOW MOORCROFT, WY (Station 06426500)

Based on an evaluation of the long-term hydrologic conditions at the three representative streamflow stations, together with the an understanding of the availability of historic streamflow records, the 30-year period 1970 through 1999 is selected as a candidate study period. The annual streamflows at each of these stations for the period 1947 to 1997 or 1999 are summarized in Table 2. The average annual flow for the period 1970 to 1999 ranges from 9% drier than the long-term period on the Cheyenne River to 12% wetter than the long-term period on the Belle Fourche River.

On the Cheyenne River, the period 1970 to 1999 includes the extended dry periods 1972 to 1977, 1980 to 1983, and 1988 to 1990 as well as the wet period from 1978 to 1979. This period contains three out of six of the driest years of the 1947 – 1999 records including 1985, 1988, and 1992. The period also contains three out of six of the wettest years of record in 1971, 1978, and 1991. The extreme dry years and wet years (driest and wettest years) are defined here as those with exceedance or non-exceedance probabilities of less than approximately 10 percent.

The 1970 to 1999 period on the Belle Fourche River contains the dry periods from 1975 to 1977, 1979 to 1986 and 1990 to 1992 as well as the wet periods 1973 to 1974 and 1993 to 1997. This period also contains three of the six driest years of the 1947 – 1999 records in 1980, 1981, and 1990 and 4 of the six wettest years of record in 1973, 1974, 1978, and 1993.

On the Beaver Creek at Newcastle (#06394000), the period 1970 to 1999 includes the extended dry periods from 1979 through 1985 and 1988 through 1990 as well as the wet periods from 1971 to 1972, 1986 to 1987, and 1996 to 1997. This period also contains three out of six of the driest years of the 1947 – 1997 records including 1980, 1988, and 1992. The period also contains three out of six of the wettest years of record in 1971, 1978, and 1997.

In summary, the period 1970 through 1999 contains extended periods of dry years at all locations 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 therefore requires less data synthesis. A study period of 1970 through 1999 is therefore appropriate for purposes of water availability modeling for the Northeast Wyoming River Basin Plan.

The remainder of this memorandum describes the methodologies used to determine the typical dry year, normal year, and wet year monthly flows required at each of the model nodes.

DATA EXTENSION

The spreadsheet modeling approach used for the Basin Plan utilizes model nodes located at historic streamflow gaging stations in order to take advantage of the historic records of streamflow at these locations. These records however contain many data gaps during the 1970 to 1999 study period (Figure 3). Monthly streamflows must therefore be estimated for those months, during the study period, with no recorded streamflow data.

The monthly record extension approach used in this study follows the procedure used by the USGS in recent studies in Montana (USGS WRI 89-4165, 1989: USGS WRI 89-4082, 1989). This mixed-station procedure uses the best base station from among all available base stations to fill in each month of missing data for a given gage. It is therefore possible that several different base stations may be used to fill in different months of missing data for a given station. The base station producing the smallest standard error of prediction is used for each particular month. The monthly record extension procedure also offers the option of using cyclic or noncyclic equations to fill in missing records. If the cyclic option is selected, an extension equation is computed for each month using only concurrent streamflows for the month. If the noncyclic option is selected, a single extension equation is computed using all concurrent streamflows. The smallest standard error criterion is used to select between the cyclic or noncyclic option for each month of missing record. For this study, the cyclic option is used only if the base station and the short record station have at least five concurrent monthly streamflows. The noncyclic option is used in all other cases. The technique used to estimate missing values in this study was developed by Hirsch and is referred to as MOVE.1 (Maintenance of Variance Extension, Type 1). This technique offers the

TABLE 2

LONG TERM AVERAGE ANNUAL FLOW COMPARISON TO 1970-1999 AVERAGE ANNUAL FLOW

	Annual Flow in Acre-Feet		
YEAR	Beaver Creek Near Newcastle, WY **06394000**	Cheyenne River at Edgemont, SD **06395000**	Belle Fourche River Below Moorcroft, WY **06426500**
1947	19,703	52,451	8,999
1948	21,855	74,782	26,989
1949	32,921	51,613	19,570
1950	10,925	27,659	7,965
1951	11,669	68,919	4,751
1952	16,476	73,500	7,726
1953	28,225	42,095	14,037
1954	6,100	14,868	2,288
1955	24,273	104,588	31,891
1956	14,573	31,719	9,290
1957	19,478	79,214	5,132
1958	13,292	74,108	5,868
1959	7,133	17,624	4,413
1960	7,443	11,881	9,097
1961	3,715	9,339	825
1962	94,071	314,408	75,153
1963	20,810	72,168	18,993
1964	28,424	40,155	40,060
1965	39,333	101,877	12,633
1966	22,155	46,363	6,120
1967	37,732	85,226	16,413
1968	18,708	35,927	6,549
1969	39,198	75,129	10,816
1970	22,458	22,264	10,842
1971	41,118	153,235	20,218
1972	33,801	30,052	14,051
1973	13,645	57,980	40,434
1974	21,996	20,970	44,264
1975	28,898	28,202	7,583
1976	20,510	27,407	7,543
1977	12,102	19,855	7,876
1978	41,784	223,740	98,331
1979	14,393	61,675	15,391
1980	7,085	32,972	3,712
1981	9,954	27,855	4,646
1982	19,917	62,767	20,283
1983	19,842	39,746	11,590
1984	21,339	74,519	18,478
1985	7,801	12,831	7,880
1986	30,004	73,186	14,496
1987	27,558	64,260	25,747
1988	7,171	8,725	15,069
1989	7,335	17,079	21,935
1990	10,762	22,894	4,576
1991	36,995	132,999	12,248
1992	6,889	9,408	4,994
1993	25,031	68,156	41,836
1994	29,359	45,633	23,223
1995	14,005	43,391	24,721
1996	37,581	52,131	20,135
1997	40,220	69,180	26,752
1998		54,230	11,136
1999		59,770	23,556
Avg 47-99	22,505	58,919	17,908
Avg 70-99	21,770	53,904	20,118

advantage over ordinary least-squares regression of preserving the variance of the unextended records (Alley and Burns, 1983). The MOVE.1 technique differs from ordinary least-squares regression in that ordinary regression minimizes the squared vertical deviations of the response variable from the regression line, whereas the MOVE.1 technique minimizes the areas of the right triangles formed by the horizontal and vertical deviations from the regression line (USGS WRI 89-4165, 1989). This procedure is carried out using a computer program developed by the USGS.

The USGS streamflow stations are divided into hydrologically similar groups with each group having at least one gage with sufficient data to develop relationships based on concurrent streamflow for the entire study period. The groupings also represent stations affected by similar reservoir operations. In particular, those stations below Keyhole Reservoir are grouped together because they all experience the same impacts from Keyhole operations. The monthly flow extension procedure is performed for each of these groupings of monthly streamflow data. There is a certain amount of overlap in hydrologic similarity among the various groupings. Some streamflow stations are therefore included in multiple groups. The station groupings and the resulting coefficients of determination (R^2) are provided in Table 3. Regression of hydrologic data resulting in $R^2>0.7$ is typically considered strong enough for data estimating. This criterion was used in evaluating the results of the regression analyses. The results of the MOVE.1 analyses are provided in Appendix B.

As shown in Table 3 in many instances no significant correlation ($R^2<0.7$) could be found using concurrent monthly streamflows between any base station and the short record station. Annual flow regression rather than monthly flow regression was performed in these instances to fill-in the missing streamflow data. The results of this analysis including the base station record used to fill-in the missing data at the short record station, the regression equation, and the resulting coefficient of determination (R^2) are summarized in Table 4. The supporting computations and graphic displays of the results of the annual flow regression analyses are provided in Appendix C. As noted in Table 4, in some cases, no significant correlation ($R^2<0.7$) could be found using the annual flow regression either. Three of these stations were dropped from the study. Four other stations on Beaver Creek and the Niobrara River were retained and the study periods for modeling were adjusted to utilize historic records only (Table 4). The monthly streamflows for the years of missing data were estimated by applying the average monthly distribution for the period of recorded streamflow to the estimated total annual flow. For those instances when records for some months are available, the recorded streamflows are used and subtracted from the estimated annual total. The remaining months of missing data are then filled-in using the average monthly distribution for these months applied to the total remaining streamflow for the partial year.

The average monthly and annual streamflows during the study period are summarized in Table 5, for the gaging stations selected for use in the water availability models. The recorded and extended monthly streamflows for each year of the study period are provided in Appendix D for each station.

NATURAL FLOW AT UNGAGED MODEL NODES

Records of streamflow from the limited number of gaging stations in planning area are used to the extent available to represent flow at model nodes. However, to fully represent water use in the various drainages, estimates of natural flow are also required at many model nodes where records from USGS or SEO streamflow stations are unavailable. HKM evaluated several alternatives for estimating natural flow at these locations including:

1. Use the streamflow records from a nearby gaging station on the same stream, adjusting for depletions and storage regulation to estimate natural flow at the location of interest.

2. Use the regression equations developed by the USGS in WRIR 88-4045 for relating drainage area and either average annual precipitation or mean basin elevation to estimate natural flow.

3. Use the recorded natural flow from a gaged stream with similar hydrologic characteristics, adjusting for the difference in drainage area at the location of interest.

TABLE 3
CORRELATION RESULTS BASED ON MONTHLY DATA

Basin	Station Number	Station Name	Natural Flow	USGS MOVE.1 EXTENSION GROUPINGS						Wtd. Avg. R^2 Value	Notes
				CHEANON7	CHECNON7	BLABNAT7	BELANON7	LBEBNON7	LBELNON7		
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO							0.74	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO							No Correlation	See Table 4
	06365900	Cheyenne River Near Dull Center, WY	NO							0.77	
	06375600	Little Thunder Creek Near Hampshire, WY	NO							No Correlation	See Table 4
	06376300	Black Thunder Creek Near Hampshire, WY	NO							No Correlation	See Table 4
	06378300	Lodgepole Creek Near Hampshire, WY	NO							No Correlation	See Table 4
	06386000	Lance Creek Near Riverview, WY	NO							No Correlation	See Table 4
	06386500	Cheyenne River Near Spencer, WY	NO							No Correlation	See Table 4
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES							No Correlation	See Table 4
	06392950	Stockade Beaver Creek Near Nearcastle, WY	NO							No Correlation	See Table 4
	06394000	Beaver Creek Near Newcastle, WY	NO							No Correlation	See Table 4
	06395000	Cheyenne River at Edgemont, SD	NO							N/A	Records available for entire study period
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek Near Piney, WY	NO							No Correlation	See Table 4
	06425750	Coal Creek Near Piney, WY	YES							No Correlation	See Table 4
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO							No Correlation	See Table 4
	06425900	Caballo Creek at Mouth Near Piney, WY	NO							No Correlation	See Table 4
	06425950	Raven Creek Near Moorcroft, WY	YES							No Correlation	See Table 4
	06426100	Stonepile Creek at Gillette, WY	YES							No Correlation	See Table 4
	06426400	Donkey Creek Near Moorcroft, WY	NO							No Correlation	See Table 4
	06426500	Belle Fourche River Below Moorcroft, WY	NO							N/A	Records available for entire study period
	USBR Gage	Belle Fourche - Keyhole Reservoir Releases	NO							N/A	Records available for entire study period
	06427500	Belle Fourche River Below Keyhole Reservoir, WY	NO							0.90	
	06428200	Belle Fourche River Near Alva, WY	NO							0.91	
	06428500	Belle Fourche River at Wyoming-South Dakota State Line	NO							N/A	Records available for entire study period
	06429500	Cold Springs Creek at Buckhorn, WY	YES							No Correlation	See Table 4
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES							0.82	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO							N/A	Records available for entire study period
Niobrara	06454000	Niobrara River at Wyoming-Nebraka State Line	NO							No Correlation	See Table 4

LEGEND	
	USGS MOVE.1 Group resulting in best R^2 value
	Station included in USGS MOVE.1 group

TABLE 4
STATIONS IN THE NORTHEAST WYOMING RIVER BASINS

Basin	Station Number	Station Name	Natural Flow	Station Used in Regression	R^2 Value	Regression Equation	Notes
Cheyenne	**06365300**	Dry Fork Cheyenne River Near Bill, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.97	Y= 0.012486X - 340.33	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.94	Y = 0.038268X - 779.37	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.93	Y = 0.12044X - 963.54	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.99	Y= 0.10146X - 98.335	
	06386000	Lance Creek Near Riverview, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.93	Y = 0.30488X - 820.91	
	06386500	Cheyenne River Near Spencer, WY	NO	Cheyenne River at Edgemont, SD (Station 06395000)	0.99	Y= 0.89571X - 8219.4	
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES		No Correlation		Study period modified to 1975-1982, 1992-1997
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO		No Correlation		Study period modified to 1975-1982, 1992-1997
	06394000	Beaver Creek Near Newcastle, WY	NO		No Correlation		Study period modified to 1975-1982, 1992-1997
Belle Fourche	**06425720**	Belle Fourche River Below Rattlesnake Creek, Near Piney, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.92	Y = 0.072446X + 192.57	
	06425750	Coal Creek Near Piney, WY	YES		No Correlation		Unable to find significant correlation with any available station
	06425780	Belle Fourche River Above Dry Creek, Near Piney, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.98	Y = 0.14088X + 176.13	
	06425900	Caballo Creek at Mouth, Near Piney, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.99	Y = 0.084892X - 297.37	
	06425950	Raven Creek Near Moorcroft, WY	YES	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.99	Y = 0.023728X - 126.42	
	06426100	Stonepile Creek at Gillette, WY	YES		No Correlation		Adjusted for diversions; Unable to find significant correlation with any available station
	06426400	Donkey Creek Near Moorcroft, WY	NO	Belle Fourche River Below Moorcroft, WY (Station 06426500)	0.99	Y = 0.27550X - 874.51	
	06429500	Cold Springs Creek at Buckhorn, WY	YES		No Correlation		Unable to find significant correlation with any available station
Niobrara	**06454000**	Niobrara River at Wyoming-Nebraska State Line	YES		No Correlation		Study period modified to 1970-1994

TABLE 5
SUMMARY OF AVERAGE MONTHLY AND ANNUAL FLOWS (1970 TO 1999 unless otherwise noted)
AT GAGED MODEL NODES

Basin	Station Number	Station Name	Natural Flow	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET													Notes
				OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL	
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO	97	64	18	22	159	545	291	1,520	1,005	361	148	93	**4,323**	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO	3	6	5	3	17	44	20	194	37	30	8	1	**366**	
	06365900	Cheyenne River Near Dull Center, WY	NO	176	101	26	36	407	798	633	3,475	2,247	854	425	66	**9,244**	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	3	4	5	5	48	86	11	824	131	135	100	2	**1,354**	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	307	16	0	51	272	846	308	1,788	671	549	405	498	**5,710**	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	1	2	1	1	2	45	33	223	91	32	34	1	**464**	
	06386000	Lance Creek Near Riverview, WY	NO	133	111	83	333	870	1,205	902	5,594	2,717	2,993	2,078	694	**17,713**	
	06386500	Cheyenne River Near Spencer, WY	NO	275	233	71	1,023	1,487	866	2,040	20,050	9,286	2,103	535	3,453	**41,423**	
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES	112	102	100	97	98	127	138	136	144	131	120	112	**1,415**	Study Period: 1975-1982, 1992-1997
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO	786	763	785	769	721	877	785	654	675	699	730	751	**8,996**	Study Period: 1975-1982, 1992-1997
	06394000	Beaver Creek Near Newcastle, WY	NO	876	804	796	881	2,381	5,716	2,353	3,250	2,339	1,106	797	497	**21,796**	Study Period: 1975-1982, 1992-1997
	06395000	Cheyenne River at Edgemont, SD	NO	1,910	1,416	684	800	3,106	8,847	4,275	14,156	10,524	4,720	3,269	1,700	**55,407**	
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek Near Piney, WY	NO	6	6	12	24	79	212	66	685	236	101	149	20	**1,596**	
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO	21	6	14	45	190	611	131	1,097	282	239	179	70	**2,887**	
	06425900	Caballo Creek at Mouth Near Piney, WY	NO	13	10	1	10	27	221	30	788	76	99	45	18	**1,339**	
	06425950	Raven Creek Near Moorcroft, WY	YES	6	0	0	2	54	169	3	78	2	7	13	0	**333**	
	06426400	Donkey Creek Near Moorcroft, WY	NO	34	18	33	20	37	1,707	145	2,309	104	17	5	4	**4,434**	
	06426500	Belle Fourche River Below Moorcroft, WY	NO	682	203	149	420	1,761	4,664	2,268	5,169	2,134	997	515	281	**19,243**	
	USBR Gage	Belle Fourche River - Total Keyhole Reservoir Discharge	NO	114	320	0	1	0	881	784	2,149	2,402	4,821	4,526	761	**16,759**	
	06427500	Belle Fourche River Below Keyhole Reservoir	NO	257	260	103	104	96	1,015	760	2,194	2,362	4,833	4,600	833	**17,417**	
	06428200	Belle Fourche River Near Alva, WY	NO	1,826	1,648	1,063	1,375	2,419	7,705	7,511	10,171	7,526	4,925	4,981	1,998	**53,148**	
	06428500	Belle Fourche River at Wyoming - South Dakota State Line	NO	2,307	2,082	1,272	1,741	3,233	10,987	10,552	15,575	12,134	6,507	5,402	2,336	**74,127**	
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES	1,312	1,307	1,285	1,237	1,092	1,231	1,288	1,881	1,776	1,499	1,480	1,334	**16,722**	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO	2,108	2,077	2,043	2,006	1,928	2,240	2,367	3,697	3,135	2,190	2,245	2,119	**28,155**	
Niobrara	06454000	Niobrara River at Wyoming-Nebraska State Line	NO	150	151	159	179	207	316	297	249	208	143	151	118	**2,328**	Study Period: 1970-1994

The downstream gaging stations are typically highly influenced by irrigation depletions and storage regulation. To develop natural flows using Alternative 1, the records for the downstream station would first need to be adjusted to remove these influences. Insufficient data is, typically, available to make these adjustments. It is therefore concluded that the first alternative does not yield reliable estimates of natural flow in most cases. The one exception is Donkey Creek, southeast of Gillette in the Belle Fourche River basin. Alternative 1 yielded the most reasonable estimates of natural flow for this location as evaluated during the calibration of the water availability models. The depletions (diversions minus return flows) used to make the adjustments to the downstream gage records are based on three representative hydrologic conditions (wet, normal, and dry years) and are taken from the water availability modeling work. The natural flow estimates for this location is therefore provided for these three representative hydrologic conditions only. This is in contrast to the estimates of natural flow at the other ungaged node locations for which natural flow estimates are provided for each month and each year within the study period. The selection of the years used to represent wet, normal, and dry conditions are discussed in the next section. The derivation of natural flow at this location is provided in Appendix E.

The USGS is currently updating the work originally developed by Lowham in the report "Streamflows in Wyoming" (USGS, 1988). Unfortunately, at the time of this writing, that work is several months away from completion. The 1988 USGS report presents regression equations, which rely on drainage area and either average annual precipitation or mean basin elevation to estimate mean annual flow. The equation for the plains region utilizes average annual precipitation and is applicable to the majority of the drainages within the planning area. According to personnel with the USGS in Cheyenne currently performing the updated work, the average annual precipitation data used in developing the equations in the 1988 report, for the plains region cannot be documented or verified. Data from the PRISM database will be used in developing the updated equations (www.ocs.orst.edu/prism/). Alternative 2 was dropped from further consideration due to the questionable validity of the original equations for the plains region.

Natural flow for the majority of the ungaged model nodes was estimated using the third alternative, which relies on measured natural flow at selected streamflow gages in the Northeast Wyoming River Basins. The natural flow gage in nearest proximity and with the most similar hydrologic conditions was used to estimate natural flow at the ungaged locations. The original selections were further evaluated and, in some cases modified, as part of the calibration of the water availability models. In addition to average annual natural flow at the ungaged model nodes, it is necessary to generate sequential monthly flows at these sites for all years of the study period. This is accomplished by selecting a natural flow gaging station having similar hydrologic characteristics and multiplying the sequential monthly flows at the gaged location by the ratio of the ungaged average annual natural flow to the gaged average annual natural flow. The time distribution of monthly flows at the ungaged sites is, therefore, represented by the streamflow at similar gaged sites. The streamflow gages used to estimate monthly and annual natural flow at the ungaged model nodes are summarized in Table 6. The average monthly and annual streamflows for the study period, for the ungaged model nodes are summarized in Table 7. The estimated monthly natural flows for each year of the study period are provided in Appendix F for each ungaged model node.

The locations of the ungaged model nodes are shown on Figure 7.

WET, DRY, AND NORMAL YEARS

Water availability models are to be developed to represent dry year, normal year, and wet year hydrologic conditions throughout the Northeast Wyoming River Basins. To this end, the annual streamflows for the study period developed through the surface water hydrology work are ranked and divided into these three hydrologic categories. Indicator gages are selected for this purpose, to represent hydrologic conditions for the entire geographic area of the Northeast Wyoming River Basins. The seven indicator gages are shown on Figure 8. The years 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 dry years, normal years, and wet years for the indicator gages are illustrated on Figure 9. As can be seen, the hydrologic conditions from year to year vary from location to location (i.e. dry

TABLE 6

STREAMFLOW GAGES USED TO ESTIMATED NATURAL FLOW AT UNGAGED MODEL NODES

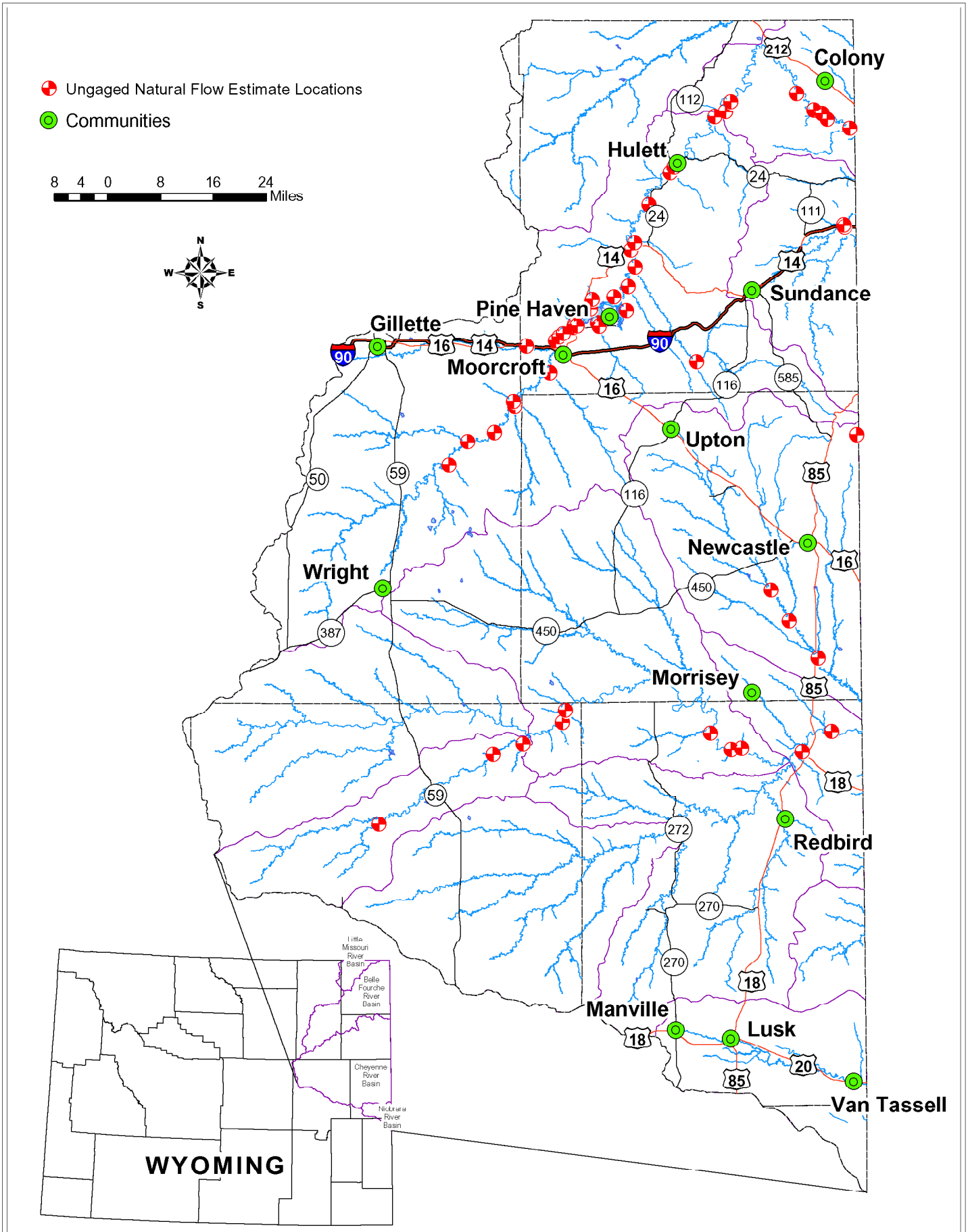
Basin	Site	Site Drainage Area (sq. mi.)	USGS Transfer Gage used to estimate annual flow	Gage Drainage Area (sq. mi.)	USGS Gage used for monthly distribution
Cheyenne	Willow Creek at Mouth in Section 28, T38N, R72W	107.1	Raven Creek Near Moorcroft (06425950)	76.0	Raven Creek Near Moorcroft (06425950)
	Woody Creek at Mouth in Section 5, T39N, R69W	14.0			
	Lake Creek at Mouth in Section 30, T40N, R68W	32.4			
	Sheep Creek at Mouth in Section 7, T40N, R67W	10.3			
	Wagonhound Creek at Mouth in Section 31, T41N, R67W	21.6			
	Snyder Creek at Mouth in Section 23, T40N, R64W	100.4			
	Boggy Creek at Mouth in Section 32, T40N, R63W	27.5			
	Sevenmile Creek at Mouth in Section 34, T40N, R63W	13.4			
	Mule Creek at Mouth in Section 6, T39N, R61W	43.2			
	Robbers' Roost Creek at Mouth in Section 23, T40N, R61W	61.2			
	Beaver Creek Just Below Mush Creek in Section 32, T44N, R62W	415.7	Raven Creek Near Moorcroft (06425950) using Wet, Dry, Normal averages		Raven Creek Near Moorcroft (06425950) using Wet, Dry, Normal averages
	Oil Creek at Mouth in Section 26, T43N, R62W	267.1	Sand Creek Near Ranch A Near Beulah (06429905)	267.0	Raven Creek Near Moorcroft (06425950)
	Blacktail Creek at Mouth in Section 2, T41N, R61W	40.9			Sand Creek Near Ranch A Near Beulah (06429905)
	Dry Beaver Creek Just Above Beaver Creek in Section 4, T47N, R60W	10.4	Beaver Creek at Mallo Camp Near Four Corners (06392900)	10.3	Beaver Creek at Mallo Camp Near Four Corners (06392900)
Belle Fourche	Dry Creek at Mouth in Section 29, T47N, R70W	19.5	Raven Creek Near Moorcroft (06425950)	76.0	Raven Creek Near Moorcroft (06425950)
	Yellow Hammer Creek at Mouth in Section 10, T47N, R70W	7.31			
	Whitetail Creek at Mouth in Section 32, T48N, R69W	10.8			
	Four Horse Creek at Mouth in Section 11, T48N, R69W	102.8			
	Timber Creek at Mouth in Section 2, T48N, R69W	26.9			
	Buffalo Creek at Mouth in Section 14, T49N, R68W	130.5			
	Donkey Creek Just Upstream of Gage in Sec. 30, T50N, R68W	14.6			
	Trail Creek at Mouth in Section 24, T50N, R68W	14.6			
	Dry Creek at Mouth in Section 24, T50N, R68W	20.4			
	Robinson Creek at Mouth in Section 18, T50N, R67W	6.24			
	Duck Creek at Mouth in Section 8, T50N, R67W	4.19	Sand Creek Near Ranch A Near Beulah (06429905)	267.0	
	Miller Creek at Mouth in Section 9, T50N, R67W	47.8			
	Smoke Creek at Mouth in Section 9, T50N, R67W	1.23			
	Berger Creek at Mouth in Section 12, T50N, R67W	2.02			
	Lone Tree Creek at Mouth in Section 26, T51N, R67W	4.39			
	Wind Creek at Mouth in Section 13, T50N, R67W	109.4			
	Deer Creek at Mouth in Section 23, T51N, R67W	23.1			
	Eggie Creek at Mouth in Section 21, T51N, R66W	3.20			
	Mule Creek at Mouth in Section 15, T50N, R66W	14.0			
	Cottonwood Creek at Mouth in Section 35, T51N, R66W	3.72			
	Arch Creek at Mouth in Section 11, T51N, R66W	88.0	Raven Creek Near Moorcroft (06425950)	76.0	
	Inyan Kara Creek at Mouth in Section 25, T52N, R66W	233.1[1]	Sand Creek Near Ranch A Near Beulah (06429905)	267.0	Sand Creek Near Ranch A Near Beulah (06429905)
		106.2[2]	Raven Creek Near Moorcroft (06425950)	76.0	Raven Creek Near Moorcroft (06425950)
	Cabin Creek at Mouth in Section 14, T52N, R66W	66.5			
	Miller Creek at Mouth in Section 12, T52N, R66W	55.0			
	Lytle Creek at Mouth in Section 8, T53N, R65W	38.0			
	Whitetail Creek at Mouth in Section 14, T54N, R65W	16.8	Sand Creek Near Ranch A Near Beulah (06429905)	267.0	Sand Creek Near Ranch A Near Beulah (06429905)
	Blacktail Creek at Mouth in Section 12, T54N, R65W	42.7			
	Beaver Creek at Mouth in Section 1, T55N, R64W	93.4			
	East Creek at Mouth in Section 32, T55N, R63W	9.72			
	Arnold Creek at Mouth in Section 28, T55N, R63W	4.52			
	Horse Creek at Mouth in Section 19, T56N, R61W	15.4			
	Pine Creek at Mouth in Section 33, T56N, R61W	35.0			
	Kilpatrick Creek at Mouth in Section 3, T55N, R61W	14.1			
	Kruger Creek at Mouth in Section 11, T55N, R61W	6.86			
	Oak Creek at Mouth in Section 20, T55N, R60W	43.9			
	South Redwater Creek Just Above Sand Creek in Section 31, T53N, R60W	115.0			
	Redwater Creek Just Above South Redwater Creek in Section 31, T53N, R60	58.4			

Notes: 1. Upper Portion of Inyan Kara Creek: Inyan Kara Creek Just Below Mason Creek in Section 9, T49N, R64W.
2. Lower Portion of Inyan Kara Creek: The remaining portion below the Upper Portion (Total Drainage Area = 339.3 sq. miles).

TABLE 7
SUMMARY OF AVERAGE MONTHLY AND ANNUAL FLOWS
AT UNGAGED NATURAL FLOW NODES

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Cheyenne	Willow Creek at Mouth in Section 28, T38N, R72W	9	0	0	3	76	238	4	109	3	10	18	0	**470**
	Woody Creek at Mouth in Section 5, T39N, R69W	1	0	0	0	10	31	0	14	0	1	2	0	**59**
	Lake Creek at Mouth in Section 30, T40N, R68W	3	0	0	1	23	72	1	33	1	3	5	0	**142**
	Sheep Creek at Mouth in Section 7, T40N, R67W	1	0	0	0	7	23	0	11	0	1	2	0	**45**
	Wagonhound Creek at Mouth in Section 31, T41N, R67W	2	0	0	1	15	48	1	22	1	2	4	0	**96**
	Snyder Creek at Mouth in Section 23, T40N, R64W	8	0	0	3	71	223	3	103	3	10	17	0	**441**
	Boggy Creek at Mouth in Section 32, T40N, R63W	2	0	0	1	20	61	1	28	1	3	5	0	**122**
	Sevenmile Creek at Mouth in Section 34, T40N, R63W	1	0	0	0	10	30	0	14	0	1	2	0	**58**
	Mule Creek at Mouth in Section 6, T39N, R61W	4	0	0	1	31	96	1	44	1	4	7	0	**189**
	Robbers' Roost Creek at Mouth in Section 23, T40N, R61W	5	0	0	2	43	136	2	63	2	6	10	0	**269**
	Beaver Creek Just Below Mush Creek in Section 32, T44N, R62W	33	0	0	10	292	1,187	15	546	16	51	77	0	**2227[1]**
	Oil Creek at Mouth in Section 26, T43N, R62W	346	0	0	61	3,958	6,405	377	2,930	87	275	2,425	0	**16,864**
	Blacktail Creek at Mouth in Section 2, T41N, R61W	200	195	193	186	163	188	191	293	262	240	215	198	**2,524**
	Dry Beaver Creek Just Above Beaver Creek in Section 4, T47N, R60W	107	99	97	92	95	111	133	136	141	130	118	107	**1,366**
Belle Fourche	Dry Creek at Mouth in Section 29, T47N, R70W	2	0	0	1	14	43	1	20	1	2	3	0	**87**
	Yellow Hammer Creek at Mouth in Section 10, T47N, R70W	1	0	0	0	5	16	0	7	0	1	1	0	**31**
	Whitetail Creek at Mouth in Section 32, T48N, R69W	1	0	0	0	8	24	0	11	0	1	2	0	**47**
	Four Horse Creek at Mouth in Section 11, T48N, R69W	8	0	0	3	73	228	4	105	3	10	17	0	**451**
	Timber Creek at Mouth in Section 2, T48N, R69W	2	0	0	1	19	60	1	27	1	3	5	0	**119**
	Buffalo Creek at Mouth in Section 14, T49N, R68W	11	0	0	3	93	290	4	133	4	12	22	0	**572**
	Donkey Creek Just Upstream of Gage in Sec. 30, T50N, R68W	0	0	0	413	1,135	3,278	1,555	4,005	946	0	0	0	**11,332[1]**
	Trail Creek at Mouth in Section 24, T50N, R68W	1	0	0	0	10	32	0	15	0	1	2	0	**61**
	Dry Creek at Mouth in Section 24, T50N, R68W	2	0	0	1	14	45	1	21	1	2	3	0	**90**
	Robinson Creek at Mouth in Section 18, T50N, R67W	1	0	0	0	4	14	0	6	0	1	1	0	**27**
	Duck Creek at Mouth in Section 8, T50N, R67W	5	0	0	4	59	115	4	53	2	5	24	0	**271**
	Miller Creek at Mouth in Section 9, T50N, R67W	58	0	0	41	672	1,314	44	604	18	57	271	0	**3,079**
	Smoke Creek at Mouth in Section 9, T50N, R67W	1	0	0	1	17	34	1	16	0	1	7	0	**78**
	Berger Creek at Mouth in Section 12, T50N, R67W	2	0	0	2	28	56	2	26	1	2	11	0	**130**
	Lone Tree Creek at Mouth in Section 26, T51N, R67W	5	0	0	4	62	121	4	55	2	5	25	0	**283**
	Wind Creek at Mouth in Section 13, T50N, R67W	133	0	0	93	1,539	3,008	101	1,382	41	129	620	0	**7,046**
	Deer Creek at Mouth in Section 23, T51N, R67W	28	0	0	20	325	635	21	292	9	27	131	0	**1,488**
	Eggie Creek at Mouth in Section 21, T51N, R66W	4	0	0	3	45	88	3	40	1	4	18	0	**206**
	Mule Creek at Mouth in Section 15, T50N, R66W	17	0	0	12	197	385	13	177	5	17	79	0	**902**
	Cottonwood Creek at Mouth in Section 35, T51N, R66W	5	0	0	3	52	102	3	47	1	4	21	0	**238**
	Arch Creek at Mouth in Section 11, T51N, R66W	7	0	0	2	62	195	3	90	3	8	15	0	**385**
	Inyan Kara Creek at Mouth in Section 25, T52N, R66W	1,154	1,142	1,122	1,083	1,028	1,311	1,128	1,750	1,553	1,319	1,310	1,165	**15,065**
	Cabin Creek at Mouth in Section 14, T52N, R66W	5	0	0	2	47	148	2	68	2	6	11	0	**291**
	Miller Creek at Mouth in Section 12, T52N, R66W	5	0	0	1	39	122	2	56	2	5	9	0	**241**
	Lytle Creek at Mouth in Section 8, T53N, R65W	3	0	0	1	27	84	1	39	1	4	6	0	**166**
	Whitetail Creek at Mouth in Section 14, T54N, R65W	83	82	81	78	69	77	81	118	112	94	93	84	**1,052**
	Blacktail Creek at Mouth in Section 12, T54N, R65W	210	209	205	198	175	197	206	301	284	240	237	213	**2,675**
	Beaver Creek at Mouth in Section 1, T55N, R64W	459	457	449	433	382	431	451	658	621	524	518	467	**5,850**
	East Creek at Mouth in Section 32, T55N, R63W	48	48	47	45	40	45	47	68	65	55	54	49	**611**
	Arnold Creek at Mouth in Section 28, T55N, R63W	22	22	22	21	18	21	22	32	30	25	25	23	**283**
	Horse Creek at Mouth in Section 19, T56N, R61W	76	75	74	71	63	71	74	108	102	86	85	77	**962**
	Pine Creek at Mouth in Section 33, T56N, R61W	172	171	168	162	143	161	169	247	233	197	194	175	**2,192**
	Kilpatrick Creek at Mouth in Section 3, T55N, R61W	69	69	68	65	58	65	68	99	94	79	78	70	**882**
	Kruger Creek at Mouth in Section 11, T55N, R61W	34	34	33	32	28	32	33	48	46	39	38	34	**431**
	Oak Creek at Mouth in Section 20, T55N, R60W	216	215	211	203	179	202	212	309	292	247	243	219	**2,748**
	South Redwater Creek Just Above Sand Creek in Section 31, T53N, R60W	565	563	553	533	470	530	555	810	765	646	637	575	**7,202**
	Redwater Creek Just Above South Redwater Creek in Section 31, T53N, R60W	287	286	281	271	239	269	282	411	388	328	324	292	**3,658**

Note: 1. Monthly and Annual Flows are averaged from the Wet, Dry, and Normal Estimated Flows.

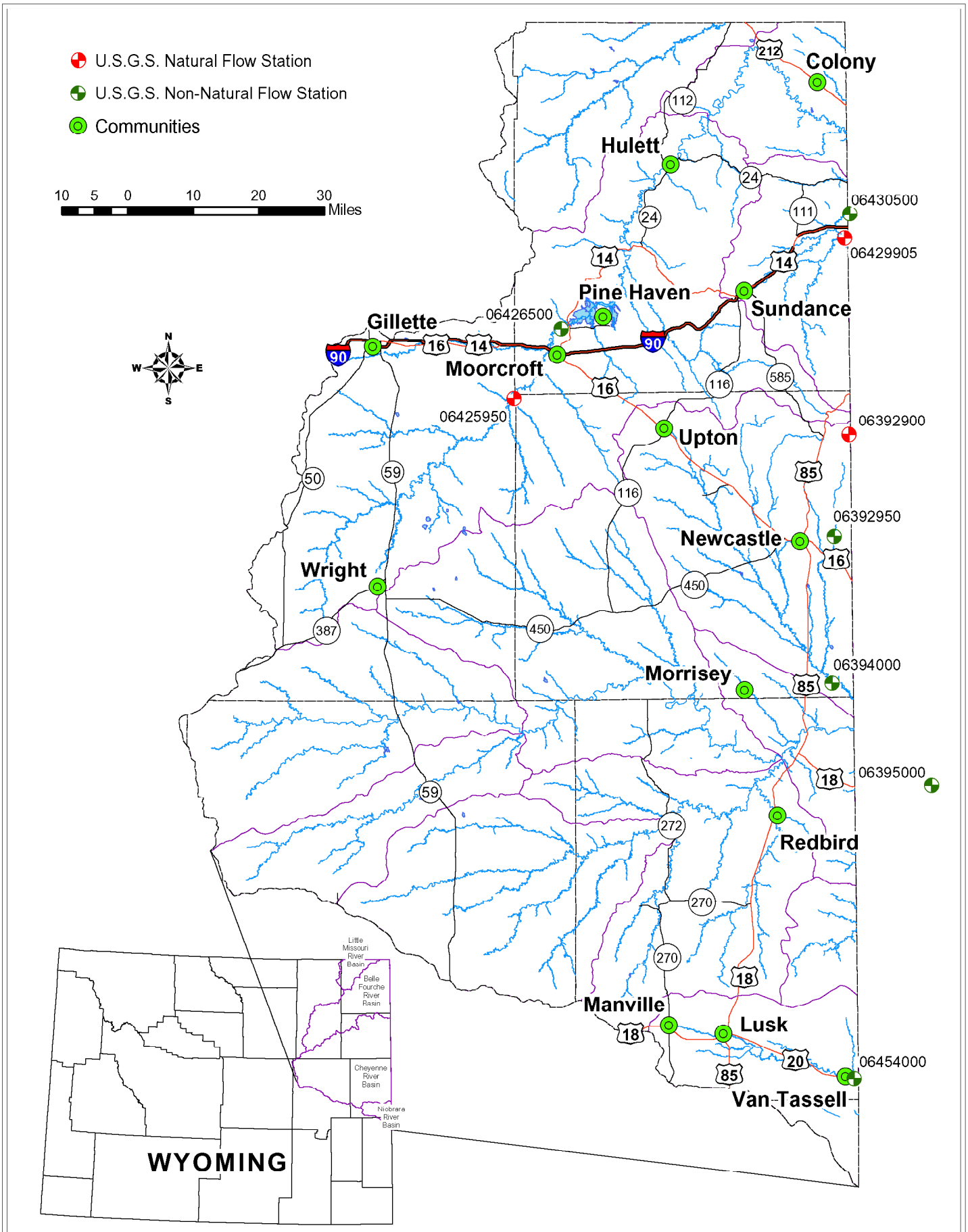


Ungaged Natural Flow Estimate Locations

HKM ENGINEERING

HKM Engineering Inc.
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, FAX (406) 656-6398

Figure 7



Indicator Gages for Selection of Dry, Normal, & Wet Years

HKM Engineering Inc.
Granite Tower Building
222 N. 32nd St., Suite 700
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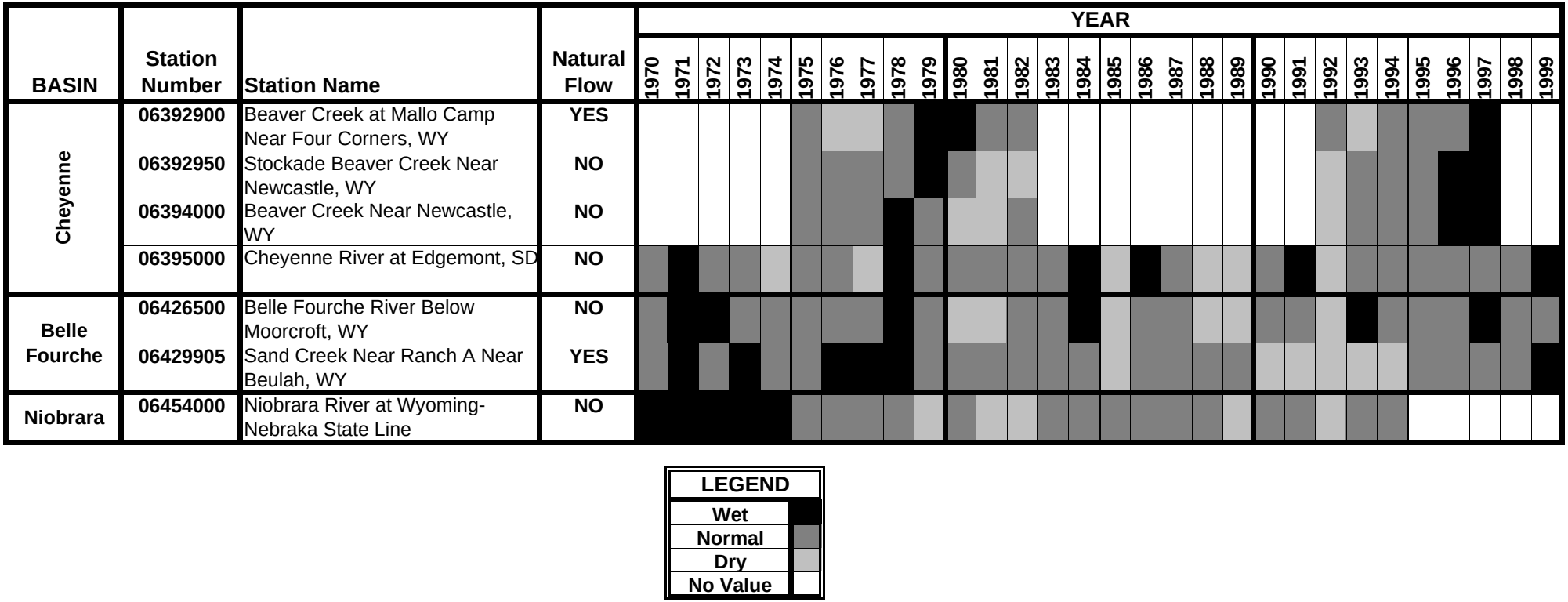
Billings, MT 59107-1318
(406) 656-6399, FAX (406) 656-6398

Figure 8

FIGURE 9

WET, DRY AND AVERAGE YEARS FOR INDICATOR STATIONS IN THE NORTHEAST WYOMING RIVER BASINS



LEGEND	
Wet	
Normal	
Dry	
No Value	

years, wet years, and normal years do not occur at all locations simultaneously). The dry, normal, and wet years selected to represent each drainage are, therefore unique to each geographic location. The years selected to represent dry, wet, and normal hydrologic conditions are summarized on Figure 10. According to the streamflow records for the Beaver Creek drainage, the hydrologic conditions vary significantly from location to location within the drainage. The wet years, dry years, and normal years for the Beaver Creek drainage are therefore, selected to best represent all locations concurrently.

The average monthly and annual streamflow for dry years, normal years, and wet years at the gaged model nodes are provided in Tables 8, 9, and 10 respectively.

The average monthly and annual streamflow for dry years, normal years, and wet years at the ungaged model nodes are provided in Tables 11, 12, and 13 respectively.

FIGURE 10
SELECTION OF WET, DRY, AND NORMAL YEARS FOR MODELING
INDICATOR STATIONS FOR THE NORTHEAST WYOMING RIVER BASINS

		Cheyenne River	
		Cheyenne River at Edgemont, SD	
Rank	Weibull Plotting Position	Year	06395000
1	3.23%	1988	8,725
2	6.45%	1992	9,408
3	9.68%	1985	12,831
4	12.90%	1989	17,079
5	16.13%	1977	19,855
6	19.35%	1974	20,970
7	22.58%	1970	22,264
8	25.81%	1990	22,894
9	29.03%	1976	27,407
10	32.26%	1981	27,855
11	35.48%	1975	28,202
12	38.71%	1972	30,052
13	41.94%	1980	32,972
14	45.16%	1983	39,746
15	48.39%	1995	43,391
16	51.61%	1994	45,633
17	54.84%	1996	52,131
18	58.06%	1998	54,230
19	61.29%	1973	57,980
20	64.52%	1979	61,675
21	67.74%	1982	62,767
22	70.97%	1987	64,260
23	74.19%	1993	68,156
24	77.42%	1997	69,180
25	80.65%	1986	73,186
26	83.87%	1984	74,519
27	87.10%	1999	104,860
28	90.32%	1991	132,999
29	93.55%	1971	153,235
30	96.77%	1978	223,740

		Belle Fourche	
		Belle Fourche River Below Moorcroft, WY	
Rank	Weibull Plotting Position	Year	06426500
1	3.23%	1985	2,434
2	6.45%	1980	3,712
3	9.68%	1988	4,576
4	12.90%	1981	4,646
5	16.13%	1992	4,994
6	19.35%	1989	6,739
7	22.58%	1976	7,543
8	25.81%	1973	7,583
9	29.03%	1977	7,876
10	32.26%	1990	8,601
11	35.48%	1974	9,163
12	38.71%	1970	10,842
13	41.94%	1998	11,136
14	45.16%	1983	11,590
15	48.39%	1991	12,248
16	51.61%	1986	14,496
17	54.84%	1979	15,391
18	58.06%	1975	16,936
19	61.29%	1996	20,135
20	64.52%	1982	20,283
21	67.74%	1994	23,223
22	70.97%	1999	23,556
23	74.19%	1995	24,721
24	77.42%	1987	25,747
25	80.65%	1997	26,752
26	83.87%	1984	27,498
27	87.10%	1971	40,434
28	90.32%	1993	41,836
29	93.55%	1972	44,264
30	96.77%	1978	98,331

		Redwater Creek	
		Sand Creek Near Ranch A Near Beulah, WY	
Rank	Weibull Plotting Position	Year	06429905
1	3.23%	1992	11,406
2	6.45%	1985	11,846
3	9.68%	1993	11,881
4	12.90%	1990	12,271
5	16.13%	1991	12,284
6	19.35%	1994	12,471
7	22.58%	1989	13,096
8	25.81%	1981	13,222
9	29.03%	1986	14,049
10	32.26%	1988	14,131
11	35.48%	1980	15,800
12	38.71%	1987	15,995
13	41.94%	1982	16,047
14	45.16%	1995	16,881
15	48.39%	1984	17,203
16	51.61%	1975	17,520
17	54.84%	1996	17,630
18	58.06%	1979	17,750
19	61.29%	1983	17,790
20	64.52%	1998	17,810
21	67.74%	1997	18,530
22	70.97%	1970	19,333
23	74.19%	1974	19,464
24	77.42%	1971	19,640
25	80.65%	1976	19,700
26	83.87%	1977	20,380
27	87.10%	1972	20,911
28	90.32%	1978	21,330
29	93.55%	1999	22,060
30	96.77%	1973	23,215

		Niobrara River	
		Niobrara River at Wyoming-Nebraka State Line	
Rank	Weibull Plotting Position	Year	06454000
1	3.85%	1982	1,549
2	7.69%	1992	1,725
3	11.54%	1989	1,751
4	15.38%	1979	1,760
5	19.23%	1981	1,794
6	23.08%	1976	1,860
7	26.92%	1990	1,882
8	30.77%	1978	1,897
9	34.62%	1975	1,917
10	38.46%	1985	1,963
11	42.31%	1984	2,054
12	46.15%	1988	2,078
13	50.00%	1983	2,120
14	53.85%	1994	2,165
15	57.69%	1980	2,434
16	61.54%	1986	2,491
17	65.38%	1987	2,503
18	69.23%	1991	2,556
19	73.08%	1977	2,606
20	76.92%	1993	2,625
21	80.77%	1970	2,859
22	84.62%	1971	3,069
23	88.46%	1973	3,173
24	92.31%	1972	3,283
25	96.15%	1974	4,081

LEGEND	
	WET
	DRY

		Beaver Creek					
		Beaver Creek at Mallo Camp Near Four Corners, WY		Stockade Beaver Creek Near Newcastle, WY		Beaver Creek Near Newcastle, WY	
Rank	Weibull Plotting Position	Year	06392900	Year	06392950	Year	06394000
1	6.67%	1977	682	1992	7,114	1992	6,889
2	13.33%	1993	834	1982	7,378	1980	7,085
3	20.00%	1976	957	1981	7,412	1981	9,954
4	26.67%	1992	1,066	1993	7,505	1977	12,102
5	33.33%	1994	1,261	1994	7,531	1995	14,005
6	40.00%	1995	1,392	1980	8,271	1979	14,393
7	46.67%	1996	1,423	1995	8,807	1982	19,917
8	53.33%	1978	1,466	1977	9,017	1976	20,510
9	60.00%	1981	1,476	1976	9,222	1993	25,031
10	66.67%	1975	1,479	1978	9,277	1975	28,898
11	73.33%	1982	1,548	1975	9,298	1994	29,359
12	80.00%	1997	1,667	1979	9,393	1996	37,581
13	86.67%	1980	1,789	1996	9,736	1997	40,220
14	93.33%	1979	1,874	1997	10,351	1978	41,784

SELECTION OF WET, DRY AND NORMAL YEARS					
Hydrologic Condition	Model Area				
	Beaver Creek	Cheyenne River	Belle Fourche River	Redwater Creek	Niobrara River
WET	1979, 1996, 1997	1971, 1978, 1984, 1986, 1991, 1999	1971, 1972, 1978, 1984, 1993, 1997	1972, 1973, 1976, 1977, 1978, 1999	1970, 1971, 1972, 1973, 1974
DRY	1977, 1992, 1993	1974, 1977, 1985, 1988, 1989, 1992	1980, 1981, 1985, 1988, 1989, 1992	1985, 1990, 1991, 1992, 1993, 1994	1979, 1981, 1982, 1989, 1992
NORMAL	All Other Yrs Between 1975 & 1982 and 1992 & 1997	All Other Yrs Between 1970 and 1999	All Other Yrs Between 1970 and 1999	All Other Yrs Between 1970 and 1999	All Other Yrs Between 1970 and 1994

TABLE 8
SUMMARY OF DRY YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999 unless otherwise noted)
AT GAGED MODEL NODES

Basin	Station Number	Station Name	Natural Flow	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET													Notes
				OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL	
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO	22	24	9	18	38	161	69	39	8	153	27	130	**698**	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO	0	1	1	0	2	5	6	4	0	11	0	0	**30**	
	06365900	Cheyenne River Near Dull Center, WY	NO	33	13	14	30	73	324	128	114	82	447	217	103	**1,577**	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	0	0	0	0	0	3	0	3	1	10	1	0	**19**	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	122	9	0	60	9	70	114	169	176	308	145	92	**1,272**	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	0	0	0	0	0	5	4	26	11	4	4	0	**54**	
	06386000	Lance Creek Near Riverview, WY	NO	104	99	41	683	240	273	347	1,008	466	545	511	230	**4,547**	
	06386500	Cheyenne River Near Spencer, WY	NO	259	216	67	953	430	283	473	1,734	762	187	51	280	**5,695**	
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES	65	61	54	50	62	66	70	72	108	91	81	81	**861**	Study Period: 1975-1982, 1992-1997
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO	722	758	744	759	675	759	648	419	506	668	557	664	**7,879**	Study Period: 1975-1982, 1992-1997
	06394000	Beaver Creek Near Newcastle, WY	NO	363	762	740	741	756	3,202	1,906	1,411	1,744	1,459	1,187	404	**14,674**	Study Period: 1975-1982, 1992-1997
	06395000	Cheyenne River at Edgemont, SD	NO	743	893	430	632	1,264	4,005	1,571	1,081	664	1,148	511	1,871	**14,811**	
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek Near Piney, WY	NO	1	3	7	12	24	53	16	155	55	36	71	5	**438**	
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO	5	2	6	13	51	128	29	284	56	146	69	13	**802**	
	06425900	Caballo Creek at Mouth Near Piney, WY	NO	1	12	0	1	7	17	4	50	6	70	7	1	**175**	
	06425950	Raven Creek Near Moorcroft, WY	YES	0	0	0	0	7	3	0	1	0	0	8	0	**20**	
	06426400	Donkey Creek Near Moorcroft, WY	NO	4	12	23	17	31	156	29	186	15	3	3	3	**481**	
	06426500	Belle Fourche River Below Moorcroft, WY	NO	26	70	61	41	464	1,460	299	443	212	1,189	183	71	**4,517**	
	USBR Gage	Belle Fourche River - Total Keyhole Reservoir Discharge	NO	0	0	0	4	2	0	1,272	4,445	4,782	8,563	7,857	995	**27,919**	
	06427500	Belle Fourche River Below Keyhole Reservoir	NO	106	99	101	105	96	100	1,362	4,476	4,872	8,172	7,803	1,102	**28,394**	
	06428200	Belle Fourche River Near Alva, WY	NO	763	990	748	372	565	3,225	2,160	4,088	3,941	5,745	6,394	2,123	**31,114**	
	06428500	Belle Fourche River at Wyoming - South Dakota State	NO	870	1,170	863	409	640	4,244	3,332	5,742	4,923	7,172	6,845	2,458	**38,668**	
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES	927	1,071	1,063	1,036	906	987	1,028	1,085	996	982	968	979	**12,026**	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO	1,465	1,615	1,582	1,543	1,398	1,642	1,665	1,700	1,671	1,441	1,538	1,577	**18,836**	
Niobrara	06454000	Niobrara River at Wyoming-Nebraska State Line	NO	118	130	134	131	138	210	180	185	142	115	115	117	**1,716**	Study Period: 1970-1994

TABLE 9
SUMMARY OF NORMAL YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999 unless otherwise noted)
AT GAGED MODEL NODES

Basin	Station Number	Station Name	Natural Flow	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET													Notes
				OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL	
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO	69	27	19	21	199	658	302	516	531	268	179	94	**2,882**	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO	2	5	5	2	14	30	16	93	20	14	8	0	**209**	
	06365900	Cheyenne River Near Dull Center, WY	NO	203	20	23	35	516	816	582	908	1,120	730	491	50	**5,494**	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	3	5	6	5	55	61	12	395	120	124	100	2	**890**	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	317	17	0	27	200	647	286	1,051	699	370	378	335	**4,326**	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	1	2	1	1	2	40	26	150	79	21	34	1	**358**	
	06386000	Lance Creek Near Riverview, WY	NO	115	110	93	201	1,040	956	754	2,998	2,471	2,988	2,280	802	**14,809**	
	06386500	Cheyenne River Near Spencer, WY	NO	186	159	48	695	1,196	748	1,534	14,793	6,889	1,938	511	3,325	**32,023**	
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES	114	102	106	95	95	113	142	154	141	129	122	111	**1,421**	Study Period: 1975-1982, 1992-1997
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO	723	713	762	723	694	827	746	600	642	628	658	686	**8,400**	Study Period: 1975-1982, 1992-1997
	06394000	Beaver Creek Near Newcastle, WY	NO	520	763	846	815	1,610	5,867	1,840	4,151	2,177	1,597	850	403	**21,439**	Study Period: 1975-1982, 1992-1997
	06395000	Cheyenne River at Edgemont, SD	NO	1,744	1,023	741	836	3,785	9,936	4,071	5,678	7,006	4,720	3,922	1,584	**45,044**	
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek Near Piney, WY	NO	7	6	11	24	86	179	61	449	246	93	150	22	**1,334**	
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO	21	6	14	48	203	484	130	690	292	174	179	68	**2,310**	
	06425900	Caballo Creek at Mouth Near Piney, WY	NO	13	7	1	11	27	183	30	487	58	81	40	13	**951**	
	06425950	Raven Creek Near Moorcroft, WY	YES	6	0	0	2	55	96	2	44	1	4	11	0	**223**	
	06426400	Donkey Creek Near Moorcroft, WY	NO	24	13	24	15	27	1,302	128	1,616	74	14	4	3	**3,245**	
	06426500	Belle Fourche River Below Moorcroft, WY	NO	846	276	205	494	1,513	3,406	2,128	2,920	1,675	804	418	376	**15,059**	
	USBR Gage	Belle Fourche River - Total Keyhole Reservoir Discharge	NO	191	533	0	0	0	8	629	380	1,340	4,723	4,080	623	**12,507**	
	06427500	Belle Fourche River Below Keyhole Reservoir	NO	359	371	108	107	98	186	557	374	1,233	4,867	4,192	695	**13,147**	
	06428200	Belle Fourche River Near Alva, WY	NO	2,083	1,922	1,197	1,347	2,606	6,675	7,476	9,812	6,582	4,667	4,803	1,918	**51,086**	
	06428500	Belle Fourche River at Wyoming - South Dakota State Line	NO	2,652	2,471	1,445	1,656	3,488	9,328	10,601	15,628	10,124	5,983	5,235	2,267	**70,878**	
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES	1,343	1,290	1,274	1,227	1,096	1,236	1,266	1,998	1,772	1,494	1,445	1,329	**16,772**	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO	2,143	2,068	2,038	1,996	1,976	2,280	2,386	4,025	3,077	2,135	2,167	2,096	**28,387**	
Niobrara	06454000	Niobrara River at Wyoming-Nebraska State Line	NO	149	144	148	142	157	299	275	257	214	147	172	105	**2,210**	Study Period: 1970-1994

TABLE 10
SUMMARY OF WET YEAR MONTHLY AND ANNUAL FLOWS (1970 TO 1999 unless otherwise noted)
AT GAGED MODEL NODES

Basin	Station Number	Station Name	Natural Flow	AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET													Notes
				OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL	
Cheyenne	06364700	Antelope Creek Near Teckla, WY	NO	258	217	28	28	162	588	482	6,013	3,421	848	176	52	**12,273**	
	06365300	Dry Fork Cheyenne River Near Bill, WY	NO	7	13	11	7	43	126	44	687	124	97	14	1	**1,174**	
	06365900	Cheyenne River Near Dull Center, WY	NO	237	434	46	46	414	1,221	1,289	14,535	7,795	1,635	436	77	**28,165**	
	06375600	Little Thunder Creek Near Hampshire, WY	NO	8	7	8	7	74	245	17	2,930	295	291	200	3	**4,084**	
	06376300	Black Thunder Creek Near Hampshire, WY	NO	464	20	0	115	752	2,218	569	5,615	1,081	1,324	748	1,391	**14,298**	
	06378300	Lodgepole Creek Near Hampshire, WY	NO	1	3	2	1	4	100	81	638	206	93	61	4	**1,193**	
	06386000	Lance Creek Near Riverview, WY	NO	215	128	97	379	990	2,883	1,898	17,967	5,708	5,456	3,037	835	**39,593**	
	06386500	Cheyenne River Near Spencer, WY	NO	559	474	144	2,078	3,418	1,800	5,123	54,135	25,000	4,514	1,091	7,012	**105,348**	
	06392900	Beaver Creek at Mallo Camp Near Four Corners, WY	YES	126	122	114	120	123	147	166	148	167	166	138	117	**1,655**	Study Period: 1975-1982, 1992-1997
	06392950	Stockade Beaver Creek Near Newcastle, WY	NO	789	770	771	780	739	1,075	918	787	689	760	884	865	**9,827**	Study Period: 1975-1982, 1992-1997
	06394000	Beaver Creek Near Newcastle, WY	NO	715	924	829	972	5,219	8,927	3,837	4,062	2,113	1,339	1,321	474	**30,731**	Study Period: 1975-1982, 1992-1997
	06395000	Cheyenne River at Edgemont, SD	NO	3,573	3,117	768	859	2,914	10,422	7,592	52,665	30,940	8,293	4,069	1,879	**127,090**	
Belle Fourche	06425720	Belle Fourche River Below Rattlesnake Creek Near Piney, WY	NO	9	9	17	34	115	470	130	1,926	386	189	224	30	**3,540**	
	06425780	Belle Fourche River Above Dry Creek Near Piney, WY	NO	39	10	22	70	290	1,476	237	3,132	477	531	290	130	**6,705**	
	06425900	Caballo Creek at Mouth Near Piney, WY	NO	26	18	1	17	47	538	55	2,429	204	182	100	51	**3,667**	
	06425950	Raven Creek Near Moorcroft, WY	YES	12	0	0	4	99	552	5	254	7	24	23	0	**979**	
	06426400	Donkey Creek Near Moorcroft, WY	NO	93	38	70	40	74	4,474	310	6,512	282	40	11	8	**11,952**	
	06426500	Belle Fourche River Below Moorcroft, WY	NO	850	118	70	577	3,802	11,643	4,656	16,641	5,432	1,384	1,138	208	**46,519**	
	USBR Gage	Belle Fourche River - Total Keyhole Reservoir Discharge	NO	0	0	0	0	0	4,378	759	5,162	3,206	1,374	2,531	943	**18,353**	
	06427500	Belle Fourche River Below Keyhole Reservoir	NO	105	90	91	93	87	4,416	766	5,372	3,239	1,391	2,620	979	**19,248**	
	06428200	Belle Fourche River Near Alva, WY	NO	2,121	1,487	977	2,462	3,715	15,275	12,966	17,333	13,942	4,878	4,102	2,114	**81,370**	
	06428500	Belle Fourche River at Wyoming - South Dakota State Line	NO	2,709	1,827	1,162	3,329	5,058	22,710	17,625	25,247	25,372	7,413	4,458	2,423	**119,333**	
	06429905	Sand Creek Near Ranch A Near Beulah, WY	YES	1,602	1,597	1,539	1,468	1,263	1,460	1,617	2,326	2,566	2,031	2,094	1,704	**21,266**	
	06430500	Redwater Creek at Wyoming-South Dakota State Line	NO	2,646	2,567	2,517	2,498	2,317	2,718	3,012	4,712	4,772	3,104	3,185	2,730	**36,778**	
Niobrara	06454000	Niobrara River at Wyoming-Nebraska State Line	NO	189	191	218	337	427	471	478	286	254	158	125	159	**3,293**	Study Period: 1970-1994

TABLE 11
SUMMARY OF DRY YEAR MONTHLY AND ANNUAL FLOWS
AT UNGAGED NATURAL FLOW NODES

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Cheyenne	Willow Creek at Mouth in Section 28, T38N, R72W	1	0	0	0	7	22	0	10	0	1	2	0	**43**
	Woody Creek at Mouth in Section 5, T39N, R69W	0	0	0	0	1	3	0	1	0	0	0	0	**5**
	Lake Creek at Mouth in Section 30, T40N, R68W	0	0	0	0	2	7	0	3	0	0	1	0	**13**
	Sheep Creek at Mouth in Section 7, T40N, R67W	0	0	0	0	1	2	0	1	0	0	0	0	**4**
	Wagonhound Creek at Mouth in Section 31, T41N, R67W	0	0	0	0	1	4	0	2	0	0	0	0	**7**
	Snyder Creek at Mouth in Section 23, T40N, R64W	1	0	0	0	7	21	0	9	0	1	2	0	**41**
	Boggy Creek at Mouth in Section 32, T40N, R63W	0	0	0	0	2	6	0	3	0	0	0	0	**11**
	Sevenmile Creek at Mouth in Section 34, T40N, R63W	0	0	0	0	1	3	0	1	0	0	0	0	**5**
	Mule Creek at Mouth in Section 6, T39N, R61W	0	0	0	0	3	9	0	4	0	0	1	0	**17**
	Robbers' Roost Creek at Mouth in Section 23, T40N, R61W	0	0	0	0	4	13	0	6	0	1	1	0	**25**
	Beaver Creek Just Below Mush Creek in Section 32, T44N, R62W	1	0	0	0	39	16	0	7	0	1	44	0	**108**
	Oil Creek at Mouth in Section 26, T43N, R62W	201	0	0	63	1,739	5,441	84	2,507	73	235	414	0	**10,757**
	Blacktail Creek at Mouth in Section 2, T41N, R61W	182	177	181	181	162	174	183	218	207	198	186	181	**2,230**
	Dry Beaver Creek Just Above Beaver Creek in Section 4, T47N, R60W	65	62	54	51	62	67	71	73	109	92	81	82	**869**
Belle Fourche	Dry Creek at Mouth in Section 29, T47N, R70W	0	0	0	0	2	1	0	0	0	0	2	0	**5**
	Yellow Hammer Creek at Mouth in Section 10, T47N, R70W	0	0	0	0	1	0	0	0	0	0	1	0	**2**
	Whitetail Creek at Mouth in Section 32, T48N, R69W	0	0	0	0	1	0	0	0	0	0	1	0	**2**
	Four Horse Creek at Mouth in Section 11, T48N, R69W	0	0	0	0	10	4	0	2	0	0	11	0	**27**
	Timber Creek at Mouth in Section 2, T48N, R69W	0	0	0	0	3	1	0	0	0	0	3	0	**7**
	Buffalo Creek at Mouth in Section 14, T49N, R68W	0	0	0	0	12	5	0	2	0	0	14	0	**33**
	Donkey Creek Just Upstream of Gage in Sec. 30, T50N, R68W	0	0	0	902	1,400	1,658	1,367	1,176	676	0	0	0	**7,179**
	Trail Creek at Mouth in Section 24, T50N, R68W	0	0	0	0	1	1	0	0	0	0	2	0	**4**
	Dry Creek at Mouth in Section 24, T50N, R68W	0	0	0	0	2	1	0	0	0	0	2	0	**5**
	Robinson Creek at Mouth in Section 18, T50N, R67W	0	0	0	0	1	0	0	0	0	0	1	0	**2**
	Duck Creek at Mouth in Section 8, T50N, R67W	1	0	0	0	47	18	0	8	0	1	36	0	**111**
	Miller Creek at Mouth in Section 9, T50N, R67W	7	0	0	2	532	200	3	91	3	9	409	0	**1,256**
	Smoke Creek at Mouth in Section 9, T50N, R67W	0	0	0	0	14	5	0	2	0	0	11	0	**32**
	Berger Creek at Mouth in Section 12, T50N, R67W	0	0	0	0	22	8	0	4	0	0	17	0	**51**
	Lone Tree Creek at Mouth in Section 26, T51N, R67W	1	0	0	0	49	18	0	8	0	1	38	0	**115**
	Wind Creek at Mouth in Section 13, T50N, R67W	17	0	0	5	1,218	458	7	208	6	21	935	0	**2,875**
	Deer Creek at Mouth in Section 23, T51N, R67W	4	0	0	1	257	97	1	44	1	5	198	0	**608**
	Eggie Creek at Mouth in Section 21, T51N, R66W	0	0	0	0	36	13	0	6	0	1	27	0	**83**
	Mule Creek at Mouth in Section 15, T50N, R66W	2	0	0	1	156	59	1	27	1	3	120	0	**370**
	Cottonwood Creek at Mouth in Section 35, T51N, R66W	1	0	0	0	41	16	0	7	0	1	32	0	**98**
	Arch Creek at Mouth in Section 11, T51N, R66W	0	0	0	0	8	3	0	2	0	0	9	0	**22**
	Inyan Kara Creek at Mouth in Section 25, T52N, R66W	919	1,051	1,068	1,017	884	960	963	1,061	939	894	896	943	**11,595**
	Cabin Creek at Mouth in Section 14, T52N, R66W	0	0	0	0	6	2	0	1	0	0	7	0	**16**
	Miller Creek at Mouth in Section 12, T52N, R66W	0	0	0	0	5	2	0	1	0	0	6	0	**14**
	Lytle Creek at Mouth in Section 8, T53N, R65W	0	0	0	0	4	1	0	1	0	0	4	0	**10**
	Whitetail Creek at Mouth in Section 14, T54N, R65W	66	76	77	73	63	69	69	76	68	64	64	68	**833**
	Blacktail Creek at Mouth in Section 12, T54N, R65W	168	193	196	186	160	175	176	194	172	164	162	173	**2,119**
	Beaver Creek at Mouth in Section 1, T55N, R64W	368	421	428	407	350	383	386	424	376	358	354	378	**4,633**
	East Creek at Mouth in Section 32, T55N, R63W	38	44	45	42	36	40	40	44	39	37	37	39	**481**
	Arnold Creek at Mouth in Section 28, T55N, R63W	18	20	21	20	17	19	19	21	18	17	17	18	**225**
	Horse Creek at Mouth in Section 19, T56N, R61W	61	69	71	67	58	63	64	70	62	59	58	62	**764**
	Pine Creek at Mouth in Section 33, T56N, R61W	138	158	160	153	131	143	145	159	141	134	133	142	**1,737**
	Kilpatrick Creek at Mouth in Section 3, T55N, R61W	56	64	65	61	53	58	58	64	57	54	54	57	**701**
	Kruger Creek at Mouth in Section 11, T55N, R61W	27	31	31	30	26	28	28	31	28	26	26	28	**340**
	Oak Creek at Mouth in Section 20, T55N, R60W	173	198	201	191	165	180	181	199	177	168	167	178	**2,178**
	South Redwater Creek Just Above Sand Creek in Section 31, T53N, R60W	399	461	458	446	390	425	443	467	429	423	417	422	**5,180**
	Redwater Creek Just Above South Redwater Creek in Section 31, T53N, R60W	203	234	232	227	198	216	225	237	218	215	212	214	**2,631**

TABLE 12
SUMMARY OF NORMAL YEAR MONTHLY AND ANNUAL FLOWS
AT UNGAGED NATURAL FLOW NODES

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Cheyenne	Willow Creek at Mouth in Section 28, T38N, R72W	11	0	0	4	97	188	4	87	3	8	23	0	**425**
	Woody Creek at Mouth in Section 5, T39N, R69W	1	0	0	0	13	25	1	11	0	1	3	0	**55**
	Lake Creek at Mouth in Section 30, T40N, R68W	3	0	0	1	29	57	1	26	1	2	7	0	**127**
	Sheep Creek at Mouth in Section 7, T40N, R67W	1	0	0	0	9	18	0	8	0	1	2	0	**39**
	Wagonhound Creek at Mouth in Section 31, T41N, R67W	2	0	0	1	20	38	1	18	1	2	5	0	**88**
	Snyder Creek at Mouth in Section 23, T40N, R64W	10	0	0	3	91	177	4	82	2	8	22	0	**399**
	Boggy Creek at Mouth in Section 32, T40N, R63W	3	0	0	1	25	48	1	22	1	2	6	0	**109**
	Sevenmile Creek at Mouth in Section 34, T40N, R63W	1	0	0	0	12	24	1	11	0	1	3	0	**53**
	Mule Creek at Mouth in Section 6, T39N, R61W	4	0	0	1	39	76	2	35	1	3	9	0	**170**
	Robbers' Roost Creek at Mouth in Section 23, T40N, R61W	6	0	0	2	55	108	2	50	1	5	13	0	**242**
	Beaver Creek Just Below Mush Creek in Section 32, T44N, R62W	35	0	0	11	299	526	14	243	7	23	60	0	**1,218**
	Oil Creek at Mouth in Section 26, T43N, R62W	402	0	0	49	5,048	5,977	70	2,767	83	261	1,971	0	**16,628**
	Blacktail Creek at Mouth in Section 2, T41N, R61W	199	196	190	180	156	179	187	324	274	244	218	200	**2,547**
	Dry Beaver Creek Just Above Beaver Creek in Section 4, T47N, R60W	115	103	107	96	96	114	143	155	142	130	124	112	**1,437**
Belle Fourche	Dry Creek at Mouth in Section 29, T47N, R70W	2	0	0	1	14	25	1	11	0	1	3	0	**58**
	Yellow Hammer Creek at Mouth in Section 10, T47N, R70W	1	0	0	0	5	9	0	4	0	0	1	0	**20**
	Whitetail Creek at Mouth in Section 32, T48N, R69W	1	0	0	0	8	14	0	6	0	1	2	0	**32**
	Four Horse Creek at Mouth in Section 11, T48N, R69W	9	0	0	3	74	130	3	60	2	6	15	0	**302**
	Timber Creek at Mouth in Section 2, T48N, R69W	2	0	0	1	19	34	1	16	0	1	4	0	**78**
	Buffalo Creek at Mouth in Section 14, T49N, R68W	11	0	0	4	94	165	4	76	2	7	19	0	**382**
	Donkey Creek Just Upstream of Gage in Sec. 30, T50N, R68W	0	0	0	235	1,126	2,518	1,451	2,883	886	0	0	0	**9,100**
	Trail Creek at Mouth in Section 24, T50N, R68W	1	0	0	0	10	18	0	9	0	1	2	0	**41**
	Dry Creek at Mouth in Section 24, T50N, R68W	2	0	0	1	15	26	1	12	0	1	3	0	**61**
	Robinson Creek at Mouth in Section 18, T50N, R67W	1	0	0	0	4	8	0	4	0	0	1	0	**18**
	Duck Creek at Mouth in Section 8, T50N, R67W	6	0	0	5	60	116	5	53	2	5	21	0	**273**
	Miller Creek at Mouth in Section 9, T50N, R67W	68	0	0	55	689	1,322	58	607	18	57	236	0	**3,110**
	Smoke Creek at Mouth in Section 9, T50N, R67W	2	0	0	1	18	34	1	16	0	1	6	0	**79**
	Berger Creek at Mouth in Section 12, T50N, R67W	3	0	0	2	29	56	2	26	1	2	10	0	**131**
	Lone Tree Creek at Mouth in Section 26, T51N, R67W	6	0	0	5	63	121	5	56	2	5	22	0	**285**
	Wind Creek at Mouth in Section 13, T50N, R67W	156	0	0	126	1,578	3,025	133	1,389	41	130	540	0	**7,118**
	Deer Creek at Mouth in Section 23, T51N, R67W	33	0	0	27	333	639	28	293	9	27	114	0	**1,503**
	Eggie Creek at Mouth in Section 21, T51N, R66W	5	0	0	4	46	88	4	41	1	4	16	0	**209**
	Mule Creek at Mouth in Section 15, T50N, R66W	20	0	0	16	202	387	17	178	5	17	69	0	**911**
	Cottonwood Creek at Mouth in Section 35, T51N, R66W	5	0	0	4	54	103	5	47	1	4	18	0	**241**
	Arch Creek at Mouth in Section 11, T51N, R66W	8	0	0	2	63	111	3	51	2	5	13	0	**258**
	Inyan Kara Creek at Mouth in Section 25, T52N, R66W	1,199	1,143	1,138	1,116	1,037	1,231	1,146	1,820	1,641	1,397	1,401	1,207	**15,476**
	Cabin Creek at Mouth in Section 14, T52N, R66W	6	0	0	2	48	84	2	39	1	4	10	0	**196**
	Miller Creek at Mouth in Section 12, T52N, R66W	5	0	0	1	40	70	2	32	1	3	8	0	**162**
	Lytle Creek at Mouth in Section 8, T53N, R65W	3	0	0	1	27	48	1	22	1	2	5	0	**110**
	Whitetail Creek at Mouth in Section 14, T54N, R65W	86	82	82	80	69	79	82	127	118	100	100	87	**1,092**
	Blacktail Creek at Mouth in Section 12, T54N, R65W	218	209	208	204	176	201	209	322	300	255	254	221	**2,777**
	Beaver Creek at Mouth in Section 1, T55N, R64W	477	458	456	446	385	439	458	704	657	557	555	483	**6,075**
	East Creek at Mouth in Section 32, T55N, R63W	50	48	47	46	40	46	48	73	68	58	58	50	**632**
	Arnold Creek at Mouth in Section 28, T55N, R63W	23	22	22	22	19	21	22	34	32	27	27	23	**294**
	Horse Creek at Mouth in Section 19, T56N, R61W	79	76	75	74	63	72	75	116	108	92	92	80	**1,002**
	Pine Creek at Mouth in Section 33, T56N, R61W	179	172	171	167	144	165	172	264	246	209	208	181	**2,278**
	Kilpatrick Creek at Mouth in Section 3, T55N, R61W	72	69	69	67	58	66	69	106	99	84	84	73	**916**
	Kruger Creek at Mouth in Section 11, T55N, R61W	35	34	33	33	28	32	34	52	48	41	41	36	**447**
	Oak Creek at Mouth in Section 20, T55N, R60W	224	215	214	210	181	207	215	331	309	262	261	227	**2,856**
	South Redwater Creek Just Above Sand Creek in Section 31, T53N, R60W	579	556	549	529	472	533	545	860	763	644	623	572	**7,225**
	Redwater Creek Just Above South Redwater Creek in Section 31, T53N, R60W	294	282	279	268	240	270	277	437	388	327	316	291	**3,669**

TABLE 13
SUMMARY OF WET YEAR MONTHLY AND ANNUAL FLOWS
AT UNGAGED NATURAL FLOW NODES

Basin	Station Name	ESTIMATED AVERAGE STREAMFLOW FOR 1970-1999 IN ACRE-FEET												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Cheyenne	Willow Creek at Mouth in Section 28, T38N, R72W	10	0	0	3	83	601	5	276	8	26	20	0	**1,032**
	Woody Creek at Mouth in Section 5, T39N, R69W	1	0	0	0	11	79	1	36	1	3	3	0	**135**
	Lake Creek at Mouth in Section 30, T40N, R68W	3	0	0	1	25	182	2	84	2	8	6	0	**313**
	Sheep Creek at Mouth in Section 7, T40N, R67W	1	0	0	0	8	58	0	27	1	2	2	0	**99**
	Wagonhound Creek at Mouth in Section 31, T41N, R67W	2	0	0	1	17	121	1	56	2	5	4	0	**209**
	Snyder Creek at Mouth in Section 23, T40N, R64W	9	0	0	3	77	563	5	259	7	24	18	0	**965**
	Boggy Creek at Mouth in Section 32, T40N, R63W	3	0	0	1	21	154	1	71	2	7	5	0	**265**
	Sevenmile Creek at Mouth in Section 34, T40N, R63W	1	0	0	0	10	75	1	35	1	3	2	0	**128**
	Mule Creek at Mouth in Section 6, T39N, R61W	4	0	0	1	33	242	2	111	3	10	8	0	**414**
	Robbers' Roost Creek at Mouth in Section 23, T40N, R61W	6	0	0	2	47	343	3	158	5	15	11	0	**590**
	Beaver Creek Just Below Mush Creek in Section 32, T44N, R62W	63	0	0	20	539	3,018	30	1,388	40	130	128	0	**5,356**
	Oil Creek at Mouth in Section 26, T43N, R62W	225	0	0	71	1,950	6,374	1,364	2,810	82	263	4,838	0	**17,977**
	Blacktail Creek at Mouth in Section 2, T41N, R61W	220	211	211	204	182	226	210	283	282	272	239	211	**2,751**
	Dry Beaver Creek Just Above Beaver Creek in Section 4, T47N, R60W	127	124	115	122	125	148	168	149	169	168	139	118	**1,672**
Belle Fourche	Dry Creek at Mouth in Section 29, T47N, R70W	3	0	0	1	25	142	1	65	2	6	6	0	**251**
	Yellow Hammer Creek at Mouth in Section 10, T47N, R70W	1	0	0	0	9	53	1	24	1	2	2	0	**93**
	Whitetail Creek at Mouth in Section 32, T48N, R69W	2	0	0	1	14	78	1	36	1	3	3	0	**139**
	Four Horse Creek at Mouth in Section 11, T48N, R69W	16	0	0	5	133	746	7	343	10	32	32	0	**1,324**
	Timber Creek at Mouth in Section 2, T48N, R69W	4	0	0	1	35	195	2	90	3	8	8	0	**346**
	Buffalo Creek at Mouth in Section 14, T49N, R68W	20	0	0	6	169	947	9	436	13	41	40	0	**1,681**
	Donkey Creek Just Upstream of Gage in Sec. 30, T50N, R68W	0	0	0	102	879	5,657	1,848	7,956	1,275	0	0	0	**17,717**
	Trail Creek at Mouth in Section 24, T50N, R68W	2	0	0	1	19	106	1	49	1	5	5	0	**189**
	Dry Creek at Mouth in Section 24, T50N, R68W	3	0	0	1	26	148	1	68	2	6	6	0	**261**
	Robinson Creek at Mouth in Section 18, T50N, R67W	1	0	0	0	8	45	0	21	1	2	2	0	**80**
	Duck Creek at Mouth in Section 8, T50N, R67W	4	0	0	1	37	153	2	71	2	7	9	0	**286**
	Miller Creek at Mouth in Section 9, T50N, R67W	49	0	0	15	425	1,750	22	805	23	75	101	0	**3,265**
	Smoke Creek at Mouth in Section 9, T50N, R67W	1	0	0	0	11	45	1	21	1	2	3	0	**85**
	Berger Creek at Mouth in Section 12, T50N, R67W	2	0	0	1	18	74	1	34	1	3	4	0	**138**
	Lone Tree Creek at Mouth in Section 26, T51N, R67W	5	0	0	1	39	161	2	74	2	7	9	0	**300**
	Wind Creek at Mouth in Section 13, T50N, R67W	113	0	0	35	973	4,004	50	1,843	53	173	232	0	**7,476**
	Deer Creek at Mouth in Section 23, T51N, R67W	24	0	0	7	206	846	11	389	11	36	49	0	**1,579**
	Eggie Creek at Mouth in Section 21, T51N, R66W	3	0	0	1	28	117	1	54	2	5	7	0	**218**
	Mule Creek at Mouth in Section 15, T50N, R66W	14	0	0	5	125	512	6	236	7	22	30	0	**957**
	Cottonwood Creek at Mouth in Section 35, T51N, R66W	4	0	0	1	33	136	2	63	2	6	8	0	**255**
	Arch Creek at Mouth in Section 11, T51N, R66W	13	0	0	4	114	639	6	294	8	28	27	0	**1,133**
	Inyan Kara Creek at Mouth in Section 25, T52N, R66W	1,255	1,227	1,126	1,049	1,145	1,900	1,242	2,233	1,905	1,511	1,448	1,259	**17,300**
	Cabin Creek at Mouth in Section 14, T52N, R66W	10	0	0	3	86	483	5	222	6	21	21	0	**857**
	Miller Creek at Mouth in Section 12, T52N, R66W	8	0	0	3	71	399	4	184	5	17	17	0	**708**
	Lytle Creek at Mouth in Section 8, T53N, R65W	6	0	0	2	49	276	3	127	4	12	12	0	**491**
	Whitetail Creek at Mouth in Section 14, T54N, R65W	89	88	81	75	73	81	89	135	137	107	102	91	**1,148**
	Blacktail Creek at Mouth in Section 12, T54N, R65W	227	225	206	191	185	207	226	344	347	271	259	231	**2,919**
	Beaver Creek at Mouth in Section 1, T55N, R64W	496	491	451	418	404	452	495	753	759	592	567	505	**6,383**
	East Creek at Mouth in Section 32, T55N, R63W	52	51	47	44	42	47	51	78	79	62	59	53	**665**
	Arnold Creek at Mouth in Section 28, T55N, R63W	24	24	22	20	20	22	24	36	37	29	27	24	**309**
	Horse Creek at Mouth in Section 19, T56N, R61W	82	81	74	69	67	75	82	124	125	98	94	83	**1,054**
	Pine Creek at Mouth in Section 33, T56N, R61W	186	184	169	157	151	169	185	282	285	222	213	189	**2,392**
	Kilpatrick Creek at Mouth in Section 3, T55N, R61W	75	74	68	63	61	68	75	114	115	89	86	76	**964**
	Kruger Creek at Mouth in Section 11, T55N, R61W	36	36	33	31	30	33	36	55	56	43	42	37	**468**
	Oak Creek at Mouth in Section 20, T55N, R60W	233	231	212	197	190	213	232	354	357	278	267	237	**3,001**
	South Redwater Creek Just Above Sand Creek in Section 31, T53N, R60W	690	688	663	632	544	629	697	1,002	1,105	875	902	734	**9,161**
	Redwater Creek Just Above South Redwater Creek in Section 31, T53N, R60W	350	349	337	321	276	319	354	509	561	444	458	373	**4,651**

REFERENCES

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Devore, Jay L., "Probability and Statistics for Engineering and the Sciences", Brooks/Cole Publishing Company. Belmont, California, 1987