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

Prepared in support of:

POWDER RIVER BASIN COAL REVIEW

Prepared for:

AECOM, Inc.
1601 Prospect Parkway
Fort Collins, CO 80525

Prepared by:

Anderson Consulting Engineers, Inc.
375 East Horsetooth Road, Bldg. 5
Fort Collins, CO 80525
(ACE Project No. WYAECOM01)

December 12, 2012

TABLE OF CONTENTS

EXECUTIVE SUMMARY ES.1

ES.1 Methodology for Water Quality Evaluation ES.1

ES.1.1 Evaluation Parameters ES.1
ES.1.2 Surface Water Quality Model ES.4

ES.2 Impacts to Water Quality ES-5

ES.2.1 Current Surface Water Quality Conditions ES.5
ES.2.2 Mixed Water Quality Conditions ES.8
ES.2.3 Observations Related to EC ES.11
ES.2.4 Observations Related to SAR ES.11
ES.2.5 Observations Related to Irrigation Suitability ES.11

ES.3 Impacts to Channel Stability ES.12

ES.3.1 Evaluation of Perennial Streams ES.12
ES.3.2 Evaluation of Ephemeral Streams ES.14

1.0 INTRODUCTION 1.1

1.1 Study Background 1.2

1.1.1 Phase I of the Study 1.3
1.1.2 Phase II of the Study 1.4

2.0 METHODOLOGY FOR WATER QUALITY EVALUATION 2.1

2.1 General 2.1
2.2 Water Quality Evaluation 2.1

2.2.1 Evaluation Criteria 2.2
2.2.2 Irrigation Suitability Diagram 2.4

2.3 Surface Water Quality Mode Input 2.6

2.3.1 Mean Monthly Stream Flow Quantity 2.6

2.3.1.1 Development of Hydrologic Database 2.6

2.3.2 Hydrologic Condition 2.10

2.4 Stream Water Quality 2.15

TABLE OF CONTENTS (continued)

2.5 CBNG Well Production Water Quantity 2.15
2.6 CBNG Well Production Water Quality 2.16
2.7 Conveyance Loss 2.18
2.8 Surface Water Quality Model 2.19

3.0 IMPACTS TO WATER QUALITY 3.1

3.1 Antelope Creek 3.3

3.1.1 Antelope Creek: Baseline Conditions (2008) 3.4
3.1.2 Antelope Creek: RFD Scenario 2020 Conditions 3.5
3.1.3 Antelope Creek: RFD Scenario 2030 Conditions 3.6

3.2 Dry Fork Cheyenne River 3.7

3.2.1 Dry Fork Cheyenne River: Baseline Conditions (2008) 3.8
3.2.2 Dry Fork Cheyenne River: RFD Scenario 2020 Conditions 3.9
3.2.3 Dry Fork Cheyenne River: RFD Scenario 2030 Conditions 3.10

3.3 Little Powder River 3.10

3.3.1 Little Powder River: Baseline Conditions (2008) 3.12
3.3.2 Little Powder River: RFD Scenario 2020 Conditions 3.13
3.3.3 Little Powder River: RFD Scenario 2030 Conditions 3.14

3.4 Upper Belle Fourche River 3.15

3.4.1 Upper Belle Fourche River: Baseline Conditions (2008) 3.16
3.4.2 Upper Belle Fourche River: RFD Scenario 2020 Conditions 3.17
3.4.3 Upper Belle Fourche River: RFD Scenario 2030 Conditions 3.18

3.5 Upper Cheyenne Creek 3.19

3.5.1 Upper Cheyenne Creek: Baseline Conditions (2008) 3.20
3.5.2 Upper Cheyenne Creek: RFD Scenario 2020 Conditions 3.21
3.5.3 Upper Cheyenne Creek: RFD Scenario 2030 Conditions 3.22

3.6 Upper Powder River 3.22

3.6.1 Upper Powder River: Baseline Conditions (2008) 3.24
3.6.2 Upper Powder River: RFD Scenario 2020 Conditions 3.25
3.6.3 Upper Powder River: RFD Scenario 2030 Conditions 3.25

3.7 Middle Powder River 3.26

TABLE OF CONTENTS (continued)

3.7.1 Middle Powder River: Baseline Conditions (2008) 3.28
3.7.2 Middle Powder River: RFD Scenario 2020 Conditions 3.29
3.7.3 Middle Powder River: RFD Scenario 2030 Conditions 3.29

3.8 Clear Creek 3.30

3.8.1 Clear Creek: Baseline Conditions (2008) 3.31
3.8.2 Clear Creek: RFD Scenario 2020 Conditions 3.32
3.8.3 Clear Creek: RFD Scenario 2030 Conditions 3.32

3.9 Crazy Woman Creek 3.33

3.9.1 Crazy Woman Creek: Baseline Conditions (2008) 3.34
3.9.2 Crazy Woman: RFD Scenario 2020 Conditions 3.35
3.9.3 Crazy Woman: RFD Scenario 2030 Conditions 3.35

3.10 Tongue River 3.36

3.10.1 Tongue River: Baseline Conditions (2008) 3.37
3.10.2 Tongue River: RFD Scenario 2020 Conditions 3.38
3.10.3 Tongue River: RFD Scenario 2030 Conditions 3.39

3.11 Sensitivity Analysis 3.39
3.12 Summary 3.42

3.12.1 Current Surface Water Quality Conditions 3.42
3.12.2 Mixed Water Quality Conditions 3.46
3.12.3 Observations Related to EC 3.48
3.12.4 Observations Related to SAR 3.49
3.12.5 Observations Related to Irrigation Suitability 3.49

4.0 CHANNEL STABILITY EVALUATION 4.1

4.1 General 4.1
4.2 Evaluation of Perennial Streams 4.2
4.3 Evaluation of Ephemeral Streams 4.10
4.4 Evaluation of Caballo Creek near Belle Ayr Coal Mine 4.15

4.4.1 Pertinent Information and Statistics 4.15
4.4.2 Hydrologic Data 4.17
4.4.3 Channel Stability 4.20
4.4.4 Summary and Conclusions 4.26

5.0 REFERENCES 5.1

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Figure ES.1-1 Task 3B Study Area and Subwatersheds ES.2
Figure 1-1 Montana and Wyoming Study Area 1.5
Figure 1-2 Federal Land Management 1.6
Figure 1-3 Surface Ownership 1.7
Figure 2.2-1 Antelope Creek Ayers Wetcott Diagram Based on Irrigation Season Existing Water Quality (2008) 2.5
Figure 3.0-1 Comparison of Mean Stream Water Quality to CBNG Water Quality 3.2
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) 3.50
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) 3.51
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) 3.52
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) 3.53
Figure 3.1-5 Antelope Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology) 3.54
Figure 3.1-6 Antelope Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology) 3.55
Figure 3.2-1 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Normal Year Hydrology USGS 06365300 Dry Fork Cheyenne River Near Bill, WY 3.56
Figure 3.2-2 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology USGS 06365300 Dry Fork Cheyenne River Near Bill, WY 3.57
Figure 3.2-3 Stream SAR Before Mixing With CBM Produced Water for Mean Monthly Flows Normal Year Hydrology USGS 06365300 Dry Fork Cheyenne River near Bill, WY 3.58
Figure 3.2-4 Stream SAR Before Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology USGS 06365300 Dry Fork Cheyenne River near Bill, WY 3.59
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) 3.60
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) 3.61
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) 3.62
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) 3.63
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) 3.64
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) 3.65
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) 3.66
Figure 3.3-6 Little Powder River Stream Water Quality Before and After Mixing with CBM Produced Water or Mean Monthly Flows (Dry Year Hydrology) 3.67

TABLE OF CONTENTS (continued)

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) 3.68
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) 3.69
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) 3.70
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) 3.71
Figure 3.4-5 Belle Fourche River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology) 3.72
Figure 3.4-6 Belle Fourche River Stream Water Quality Before and After Mixing with CBM Produced Water or Mean Monthly Flows (Dry Year Hydrology) 3.73
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) 3.74
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) 3.75
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) 3.76
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) 3.77
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) 3.78
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) 3.79
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) 3.80
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) 3.81
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) 3.82
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) 3.83
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) 3.84
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) 3.85
Figure 3.7-1 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Powder River near Moorhead, MT (USGS 06324500) .. 3.86
Figure 3.7-2 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Powder River near Moorhead, MT (USGS 06324500) 3.87

TABLE OF CONTENTS (continued)

Figure 3.7-3 Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Powder River near Moorhead, MT (USGS 06324500) .. 3.88
Figure 3.7-4 Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Powder River near Moorhead, MT (USGS 06324500)..... 3.89
Figure 3.7-5 Middle Powder River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology) 3.90
Figure 3.7-6 Middle Powder River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)..... 3.91
Figure 3.8-1 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Clear Creek near Arvada, WY (USGS 06324000)..... 3.92
Figure 3.8-2 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Clear Creek near Arvada, WY (USGS 06324000) 3.93
Figure 3.8-3 Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Clear Creek near Arvada, WY (USGS 06324000)..... 3.94
Figure 3.8-4 Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Clear Creek near Arvada, WY (USGS 06324000) 3.95
Figure 3.8-5 Clear Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)..... 3.96
Figure 3.8-6 Clear Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)..... 3.97
Figure 3.9-1 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Crazy Woman Creek near Arvada, WY (USGS 06316400)..... 3.98
Figure 3.9-2 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Crazy Woman Creek near Arvada, WY (USGS 06316400) ... 3.99
Figure 3.9-3 Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Crazy Woman Creek near Arvada, WY (USGS 6316400) 3.100
Figure 3.9-4 Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Crazy Woman Creek near Arvada, WY (USGS 06316400) 3.101
Figure 3.9-5 Crazy Woman Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology) 3.102
Figure 3.9-6 Crazy Woman Creek Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology)..... 3.103
Figure 3.10-1 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Tongue River near Birney Day School, near Birney, MT (USGS 06037616) 3.104
Figure 3.10-2 Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Tongue River near Birney Day School, near Birney, MT (USGS 06037616) 3.105
Figure 3.10-3 Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows Normal Year Hydrology Tongue River near Birney Day School, near Birney, MT (USGS 06037616) 3.106

TABLE OF CONTENTS (continued)

Figure 3.10-4 Stream SAR Before and After Mixing with CBM Produced Water for Mean Monthly Flows Dry Year Hydrology Tongue River near Birney Day School, near Birney, MT (USGS 06037616) 3.107
Figure 3.10-5 Tongue River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology) 3.108
Figure 3.10-6 Tongue River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Dry Year Hydrology) 3.109
Figure 4.2-1 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Belle Fourche River 4.3
Figure 4.2-2 Estimated Recurrence Intervals for Observed Annual Peak Discharge for Clear Creek 4.3
Figure 4.2-3 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Crazy Woman Creek 4.4
Figure 4.2-4 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Little Powder River 4.4
Figure 4.2-5 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Middle Powder River 4.5
Figure 4.2-6 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Tongue River 4.5
Figure 4.2-7 The Relationship Between Measured Discharge and Channel Width for the Belle Fourche River 4.7
Figure 4.2-8 The Relationship Between Measured Discharge and Channel Width for Clear Creek 4.7
Figure 4.2-9 The Relationship Between Measured Discharge and Channel Width for Crazy Woman Creek 4.8
Figure 4.2-10 The Relationship Between Measured Discharge and Channel Width for the Little Powder River 4.8
Figure 4.2-11 The Relationship Between Measured Discharge and Channel Width for Middle Powder River 4.9
Figure 4.2-12 The Relationship Between Measured Discharge and Channel Width for the Tongue River 4.9
Figure 4.3-1 CEM Channel Types 4.11
Figure 4.4-1 Vicinity Map 4.16
Figure 4.4-2 Hydrologic Data for Caballo Creek (1985-2004) 4.17
Figure 4.4-3 Average Annual Precipitation Data (1984-2004) 4.19
Figure 4.4-4 Palmer Drought Index Data (1980-2000) 4.20
Figure 4.4-5 This view is looking downstream on Caballo Creek at the BA-6 v-notch weir gauging site 4.21
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 4.22
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 4.22
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 4.23

TABLE OF CONTENTS (continued)

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 4.23
Figure 4.4-10 This is a view of the confluence of Caballo Creek and Bone Pile Creek 4.24
Figure 4.4-11 The view illustrates the diversion channel immediately downstream of the confluence of Caballo Creek and Bone Pile Creek 4.24
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 4.25

LIST OF TABLES

Table ES.1-1 Summary of Numeric Limits for SAR and EC PRB Study Area ES.3
Table ES.2-1 Summary of Water Quality Analysis (Normal Year)..... ES.6
Table ES.2-2 Summary of Water Quality Analysis (Dry Year) ES.7
Table ES.3-1 Impact of CBNG Production Water on Perennial Streams ES.13
Table 2.2-1 Summary of Montana DEQ Numeric Limits for SAR and EC in the Powder River and Tongue River Basins 2.3
Table 2.2-2 Summary of Pertinent Stream Standards 2.4
Table 2.3-1 Summary of Available USGS Streamflow Data 2.8
Table 2.3-2 Data Extension/Filling Protocols 2.9
Table 2.3-3 Determination of Hydrologic Condition at Indicator Gages 2.11
Table 2.3-4 Summary of Hydrologic Condition at Indicator Gages 2.12
Table 2.3-5 Results of Hydrologic Condition Evaluation..... 2.13
Table 2.3-6 Mean Monthly Streamflow for the Dry and Normal Hydrologic Condition 2.14
Table 2.4-1 Mean Monthly Stream EC and SAR Values 2.15
Table 2.5-1 CBNG-Related Water Production Discharge..... 2.16
Table 2.6-1 CBNG-Related Water Quality..... 2.17
Table 2-7.1 CBNG Impoundments and CBNG Groundwater discharge by Method 2.19
Table 3.1-1 Surface Water Impact Analysis of the Antelope Creek Subwatershed..... 3.3
Table 3.2-1 Surface Water Impact Analysis of the Dry Fork Cheyenne River Subwatershed..... 3.7
Table 3.3-1 Surface Water Impact Analysis of the Little Powder River Subwatershed 3.11
Table 3.4-1 Surface Water Impact Analysis of the Upper Belle Fourche River Subwatershed 3.15
Table 3.5-1 Surface Water Impact Analysis of the Upper Cheyenne River Subwatershed 3.20
Table 3.6-1 Surface Water Impact Analysis of the Upper Powder River Subwatershed 3.23
Table 3.7-1 Surface Water Impact Analysis of the Middle Powder River Subwatershed..... 3.27
Table 3.8-1 Surface Water Impact Analysis of the Clear Creek Subwatershed 3.31
Table 3.9-1 Surface Water Impact Analysis of the Crazy Woman Creek Subwatershed 3.33
Table 3.10-1 Surface Water Impact Analysis of the Tongue River Subwatershed 3.37
Table 3.12.1 Summary of Water Quality Analysis (Normal Year)..... 3.43
Table 3.12.2 Summary of Water Quality Analysis (Dry Year) 3.44
Table 4.2-1 Impact of CBNG Production Water on Perennial Streams 4.6

TABLE OF CONTENTS (continued)

LIST OF APPENDICES

Appendix 2A: Stream Standards
Appendix 2B: Streamflow Database
Appendix 2C: Surface Water Quality Database
Appendix 2D: CBNG Water Pumpage-Discharge-Recharge
Appendix 2E: Greystone 2003
Appendix 3A: Water Quality Modeling Results Dry Year
Appendix 3A: Water Quality Modeling Results Normal Year
Appendix 4A: CBNG Discharge Analysis Dry Year
Appendix 4A: CBNG Discharge Analysis Normal Year

EXECUTIVE SUMMARY

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

Completion of the work associated with Task 3B relied on information and data provided in the PRB Coal Review Task 2 Report (AECOM 2011a) and data from the USGS and the Wyoming Department of Environmental Quality, Water Quality and Land Quality Divisions. The Task 2 Report defines the past and present development actions within the study that have contributed to the current environmental and socioeconomic conditions in the PRB study area. The Task 2 Report also defines the Reasonably Foreseeable Development (RFD) scenarios in the Wyoming and Montana PRB for years 2020 and 2030. The RFD scenarios for the Wyoming PRB study area as presented in the Task 2 Report provide the basis for the analysis of potential cumulative impacts to surface water resources in the Task 3 component of the PRB Coal Review.

ES.1 Methodology for Water Quality Evaluation

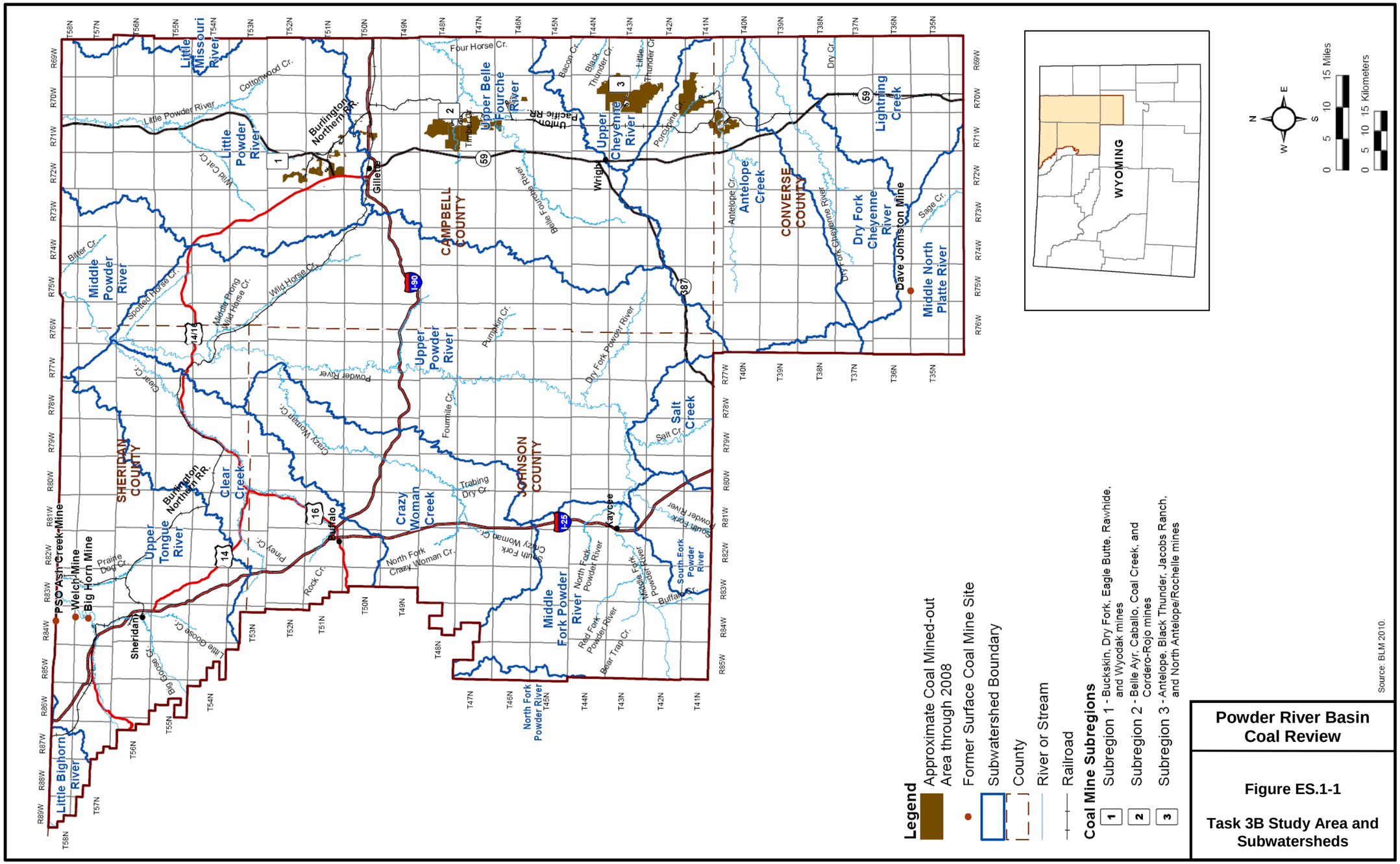
The cumulative impact assessment addresses current conditions (2008) and two future RFD scenarios for years 2020 and 2030. Based on the information developed in support of the assessment and documented in the Task 2 Report (AECOM 2011), the impacts have been addressed on a subwatershed basis. The subwatersheds associated with the work effort are presented in **Figure ES.1-1.**

ES.1.1 Evaluation Parameters

Key water quality parameters for predicting the potential effects of CBNG development focused on the suitability of surface water for irrigated agriculture. Consequently, sodium adsorption ratio, or SAR, and salinity, measured by electrical conductivity or EC, were utilized for the prediction.

The Montana Department of Environmental Quality (2011) provides the following summary of EC and SAR with respect to irrigation suitability:

Electrical Conductivity (EC) is a measure of the amount of dissolved solids (salts) in water and is generally expressed as microsiemens per centimeter (uS/cm). As the EC in the soil water increases, a threshold is



Powder River Basin Coal Review

Figure ES.1-1

Task 3B Study Area and Subwatersheds

8/17/2012

X:\0Projects\BLM_PRB_Phase_II_60143410\Figures\DOC\440_SurfaceWater\Figure_1-3_StudyArea_20120817.mxd

reached where further increases in EC cause decreases in plant growth. The EC in the soil water is directly affected by the EC of the irrigation water, and it is important to distinguish between the two.

The EC of the soil water may be higher than the EC of the irrigation water because plants and evaporation remove water from the soil but do not remove salts. Unless salts are removed or leached from the soil by excess water, the concentration of salts in the soil will build up as irrigation water is added over time.

*The sodium adsorption ratio (SAR) is a measure of the abundance of sodium relative to the abundance of calcium and magnesium in water. It is directly related to the amount of sodium that is absorbed by soils. A high SAR in irrigation water has the potential to impair soil structure and thus, the permeability of the soil leading to a lack of soil moisture. This is particularly so when the EC of the soil water or applied water is insufficient to counteract the negative effects of adsorbed sodium on soil structure (*MDEQ, 2011).

The formula for calculating sodium adsorption ratio is:

$$SAR = (Na) / [(Ca) + (Mg) /2]^{½}$$

where sodium, calcium, and magnesium are in milliequivalents/liter.

Most restrictive and least restrictive regulatory standards for EC and SAR applicable to the subwatersheds were developed and utilized in the cumulative impact assessment. The limits presented in **Table ES.1-1** were utilized during the comparison of EC and SAR values for resulting mixtures of existing streamflows and water discharges from CBNG wells under the base year (2008) and RFD projections for the years 2020 and 2030.

Table ES.1-1 Summary of Numeric Limits for SAR and EC PRB Study Area

Montana					
Water Body	Season	EC		SAR	
		Monthly Average us/cm	Instantaneous us/cm	Monthly Average	Instantaneous
Tongue River / Rosebud Creek	Nov. 1 - Mar. 1	1500	2500	5	7.5
Tongue River / Rosebud Creek	Mar. 2 - Oct. 31	1000	1500	3	4.5
Powder River / Little Powder River	Nov. 1 - Mar. 1	2500	2500	6.5	9.75
Powder River / Little Powder River	Mar. 2 - Oct. 31	2000	2500	5	7.5
South Dakota					
Water Body	Season	EC		SAR	
		Monthly Average us/cm	Daily Max us/cm	Monthly Average	Instantaneous
Belle Fourche	NA	2500	4375	6	NA
Irrigation Waters	NA			10	NA

Source: MDEQ Water Quality Standards of Classification (2012)
South Dakota Legislative Council (2012)

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

ES.1.2 Surface Water Quality Model

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

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

- Mean Monthly Streamflow (acre-feet)
- Stream Water Quality (SAR and EC)
- CBNG Well Production Water (mmgpy)
- CBNG Well Production Water Quality (SAR and EC)
- Channel Loss (%)

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 Phase II Task 2 Report.
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 computed using streamflow data obtained from the USGS. Two hydrologic conditions were evaluated; a dry year study period and a normal year study period. The dry year analysis was utilized to evaluate the maximum likely impacts to surface water quality, assuming limited flow in the receiving streams.
4. Water quality data (SAR and EC) for ~~both~~ the CBNG groundwater discharge was obtained from the Wyoming Department of Environmental Quality, Water Quality Division.
5. Water quality data (SAR and EC) for the receiving drainages were obtained from the USGS.
6. 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.
7. Monthly estimates of stream water quality before and after mixing with the CBNG groundwater are determined to support a comparative evaluation of EC and SAR and also plotted on the Ayers-Westcot diagram to ascertain the impact on water for irrigation.

ES.2 Impacts to Water Quality

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

ES.2.1 Current Surface Water Quality Conditions

With respect to pertinent stream standards included in the impact analysis, several of the surface water sources exceed the standard during many months of the years under the base year (2008) condition. Specific observations related to the mean monthly water quality of the surface water sources are listed below:

Base year (2008) water quality in several of the subwatersheds evaluated is suitable for irrigation throughout the entire year in both the dry-year and normal-year hydrologic conditions:

- Antelope Creek,
- Upper Belle Fourche,
- Upper Cheyenne River,
- Upper Powder River,
- Little Powder River,
- Dry Fork Cheyenne River,
- Clear Creek,
- Crazy Woman Creek, and
- Middle Powder River

Of the ten subwatershed evaluated, the only one in which base year water quality is not suitable during any portion of the year is the Upper Tongue River which is not suitable in the months of May and June.

Table ES.2-1 Summary of Water Quality Analysis (Normal Year)

Item	Baseline 2008	2008	2020	2030
	Before Mixing	(After Mixing)	(After Mixing)	(After Mixing)
Antelope Creek (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Nonsuitable in Sep, Oct	Nonsuitable in Jan, Sep thru Dec	Nonsuitable Sep and Oct
Stream Standard	EC Exceeded Jan, Feb, Apr thru Jun, Nov, and Dec	EC Exceeded in Apr, May	EC Exceeded in no months	EC Exceeded in Apr, May
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Dry Fork Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Same (No CBNG Discharge)	Reduced
SAR	Stream < CBNG	Increased	Same (No CBNG Discharge)	Increased
Irrigation Suitability	Suitable all season	Not suitable Sep	Same (No CBNG Discharge)	Not suitable Jan, Jul through Oct
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	Same (No CBNG Discharge)	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	Same (No CBNG Discharge)	SAR Exceeded in no months
Little Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded all months except Mar	EC Exceeded all months except Jan thru Mar and Oct, Nov	EC Exceeded all months except Mar	EC Exceeded all months except Mar
	SAR Exceeded all months except Feb and Mar	SAR Exceeded all months	SAR Exceeded all months except Mar	SAR Exceeded all months except Mar
Upper Belle Fourche (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Oct thru Feb	EC Exceeded in Jan, Feb	EC Exceeded Dec through Feb	EC Exceeded Nov through Feb
	SAR Exceeded in Sep thru Jan	SAR Exceeded in Jan, Aug thru Dec	SAR Exceeded Sep through Jan	SAR Exceeded Sep through Jan
Upper Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Reduced	Same (No CBNG Discharge)
SAR	Stream ~= CBNG	No Significant Change	No Significant Change	Same (No CBNG Discharge)
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Same (No CBNG Discharge)
Stream Standard	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	Same (No CBNG Discharge)
	SAR Exceeded Oct through Jan	SAR Exceeded Jan, Oct thru Dec	SAR Exceeded Jan, Apr, Oct thru Dec	Same (No CBNG Discharge)
Upper Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec
	SAR Exceeded Mar, Apr, Jul thru Oct	SAR Exceeded all months	SAR Exceeded all months ex Feb, Jun	SAR Exceeded all months except Feb, May, Jun
Middle Powder River (1)				
EC	Stream ~= CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Clear Creek (1)				
EC	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
SAR	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Stream Standard	EC Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Crazy Woman Creek (1)				
EC	Stream ~= CBNG	Same (No CBNG Discharge Conveyed to Stream)	No Significant Change	No Significant Change
SAR	Stream < CBNG	Same (No CBNG Discharge Conveyed to Stream)	Increased	Increased
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Suitable all season	Suitable all season
Stream Standard	EC Exceeds in Sep	Same (No CBNG Discharge Conveyed to Stream)	EC Exceeded in Sep	EC Exceeded in Sep and Oct
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	SAR Exceeded in no months	SAR Exceeded in no months
Upper Tongue River (1)				
EC	Stream < CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	No Significant Change	Increased	Increased
Irrigation Suitability	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months

(1) All references to comparative changes in water quality refer to the relative difference between the "after mixing" and "before mixing" conditions.

Table ES.2-2 Summary of Water Quality Analysis (Dry Year)

Item	Baseline 2008	2008	2020	2030
	Before Mixing	(After Mixing)	(After Mixing)	(After Mixing)
Antelope Creek (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Nonsuitable in Jan, Feb, Sep thru Dec	Nonsuitable in Jan, Feb, Sep thru Dec	Nonsuitable in Jan, Feb, Sep thru Dec
Stream Standard	EC Exceeded Jan, Feb, Apr thru Jun, Nov, and Dec	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Dry Fork Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Same (No CBNG Discharge)	Reduced
SAR	Stream < CBNG	Increased	Same (No CBNG Discharge)	Increased
Irrigation Suitability	Suitable all season	Not suitable Jan, Jul, Sep, and Oct	Same (No CBNG Discharge)	Not suitable Jan thru Apr, Jul - Dec
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	Same (No CBNG Discharge)	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	Same (No CBNG Discharge)	SAR Exceeded in no months
Little Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded all months except Mar	EC Exceeded all months except Feb, Mar and Oct	EC Exceeded all months except Mar and Feb	EC Exceeded all months except Feb and Mar
	SAR Exceeded all months except Feb and Mar	SAR Exceeded all months	SAR Exceeded all months except Mar	SAR Exceeded all months except Mar
Upper Belle Fourche (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Oct thru Feb	EC Exceeded in Jan and Dec	EC Exceeded Dec through Feb	EC Exceeded Nov thru Feb
	SAR Exceeded in Sep thru Jan	SAR Exceeded in Jul thru Feb	SAR Exceeded Aug thru Jan	SAR Exceeded Sep thru Jan
Upper Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Reduced	Same (No CBNG Discharge)
SAR	Stream ~= CBNG	No Significant Change	No Significant Change	Same (No CBNG Discharge)
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Same (No CBNG Discharge)
Stream Standard	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	Same (No CBNG Discharge)
	SAR Exceeded Oct through Jan	SAR Exceeded Oct through Jan	SAR Exceeded Oct through Jan, Apr	Same (No CBNG Discharge)
Upper Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec
	SAR Exceeded Mar, Apr, Jul thru Oct	SAR Exceeded all months	SAR Exceeded all months	SAR Exceeded all months except Feb
Middle Powder River (1)				
EC	Stream ~= CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep
	SAR Exceeded in no months	SAR Exceeded Aug and Oct	SAR Exceeded in no months	SAR Exceeded in no months
Clear Creek (1)				
EC	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
SAR	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Stream Standard	EC Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Crazy Woman Creek (1)				
EC	Stream ~= CBNG	Same (No CBNG Discharge Conveyed to Stream)	No Significant Change	No Significant Change
SAR	Stream < CBNG	Same (No CBNG Discharge Conveyed to Stream)	Increased	Increased
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Suitable all season	Suitable all season
Stream Standard	EC Exceeds in Sep	Same (No CBNG Discharge Conveyed to Stream)	EC Exceeded in Sep and Oct	EC Exceeded in Sep and Oct
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	SAR Exceeded in no months	SAR Exceeded in Sep and Oct
Upper Tongue River (1)				
EC	Stream < CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	No Significant Change	Increased	Increased
Irrigation Suitability	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months

(1) All references to comparative changes in water quality refer to the relative difference between the "after mixing" and "before mixing" conditions.

With respect to the pertinent stream standards, surface waters in several of the subwatersheds evaluated exceed one or both of the standards for EC and SAR during at least one month of the year. Based upon the available water quality data, the only subwatersheds in which standards are not exceeded for either parameter are:

- Clear Creek,
- Dry Fork Cheyenne River, and the
- Upper Tongue River.

Surface water in several of the subwatershed exceed pertinent stream standards for both EC and SAR throughout much of the year, including the irrigation season. Subwatersheds where this relationship exists are:

- Upper Belle Fourche River,
- Upper Cheyenne River
- Upper Powder, and
- the Little Powder River

In the remaining three subwatersheds, the pertinent stream standard for SAR is not exceeded throughout the entire year but the standard for EC is for at least one month. These streams and descriptions of the EC exceedence are:

- Antelope Creek exceeds the standard for EC most of the year.
- Crazy Woman Creek exceeds the standard for EC only during the month of September
- Middle Powder River exceeds the standard for EC during the months of August and September.

ES.2.2 Mixed Water Quality Conditions

Specific observations related to the pertinent stream standards *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 discharge in Antelope Creek is very low in relation to the projected CBNG production water in RFD 2020 scenario when 7.1 cfs is ultimately discharged. Consequently the quality of the CBNG production water dominates the nature of the mixed waters. The mixed

water quality reflects a reduction in EC that meets the pertinent stream standard throughout the year. Levels of SAR are increased but continue to meet the pertinent standard.

- CBNG well production water in the Dry Fork Cheyenne River subwatershed peaks with the RFD 2030 scenario when 1.5 cfs is ultimately discharged to surface water. Quality of the CBNG production water dominates the character of the mixed waters due to the relative magnitudes (1.5 cfs CBNG water compared to less than 1 cfs surface water). Consequently EC is reduced and continues to remain below the pertinent stream standard throughout the year. SAR levels are increased throughout the year, however, they remain below the pertinent stream standard in all months.

- Within the Little Powder River subwatershed, CBNG production water would peak in the base year (2008) scenario when 9.6 cfs would ultimately be discharged to surface waters. The quantity of CBNG well production water in the Little Powder River subwatershed is similar in magnitude to the ambient streamflow. Following mixing, the surface water in the Little Powder River reflects an overall reduction in EC but continues to exceed the pertinent standard most of the year. The SAR values reflect an increase and exceed the pertinent standard for the entire year in comparison to the base year (2008) condition when it was exceeded in ten months.

- Following mixing, surface water in the Upper Belle Fourche River reflect an overall reduction in EC and an increase in SAR. The peak discharge of CBNG production water occurs in the base year (2008) when 10.0 cfs is ultimately discharged to surface waters. This quantity is of a similar and often greater magnitude to the amount of streamflow. The pertinent stream standard for EC would be exceeded in fewer months than prior to mixing (January and December). The pertinent standard for SAR would be exceeded in more months following mixing than under the base year (2008) condition. Following mixing, the SAR standard would be exceeded July through February.

- Within the Upper Cheyenne Powder River subwatershed, CBNG production water would be relatively low in comparison to other subwatershed and would peak in the base year (2008) scenario and the RFD 2020 scenario when 0.4 cfs would ultimately be discharged to surface waters. Ambient stream flows are considerably higher most of the year. Following mixing, the surface water in the Upper Cheyenne River reflects an overall slight reduction in EC but continues to exceed the pertinent standard in the months of July and August. The SAR values reflect a minimal increase but would result in no additional months exceeding the pertinent standard in comparison to the base year condition (2008). The pertinent stream standard for SAR would be exceeded during the low-flow months of October through January.

- In the Upper Powder River subwatershed, projected CBNG production water is higher in quantity than any of the other subwatersheds evaluated. The peak CBNG production water would occur in the base year (2008) when 60.3 cfs is ultimately discharged to the river. However, because stream flow in the river is also high, the relative impacts upon mixing of the two waters are diminished. The surface water in the Upper Powder River demonstrates a minimal reduction in EC and a minor increase in SAR following mixing. EC values continue to exceed the pertinent stream standard throughout the majority of the year (March, April, July through October and December). SAR values exceed the pertinent stream standard throughout the year.

- Within the Middle Powder River subwatershed, CBNG production water would be relatively low in comparison to other subwatersheds and would peak in the base year (2008) scenario when 3.0 cfs would ultimately be discharged to surface waters. Ambient stream flows are significantly higher than CBNG production water discharge year round, consequently impacts of mixing are minimized. Following mixing, the surface water in the Middle Powder River reflects a minimal change as the EC levels in the CBNG production water and the surface water are similar. The pertinent standard for EC would continue to be exceeded in August and September. The SAR values in the subwatershed are among the highest of all subwatersheds evaluated: 28.0. Due to the relative magnitude of the CBNG production water SAR values, the surface water would continue to exceed the pertinent stream standard in two months (September and October). However, due to the higher quantity of streamflow, the impacts of mixing water with a much higher SAR level would be minimal.

- No CBNG production water would ultimately be discharged to surface water within the Clear Creek subwatershed. Consequently, the water quality in this surface water source remains the same as that described for the base year (2008) condition.

- Within the Crazy Woman Creek subwatershed, CBNG production water would be relatively low in comparison to other subwatershed and would peak in RFD 2030 scenario when 2.0 cfs would ultimately be discharged to surface waters. Ambient stream flows are considerably higher most of the year. Following mixing, the surface water in Crazy Woman Creek reflects an overall minimal reduction in EC but continues to exceed the pertinent standard in the late irrigation season months of September and October. The SAR values associated with the CBNG production water in the subwatershed are among the highest of all subwatersheds evaluated: 26.98. Although the base year (2008) SAR values in Crazy Woman Creek meet the pertinent stream standards, due to the relative magnitude of the CBNG production water SAR values, the surface water would exceed the pertinent stream standard in two months (September and October).

- The peak discharge of CBNG production water within the Upper Tongue River subwatershed occurs in the base year (2008) scenario when 2.7 cfs is ultimately discharged to surface waters. This quantity is a relatively minor amount in comparison to the surface water where the minimum streamflow is approximately 128 cfs. Following mixing there would be minimal changes in EC and SAR levels despite the observation that CBNG production water SAR values in this subwatershed are the highest of all evaluated: 40.0. The pertinent stream standards for EC and SAR would not be exceeded throughout the year.

ES.2.3 Observations Related to EC

The EC associated with the surface water sources is typically higher than the EC associated with the CBNG well production water. Consequently, the simple mixing approach utilized during the evaluation results in a reduction or improvement in EC after mixing with CBNG production water. In every instance, the most significant reduction in EC correlates to those scenarios (base year 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 Middle Powder River, Upper Belle Fourche River, and Crazy Woman Creek, this observation was consistent for all surface water sources evaluated during this study. Within these basins, the EC associated with the CBNG well production water was the most elevated and similar to the EC of the surface water.

ES.2.4 Observations Related to SAR

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

ES.2.5 Observations Related to Irrigation Suitability

The suitability of the mixed water for irrigation purposes is also related to EC and SAR. The analysis for irrigation suitability relied solely on utilization of the Ayers Westcot Diagram. In general, the water most suitable for irrigation consists of a source with relatively low SAR and relatively high EC. Elevated SAR

values may reduce permeability in clayey soils thereby reducing the rate of water infiltration. This relationship in EC and SAR is depicted in the Ayers Westcot Diagram in terms of the suitability of water sources for irrigation purposes. In those instances where the SAR is significantly increased and the EC is moderately low, the water source was considered unsuitable. This observation was specifically noted in the surface water sources associated with Antelope Creek, the Dry Fork Cheyenne River and the Upper Tongue River. For these streams, the results demonstrated unsuitable water sources during a portion of the irrigation season during the normal-year and dry-year conditions.

In general, the increased levels of SAR in the CBNG well production water directly relates to the reduction in the suitability of the water for irrigation purposes in streams receiving a large component of CBNG discharge. This trend is amplified for all streams during periods when CBNG well production water represents the majority of the flows available for irrigation purposes.

ES.3 Impacts to Channel Stability

The cumulative impact assessment includes an evaluation of channel stability with respect to the surface water resources within the study area. In general, the impacts to channel stability largely relate to the water quantity associated with the discharges from current or projected coal mining activities, CBNG wells or conventional oil and gas wells compared to the runoff characteristics of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages.

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

ES.3.1 Evaluation of Perennial Streams

Examination of United States Geological Survey (USGS) records provided the basis of the evaluation of perennial streams associated with the following:

- Belle Fourche River (USGS Gage 06426500),
- Clear Creek (USGS Gage 06324000),

- Crazy Woman Creek (USGS Gage 06316400),
- Little Powder River (USGS Gage 06324970),
- Middle Powder River (USGS Gage 06324500), and
- Upper Tongue River (USGS Gage 06307616).

For these perennial streams, a hydraulic geometry relationship was developed that related channel width as a function of discharge. The hydraulic geometry relationships were developed from all data classified as good (G) or fair (F) by the USGS during the data collection efforts. Using the relationships developed, channel width in the range of the channel forming discharge was computed for the existing condition and for the maximum CBNG well production condition by adding the predicted CBNG discharge to the existing condition discharge **(Table ES.3-1)**. The estimated change in width for these streams ranged from less than 0.1% to 0.62%. These results suggest that for the larger, perennial streams the effect of the CBNG well production water will be minimal.

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

Location	Channel Forming Discharge [1] (cfs)	CBNG Discharge		Estimated Width		Potential Impact [Increased Width]	
		(cfs)	(%)	Existing Conditions (ft)	Combined Discharge (ft)	(ft)	(%)
Belle Fourche River	600–820	3.00	0.50-0.37	66.57-74.0	66.68-74.09	0.11-0.09	0.17-0.12
Clear Creek	1740-2370	0.00	0.00-0.00	111.38-120.71	111.38-120.71	0.0-0.0	0.0-0.0
Crazy Woman Creek	580-830	0.60	0.10-0.07	33.85-36.17	33.86-36.40	0.01-0.22	0.02-0.62
Little Powder Creek	290-490	2.90	1.02-0.61	52.87-65.56	53.09-65.72	0.22-0.16	0.42-0.24
Middle Powder Creek	4000-5720	2.98	0.07-0.05	213.42-230.05	213.45-230.08	0.03	0.02-0.01
Upper Tongue River	1900-2100	0.80	0.04-0.04	136.11-137.44	136.11-137.45	0.00-0.01	0.0

[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. Applying the geomorphic relationships to the existing data resulted in the following observations:

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

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

ES.3.2 Evaluation of Ephemeral Streams

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

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

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

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

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

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

Ephemeral drainage channels that are presently experiencing active headcutting and erosion should be identified. Monitoring of the erosion should be conducted as specified above. Where erosion of the channel is considered significant, mitigation measures should be implemented and the channel stabilized. Mitigation measures identified in the Draft EIS for the Seminoe Road Natural Gas Development Project (BLM, 2005) may be worthy of consideration and include grade control structures, check dams, impact basins, channel reconstruction, and other possible engineered erosion control measures. Coordination with Ms. Kathy Brus of the BLM in Buffalo was conducted to determine the results of monitoring the erosion along the ephemeral drainages. The results of this coordination effort indicated: (1) a reduction in water production has been realized within the basin; (2) operators have focused discharge of water into larger perennial stream systems; and (3) channel monitoring at 5 locations along the ephemeral drainages has not provided any conclusive results (BLM 2012.

1.0 INTRODUCTION

The PRB of Wyoming and Montana is a major energy development area with diverse resource and 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 of the region. The PRB also has produced large amounts of oil and natural gas resources. Over the last decade, this region has experienced nationally significant development of natural gas from coal seams (coal bed natural gas [CBNG]).

The Powder River Basin (PRB) Coal Review is a regional technical study for assessing the existing conditions and the projected future cumulative impacts associated with past, present, and reasonably foreseeable development (RFD) activities in the PRB. For purposes of this study, the Wyoming PRB cumulative effects study area (**Figure 1-1**) comprises all of Campbell County, all of Sheridan and Johnson counties outside of 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 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, which is administered by the U.S. Forest Service (FS) (**Figure 1-2).** The Montana portion of the PRB cumulative effects study area (**Figure 1-1**) comprises the area of relevant coal mines and the air quality cumulative effects study area, including portions of Rosebud, Custer, Powder River, Big Horn, and Treasure counties. It encompasses the area administered by the BLM Miles City Field Office and the Billings Field Office (**Figure 1-2**).

This Task 3B component of the Coal Review provides an assessment of the water resources cumulative impacts 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 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 Phase I PRB Coal Review.

This Task 3 report summarizes the cumulative impacts related to surface water quality and channel stability issues associated with energy-related development activities that have occurred in the PRB through the end of base year 2008 and the projected RFD activities for future years 2020 and 2030. The Task 2 component of the study provides the basis for these analyses of cumulative impacts. This study is being conducted by AECOM, Inc. dba AECOM Environment (AECOM) under the direction of the Bureau of Land Management (BLM) High Plains District Office and Wyoming State Office. The water quality and

channel stability component of the study has been conducted by Anderson Consulting Engineers, Inc. (ACE) under contract to AECOM.

1.1 Study Background

During the 1970s and early 1980s, federal coal leasing in the PRB was a high profile activity as over 90 percent of the coal is federally owned. Between 1974 and 1982, the BLM issued three and started a fourth separate regional coal environmental impact statement (EIS), all addressing federal coal leasing and development, as well as other regional development.

In 1982, the BLM temporarily halted further coal leasing. However, mining continued on existing leases. When leasing resumed in 1990, the existing mines were mature operations, and there was no need for regional leasing to open new mines. However, many of the mines were depleting their original reserves, so there was a need for maintenance leasing to provide the reserves to enable existing mines to meet the expanding demand. At that time, the Powder River Regional Coal Team decertified the region, allowing BLM to use the lease by application (LBA) process to meet this need.

To date, the BLM continues to use the LBA process to meet the need for maintenance coal leasing. Each LBA requires preparation of an EIS or environmental assessment (EA), as appropriate, as part of the leasing process. As required under the National Environmental Policy Act (NEPA), each EIS and EA must include an evaluation of the cumulative impacts on the environment that result from the incremental impact of the action (e.g., an LBA) when added to other past, present, and reasonably foreseeable future actions.

Starting with the first LBAs, the BLM met the need for cumulative analysis in each EIS or EA with a discrete analysis that was updated for each subsequent EIS or EA. In the mid-1990s, the BLM conducted a study called the Coal Development Status Check (BLM 1996) to evaluate how actual development levels compared to the development levels predicted in the earlier regional EISs. In the late 1990s, annual coal production and associated impacts drew closer to the maximum projections in the regional EISs. Furthermore, the large scale oil and gas development associated with CBNG activity had not been foreseen in those EISs. To meet the need of the coal mine LBA EISs and EAs at that time, the BLM used the cumulative analysis from their Wyodak Final EIS (BLM 1999) and their PRB Oil and Gas Final EIS (BLM 2003), particularly for air and water resources. Both EISs projected regional development, including CBNG activity. They both also used market demand projections to estimate future levels of coal development.

In early 2003, Montgomery Watson Harza (MWH), in coordination with the BLM, completed a study of PRB coal demand through 2020 (MWH 2003). The study projected production to increase at a steady pace, with current mines able to meet the demand as long as the existing mines continued to have access to additional coal reserves. Therefore, the need for leasing using LBAs will continue into the foreseeable future. As part of processing these LBAs, BLM will need to maintain a current cumulative impact analysis. The PRB Coal Review study was developed to meet that need.

Initiated in 2003, Phase I of the PRB Coal Review included the identification of current conditions (Task 1 reports); identification of base year (2003 and subsequently 2007) and RFD energy-related activities (including future coal production scenarios) for 2010, 2015, and 2020 (Task 2 report); and predicted future cumulative impacts (Task 3 reports) in the PRB. Phase II of the PRB Coal Review was initiated in January 2010 to update the Phase I analyses. Under Phase II of the study, base year information and current conditions descriptions have been updated through the end of 2008. Also, new RFD projects have been developed, and projected cumulative impacts will be analyzed for 2020 and 2030.

The PRB Coal Review provides data, models, and projections to facilitate cumulative analyses for BLM's future land use planning efforts and for the cumulative impact sections of future coal mine LBA EISs and EAs in compliance with NEPA. It should be noted that the PRB Coal Review itself is not a NEPA document. It also is not a policy study, analysis of regulatory actions, or an analysis of the impacts of project-specific development.

1.1.1 Phase I of the Study

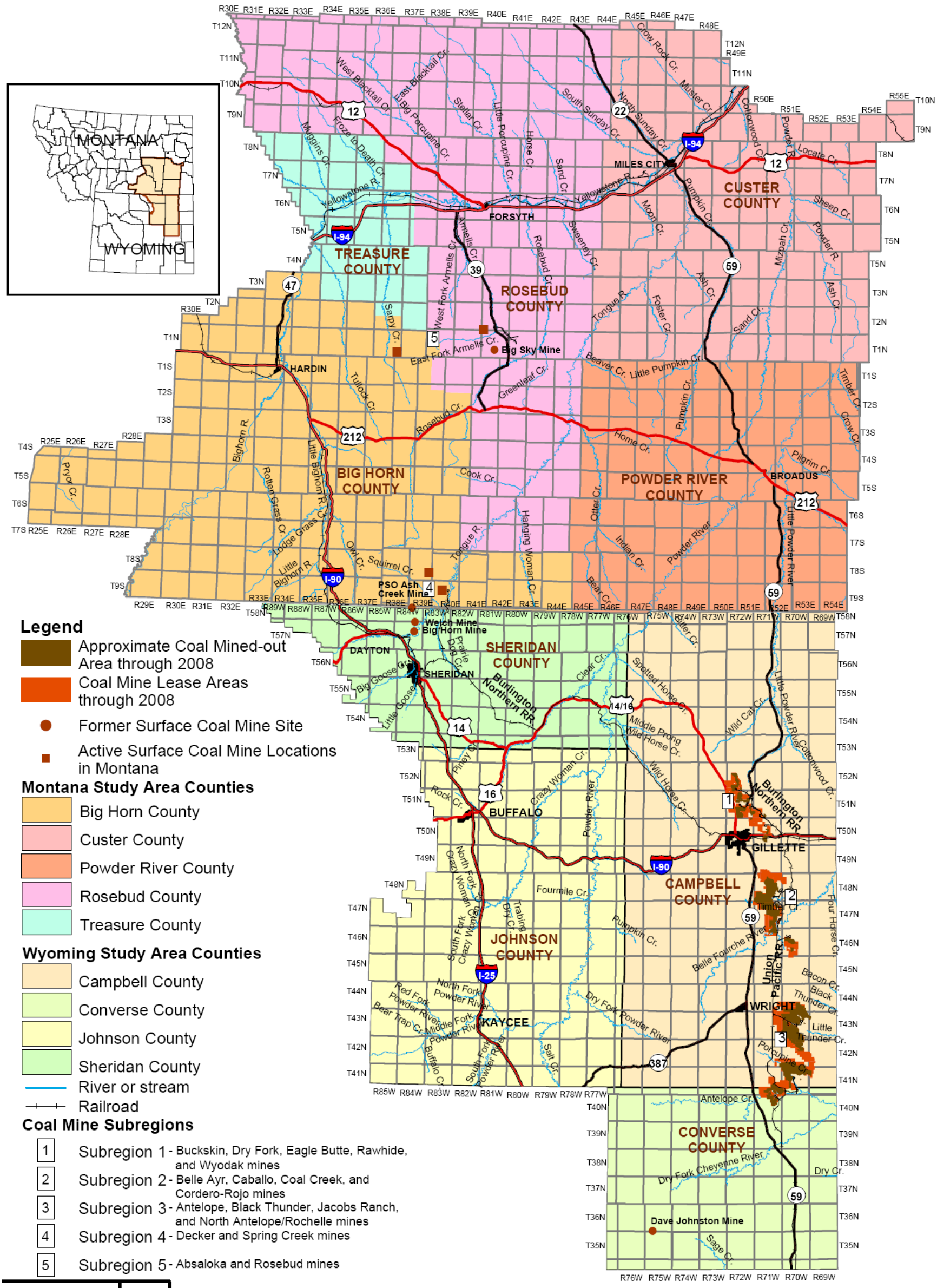
Phase I of the PRB Coal Review was developed as a regional technical study for assessing the existing environmental and socioeconomic conditions in the PRB study area as of the end of 2003 and the projected future cumulative impacts associated with ongoing energy-related development in the PRB for years 2010, 2015, and 2020. Subsequent updates to the Task 2 report during Phase I provided updates of both the existing conditions through the end of 2007 and the projected future cumulative impacts for years 2010, 2015, and 2020. The past and present activities identified in the original Task 2 report (ENSR 2005) were based on data available at the end of 2003 and provided the basis for the resource-specific descriptions of existing conditions presented in the PRB Coal Review Task 1 reports. The past and present activities described in the updated Task 2 report (AECOM 2009a) were based on the available data for energy-related development in the study area through base year 2007 and reflected updated information on the status of existing projects, as well as identification of newly constructed and operational projects since 2003.

The RFD scenarios presented in the original Task 2 report (ENSR 2005) were based on information available through the end of 2004 and provided the basis for the analysis of potential cumulative impacts in the Task 3 reports. The RFD scenarios presented in the updated Task 2 report (AECOM 2009a) reflected updated information available on previously identified foreseeable development, as well as information on newly identified foreseeable development projected to be operational or constructed by 2010, 2015, or 2020. Specific to the water quality and channel stability component of the study, the Task 3B report (ACE 2009) documented the base year 2003 conditions and presented the results of the modeled cumulative impacts in the six subwatersheds in the eastern portion of the Wyoming PRB for future years 2010, 2015, and 2020.

1.1.2 Phase II of the Study

Identical to Phase I, Phase II of the PRB Coal Review is a regional technical study to determine the base year (2008) conditions and assess potential future (2020 and 2030) cumulative effects of projected development-related activities in the PRB. Phase II of the study was initiated due to the ongoing energy-related development in the PRB, the elapsed time since initiation of Phase I of the study, and the BLM's need to maintain up-to-date development projections and related predicted future cumulative impact analyses for use in the agency LBA EISs and EAs. Under Phase II, the existing and projected future energy-related development activities have been updated (Task 2) based on updated information, and the air quality, water resources, socioeconomic, and environmental resources base year analyses (Task 1) and projected cumulative impact analyses (Task 3) subsequently will be updated.

Specific to the water quality and channel stability component of the study, this Task 3B report documents the base year 2008 conditions and presents the result of modeled cumulative impacts in the Wyoming PRB for future years 2020 and 2030. This evaluation was conducted for the ten subwatersheds in the Wyoming PRB study area where CBNG water discharge is projected to occur in future years.



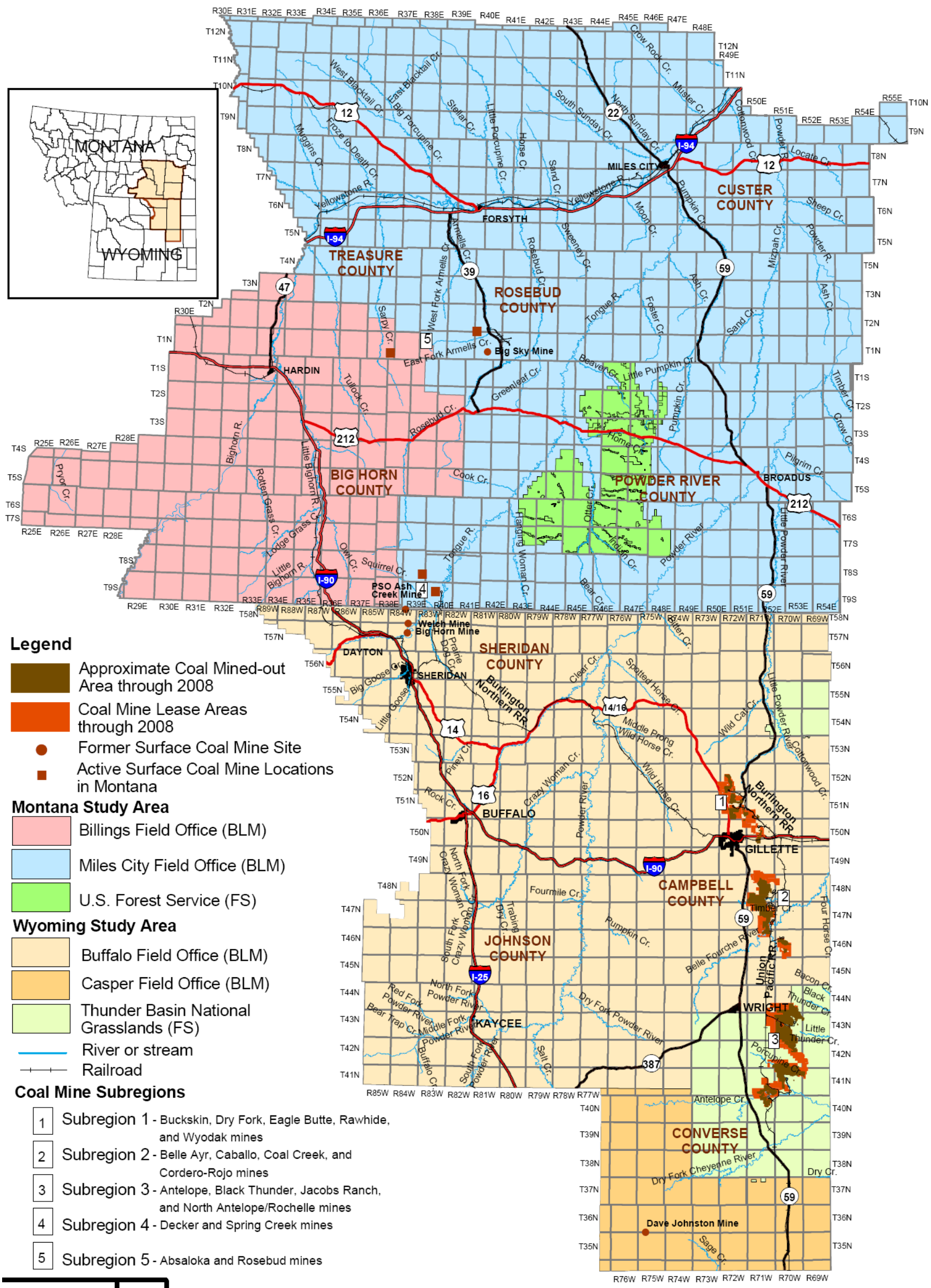
Note: Approximate coal mined-out areas were not available for the Montana mine sites.

Source: BLM 2003, 2010a.

Powder River Basin Coal Review

Figure 1-1

Montana and Wyoming Study Area



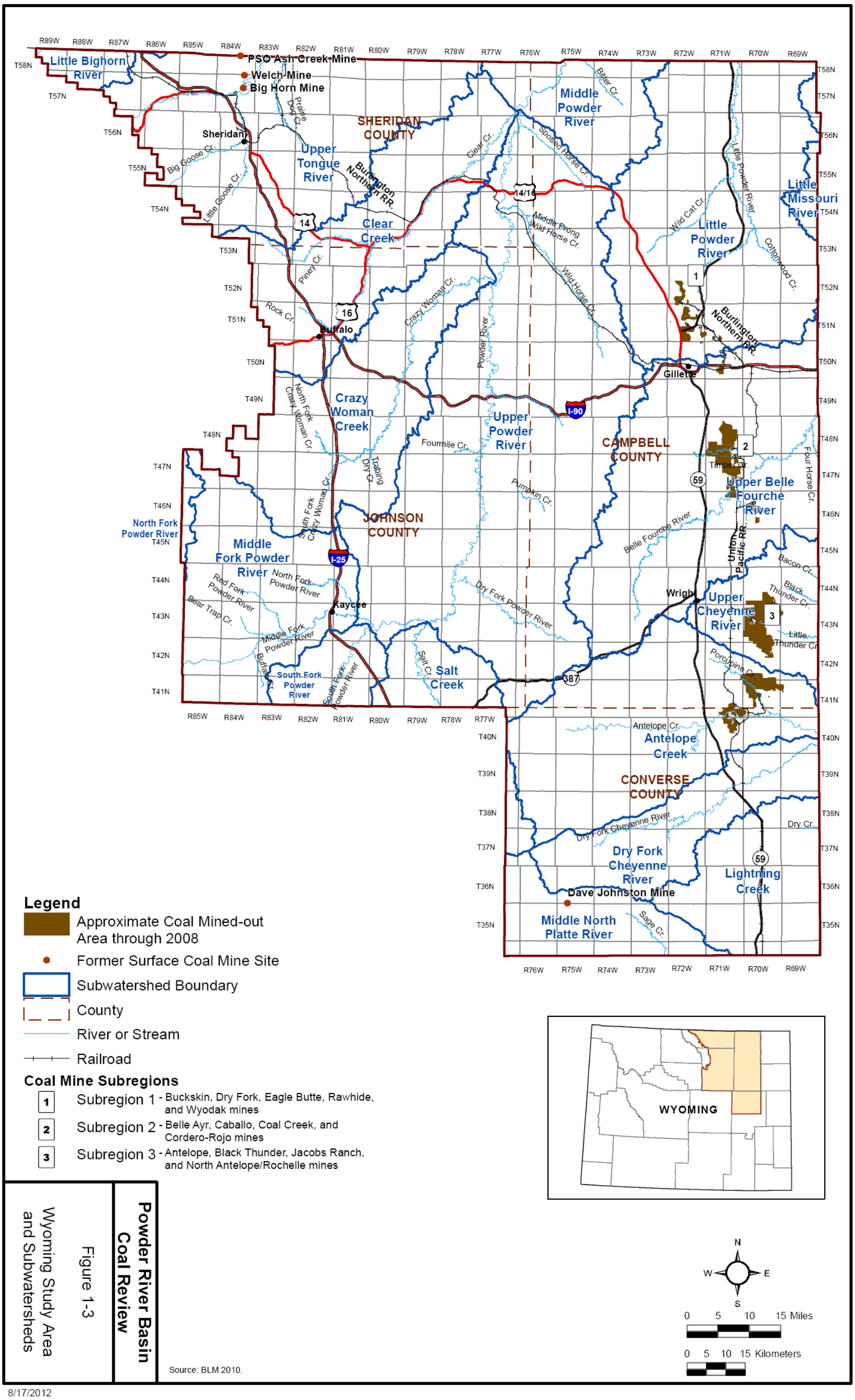
Powder River Basin Coal Review

Figure 1-2

Federal Land Management

Note: Approximate coal mined-out areas were not available for the Montana mine sites.

Source: BLM 2003, 2010.



Powder River Basin Coal Review

Figure 1-3

Wyoming Study Area and Subwatersheds

2.0 METHODOLOGY FOR WATER QUALITY EVALUATION

2.1 General

The cumulative impact assessment addresses current conditions (2008) and two future RFD scenarios for years 2020 and 2030. Based on the information developed in support of the assessment and documented in the Task 2 Report (AECOM, 2011a), 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
- Clear Creek
- Crazy Woman Creek
- Upper Tongue River
- Middle Fork 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 2 Report (AECOM 2011a), 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 Evaluation

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

The Montana Department of Environmental Quality (2011) provides the following summary of EC and SAR with respect to irrigation suitability:

Electrical Conductivity (EC) is a measure of the amount of dissolved solids (salts) in water and is generally expressed as microsiemens per centimeter (uS/cm). As the EC in the soil water increases, a threshold is reached where further increases in EC cause decreases in plant growth. The EC in the soil water is directly affected by the EC of the irrigation water, and it is important to distinguish between the two.

The EC of the soil water may be higher than the EC of the irrigation water because plants and evaporation remove water from the soil but do not remove salts. Unless salts are removed or leached from the soil by excess water, the concentration of salts in the soil will build up as irrigation water is added over time.

*The sodium adsorption ratio (SAR) is a measure of the abundance of sodium relative to the abundance of calcium and magnesium in water. It is directly related to the amount of sodium that is absorbed by soils. A high SAR in irrigation water has the potential to impair soil structure and thus, the permeability of the soil leading to a lack of soil moisture. This is particularly so when the EC of the soil water or applied water is insufficient to counteract the negative effects of adsorbed sodium on soil structure. (*MDEQ, 2011).

The formula for calculating sodium adsorption ratio is:

$$SAR = (Na) / [(Ca) + (Mg) /2]^{½}$$

where sodium, calcium, and magnesium are in milliequivalents/liter.

2.2.1 Evaluation Criteria

The States of Montana and South Dakota both administer numeric stream standards for EC and SAR; the State of Wyoming does not.

The State of Montana has adopted numeric standards specific to the Tongue River and the Powder River. Because of the sensitivity of irrigated crops to EC and SAR, there are more restrictive numeric standards for the irrigation season (March 2nd through October 31st). Table 2.2-1 summarizes the numeric stream standards adopted by the Montana Department of Environmental Quality (MDEQ).

Table 2.2-1 Summary of Montana DEQ Numeric Limits for SAR and EC in the Powder and Tongue River Basins

Montana					
Water Body	Season	EC		SAR	
		Monthly Average	Instantaneous	Monthly Average	Instantaneous
		us/cm	us/cm		
Tongue River / Rosebud Creek	Nov. 1 - Mar. 1	1500	2500	5	7.5
Tongue River / Rosebud Creek	Mar. 2 - Oct. 31	1000	1500	3	4.5
Powder River / Little Powder River	Nov. 1 - Mar. 1	2500	2500	6.5	9.75
Powder River / Little Powder River	Mar. 2 - Oct. 31	2000	2500	5	7.5
South Dakota					
Water Body	Season	EC		SAR	
		Monthly Average	Daily Max	Monthly Average	Instantaneous
		us/cm	us/cm		
Belle Fourche	NA	2500	4375	6	NA
Irrigation Waters	NA			10	NA

Source: Montana DEQ Water Quality Standards of Classification (2012)
South Dakota Department of Environment and Natural Resources (2012)

The State of South Dakota has also adopted numeric stream standards for EC and SAR as well. Although there is no differentiation of standards based upon the irrigation season, the Belle Fourche River has had specific criteria prescribed by South Dakota Department of Environment and Natural Resources (DNER).

The State of Wyoming's Agricultural Use Protection Policy (Chapter 1, Section 20) consists of a narrative approach to prevent degredation of agricultural water supplies and prescribes methods of defining discharge limits through the Wyoming Department of Environmental Quality's (WDEQ) WYPDES permitting process. Numeric standards are not employed.

For the purposes of this study, the stream standard most pertinent to each water body was selected for comparison of pre- and post-mixing water quality. For those streams flowing into Montana, MDEQ numeric stream standards were used. Likewise, for those streams flowing into South Dakota, numeric standards administered by the South Dakota DNER were used. Because numeric standards are not utilized in Wyoming, the standard of the state the stream system in ultimately tributary to was used.

The limits presented in **Table 2.2-2** 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 2008 (baseline), 2020, 2030. **Appendix 2A** contains information pertaining to water quality standards of the three states.

Table 2.2-2 Summary of Pertinent Stream Standards

	Antelope Creek	Dry Fork Cheyenne River	Little Powder River	Upper Belle Fourche River	Upper Cheyenne River	Upper Powder River	Clear Creek	Crazy Woman CreeK	Middle Powder River	Upper Tongue River
Source	South Dakota	South Dakota	Montana	South Dakota	South Dakota	Montana	Montana	Montana	Montana	Montana
Pertinent Stream Standard for EC (uS/cm)										
Jan	2500	2500	2500	2500	2500	2500	2500	2500	2500	1500
Feb	2500	2500	2500	2500	2500	2500	2500	2500	2500	1500
Mar	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Apr	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
May	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Jun	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Jul	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Aug	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Sep	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Oct	2500	2500	2000	2500	2500	2000	2000	2000	2000	1000
Nov	2500	2500	2500	2500	2500	2500	2500	2500	2500	1500
Dec	2500	2500	2500	2500	2500	2500	2500	2500	2500	1500
	Pertinent Stream Standard for SAR									
Jan	10	10	6.5	6	10	6.5	6.5	6.5	6.5	5
Feb	10	10	6.5	6	10	6.5	6.5	6.5	6.5	5
Mar	10	10	5	6	10	5	5	5	5	3
Apr	10	10	5	6	10	5	5	5	5	3
May	10	10	5	6	10	5	5	5	5	3
Jun	10	10	5	6	10	5	5	5	5	3
Jul	10	10	5	6	10	5	5	5	5	3
Aug	10	10	5	6	10	5	5	5	5	3
Sep	10	10	5	6	10	5	5	5	5	3
Oct	10	10	5	6	10	5	5	5	5	3
Nov	10	10	6.5	6	10	6.5	6.5	6.5	6.5	5
Dec	10	10	6.5	6	10	6.5	6.5	6.5	6.5	5

(1) Most appropriate regulatory

2.2.2 Irrigation Suitability Diagram

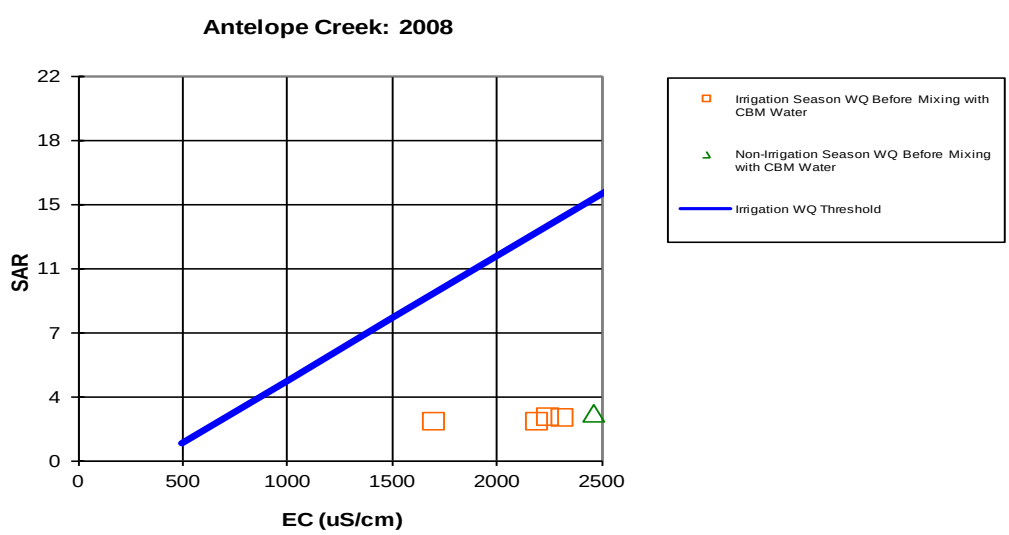
The Ayers and Westcot (1985) irrigation suitability diagram (also referred to as the "Hanson Diagram"; Hanson, Grattan, Fulton, 1999) was used to compare water quality before and after mixing with discharges from CBNG wells. The diagonal line on the diagram is used as the no-impact threshold for SAR 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 (2008 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.

Figure 2.2-1 Antelope Creek Ayers Wetcott Diagram Based on Irrigation Season Existing Water Quality (2008)



2.3 Surface Water Quality Model Input

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, 2003) was modified and utilized for the cumulative impact assessment. This spreadsheet model employs a steady-state, mass-balance approach to estimate steady-state concentrations of EC and SAR after two or more inflows are mixed. Input parameters to the spreadsheet model are described below.

- Mean Monthly Streamflow (acre-feet)
- Stream Water Quality (SAR and EC)
- CBNG Well Production Water (mmgpy)
- CBNG Well Production Water Quality (SAR and EC)
- Channel Loss (%)

In the sections which follow, each of the input parameters listed above are discussed. Within each section, the methodologies utilized to develop the project database and the assumptions associated with each are presented.

2.3.1 Mean Monthly Stream Flow Quantity

Mean monthly and annual flows at pertinent gauging stations for the major drainages within each subwatershed were obtained using methods consistent with the Wyoming Water Development Commission's (WWDC's) basin planning process. Specifically, protocols described in 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) were followed to the extent possible to collect the historic records of streamflow, extend or fill-in streamflow data where records are unavailable, and to determine average dry, normal, and wet year hydrologic conditions.

The hydrologic period of record utilized in the WWDC investigations extended from 1970 to 1999. Consequently, in order to meet the objectives of this study, which assumes a base year of 2008 for comparison of various development scenarios, the WWDC data could not be used directly but required updating.

2.3.1.1 Development of Hydrologic Database

For the purposes of this investigation, a study period of 30 years was desirable in order to include a sampling of dry, normal and wet years. Therefore, the hydrologic study period was determined to

extend from 1978 through 2008. The period of record for each of the ten stream gages utilized in this investigation is presented in **Table 2.3-1**. As indicated in this table, only four of the ten gages had complete data records for this period.

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).

Estimation of missing data was completed using regressional analysis relying upon information from nearby gages. Existing data were compared with data from gages with complete records and that gage with the best correlation was selected to estimate the missing data. The general approach to the data extension/filling effort was to determine the statistical relationship between annual runoff volumes recorded at various gages. 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 applied to the total remaining streamflow for the partial year.

Table 2.3-2 summarizes pertinent information for each of the gages included in the study with respect to correlation between gage records and the methods used to extend/fill each. Note that two gages were used in this effort in addition to the ten included in the study:

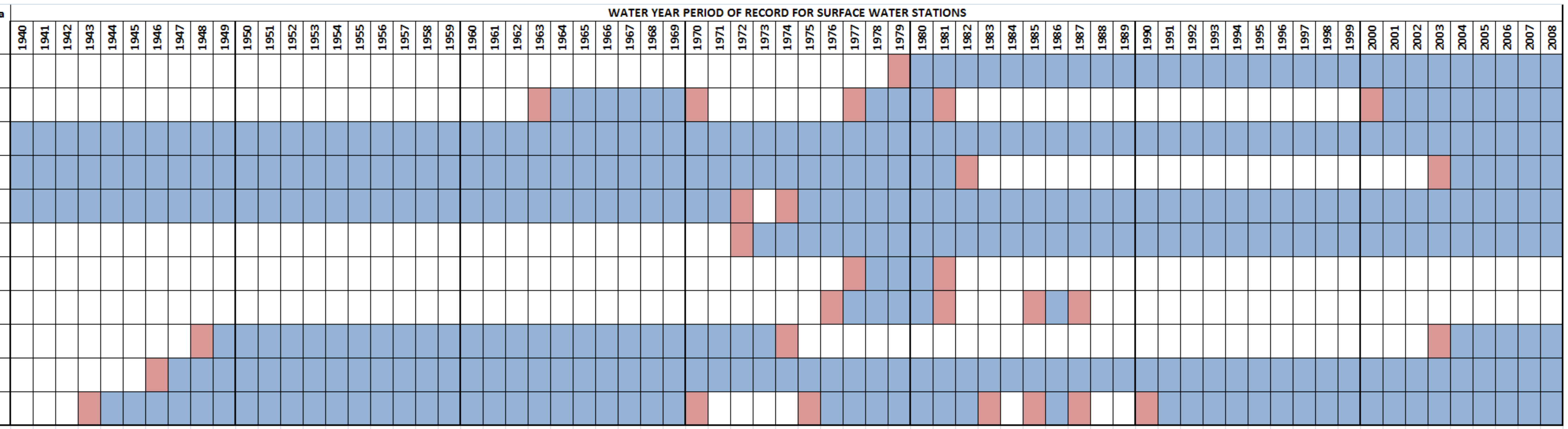
- The Cheyenne River near Edgemont gage (USGS gage 06395000) was used to extend/fill gages due to its complete record and high correlation with selected gages.

- The USBR gage located at Keyhole Reservoir was used to develop a regression relationship between streamflows at the upstream of the Belle Fourche River below Moorcroft (USGS gage 06426500) as recommended in the HKM memoranda.

Appendix 2B presents the results completed hydrologic database.

Table 2.3-1 Summary of Available USGS Streamflow Data

Station Number	Station Name	Some Data prior to 1940
06307616	Tongue River at Birney Day School Br nr Birney, MT	
06316400	Crazy Woman Creek at Upper Sta, Near Arvada, WY	
06317000	Powder River at Arvada, WY	YES
06324000	Clear Creek near Arvada, WY	YES
06324500	Powder River at Moorhead, MT	YES
06324970	Little Powder River ab Dry Creek, near Weston, WY	
06364700	Antelope Creek near Teckla, WY	
06365300	Dry Fork Cheyenne River near Bill, WY	
06386500	Cheyenne River near Spencer, WY	
06395000	Cheyenne R at Edgemont, SD	
06426500	Belle Fourche River below Moorcroft, MT	



Monthly flow reported for partial year (red)

Monthly flow reported for entire year (blue)

Table 2.3-2 Data Extension/Filling Protocols

Station Number	Station Name	Station Used in Regression	R^2 Value	Regression Equation	Notes
06307616	Tongue River at Birney Day School Br nr Birney, MT	Tongue River at Tongue R Dam nr Decker, MT (USGS STA 06307500)	0.99	Y = 1.0129X - 4280.9	Data extension applied to water year 1979
06316400	Crazy Woman Creek at Upper Sta, Near Arvada, WY	Powder River at Arvada, WY (USGS STA 06317000)	0.80	Y = 0.1936X - 5965.7	Data extension applied to water years 1981 - 1999
06317000	Powder River at Arvada, WY	Complete period of record available (no regression performed)	N/A	N/A	
06324000	Clear Creek near Arvada, WY	Powder River at Moorhead, MT (USGS STA 06324500)	0.72	Y = 0.3351X + 16116	Data extension applied to water years 1983 - 2002 and first 4 months of water year 2003
06324500	Powder River at Moorhead, MT	Complete period of record available (no regression performed)	N/A	N/A	
06324970	Little Powder River ab Dry Creek, near Weston, WY	Complete period of record available (no regression performed)	N/A	N/A	
06364700	Antelope Creek near Teckla, WY	Cheyenne R at Edgemont, SD (USGS STA 06395000)	0.98	$Y = 0.0013X^{1.3568}$	Data extension applied to water years 1982 - 2008
06365300	Dry Fork Cheyenne River near Bill, WY	Cheyenne R at Edgemont, SD (USGS STA 06395000)	0.70	$Y = 0.0048X^{1.0122}$	Data extension applied to water years 1982 - 1985 and 1988 - 2008
06386500	Cheyenne River near Spencer, WY	Cheyenne R at Edgemont, SD (USGS STA 06395000)	0.93	Y = 0.6786X - 3116	Data extenstion applied to water years 1979 - 2003
06395000	Cheyenne R at Edgemont, SD	Complete period of record available (no regression performed)	N/A	N/A	
06426500	Belle Fourche River below Moorcroft, MT	USBR Keyhole Reservoir	0.75	Y = 0.5979X + 498.33	Data extension applied to water years 1984 - 1985 and 1988 - 1990

2.3.2 Hydrologic Condition

The thirty year 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. A surface water hydrology database was developed to represent dry year, normal year, and wet year hydrologic conditions. Consequently, the annual streamflows at key gages with complete data records 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 (**Table 2.3-3**).

Table 2.3-4 displays the results of this analysis graphically. This figure was then used to select the water years which indicated dry, normal, and wet hydrologic conditions across the study area. Based upon this review and analysis, the years selected as representative of dry, normal, and wet year conditions are presented in **Table 2.3-5**. Average monthly flows were then computed using the results of this analysis as summarized in **Table 2.3-6**.

Table 2.3-3 Determination of Hydrologic Condition at Indicator Gages

Rank	Weibull Plotting Position	CHEYENNE R AT EDGEMONT,SD 06395000		LITTLE POWDER RIVER AB DRY CREEK, NEAR WESTON, WY 06324970		POWDER RIVER AT ARVADA, WY 06317000		Powder River at Moorhead MT 06324500		Tongue R at Birney Day School Br nr Birney MT 06307616	
1	3.23%	2006	5,846	1992	1,083	2004	63,352	2004	85,205	2002	96,520
2	6.45%	2007	6,517	2002	1,206	2002	80,389	2001	108,909	2004	109,472
3	9.68%	2004	6,607	2004	1,425	2006	85,933	1989	115,501	2006	119,436
4	12.90%	1988	8,723	1991	2,902	1989	93,212	2006	119,003	2001	132,919
5	16.13%	2002	9,167	1989	2,919	2001	93,728	2002	119,099	1989	147,924
6	19.35%	1992	9,413	2000	3,550	1985	98,884	1985	158,824	1985	179,863
7	22.58%	2005	12,037	1988	4,006	1988	113,008	1988	196,277	1987	209,154
8	25.81%	1985	12,833	1980	4,151	1981	117,191	1980	204,386	2003	230,693
9	29.03%	1989	17,080	1981	4,412	1992	121,481	2003	210,248	2000	239,614
10	32.26%	1990	22,882	2001	5,729	2003	125,123	1994	225,151	1982	239,888
11	35.48%	1981	27,859	2005	5,905	2000	127,066	1979	229,624	1988	239,990
12	38.71%	2003	31,051	2003	5,945	2005	127,746	2000	232,684	1994	250,907
13	41.94%	2000	31,448	2006	6,932	1994	131,969	2005	245,095	1980	253,769
14	45.16%	1980	32,977	1985	6,950	1980	133,554	2007	252,408	2005	258,178
15	48.39%	1983	39,749	1998	7,780	1990	137,268	1992	252,587	1992	264,363
16	51.61%	2001	40,466	1979	7,953	2007	148,987	1990	255,427	1998	268,546
17	54.84%	1995	43,404	1990	10,058	1986	166,429	1982	259,974	1979	271,913
18	58.06%	1994	45,626	1987	11,882	1991	174,643	1981	262,402	1981	275,357
19	61.29%	2008	46,101	1983	13,619	1996	183,391	1986	276,360	1986	292,716
20	64.52%	1996	52,134	1986	13,885	1979	212,007	1996	334,956	1991	304,479
21	67.74%	1998	54,222	1993	17,650	1982	217,158	1983	345,357	1990	305,480
22	70.97%	1979	61,681	1982	19,216	1997	225,125	1987	350,930	1993	315,708
23	74.19%	1982	62,755	1999	19,246	1998	227,959	1991	354,800	1983	316,378
24	77.42%	1987	64,257	1994	21,029	1983	239,510	1998	364,774	1999	340,058
25	80.65%	1993	68,163	1984	24,536	1987	243,957	1993	422,531	1996	352,755
26	83.87%	1997	69,178	2008	28,541	2008	265,798	1997	440,424	2007	372,728
27	87.10%	1986	73,170	2007	36,170	1993	273,488	1984	476,639	1997	408,810
28	90.32%	1984	74,526	1997	39,305	1984	274,313	1999	507,558	2008	420,989
29	93.55%	1999	104,860	1996	40,535	1999	310,103	2008	525,740	1995	446,057
30	96.77%	1991	133,016	1995	41,091	1995	460,138	1995	575,624	1984	467,632

Table 2.3-4 Summary of Hydrologic Condition at Indicator Gages

Station Number	Station Name	Water Year																													
		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
06307616	Tongue River at Birney Day School Br nr Birney, MT						Wet	Dry				Dry						Wet	Wet	Wet				Dry	Dry		Dry		Dry	Wet	Wet
06317000	Powder River at Arvada, WY						Wet	Dry		Wet		Dry				Wet		Wet				Wet		Dry	Dry		Dry		Dry		Wet
06324500	Powder River at Moorhead, MT						Wet	Dry				Dry				Wet		Wet		Wet		Wet		Dry	Dry		Dry		Dry		Wet
06324970	Little Powder River ab Dry Creek, near Weston, WY						Wet					Dry		Dry	Dry			Wet	Wet	Wet			Dry		Dry		Dry			Wet	Wet
06395000	Cheyenne R at Edgemont, SD						Wet		Wet		Dry			Wet	Dry	Wet				Wet		Wet			Dry		Dry		Dry	Dry	

Wet
Normal
Dry

Table 2.3-5 Results of Hydrologic Condition Evaluation

Year	Hydrologic Condition	Year	Hydrologic Condition
1979	Normal	1994	Normal
1980	Normal	1995	Wet
1981	Normal	1996	Normal
1982	Normal	1997	Wet
1983	Normal	1998	Normal
1984	Wet	1999	Wet
1985	Dry	2000	Normal
1986	Normal	2001	Dry
1987	Normal	2002	Dry
1988	Normal	2003	Normal
1989	Dry	2004	Dry
1990	Normal	2005	Normal
1991	Normal	2006	Dry
1992	Normal	2007	Normal
1993	Wet	2008	Wet

Table2.3-6 Mean Monthly Streamflow for the Dry and Normal Hydrologic Condition

	Antelope Creek Near Teckla, WY	Little Powder River above Dry Creek Near Weston, WY	Belle Fourche River Below Moorcroft, WY	Cheyenne River Near Spencer, WY	Powder River at Arvada, WY	Dry Fork Cheyenne River Near Bill, WY	Clear Creek near Arvada, WY	Crazy Woman Creek at Upper Sta, near Arvada, WY	Powder River near Moorhead, MT	Tongue River at Birney Day School, Near Birney, MT
Station Number:	6364700	6324970	6426500	6386500	6317000	6365300	6324000	6316400	6324500	6307616
Month	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
DRY YEAR CONDITION										
Oct	3	118	212	98	4,639	1	2,655	244	9,756	10,500
Nov	4	78	314	160	6,228	3	2,703	460	9,978	8,940
Dec	6	70	389	114	5,884	4	2,155	553	8,020	8,529
Jan	5	77	326	67	5,971	2	2,298	441	8,702	8,332
Feb	8	229	456	26	5,367	10	1,947	540	7,643	7,153
Mar	99	1,348	1,745	523	16,811	14	2,931	1,174	19,750	8,396
Apr	99	466	1,069	301	12,354	10	3,413	1,392	17,337	10,790
May	166	476	935	2,683	13,126	16	3,656	3,748	14,163	14,298
Jun	73	189	566	1,118	5,166	15	3,580	4,583	6,973	15,181
Jul	145	383	340	290	5,202	2	2,006	1,379	5,934	17,719
Aug	89	663	240	1,836	2,446	5	1,178	448	4,740	12,716
Sep	2	97	249	22	2,722	0	1,968	148	4,763	8,468
NORMAL YEAR CONDITION										
Oct	11	265	419	348	9,158	4	5,561	949	16,099	13,950
Nov	15	196	306	567	9,165	9	5,377	1,154	14,419	12,677
Dec	24	146	274	418	6,705	10	4,601	1,180	10,047	10,726
Jan	21	233	340	244	6,776	5	4,240	1,061	10,737	10,403
Feb	34	2,264	1,345	95	11,172	29	3,485	1,145	17,298	10,769
Mar	416	2,716	3,627	1,938	21,065	38	5,457	2,492	29,521	14,422
Apr	433	1,014	1,228	1,117	19,501	29	5,621	1,938	26,240	16,806
May	606	2,499	2,309	10,112	32,854	42	13,937	4,668	50,187	42,642
Jun	304	1,401	1,333	4,184	26,253	50	17,190	7,118	54,069	65,801
Jul	572	571	1,008	1,088	11,137	6	7,225	2,596	20,020	32,961
Aug	363	275	414	5,760	5,107	14	5,060	678	10,242	24,651
Sep	8	314	323	83	4,908	1	5,696	395	10,759	19,020

2.4 Stream Water Quality

Surface water quality of study area streams was characterized using data obtained from the USGS (Kirk Miller, Pers. Communication, 2012). Estimates of mean monthly SAR and EC values were computed for each of the ten watersheds. Data collected for each watershed was sorted by month and arithmetic means computed for each month. **Table 2.4-1** summarizes the results of this effort. **Appendix 2C** contains the database obtained from the USGS.

Table 2.4-1 Mean Monthly Stream EC and SAR Values

	Antelope Creek Near Teckla, WY	Belle Fourche River Below Moorcroft, WY	Cheyenne River Near Spencer, WY	Powder River at Arvada, WY	Little Powder River above Dry Creek Near Weston, WY	Dry Fork Cheyenne River Near Bill, WY	Clear Creek near Arvada, WY	Crazy Woman Creek near Arvada, WY	Powder River near Moorhead, MT	Tongue River at Stateline near Decker, MT
Month	6364700	6426500	6386500	6317000	6324970	6365300	6324000	6316400	6324500	6306300
Sodium Adsorption Ratio (SAR)										
Jan	2.79	6.68	10.64	6.02	7.71	0.98	1.29	1.86	4.44	0.70
Feb	2.82	5.53	8.03	5.69	6.17	0.92	1.35	1.71	4.15	0.79
Mar	2.80	3.98	7.77	5.43	4.65	0.82	1.30	1.76	4.62	0.90
Apr	3.11	4.67	9.94	5.66	6.01	1.00	1.32	2.28	4.73	0.84
May	3.27	4.36	7.86	4.83	6.19	1.11	1.13	2.04	4.10	0.47
Jun	3.13	4.57	7.46	4.44	6.15	0.92	0.96	1.43	3.29	0.40
Jul	2.61	4.76	6.08	6.56	6.18	1.40	1.36	2.07	3.85	0.67
Aug	2.35	5.17	5.69	7.22	5.96	0.80	1.62	2.20	4.16	1.02
Sep	2.35	6.41	9.49	9.42	6.79	0.90	1.51	2.76	4.13	0.82
Oct	2.57	6.20	11.15	7.28	6.13	1.05	1.34	2.42	4.59	0.75
Nov	2.95	6.21	10.32	6.09	6.95	1.14	1.27	2.00	4.46	0.75
Dec	2.98	6.78	11.05	6.29	7.96	1.05	1.30	1.92	4.30	0.75
Average	**2.81**	**5.44**	**8.79**	**6.24**	**6.40**	**1.01**	**1.31**	**2.04**	**4.24**	**0.74**
Electrical Conductivity (EC)										
Jan	2708	3567	5113	2388	3229	1830	1074	1623	1995	659
Feb	2684	2916	3558	2237	2557	1800	1092	1334	1698	697
Mar	2459	1738	3674	2079	1836	1592	1018	1234	1891	728
Apr	2814	2228	4376	2244	2664	1788	1024	1641	1961	699
May	2698	1941	3152	1734	2538	1723	789	1467	1524	368
Jun	2689	2310	2544	1714	2537	1632	568	1007	1308	318
Jul	2238	2063	1749	2893	2448	No available data	976	1593	1807	504
Aug	1693	2142	1722	3033	2470	1285	1274	1774	2175	740
Sep	2185	2496	3993	3438	3147	1150	1221	2036	2013	682
Oct	2307	2525	4953	2590	2684	1775	1055	1994	1986	678
Nov	2789	2592	5158	2343	3125	2098	1122	1621	1925	703
Dec	2841	3433	5884	2570	3874	2020	1109	1612	2108	693
Average	**2508.62**	**2495.83**	**3823.02**	**2438.61**	**2759.05**	**1699.27**	**1026.88**	**1578.01**	**1865.88**	**622.45**

2.5 CBNG Well Production Water Quantity

Production water from existing and projected CBNG wells was obtained from the Phase II Task 2 Report for the Powder River Basin Coal Review (AECOM, 2011a). Sources for these data included, but were not limited to, an oil and gas production and well history database by IHS Energy Services (IHS, 2010) and a data provided by the Wyoming Oil and Gas Conservation Commission (WOGCC, 2010). **Appendix 2D** was extracted from the Phase II Task 2 Report. CBNG-related water is managed in several methods. For the purposes of this study, CBNG-related water discharged to unlined on-channel containment or discharged directly to surface drainages was assumed to potentially impact surface water quality (**Table 2.5-1**).

Table 2.5-1 CBNG –Related Water Production Discharge

Sub-Basin	Gage	Annual CBNG-Related Disposal (1)					
		2008		2020		2030	
		(mmgpy)	(cfs)	(mmgpy)	(cfs)	(mmgpy)	(cfs)
Antelope Creek	6364700	594	2.5	1,679	7.1	584	2.5
Dry Fork Cheyenne River	6365300	100	0.4	-	0.0	349	1.5
Little Powder River	6324970	2,276	9.6	528	2.2	215	0.9
Upper Belle Fourche River	6426500	2,352	10.0	943	4.0	186	0.8
Upper Cheyenne River	6386500	103	0.4	84	0.4	1	0.0
Upper Powder River	6317000	14,223	60.3	8,093	34.3	3,489	14.8
Clear Creek	6324000	-	-	-	-	-	-
Crazy Woman Cree	6316400	30	0.1	143	0.6	474	2.0
Middle Powder River	6324500	2,341	9.9	757	3.2	177	0.8
Upper Tongue River	6307616	629	2.7	173	0.7	528	2.2

2.6 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, 2003). In addition, the Wyoming DEQ/WQD (2006) provided pertinent, and more recent water quality data to AECOM from a Microsoft Access data base relevant to the effluent water quality from CBNG wells in all watersheds. 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. Using a Geographic Information System (GIS), the location of each well was plotted based upon the latitude and longitude included within the WDEQ database. Using watershed boundaries delineated by the USGS, wells within each watershed were selected. Then, for each watershed, mean EC and SAR values were computed as the arithmetic mean of all EC and SAR data collected within each respective watershed. **Table 2.6-1** presents the results of the analysis related to CBNG discharge water quality.

Note that there were no samples available characterizing EC of CBNG-related discharge water quality within the Clear Creek watershed. Consequently, EC values for Crazy Woman Creek (adjoining watershed) were used to characterize Clear Creek water quality.

Table 2.6-1 CBNG-Related Water Quality

	Belle Fourche River Below Moorcroft, WY	Antelope Creek Near Teckla, WY	Cheyenne River Near Spencer, WY	Powder River at Arvada, WY	Clear Creek near Arvada, WY	Crazy Woman Creek near Arvada, WY	Powder River near Moorhead, MT	Little Powder River above Dry Creek Near Weston, WY	Tongue River at Stateline near Decker, MT	Dry Fork Cheyenne River Near Bill, WY
	6426500	6364700	6386500	6317000	6324000	6316400	6324500	6324970	6306300	6365300
Statistic	**Sodium Adsorption Ratio (SAR)**									
Mean	8.83	7.68	8.08	21.70	1717.62	26.98	27.74	10.66	40.22	6.68
Standard Error	0.21	0.25	1.19	0.49	29.36	2.79	2.53	0.36	1.07	0.10
Median	8	7	6.1	17	1695	25.65	23.5	10.2	35.3	6.5
Mode	6.9	6.8	6.2	11.3	1700	N/A	19.4	9	22.9	6.5
Standard Deviation	19.50	9.14	28.51	37.73	382.83	7.89	70.19	17.80	18.82	0.57
Sample Variance	380.4	83.5	812.7	1423.5	146562.0	62.2	4927.2	317.0	354.3	0.3
Kurtosis	2325.0	454.2	405.9	296.5	17.8	-2.4	549.8	1903.8	-1.2	0.4
Skewness	44.2	21.0	19.2	15.8	2.6	0.1	22.3	42.1	0.3	0.4
Range	1159.28	220	631.5	1000	3843	17.2	1810	837	76.5	2.5
Minimum	0.72	0	0.5	0	687	18.6	0	0	0.7	5.3
Maximum	1160	220	632	1000	4530	35.8	1810	837	77.2	7.8
Sum	77393.01	10612.1	4648.3	127173.45	291996	215.8	21272.8	26354.42	12507.1	200.4
Count	8764	1381	575	5861	170	8	767	2473	311	30
Confidence Level(95.0%)	0.41	0.48	2.34	0.97	57.96	6.59	4.98	0.70	2.10	0.21
Statistic	**Electrical Conductivity (EC)**									
Mean	1095.29	942.07	804.00	2182.98	No EC Data were available for Clear Creek watershed CBNG Wells	2177.90	1929.05	1482.10	1948.09	720.25
Standard Error	3.32	9.38	7.95	11.44		257.54	18.34	7.14	14.78	37.82
Median	1060	845	719	1940		1940	1880	1470	1870	714
Mode	1020	1140	1030	1520		N/A	1820	1480	1830	723
Standard Deviation	350.65	365.97	210.77	997.23		1151.74	688.35	458.14	394.47	213.94
Sample Variance	122953.2	133933.0	44424.7	994472.7		1326502.8	473822.7	209892.0	155610.2	45769.2
Kurtosis	39.2	3.0	0.8	19.0		6.0	547.2	123.8	3.1	2.5
Skewness	2.3	1.3	0.9	2.0		2.0	18.4	7.0	-0.2	1.5
Range	9889	3017	1705	19800		5133	22320	11299.8	3097	845
Minimum	0	363	0	0		897	0	1.2	83	465
Maximum	9889	3380	1705	19800		6030	22320	11301	3180	1310
Sum	12199314.16	1433827	565215.4	16577583.88		43558	2718026.4	6104777.26	1387042	23048
Count	11138	1522	703	7594		20	1409	4119	712	32
Confidence Level(95.0%)	6.51	18.40	15.61	22.43		539.03	35.97	14.00	29.02	77.13

2.7 Conveyance Loss

Information contained in the Powder River Basin Coal Review Impoundment Study report (AECOM 2011b) indicated the following:

"CBNG wells are regulated by the WOGCC as oil and gas wells and by the WSEO as water production wells. In the Wyoming PRB, CBNG-produced water primarily is discharged to ephemeral drainages/on-channel impoundments or off-channel impoundments, with discharge to playas or through injection used to a lesser degree in some locations of the basin. CBNG water discharge is regulated by the WDEQ for both quantity and quality. On public lands administered by the BLM, CBNG development also is regulated by the BLM through permit requirements associated with applications for permit to drill (APDs) and NEPA analyses. The BLM also regulates CBNG wells and water discharge where public minerals are located beneath private lands. Potential CBNG-related impacts to shallow groundwater quality are regulated by the WDEQ (which requires compliance monitoring wells for all impoundments) and the BLM. WDEQ regulations for unlined on-channel and off-channel impoundments are presented in Guidance Document: Compliance Monitoring and Siting Requirements for Unlined Impoundments Receiving Coalbed Methane Produced Water (WDEQ – Water Quality Division [WQD] 2010b). The WDEQ regulations prohibit development of impoundments above Class I and Class II groundwater, thus limiting impoundments to areas where the shallow groundwater is not used for municipal or domestic consumption. The WOGCC has siting guidelines and permitting requirements for off-channel CBNG impoundments on fee or state leases. The WSEO regulates the design of on-channel impoundments due to the potential effects on water rights."

Table 2.7-1 presents the total number of CBNG-related impoundments as of 2009 and CBNG groundwater discharge volumes by method for base year 2008. These data are presented in the Impoundment Study report (AECOM 2011b) and Task 2 Report (AECOM 2011a), respectively.

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. Further discussion relative to conveyance loss studies in the study area and selection of an appropriate conveyance loss value for analysis purposes is presented in the PRB Coal Review Groundwater Model Protocol (AECOM 2011c).

Table 2.7-1
CBNG Impoundments and CBNG Groundwater Discharge by Method

Subwatershed	Total Number of CBNG Impoundments in 2009[1]	CBNG Groundwater Discharge by Method in 2008[2] (barrels per year)			
		Headwater Reservoir or Unliined Off-channel Containment	Unlined On-channel Containment or Direct Discharge	Playa Lake Containment	Injection
Antelope Creek	213	0	14,151,625	0	0
Clear Creek	64	11,033,462	0	0	1,091,221
Crazy Woman Creek	75	2,900,684	720,135	0	1,415,091
Dry Fork Cheyenne River	21	0	2,385,740	0	0
Little Powder River	416	1,831,271	54,194,172	171,682	1,030,090
Middle Powder River	242	0	55,736,256	0	0
Salt Creek	2	0	180	0	22,273
Upper Belle Fourche River	674	56,061	56,004,665	0	0
Upper Cheyenne River	25	0	2,449,880	3,355,522	0
Upper Powder River	2,050	5,247,699	338,651,505	699,693	5,247,699
Upper Tongue River	309	80,427,040	16,487,543	1,608,541	2,010,676
Total	**4,091**	**101,496,216**	**540,781,700**	**5,835,438**	**10,817,050**

[1] Reflects the total number of on-channel and off-channel impoundments in the Wyoming PRB as identified in the Impoundment Study report (AECOM 2011b).
[2] Discharge volumes based on 2008 annual CBNG groundwater production provided by BLM (2011) and subwatershed-specific allocation rates as identified in the Task 2 report (AECOM 2011a).

2.8 Surface Water Quality Model

The mixing analysis integrated into the spreadsheet model is described in detail in **Appendix 2E**; this information was obtained from the technical report prepared by Greystone Environmental Consultants, Inc. and ALL Consulting (January 2003). The results of the spreadsheet modeling are presented in **Appendix 2F**.

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 Phase II Task 2 Report.

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 computed using streamflow data obtained from the USGS. Two hydrologic conditions were evaluated; a dry year study period and a normal year study period. The dry year analysis was utilized to evaluate the maximum likely impacts to surface water quality, assuming limited flow in the receiving streams.
4. Water quality data (SAR and EC) for ~~both~~ the CBNG groundwater discharge was obtained from the Wyoming Department of Environmental Quality, Water Quality Division.
5. Water quality data (SAR and EC) for the receiving drainages were obtained from the USGS.
6. 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.
7. Monthly estimates of stream water quality before and after mixing with the CBNG groundwater are determined to support a comparative evaluation of EC and SAR and also plotted on the Ayers-Westcot diagram to ascertain the impact on water for irrigation.

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 2E**, 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.

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 base year conditions (2008) and each of two future RFD scenarios for years 2020 and 2030 for both the dry and normal hydrologic conditions. These graphs include:

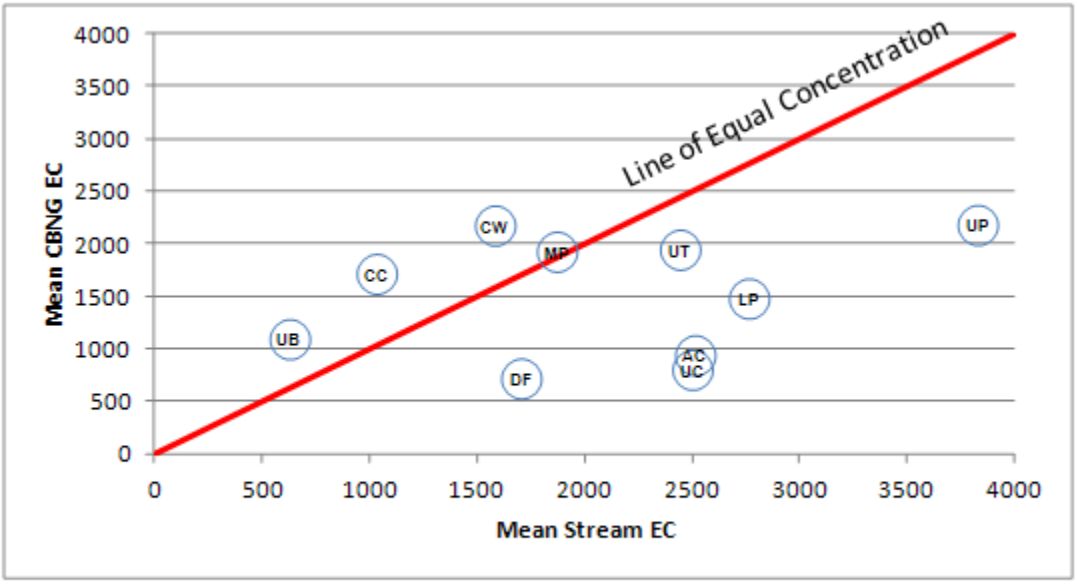
- illustration of EC for mean monthly flows before and after mixing with projected CBNG discharges;
- illustration of SAR for mean monthly flows before and after mixing with projected CBNG discharges; and an
- illustration of projected water quality (for irrigation purposes) for mean monthly flows for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

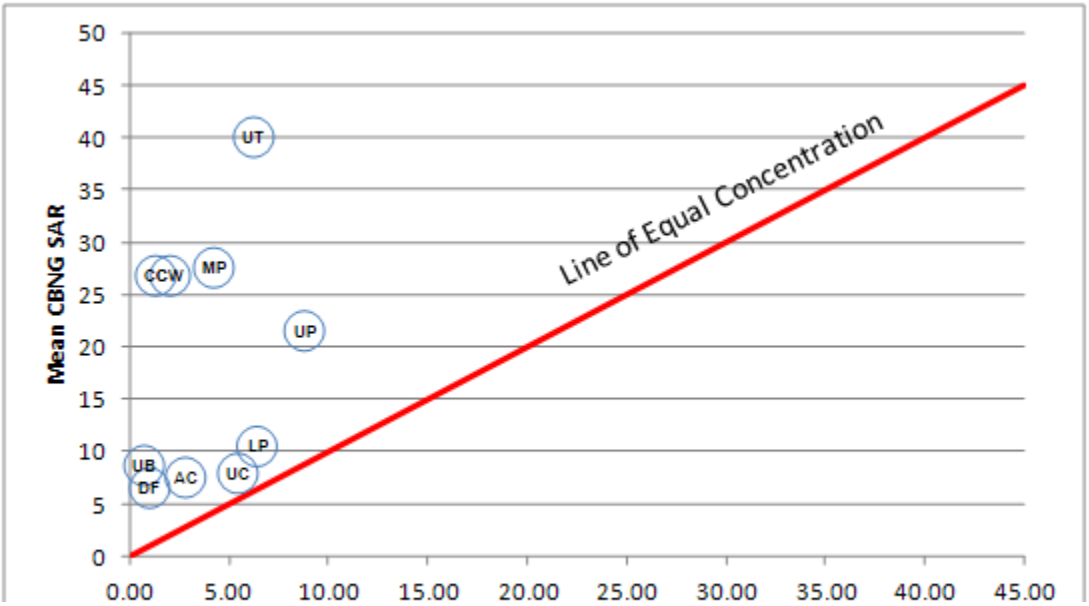
The first two graphs include lines depicting the pertinent stream standard to facilitate evaluation of the impacts (refer to Chapter 2 for discussions of sources for stream standards and all data used in the water quality evaluation). With respect to the third graph, water quality that meets the Ayers-Westcot threshold should fall 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. As indicated in **Figure 3.0-1**, mean CBNG discharge water EC levels are typically lower than the receiving waters. On the other hand, mean CBNG discharge water SAR levels were higher than the receiving waters in all cases. It should be noted that the CBNG discharge quantities are a function of production levels and not natural hydrologic functions. Therefore, the CBNG estimates are independent of hydrologic condition and are assumed to remain constant.

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. Impacts during high flow conditions are also important due to the potential dilution affects realized when mixing the CBNG discharge waters. Therefore, attention is also given to the impacts associated with the maximum monthly flow associated with the dry-year and normal-year hydrologic conditions. Detailed results of the comparative evaluation of all monthly flows associated with the dry-year and normal-year hydrologic conditions are presented in **Appendix 3A.**

Figure 3.0-1 Comparison of Mean Stream Water Quality to CBNG Water Quality





3.1 Antelope Creek

Results of the impacts to water quality in the Antelope Creek subwatershed under the base year condition and each of the two 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 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	10	2500	Sep	0.14	2.35	2185.00	0.80	7.68	942.07	0.94	6.88	1130.0
	2020							2.10			2.24	7.35	1021.0
	2030							0.70			0.84	6.78	1152.3
Maximum Stream Discharge	2008	10	2500	May	9.86	3.27	2697.7	0.80	7.68	942.07	10.66	3.60	2565.9
	2020							2.10			11.96	4.04	2389.4
	2030							0.70			10.56	3.56	2581.3
	Dry Year												
Minimum Stream Discharge	**2008**	**10**	**2500**	**Sep**	**0.03**	**2.35**	**2185.00**	0.80	**7.68**	**942.07**	0.83	7.49	987.4
	2020							**2.10**			**2.13**	**7.61**	**959.7**
	2030							0.70			0.73	7.46	993.6
Maximum Stream Discharge	2008	10	2500	May	2.70	3.27	2697.7	0.80	7.68	942.07	3.50	4.28	2296.6
	2020							2.10			4.80	5.20	1929.8
	2030							0.70			3.40	4.18	2336.4

Table 3.1-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically higher than those of Antelope Creek. Therefore, mixing of the two waters will generally raise SAR levels in Antelope Creek.
- CBNG discharge water EC levels are typically lower than those of Antelope Creek. Therefore, mixing of the two waters will generally reduce EC levels in Antelope Creek.

The peak CBNG discharge in the watershed is realized in RFD Scenario 2020 when 2.10 cfs is ultimately 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.

Ambient water quality periodically exceeds the stream standard for EC. As discussed above, the lower EC values of the CBNG discharge water will generally reduce the EC values of Antelope Creek. During normal hydrologic conditions, effects of mixing are reduced and stream standards may continue to be exceeded for the EC criteria.

Maximum environmental impacts would be anticipated during dry hydrologic conditions in the month of September when minimum monthly streamflows are experienced. For RFD Scenario 2020, the dry-year hydrologic conditions presented in **Table 3.1-1** illustrate the impacts associated with mixing 2.10 cfs of CBNG discharge water with 0.03 cfs of receiving water. At these flow rates, the CBNG discharge water dominates the quality of the mixed water. The combined streamflow of approximately 2.13 cfs reflects a resultant water quality, associated with the minimum monthly flow that appears to be adequate to meet the stream standard for both SAR and EC.

In the following sections, specific impacts related to mixing CBNG discharge waters with Antelope Creek receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.1.1 Antelope Creek: Base Year Conditions (2008)

The results of the water quality impact assessment under base year (2008) conditions and each RFD Scenario 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
  - Mean monthly EC values in Antelope Creek exceed stream standards during seven months of the year (Jan, Feb, Apr, May, Jun, Nov, and Dec) under base year (2008) conditions.
  - Mean monthly SAR values in Antelope Creek do not exceed stream standards during the entire year under base year (2008) conditions.
- <u>Following Mixing</u>
  - During normal hydrologic conditions, the lower EC values of the CBNG discharge water reduce stream EC sufficiently to meet stream standards for all months except April and May.

During dry year conditions, the higher relative proportion of CBNG discharge water results in a dilution of Antelope Creek EC values to the point where stream standards are not exceeded the entire year.

- The resultant SAR values increase but continue to meet stream standards for both hydrologic conditions.

- Ayers and Westcot Diagram
  - For both the dry-year and normal-year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the dry and normal year conditions, the data indicate a significant reduction in infiltration following mixing with CBNG production water.
  - Following mixing during the dry year conditions, irrigation season water would be unsuitable for irrigation purposes during the months of September and October and the non-irrigation months of November, December, January and February.
  - Following mixing during normal year hydrologic conditions, the irrigation suitability threshold would be exceeded during the irrigation season months of September and October.

3.1.2 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, 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 2020, the observations presented below are based on the information presented in these figures.

This RFD scenario involves the maximum CBNG production water of the scenarios evaluated.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.1.1.
- Following Mixing
  - During normal hydrologic conditions, the resultant EC values decrease sufficiently to meet the stream standard for EC for both the dry year and normal year.
  - The resultant SAR values increase but continue to meet the stream standard for SAR for both hydrologic conditions.

- Ayers and Westcot Diagram
  - For both the dry and normal year conditions, the data indicate a significant reduction in infiltration following mixing with CBNG production water.
  - Following mixing during the dry year conditions, irrigation season water would be unsuitable for irrigation purposes during the months of September and October and the non-irrigation months of November, December, January and February.
  - Following mixing during normal year hydrologic conditions, the irrigation suitability threshold would be exceeded during the irrigation season months of September and October and the non-irrigation season months of November, December, and January.

3.1.3 Antelope Creek: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.1.1.
- Following Mixing
  - During normal hydrologic conditions, the lower EC values of the CBNG discharge water reduce stream EC, however the stream standard would continue to be exceeded during the irrigation season months of April and May. During dry year conditions, mixing with CBNG discharge water would reduce EC to levels below the stream standard for the entire year.
  - The resultant SAR values increase but continue to meet the pertinent stream standard for SAR for both hydrologic conditions.
- Ayers and Westcot Diagram
  - For both the dry and normal year conditions, the data indicate a significant reduction in infiltration following mixing with CBNG production water.
  - Following mixing during the dry year conditions, irrigation season water would be unsuitable for irrigation purposes during the months of September and October and the non-irrigation months of November, December, January and February
  - Following mixing during normal year hydrologic conditions, the irrigation suitability threshold would be exceeded during the irrigation season months of September and October.

3.2 Dry Fork Cheyenne River

Results of the impacts to water quality in the Dry Fork Cheyenne River subwatershed under the base year condition and each of the two 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 hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.2-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.2-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically higher than those of the Dry Fork Cheyenne River. Therefore, mixing of the two waters will generally raise SAR levels in Dry Fork Cheyenne River.
- CBNG discharge water EC levels are typically lower than those of Dry Fork Cheyenne River. Therefore, mixing of the two waters will generally reduce EC levels in Dry Fork Cheyenne River.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	10	2500	Sep	0.01	0.90	1150	0.10	6.68	720.25	0.11	5.96	774
	2020							0.00			0.01	0.90	1150
	2030							0.44			0.45	6.50	734
Maximum Stream Discharge	2008	10	2500	Jun	0.84	0.92	1632	0.10	6.68	720.25	0.94	1.53	1535
	2020							0.00			0.84	0.92	1632
	2030							0.44			1.28	2.90	1318
	Dry Year												
Minimum Stream Discharge	**2008**	**10**	**2500**	**Sep**	**0.01**	**0.90**	**1150.00**	0.10	**6.68**	**720.25**	0.11	6.40	740.9
	2020							0.00			0.01	0.90	1150.0
	2030							**0.44**			**0.45**	**6.61**	**725.1**
Maximum Stream Discharge	2008	10	2500	May	0.27	1.11	1722.5	0.10	6.68	720.25	0.37	2.63	1449.2
	2020							0.00			0.27	1.11	1722.5
	2030							0.44			0.71	4.58	1098.5

No CBNG discharge is anticipated for the RFD 2020 scenario as indicated in Table 3.2-1. The peak CBNG discharge in the watershed is realized for RFD Scenario 2030 when 0.44 cfs is conveyed into the Dry Fork Cheyenne River. Under both the RFD 2020 and 2030 scenarios, resulting stream water quality after mixing is roughly equivalent to that of the CBNG discharge water due to the low or non-existing stream flows. For RFD Scenario 2020, the dry-year hydrologic conditions presented in **Table 3.2-1** illustrate the fact that there would be no CBNG discharge water and minimal streamflow.

For RFD Scenario 2030, the dry-year hydrologic conditions presented in **Table 3.2-1** illustrate the impacts associated with mixing 0.01 cfs (September) of streamflow in the Dry Fork Cheyenne River with 0.44 cfs of CBNG well discharge water on both SAR and EC. The resultant streamflow consists almost entirely of CBNG produced water. The resulting EC would decrease, whereas the SAR would increase.

During normal-year hydrologic conditions, maximum mean monthly streamflow occurs in the month of June when 0.84 cfs occurs. In these conditions, the effects of mixing are less pronounced due to the higher proportion of receiving water. The pertinent stream standard would be anticipated to be met in both hydrologic conditions for each RFD scenarios.

In the following sections, specific impacts related to mixing CBNG discharge waters with Dry Fork Cheyenne River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.2.1 Dry Fork Cheyenne River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year 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 would occur in this subwatershed in 2020. Given the information in the referenced figures, the observations presented below represent the existing water quality in the river for both hydrologic conditions.

Summary of Impacts

- <u>Before mixing</u>
    - Under base year (2008) conditions, Mean monthly EC values in the Dry Fork Cheyenne River meet the pertinent stream standard for all months of both the dry-year and normal-year hydrologic conditions.
    - Mean monthly SAR values in the Dry Fork Cheyenne River meet the pertinent stream standard for all months of both the dry-year and normal-year hydrologic conditions under base year (2008) conditions.

- Following mixing
  - Following mixing, the lower EC values associated with the CBNG discharge water will reduce the EC levels in the Dry Fork Cheyenne River. Consequently, the pertinent stream standard will continue to be met for all months of both the dry-year and normal-year conditions.
  - Following mixing, the higher SAR values associated with the CBNG discharge water will increase SAR levels in the Dry Fork Cheyenne River. The increased SAR levels are not expected to exceed the pertinent stream standard for all months of both the dry-year and normal-year conditions.
- Ayers Wescott Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - The data indicate that following mixing with CBNG production water, infiltration will decrease. Under normal hydrologic conditions, the irrigation suitability threshold will be exceeded in September. During dry-year hydrologic conditions, the irrigation suitability threshold will be exceeded in four months (Jan, Jul, Sep, and Oct).

3.2.2 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**. Under the RFD Scenario 2020 conditions, no CBNG production water would occur. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.2.1.
- Following Mixing
  - No CBNG discharge water. Therefore results are the same as the base year condition before mixing (2008) presented in Section 3.2.1.
- Ayers and Westcot Diagram
  - No CBNG discharge water. Therefore results are the same as the base year condition before mixing (2008) presented in Section 3.2.1.

3.2.3 Dry Fork Cheyenne River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.2.1.
- Following Mixing
  - Following mixing, the lower EC values associated with the CBNG discharge water will reduce the EC levels in the Dry Fork Cheyenne River. Consequently, the pertinent stream standard will continue to be met for all months of both the dry-year and normal-year conditions.
  - Following mixing, the higher SAR values associated with the CBNG discharge water will increase SAR levels in the Dry Fork Cheyenne River. The increased SAR levels are not expected to exceed the pertinent stream standard for all months of both the dry-year and normal-year conditions.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - Following mixing, infiltration could be expected to decrease significantly in both the dry and normal year hydrologic conditions. Under the normal hydrologic condition, the irrigation suitability threshold would be exceeded in seven months (January and July through October). In the dry hydrologic condition, the irrigation suitability threshold would be exceeded in ten months (January through April and August through December).

3.3 Little Powder River

Results of the impacts to water quality in the Little Powder River subwatershed under the base year condition and each of the two 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 hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.3-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be

realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.3-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically higher than those of the Little Powder River. Therefore, mixing of the two waters will generally raise SAR levels in Little Powder River.
- CBNG discharge water EC levels are typically lower than those of Little Powder River. Therefore, mixing of the two waters will generally reduce EC levels in Little Powder River.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	6.5	2500	Dec	2.37	7.96	3874	2.90	10.66	1482.10	5.27	9.44	2559
	2020							0.70			3.07	8.57	3329
	2030							0.30			2.67	8.26	3606
Maximum Stream Discharge	2008	5	2000	Mar	44.17	4.65	1836	2.90	10.66	1482.10	47.07	5.02	1814
	2020							0.70			44.87	4.75	1830
	2030							0.30			44.47	4.69	1833
	Dry Year												
Minimum Stream Discharge	**2008**	**6.5**	**2500**	**Dec**	**1.14**	**7.96**	**3874.09**	**2.90**	**10.66**	**1482.10**	**4.04**	**9.89**	**2158.5**
	2020							0.70			1.84	8.98	2965.7
	2030							0.30			1.44	8.52	3376.9
Maximum Stream Discharge	2008	5	2000	Mar	21.92	4.65	1835.50	2.90	10.66	1482.10	24.82	5.35	1794.2
	2020							0.70			22.62	4.84	1824.6
	2030							0.30			22.22	4.73	1830.7

The peak CBNG discharge in the watershed is realized for RFD Scenario 2008 when 2.90 cfs is ultimately 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.

Ambient water quality periodically exceeds the stream standard for EC. As discussed above, the lower EC values of the CBNG discharge water will generally reduce the EC values of the Little Powder River. Depending upon the relative magnitudes of the flows, the pertinent stream standards may continue to be exceeded.

Maximum environmental impacts would be anticipated during dry hydrologic conditions in the month of December when minimum monthly streamflows are experienced. For base year 2008, the dry-year hydrologic conditions presented in **Table 3.3-1** illustrate the impacts associated with mixing 2.90 cfs of

CBNG discharge water with 1.14 cfs of receiving water. At these flow rates, the CBNG discharge is of a similar magnitude to the receiving water but the EC levels are not low enough to lower the mixed water EC levels below the pertinent stream standard in the normal-year hydrologic condition. During dry-year hydrologic conditions, the magnitude of the CBNG discharge is great enough to dilute the EC levels in the Little Powder River to levels below the standard.

With respect to SAR, the data indicate that levels are exceeded in the Little Powder River during the minimum flow months of November, December and January. Elevated SAR levels in the CBNG discharge water raise the Little Powder River SAR further and the stream standard would continue to be exceeded in both the dry-year and normal-year hydrologic conditions.

In the following sections, specific impacts related to mixing CBNG discharge waters with the Little Powder River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.3.1 Little Powder River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
  - Mean monthly EC values in the Little Powder River exceed the pertinent stream standard for all months of the year except for the month of March under base year conditions (2008).
  - Mean monthly SAR values in the Little Powder River exceed the pertinent stream standard for all months of the year except February and March under base year conditions (2008).
- <u>Following Mixing</u>
  - For the dry-year hydrologic condition, the resultant EC values decrease in all months but continue to exceed the pertinent stream standard for EC for the majority of the year (except for February, March, and October).
  - For the normal-year hydrologic condition, resultant EC values would be expected to decrease in a manner similar to the dry-year. EC stream standard would be exceeded in seven months (April through September and December).

- The resultant SAR values increase and exceed the pertinent standard for SAR in all months of both hydrologic conditions.

- Ayers and Westcot Diagram
  - For both the dry-year and normal-year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the normal the dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water. Following mixing, the irrigation suitability threshold is not exceeded during any months.
  - Under normal-year conditions, the data also indicate a decrease in infiltration following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.3.2 Little Powder River: RFD Scenario 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.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.3.1.
- Following Mixing
  - For the dry-year hydrologic condition, the resultant EC values decrease in all months but continue to exceed the pertinent stream standard for EC for all months except February and March.
  - For the normal-year hydrologic condition, resultant EC values would be expected to decrease yet to a much lower extent than in the dry-year hydrologic condition. Under this hydrologic condition, the pertinent EC stream standard would be exceeded the entire year with the exception of March.
  - The resultant SAR values increase and exceed the pertinent standard for SAR in all months except March of both hydrologic conditions.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.

- For both the normal the dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water. Following mixing, the irrigation suitability threshold is not exceeded during any months.
- Under normal-year conditions, the data also indicate a decrease in infiltration following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.3.3 Little Powder River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.3.1.
- Following Mixing
  - For the dry-year hydrologic condition, the resultant EC values decrease in all months but continue to exceed the pertinent stream standard for EC for all months except February and March.
  - For the normal-year hydrologic condition, resultant EC values would be expected to decrease yet to a lower extent than in the dry-year hydrologic condition. Under this hydrologic condition, the pertinent EC stream standard would be exceeded the entire year with the exception of March.
  - The resultant SAR values increase and exceed the pertinent standard for SAR in all months except March of both hydrologic conditions.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the normal and dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water. Following mixing, the irrigation suitability threshold is not exceeded during any months.
  - Under normal-year conditions, the data also indicate a decrease in infiltration following mixing with CBNG production water; overall, the data indicate 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 base year condition and each of the two 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 hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.4-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.4-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically higher than those of the Upper Belle Fourche River. Therefore, mixing of the two waters will generally raise SAR levels in Upper Belle Fourche.
- CBNG discharge water EC levels are typically lower than those of Upper Belle Fourche River. Therefore, mixing of the two waters will generally reduce EC levels in Upper Belle Fourche.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	6	2500	Dec	4.45	6.78	3433	3.00	8.83	1095.29	7.45	7.61	2492
	2020							1.20			5.65	7.22	2937
	2030							0.20			4.65	6.87	3333
Maximum Stream Discharge	2008	6	2500	Mar	58.98	3.98	1738	3.00	8.83	1095.29	61.98	4.22	1707
	2020							1.20			60.18	4.08	1725
	2030							0.20			59.18	4.00	1736
	Dry Year												
Minimum Stream Discharge	**2008**	**6**	**2500**	**Oct**	**3.45**	**6.20**	**2524.74**	**3.00**	**8.83**	**1095.29**	**6.45**	**7.43**	**1860.0**
	2020							1.20			4.65	6.88	2155.9
	2030							0.20			3.65	6.35	2446.4
Maximum Stream Discharge	2008	6	2500	Mar	28.39	3.98	1738.13	3.00	8.83	1095.29	31.39	4.45	1676.7
	2020							1.20			29.59	4.18	1712.1
	2030							0.20			28.59	4.02	1733.6

The peak CBNG discharge in the watershed is realized in base year (2008) when 3.00 cfs is ultimately conveyed into the Upper Belle Fourche River. The quantity of water discharged into the Upper Belle

Fourche River would be less in the other RFD scenarios and would consequently result in a reduction in impacts to the existing water quality.

Ambient water quality periodically exceeds the stream standard for both EC and SAR. As discussed above, the lower EC values of the CBNG discharge water will generally reduce the EC values of the Upper Belle Fourche River while CBNG SAR will increase it. Consequently, the mixing with CBNG discharge water can tend to improve receiving water quality with respect to EC but degrade it with respect to SAR.

Maximum environmental impacts would be anticipated during dry hydrologic conditions in the month of October when minimum monthly streamflows are experienced. For base year 2008, the dry-year hydrologic conditions presented in **Table 3.4-1** illustrate the impacts associated with mixing 3.00 cfs of CBNG discharge water with 3.45 cfs of receiving water in the month of October. Prior to mixing, EC levels exceed the stream standard. Following mixing, the resultant water quality would be expected to meet pertinent stream standards with respect to EC. SAR levels exceed the stream standard in October prior to mixing, Following mixing, the SAR would increase and the standard continue to be exceeded.

In the following sections, specific impacts related to mixing CBNG discharge waters with the Upper Belle Fourche receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.4.1 Upper Belle Fourche River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
    - Mean monthly EC values in the Upper Belle Fourche River exceed the pertinent stream standard during the months of October through February under the base year (2008) condition.

    - Mean monthly SAR values in the Upper Belle Fourche River exceed the pertinent stream standard during the months of September through January.

- Following Mixing
  - The resultant EC values decrease sufficiently to limit the months when the pertinent stream standard is exceeded to only the months of January and February during normal-year hydrologic conditions. During dry-year hydrologic conditions, the pertinent standard for EC is exceeded in the months of December and January.
  - For the normal-year hydrologic condition, the resultant SAR values exceed the pertinent stream standard from August through January. During the dry-year hydrologic condition, the resultant SAR values exceed the pertinent stream standard from July through February.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the normal and dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.4.2 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.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.4.1.
- Following Mixing
  - The resultant EC values decrease following mixing with CBNG discharge water. Following mixing, the pertinent stream standard would be exceeded during the period of December through February in both the dry-year and normal-year hydrologic conditions.
  - The resultant SAR values increase slightly following mixing with CBNG discharge water. Following mixing, the pertinent stream standard would be exceeded during the period of September through January in the normal-year hydrologic condition and August through January in the dry-year hydrologic condition.

- Ayers and Westcot Diagram
  - For both the normal and dry-year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the normal and dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.4.3 Upper Belle Fourche River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.4.1.
- Following Mixing
  - In relation to the magnitude of the Upper Belle Fourche River streamflow (3.45 cfs at minimum dry-year streamflow), the CBNG discharge (0.20 cfs as indicated in Table 3.4-1) is minor in magnitude; consequently the impacts associated with this scenario are minimal.
  - The resultant EC values decrease slightly. The pertinent standard for EC is not exceeded during the irrigation season. During the non-irrigation season, the standard is exceeded during the months of November through February in both hydrologic conditions.
  - For both hydrologic conditions, the resultant SAR values exceed the pertinent stream standard from September through January.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For both the normal and dry year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.

- Under normal-year conditions, the data also indicate a decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.5 Upper Cheyenne River

Results of the impacts to water quality in the Upper Cheyenne River subwatershed under the base year condition and each of the two 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 hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.5-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.5-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are roughly equivalent to the Upper Cheyenne River water. Depending upon the month, the CBNG SAR level may be higher or lower than corresponding levels in the Upper Cheyenne River.
- CBNG discharge water EC levels are typically lower than those of Upper Cheyenne River. Therefore, mixing of the two waters will generally reduce EC levels in Upper Cheyenne River.

The peak CBNG discharge in the watershed is realized for the base year 2008 and RFD Scenario 2020 when 0.10 cfs is ultimately conveyed into the Upper Cheyenne River. In the RFD scenario 2030, effectively no water is discharged into the Upper Cheyenne River (1 mmgpy = 0.004 cfs)

Ambient water quality periodically exceeds the stream standard for both EC and SAR; particularly with respect to EC. As discussed above, the lower EC values of the CBNG discharge water will generally reduce the EC values of the Upper Cheyenne River while CBNG SAR impacts vary from month to month.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	10	2500	Sep	1.39	9.49	3993	0.10	8.08	804.00	1.49	9.39	3779
	2020							0.10			1.49	9.39	3779
	2030							0.00			1.39	9.49	3993
Maximum Stream Discharge	2008	10	2500	May	164.45	7.86	3152	0.10	8.08	804.00	164.55	7.86	3150
	2020							0.10			164.55	7.86	3150
	2030							0.00			164.45	7.86	3152
	Dry Year												
Minimum Stream Discharge	**2008**	**10**	**2500**	**Sep**	**0.37**	**9.49**	**3992.50**	**0.10**	**8.08**	**804.00**	**0.47**	**9.19**	**3320.9**
	2020							0.10			0.47	9.19	3320.9
	2030							0.00			0.37	9.49	3992.5
Maximum Stream Discharge	2008	10	2500	May	43.63	7.86	3151.91	0.10	8.08	804.00	43.73	7.86	3146.5
	2020							0.10			43.73	7.86	3146.5
	2030							0.00			43.63	7.86	3151.9

Maximum environmental impacts would be anticipated during dry hydrologic conditions in the month of September when minimum monthly streamflows are experienced. For base year 2008 and RFD Scenario 2020, the dry-year hydrologic conditions presented in **Table 3.5-1** illustrate the impacts associated with mixing 0.10 cfs of CBNG discharge water with 0.37 cfs of receiving water. The resultant water quality would be relatively unchanged.

In the following sections, specific impacts related to mixing CBNG discharge waters with the Upper Cheyenne River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.5.1 Upper Cheyenne River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
  - Mean monthly EC values in the Upper Cheyenne River exceed the pertinent stream standard for all months with the exception of two months during the irrigation season: July and August under base year (2008) conditions.
  - Under base year (2008) conditions, mean monthly values for SAR are less than the pertinent stream standard for most of the irrigation season; the standard is exceeded in October. During the non-irrigation season, the standard would be exceeded in November, December, and January.

- Following Mixing
  - The resultant EC values decrease slightly but continue to exceed the pertinent stream standard in the same months as before mixing during both the normal-year and dry-year hydrologic condition. The only months during which the standard is not exceeded would be July and August.
  - Following mixing, the SAR values would display the same pattern as before mixing. Mean monthly values for SAR would be less than the pertinent stream standard for most of the irrigation season; the standard would be expected to be exceeded in October. During the non-irrigation season, the standard would be expected to be exceeded in November, December, and January.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - The data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.5.2 Upper Cheyenne River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.5-1, 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.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.5.1.
- Following Mixing
  - The resultant EC values decrease slightly but continue to exceed the pertinent stream standard in the same months as before mixing during both the normal-year and dry-year hydrologic condition. The only months during which the standard is not exceeded would be July and August.
  - Following mixing, the SAR values would display the same pattern as before mixing. Mean monthly values for SAR would be less than the pertinent stream standard for most of the irrigation season; the standard would be expected to be exceeded in the months of April

and October. During the non-irrigation season, the standard would be expected to be exceeded in November, December, and January.

- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - The data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.5.3 Upper Cheyenne River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.5.1.
- Following Mixing
  - Effectively no CBNG production water is discharged to the stream as discussed above. Therefore, results are the same as the base year 2008 conditions before mixing presented in Section 3.5.1.
- Ayers and Westcot Diagram
  - Effectively no CBNG production water is discharged to the stream as discussed above. Therefore, results are the same as the base year 2008 conditions before mixing presented in Section 3.5.1.

3.6 Upper Powder River

Results of the impacts to water quality in the Upper Powder River subwatershed under the base year condition and each of the two 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 hydrologic condition and the normal-year hydrologic condition. The information in **Table 3.6-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact

analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.6-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically considerably higher than those of the Upper Powder River. Therefore, mixing of the two waters will generally raise SAR levels in the Upper Powder River.
- CBNG discharge water EC levels are typically lower than those of Upper Powder River. However, depending upon the specific month, the CBNG EC level may be higher or lower than corresponding levels in the Upper Powder River.

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

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	5	2000	Sep	82.48	9.42	3438	18.10	21.70	2182.98	100.58	11.63	3212
	2020							10.30			92.78	10.78	3299
	2030							4.40			86.88	10.04	3375
Maximum Stream Discharge	2008	5	2000	May	534.32	4.83	1734	18.10	21.70	2182.98	552.42	5.38	1749
	2020							10.30			544.62	5.15	1742
	2030							4.40			538.72	4.97	1738
	Dry Year												
Minimum Stream Discharge	**2008**	**5**	**2000**	**Aug**	**39.78**	**7.22**	**3033.26**	**18.10**	**21.70**	**2182.98**	**57.88**	**11.75**	**2767.4**
	2020							10.30			50.08	10.20	2858.4
	2030							4.40			44.18	8.66	2948.6
Maximum Stream Discharge	2008	5	2000	Mar	273.40	5.43	2079.05	18.10	21.70	2182.98	291.50	6.44	2085.5
	2020							10.30			283.70	6.02	2082.8
	2030							4.40			277.80	5.69	2080.7

The peak CBNG discharge in the watershed is realized for the base year conditions (i.e., 2008) when 18.10 cfs is ultimately conveyed into the Upper Powder River. The quantity of water discharged 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 2008, **Table 3.6-1** illustrates the impacts associated with mixing 39.78 cfs (occurring in the month of August) of streamflow in the Upper Powder River with 18.10 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC slightly decreases but remains above the pertinent stream standard. SAR is increased compared to existing stream water quality conditions. The combined streamflow of approximately

57.88 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to exceed the pertinent stream standard for both EC and SAR. It is important to note that the stream standards for both EC and SAR are exceeded prior to mixing with CBNG production water in the Upper Powder River.

In the following sections, specific impacts related to mixing CBNG discharge waters with Upper Powder River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.6.1 Upper Powder River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
  - Mean monthly EC values in the Upper Powder River exceeds the pertinent stream standard for most of the year, including the months of: March, April, July, August, September, October, and December under base year (2008) conditions.
  - Mean monthly SAR values in the Upper Powder River exceed the pertinent stream standard for half of the year, including the months of: March, April, and July through October under base year (2008) conditions.
- <u>Following Mixing</u>
  - The resultant EC values slightly decrease but continue to exceed the pertinent stream standard for December (non-irrigation season) and March, April, and July through October (irrigation season) in both the normal-year and dry-year hydrologic conditions.
  - The resultant SAR values would all increase following mixing. The pertinent stream standard would be exceeded in all months of the year for both hydrologic conditions
- <u>Ayers and Westcot Diagram</u>
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.

- Under normal-year conditions, the data also indicate a minor decrease in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.6.2 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.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.6.1.
- Following Mixing
  - The resultant EC values slightly decrease but continue to exceed the pertinent stream standard for December (non-irrigation season) and March, April, and July through October (irrigation season) in both the normal-year and dry-year hydrologic conditions.
  - The resultant SAR values would all increase following mixing. In the normal-year hydrologic condition, the standard would be exceeded through the entire year with the exception of the months of February and June. In the dry-year hydrologic condition, the pertinent stream standard would be exceeded in all months of the year.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a minor reduction in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.6.3 Upper Powder River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 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 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.6.1.
- Following Mixing
  - The resultant EC values slightly decrease but continue to exceed the pertinent stream standard for December (non-irrigation season) and March, April, and July through October (irrigation season) in both the normal-year and dry-year hydrologic conditions.
  - The resultant SAR values would all increase following mixing. In the dry-year hydrologic condition, the stream standard would be exceeded for all months except February. In the normal-year hydrologic condition, the pertinent stream standard would be exceeded in all months of the year with the exception of February, May and June.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate a minor reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a minor reduction in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.7 Middle Powder River

Results of the impacts to water quality in the Middle Powder River subwatershed under the base year condition and each of the two future RFD scenarios are presented in **Table 3.7-1**. **Table 3.7-1** 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 3.7-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.7-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions

are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically significantly higher than those of the Middle Powder River. Therefore, mixing of the two waters will generally raise SAR levels in the Middle Powder River.
- CBNG discharge water EC levels are typically similar to those of the Middle Powder River; depending upon the specific month, the CBNG EC level may be higher or lower than corresponding levels in the Upper Powder River.

Table 3.7-1 Surface Water Impact Analysis of the Middle Powder River Subwatershed

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	6.5	2500	Dec	163.39	4.30	2108.18	3.00	27.74	1929.05	166.39	4.72	2105.0
	2020							1.00			164.39	4.44	2107.1
	2030							0.20			163.59	4.33	2108.0
Maximum Stream Discharge	2008	5	2000	Jun	908.66	3.29	1307.6	3.00	27.74	1929.05	911.66	3.37	1309.6
	2020							1.00			909.66	3.32	1308.2
	2030							0.20			908.86	3.30	1307.7
	Dry Year												
Minimum Stream Discharge	**2008**	**5**	**2000**	**Aug**	**77.09**	**4.16**	**2175.15**	**3.00**	**27.74**	**1929.05**	**80.09**	**5.04**	**2165.9**
	2020							1.00			78.09	4.46	2172.0
	2030							0.20			77.29	4.22	2174.5
Maximum Stream Discharge	2008	5	2000	Mar	321.20	4.62	1890.59	3.00	27.74	1929.05	324.20	4.83	1890.9
	2020							1.00			322.20	4.69	1890.7
	2030							0.20			321.40	4.63	1890.6

The peak CBNG discharge in the watershed is realized for the base year conditions (2008) when 3.0 cfs is conveyed into the Middle Powder River. The quantity of water discharged into the Middle 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 2008, **Table 3.7-1** illustrates the impacts associated with mixing 77.09 cfs (occurring in the month of August) of streamflow in the Middle Powder River with 3.0 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC slightly decreases (but continues to exceed water quality standards) thereby improving water quality incrementally, whereas the SAR is increased compared to existing stream water quality conditions. The combined streamflow of approximately 80.09 cfs reflects a resultant water quality, associated with the minimum mean monthly flow that appears to slightly exceed the pertinent stream standards for both EC and SAR.

In the following sections, specific impacts related to mixing CBNG discharge waters with Upper Powder River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.7.1 Middle Powder River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year conditions and all RFD Scenarios are presented in **Figures 3.7-1, 3.7-2, 3.7-3, 3.7-4, 3.7-5 and 3.7-6**. 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Mean monthly EC values in the Middle Powder River meet the pertinent stream standard for EC for all months with the exception of August and September.
  - Mean monthly values for SAR meet the pertinent stream standard for the entire year.
- Following Mixing
  - The resultant EC values change slightly: some increase while others decrease. The resultant water quality would continue to meet the pertinent stream standard for EC for all months with the exception of August and September during both the dry-year and normal-year hydrologic conditions.
  - The resultant SAR values are increased slightly. Following mixing, the pertinent stream standard for SAR would continue to be met for most of the year under both the dry-year and normal-year hydrologic conditions. The exception to this conclusion is for the months of August and October when the pertinent stream standard is slightly exceeded in the dry-year.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate a slight reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a slight reduction in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.7.2 Middle Powder River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.7-1, 3.7-2, 3.7-3, 3.7-4, 3.7-5 and 3.7-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.7.1.
- Following Mixing
  - The resultant EC values change slightly: some increase while others decrease. The resultant water quality would continue to meet the pertinent stream standard for EC for all months with the exception of August and September during both the dry-year and normal-year hydrologic conditions.
  - The resultant SAR values are increased slightly. Following mixing, the pertinent stream standard for SAR would continue to be met for the entire year under both the dry-year and normal-year hydrologic conditions.
- Ayers and Westcot Diagram.
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate a negligible reduction in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate a slight reduction in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.7.3 Middle Powder River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 conditions are also presented in **Figures 3.7-1, 3.7-2, 3.7-3, 3.7-4, 3.7-5 and 3.7-6**. For RFD Scenario 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.7.1.
- Following Mixing
  - The resultant EC values slightly decrease and continue to meet the pertinent stream standard for EC for all months with the exception of August and September during both the dry-year and normal-year hydrologic conditions.
  - The resultant SAR values are increased slightly. Following mixing, the pertinent stream standard for SAR would continue to be met for the entire year under both the dry-year and normal-year hydrologic conditions.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year prior to mixing with CBNG production water.
  - For the dry-year conditions, the data indicate only negligible reductions in infiltration following mixing with CBNG production water; overall the data indicate the mixed water is suitable for irrigation the entire dry year.
  - Under normal-year conditions, the data also indicate only negligible reductions in infiltration is realized following mixing with CBNG production water; overall, the data indicate that the mixed water is suitable for irrigation during a normal year.

3.8 Clear Creek

Under the base year (2008) and two RFD scenarios, no CBNG production water would be discharged to on channel impoundments or ephemeral drainages. Therefore, no CBNG production water would be conveyed to Clear Creek. Consequently there would be no direct impacts anticipated from CBNG production waters.

Results of the spreadsheet modeling of water quality in the Clear Creek subwatershed under the base year condition and each of the two future RFD scenarios are presented in **Table 3.8-1**. **Table 3.8-1** 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 3.8-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario.

Table 3.8-1 Surface Water Impact Analysis of the Clear Creek Subwatershed

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	6.5	2500	Feb	62.75	1.35	1092.40	0.00	NA	NA	62.75	1.35	1092.4
	2020							0.00			62.75	1.35	1092.4
	2030							0.00			62.75	1.35	1092.4
Maximum Stream Discharge	2008	5	2000	Jun	288.88	0.96	567.6	0.00	NA	NA	288.88	0.96	567.6
	2020							0.00			288.88	0.96	567.6
	2030							0.00			288.88	0.96	567.6
	Dry Year												
Minimum Stream Discharge	**2008**	5	2000	Aug	19.16	1.62	1273.88	0.00	NA	NA	19.16	1.62	1273.9
	2020							0.00			19.16	1.62	1273.9
	2030							0.00			19.16	1.62	1273.9
Maximum Stream Discharge	**2008**	5	2000	Jun	60.17	0.96	567.57	0.00	NA	NA	60.17	0.96	567.6
	2020							0.00			60.17	0.96	567.6
	2030							0.00			60.17	0.96	567.6

As previously discussed, there would be no CBNG production water conveyed to Clear Creek under the base year (2008) or the two RFD scenarios.

3.8.1 Clear Creek: Base Year Conditions (2008)

The results of the water quality impact assessment under base year conditions and all RFD Scenarios are presented in **Figures 3.8-1, 3.8-2, 3.8-3, 3.8-4, 3.8-5 and 3.8-6**. 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
  - Mean monthly EC values in Clear Creek meet the pertinent stream standard for EC in all months of the year.
  - Mean monthly SAR values in Clear Creek meet the pertinent stream standard for SAR in all months of the year.
- <u>Following Mixing</u>
  - No CBNG production water would be discharged to on-channel impoundments or ephemeral drainages. Therefore no CBNG production water would be conveyed to Clear Creek. The resultant water would be identical to the water quality before mixing.
- <u>Ayers and Westcot Diagram</u>
  - The data indicate that the water is suitable for irrigation throughout the year for the base year (2008).

3.8.2 Clear Creek: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.8-1, 3.8-2, 3.8-3, 3.8-4, 3.8-5 and 3.8-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.8.1.
- Following Mixing
  - No CBNG production water would be discharged to on-channel impoundments or ephemeral drainages. Therefore no CBNG production water would be conveyed to Clear Creek. The resultant water would be identical to the water quality before mixing.
- Ayers and Westcot Diagram
  - The data indicate that the water is suitable for irrigation throughout the year.

3.8.3 Clear Creek: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 conditions are also presented in **Figures 3.8-1, 3.8-2, 3.8-3, 3.8-4, 3.8-5 and 3.8-6**. For RFD Scenario 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.8.1.
- Following Mixing
  - No CBNG production water would be discharged to on-channel impoundments or ephemeral drainages. Therefore no CBNG production water would be conveyed to Clear Creek. The resultant water would be identical to the water quality before mixing.
- Ayers and Westcot Diagram
  - The data indicate that the water is suitable for irrigation throughout the year.

3.9 Crazy Woman Creek

Results of the impacts to water quality in the Crazy Woman Creek subwatershed under the base year (2008) condition and each of the two future RFD scenarios are presented in **Table 3.9-1**. **Table 3.9-1** 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 3.9-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.9-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically higher than those of Crazy Woman Creek. Therefore, mixing of the two waters will generally raise SAR levels in Crazy Woman Creek.
- CBNG discharge water EC levels are typically higher than those of Crazy Woman Creek. Therefore, mixing of the two waters will generally raise EC levels in Crazy Woman Creek.

Table 3.9-1 Surface Water Impact Analysis of the Crazy Woman Creek Subwatershed

	Scenario	Stream Standard		Existing Stream Water Quality				CBNG Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	5	2000	Sep	6.65	2.76	2036.29	0.00	26.98	2177.90	6.65	2.76	2036.3
	2020							0.20			6.85	3.46	2040.4
	2030							0.60			7.25	4.76	2048.0
Maximum Stream Discharge	2008	5	2000	Jun	119.62	1.43	1006.5	0.00	26.98	2177.90	119.62	1.43	1006.5
	2020							0.20			119.82	1.47	1008.5
	2030							0.60			120.22	1.56	1012.4
	Dry Year												
Minimum Stream Discharge	2008	**5**	**2000**	**Sep**	**2.49**	**2.76**	**2036.29**	0.00	**26.98**	**2177.90**	2.49	2.76	2036.3
	2020							0.20			2.69	4.56	2046.8
	2030							**0.60**			**3.09**	**7.47**	**2063.8**
Maximum Stream Discharge	2008	5	2000	Jun	77.02	1.43	1006.52	0.00	26.98	2177.90	77.02	1.43	1006.5
	2020							0.20			77.22	1.50	1009.5
	2030							0.60			77.62	1.63	1015.6

Results of the impacts to water quality in the Crazy Woman Creek subwatershed under the base year (2008) and two RFD scenarios are presented in **Table 3.9-1**. **Table 3.9-1** 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 3.9-1** is obtained from the results of the spreadsheet model documented in **Appendix 3A** and specifically evaluates the impact analysis for the minimum mean monthly flow in Crazy Woman Creek in the base year and the two RFD scenarios. 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 RFD scenario 2030 when 0.60 cfs is conveyed into the Crazy Woman Creek. The quantity of water discharged into the Crazy Woman Creek would be less in the base year (2008) and 2020 RFD scenario and would consequently result in a reduction in impacts to the existing water quality. For the dry-year hydrologic conditions for 2030, **Table 3.9-1** illustrates the impacts associated with mixing 2.49 cfs (occurring in the month of September) of streamflow in the Crazy Woman Creek with 0.60 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC increases. SAR also increases. The combined streamflow of approximately 3.09 cfs reflects a resultant water quality, associated with the minimum mean monthly flow, that appears to exceed the pertinent stream standard for both EC and SAR.

The existing stream water quality data identify the minimum mean monthly flow (2008) 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 base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

3.9.1 Crazy Woman Creek: Base Year Conditions (2008)

The results of the water quality impact assessment under base year conditions and all RFD Scenarios are presented in **Figures 3.9-1, 3.9-2, 3.9-3, 3.9-4, 3.9-5 and 3.9-6**. 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- <u>Before Mixing</u>
    - With the exception of the month of September, the mean monthly EC values in Crazy Woman Creek meet the pertinent stream standard for EC for both hydrologic conditions.

- Under base year (2008) conditions, mean monthly SAR values in Crazy Woman Creek meet the pertinent stream standard for SAR in both the dry-year and normal-year hydrologic condition.

- Following Mixing
  - Under this scenario, there would be no CBNG production water discharged to Crazy Woman Creek following conveyance losses. Consequently, the resultant EC and SAR values would be unaffected.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year.

3.9.2 Crazy Woman Creek: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.9-1, 3.9-2, 3.9-3, 3.9-4, 3.9-5 and 3.9-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.9.1.
- Following Mixing
  - The resultant EC values slightly increase but do not exceed the pertinent stream standard for all months with the exception of September for the normal-year and September and October for the dry-year hydrologic condition.
  - The resultant SAR values are increased throughout the year, however, the pertinent stream standard is not exceeded in any months.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year following mixing with CBNG production water.

3.9.3 Crazy Woman Creek: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 conditions are also presented in **Figures 3.9-1, 3.9-2, 3.9-3, 3.9-4, 3.9-5 and 3.9-6**. For RFD Scenario 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.9.1.
- Following Mixing
  - The resultant EC values slightly increase but do not exceed the pertinent stream standard for all months with the exception of September and October for both the dry-year and normal-year hydrologic condition.
  - The resultant SAR values are increased throughout the year and the pertinent stream standard is not exceeded in the normal year. In the dry-year hydrologic condition, the standard is exceeded in September and October.
- Ayers and Westcot Diagram
  - For both the normal and dry year hydrologic conditions, the data indicate that the water is suitable for irrigation throughout the year following mixing with CBNG production water.

3.10 Upper Tongue River

Results of the impacts to water quality in the Upper Tongue River subwatershed under the base year (2008) condition and each of the two future RFD scenarios are presented in **Table 3.10-1**. **Table 3.10-1** 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 3.10-1** is obtained from the results of the spreadsheet model documented in Appendix 3A and specifically evaluates the impact analysis for the maximum and minimum mean monthly flows for each RFD scenario. As noted above, impacts to water quality are typically maximized during the low flow months; however in those months where the CBNG production water is of higher quality than the receiving waters, improvements may be realized. Consequently, the comparative evaluation of water quality initially focused on both the minimum and maximum monthly flow associated with the dry-year and normal-year conditions.

Table 3.10-1 identifies the minimum and maximum mean monthly flows for the normal and dry year hydrologic conditions. Corresponding receiving water EC and SAR data for both hydrologic conditions are also tabulated. Typically, the month in which the minimum or maximum flows occur varies between normal and dry years. The base year (2008) EC and SAR data may demonstrate an increase or decrease from the normal year to dry year depending on the month in which the minimum flow occurs.

The table indicates:

- CBNG discharge water SAR levels are typically significantly higher than those of the Upper Tongue River. Therefore, mixing of the two waters will generally raise SAR levels in the Upper Tongue River.
- CBNG discharge water EC levels are typically higher to those of the Upper Tongue River. Therefore, mixing of the two waters will generally raise SAR levels in the Upper Tongue River.

Table 3.10-1 Surface Water Impact Analysis of the Upper Tongue River Subwatershed

	Scenario	Stream Standard		Existing Stream Water Quality				CBM Discharge			Resulting Stream Water Quality		
		SAR	EC (uS/cm)	Month	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)	Flow (cfs)	SAR	EC (uS/cm)
	Normal Year												
Minimum Stream Discharge	2008	5	1500	Jan	169.19	0.70	658.78	0.80	40.22	1948.09	169.99	0.88	664.8
	2020							0.20			169.39	0.74	660.3
	2030							0.70			169.89	0.86	664.1
Maximum Stream Discharge	2008	3	1000	Jun	1105.83	0.40	317.7	0.80	40.22	1948.09	1106.63	0.43	318.9
	2020							0.20			1106.03	0.41	318.0
	2030							0.70			1106.53	0.42	318.8
	Dry Year												
Minimum Stream Discharge	2008	5	1500	Feb	128.79	0.79	697.45	0.80	40.22	1948.09	129.59	1.03	705.2
	2020							0.20			128.99	0.85	699.4
	2030							0.70			129.49	1.00	704.2
Maximum Stream Discharge	2008	3	1000	Jul	288.17	0.67	504.43	0.80	40.22	1948.09	288.97	0.78	508.4
	2020							0.20			288.37	0.69	505.4
	2030							0.70			288.87	0.76	507.9

The peak CBNG discharge in the watershed is realized for the base year conditions (i.e., 2008) when 0.80 cfs is conveyed into the Upper Tongue River. The quantity of water discharged into the Upper Tongue 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 2008, **Table 3.10-1** illustrates the impacts associated with mixing 128.79 cfs (occurring in the month of February) of streamflow in the Upper Tongue River with 0.80 cfs of CBNG well discharge water on both SAR and EC. After the flows mix, the resulting EC and SAR values both increase. The combined streamflow of approximately 129.59 cfs reflects a resultant water quality, associated with the minimum mean monthly flow that appears to meet the pertinent stream standards for both EC and SAR.

In the following sections, specific impacts related to mixing CBNG discharge waters with Upper Tongue River receiving waters are discussed for the base year (2008) and the two RFD scenarios.

3.10.1 Upper Tongue River: Base Year Conditions (2008)

The results of the water quality impact assessment under base year conditions and all RFD Scenarios are presented in **Figures 3.10-1, 3.10-2, 3.10-3, 3.10-4, 3.10-5 and 3.10-6**. 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 base year conditions (2008), the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Mean monthly EC values in the Tongue Powder River meet the pertinent stream standard for EC for all months of the year.
  - Mean monthly values for SAR meet the pertinent stream standard for all months of the year.
- Following Mixing.
  - The resultant EC values slightly increase and continue to meet the pertinent stream standard for EC for all months.
  - The resultant SAR values slightly increase and continue to meet the pertinent stream standard for SAR for all months.
- Ayers and Westcot Diagram.
  - For both the normal-year and dry-year hydrologic conditions, the data indicate that with the exception of the months of May and June, the water is suitable for irrigation throughout the year following mixing with CBNG production water.

3.10.2 Upper Tongue River: RFD Scenario 2020 Conditions

The results of the water quality impact assessment under RFD Scenario 2020 conditions are also presented in **Figures 3.10-1, 3.10-2, 3.10-3, 3.10-4, 3.10-5 and 3.10-6**. For RFD Scenario 2020, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.10.1.
- Following Mixing
  - The resultant EC values slightly increase and continue to meet the pertinent stream standard for EC for all months.
  - The resultant SAR values slightly increase and continue to meet the pertinent stream standard for SAR for all months.
- Ayers and Westcot Diagram
  - For both the normal-year and dry-year hydrologic conditions, the data indicate that with the exception of the months of May and June, the water is suitable for irrigation throughout the year following mixing with CBNG production water.

3.10.3 Upper Tongue River: RFD Scenario 2030 Conditions

The results of the water quality impact assessment under RFD Scenario 2030 conditions are also presented in **Figures 3.10-1, 3.10-2, 3.10-3, 3.10-4, 3.10-5 and 3.10-6**. For RFD Scenario 2030, the observations presented below are based on the information presented in these figures.

Summary of Impacts

- Before Mixing
  - Same as the base year conditions (2008) presented in Section 3.10.1.
- Following Mixing
  - The resultant EC values slightly increase and continue to meet the pertinent stream standard for EC for all months.
  - The resultant SAR values slightly increase and continue to meet the pertinent stream standard for SAR for all months.
- Ayers and Westcot Diagram
  - For both the normal-year and dry-year hydrologic conditions, the data indicate that with the exception of the months of May and June, the water is suitable for irrigation throughout the year following mixing with CBNG production water.

3.11 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 3A. In general, the results are summarized below.

Antelope Creek

Dry Year

The maximum difference in the predicted values for EC ranged from 0.91% to 0.96%

The maximum difference in predicted values for SAR ranged from 3.16% to 3.19%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.68% to 0.86%

The maximum difference in predicted values for SAR ranged from 3.01% to 3.14%

Dry Fork Cheyenne River

Dry Year

The maximum difference in the predicted values for EC ranged from 0% to 5.16%

The maximum difference in predicted values for SAR ranged from 0% to 1.55%

Normal Year

The maximum difference in the predicted values for EC ranged from 0% to 4.99%

The maximum difference in predicted values for SAR ranged from 0% to 1.54%

Little Powder River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.05% to 0.25%

The maximum difference in predicted values for SAR ranged from 0.87% to 2.60%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.02% to 0.05%

The maximum difference in predicted values for SAR ranged from 0.49% to 2.09%

Upper Belle Fourche River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.01% to 0.09%

The maximum difference in predicted values for SAR ranged from 0.19% to 1.34%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.13%

The maximum difference in predicted values for SAR ranged from 0.00% to 1.10%

Upper Cheyenne River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.05%

The maximum difference in predicted values for SAR ranged from 0.00% to 2.72%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.01%

The maximum difference in predicted values for SAR ranged from 0.00% to 0.85%

Upper Powder River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.04% to 0.13%

The maximum difference in predicted values for SAR ranged from 0.57% to 1.31%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.02% to 0.07%

The maximum difference in predicted values for SAR ranged from 0.31% to 0.90%

Middle Powder River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.02%

The maximum difference in predicted values for SAR ranged from 0.07% to 0.98%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.91% to 0.96%

The maximum difference in predicted values for SAR ranged from 3.16% to 3.19%

Clear Creek

Under the base year (2008) and two RFD scenarios, no CBNG production water would be discharged to on-channel impoundments or ephemeral drainages in this subwatershed.

Crazy Woman Creek

Dry Year

The maximum difference in the predicted values for EC ranged from 0.00% to 1.19%

The maximum difference in predicted values for SAR ranged from 0.00% to 5.66%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.74%

The maximum difference in predicted values for SAR ranged from 0.00% to 4.13%

Upper Tongue River

Dry Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.01%

The maximum difference in predicted values for SAR ranged from 0.61% to 0.68%

Normal Year

The maximum difference in the predicted values for EC ranged from 0.00% to 0.01%

The maximum difference in predicted values for SAR ranged from 0.17% to 0.57%

3.12 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 3.12-1** and **Table 3.12-2**. 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.

3.12.1 Current Surface Water Quality Conditions (2008 Base Year Before Mixing)

With respect to pertinent stream standards included in the impact analysis, several of the surface water sources exceed the standard during many months of the years under the base year (2008) condition. Specific observations related to the mean monthly water quality of the surface water sources are listed below:

Table 3.12-1 Summary of Water Quality Analysis (Normal Year)

Item	Baseline 2008	2008	2020	2030
	Before Mixing	(After Mixing)	(After Mixing)	(After Mixing)
Antelope Creek (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Nonsuitable in Sep, Oct	Nonsuitable in Jan, Sep thru Dec	Nonsuitable Sep and Oct
Stream Standard	EC Exceeded Jan, Feb, Apr thru Jun, Nov, and Dec	EC Exceeded in Apr, May	EC Exceeded in no months	EC Exceeded in Apr, May
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Dry Fork Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Same (No CBNG Discharge)	Reduced
SAR	Stream < CBNG	Increased	Same (No CBNG Discharge)	Increased
Irrigation Suitability	Suitable all season	Not suitable Sep	Same (No CBNG Discharge)	Not suitable Jan, Jul through Oct
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	Same (No CBNG Discharge)	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	Same (No CBNG Discharge)	SAR Exceeded in no months
Little Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded all months except Mar	EC Exceeded all months except Jan thru Mar and Oct, Nov	EC Exceeded all months except Mar	EC Exceeded all months except Mar
	SAR Exceeded all months except Feb and Mar	SAR Exceeded all months	SAR Exceeded all months except Mar	SAR Exceeded all months except Mar
Upper Belle Fourche (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Oct thru Feb	EC Exceeded in Jan, Feb	EC Exceeded Dec through Feb	EC Exceeded Nov through Feb
	SAR Exceeded in Sep thru Jan	SAR Exceeded in Jan, Aug thru Dec	SAR Exceeded Sep through Jan	SAR Exceeded Sep through Jan
Upper Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Reduced	Same (No CBNG Discharge)
SAR	Stream ~= CBNG	No Significant Change	No Significant Change	Same (No CBNG Discharge)
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Same (No CBNG Discharge)
Stream Standard	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	Same (No CBNG Discharge)
	SAR Exceeded Oct through Jan	SAR Exceeded Jan, Oct thru Dec	SAR Exceeded Jan, Apr, Oct thru Dec	Same (No CBNG Discharge)
Upper Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec
	SAR Exceeded Mar, Apr, Jul thru Oct	SAR Exceeded all months	SAR Exceeded all months ex Feb, Jun	SAR Exceeded all months except Feb, May, Jun
Middle Powder River (1)				
EC	Stream ~= CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Clear Creek (1)				
EC	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
SAR	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Stream Standard	EC Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Crazy Woman Creek (1)				
EC	Stream ~= CBNG	Same (No CBNG Discharge Conveyed to Stream)	No Significant Change	No Significant Change
SAR	Stream < CBNG	Same (No CBNG Discharge Conveyed to Stream)	Increased	Increased
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Suitable all season	Suitable all season
Stream Standard	EC Exceeds in Sep	Same (No CBNG Discharge Conveyed to Stream)	EC Exceeded in Sep	EC Exceeded in Sep and Oct
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	SAR Exceeded in no months	SAR Exceeded in no months
Upper Tongue River (1)				
EC	Stream < CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	No Significant Change	Increased	Increased
Irrigation Suitability	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months

(1) All references to comparative changes in water quality refer to the relative difference between the "after mixing" and "before mixing" conditions.

Table 3.12-2 Summary of Water Quality Analysis (Dry Year)

Item	Baseline 2008	2008	2020	2030
	Before Mixing	(After Mixing)	(After Mixing)	(After Mixing)
Antelope Creek (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Nonsuitable in Jan, Feb, Sep thru Dec	Nonsuitable in Jan, Feb, Sep thru Dec	Nonsuitable in Jan, Feb, Sep thru Dec
Stream Standard	EC Exceeded Jan, Feb, Apr thru Jun, Nov, and Dec	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months
Dry Fork Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Same (No CBNG Discharge)	Reduced
SAR	Stream < CBNG	Increased	Same (No CBNG Discharge)	Increased
Irrigation Suitability	Suitable all season	Not suitable Jan, Jul, Sep, and Oct	Same (No CBNG Discharge)	Not suitable Jan thru Apr, Jul - Dec
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	Same (No CBNG Discharge)	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	Same (No CBNG Discharge)	SAR Exceeded in no months
Little Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded all months except Mar	EC Exceeded all months except Feb, Mar and Oct	EC Exceeded all months except Mar and Feb	EC Exceeded all months except Feb and Mar
	SAR Exceeded all months except Feb and Mar	SAR Exceeded all months	SAR Exceeded all months except Mar	SAR Exceeded all months except Mar
Upper Belle Fourche (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Oct thru Feb	EC Exceeded in Jan and Dec	EC Exceeded Dec through Feb	EC Exceeded Nov thru Feb
	SAR Exceeded in Sep thru Jan	SAR Exceeded in Jul thru Feb	SAR Exceeded Aug thru Jan	SAR Exceeded Sep thru Jan
Upper Cheyenne River (1)				
EC	Stream > CBNG	Reduced	Reduced	Same (No CBNG Discharge)
SAR	Stream ~= CBNG	No Significant Change	No Significant Change	Same (No CBNG Discharge)
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Same (No CBNG Discharge)
Stream Standard	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	EC Exceeded all months except Jul, Aug	Same (No CBNG Discharge)
	SAR Exceeded Oct through Jan	SAR Exceeded Oct through Jan	SAR Exceeded Oct through Jan, Apr	Same (No CBNG Discharge)
Upper Powder River (1)				
EC	Stream > CBNG	Reduced	Reduced	Reduced
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec	EC Exceeded Mar, Apr, Jul thru Oct and Dec
	SAR Exceeded Mar, Apr, Jul thru Oct	SAR Exceeded all months	SAR Exceeded all months	SAR Exceeded all months except Feb
Middle Powder River (1)				
EC	Stream ~= CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	Increased	Increased	Increased
Irrigation Suitability	Suitable all season	Suitable all season	Suitable all season	Suitable all season
Stream Standard	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep	EC Exceeded in Aug and Sep
	SAR Exceeded in no months	SAR Exceeded Aug and Oct	SAR Exceeded in no months	SAR Exceeded in no months
Clear Creek (1)				
EC	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
SAR	NA	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Stream Standard	EC Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)	Same (No CBNG Discharge Conveyed to Stream)
Crazy Woman Creek (1)				
EC	Stream ~= CBNG	Same (No CBNG Discharge Conveyed to Stream)	No Significant Change	No Significant Change
SAR	Stream < CBNG	Same (No CBNG Discharge Conveyed to Stream)	Increased	Increased
Irrigation Suitability	Suitable all season	Same (No CBNG Discharge Conveyed to Stream)	Suitable all season	Suitable all season
Stream Standard	EC Exceeds in Sep	Same (No CBNG Discharge Conveyed to Stream)	EC Exceeded in Sep and Oct	EC Exceeded in Sep and Oct
	SAR Exceeded in no months	Same (No CBNG Discharge Conveyed to Stream)	SAR Exceeded in no months	SAR Exceeded in Sep and Oct
Upper Tongue River (1)				
EC	Stream < CBNG	No Significant Change	No Significant Change	No Significant Change
SAR	Stream < CBNG	No Significant Change	Increased	Increased
Irrigation Suitability	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun	Not suitable May and Jun
Stream Standard	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months	EC Exceeded in no months
	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months	SAR Exceeded in no months

(1) All references to comparative changes in water quality refer to the relative difference between the "after mixing" and "before mixing" conditions.

Base year (2008) water quality in several of the subwatersheds evaluated is suitable for irrigation throughout the entire year in both the dry-year and normal-year hydrologic conditions:

- Antelope Creek,
- Upper Belle Fourche,
- Upper Cheyenne River,
- Upper Powder River,
- Little Powder River,
- Dry Fork Cheyenne River,
- Clear Creek,
- Crazy Woman Creek, and
- Middle Powder River

Of the ten subwatershed evaluated, the only one in which base year water quality is not suitable during a portion of the year is the Upper Tongue River which is not suitable in the months of May and June.

With respect to the pertinent stream standards, surface waters in several of the subwatersheds evaluated exceed one or both of the standards for EC and SAR during at least one month of the year. Based upon the available water quality data, the only subwatersheds in which standards are not exceeded for either parameter are:

- Clear Creek,
- Dry Fork Cheyenne River, and the
- Upper Tongue River.

Surface water in several of the subwatersheds exceeds pertinent stream standards for <u>both</u> EC and SAR throughout much of the year, including the irrigation season. Subwatersheds where this relationship exists are:

- Upper Belle Fourche River,
- Upper Cheyenne River
- Upper Powder, and
- the Little Powder River

It is important to note that due to the EC and SAR relationship with respect to irrigation suitability, there are instances where, although pertinent stream standards may be exceeded for one or both of the two parameters, the irrigation suitability threshold is not exceeded.

In the remaining three subwatersheds, the pertinent stream standard for SAR is not exceeded throughout the entire year but the standard for EC is for at least one month. These streams and descriptions of the EC exceedence are:

- Antelope Creek exceeds the standard for EC most of the year.
- Crazy Woman Creek exceeds the standard for EC only during the month of September
- Middle Powder River exceeds the standard for EC during the months of August and September.

3.12.2 Mixed Water Quality Conditions

Specific observations related to the pertinent stream standards *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 discharge in Antelope Creek is very low in relation to the projected CBNG production water in RFD 2020 scenario when 7.1 cfs is ultimately discharged. Consequently the quality of the CBNG production water dominates the nature of the mixed waters. The mixed water quality reflects a reduction in EC that meets the pertinent stream standard throughout the year. Levels of SAR are increased but continue to meet the pertinent standard.

- CBNG well production water in the Dry Fork Cheyenne River subwatershed peaks with the RFD 2030 scenario when 1.5 cfs is ultimately discharged to surface water. Quality of the CBNG production water dominates the character of the mixed waters due to the relative magnitudes (1.5 cfs CBNG water compared to less than 1 cfs surface water). Consequently EC is reduced and continues to remain below the pertinent stream standard throughout the year. SAR levels are increased throughout the year, however, they remain below the pertinent stream standard in all months.

- Within the Little Powder River subwatershed, CBNG production water would peak in the base year (2008) scenario when 9.6 cfs would ultimately be discharged to surface waters. The quantity of CBNG well production water in the Little Powder River subwatershed is similar in magnitude to the ambient streamflow. Following mixing, the surface water in the Little Powder River reflects an overall reduction in EC but continues to exceed the pertinent standard most of

the year. The SAR values reflect an increase and exceed the pertinent standard for the entire year in comparison to the base year (2008) condition when it was exceeded in ten months.

- Following mixing, surface water in the Upper Belle Fourche River reflect an overall reduction in EC and an increase in SAR. The peak discharge of CBNG production water occurs in the base year (2008) when 10.0 cfs is ultimately discharged to surface waters. This quantity is of a similar and often greater magnitude to the amount of streamflow. The pertinent stream standard for EC would be exceeded in fewer months than prior to mixing (January and December). The pertinent standard for SAR would also be exceeded in more months following mixing than under the base year (2008) condition. Following mixing, the SAR standard would be exceeded July through February.

- Within the Upper Cheyenne Powder River subwatershed, CBNG production water would be relatively low in comparison to other subwatershed and would peak in the base year (2008) scenario and the RFD 2020 scenario when 0.4 cfs would ultimately be discharged to surface waters. Ambient stream flows are considerably higher most of the year. Following mixing, the surface water in the Upper Cheyenne River reflects an overall slight reduction in EC but continues to exceed the pertinent standard in the months of July and August. The SAR values reflect a minimal increase but would result in no additional months exceeding the pertinent standard in comparison to the base year condition (2008). The pertinent stream standard for SAR would be exceeded during the low-flow months of October through January.

- In the Upper Powder River subwatershed, projected CBNG production water is higher in quantity than any of the other subwatersheds evaluated. The peak CBNG production water would occur in the base year (2008) when 60.3 cfs is ultimately discharged to the river. However, because stream flow in the river is also high, the relative impacts upon mixing of the two waters are diminished. The surface water in the Upper Powder River demonstrates a minimal reduction in EC and a minor increase in SAR following mixing. EC values continue to exceed the pertinent stream standard throughout the majority of the year (March, April, July through October and December). SAR values exceed the pertinent stream standard throughout the year.

- Within the Middle Powder River subwatershed, CBNG production water would be relatively low in comparison to other subwatershed and would peak in the base year (2008) scenario when 3.0 cfs would ultimately be discharged to surface waters. Ambient stream flows are significantly higher than CBNG production water discharge year round, consequently impacts of mixing are minimized. Following mixing, the surface water in the Middle Powder River reflects a minimal change as the EC levels in the CBNG production water and the surface water are similar. The

pertinent standard for EC would continue to be exceeded in August and October. The SAR values in the subwatershed are among the highest of all subwatersheds evaluated: 28.0. Due to the relative magnitude of the CBNG production water SAR values, the surface water would continue to exceed the pertinent stream standard in two months (September and October). However, due to the higher quantity of streamflow, the impacts of mixing water with a much higher SAR level would be minimal.

- No CBNG production water would ultimately be discharged to surface water within the Clear Creek subwatershed. Consequently, the water quality in this surface water source remains the same as that described for the base year (2008) condition.

- Within the Crazy Woman Creek subwatershed, CBNG production water would be relatively low in comparison to other subwatershed and would peak in RFD 2030 scenario when 2.0 cfs would ultimately be discharged to surface waters. Ambient stream flows are considerably higher most of the year. Following mixing, the surface water in Crazy Woman Creek reflects an overall minimal reduction in EC but continues to exceed the pertinent standard in the late irrigation season months of September and October. The SAR values in the subwatershed are among the highest of all subwatersheds evaluated: 26.98. Although the base year (2008) SAR values in Crazy Woman Creek meet the pertinent stream standards, due to the relative magnitude of the CBNG production water SAR values, the surface water would exceed the pertinent stream standard in two months (September and October).

- The peak discharge of CBNG production water within the Upper Tongue River subwatershed occurs in the base year (2008) scenario when 2.7 cfs is ultimately discharged to surface waters. This quantity is a relatively minor amount in comparison to the surface water where the minimum streamflow is approximately 128 cfs. Following mixing there would be minimal changes in EC and SAR levels despite the observation that CBNG production water SAR values in this subwatershed are the highest of all evaluated: 40.0. The pertinent stream standards for EC and SAR would not be exceeded throughout the year.

3.12.3 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 (base year 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 Middle Powder River, Upper Belle Fourche River, and Crazy Woman Creek, this observation was consistent for all surface water sources evaluated during this study. Within these basins, the EC associated with the CBNG well production water was the most elevated and similar to the EC of the surface water.

3.12.4 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 (base year 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.

3.12.5 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, the Dry Fork Cheyenne River and the Upper Tongue River. For these streams, the results demonstrated unsuitable water sources during a portion of the irrigation season during the normal-year and dry-year conditions.

In general, the increased levels of SAR in the CBNG well production water directly relates to the reduction in the suitability of the water for irrigation purposes in streams receiving a large component of CBNG discharge. This trend is amplified for all streams during periods when CBNG well production water represents the majority of the flows available for irrigation purposes.

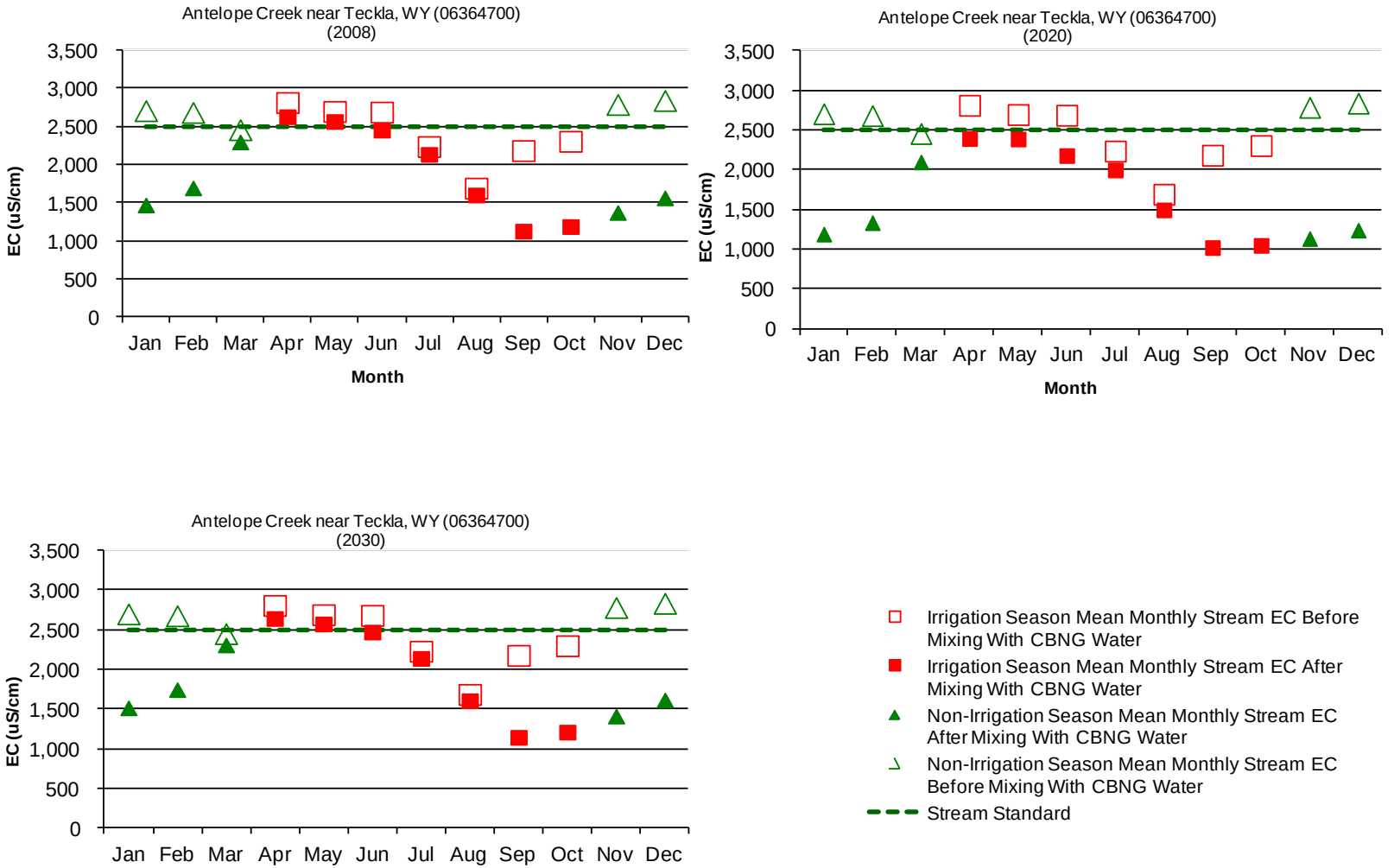


Figure 3.1-1
Stream EC Before and After Mixing With CBNG Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Antelope Creek near Teckla, WY (06364700)

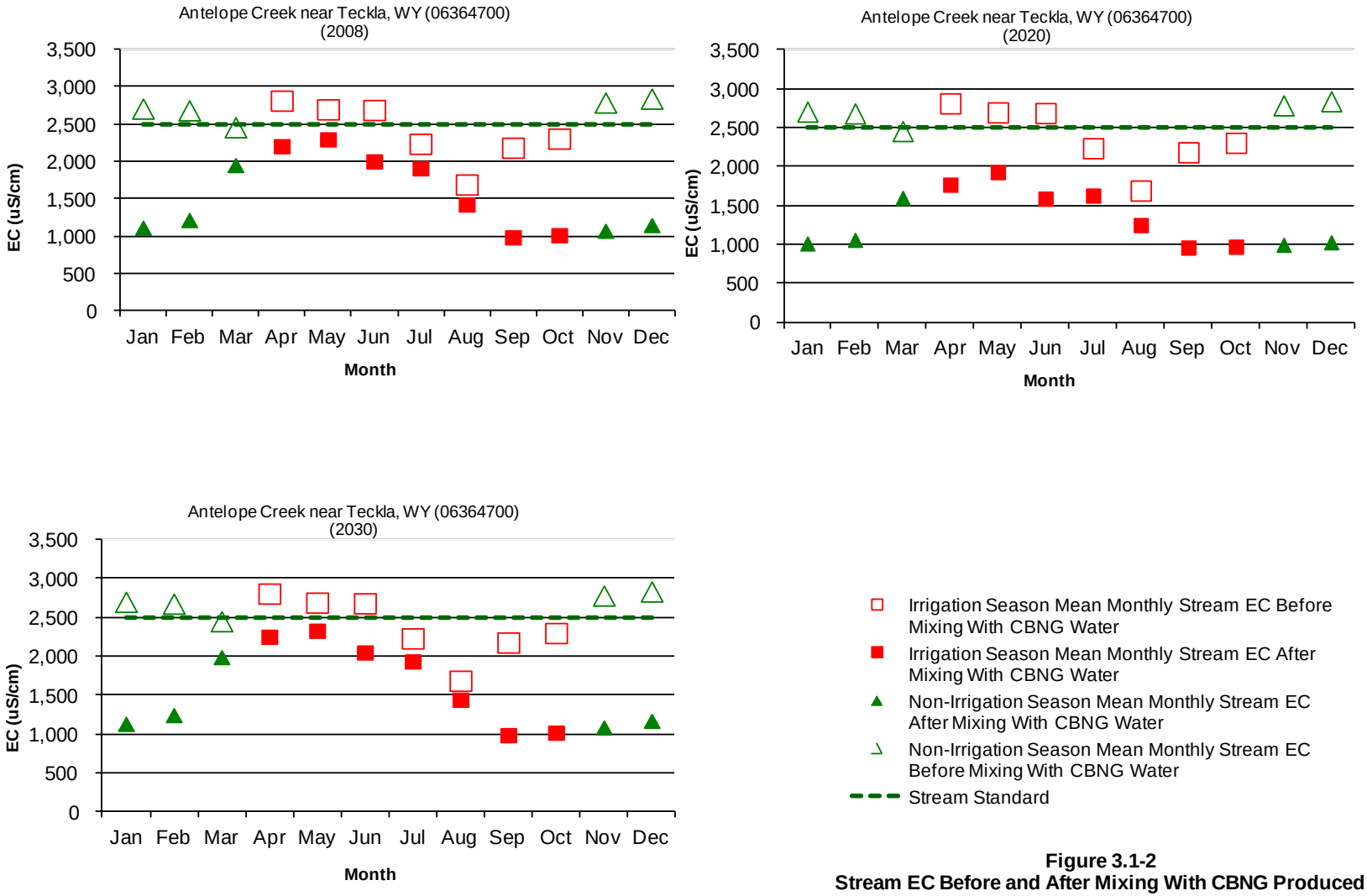


Figure 3.1-2
Stream EC Before and After Mixing With CBNG Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Antelope Creek near Teckla, WY (06364700)

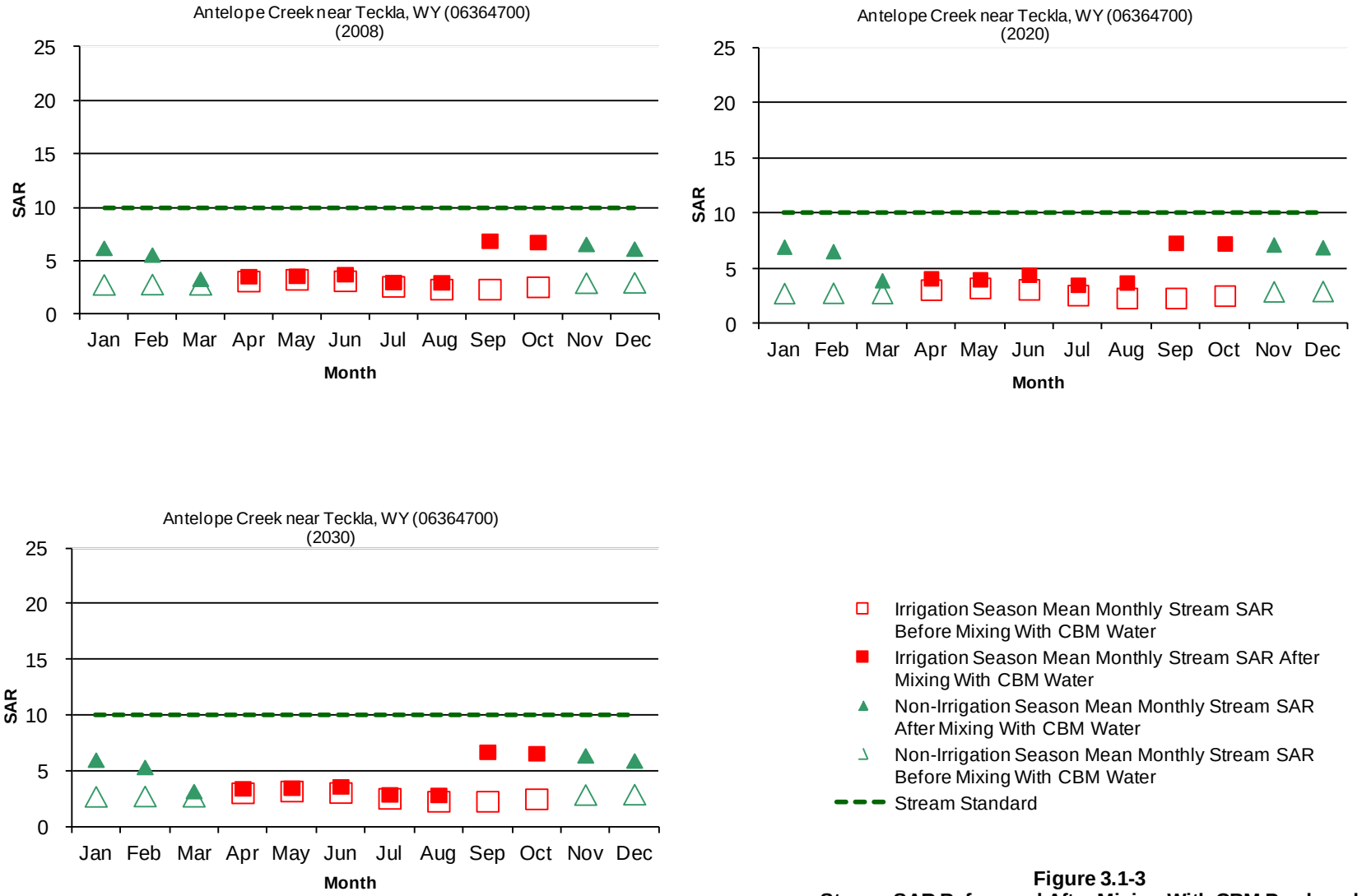


Figure 3.1-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Antelope Creek near Teckla, WY (06364700)

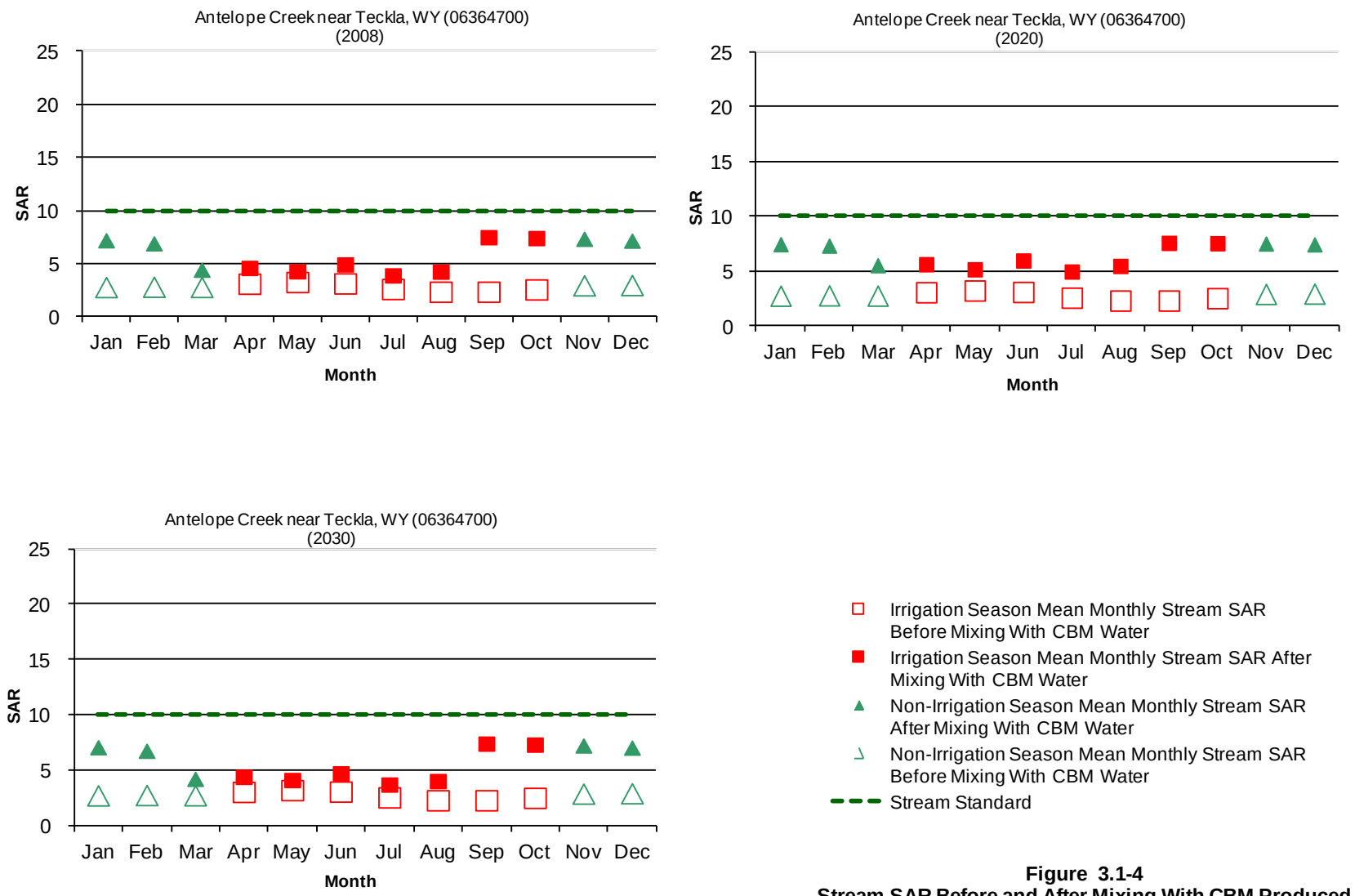


Figure 3.1-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Antelope Creek near Teckla, WY (06364700)

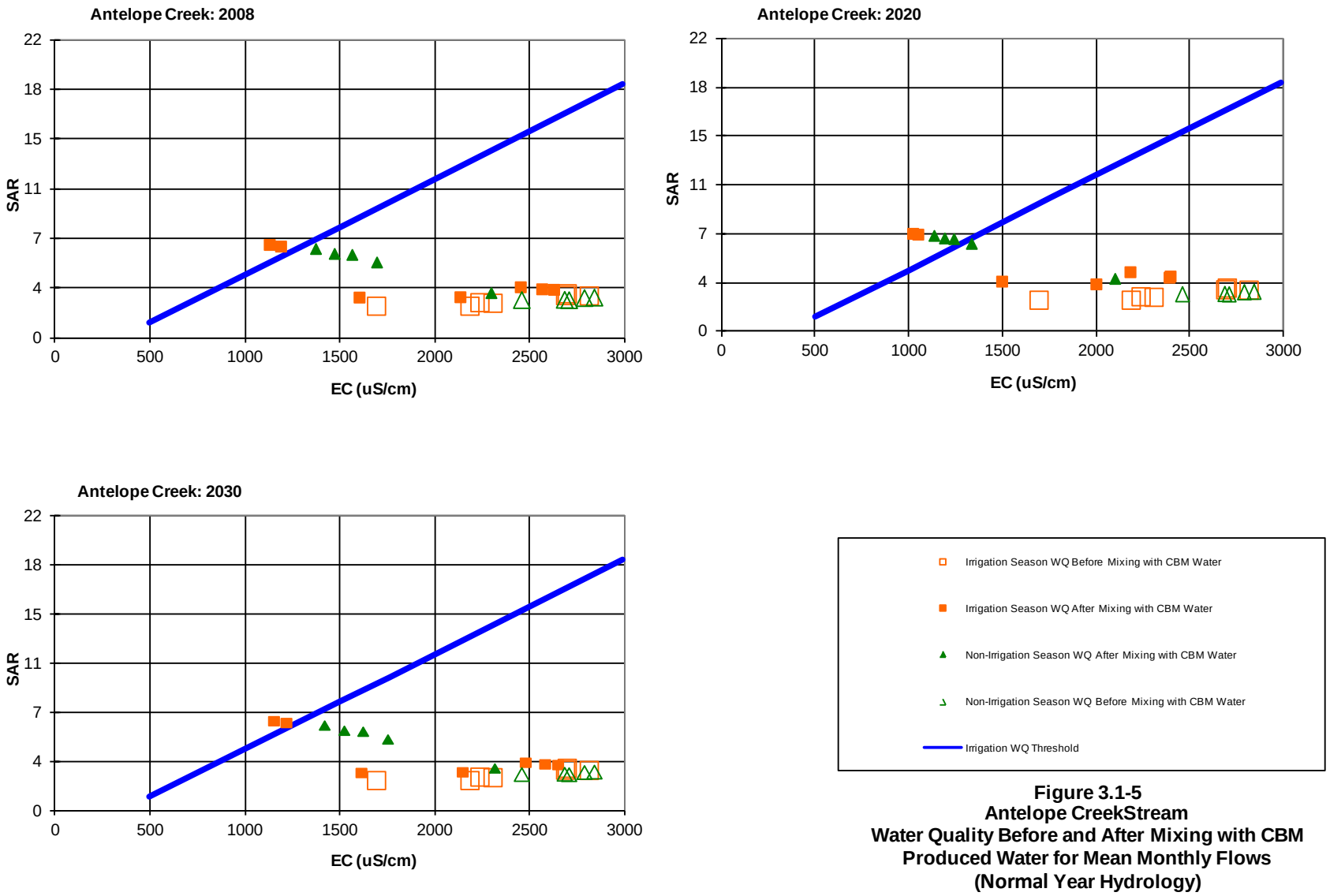


Figure 3.1-5
Antelope CreekStream
Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

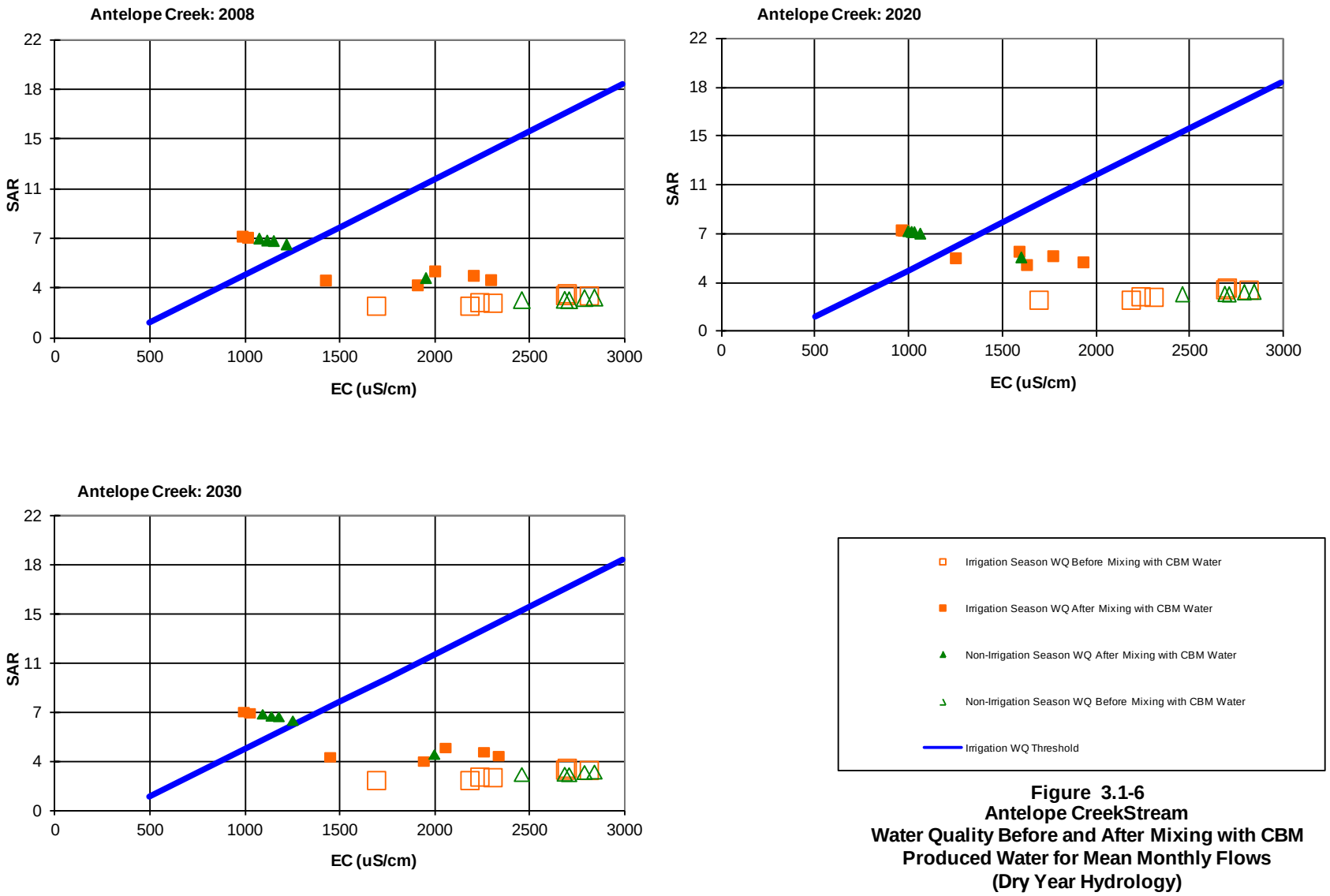


Figure 3.1-6
Antelope CreekStream
Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

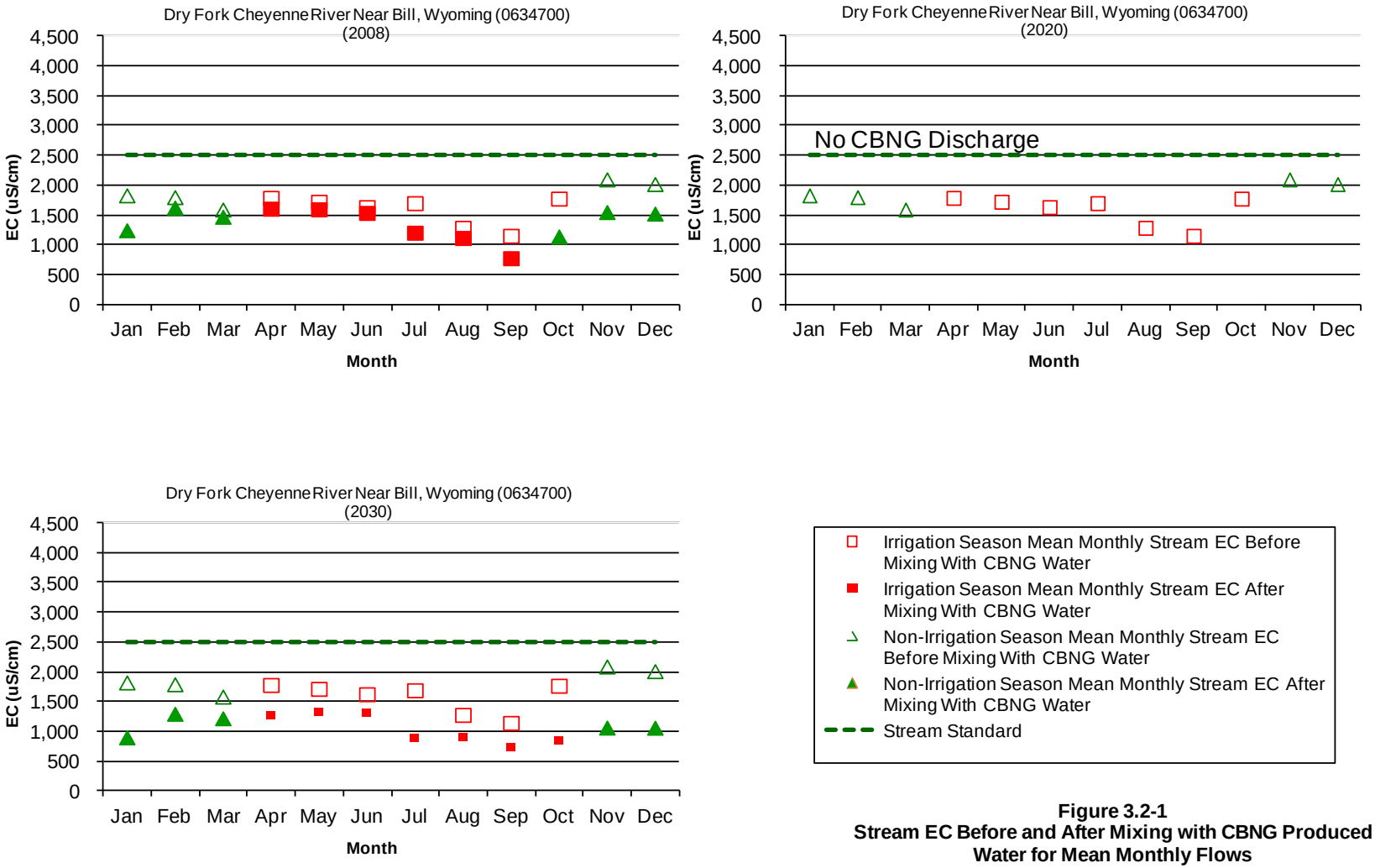


Figure 3.2-1
Stream EC Before and After Mixing with CBNG Produced Water for Mean Monthly Flows
Normal Year Hydrology
USGS 06365300 Dry Fork Cheyenne River Near Bill, WY

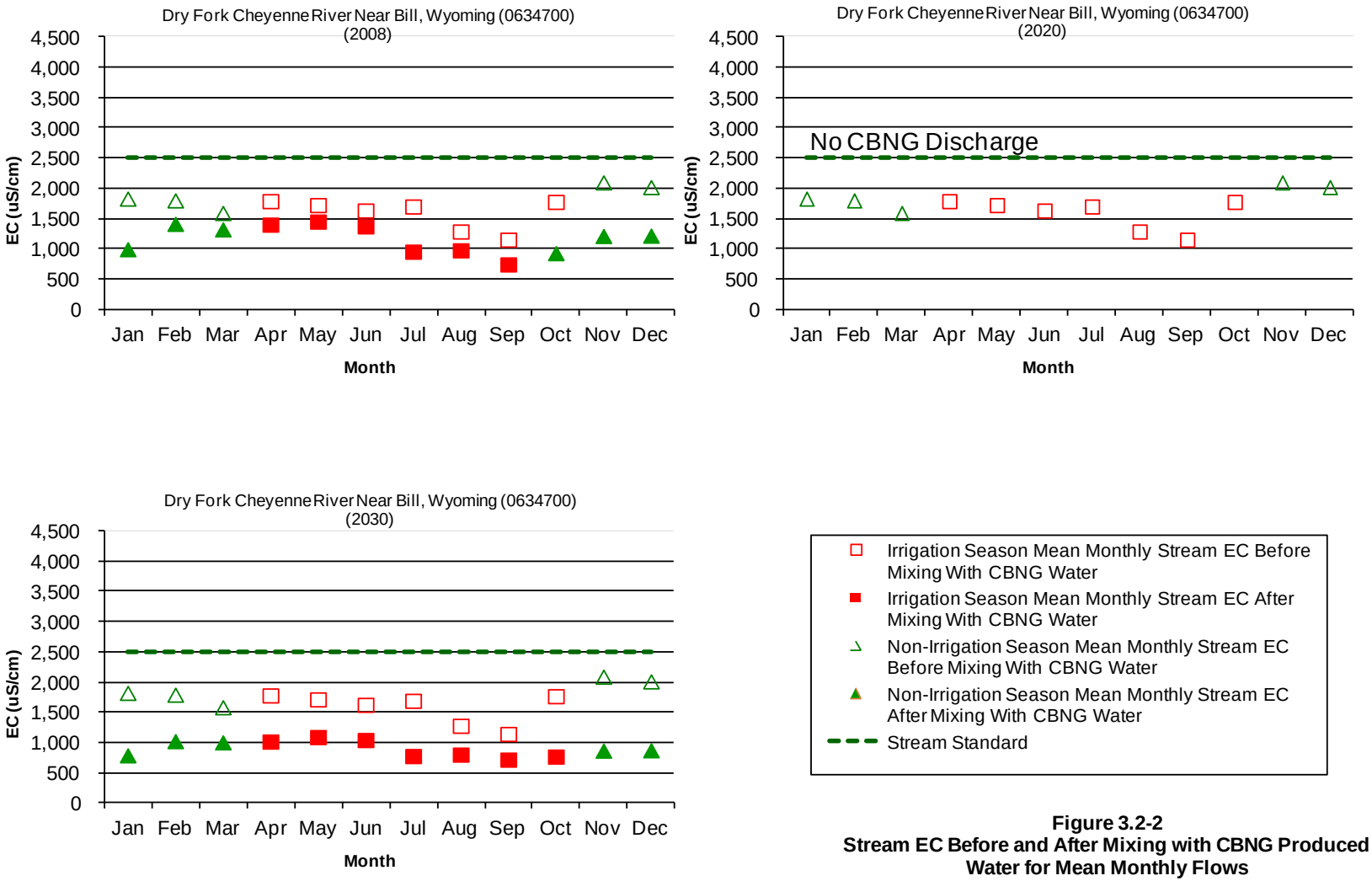


Figure 3.2-2
Stream EC Before and After Mixing with CBNG Produced Water for Mean Monthly Flows
Dry Year Hydrology
USGS 06365300 Dry Fork Cheyenne River Near Bill, WY

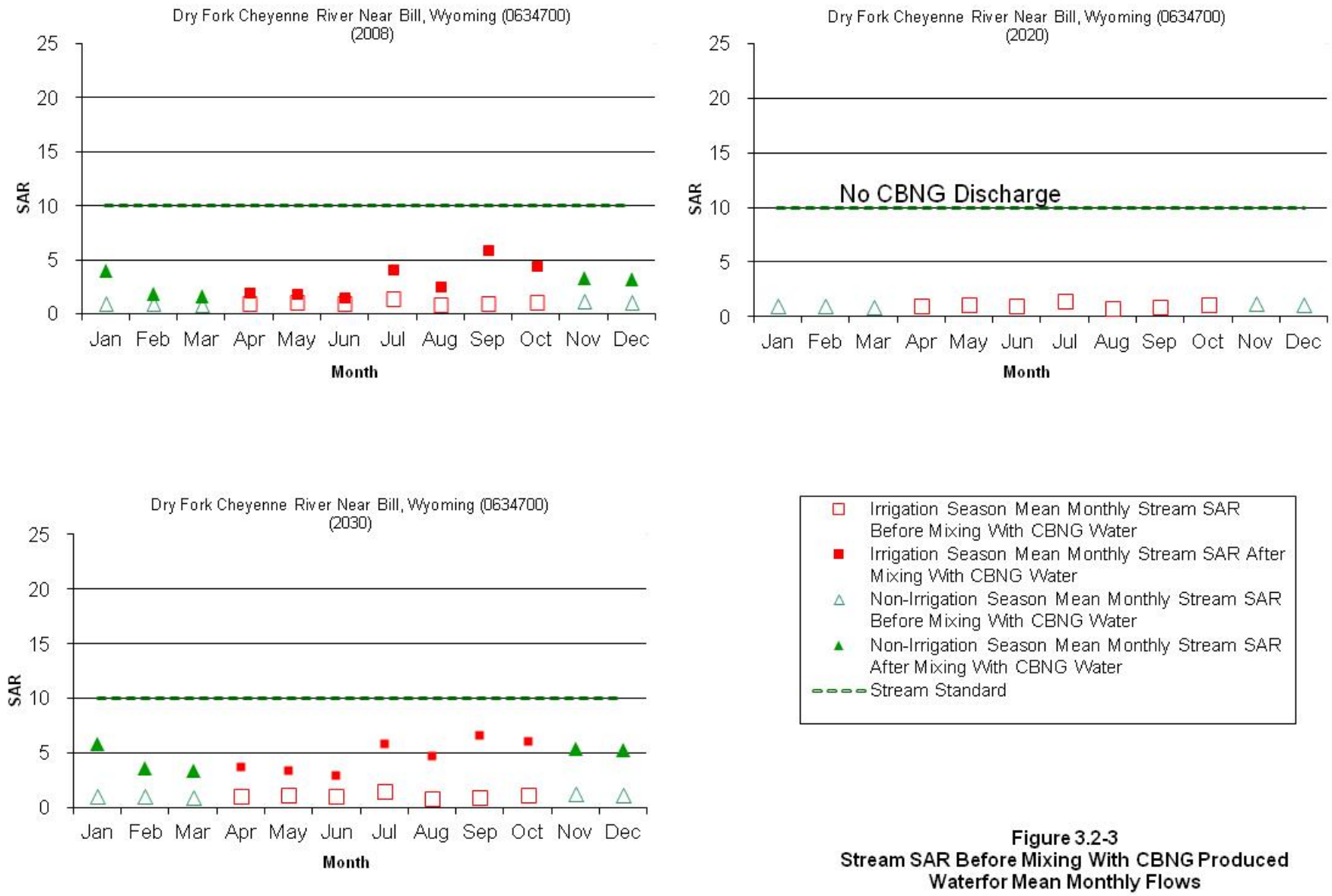


Figure 3.2-3
Stream SAR Before Mixing With CBNG Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
USGS 06365300 Dry Fork Cheyenne River near Bill, WY

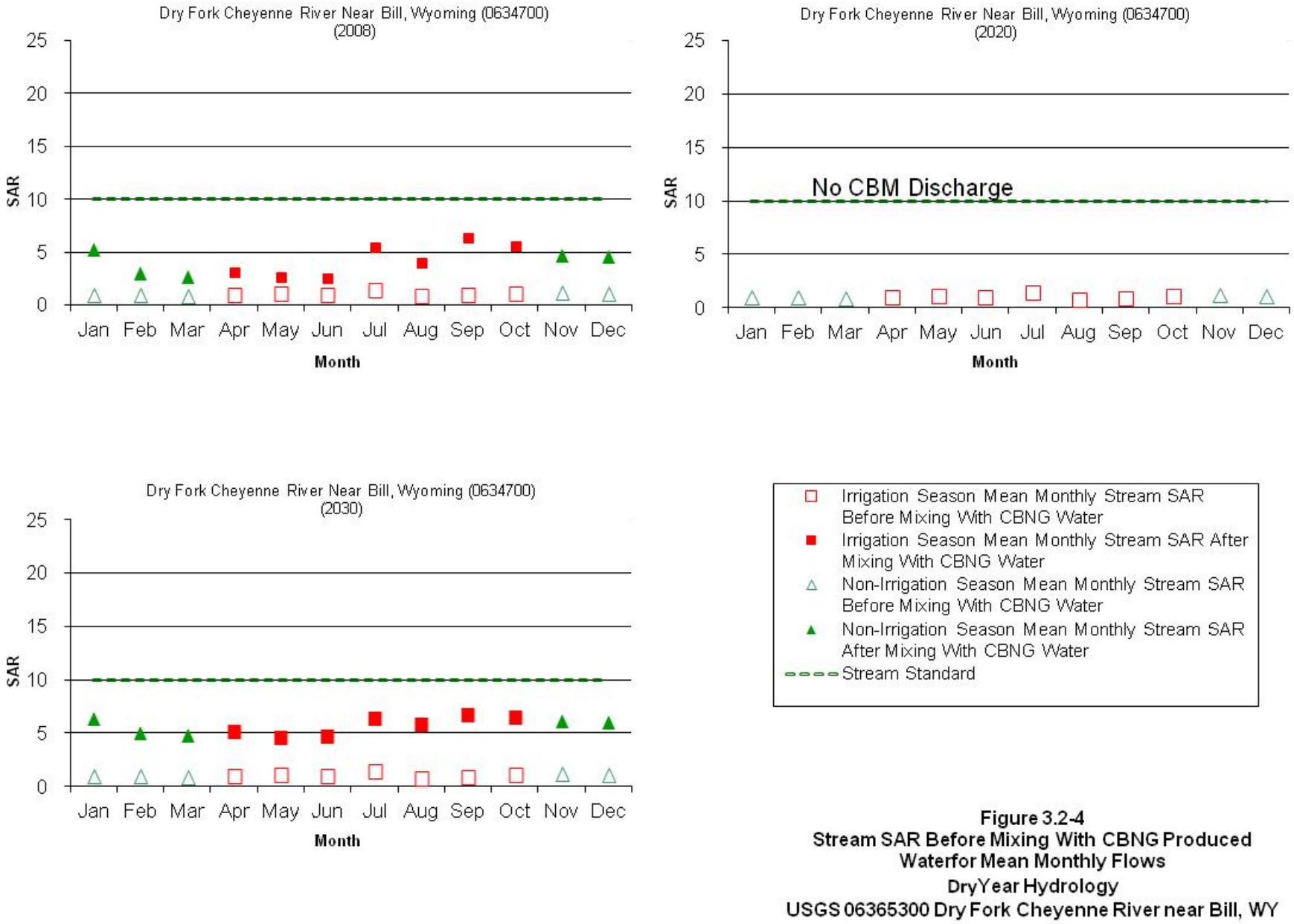


Figure 3.2-4
Stream SAR Before Mixing With CBNG Produced Waterfor Mean Monthly Flows
DryYear Hydrology
USGS 06365300 Dry Fork Cheyenne River near Bill, WY

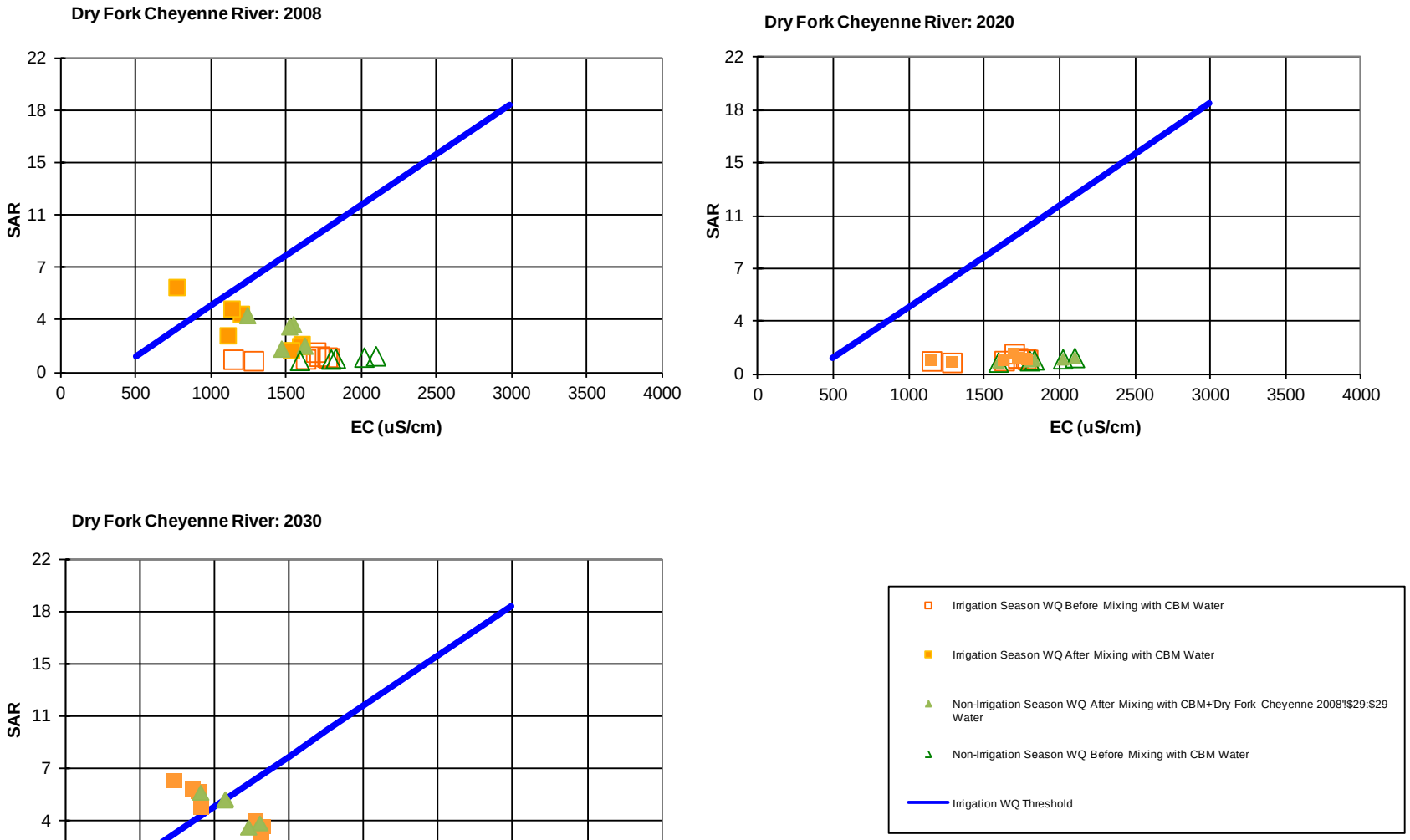


Figure 3.2-5
Dry Fork Cheyenne River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

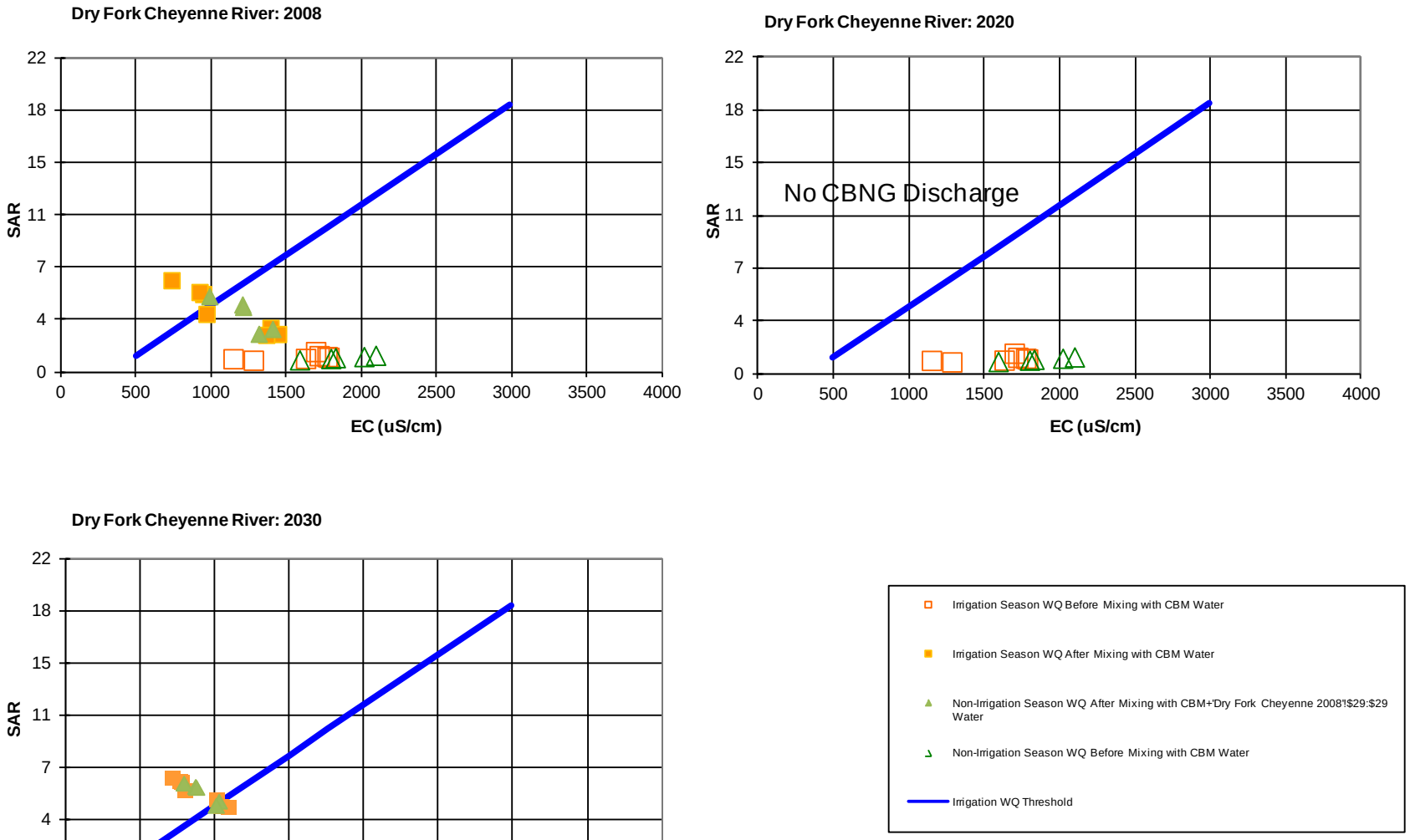


Figure 3.2-6
Dry Fork Cheyenne River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(DryYear Hydrology)

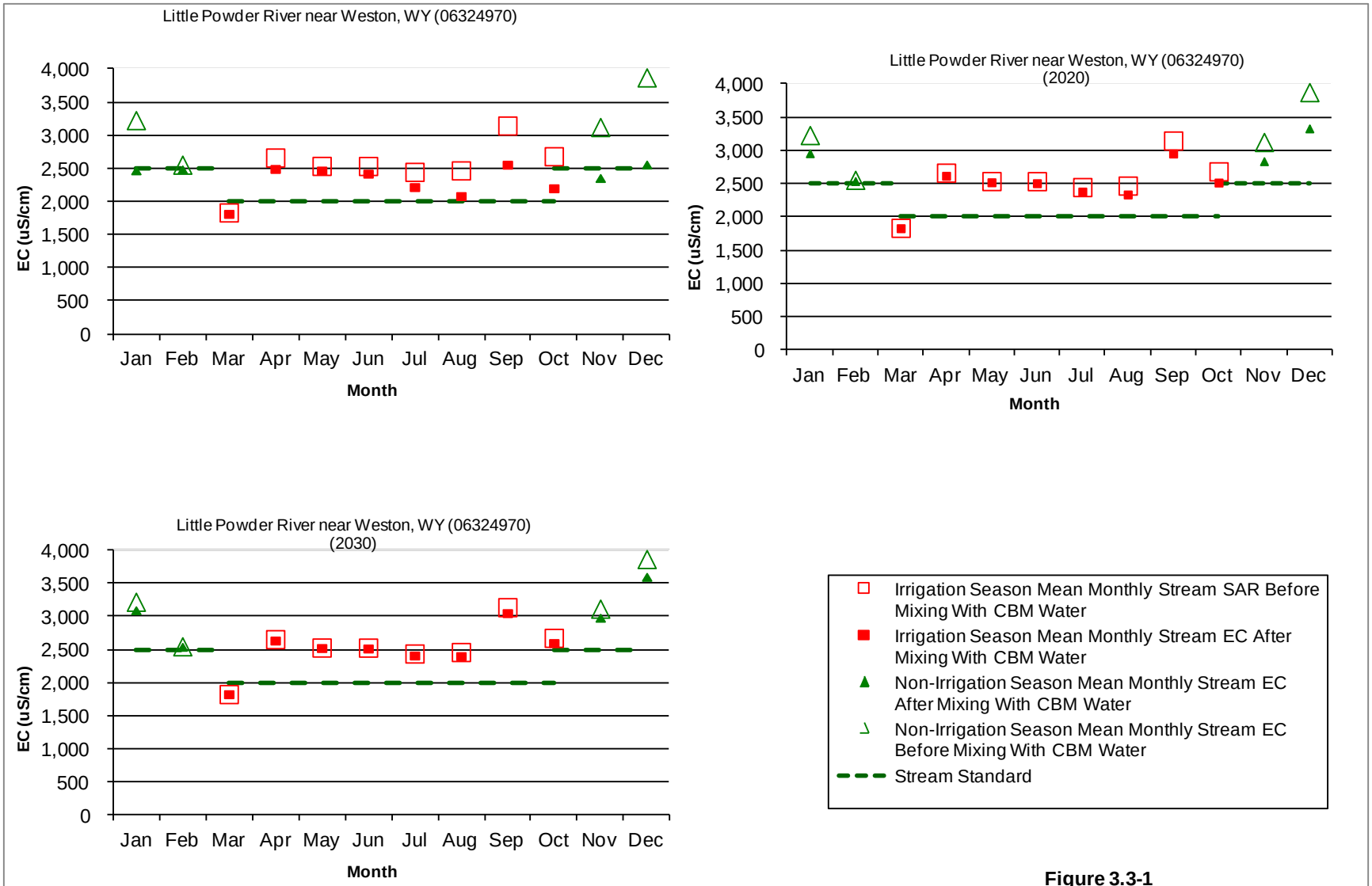


Figure 3.3-1
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Little Powder River near Weston, WY (06324970)

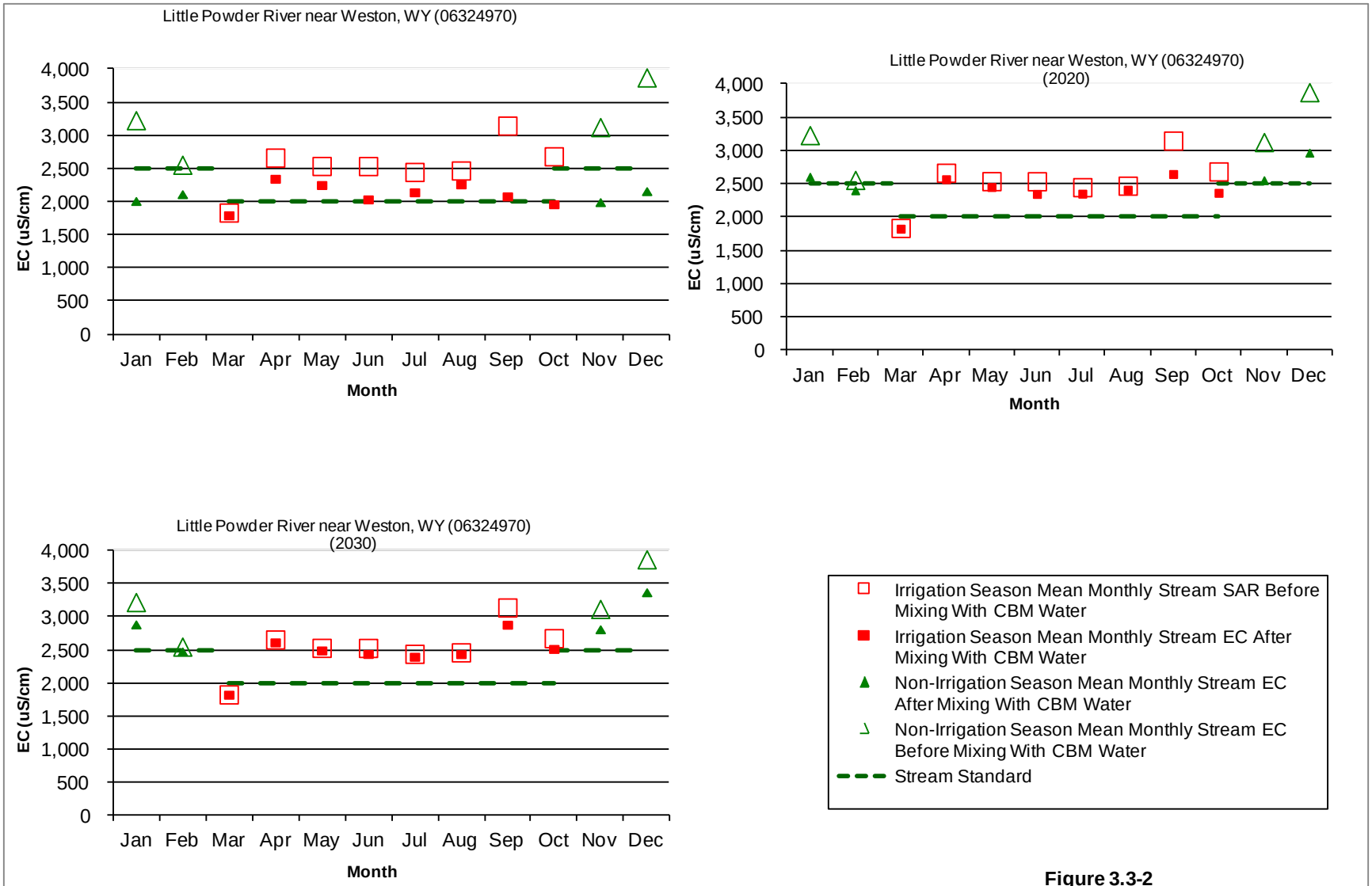


Figure 3.3-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Little Powder River near Weston, WY (06324970)

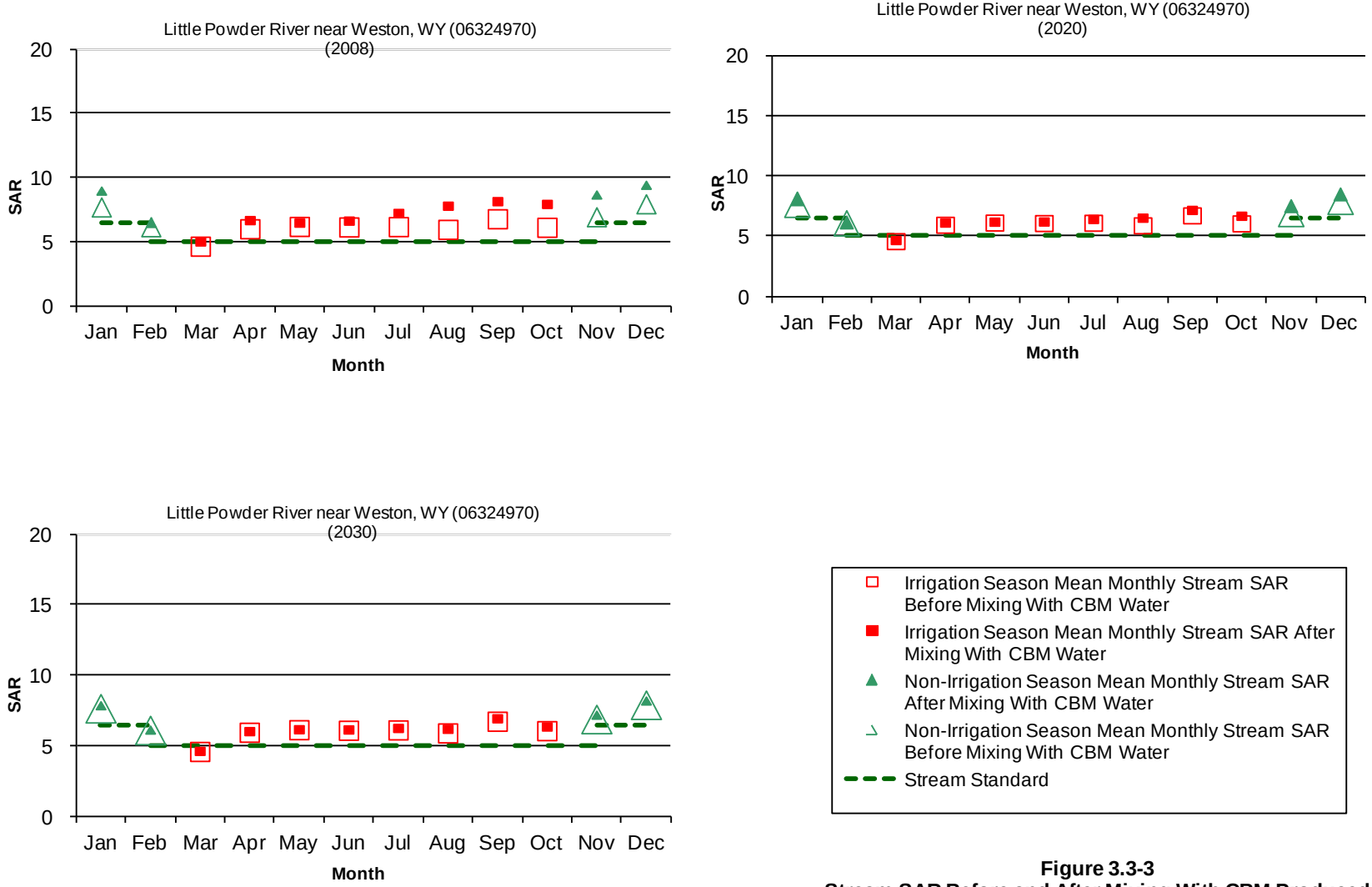


Figure 3.3-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Little Powder River near Weston, WY (06324970)

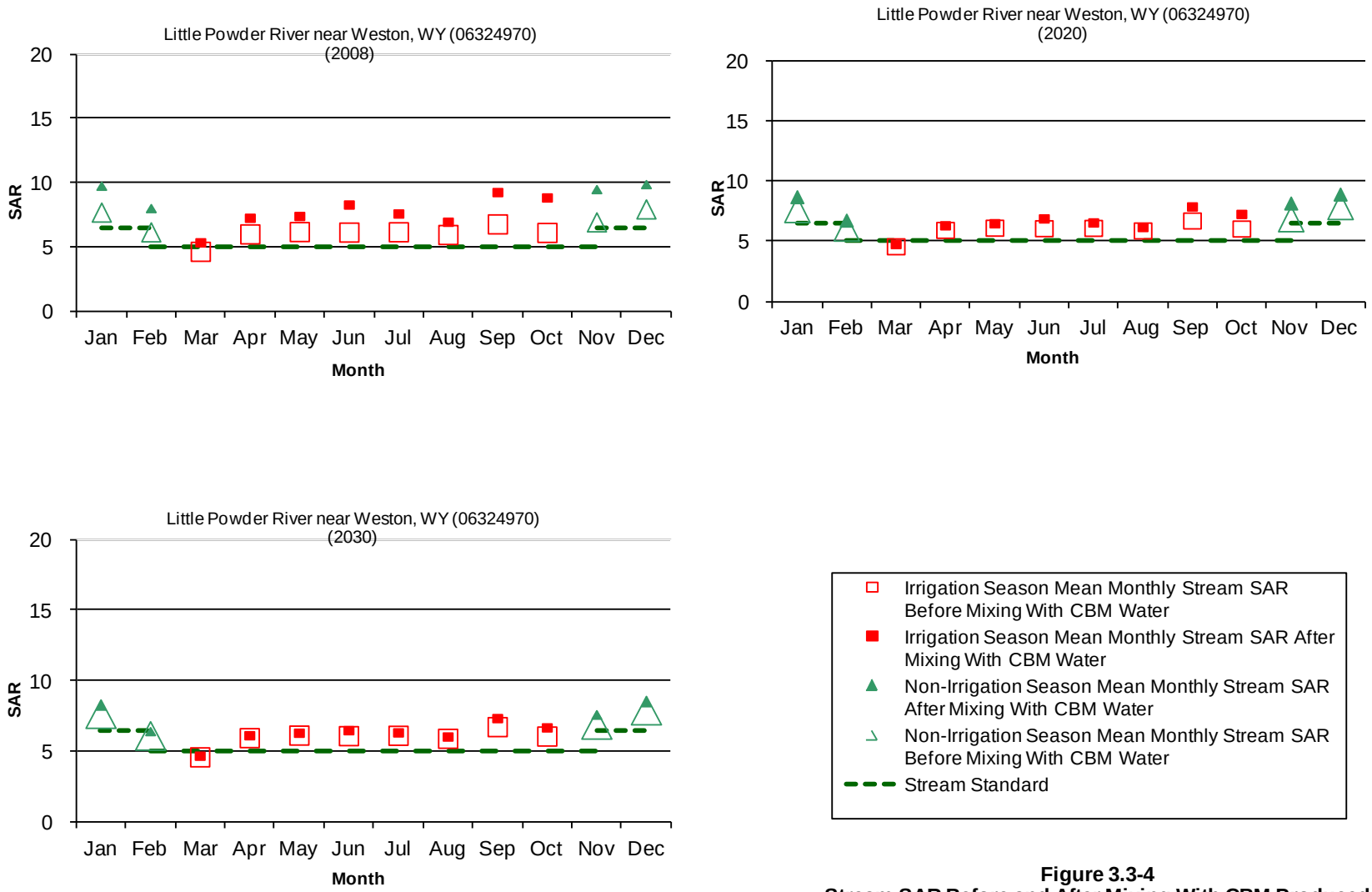


Figure 3.3-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
DryYear Hydrology
Little Powder River near Weston, WY (06324970)

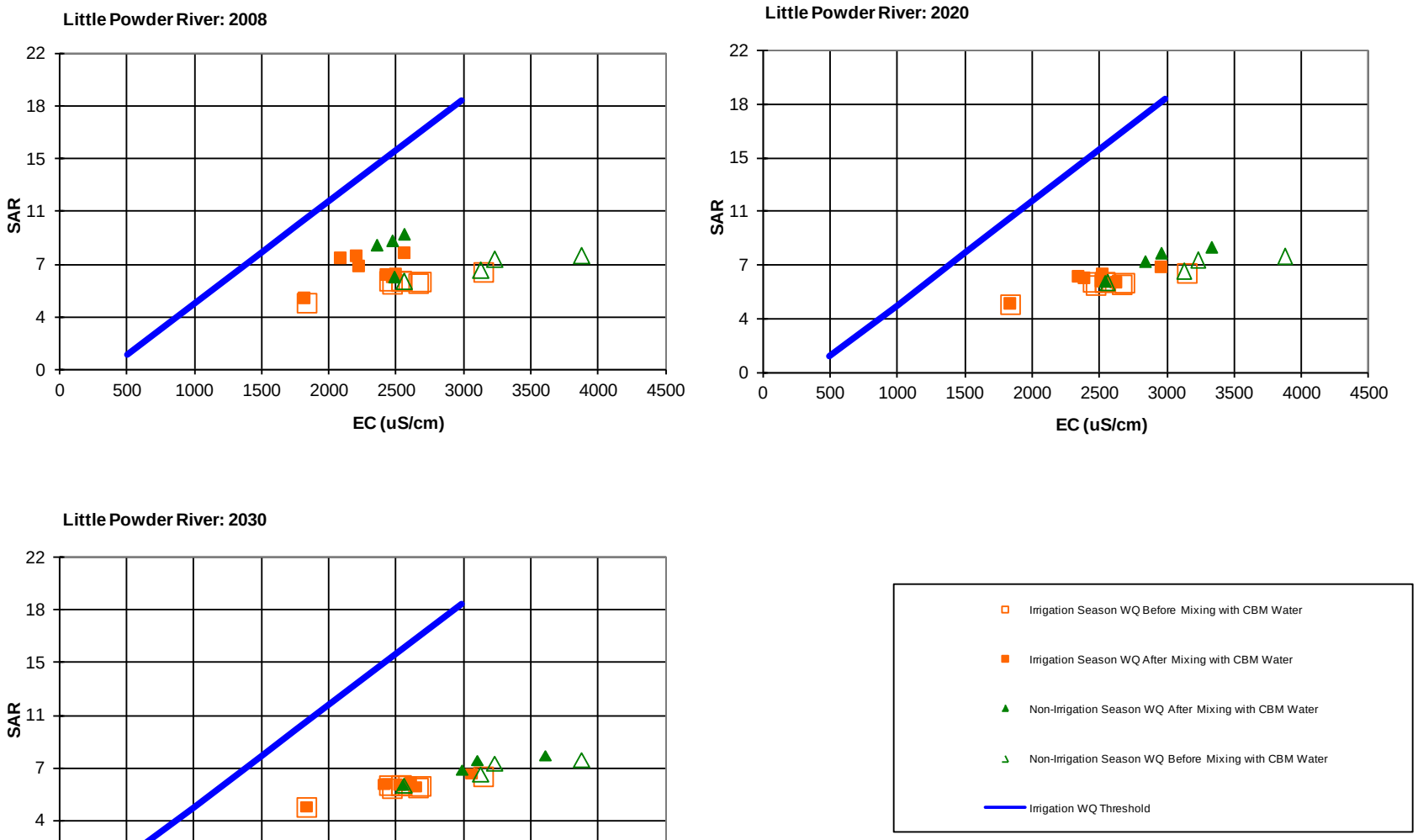


Figure 3.3-5
Little Powder River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

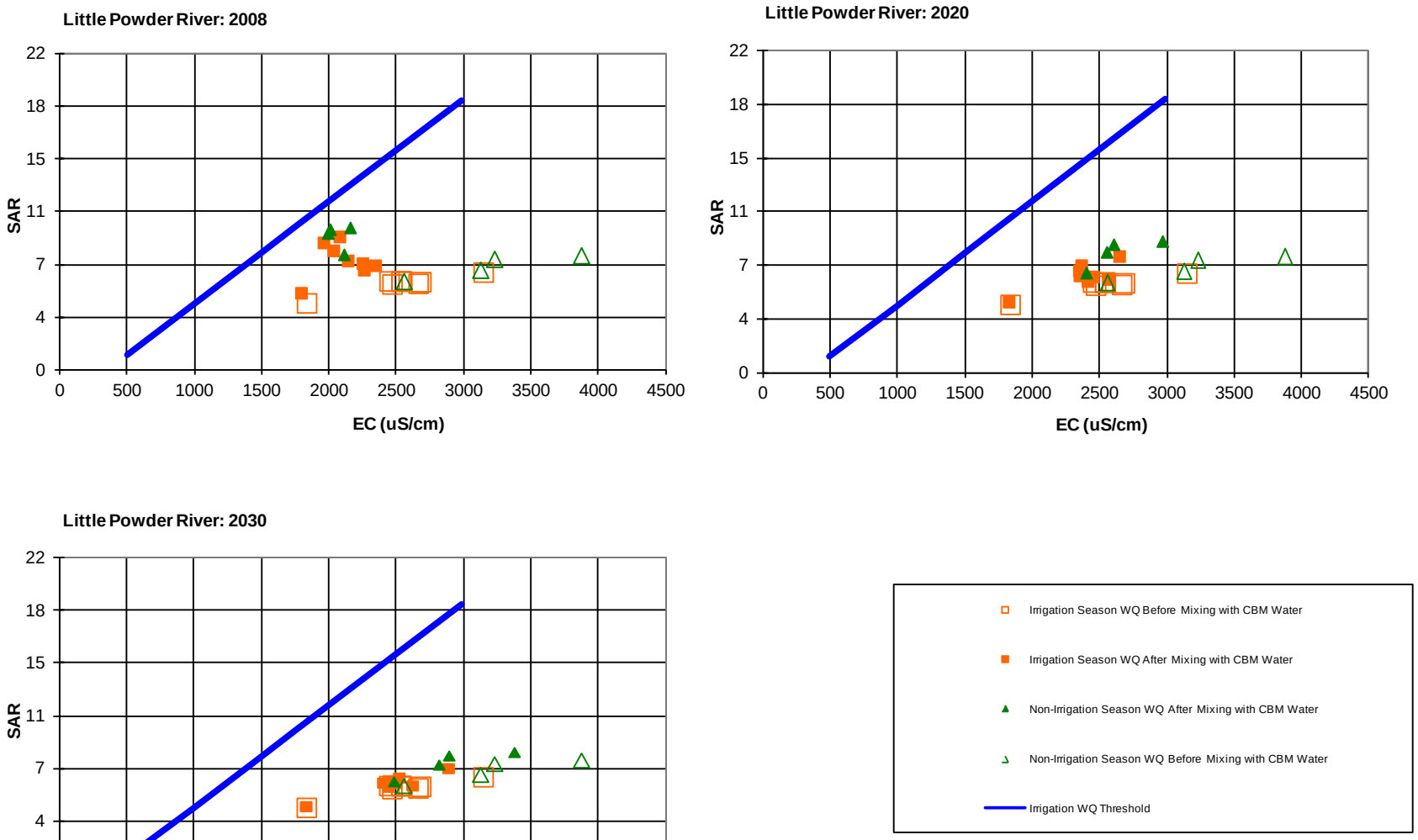


Figure 3.3-6
Little Powder River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

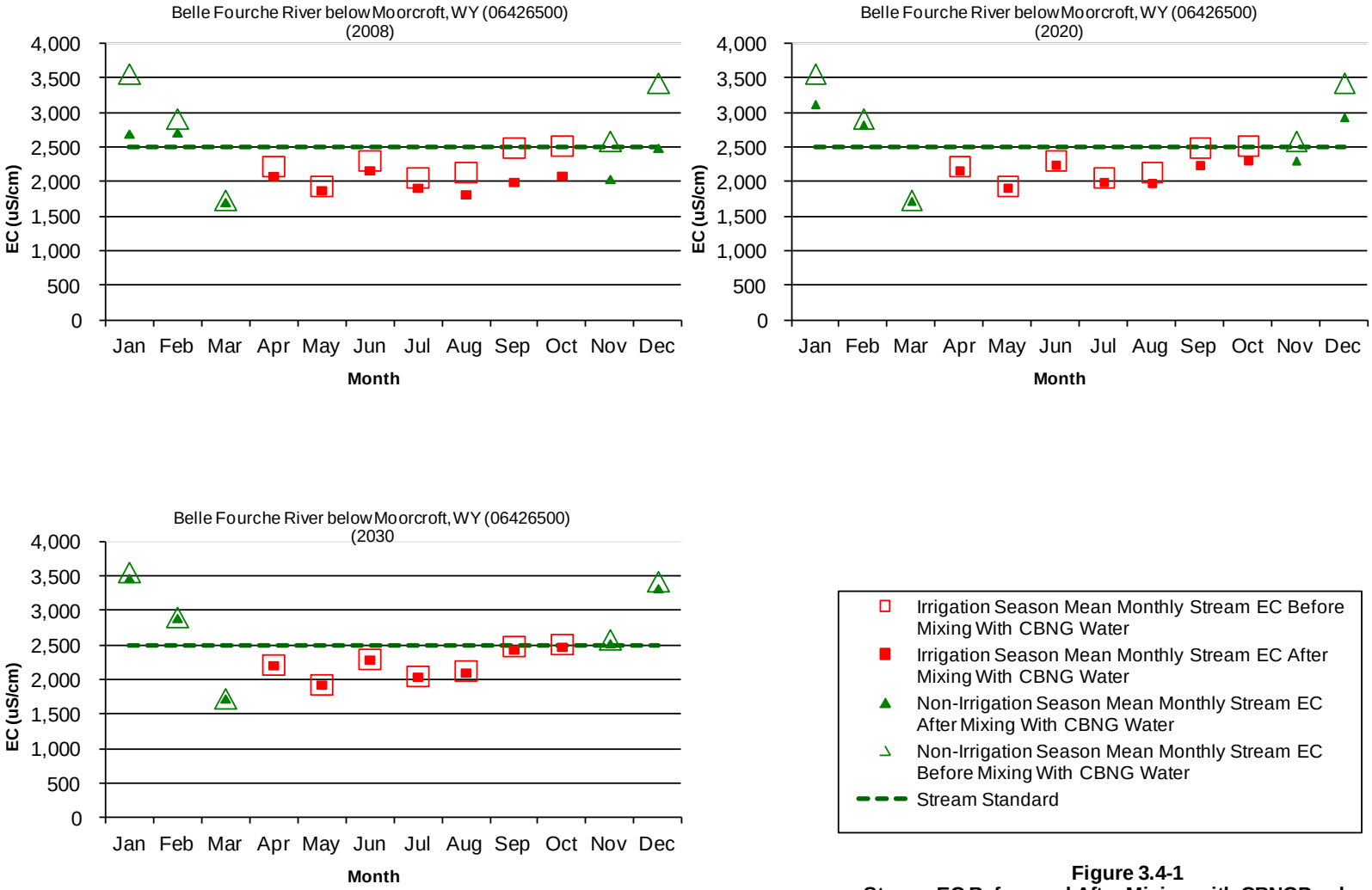


Figure 3.4-1
Stream EC Before and After Mixing with CBNGProduced Water for Mean Monthly Flows
Normal Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

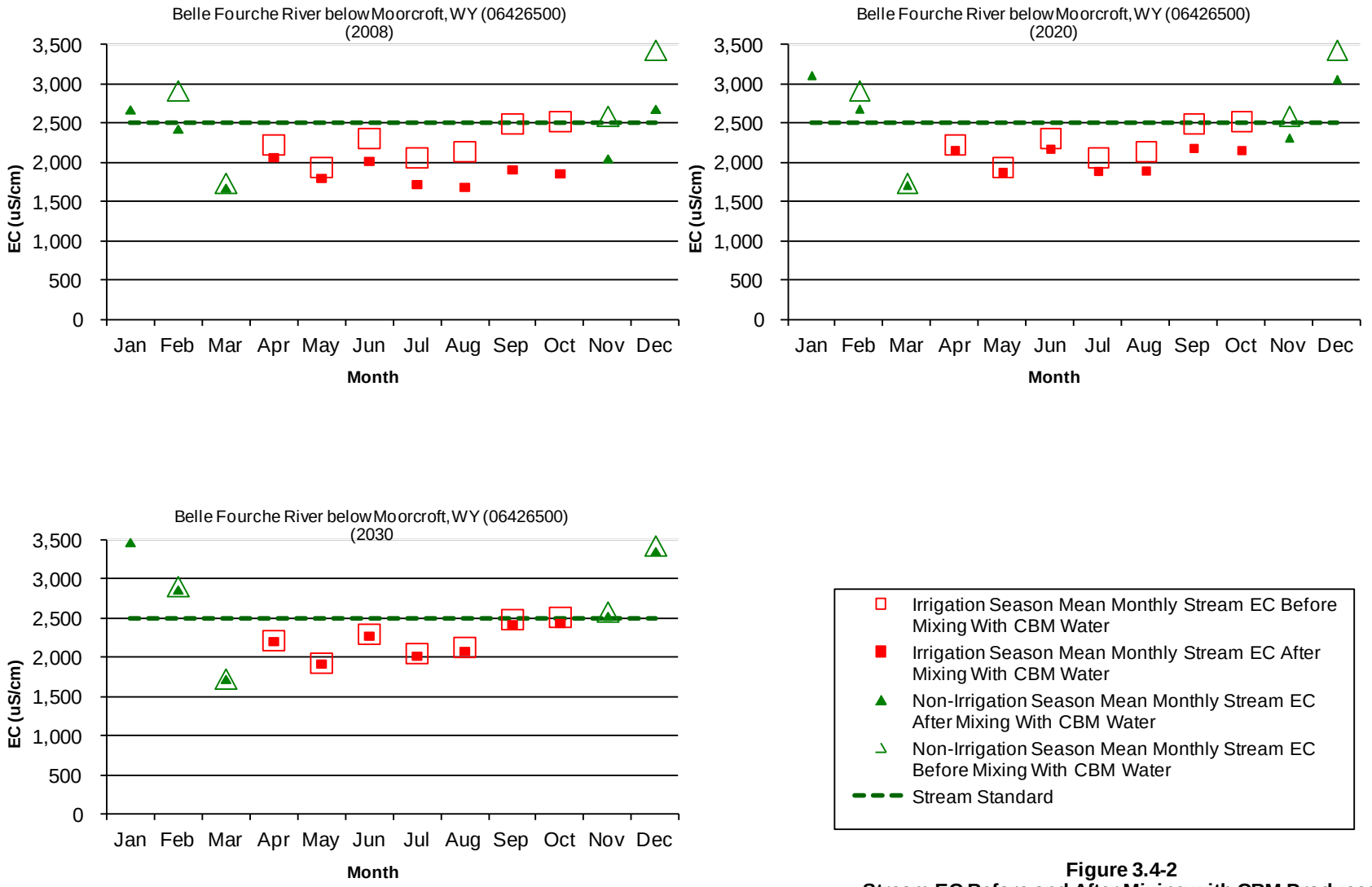


Figure 3.4-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
DryYear Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

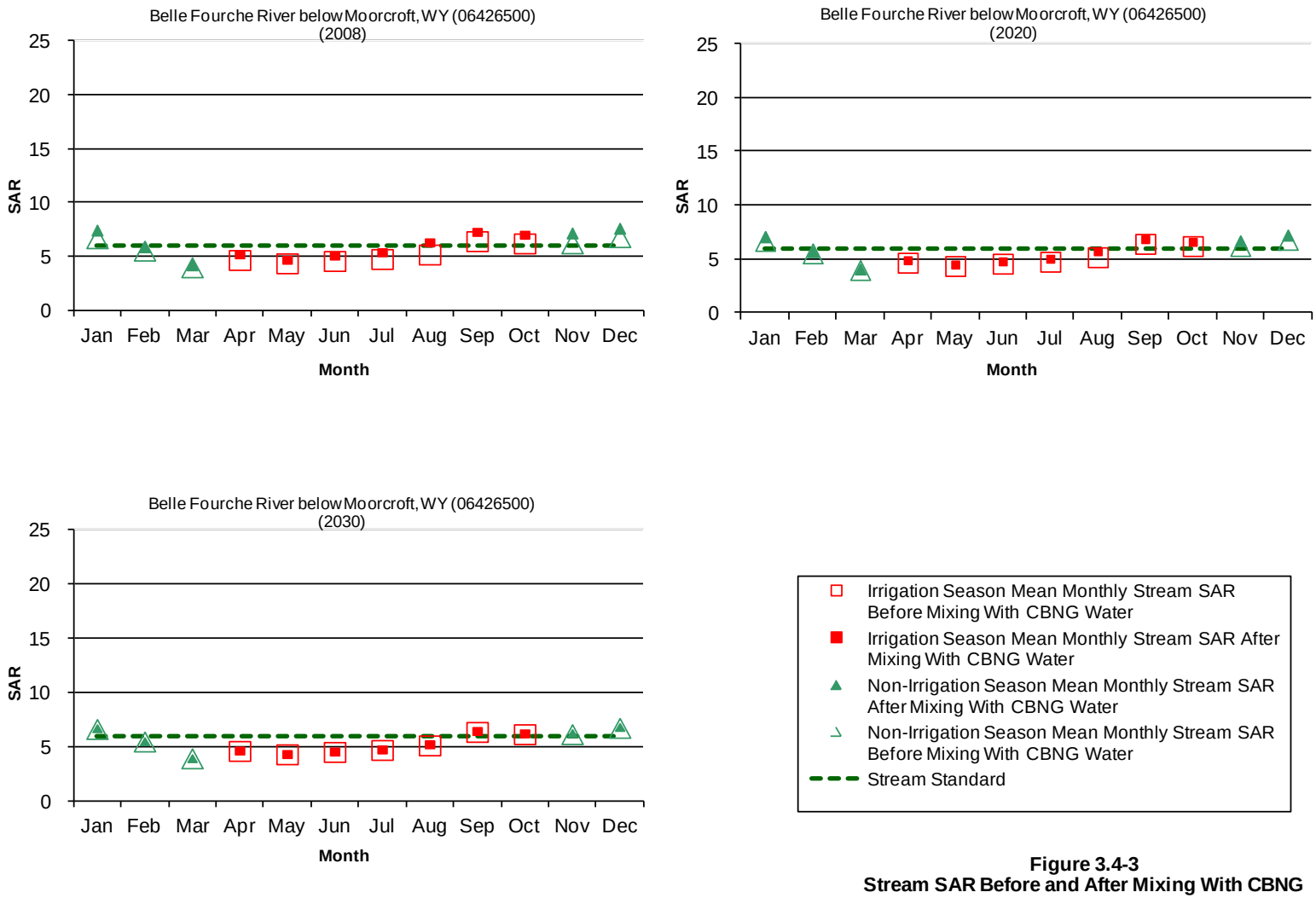


Figure 3.4-3
Stream SAR Before and After Mixing With CBNG Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

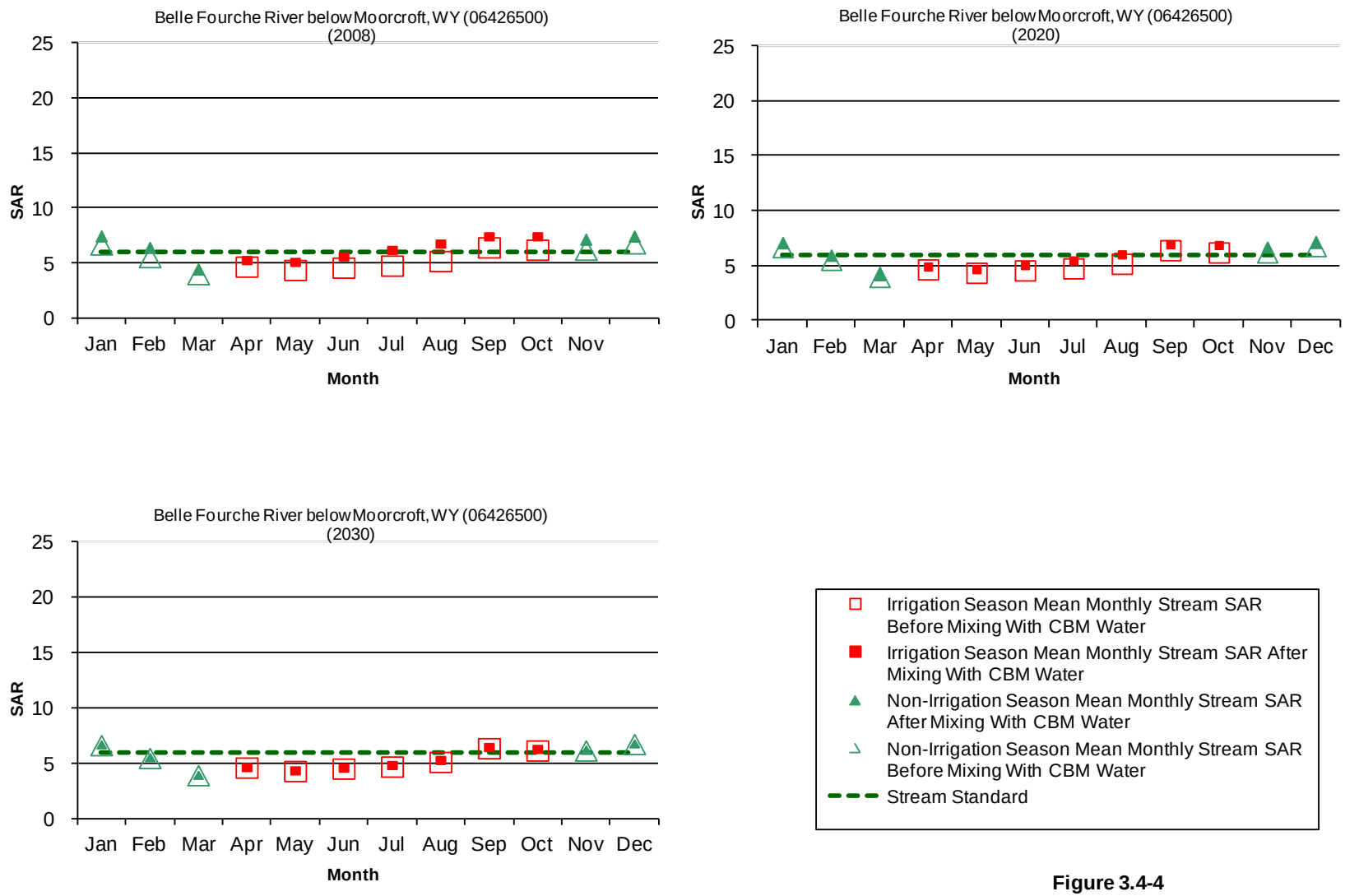


Figure 3.4-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Belle Fourche River below Moorcroft, WY (06426500)

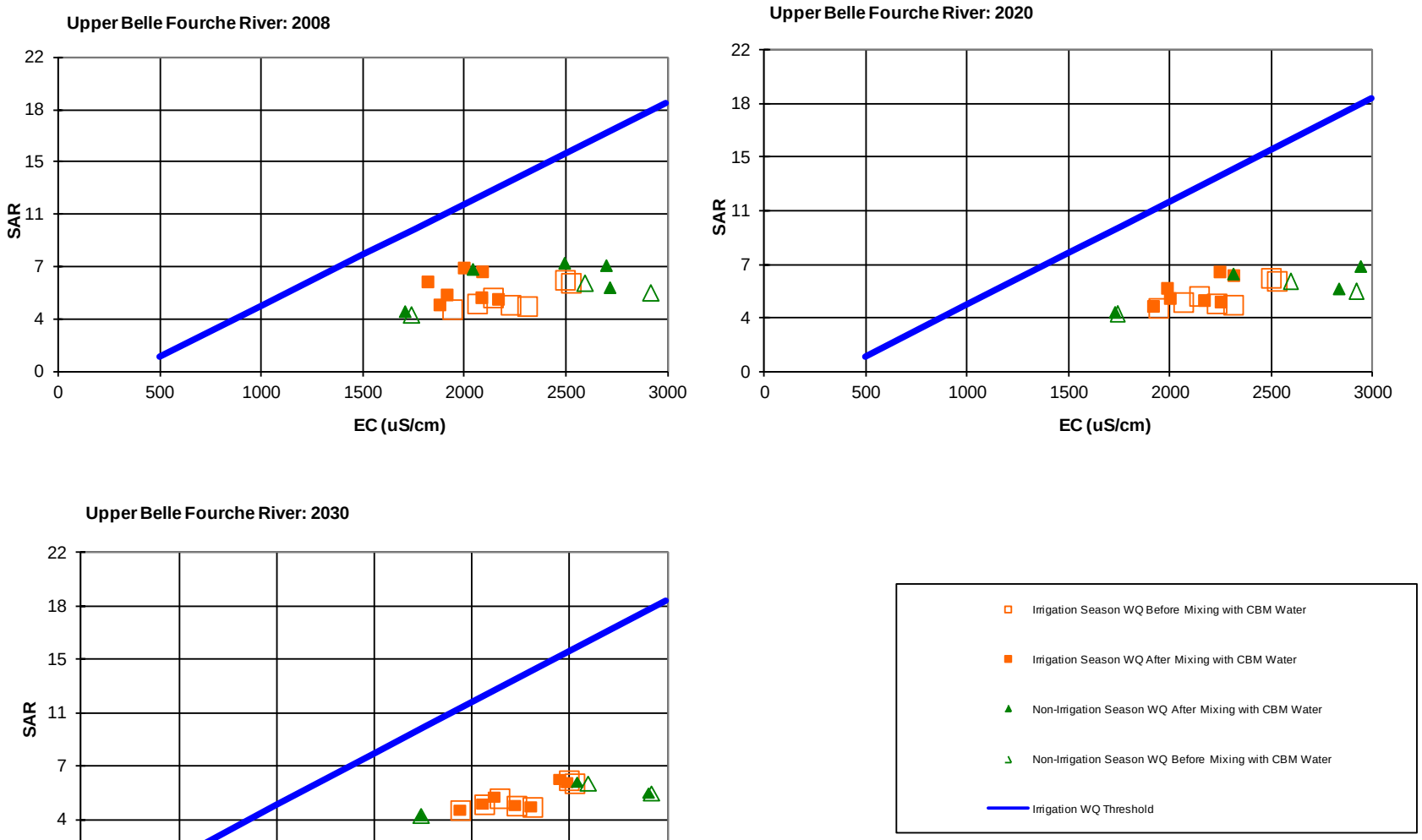


Figure 3.4-5
Belle Fourche River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

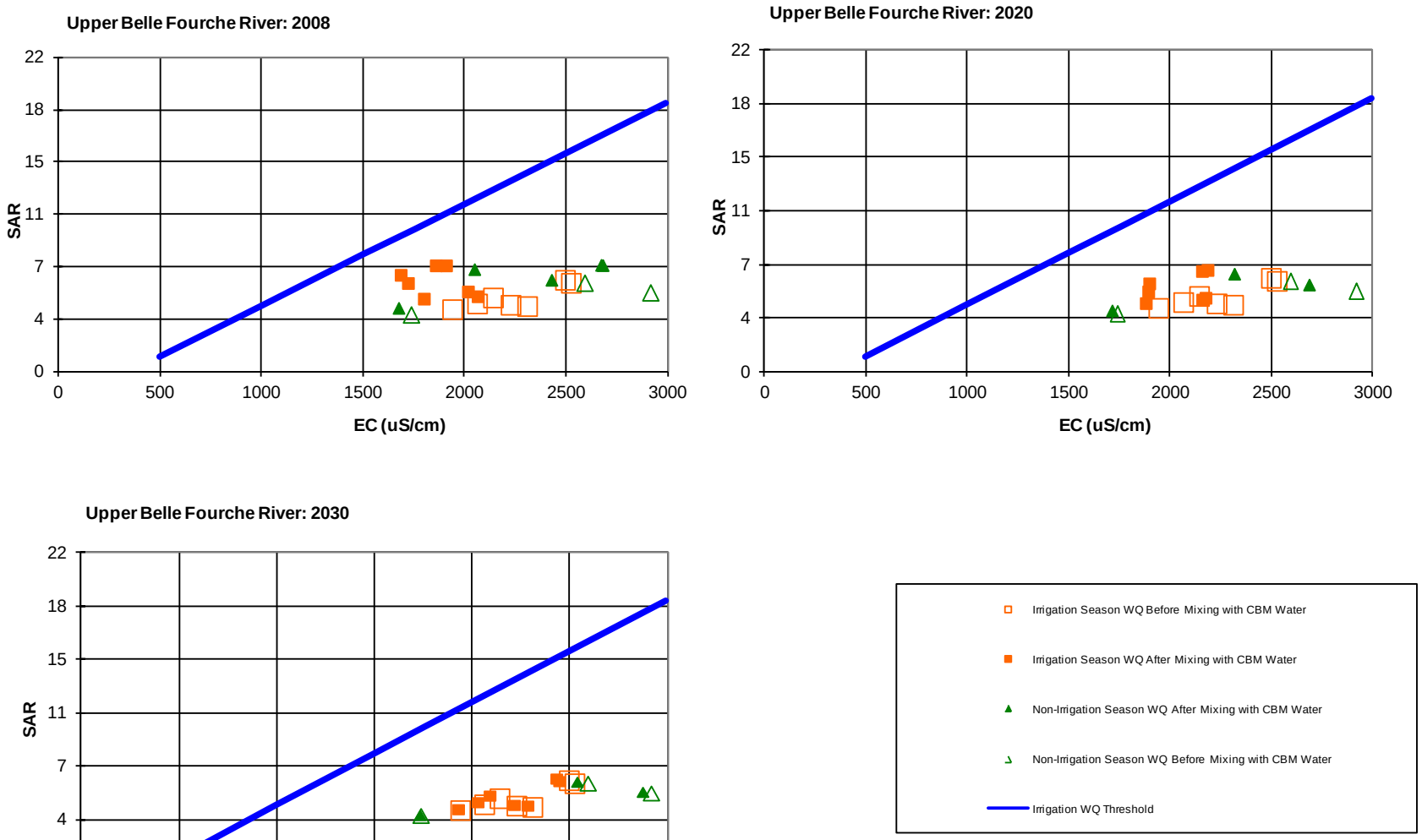


Figure 3.4-6
Belle Fourche River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(DryYear Hydrology)

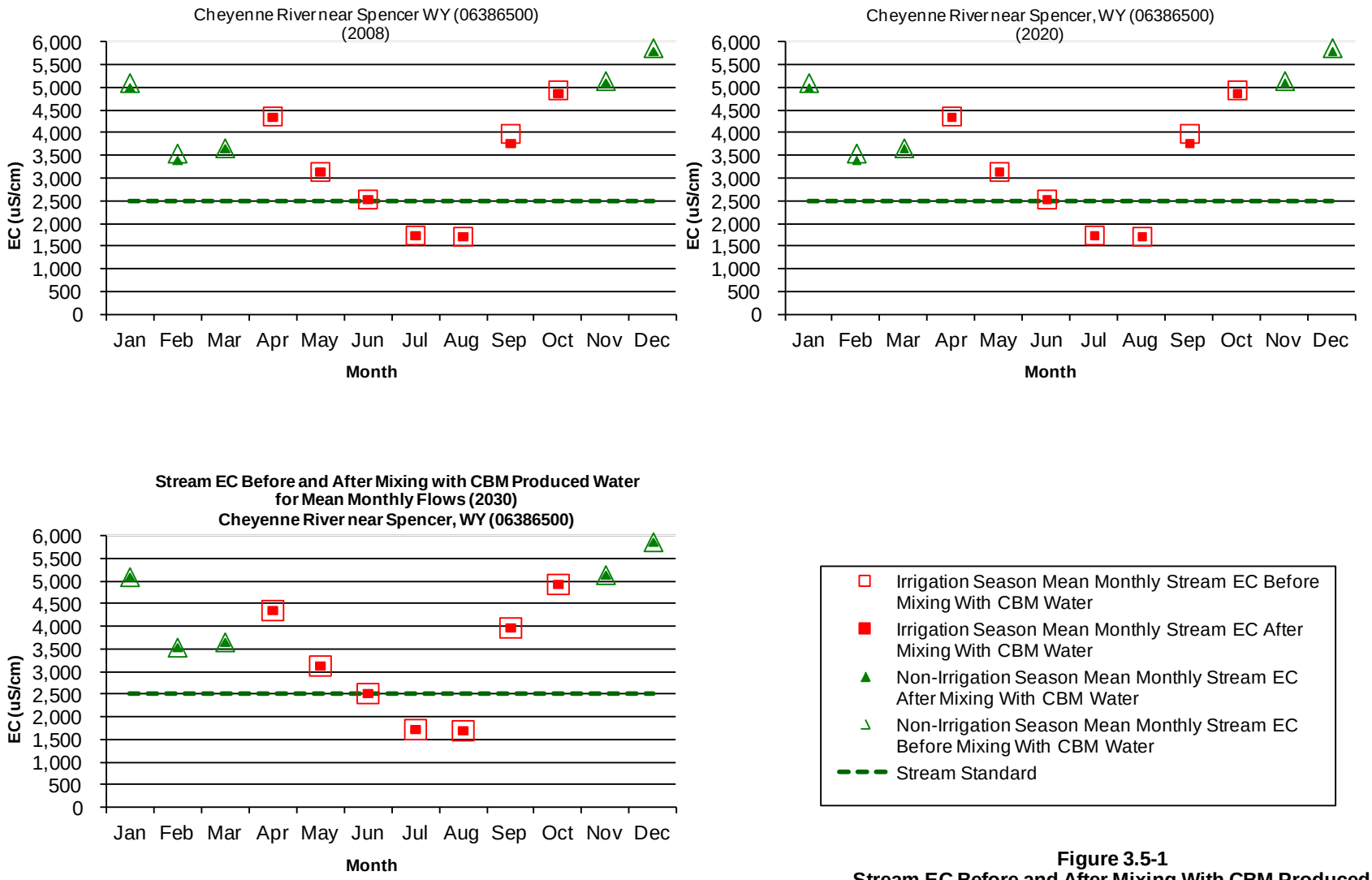


Figure 3.5-1
Stream EC Before and After Mixing With CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Cheyenne River near Spencer, WY (06386500)

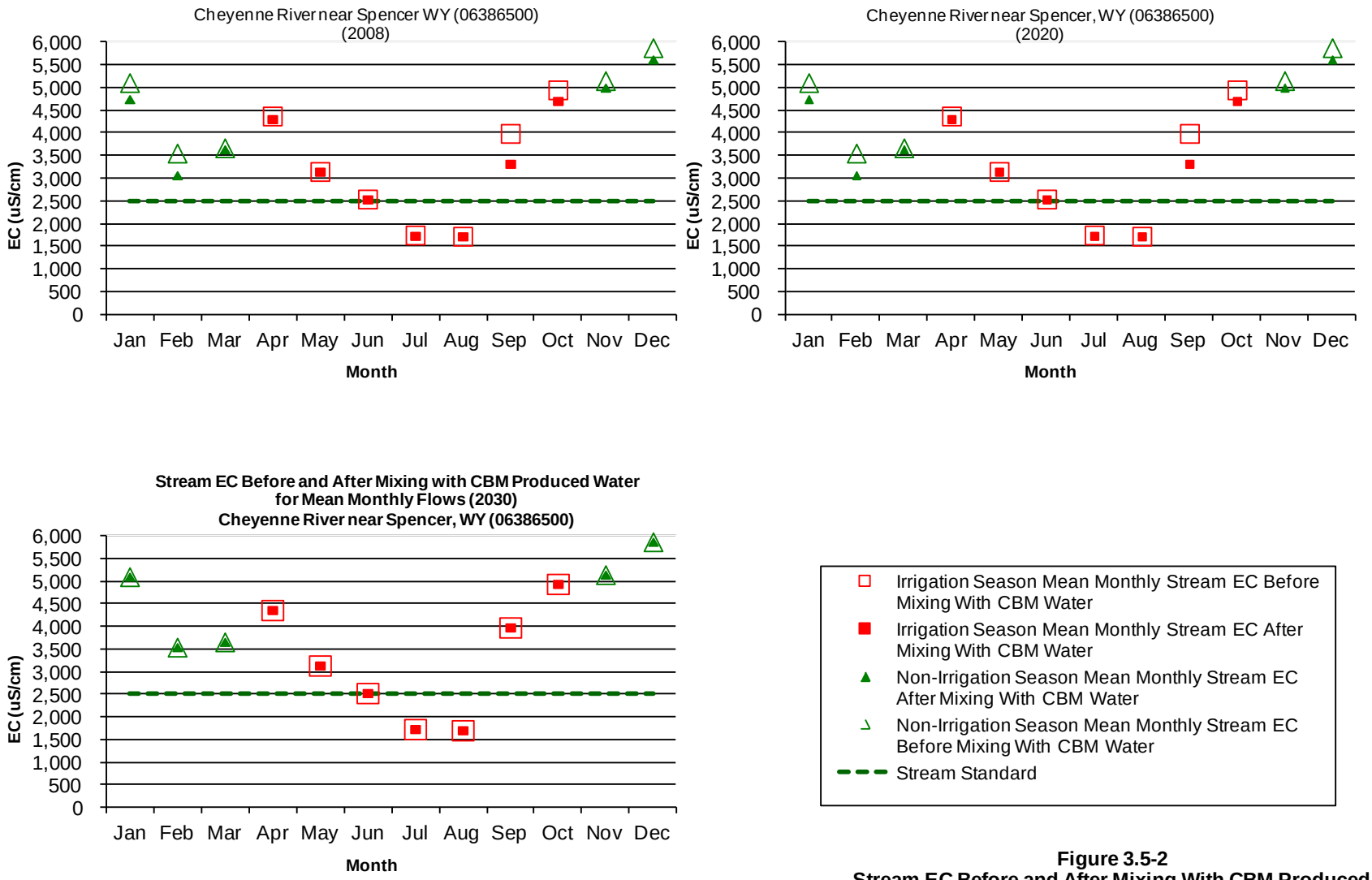


Figure 3.5-2
Stream EC Before and After Mixing With CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Cheyenne River near Spencer, WY (06386500)

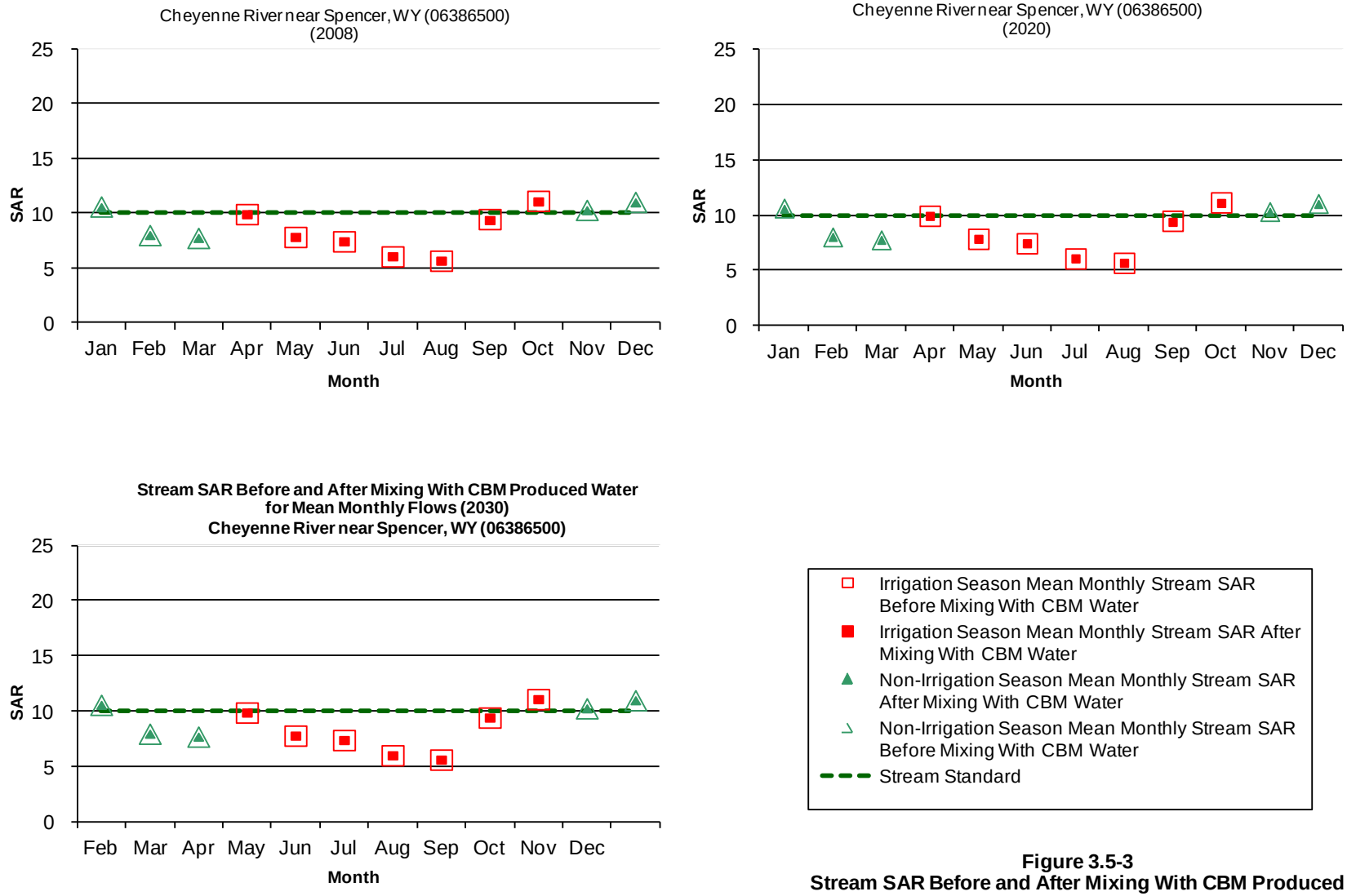
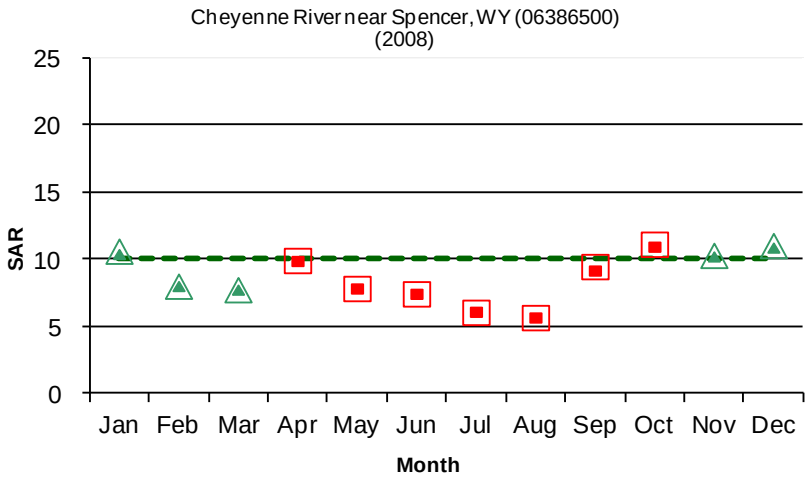
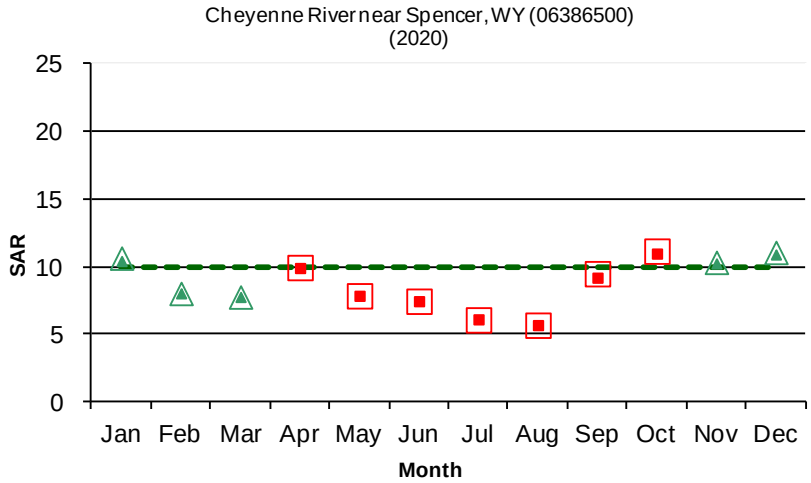


Figure 3.5-3
Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Cheyenne River near Spencer, WY (06386500)





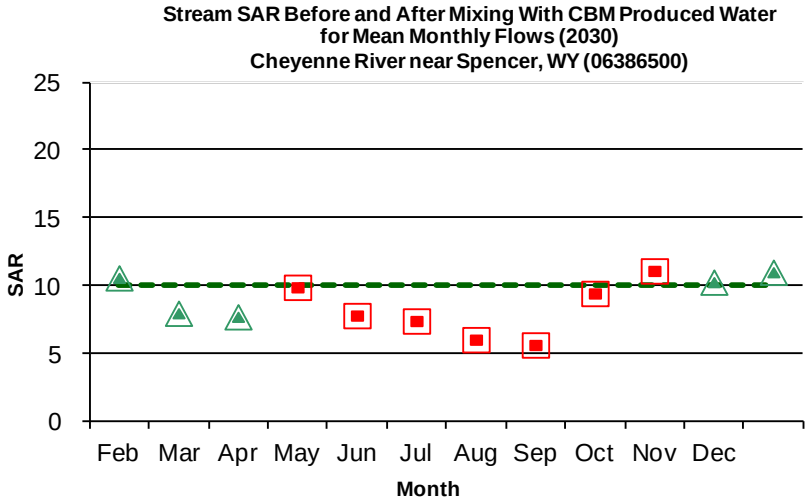


Figure 3.5-4
Stream SAR Before and After Mixing With CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Cheyenne River near Spencer, WY (06386500)

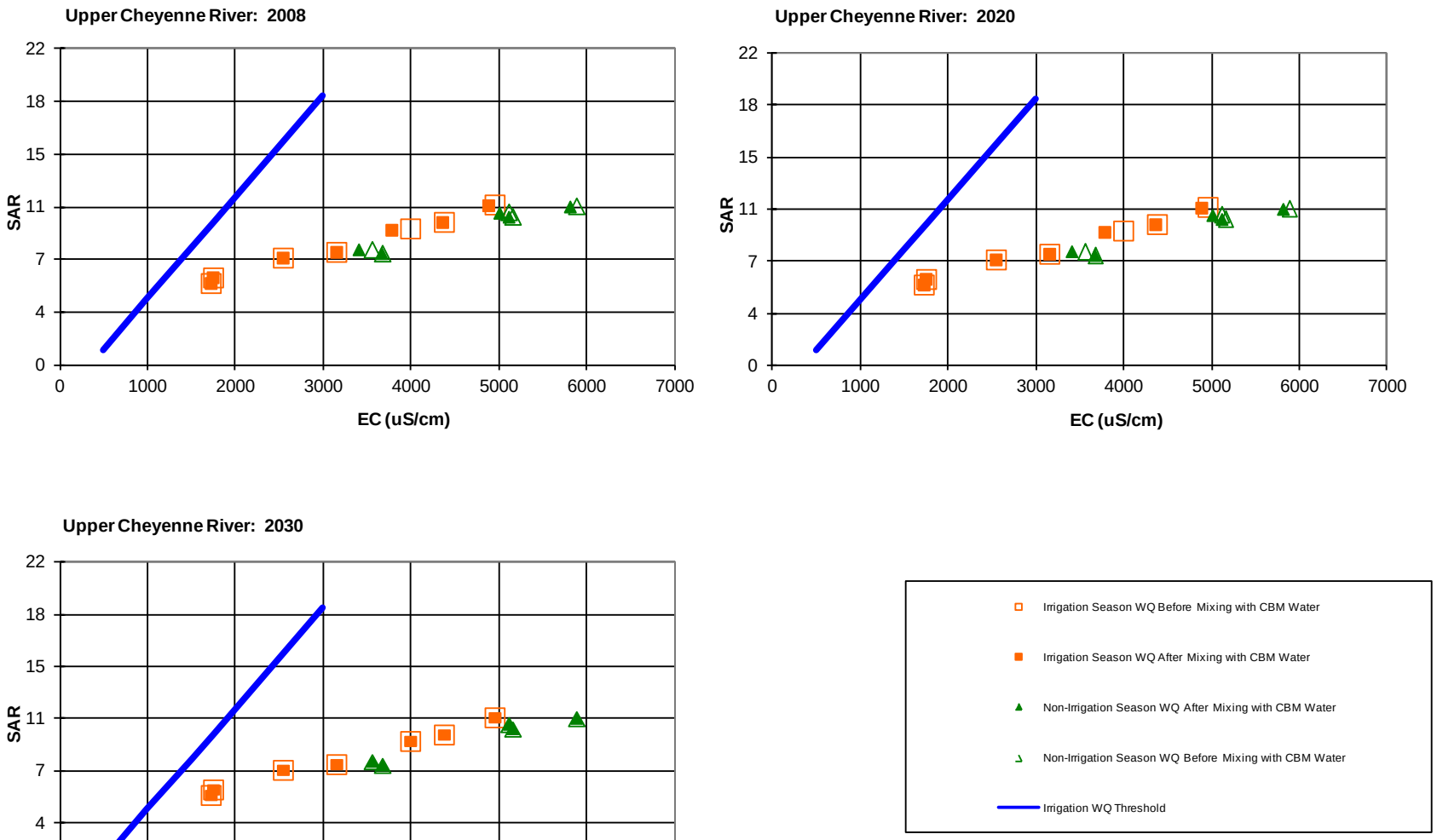


Figure 3.5-5
Upper Cheyenne River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

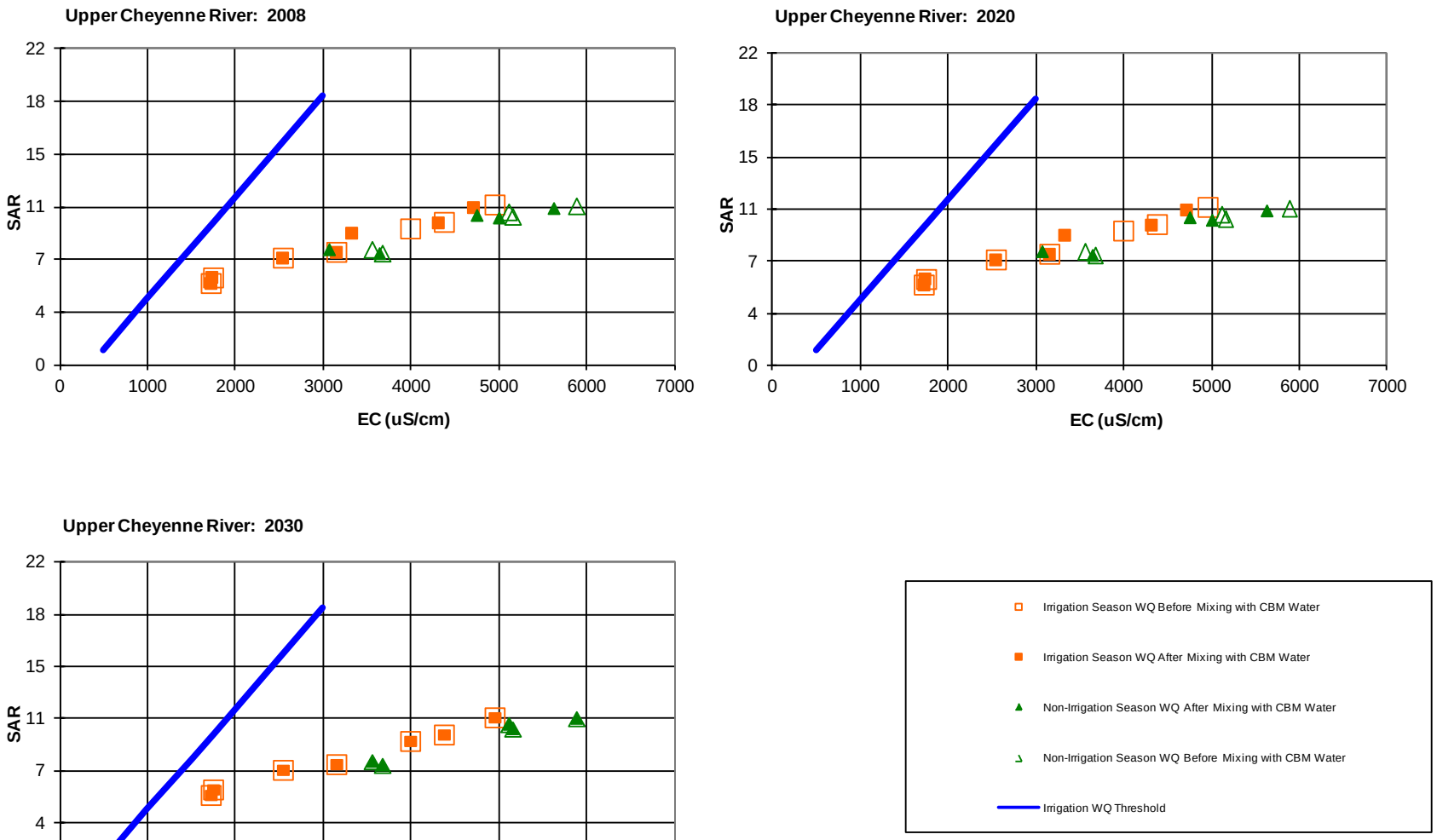


Figure 3.5-6
Upper Cheyenne River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

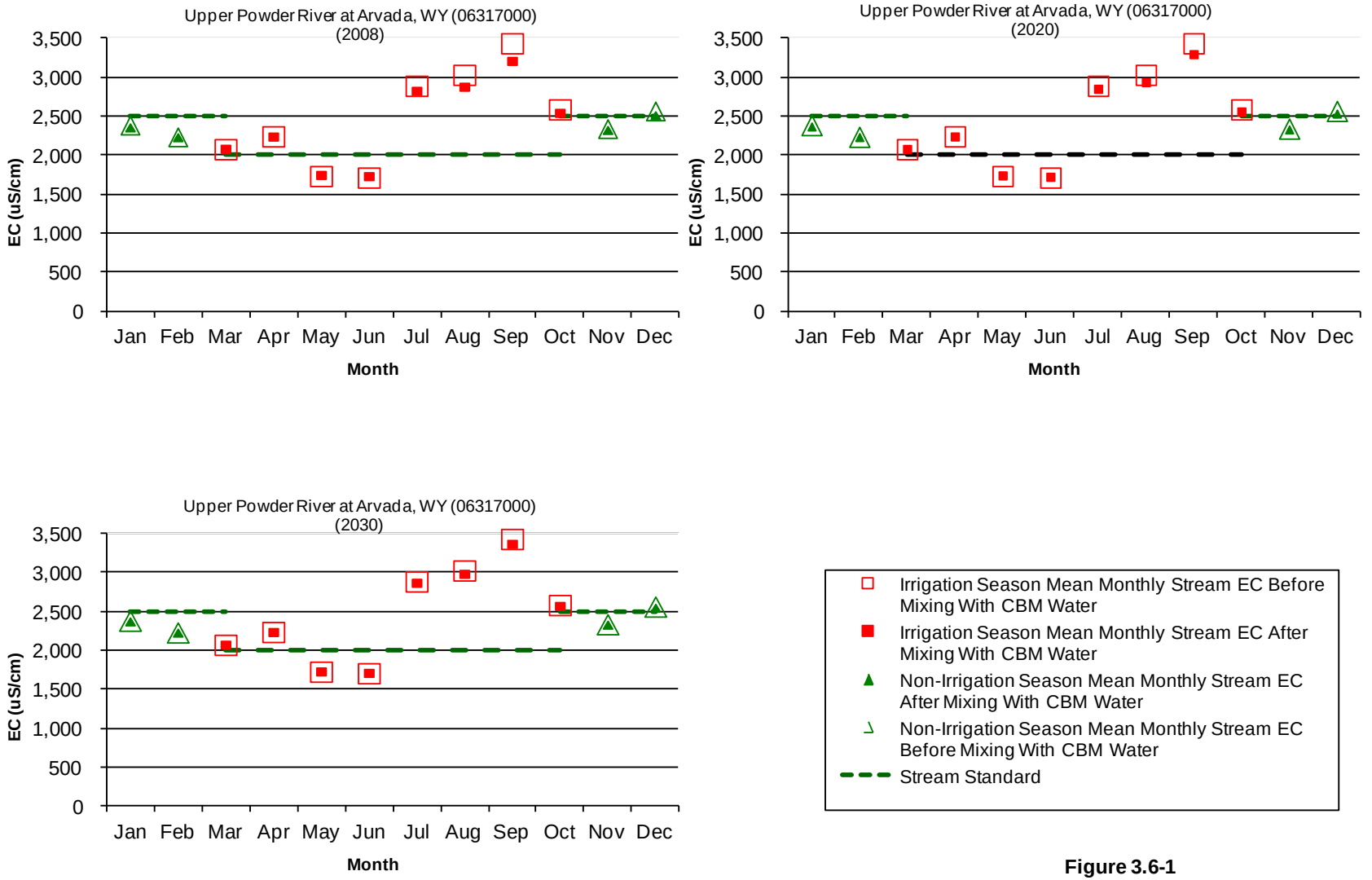


Figure 3.6-1
Stream EC Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Upper Powder River at Arvada, WY (06317000)

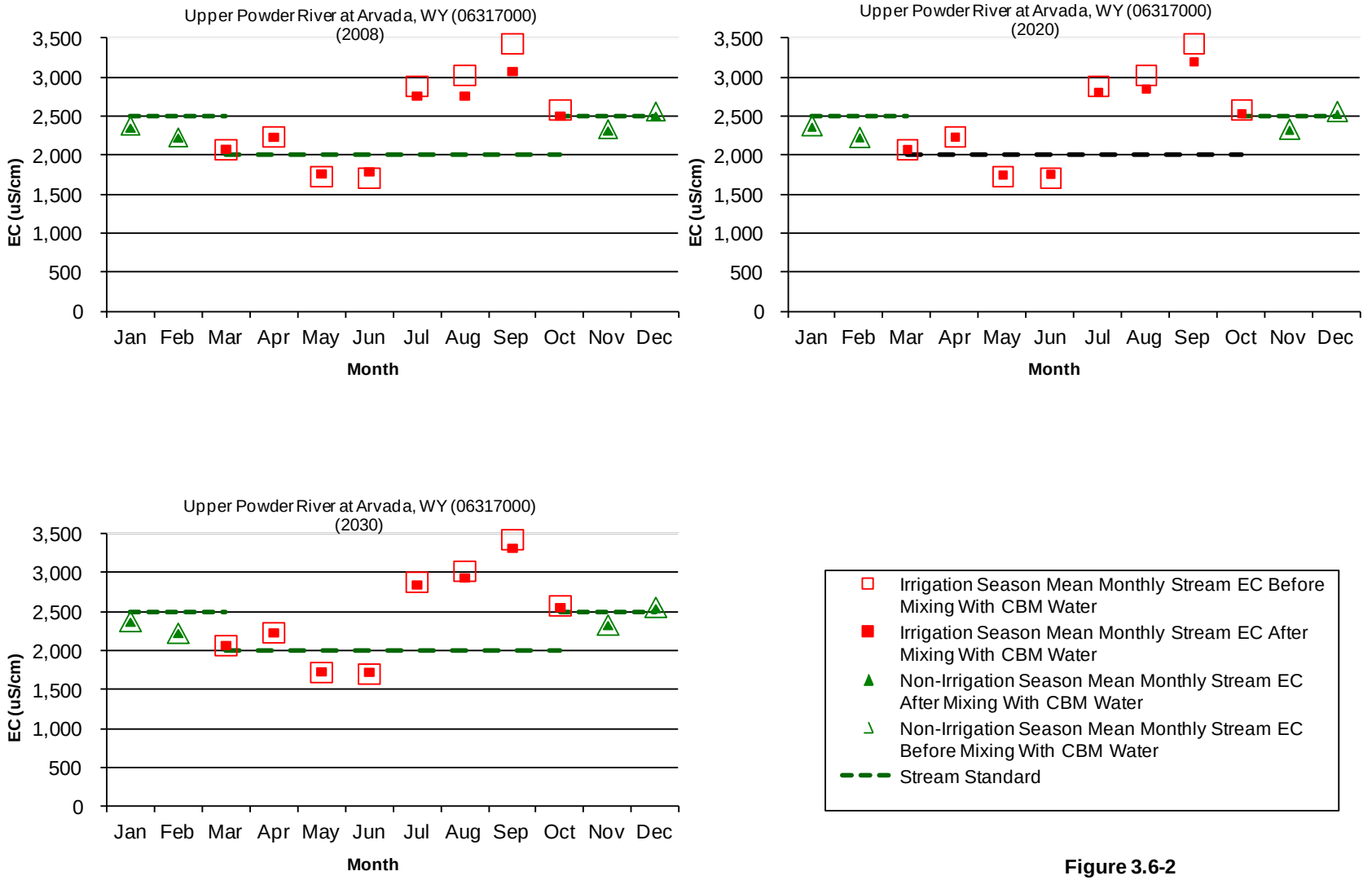


Figure 3.6-2
Stream EC Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Upper Powder River at Arvada, WY (06317000)

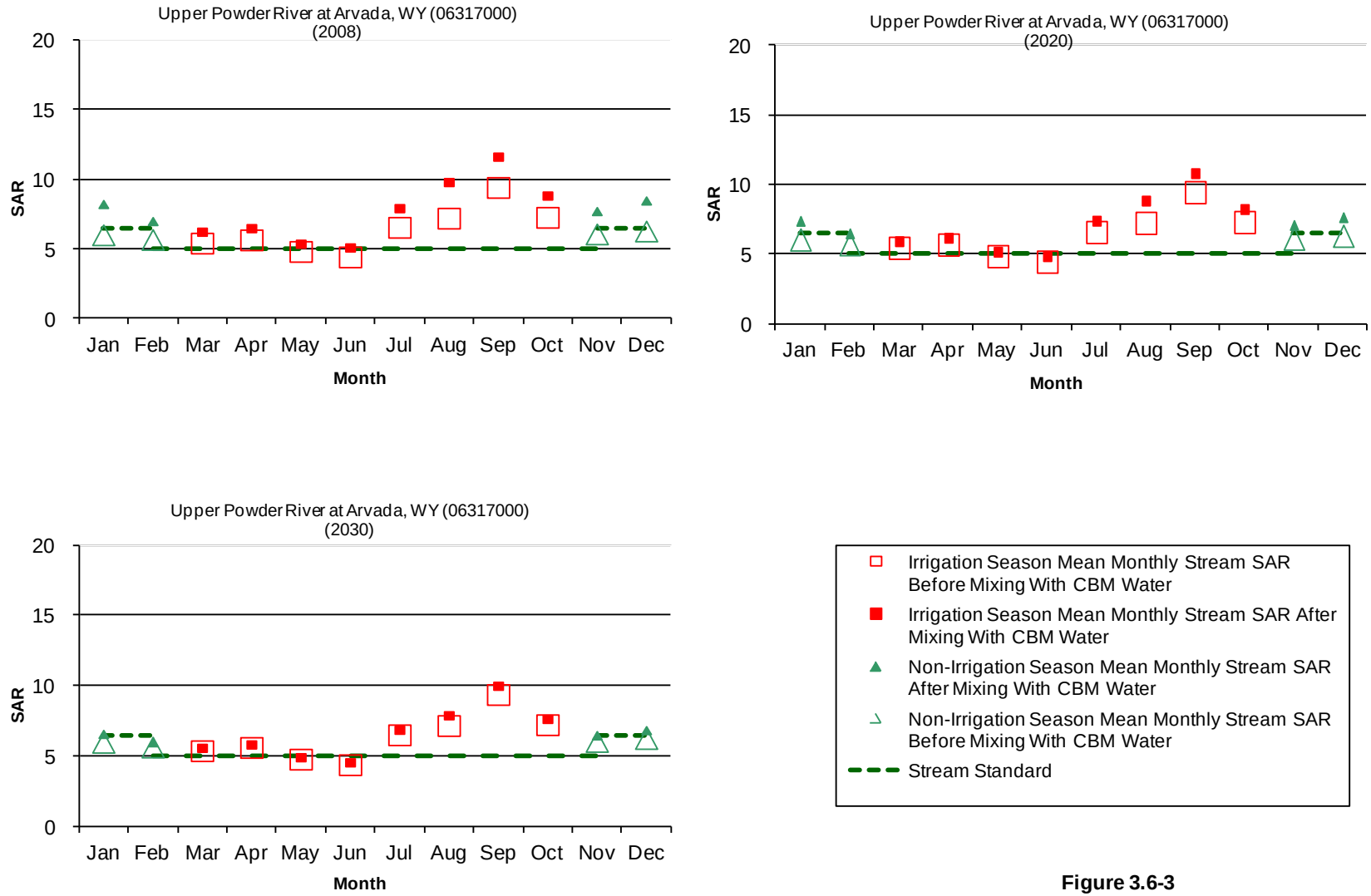


Figure 3.6-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Upper Powder River at Arvada, WY (06317000)

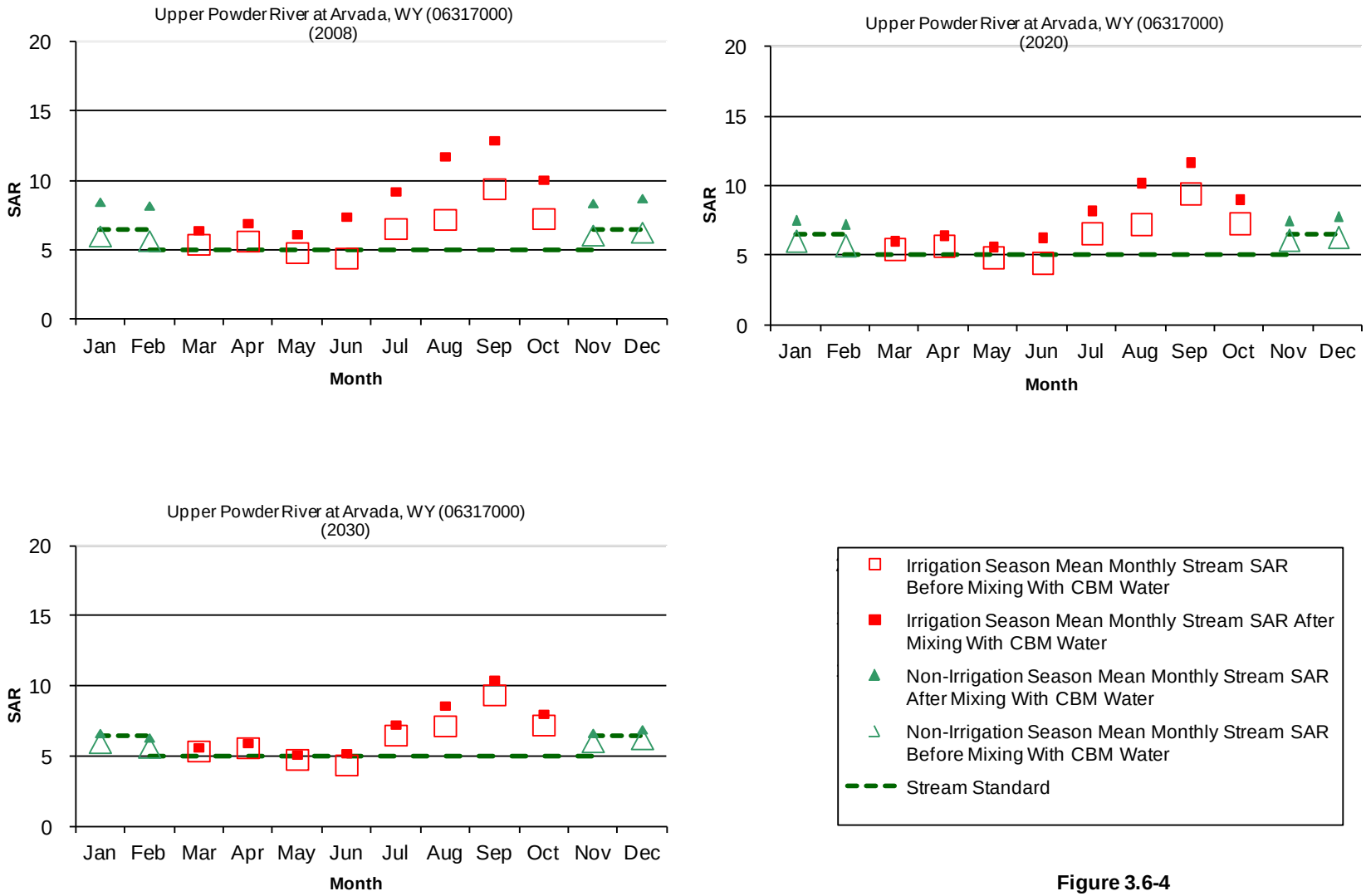


Figure 3.6-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Upper Powder River at Arvada, WY (06317000)

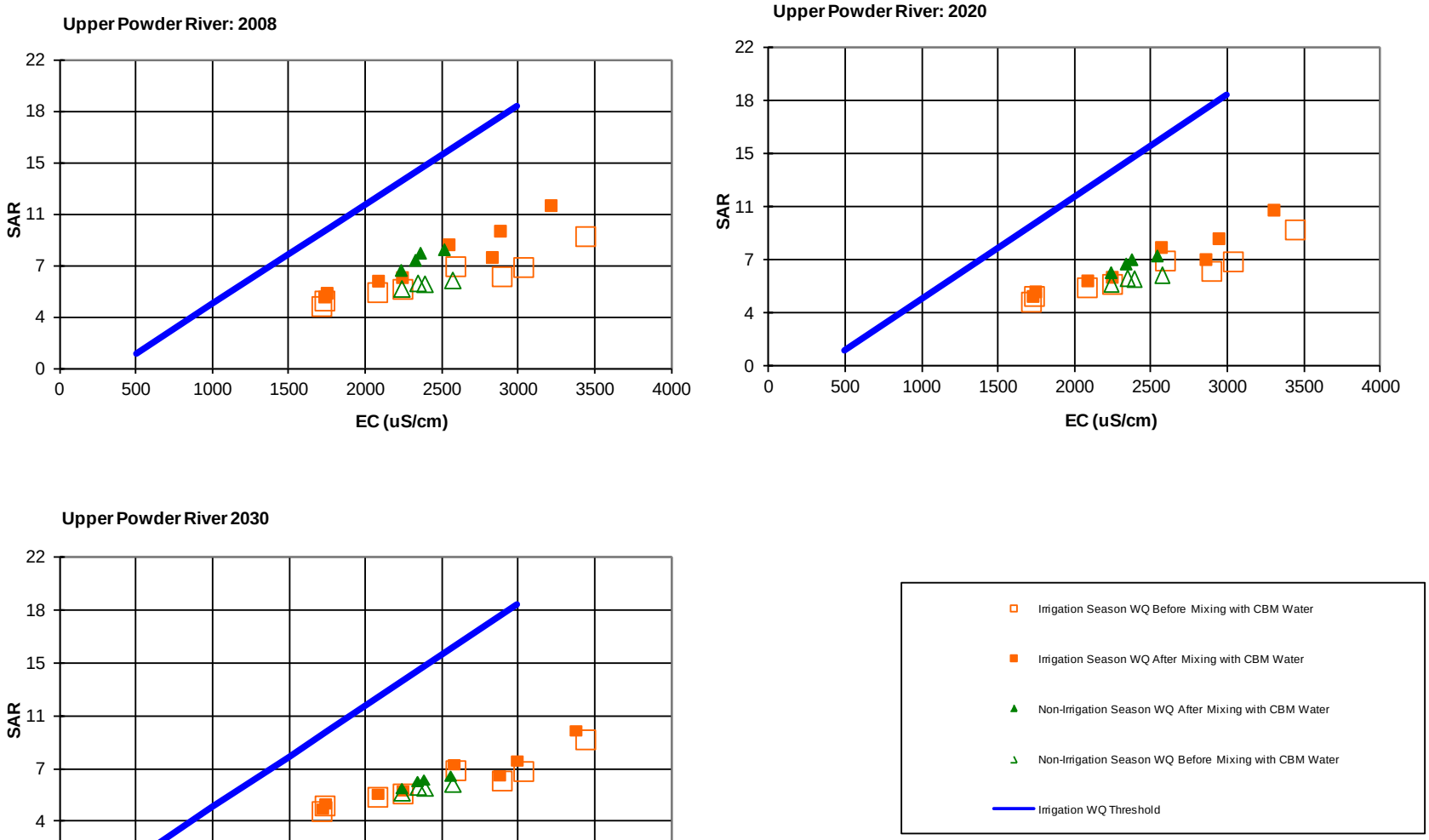


Figure 3.6-5
Upper Powder River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

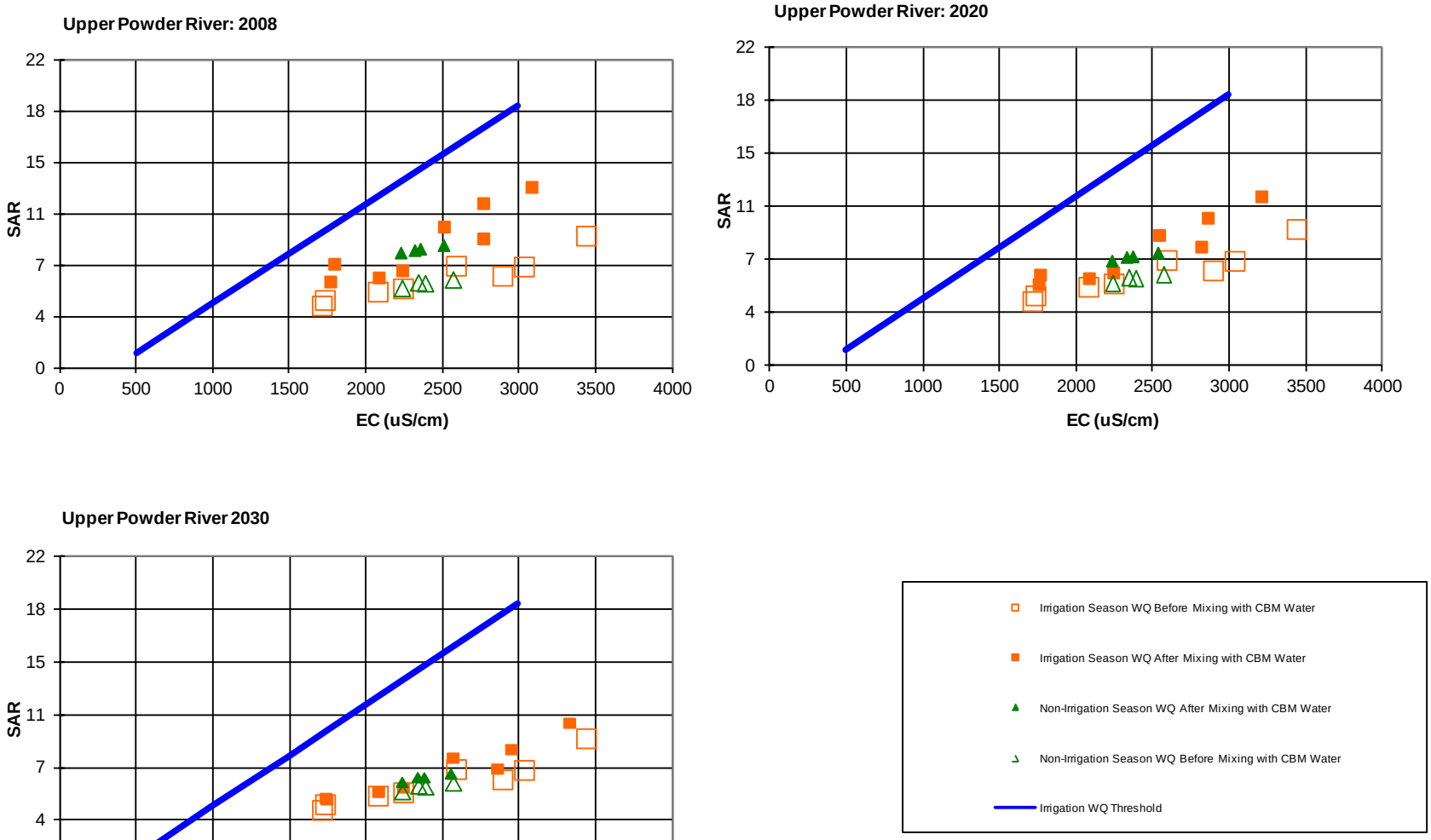


Figure 3.6-6
Upper Powder River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

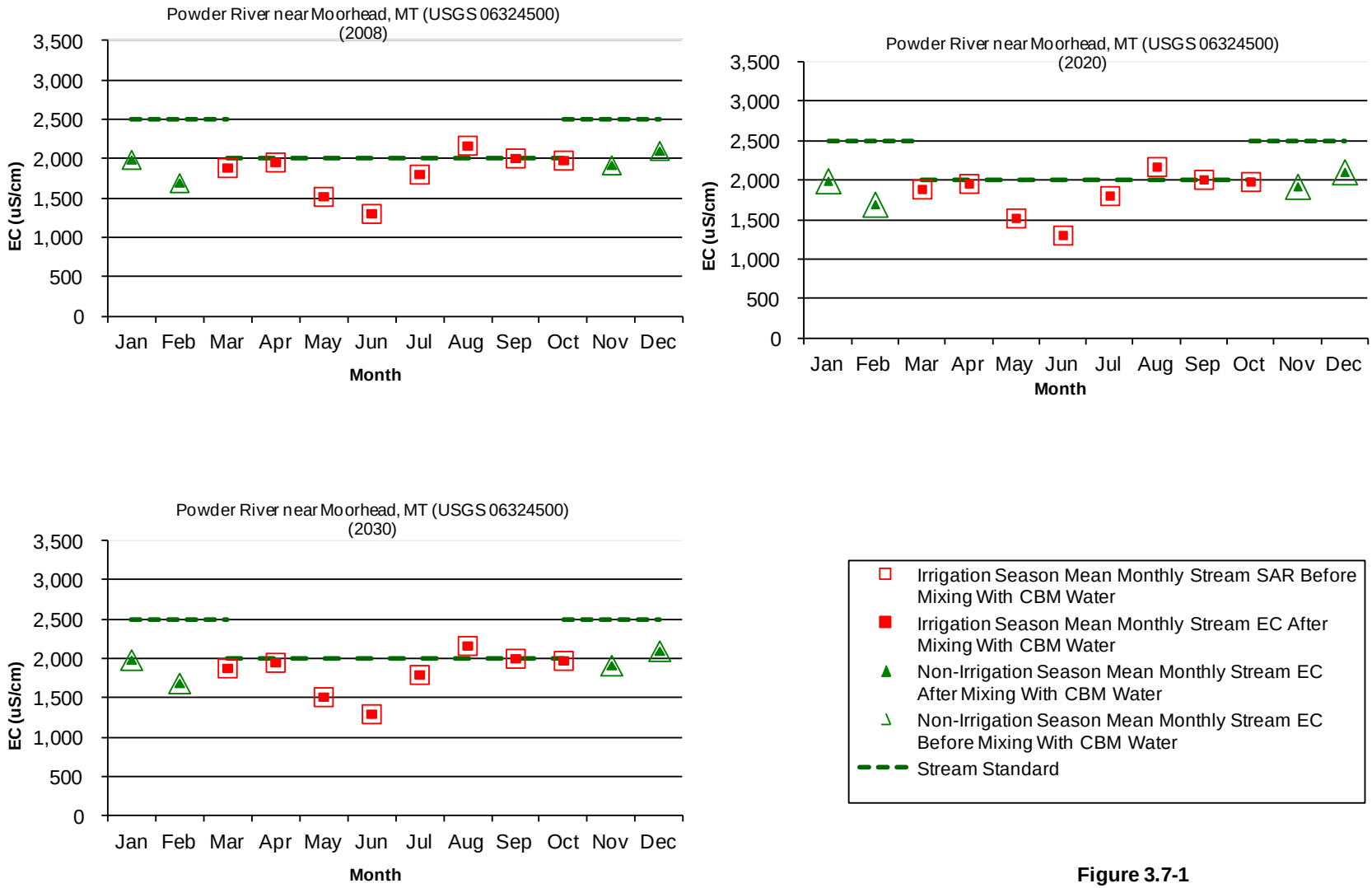


Figure 3.7-1
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Powder River near Moorhead, MT (USGS 06324500)

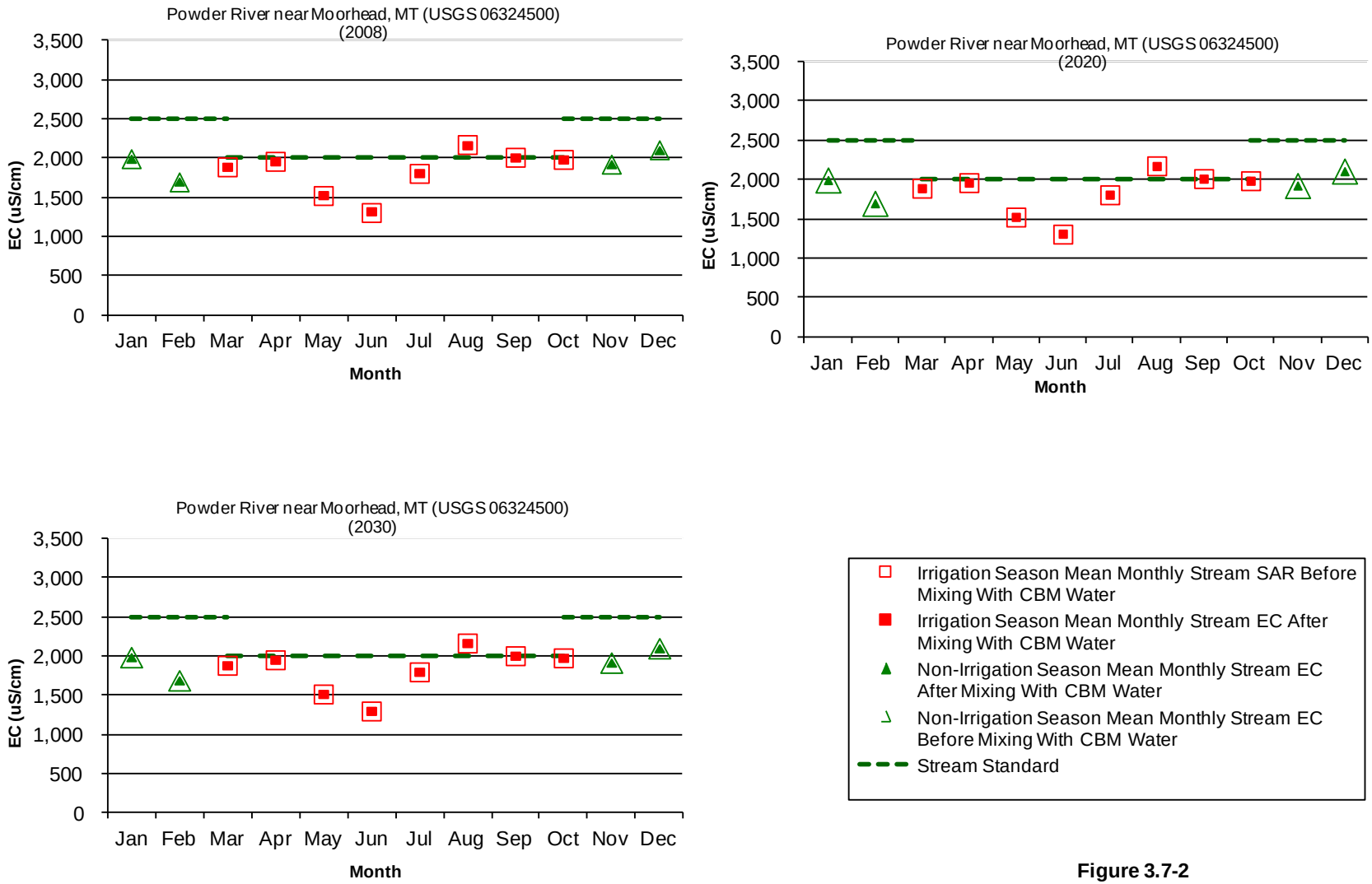


Figure 3.7-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Powder River near Moorhead, MT (USGS 06324500)

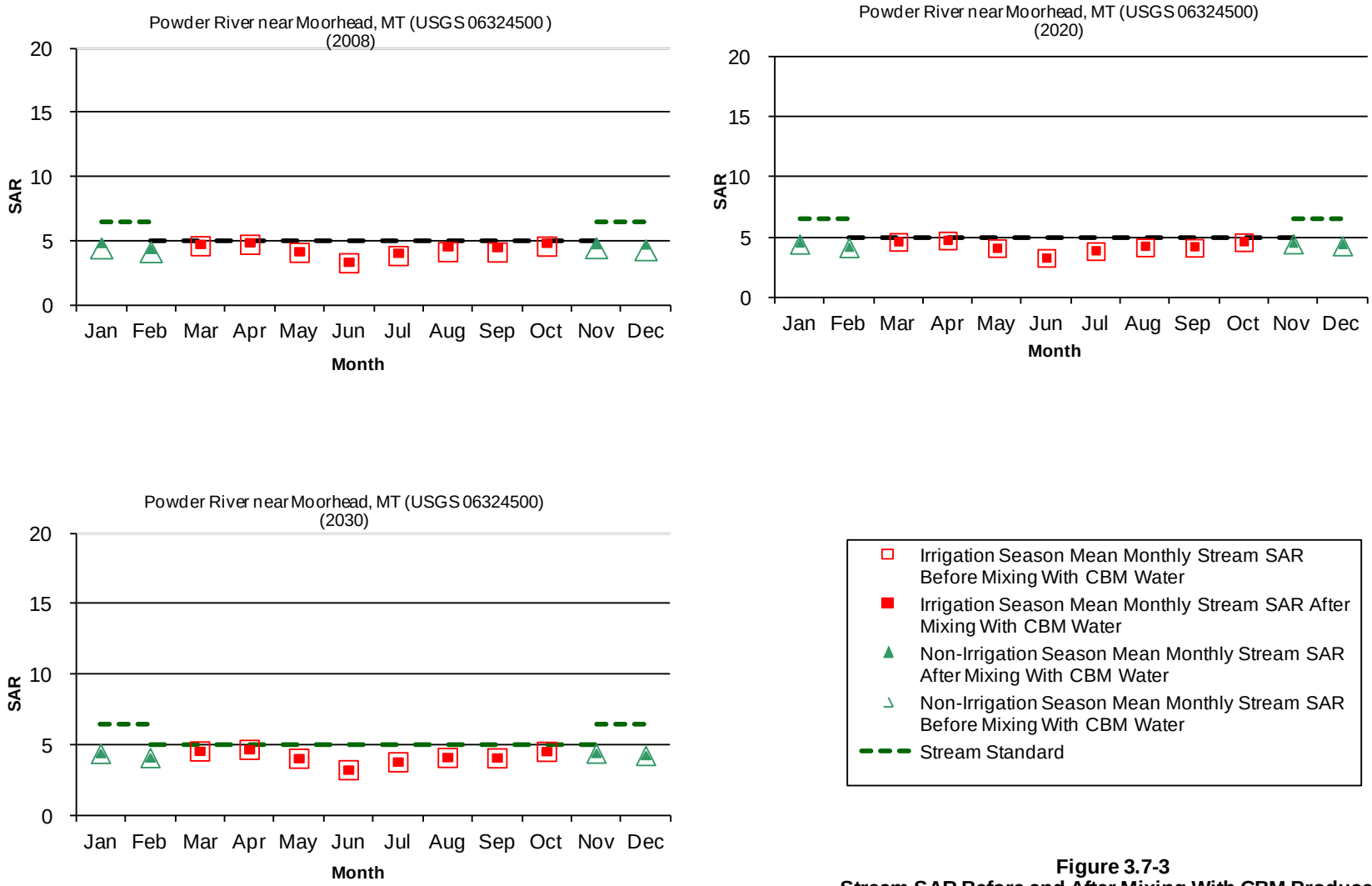


Figure 3.7-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Powder River near Moorhead, MT (USGS 06324500)

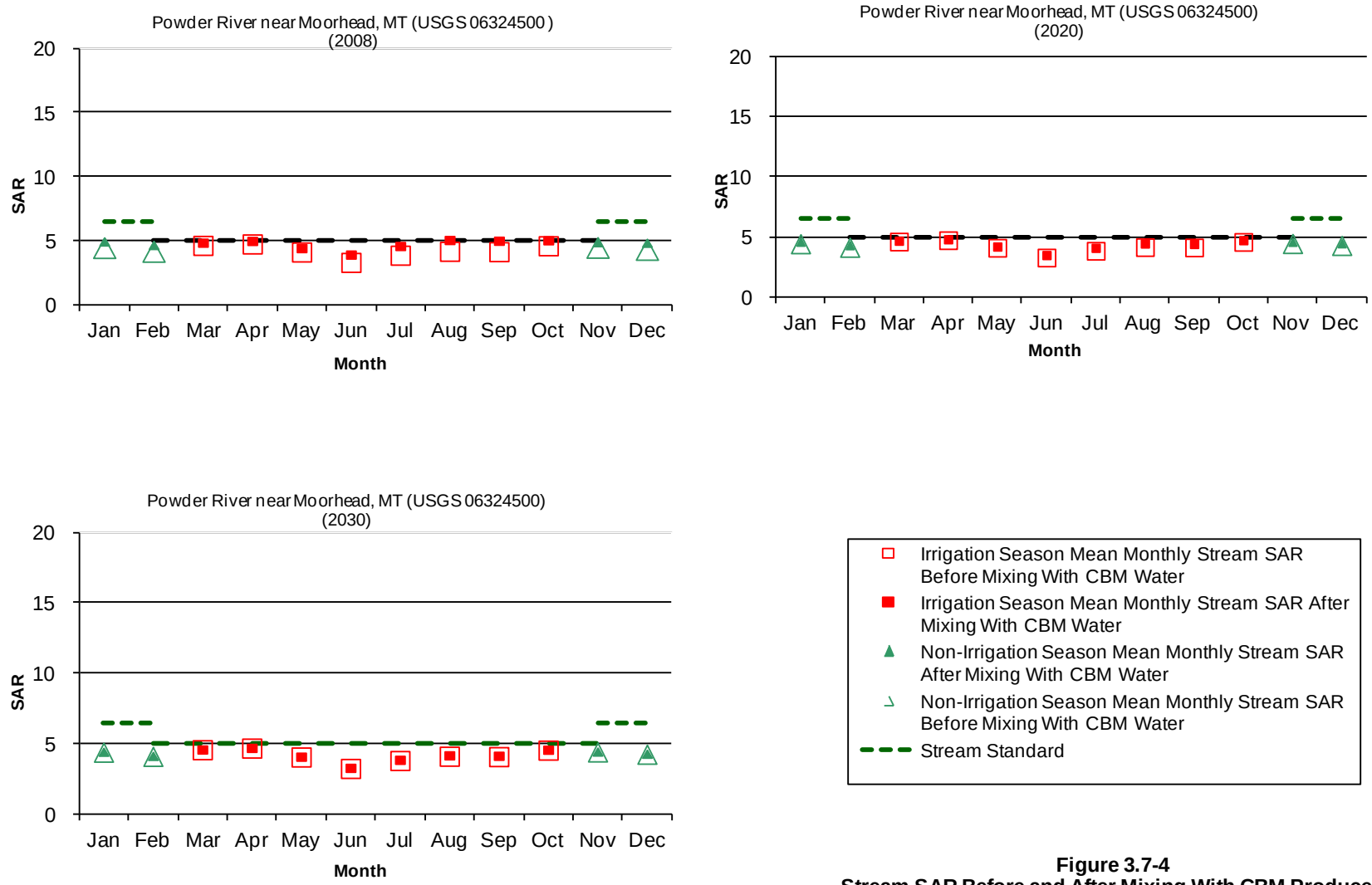


Figure 3.7-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Powder River near Moorhead, MT (USGS 06324500)

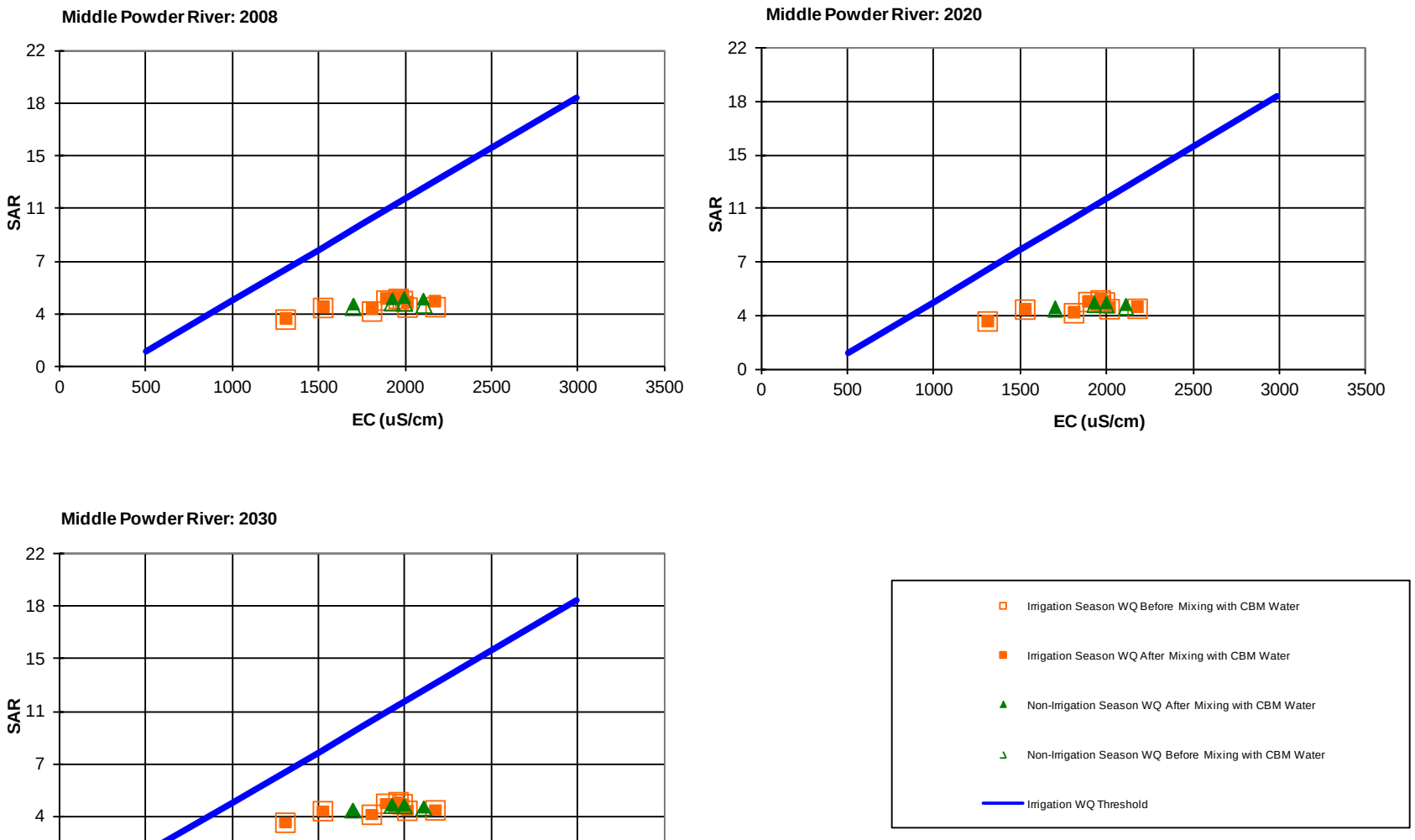


Figure 3.7-5
Middle Powder
River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

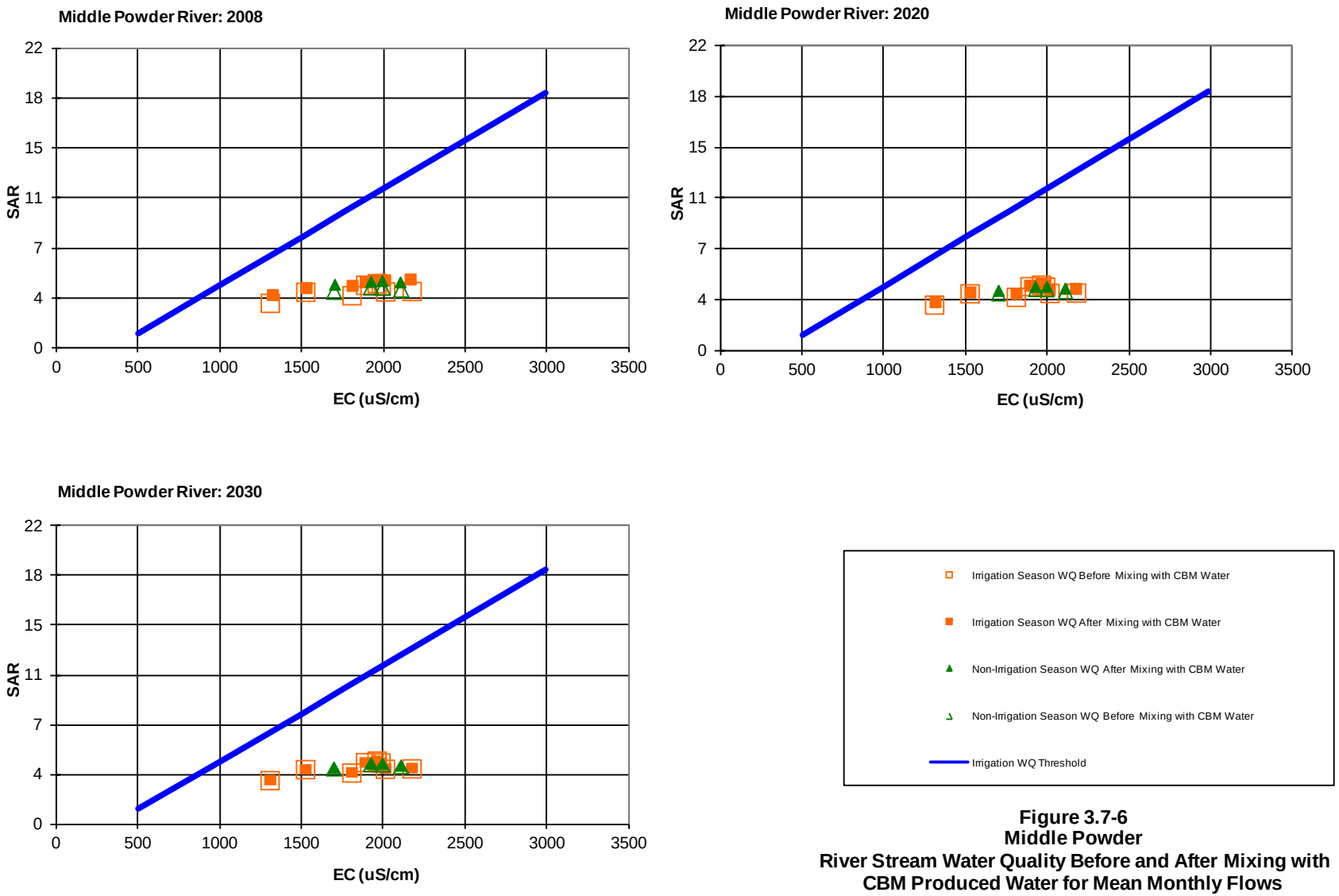
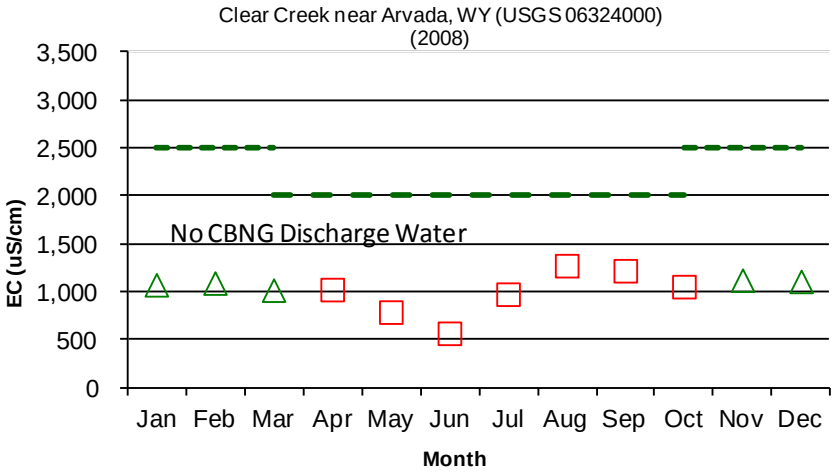
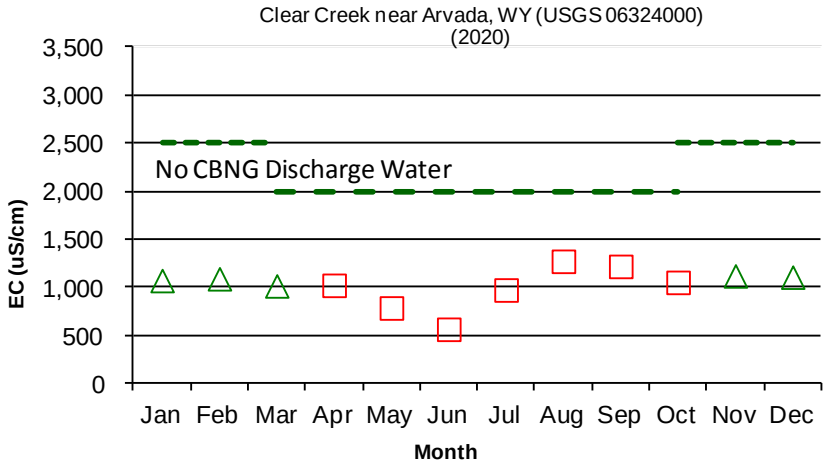


Figure 3.7-6
Middle Powder
River Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)





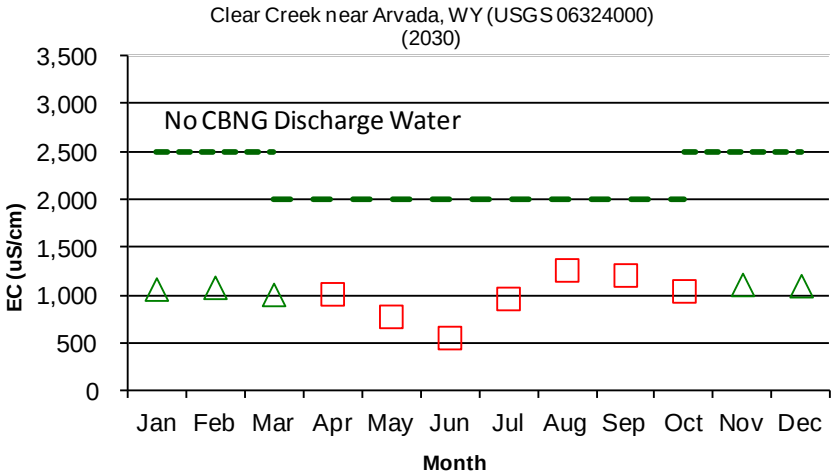
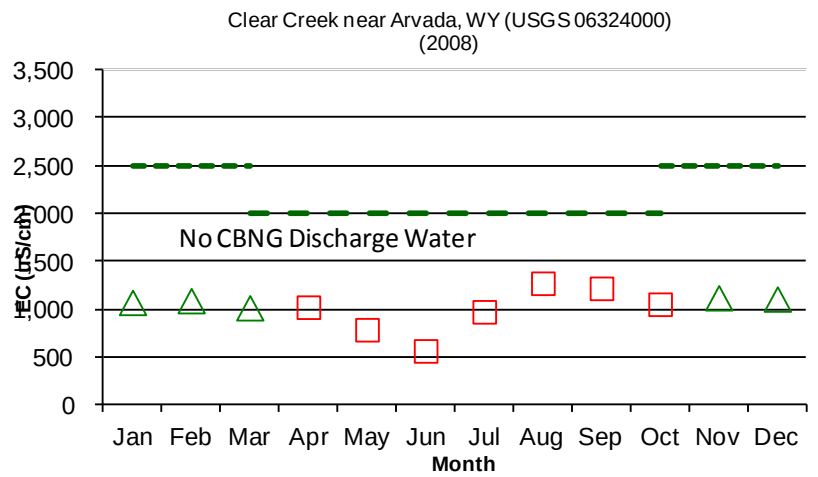
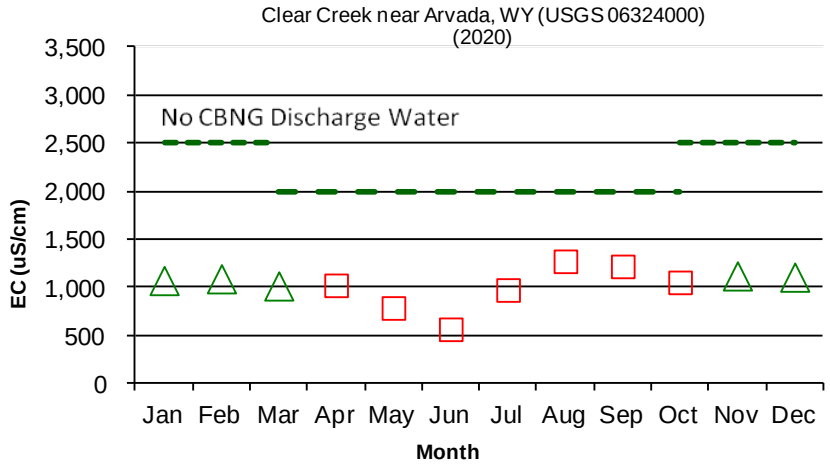


Figure 3.8-1
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Clear Creek near Arvada, WY (USGS 06324000)





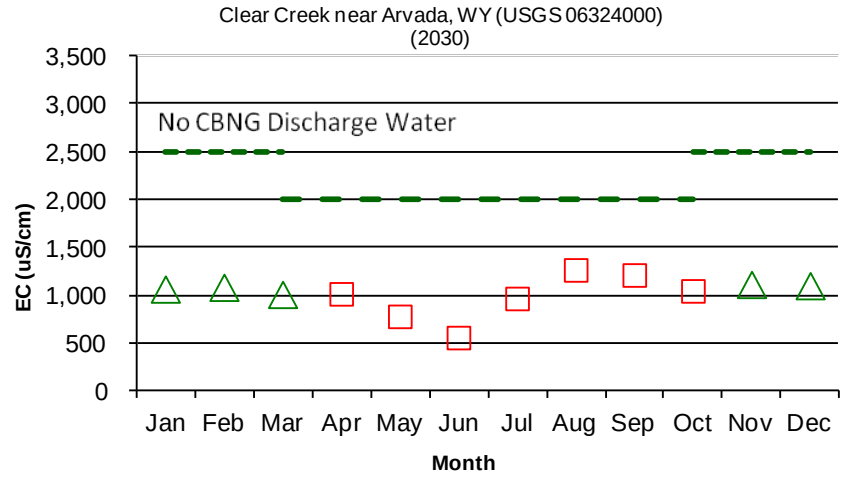


Figure 3.8-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Clear Creek near Arvada, WY (USGS 06324000)

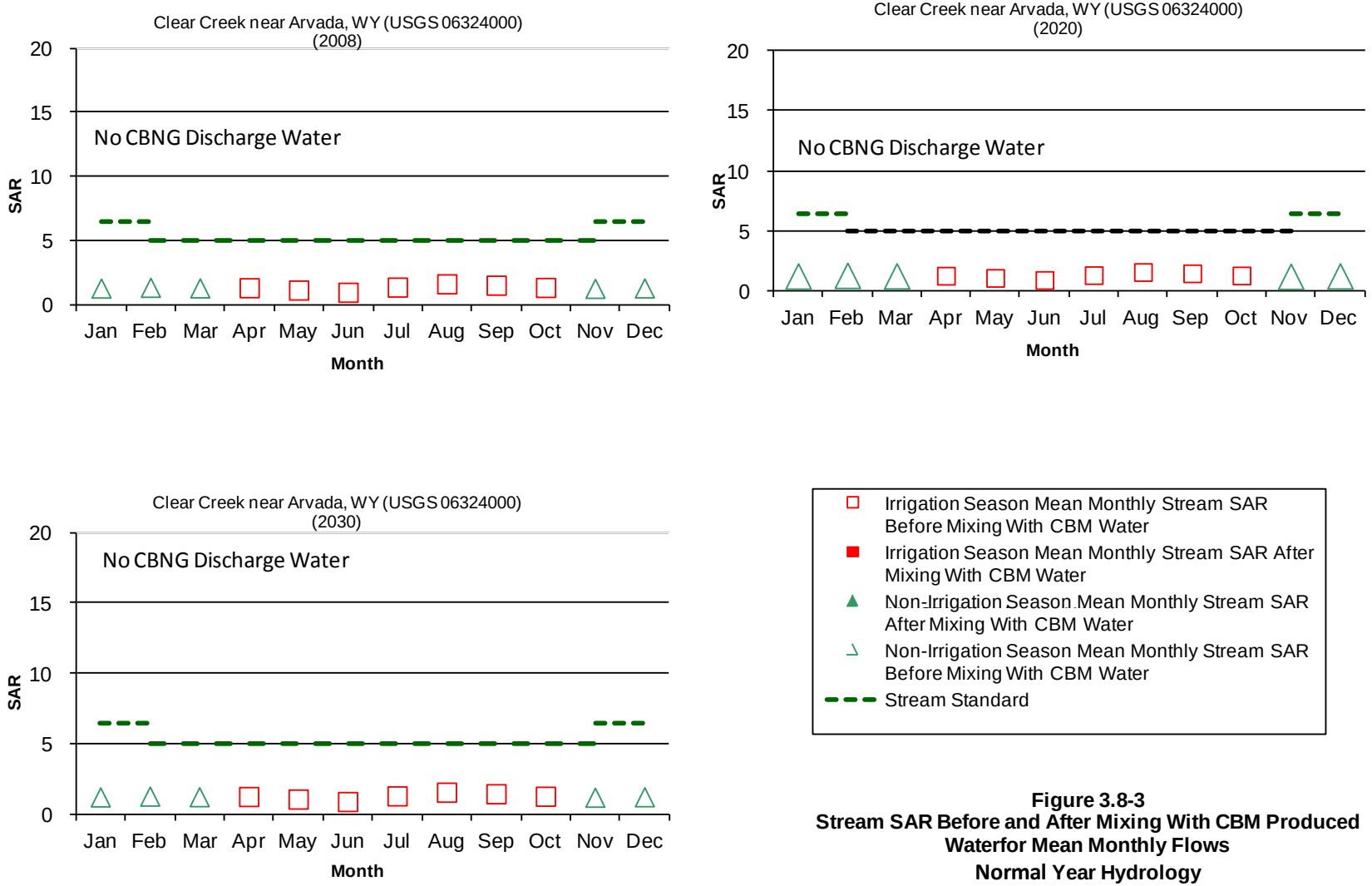


Figure 3.8-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Clear Creek near Arvada, WY (USGS 06324000)

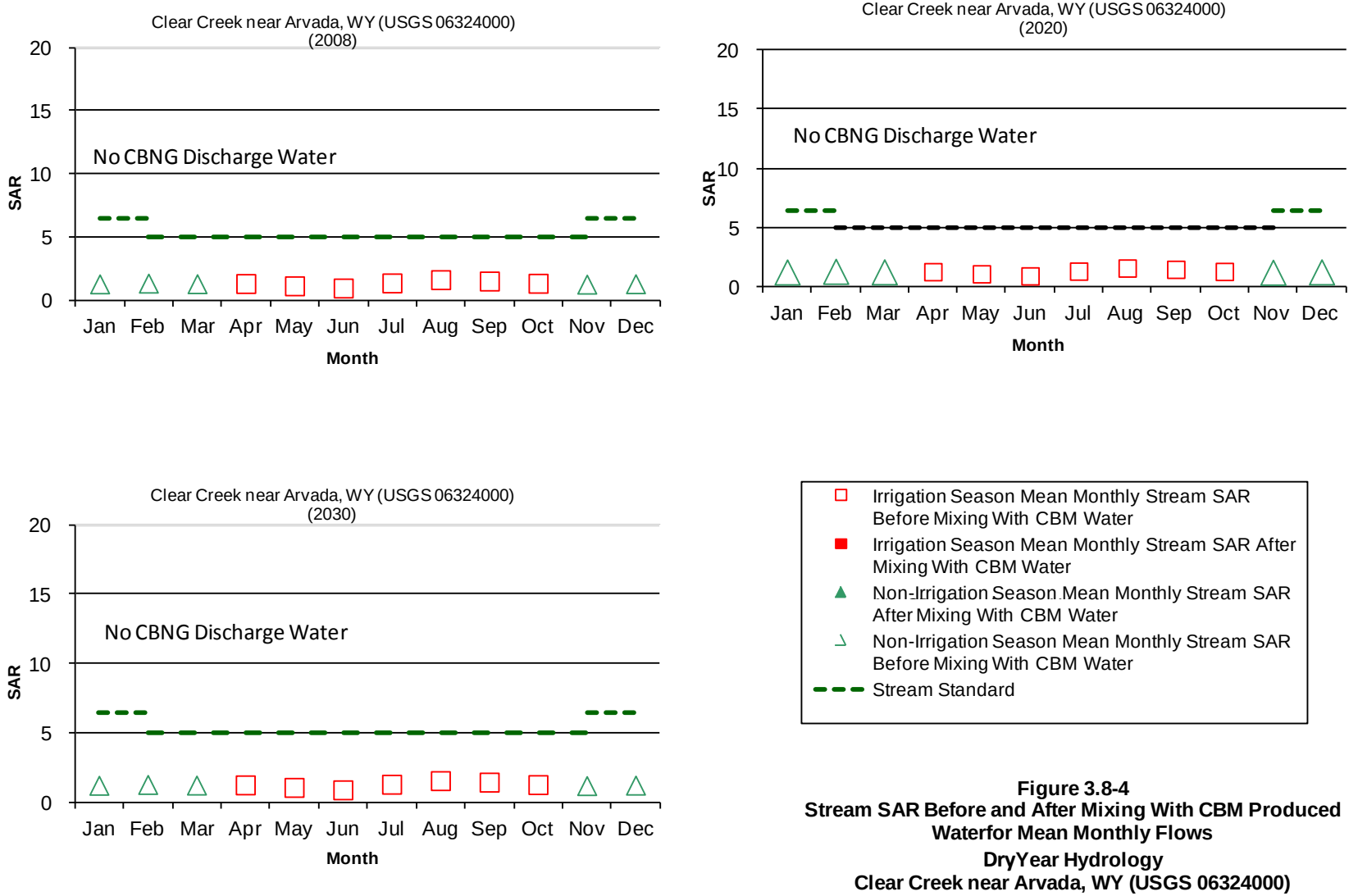


Figure 3.8-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
DryYear Hydrology
Clear Creek near Arvada, WY (USGS 06324000)

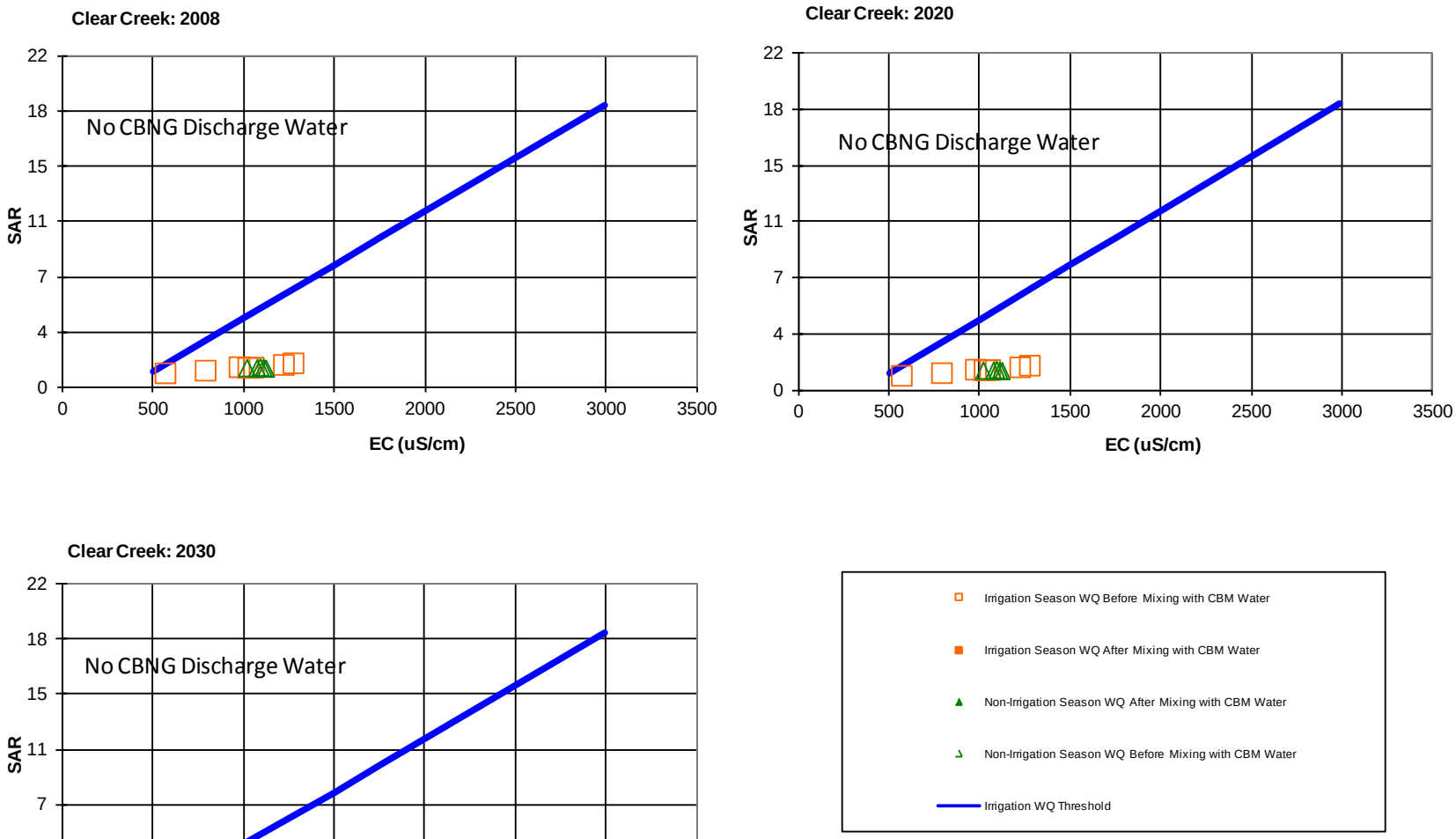


Figure 3.8-5
Clear Creek
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

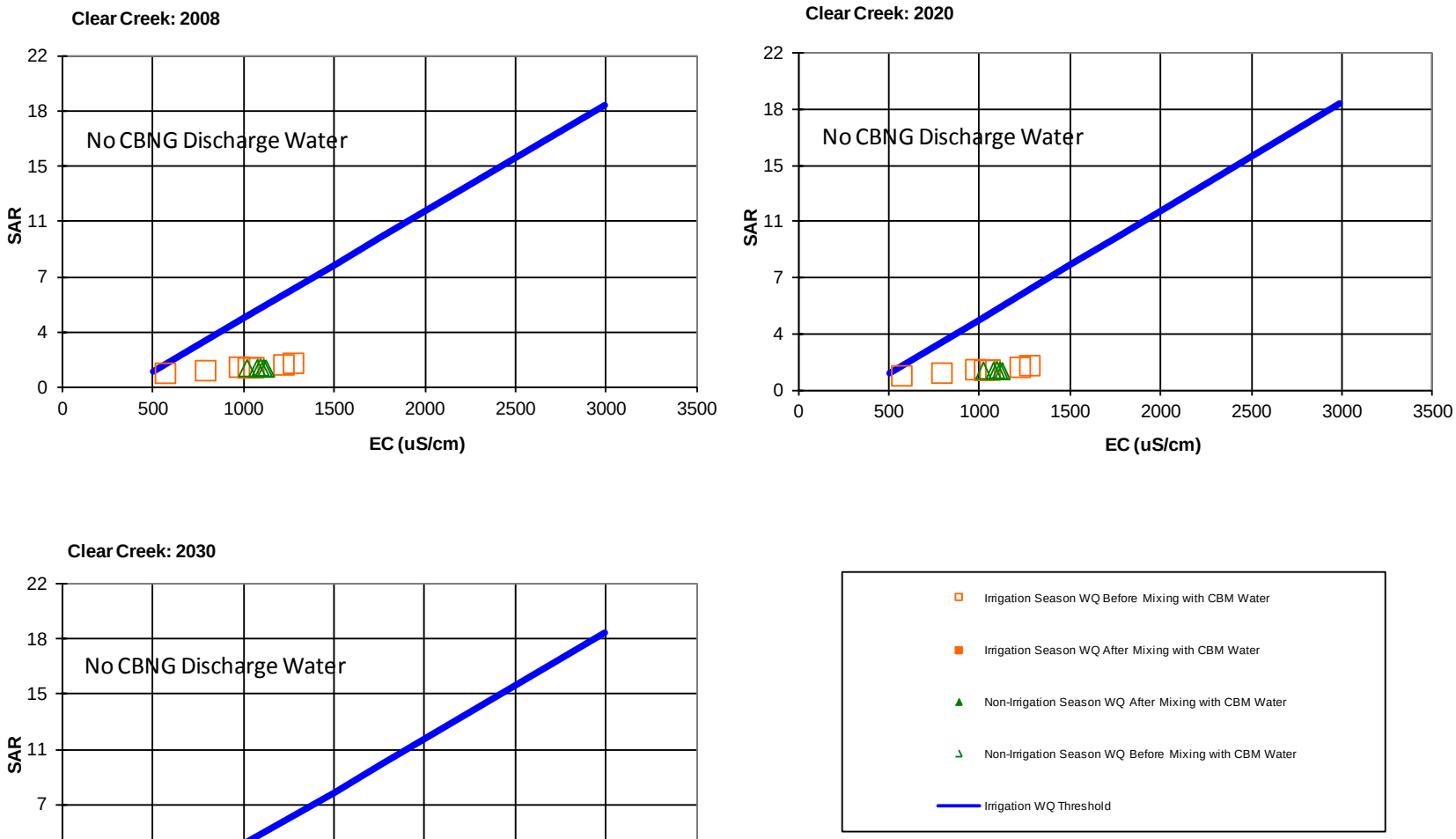


Figure 3.8-6
Clear Creek
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

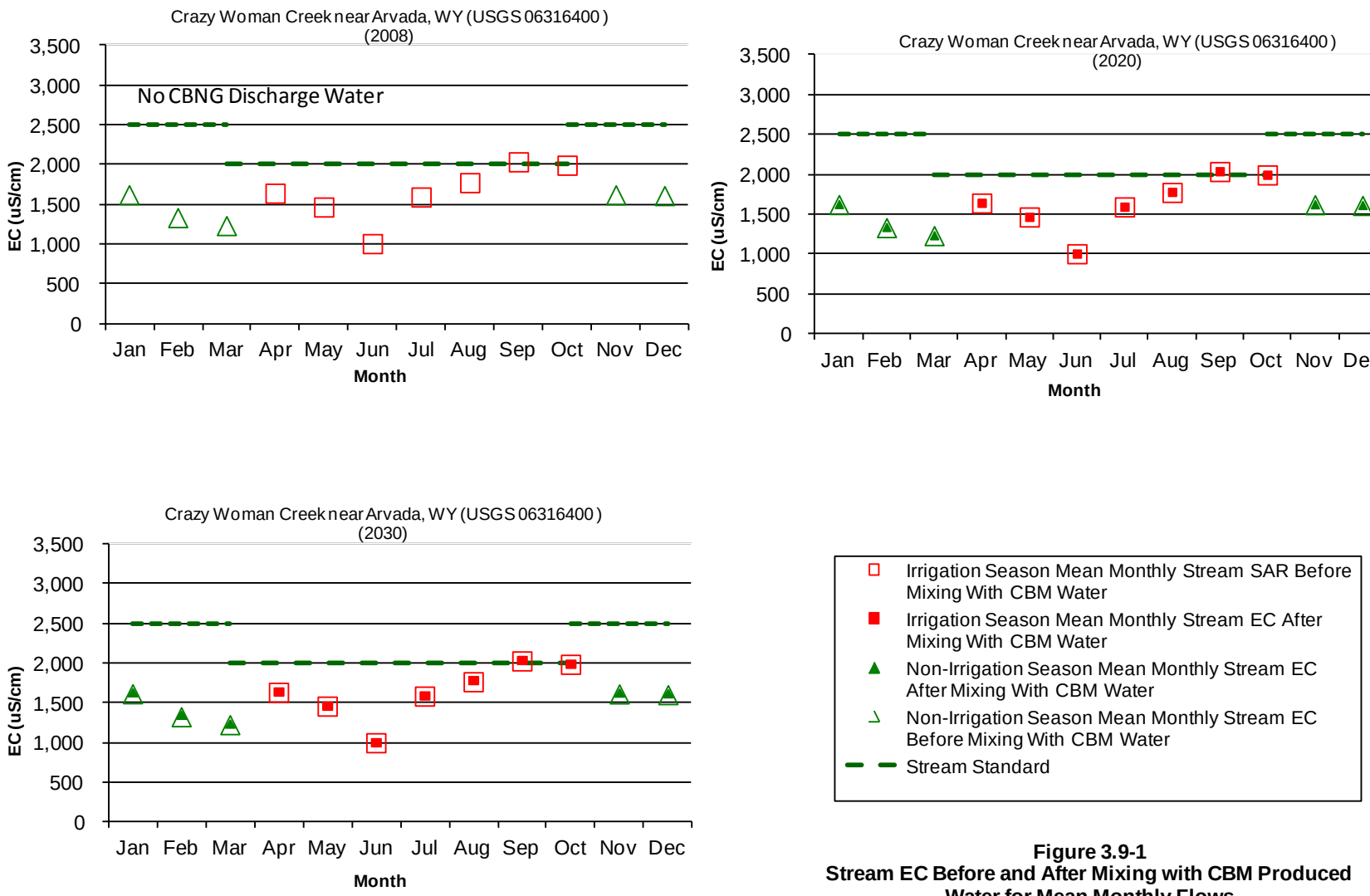
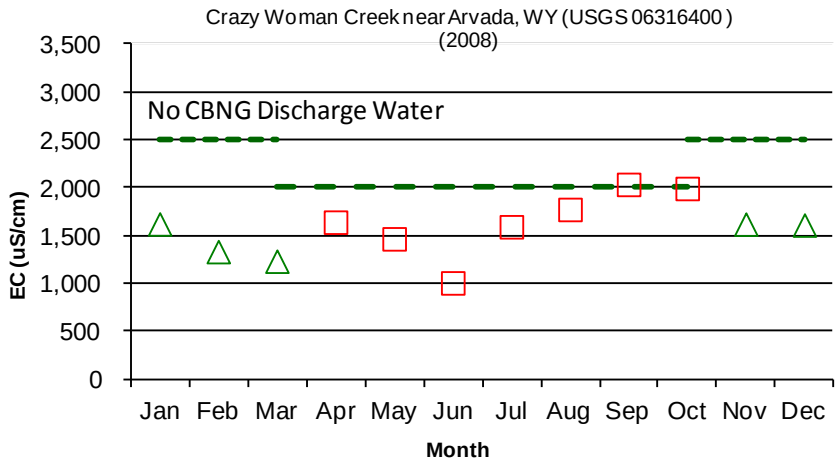
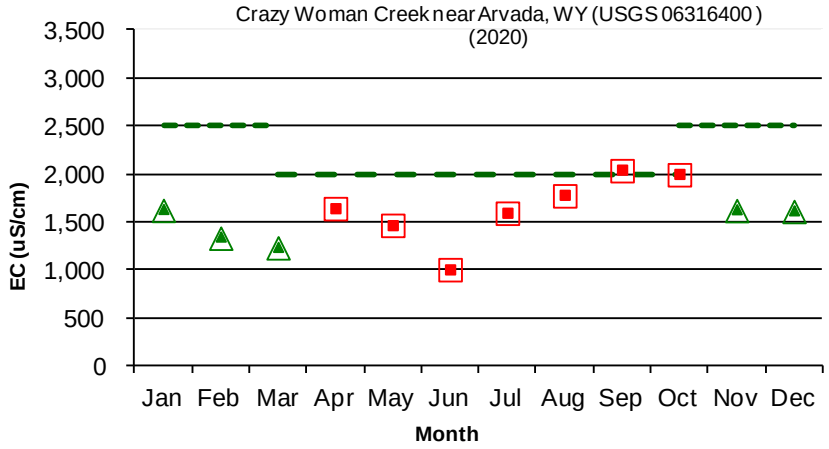


Figure 3.9-1
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Crazy Woman Creek near Arvada, WY (USGS 06316400)





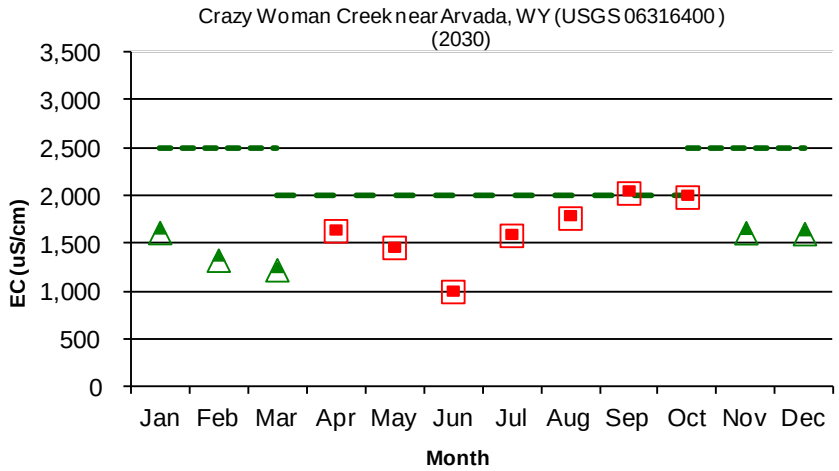


Figure 3.9-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Crazy Woman Creek near Arvada, WY (USGS 06316400)

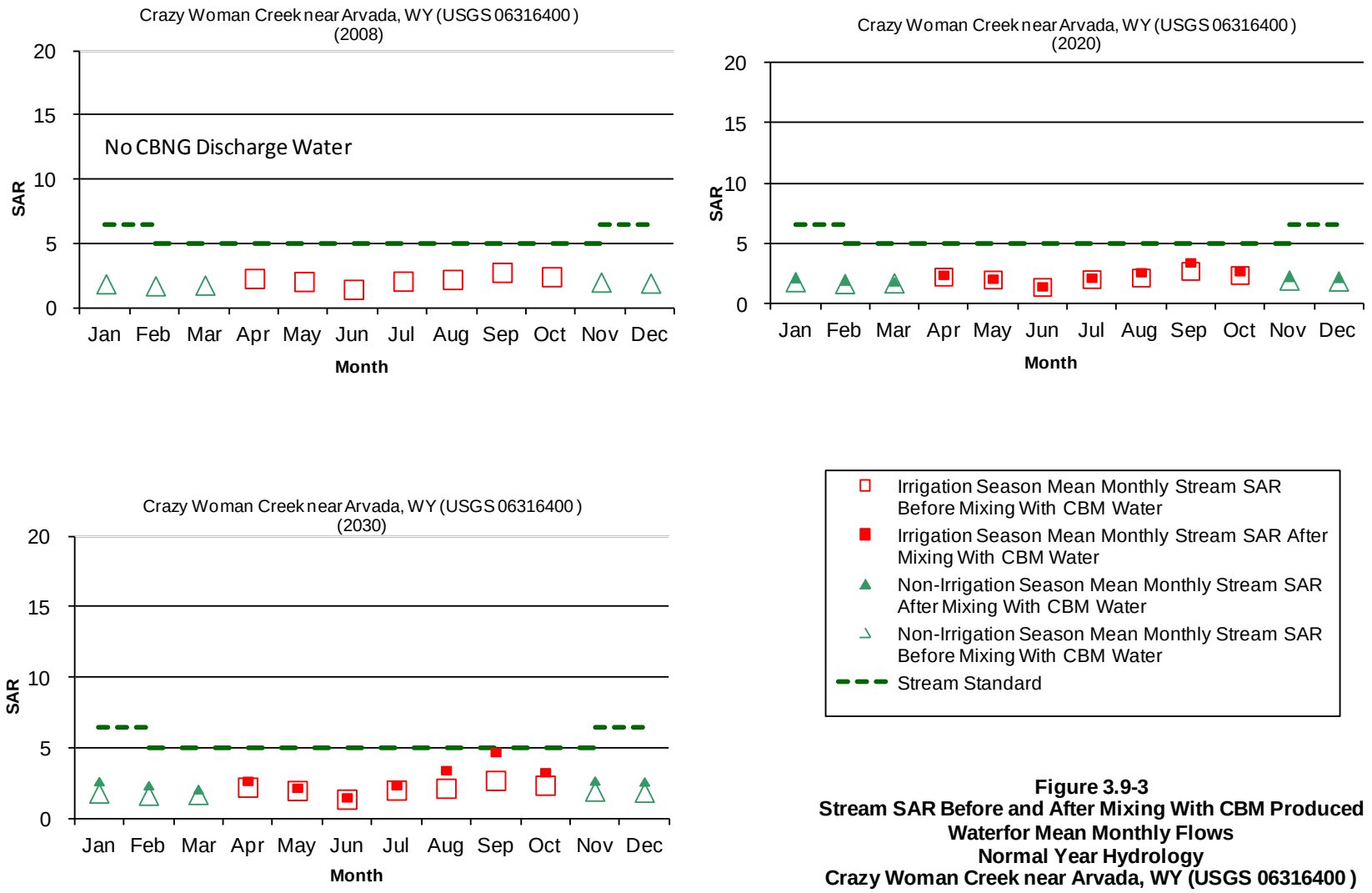


Figure 3.9-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Crazy Woman Creek near Arvada, WY (USGS 06316400)

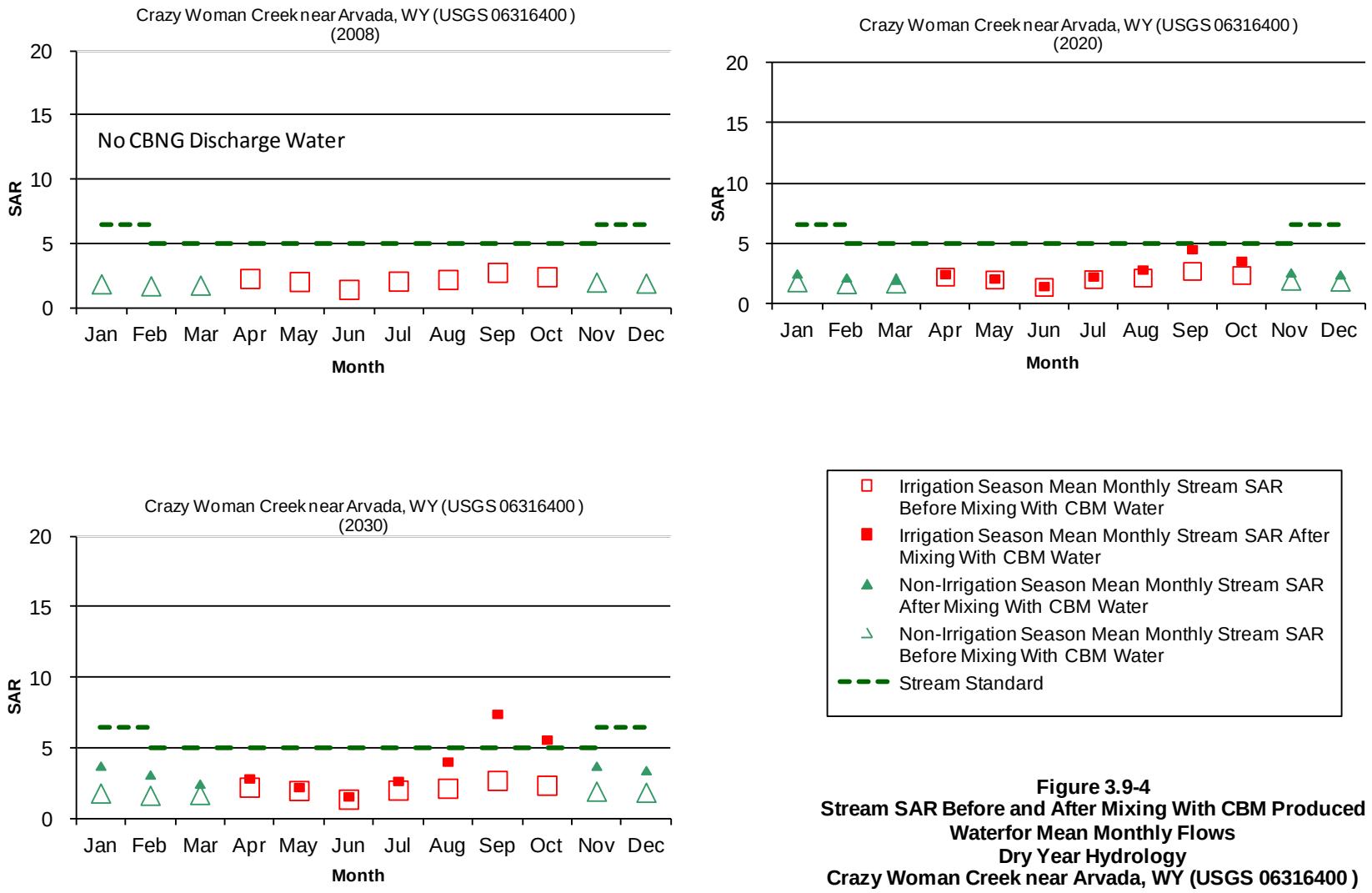


Figure 3.9-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Crazy Woman Creek near Arvada, WY (USGS 06316400)

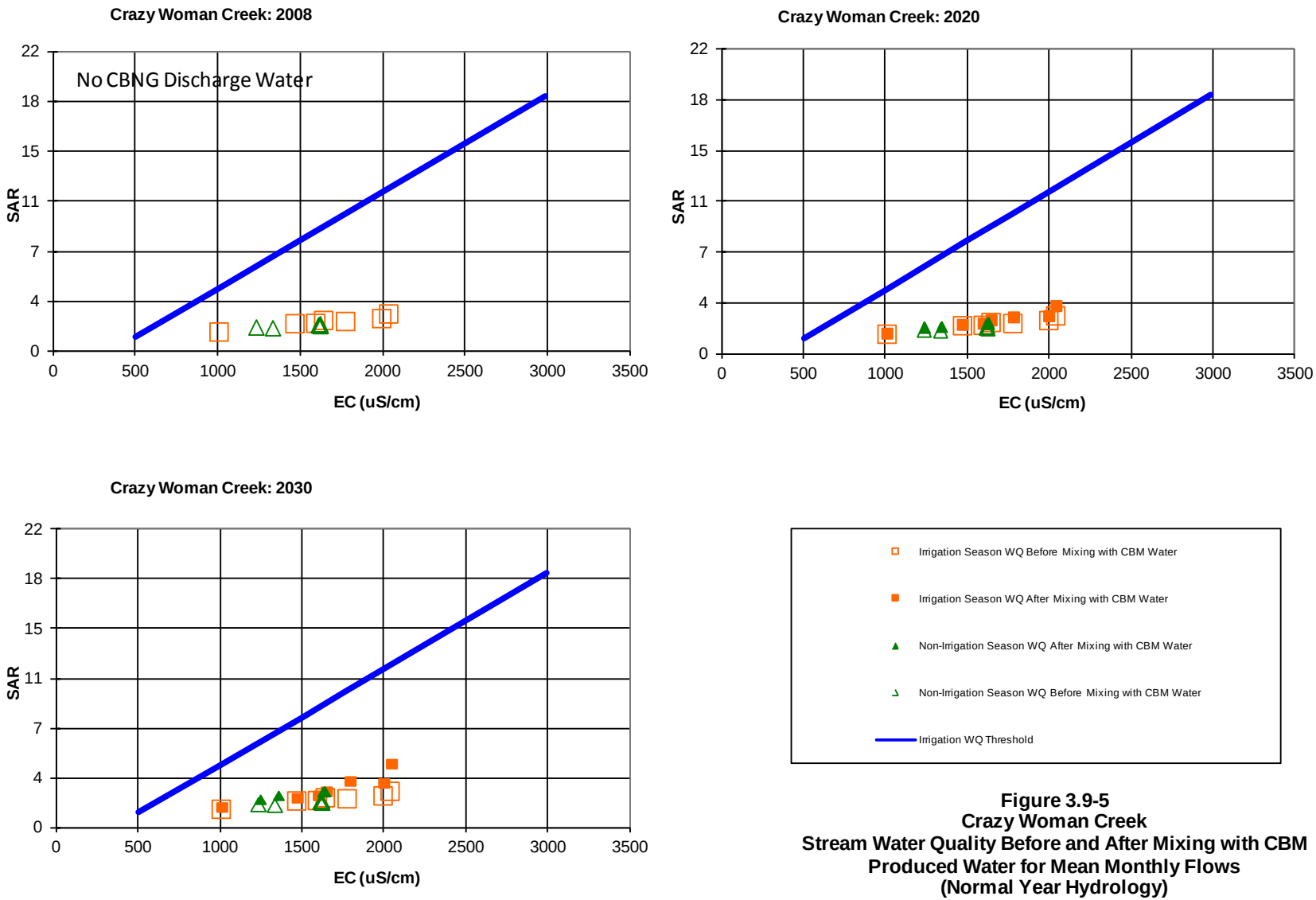


Figure 3.9-5
Crazy Woman Creek
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

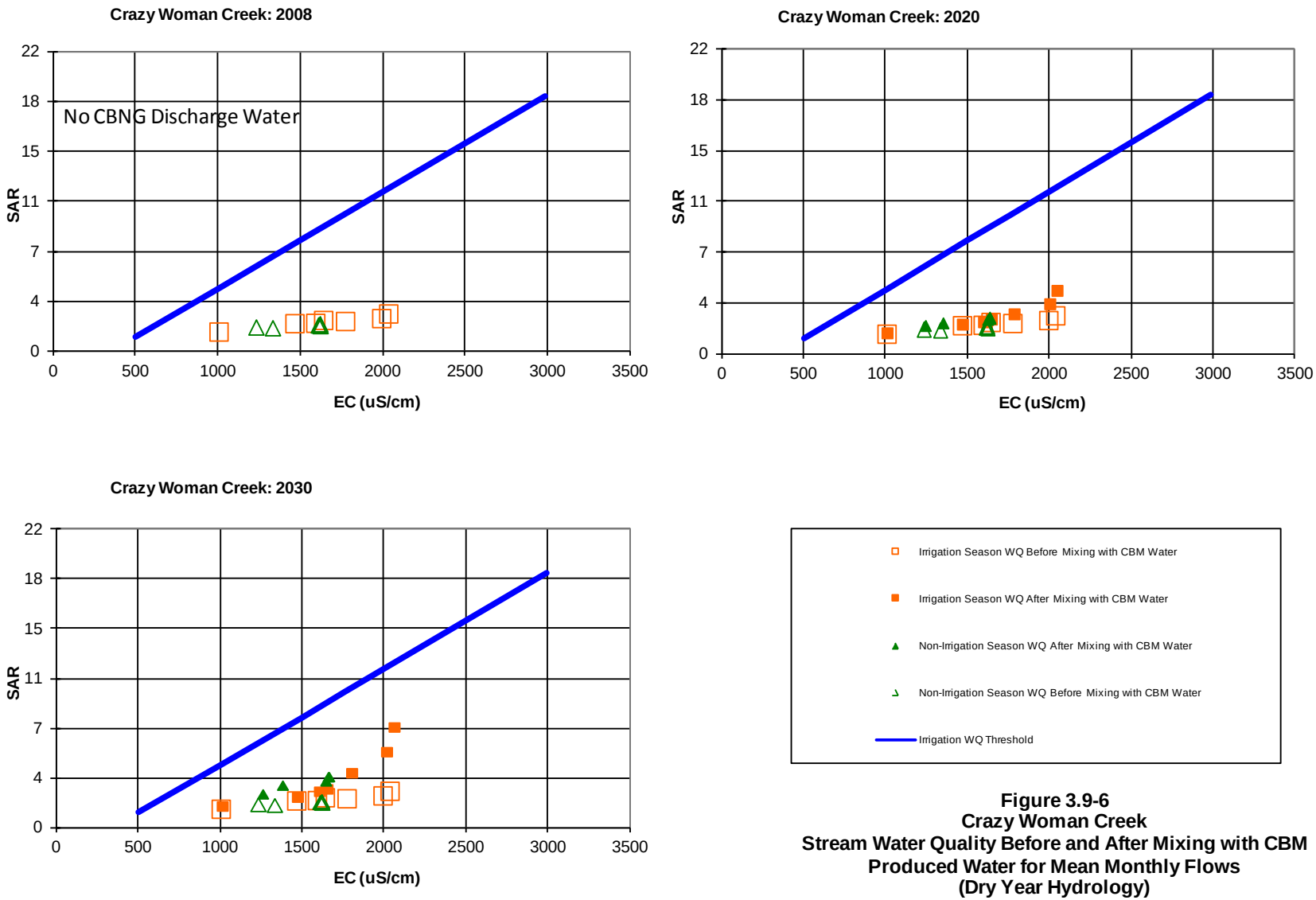


Figure 3.9-6
Crazy Woman Creek
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

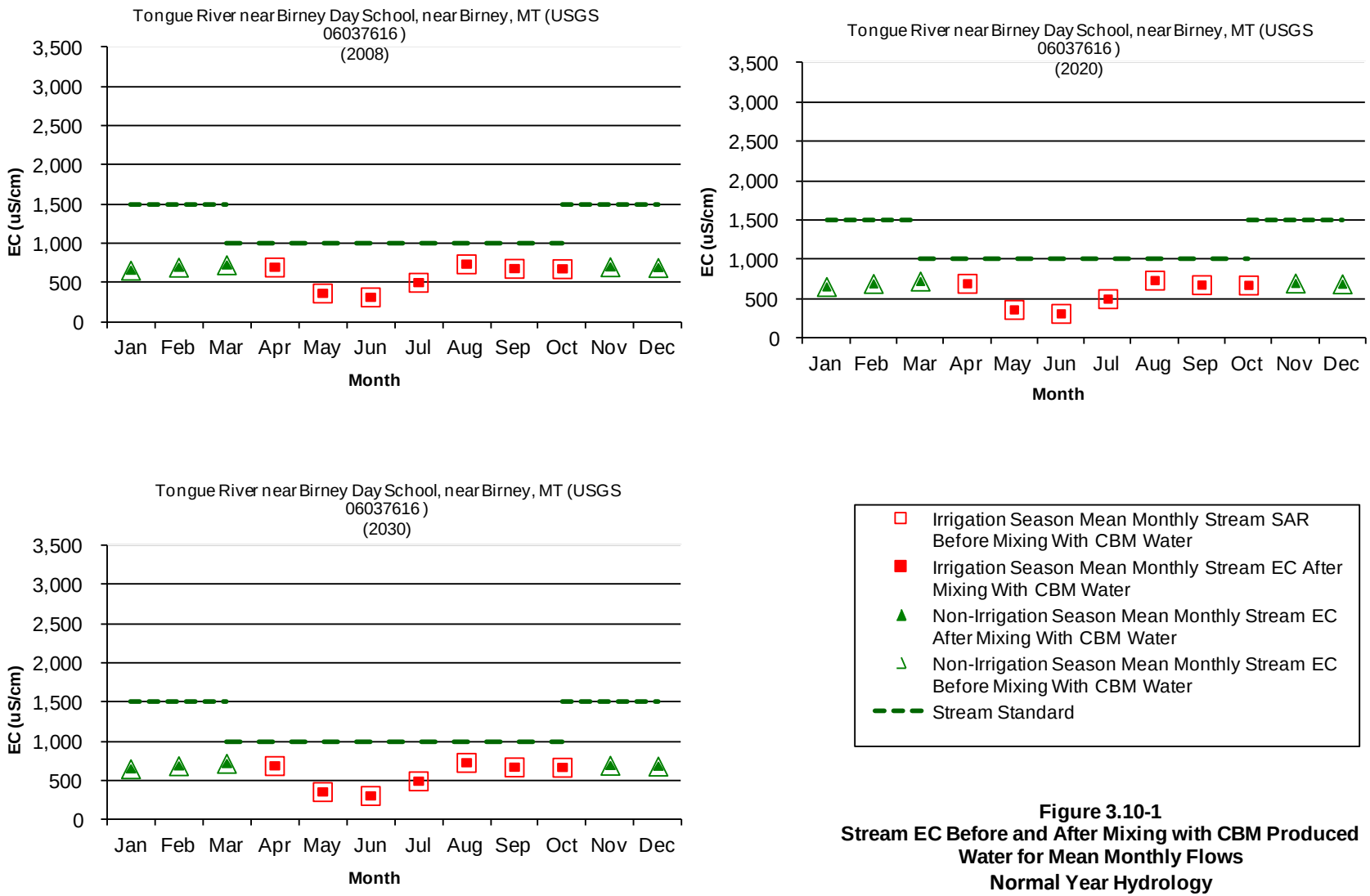
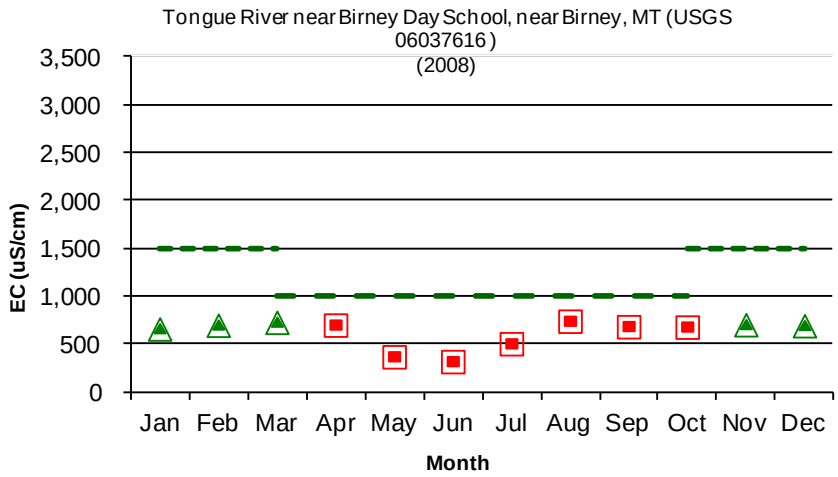
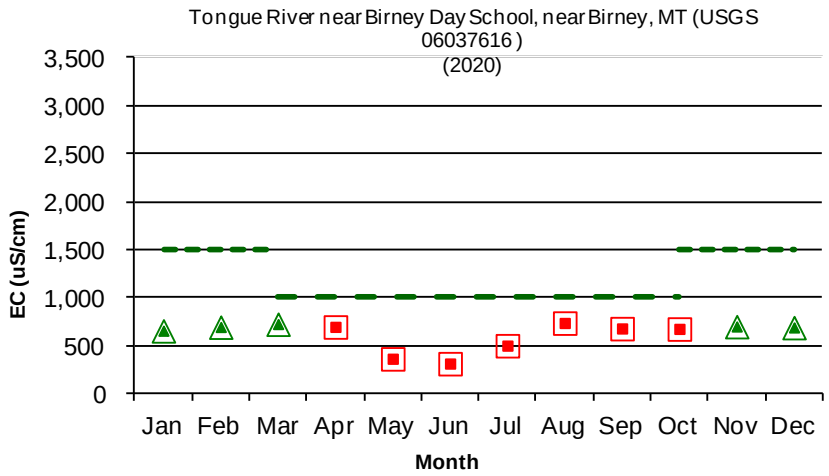
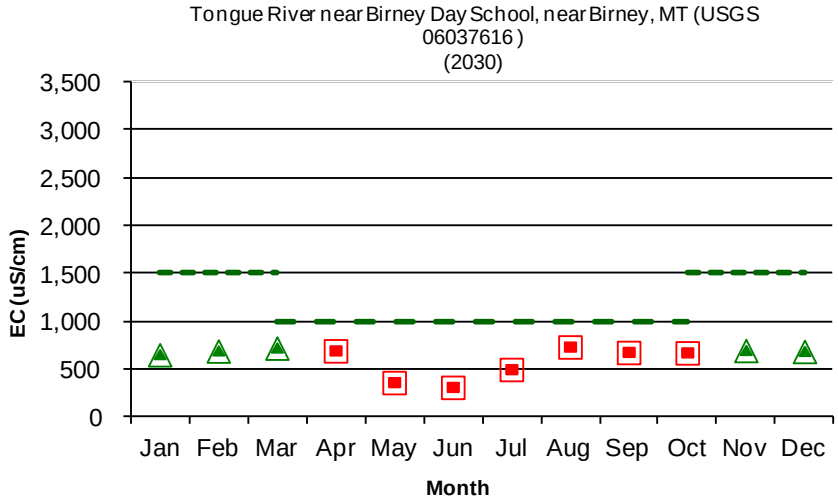


Figure 3.10-1
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Normal Year Hydrology
Tongue River near Birney Day School, near Birney, MT (USGS 06037616)







- Irrigation Season Mean Monthly Stream SAR Before Mixing With CBM Water
- Irrigation Season Mean Monthly Stream EC After Mixing With CBM Water
- Non-Irrigation Season Mean Monthly Stream EC After Mixing With CBM Water
- Non-Irrigation Season Mean Monthly Stream EC Before Mixing With CBM Water
- Stream Standard

Figure 3.10-2
Stream EC Before and After Mixing with CBM Produced Water for Mean Monthly Flows
Dry Year Hydrology
Tongue River near Birney Day School, near Birney, MT (USGS 06037616)

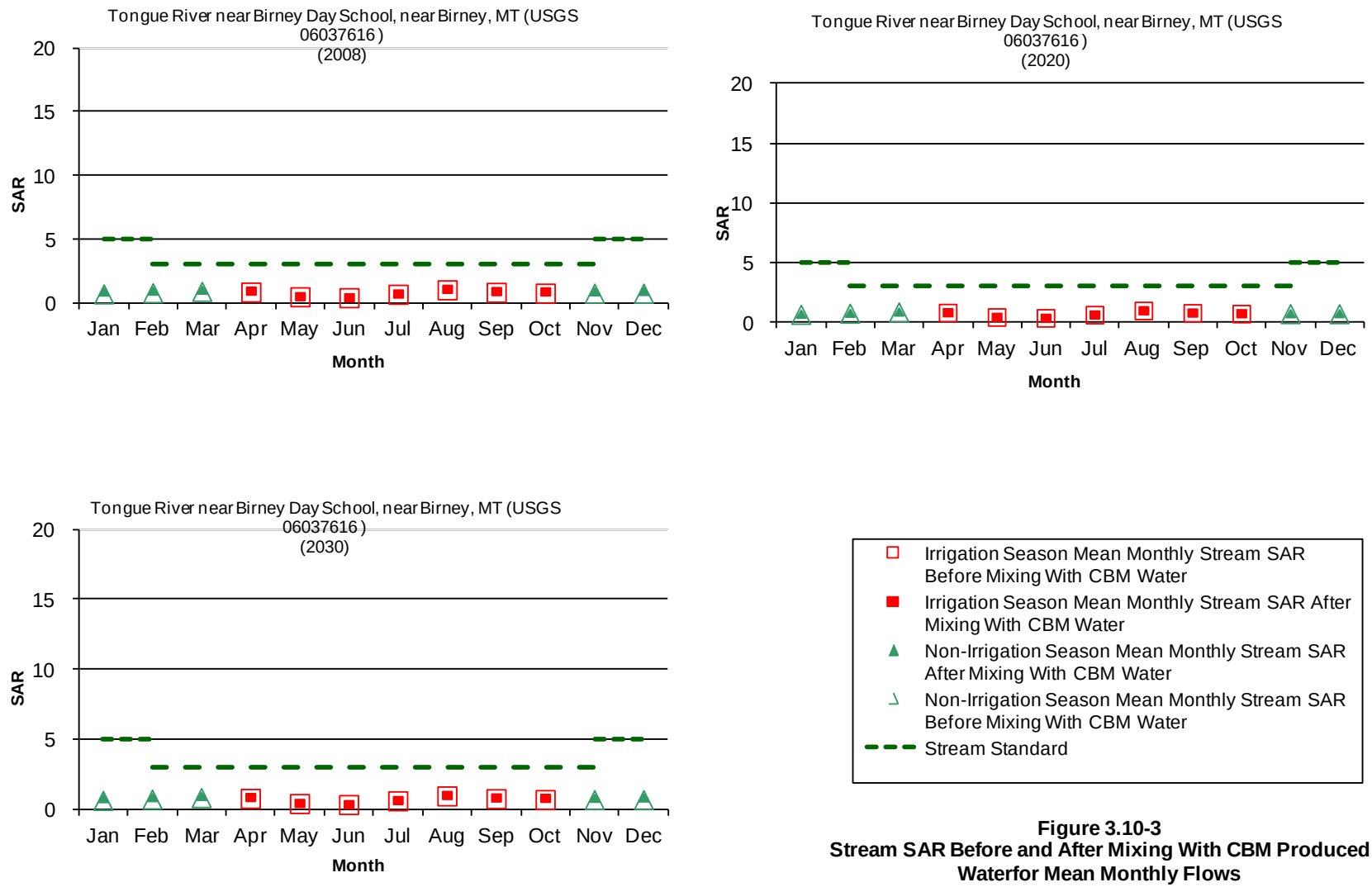


Figure 3.10-3
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Normal Year Hydrology
Tongue River near Birney Day School, near Birney, MT (USGS 06037616)

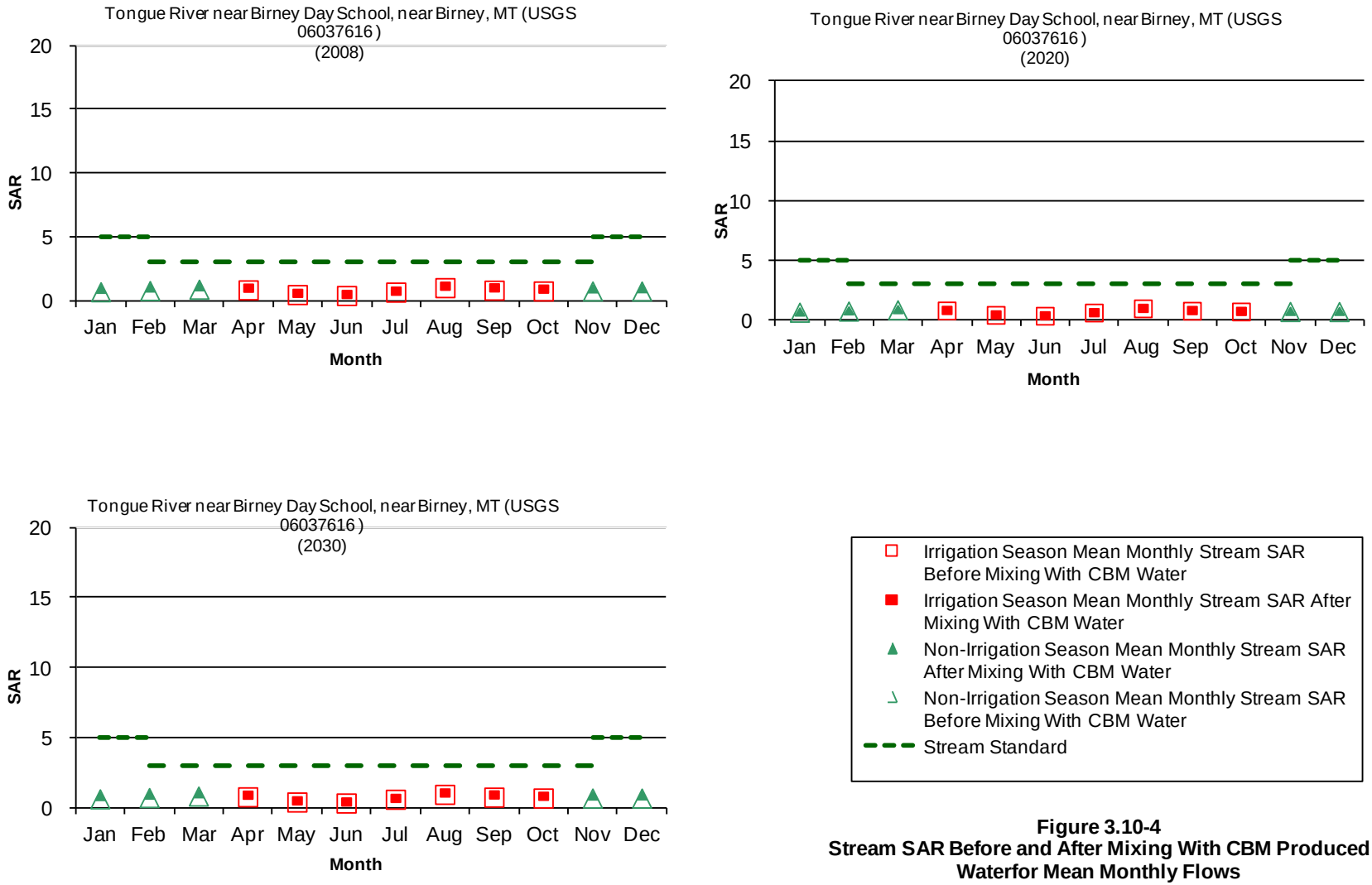


Figure 3.10-4
Stream SAR Before and After Mixing With CBM Produced Waterfor Mean Monthly Flows
Dry Year Hydrology
Tongue River near Birney Day School, near Birney, MT (USGS 06037616)

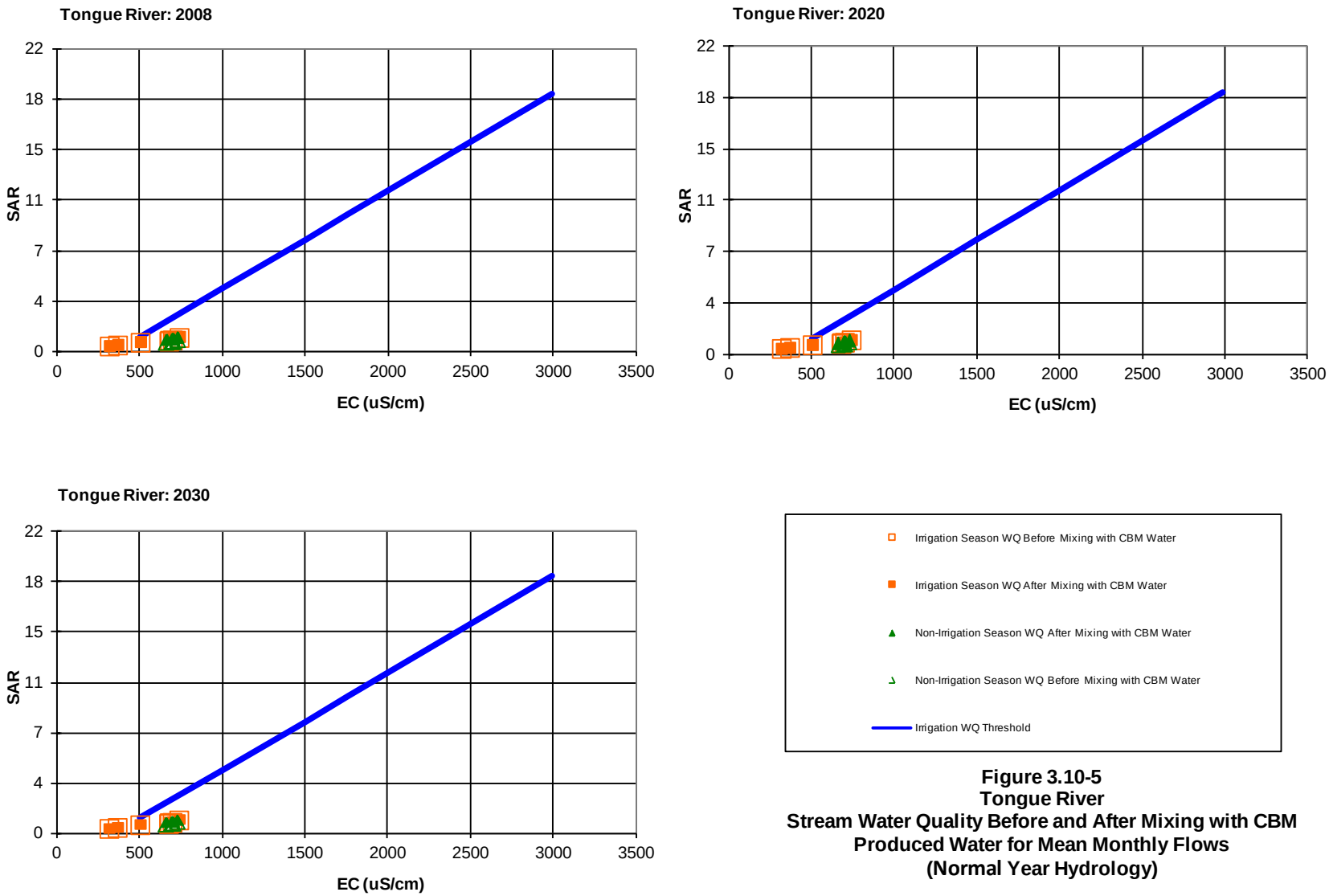


Figure 3.10-5
Tongue River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

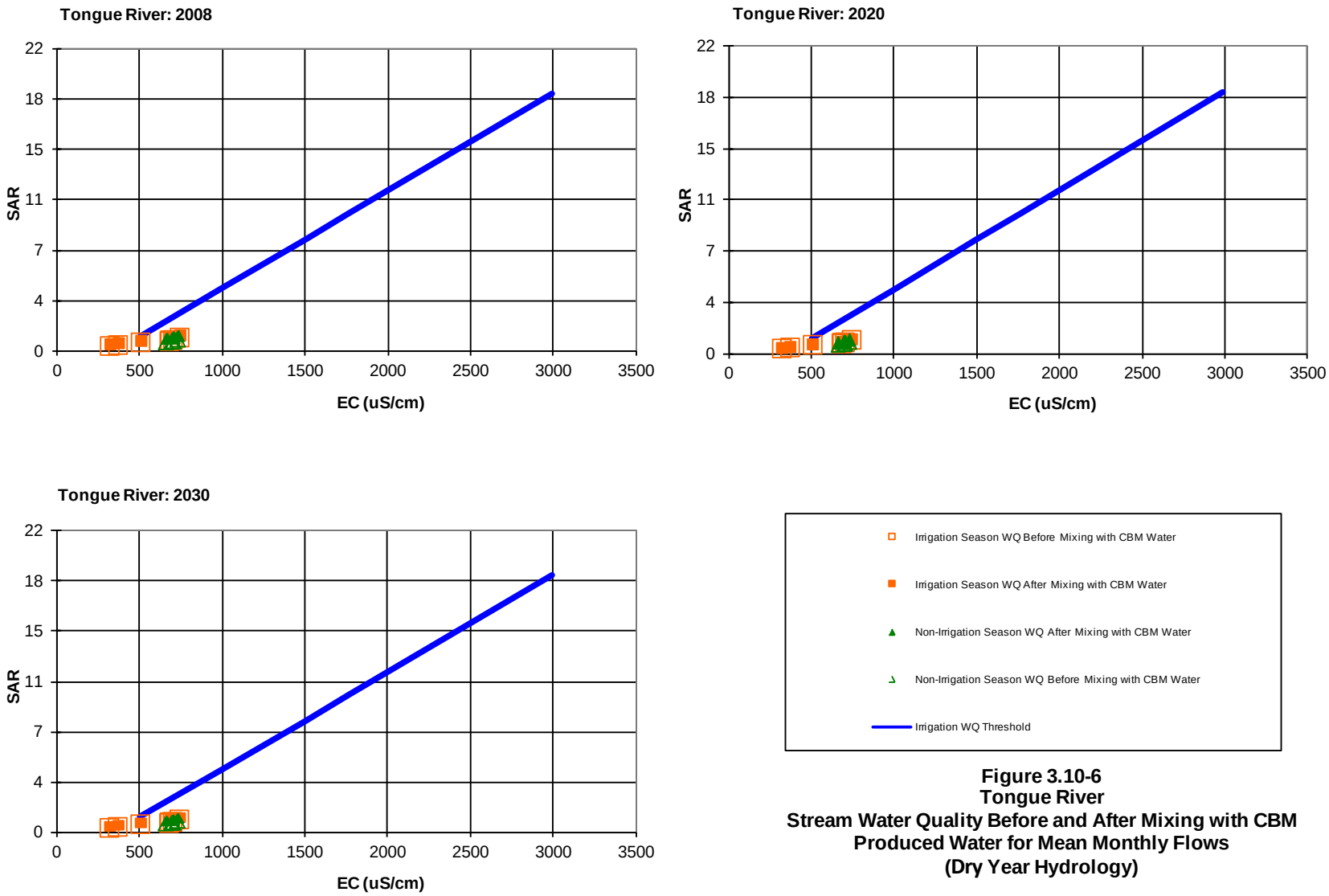


Figure 3.10-6
Tongue River
Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Dry Year Hydrology)

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:

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

where Q represents mean annual discharge
- b represents channel width
- d represents depth
- λ 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 provided the basis of the evaluation of perennial streams associated with the following:

- Belle Fourche River (USGS Gage 06426500),
- Clear Creek (USGS Gage 06324000),
- Crazy Woman Creek (USGS Gage 06316400),
- Little Powder River (USGS Gage 06324970),
- Middle Powder River (USGS Gage 06324500), and
- Upper Tongue River (USGS Gage 06307616)

Based on the CBNG discharge data presented in Appendix 4A, the annual streamflow in these streams will increase by the maximum values indicated below:

- Belle Fourche River (maximum increase of 3 cfs),
- Clear Creek (no additional surface water flow into the stream from CBNG discharge),
- Crazy Woman Creek (maximum increase of 0.6 cfs),
- Little Powder River (maximum increase of 2.90 cfs),
- Middle Powder River (maximum increase of 2.98 cfs), and
- Upper Tongue River (maximum increase of 0.8 cfs)

Figure 4.2-1 through Figure 4.2-6 provide estimates of peak annual discharge recurrence interval for these perennial streams. A common range for the channel forming discharge is between the 1.5-year and 2-year recurrence interval. Using this information, the channel forming discharge is estimated to be in the range indicated below:

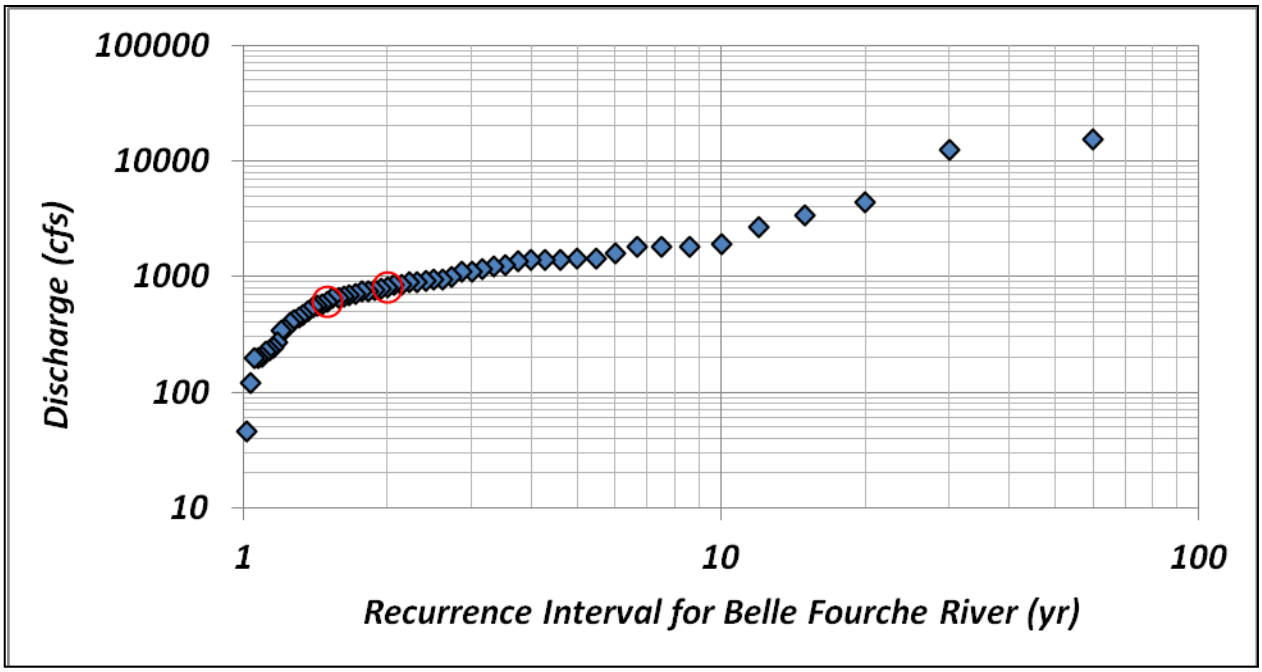


Figure 4.2-1 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Belle Fourche River

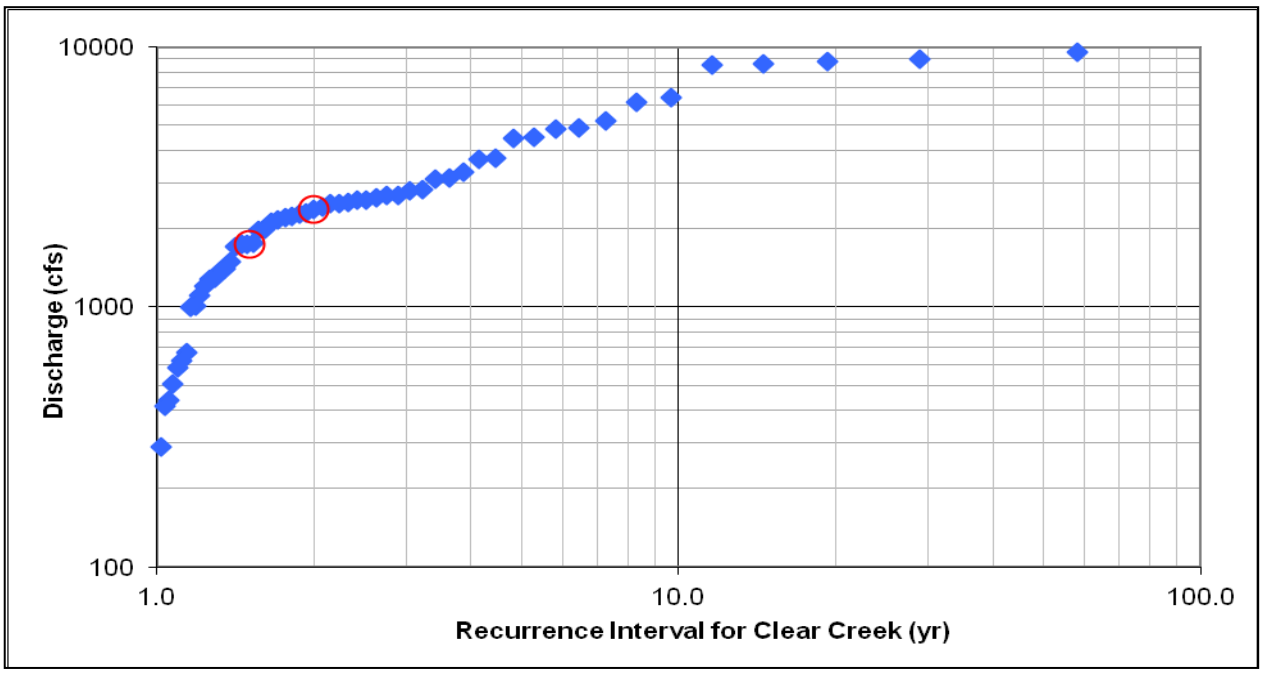


Figure 4.2-2 Estimated Recurrence Intervals for Observed Annual Peak Discharge for Clear Creek

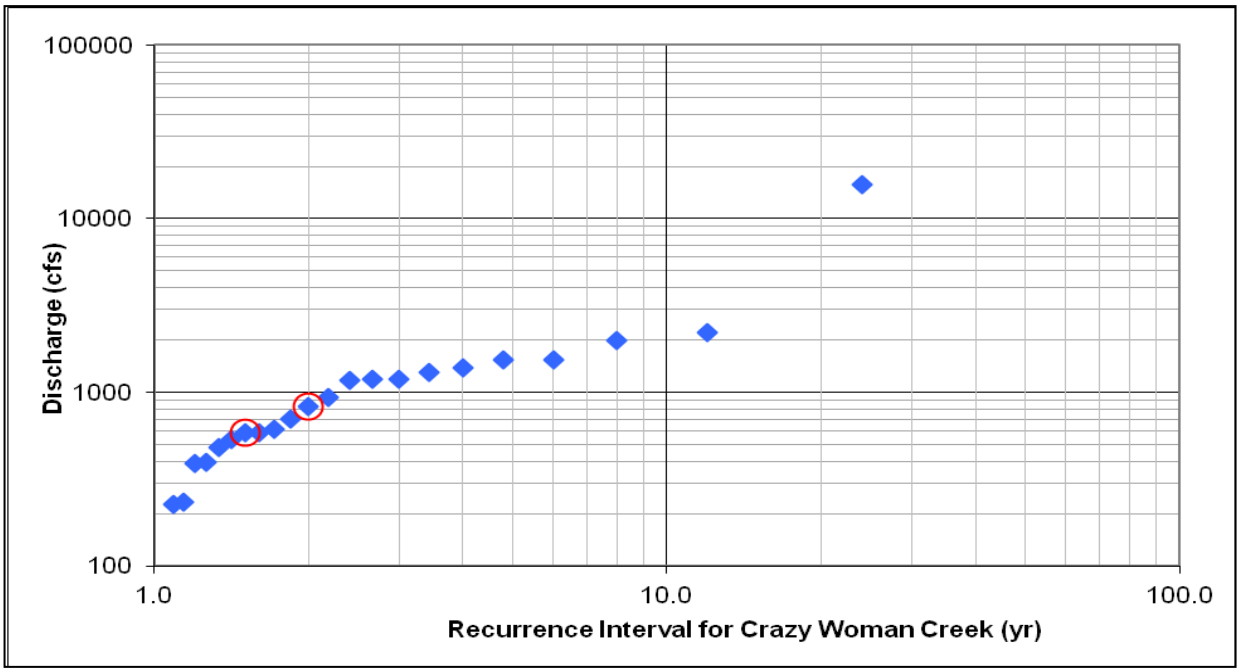


Figure 4.2-3 Estimated Recurrence Intervals for Observed Annual Peak Discharge for Crazy Woman Creek

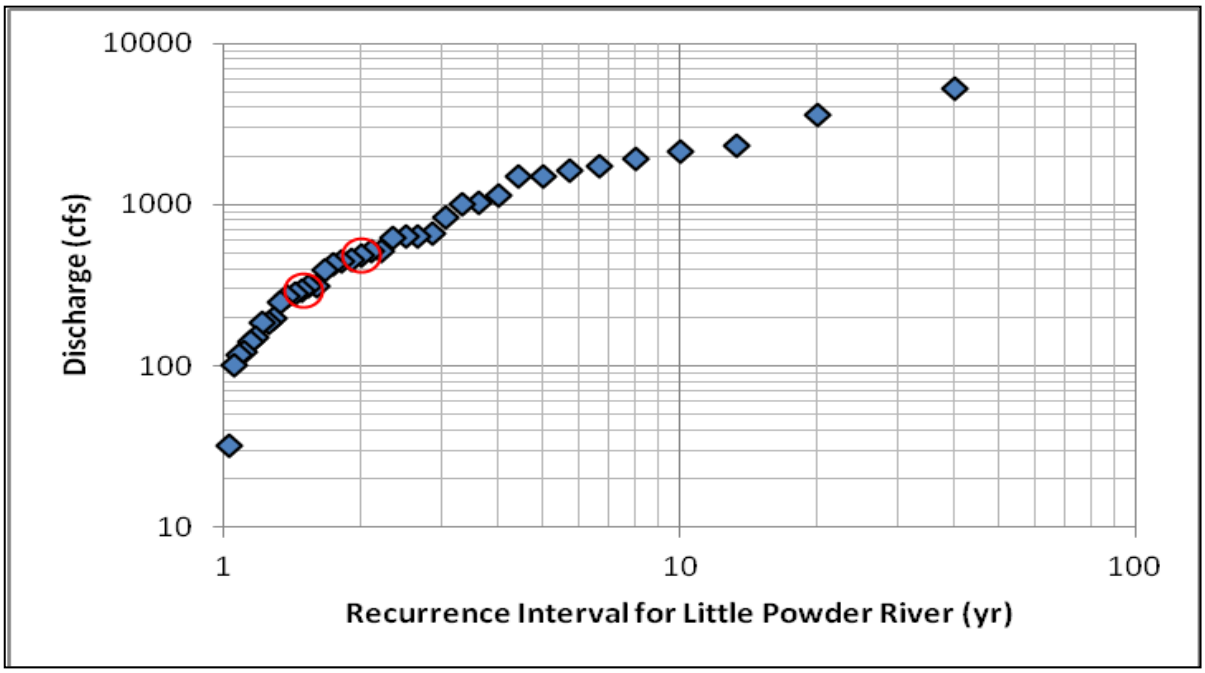


Figure 4.2-4 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Little Powder River

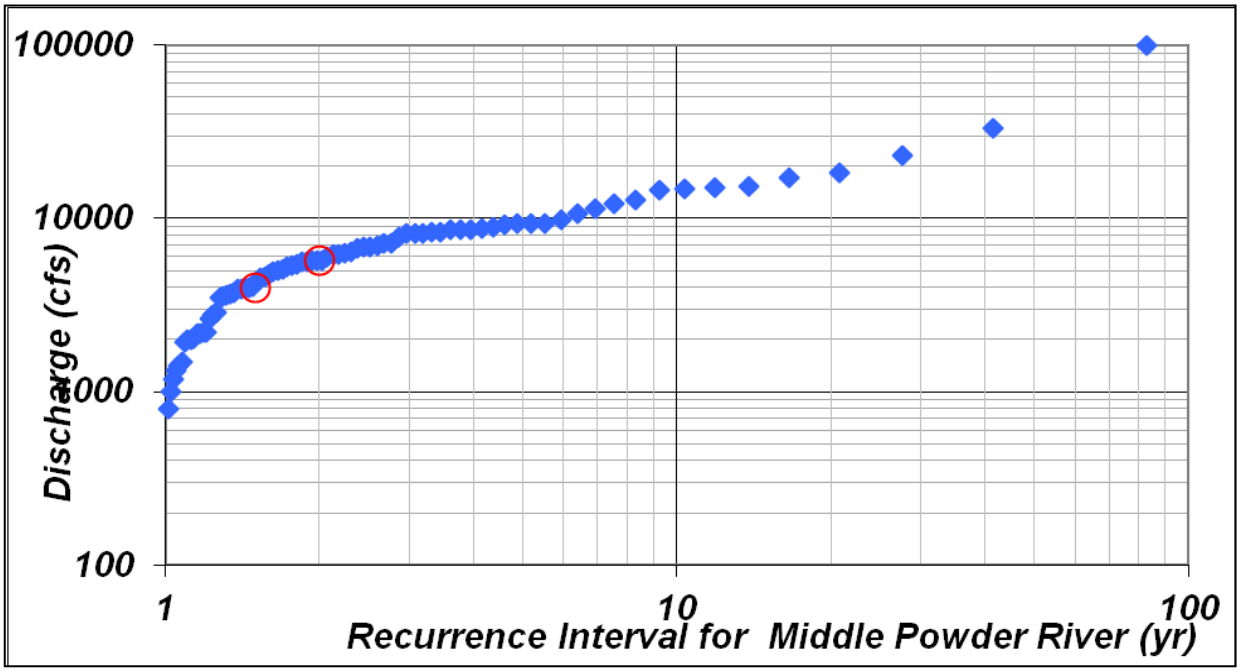


Figure 4.2-5 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Middle Powder River

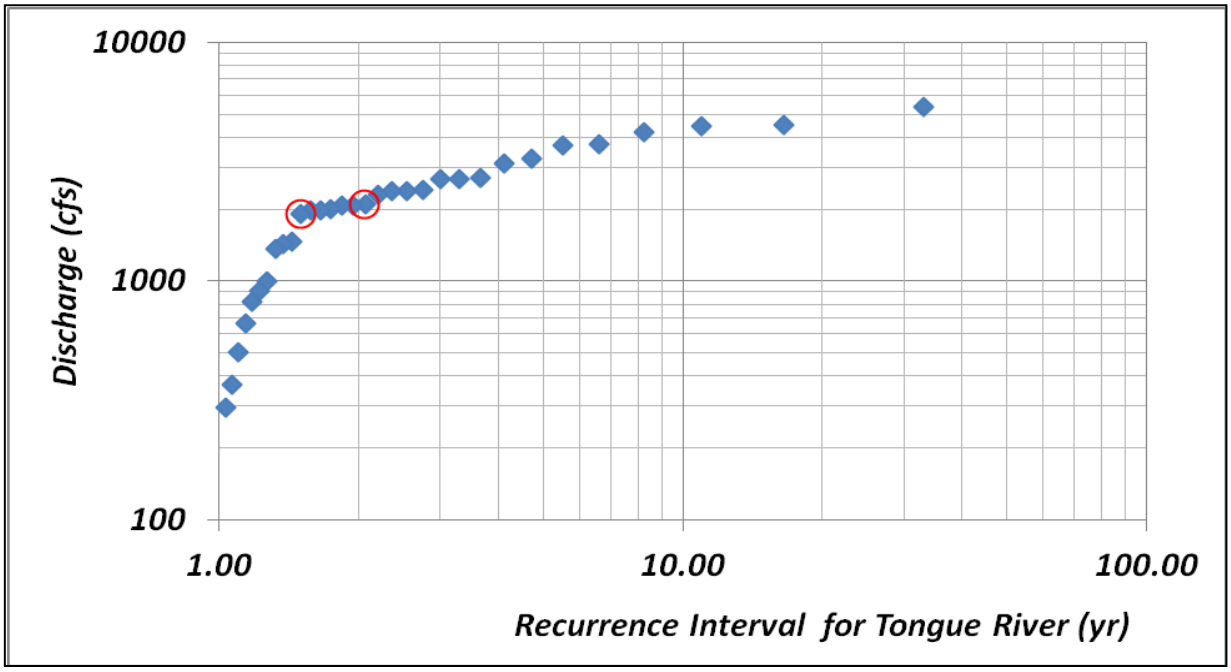


Figure 4.2-6 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Upper Tongue River

- Belle Fourche River (range from 600 cfs to 820 cfs),
- Clear Creek (range from 1,740 cfs to 2,370 cfs),
- Crazy Woman Creek (range from 580 cfs to 830 cfs),
- Little Powder River (range from 290 cfs to 490 cfs),
- Middle Powder River (range from 4,000 cfs to 5,720 cfs), and
- Upper Tongue River (1,900 cfs to 2,100 cfs)

Figure 4.2-7 through Figure 4.2-12 present a hydraulic geometry relationship for channel width as a function of discharge for the perennial streams identified above. The hydraulic geometry relationships were developed from all data classified as good (G) or fair (F) 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 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 these streams ranged from less than 0.1%, to 0.62%. These results suggest that for the larger, perennial streams the effect of the CBNG well production water will be minimal. Similar results were realized using regression equations developed by Lowham (USGS WRIR 88-4045, 1988) that reflected a relationship between discharge and channel width.

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)	(%)
Belle Fourche River	600–820	3.00	0.50-0.37	66.57-74.0	66.68-74.09	0.11-0.09	0.17-0.12
Clear Creek	1740-2370	0.00	0.00-0.00	111.38-120.71	111.38-120.71	0.0-0.0	0.0-0.0
Crazy Woman Creek	580-830	0.60	0.10-0.07	33.85-36.17	33.86-36.40	0.01-0.22	0.02-0.62
Little Powder Creek	290-490	2.90	1.02-0.61	52.87-65.56	53.09-65.72	0.22-0.16	0.42-0.24
Middle Powder Creek	4000-5720	2.98	0.07-0.05	213.42-230.05	213.45-230.08	0.03	0.02-0.01
Upper Tongue River	1900-2100	0.80	0.04-0.04	136.11-137.44	136.11-137.45	0.00-0.01	0.0

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

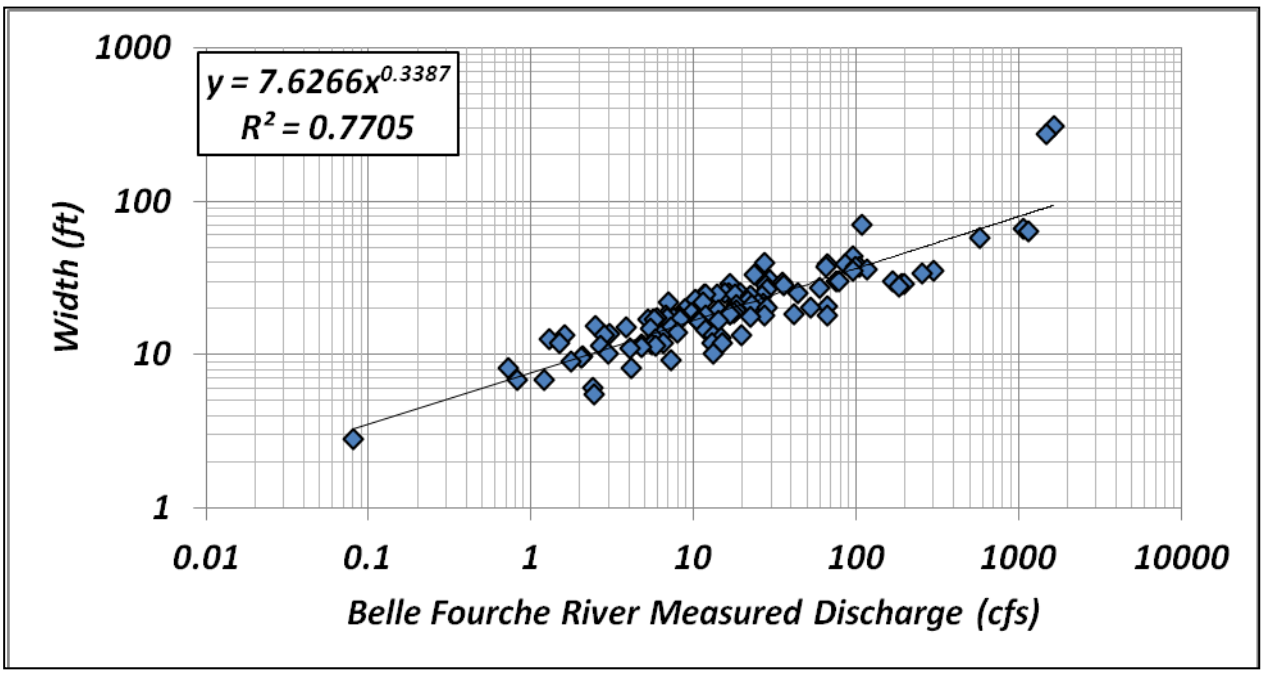


Figure 4.2-7 The Relationship Between Measured Discharge and Channel Width for the Belle Fourche River

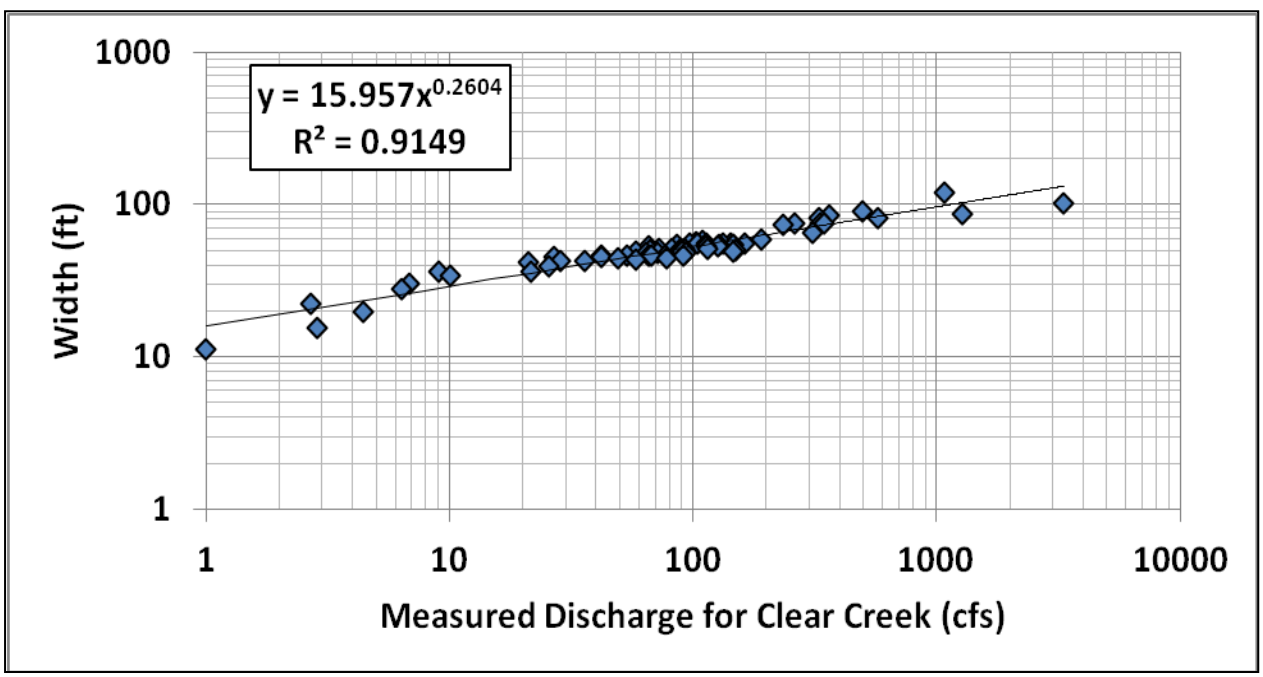


Figure 4.2-8 The Relationship Between Measured Discharge and Channel Width for Clear Creek

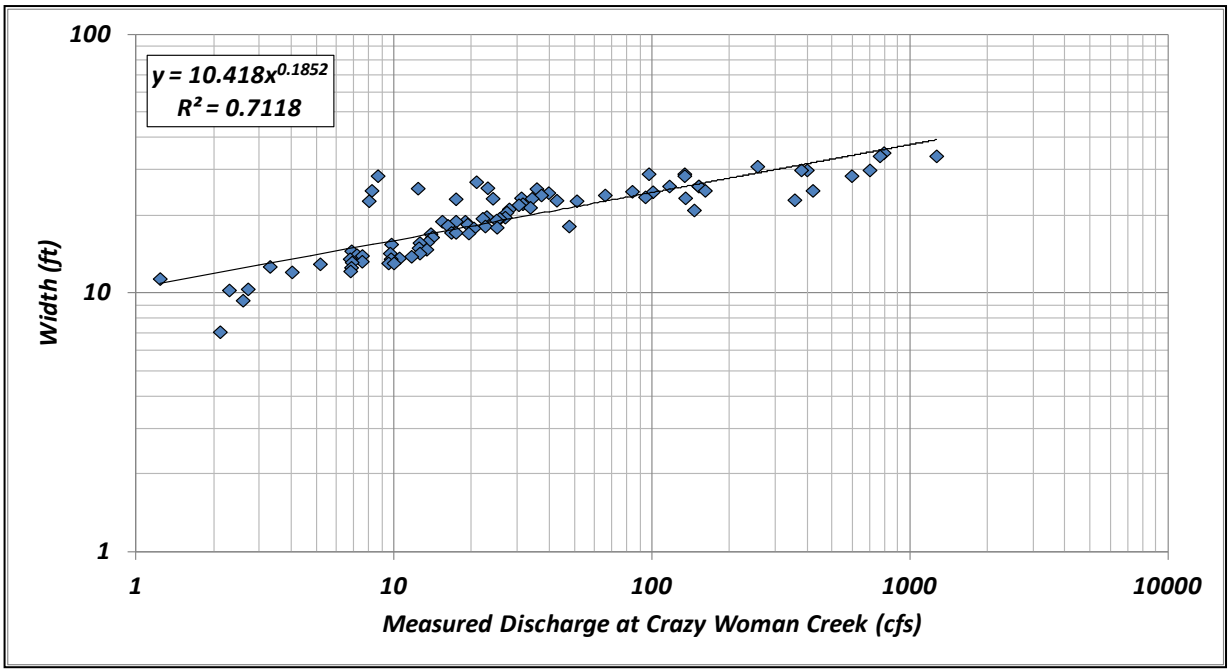


Figure 4.2-9 The Relationship Between Measured Discharge and Channel Width for Crazy Woman Creek

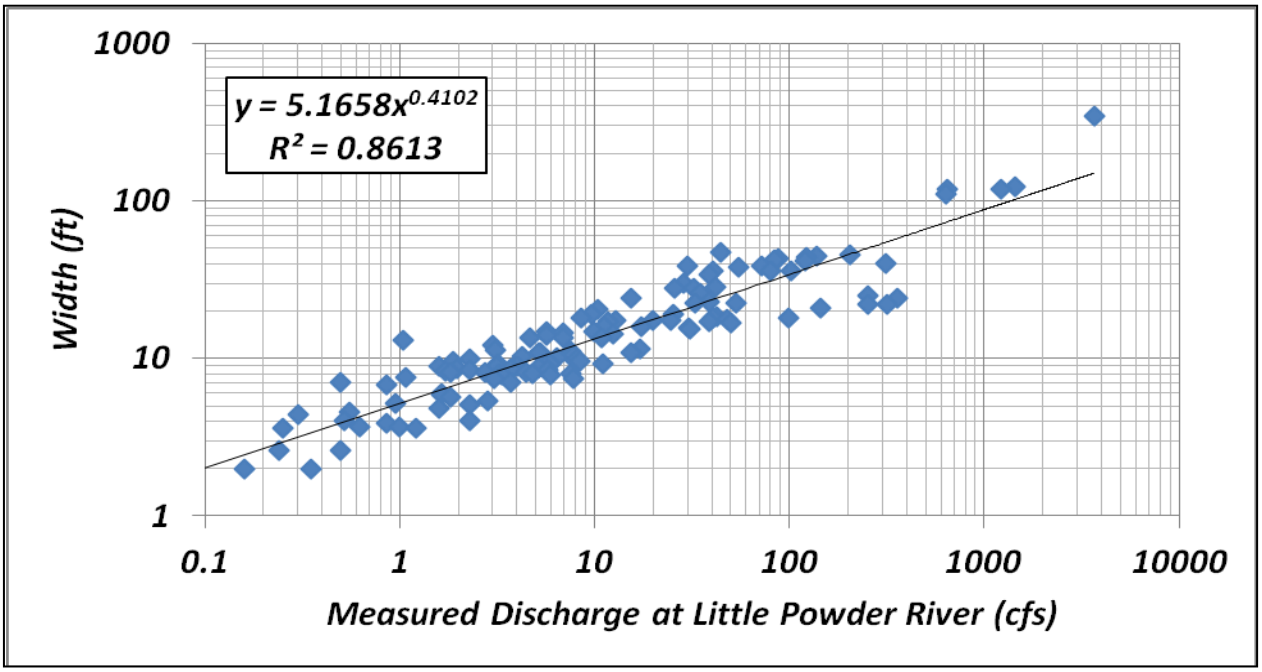


Figure 4.2-10 The Relationship Between Measured Discharge and Channel Width for the Little Powder River

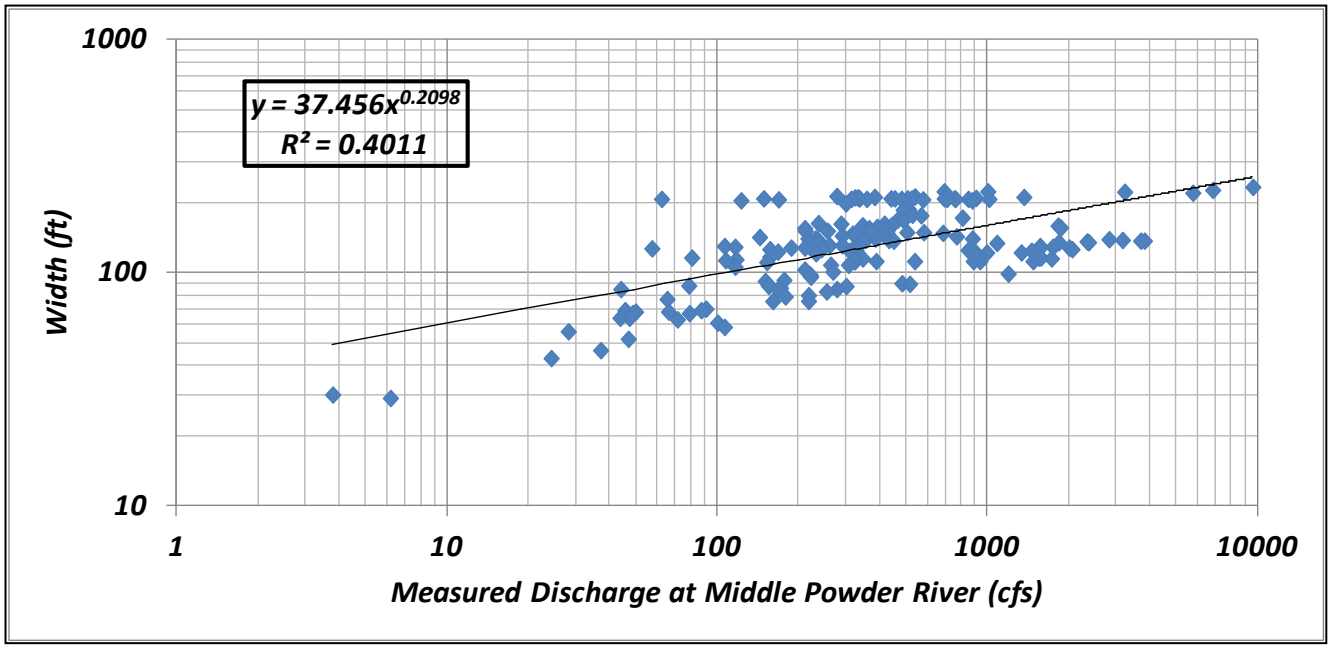


Figure 4.2-11 The Relationship Between Measured Discharge and Channel Width for the Middle Powder River

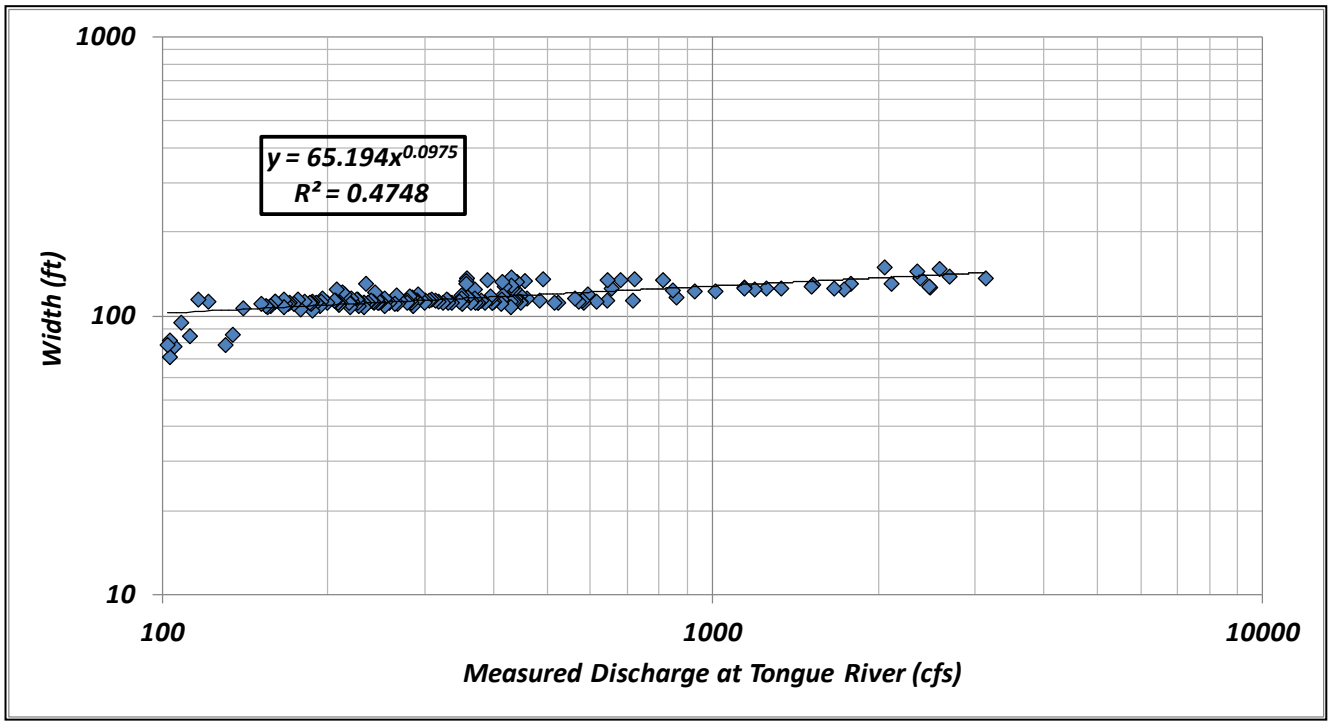


Figure 4.2-12 The Relationship Between Measured Discharge and Channel Width for the Upper Tongue River

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:

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

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. It should be noted, however, that multiple discharge locations of CBNG well production water into a specific reach of an ephemeral drainage may initiate or exacerbate erosion within the conveyance channel and may accelerate or disrupt the evolutionary transition of the channel from one phase to another (e.g., a transition of from Type I to Type II, or an incision or re-entrenchment of the channel from Type IV to Type II).

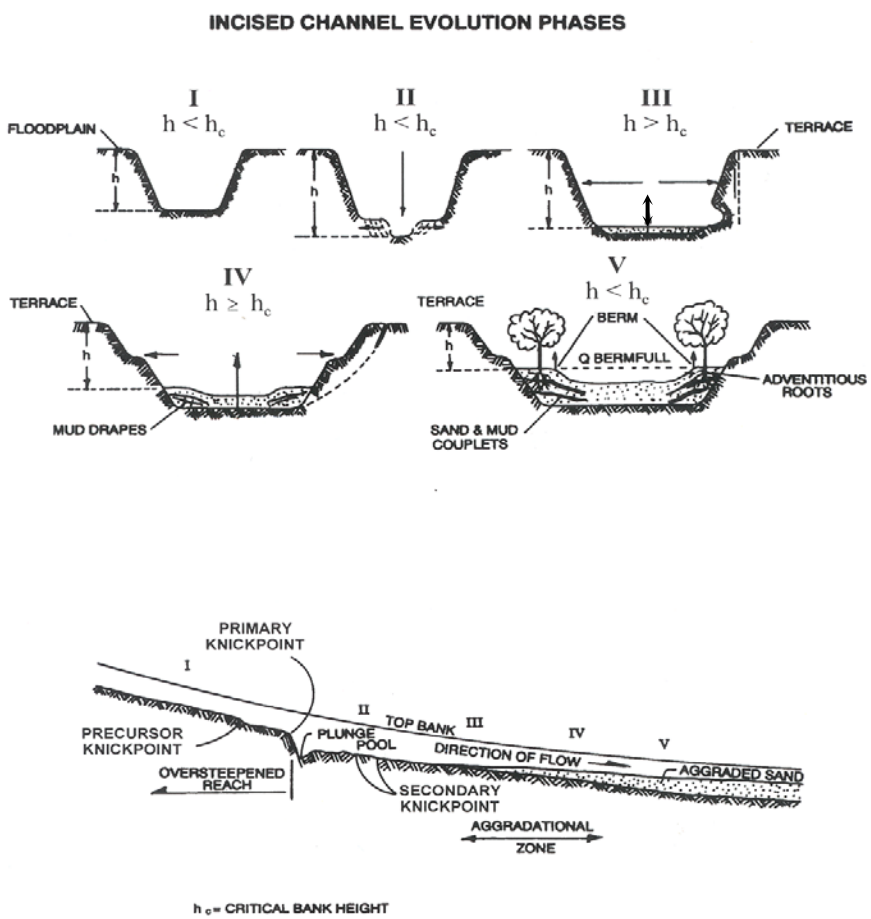


Figure 4.3-1 CEM Channel Types

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.

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 CBNG 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:

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

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. Coordination with Ms. Kathy Brus of the BLM in Buffalo was conducted to determine the results of monitoring the erosion along the ephemeral drainages. The results of this coordination effort indicated: (1) a reduction in water production has been realized within the basin; (2) operators have focused discharge of water into larger perennial stream systems; and (3) channel monitoring at 5 locations along the ephemeral drainages has not provided any conclusive results (BLM 2012).

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.

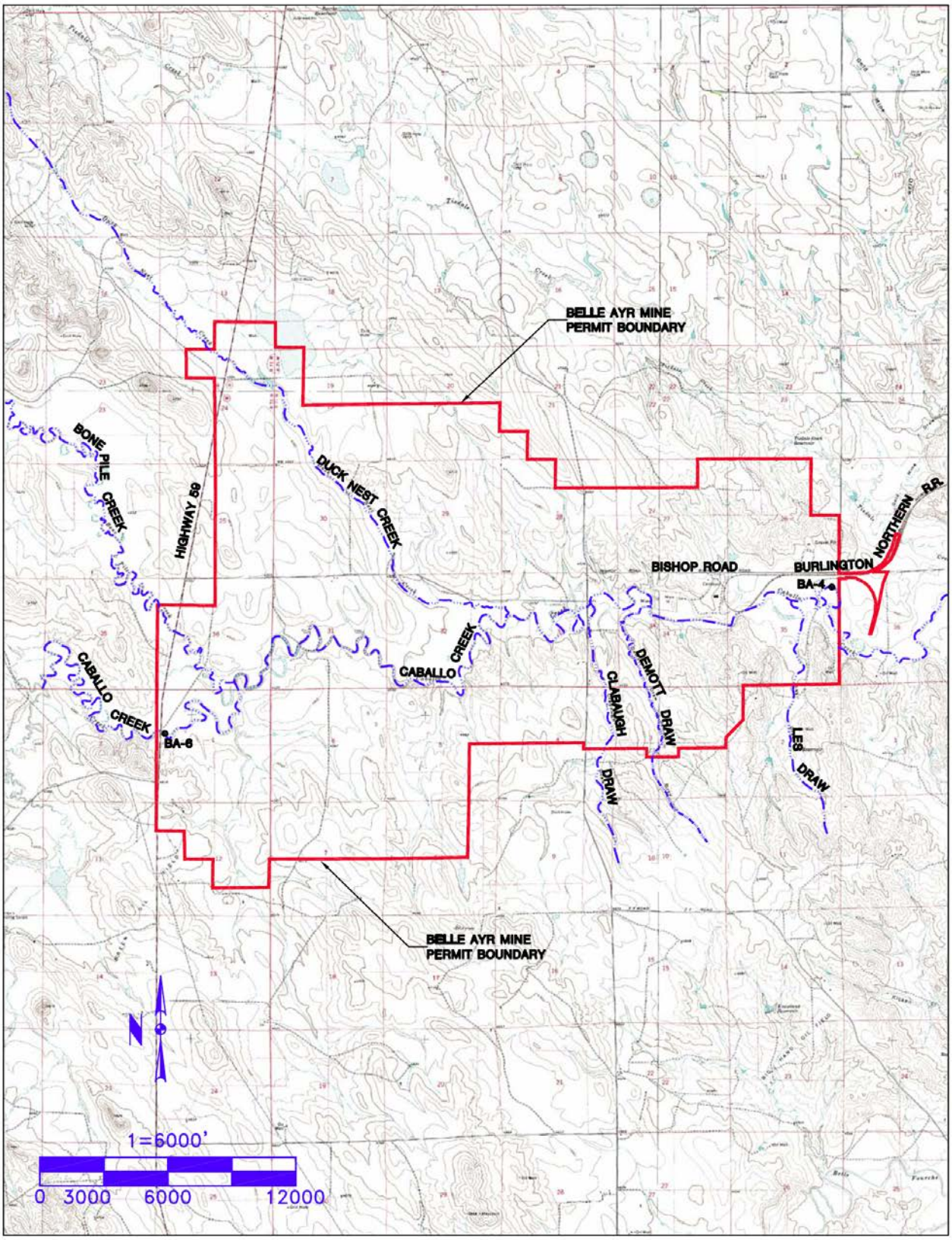


Figure 4.4-1 Vicinity Map

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 2010. 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.

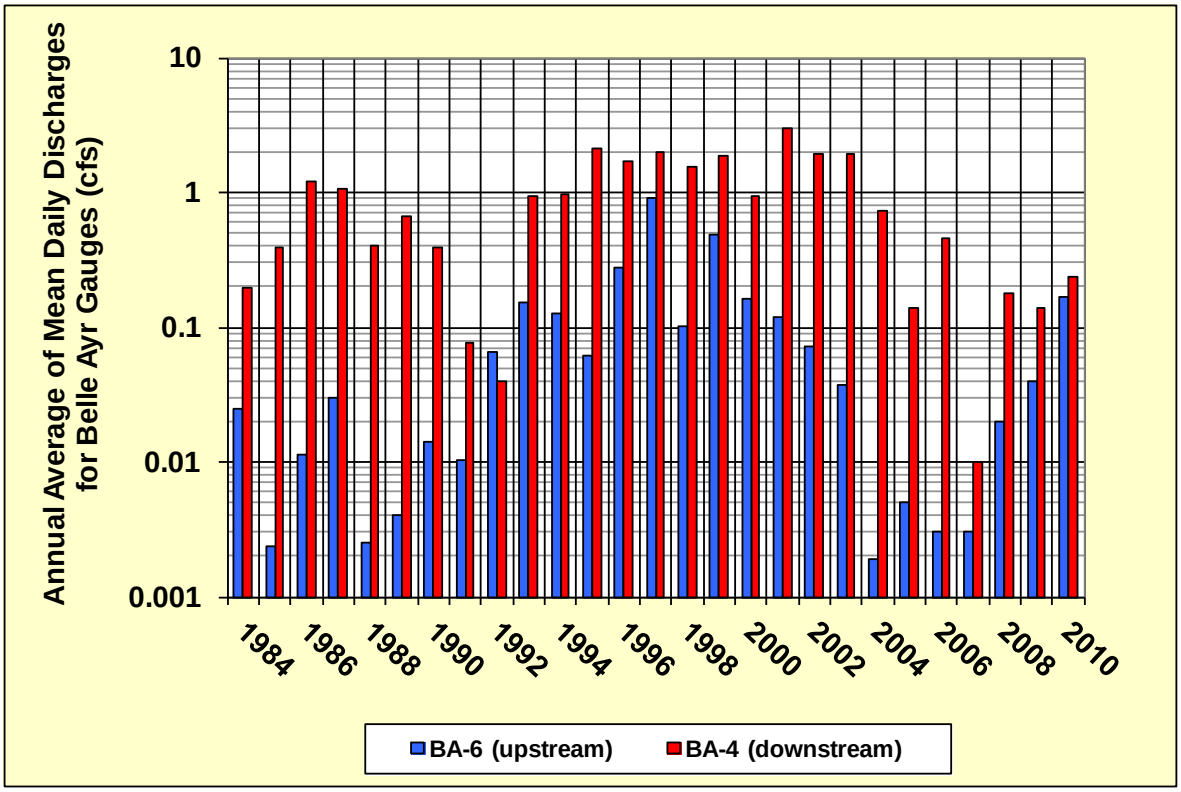


Figure 4.4-2 Hydrologic Data for Caballo Creek (1984-2010)

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 1.1 cfs (from 1993 to 2010). This represents an increase of 0.6 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 0.15 cfs (from 1993 to 2010). This represents an increase of 0.13 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 2010), 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 17.75 inches (for the time period from 1993 to 2010). This represents an increase of 3.39 inches or 24% 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.

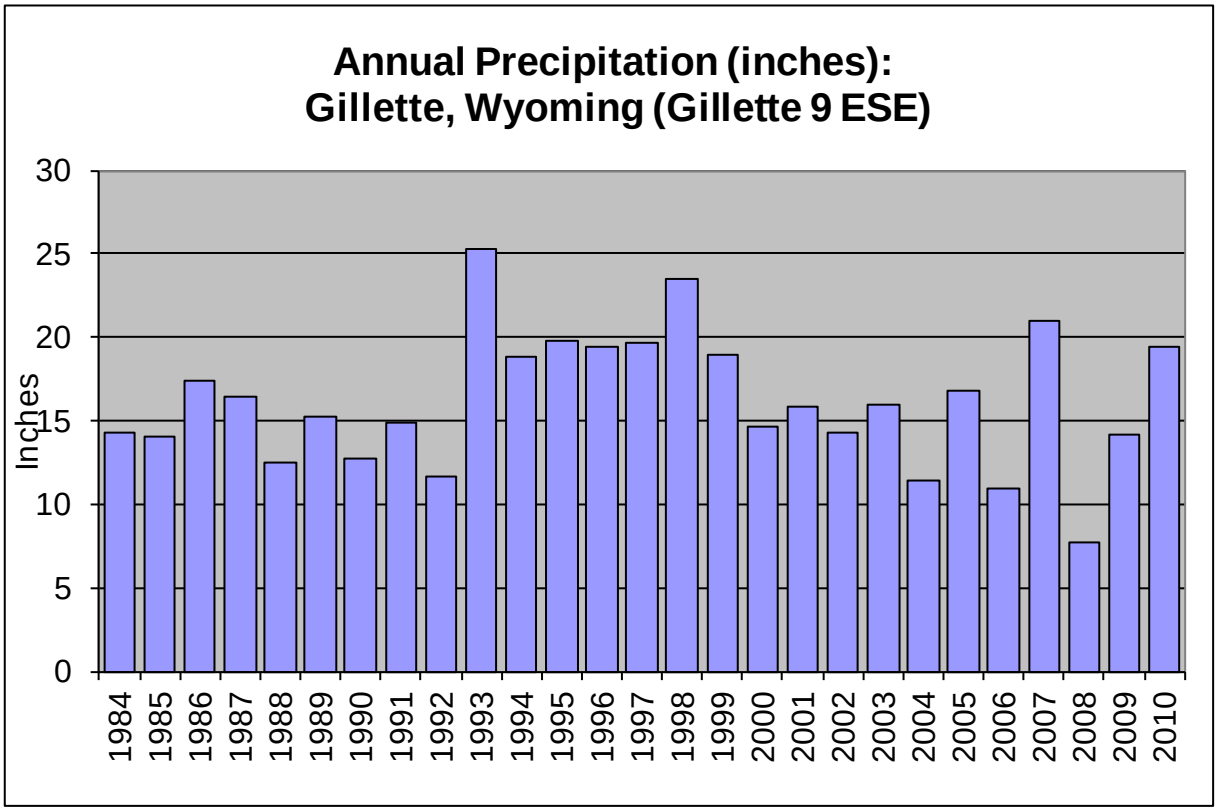


Figure 4.4-3 Average Annual Precipitation Data (1984-2010)

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 are presented in **Figure 4.4-4**. An evaluation of the data in **Figure 4.4-4** results in the following observations:

- 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 and extend through 2007.

- 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.

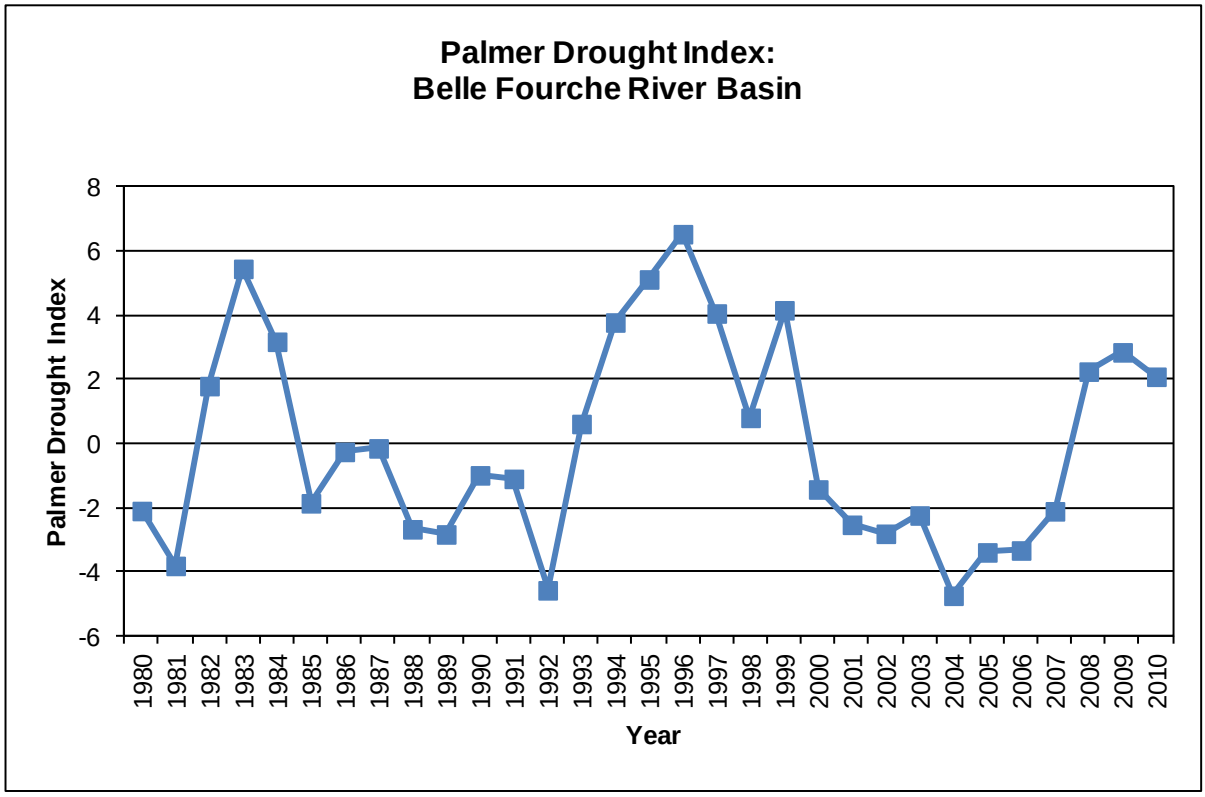


Figure 4.4-4 Palmer Drought Index Data (1980-2010)

- 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:

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

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.

5.0 REFERENCES

Anderson Consulting Engineers, Inc. (ACE). 2009. Task 3B Report-Water Resources Cumulative Impact Assessment, Water Quality and Channel Stability.

AECOM. 2009. Update of the Task 2 Report for the Powder River Basin Coal Review - Past and Present and Reasonably Foreseeable Development Activities. Prepared for the Bureau of Land Management High Plains District Office and Wyoming State Office. December 2009.

AECOM. 2011a. Task 2 Report for the Powder River Basin Coal Review - Past and Present and Reasonably Foreseeable Development Activities. Prepared for the Bureau of Land Management High Plains District Office and Wyoming State Office. December 2011.

AECOM. 2011b. Powder River Basin Coal Review Impoundment Study. Prepared for the Bureau of Land Management High Plains District Office and Wyoming State Office. April 2011.

AECOM. 2011c. PRB Coal Review Groundwater Model Protocol.

Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage, Paper 29 (Rev 1). Food and Agriculture Organization of the United Nations.

Bureau of Land Management (BLM). 1996. Coal Development Status Check Powder River Federal Coal Region Montana and Wyoming Data Tables. Data Compiled by: Wyoming Bureau of Land Management Buffalo Resource Area, Casper District, and State Offices, and Montana Bureau of Land Management Powder River Resource Area, Miles City District and State Offices.

Bureau of Land Management (BLM). 1999. Wyodak Coal Bed Natural Gas Project Final Environmental Impact Statement. Buffalo Field Office. May 1999.

Bureau of Land Management (BLM). 2003. Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project. Wyoming State Office and Buffalo Field Office Cheyenne and Buffalo, Wyoming. January 2003.

Bureau of Land Management (BLM). 2005. Draft Environmental Impact Statement for the Seminoe Road Natural Gas Development Project, Carbon County, Wyoming. November 2005.

Bureau of Land Management (BLM). 2012. Personal communication with Kathy Brus.

ENSR. 2005. Task 2 Report for the Powder River Basin Coal Review - Past and Present and Reasonably Foreseeable Development Activities. Prepared for the Bureau of Land Management Casper Field Office and Wyoming State Office. Revised October 2005 (with errata).

Greystone Environmental Consultants, Inc., ALL Consulting. 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. January 2003.

Hanson, Grattan and Fulton. 1999. Agricultural salinity and drainage. DANR resources publication 3375. University of California, Davis.

Harvey, M. D., and Watson, C.C. 1986. Fluvial processes and morphological thresholds in incised channel restoration. Water Res. Bulletin, 3(3):359-368.

HKM Engineering, Inc., Lord Consulting, and Watts and Associates. 2002a. Powder/Tongue River Basin Plan. Prepared for Wyoming Water Development Commission Basin Planning Program. February 2002.

HKM Engineering, Inc., Lord Consulting, and Watts and Associates. 2002b. Northeast Wyoming River Basins Plan. Prepared for Wyoming Water Development Commission Basin Planning Program. February 2002.

HIS Energy Services TM (HIS). 2010. PI/DWIGHTS Rocky Mountain Oil and Gas Production and Well History Database

Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering. American Society of Civil Engineering Proceedings, v 81, No. 745.

Lowhan, H.W. 1988. Streamflows in Wyoming. USGS WRIR 88-4045.

Martin, L.J., D.L. Naftz, H.W. Lowham, and J.G. Rankl. 1988. Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, NE Wyoming. USGS WRI 88-4046.

Montana Department of Environmental Quality (MDEQ), 2011. A Review of the Rationale for EC and SAR Standards, Prepared by the Montana Department of Environmental Quality, Water Quality Planning Bureau, Water Quality Standards Section.

Montgomery Watson Harza (MWH). 2003. Coal Planning Estimates Report. Prepared for the Bureau of Land Management Wyoming State Office. March 2003.

Schumm, S.A., Harvey, M. D., and Watson, C. C. 1981. Yazoo Basin geomorphology. Soil Conservation Service, Project SCS-23-MS-80.

Schumm, S. A., Harvey, M. D., and Watson, C. C. 1984. Incised Channels: Morphology, Dynamics and Control. Littleton, CO: Water Resources Publications.

Schumm, S.A. 1977. The Fluvial System. John Wiley and Sons, Inc.

Simon, A., and Hupp, C. R. 1987. Channel evolution in modified alluvial streams. U.S. Geological Survey, Washington, DC.

South Dakota Department of Environmental Quality. 2012. Surface Water Quality Standards, South Dakota Legislature Administrative Rules, Chapter 74:51:01:53.

United States Geological Survey (USGS). 2012. Personal communication with Kirk Miller.

Watson, C. C., Harvey, M. D., Biedenharn, D. S., and Combs, P. G. 1988. Geotechnical and hydraulic stability numbers for channel rehabilitation: Part I, The approach. Proc., ASCE Hyd. Div. 1988 National Conf., Abt, S. R., and Gessler, J. (Eds.).

Wyoming Department of Environmental Quality, Water Quality Division (WDEQ/WQD). 2010b. Compliance Monitoring and Siting Requirements for Unlined Impoundments Receiving Coalbed Methane Produced Water.

Wyoming Department of Environmental Quality, Water Quality Division (WDEQ/WQD). 2006. WDEQ CBNG effluent water quality database provided to ACE by AECOM on February 8, 2006.

Wyoming Oil and Gas Conservation Commission (WOGCC). 2005a. Wyoming Oil and Gas Supervisor, Wyoming Oil and Gas Conservation Commission. Personal communication with W. Berg, ENSR, regarding Application Permit to Drill approvals. April 13, 2005.

Wyoming Oil and Gas Conservation Commission (WOGCC). 2010. Statistics. Internet website: http://wogcc.state.wy.us/online_stats_bk/main_menu.cfm. Accessed on September 16, 2010 by AECOM.

Wyoming Oil and Gas Conservation Commission (WOGCC). 2010b. CBM Well Database. Internet web site: http://www.wogcc.state.wy.us/ urecordsMenu.cfm.

APPENDIX 2A

STREAM STANDARDS

Subchapter 6

Surface Water Quality Standards and Procedures

17.30.601 POLICY (1) The following standards are adopted to conserve water by protecting, maintaining, and improving the quality and potability of water for public water supplies, wildlife, fish and aquatic life, agriculture, industry, recreation, and other beneficial uses. (History: 75-5-201, 75-5-301, MCA; IMP, 75-5-301, MCA; Eff. 12/31/72; AMD, Eff. 11/4/73; AMD, Eff. 9/5/74; AMD, 1980 MAR p. 2252, Eff. 8/1/80; TRANS, from DHES, 1996 MAR p. 1499.)

17.30.602 DEFINITIONS In this subchapter the following terms have the meanings indicated below and are supplemental to the definitions given in 75-5-103, MCA:

(1) "Acutely toxic conditions" means conditions lethal to aquatic organisms passing through the mixing zone. Lethality is a function of the magnitude of pollutant concentrations and the duration of organism exposure to those concentrations.

(2) "Bioconcentrating parameters" means the parameters listed in department Circular DEQ-7 which have a bioconcentration factor greater than 300.

(3) "Carcinogenic parameters" means the parameters categorized as carcinogens in department Circular DEQ-7.

(4) "Chlorophyll a" means the mass of chlorophyll a pigment after correction for phaeophytins.

(5) "Chronic toxicity" means that death or functional impairment occurs or can be expected to occur to organisms exposed for periods of time exceeding 96 hours.

(6) "Conduit" means any artificial or natural duct, either open or closed, capable of conveying liquids or pollutants.

(7) "Conventional water treatment" means in order of application the processes of coagulation, sedimentation, filtration, and disinfection. If determined necessary by the department it also includes taste and odor control and lime softening.

(8) "Dewatered stream" means a perennial or intermittent stream from which water has been removed for one or more beneficial uses.

(9) "Electrical conductivity (EC)" means the ability of water to conduct an electrical current at 25°C. The electrical conductivity of water represents the amount of total dissolved solids in the water and is expressed as microSiemens/centimeter (µS/cm) or micromhos/centimeter (µmhos/cm) or equivalent units and is corrected to 25°C.

(a) the geometric mean number of Escherichia coli bacteria may not exceed 630 colony forming units per 100 milliliters and 10% of the samples may not exceed 1,260 colony forming units per 100 milliliters during any 30-day period;

(b) EC shall not exceed 3000 µS/cm;

(c) the surface and ground water standards listed in DEQ-7 do not apply. (History: 75-5-301, MCA; IMP, 75-5-301, MCA; NEW, 2003 MAR p. 1274, Eff. 6/27/03; AMD, 2006 MAR p. 528, Eff. 2/24/06.)

Rules 17.30.659 through 17.30.669 reserved

17.30.670 NUMERIC STANDARDS FOR ELECTRICAL CONDUCTIVITY (EC) AND SODIUM ADSORPTION RATIO (SAR) (1) No person may violate the numeric water quality standards or the criteria for determining nonsignificant changes in water quality identified in (2) through (6).

(2) The numeric standards for electrical conductivity (EC) and sodium adsorption ratio (SAR) for the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers from November 1 through March 1 are as follows:

(a) for Rosebud Creek and the Tongue River, the monthly average numeric water quality standard for EC is 1500 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 5.0 and no sample may exceed an SAR value of 7.5; and

(b) for the Powder River and the Little Powder River, the monthly average numeric water quality standard for EC is 2500 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 6.5 and no sample may exceed an SAR value of 9.75.

(3) The numeric standards for EC and SAR for the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers from March 2 through October 31 are as follows:

(a) for Rosebud Creek and the Tongue River, the monthly average numeric water quality standard for EC is 1000 µS/cm and no sample may exceed an EC value of 1500 µS/cm. The monthly average numeric water quality standard for SAR is 3.0 and no sample may exceed an SAR value of 4.5; and

(b) for the Powder River and Little Powder River, the monthly average numeric water quality standard for EC is 2000 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 5.0 and no sample may exceed an SAR value of 7.5.

(4) For all tributaries and other surface waters in the Rosebud Creek, Tongue, Powder, and Little Powder river watersheds, the monthly average numeric water quality standard for EC is 500 µS/cm and no sample may exceed an EC value of 500 µS/cm. The monthly average numeric water quality standard for SAR from March 2 through October 31 is 3.0 and no sample may exceed an SAR value of 4.5. The monthly average numeric water quality standard for SAR from November 1 through March 1 is 5.0 and no sample may exceed an SAR value of 7.5.

(5) For the Tongue River Reservoir, the monthly average numeric water quality standard for EC is 1000 µS/cm and no sample may exceed an EC value of 1500 µS/cm. The monthly average numeric water quality standard for SAR is 3.0 and no sample may exceed an SAR value of 4.5.

(6) EC and SAR are harmful parameters for the purposes of the Montana Water Quality Act, Title 75, chapter 5, MCA. (History: 75-5-301, 75-5-303, MCA; IMP, 75-5-301, 75-5-303, MCA; NEW, 2003 MAR p. 779, Eff. 4/25/03; AMD, 2006 MAR p. 1733, Eff. 5/19/06.)

NEXT PAGE IS 17-2775

South Dakota Legislature

Administrative Rules

My Legislative Research
Rules Menu/Quick Find
Current Register
Rules List
Rules Text Search
Rules Manual
Price List
Register Archive
Register Text Search
RSS Feeds

Download Section in Microsoft Word Format Printer Friendly

74:51:01:53. Criteria for irrigation waters. The criteria of parameters for irrigation waters and their allowable variations that are not included under § 74:51:01:55 and Appendix B, unless set under § 74:51:01:24, are as found in the following table:

Parameter	Criteria	Unit of Measure	Special Conditions
Conductivity at 25°C	≤ 2,500	micromhos/cm	30-day average
	≤ 4,375	micromhos/cm	daily maximum
Sodium adsorption ratio	≤ 10		see definition

Source: SL 1975, ch 16, § 1; 4 SDR 32, effective December 4, 1977; transferred from § 34:04:02:43, effective July 1, 1979; 10 SDR 145, effective July 4, 1984; 13 SDR 129, 13 SDR 141, effective July 1, 1987; 14 SDR 86, effective December 24, 1987; 19 SDR 111, effective January 31, 1993; transferred from § 74:03:02:43, July 1, 1996; 24 SDR 10, effective July 20, 1997.

General Authority: SDCL 34A-2-11, 34A-2-93.

Law Implemented: SDCL 34A-2-10, 34A-2-11.

Back to 74:51:01 | 74:51:01:53

Home | Contact | Help | Privacy Policy | South Dakota Homepage

Copyright © 2012 South Dakota Legislature, all rights reserved.

South Dakota Legislature

Administrative Rules

My Legislative Research
Rules Menu/Quick Find
Current Register
Rules List
Rules Text Search
Rules Manual
Price List
Register Archive
Register Text Search
RSS Feeds

Download Section in Microsoft Word Format Printer Friendly

74:51:01:53.01. Site specific criterion for irrigation waters -- Belle Fourche River from the Wyoming-South Dakota border to its confluence with the Cheyenne River. The following site-specific criterion for irrigation waters is established for the Belle Fourche River from the Wyoming-South Dakota border to its confluence with the Cheyenne River:

Sodium adsorption ratio	≤ 6		See definition

Source: 31 SDR 29, effective September 13, 2004.
General Authority: SDCL 34A-2-11, 34A-2-93.
Law Implemented: SDCL 34A-2-10, 34A-2-11.

Back to 74:51:01 | 74:51:01:53.01

Copyright © 2012 South Dakota Legislature, all rights reserved.

AGRICULTURAL USE PROTECTION POLICY[1]
(Chapter 1, Section 20)

I. Purpose

All surface waters in Wyoming are protected to some extent for agricultural uses. "Agricultural uses" are described in Chapter 1, Section 3 as being either stock watering or irrigation. The standard that applies to the protection of these uses is contained in Chapter 1, Section 20 which states:

> *Section 20.* ***Agricultural Water Supply.*** *All Wyoming surface waters which have the natural water quality potential for use as an agricultural water supply shall be maintained at a quality which allows continued use of such waters for agricultural purposes.*
>
> *Degradation of such waters shall not be of such an extent to cause a measurable decrease in crop or livestock production.*
>
> *Unless otherwise demonstrated, all Wyoming surface waters have the natural water quality potential for use as an agricultural water supply.*

All water quality standards are established for two reasons. The first is to provide a benchmark against which a determination can be made as to whether a waterbody is impaired and requires some kind of corrective action. The second is to provide a basis for establishing permit limits on regulated activities (WYPDES & Section 404 permits). The purpose of this policy is to provide guidelines to be used by the Water Quality Division when translating the narrative goals expressed in the Section 20 standard into appropriate WYPDES permit limits where maintaining agricultural use of the receiving waters is an issue.

Agricultural use of surface water is an opportunistic endeavor. The varying uses as well as the different qualities of the water found in the state are many and the farming and ranching industries have always had to make do with what water is available. The goal expressed in the Section 20 standard is simply to maintain surface water quality at a level that will continue to support the local agricultural uses that have developed around it.

Though the goal is simple, achieving it is not. For the most part, managing water quality for continued agricultural support requires managing the concentration and chemical makeup of dissolved solids. Because of local differences in crop types, soil types and natural water

[1] This policy was finalized in August, 2006 in conjunction with the Triennial Review of the Chapter 1 surface water standards. A modified version of this policy is under consideration by the Wyoming Environmental Quality Council for adoption as an appendix to the Chapter 1 rules. Until a final decision is rendered on that rulemaking, the provisions of this policy remain in effect for establishing effluent limits on discharges that may affect agricultural uses. The only exception is that the formula for calculating SAR limits has been updated to be SAR < ($EC_{ds/M}$ X 6.67) – 3.33.

quality and availability, it isn't possible to establish simple numeric criteria for pollutants such as TDS and SAR that will allow an efficient use of surface water for irrigation purposes. The determination of what is acceptable water quality for irrigation must necessarily involve an evaluation of local agricultural practices and background water quality conditions. For livestock watering uses, it is somewhat less complicated because there are fewer variables to consider.

"Measurable Decrease"

The first part of translating the standard is defining what is meant by *"measurable decrease in crop or livestock production"*. The phrase implies that there is a pre-existing agricultural use of a stream or drainage prior to an application for aWYPDES discharge permit. For livestock watering purposes, a pre-existing use will always be assumed. For irrigation purposes, there needs to be either a current irrigation structure or mechanism in place for diverting water from the stream channel, or a substantial acreage of naturally sub-irrigated pasture within a stream floodplain. Where neither of these conditions exist, there can be no irrigation use, nor loss in crop production attributable to water quality.

Where there are pre-existing agricultural uses, it may often be impossible to measure a loss in crops or livestock that can be attributed to water quality because of the many other factors that will affect actual production. It is also important to be able to predict the probability of a measurable decrease in production rather than relying solely on after-the-fact measurements. Therefore, the implementation of the narrative criteria through WYPDES permits will always involve making reasonable judgments and assumptions.

Effluent limits on historic discharges of produced water will not be affected by this policy in relation to the protection of agricultural uses. Where discharges have been occurring for many years, the permitted quality of those discharges shall be considered to be "background" conditions and be fully protective of the agricultural uses that have developed around them. Therefore, it is not necessary to modify those discharges in order to achieve the goal of "no measurable decrease" in crop or livestock production. It would only be necessary to maintain the existing quality of the discharge. It is important to note, however, that effluent limits on historic discharges may be made where the quality of the discharge is shown to constitute a hazard to humans, livestock or wildlife.

II. Livestock Watering

The basic concept in protecting a livestock watering use is to ensure that water quality is not acutely toxic to livestock or does not contain pollutants in concentrations that would affect growth or reproduction. There are basic effluent limitations provided in the WYPDES permit regulations *(Chapter 2 of the Water Quality Rules and Regulations)* that are intended to ensure that the water is safe for livestock to drink. These limits are:

5000 mg/L TDS;
3000 mg/L Sulfate;
2000 mg/L Chloride;

and each must be achieved at the end-of-pipe prior to mixing with the receiving stream. In addition to the basic effluent limitations the following limits for livestock protection may be incorporated into WYPDES permits when there is reason to believe they may be associated with a discharge:

Selenium	50 µg/L	Total Recoverable
Fluoride	4000 µg/L	Dissolved
Arsenic	20 µg/L	Total Recoverable
Copper	500 µg/L	Dissolved
Cadmium	50 µg/L	Dissolved
Boron	5000 µg/L	Dissolved
Chromium	1000 µg/L	Dissolved
Lead	100 µg/L	Dissolved
Mercury	10 µg/L	Dissolved
Zinc	2500 µg/L	Dissolved

Livestock watering waver

An exception to the limits above may be made whenever the background water quality of the receiving water is worse than the value listed for the associated pollutant or when the livestock producer requests use of the water and thereby accepts any potential risk to his livestock.

III. Irrigation

The interpretation of the Section 20 standard for irrigation is more complex than for livestock watering because there are more variables than just the quality of the water to consider. However, after considering the local circumstances relative to irrigation and crop production, effluent limits can be established on WYPDES permits that will be protective of the pre-existing irrigation uses. The goal is to ensure that pre-existing irrigated crop production will not be diminished as a result of the lowering of water quality.

The basic water quality parameters of concern in regard to irrigation are electrical conductivity (EC) and sodium adsorption ratio (SAR). Protection of irrigation uses where WYPDES permits are involved amounts to deriving appropriate effluent limits for EC and SAR in each instance.

A. Identification and Protection of Irrigation Uses.

Implementation of the Section 20 standard through the WYPDES permitting program involves a sequence of decisions based upon the amount and quality of data that is available to the permit writer. The most basic question is whether a proposed discharge will reach irrigated lands. If the discharge will not reach an irrigated field, either because of natural conditions or water management techniques, it could not affect crop production on that field. For the purposes of this policy, irrigated lands include the following:

1. Artificially Irrigated Lands: Artificially irrigated lands are those where water is intentionally applied for agricultural purposes. Artificially irrigated lands will be identified by the presence of canals, ditches, spreader dikes, spray irrigation systems or any other constructed mechanism intended to divert water from a stream channel for application on adjacent lands.

2. Naturally Irrigated Lands: Naturally irrigated lands are areas of land along stream channels that have enhanced vegetative production due to periodic natural flooding or sub-irrigation. Naturally irrigated lands are those lands where a stream channel is underlain by unconsolidated material and on which the combination of stream flow and channel geometry provides for enhanced productivity of agriculturally significant plants. Naturally irrigated lands may be identified by an evaluation of infra-red aerial photography, surficial geologic maps, wetland mapping, landowner testimony or any combination of that information.

Appropriate effluent limits for EC and SAR will be calculated and applied to WYPDES discharge permits in all instances where the produced water discharge may reach any artificially irrigated lands.

EC and SAR limits will also be applied to WYPDES permits where the produced water discharge may reach stream segments containing sufficient acreage of naturally irrigated land to be considered agriculturally significant. In general, stream segments containing single parcels of naturally irrigated land greater than 20 acres in size or multiple parcels in near proximity that total more than 20 acres shall be considered agriculturally significant. In making this estimation, small drainage bottoms may be excluded from consideration. Two specific criteria which may be used to exclude lands include lack of a persistent active channel and unconsolidated floodplain deposits which are generally less than 50 feet in width.

If there are no pre–existing diversions within reach of a discharge or if the water will be impounded or managed so as not to reach a diversion during the irrigation season, there would be no potential to adversely affect crop production. Likewise, if there are no agriculturally significant, naturally irrigated lands within reach of a discharge there would be no potential to adversely affect crop production. In these circumstances, permit limits would be established to protect other relevant water uses (e.g. livestock watering, wildlife, aquatic life etc.).

B. Data and Information

There is a minimum amount of data that must be collected in every circumstance in order to identify existing irrigation uses and to appropriately set effluent limits on discharges that may affect those uses. Additional information that is beyond the minimum requirements can also be considered to fine tune the permitting decisions in a way that best addresses the various interests for the water.

At a minimum the following information must be obtained:

- Location(s) of irrigation diversions and/or naturally irrigated acreage;
- Crops grown under irrigation;
- Published tolerance values for the most sensitive crop;
- Season of use
- Description of Irrigation Practices

C. Establishing Effluent Limits

A 3-tiered decision making process will be used to establish appropriate effluent limits for EC and SAR whenever a proposed discharge will likely reach irrigated lands. Tier 1 refers to a procedure for setting default EC and SAR limits and is useful in situations where the irrigated crops are salt-tolerant and/or the discharge water quality is relatively good. Tier 2 refers to a process whereby the default limits may be refined to equal background water quality conditions and is intended to be used in situations where the background EC and SAR is worse than the effluent quality. As a final measure, Tier 3 applies where background EC and SAR is better than the effluent quality. The purpose of a Tier 3 analysis is to provide sufficient justification to establish effluent limits that are of a lower quality than the pre-discharge background conditions. Under Tier 3, effluent limits may be established based upon local site conditions and irrigation practices to a level that can be demonstrated to cause no harm to the existing irrigation uses.

1. Tier 1 -Default EC and SAR limits

Default limits for EC and SAR may be used where the quality of the discharge water is relatively good or the irrigated crops are salt-tolerant. The default values shall be based upon the published soil EC tolerance values for the most sensitive crop and shall be calculated as follows:

a. Default EC limits will be based upon 100 percent yield threshold values for soil EC reported by the USDA Agricultural Research Service (ARS) Salt Tolerance Database. In the event that the species of interest is not included in the ARS Salt Tolerance Database, then the following alternative references can be consulted:

(1) Hanson et al. 2006[2]. Agricultural Salinity and Drainage. DANR Pub. 3375, Univ. of Calif. Davis;

(2) Ayers and Westcot. 1985. Water Quality for Agriculture. UN FAO Irrigation and Drainage Pager 29 (revised); and

(3) CPHA. 2002. Western Fertilizer Handbook. 9th Edition. Interstate Pub., Inc., Danville, IL.

The relationship between soil EC values and irrigation water EC values will be: EC (soil) = 1.5 EC (water), i.e., the published soil EC threshold obtained from the appropriate reference will be divided by the soil concentration factor of 1.5 to establish the discharge EC limit.

However, in circumstances where the background water quality of the receiving water(s) is known to be significantly better than would otherwise be required based on a theoretical 100% yield, effluent limits may be set to maintain that higher quality.

b. Default SAR values will be extrapolated from the Hanson et al. (2006)[2] Chart *(see Figure 1 attached)* based upon the default EC value in each circumstance up to a maximum default value of 10. The effluent limit for SAR will be determined in conjunction with EC so that the relationship of SAR to EC remains within the "no reduction in rate of infiltration" zone of Figure 1. The maximum SAR limit is, therefore, set below the line separating the "no reduction in rate of infiltration" zone from the "slight to moderate reduction in infiltration" zone in the Hanson et al. diagram, which is represented by the following equation: SAR < (6.67 x EC) – 3.33[3]. It must be noted that SAR values are tied to the EC concentration and might need to be adjusted to correlate to the actual EC concentration rather than the theoretical maximum.

Use of the Hanson diagram to extrapolate default effluent limits for SAR is capped at a maximum SAR of 10 to minimize the potential for sodium build-up in poorly drained soils. This 10 SAR cap is only intended to apply when utilizing the default procedure and may be modified according to the provisions of section C.2 "Refining EC and SAR Limits", described below.

[2] This reference has been updated to the 2006 version of the Agricultural Salinity and Drainage Manual from the previously cited 1999 version

[3] This Formula has been updated from the previously used SAR < ($EC_{ds/M}$ X 7.10) – 2.48 in accordance with the 2006 Salinity and Drainage Manual.

c. At a minimum, the EC and SAR limits will apply during the irrigation season and when flows are sufficient to support the use. On sub-irrigated lands and passively irrigated lands such as those under spreader dike systems, the irrigation season shall generally be considered to be year-round.

2. Refining EC and SAR limits (Tiers 2&3)

Establishing EC and SAR limits based simply on the most sensitive crop is the most stringent approach and would be protective of the irrigation use in all circumstances. It may be possible to refine those values if additional information is available showing that less stringent effluent limits would be adequately protective. This type of showing can be made by demonstrating that background water quality conditions are of a lower quality than the default values or by demonstrating that because of local soil conditions and irrigation practices there would be no harm to crop production from less stringent EC and SAR limits.

a. Tier 2 - Background Water Quality

If sufficient data is available to demonstrate or calculate that the pre-existing background water quality at the point(s) of diversion is worse than the effluent quality, EC and SAR effluent limits may be based upon those background conditions rather than tolerance values for the most sensitive crop.

(1). Measured Data: Background water quality may be established based upon published pre-discharge historic data. Generally, this data only exists on larger, perennial, mainstem stream channels where historic gauging has taken place. Actual measured data is the most reliable means of establishing background and must be considered on those waters where it is available.

(2). Calculated Background: On intermittent and ephemeral stream channels, pre-discharge water quality data is usually scarce or non-existent and very difficult to collect. In these circumstances, background water quality can be estimated by conducting soil surveys on land that has been historically irrigated from the subject stream.

In the event that soil studies are used as a means to estimate baseline water quality for a given drainage, the following requirements apply:

(i) Sample Site Selection: Soil samples shall be taken at semi-random sites within each contiguous irrigated segment downstream of the proposed discharge. "Semi-random" in this case is intended to mean that the applicant will identify the various major distinguishing terrain zones within each

irrigated segment and select sample sites randomly within each terrain zone. For example, the channel bottom may constitute one terrain zone, the first small terrace above the channel bottom may be another terrain zone, and the adjacent meadow or field may be a single remaining terrain zone, or that meadow / field may actually be comprised of several other known zones such as discharge-affected soils vs. non-affected soils, sub-irrigated reaches vs. non-sub-irrigated reaches, etc..

(ii) Number of Sample Sites: Listed below are the minimum number of soil sample sites required for each of the identified terrain zones (based on zone area) within a contiguous irrigated segment:

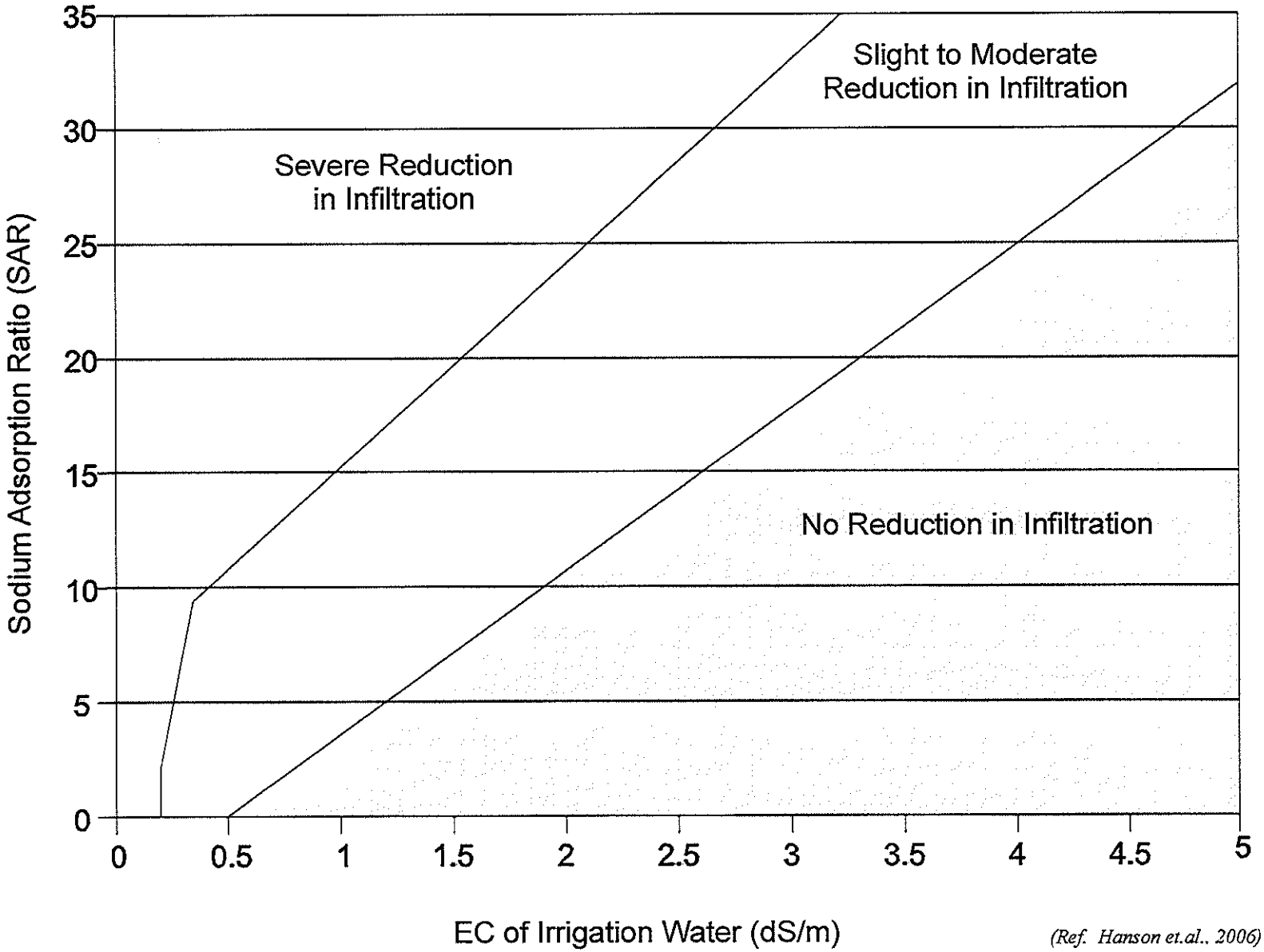
Zone Area	**Minimum Number of Sample Sites**
0 – 5 acres	3
5 - 10	5
10 + acres	7

(iii) Sample Collection: Sample sites must be located a minimum of 50 feet apart from one another. Each sample site shall be sampled at a minimum of four depths (0-12", 13-24", 25-36", 37-48"). If alfalfa is present within the terrain zone, each sample site within that terrain zone must be sampled at a total of 6 depths (at the above-noted depths, plus 49-60" and 61-72"). Each 12-inch depth sample must be analyzed either individually or combined (composited) with other corresponding depth samples from the other sample sites within the same terrain zone (i.e., all 0-12" samples from a given terrain zone bulked together and analyzed as a single composite sample).

(iv) Sample Analysis: At a minimum, a saturated paste extract for each sample shall be analyzed for EC. Though not necessary for the estimation of background water conductivity, it is advisable to also analyze the soil samples for pH, SAR, soil texture and exchangeable sodium percentage (ESP) to avoid having to duplicate the sampling if the results indicate that a "no harm analysis" *(item b. below)* needs to be completed. Percent organic matter shall be analyzed in the surface 0-12 inch samples only. In addition, analyses to identify the clay mineralogy types present in the soils may also be warranted.

Figure 1

Hanson Chart



(Ref. Hanson et.al., 2006)

(v) Soil Report Preparation: At a minimum the applicant shall submit:

i. A map or diagram identifying where each of the soil sample sites were located. At a minimum, the map or diagram must show the basic topography and stream course, irrigation structures *(if present - such as spreader dams or head gates)*, estimated boundaries of the irrigated acreage, surface ownership of the irrigated acreage *(including downstream irrigated areas)* and section / township / range identification. This map must also show any delineated terrain zones, plus elevations of the terrain zones;

ii. An accompanying location table which includes the quarter / quarter, section, township, range, and latitude / longitude for each sample site;

iii. Summary data table showing the analytical results for each of the soil parameters listed above, for each depth, at each sample site.

iv. All associated lab sheets.

b. Tier 3 - No Harm Analysis

The actual effects of EC and SAR on crop production are variable based upon soil type and chemistry and may be mitigated to some extent by managing irrigation practices. EC and SAR effluent limits may also be established based upon a scientifically defensible site specific study that examines local soil characteristics, natural water quality, expected crop yield, irrigation practices and/or any other relevant factor related to crop production.

Because of the very site-specific nature of this approach and the number and complexity of variables that may need to be considered, it is not very useful to specify any particular type of analysis in this policy. When taking this approach, however, there is a burden of proof placed upon the applicant to demonstrate through a comprehensive study that levels of EC and/or SAR higher than either the default values or estimated background water quality would most likely not measurably harm an existing irrigation use. This approach will allow a degree of creativity regarding landowner preferences and management. Refined limits for EC and SAR resulting from a "no harm" analysis should incorporate a reasonable margin of safety to account for variables that cannot be precisely measured or modeled.

c. Irrigation Waiver

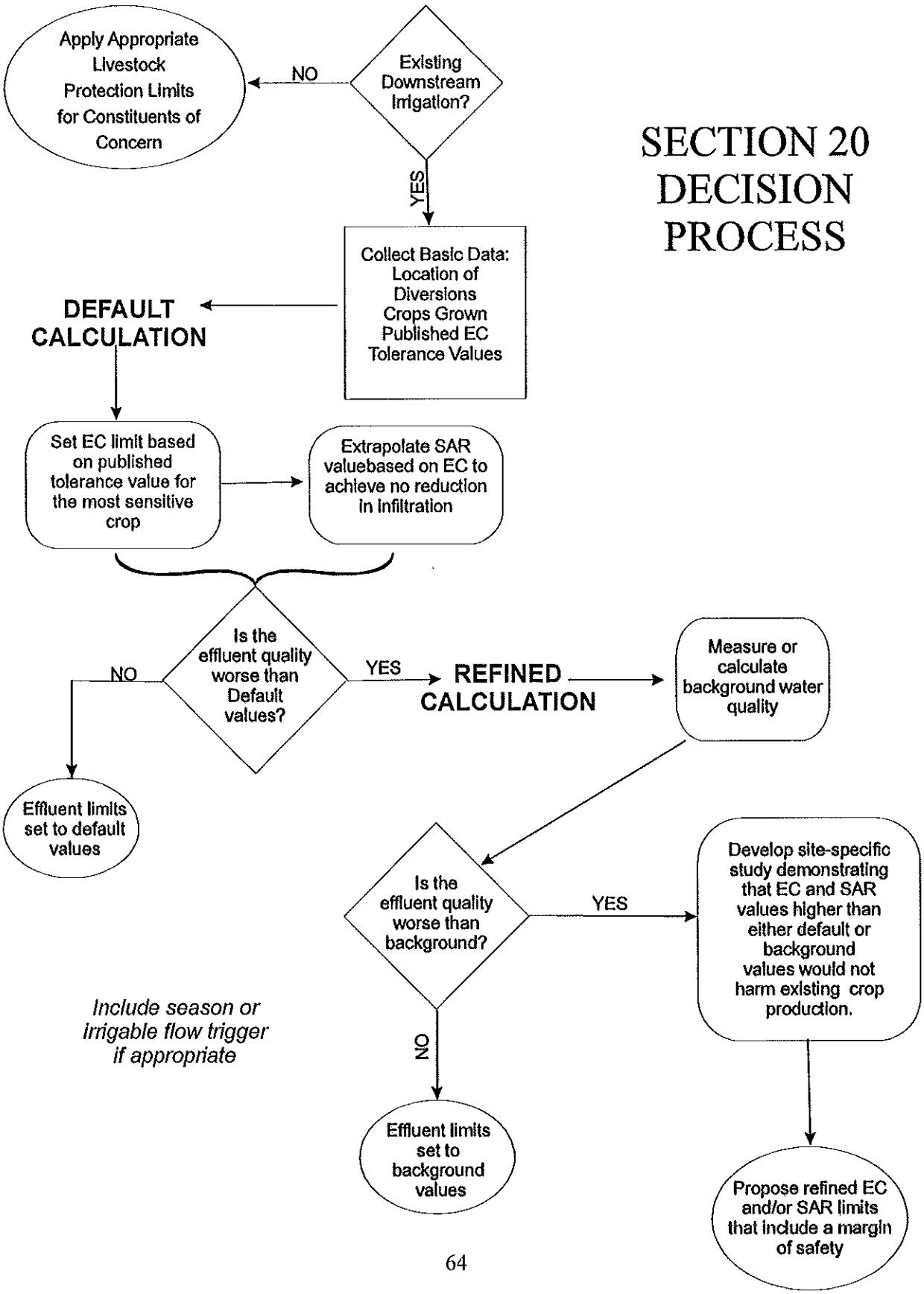
An exception to EC or SAR limits established under the Tier 1, 2 or 3 procedures may be made when affected landowners request use of the water and thereby accept any potential risk to crop production on their lands. Irrigation waivers will only be granted in association with an irrigation management plan that provides reasonable assurance that the lower quality water will be confined to the targeted lands.

d. Reasonable Access Requirement

The procedure for establishing default EC and SAR limits is intended to provide the ability to permit the discharge of high quality water without an obligation to conduct site specific studies. In practice, the use of the default procedure will only apply where permitted discharges are of exceptionally high quality. In many applications, appropriate limits for EC and SAR will have to be based on refined procedures rather than default. Because the refined procedures require the acquisition of site-specific data, it is necessary that permit applicants and/or the DEQ have reasonable access to obtain the required information. In circumstances where a landowner chooses to deny access for the purpose of developing a Section 20 analysis, EC and SAR limits will be based upon the best information that can be reasonably obtained and may be less stringent than Tier 1 default limits.

WJD/7-0156.DOC
revised 11/20/2008

SECTION 20 DECISION PROCESS



APPENDIX 2B

STREAMFLOW DATABASE

USGS 06364700 ANTELOPE CREEK NEAR TECKLA, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	9	10	21	15	36	1051	1333	507	655	830	621	38	5127
1980	13	15	28	23	47	424	426	256	222	3	13	1	1470
1981	6	11	14	15	11	15	12	24	130	595	464	1	1299
1982	17	22	36	32	51	592	593	998	441	873	536	11	4201
1983	9	12	20	17	27	318	319	537	237	470	288	6	2261
1984	21	28	46	41	64	747	749	1260	557	1103	676	14	5305
1985	2	3	4	4	6	69	69	116	51	101	62	1	488
1986	20	27	45	40	62	729	731	1229	543	1076	660	14	5175
1987	17	23	38	33	52	611	613	1030	455	902	553	11	4338
1988	1	2	3	2	3	41	41	69	30	60	37	1	289
1989	3	4	6	6	9	101	102	171	75	149	92	2	719
1990	4	6	9	8	13	150	151	254	112	222	136	3	1069
1991	46	62	101	89	141	1639	1644	2764	1221	2420	1484	31	11643
1992	1	2	3	2	4	45	45	76	34	67	41	1	320
1993	19	25	41	36	57	662	664	1116	493	977	599	12	4700
1994	11	14	24	21	33	384	385	647	286	567	347	7	2726
1995	10	13	22	20	31	359	360	605	267	530	325	7	2548
1996	13	17	28	25	39	460	461	776	343	679	416	9	3267
1997	19	25	42	37	58	675	677	1139	503	997	611	13	4795
1998	14	18	30	26	42	485	487	818	361	716	439	9	3446
1999	33	45	73	65	102	1187	1191	2002	885	1753	1075	22	8432
2000	6	9	14	13	20	232	232	391	173	342	210	4	1645
2001	9	12	20	18	28	326	327	550	243	482	295	6	2317
2002	1	2	3	2	4	44	44	73	32	64	39	1	309
2003	6	9	14	12	20	228	228	384	170	336	206	4	1617
2004	1	1	2	2	2	28	28	47	21	41	25	1	198
2005	2	2	4	3	5	63	63	106	47	93	57	1	447
2006	1	1	1	1	2	24	24	40	18	35	21	0	168
2007	1	1	2	1	2	27	27	46	20	40	25	1	194
2008	11	15	24	21	33	389	391	656	290	575	352	7	2765

NOTE: See Antelope Creek Analysis spreadsheet
Cheyenne River at Edgemont, SD data was used to estimate Antelope Creek missing months (annual regression)
Monthly regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06426500 BELLE FOURCHE RIVER BELOW MOORCROFT, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	242	263	289	194	187	8030	1976	542	1702	1666	283	21	15395
1980	14	132	117	97	1047	1217	234	140	346	17	293	52	3706
1981	7	54	126	100	122	57	3	264	188	2951	769	5	4645
1982	250	20	42	36	2083	1138	306	4138	4368	3972	1998	1934	20284
1983	1445	259	323	1703	4376	849	815	591	335	97	787	5	11585
1984	877	442	593	537	1741	7770	1325	7943	7163	0	0	0	28391
1985	0	525	498	445	471	2398	526	13	0	0	0	0	4878
1986	29	112	82	90	1855	3603	1732	4126	684	210	48	1916	14487
1987	2035	590	122	138	1238	12888	3005	2244	982	1568	532	391	25734
1988	0	264	420	512	2040	2659	555	97	0	79	0	41	6666
1989	225	283	557	518	713	3567	963	1984	110	352	0	688	9961
1990	235	513	668	670	3756	2907	1277	1664	0	304	122	0	12116
1991	36	97	55	2	66	105	412	8934	2124	227	172	7	12237
1992	135	190	122	46	168	360	160	83	738	2958	31	4	4995
1993	18	99	26	25	22	4741	3029	14831	12050	2921	3523	556	41839
1994	595	478	652	524	3965	12347	1101	2324	479	467	178	108	23218
1995	4181	451	526	465	480	2152	594	11252	2797	879	689	259	24725
1996	1156	857	664	633	1093	7655	1940	3087	1392	386	762	500	20126
1997	378	402	264	3290	5504	5386	5534	2509	904	1291	1070	215	26747
1998	299	286	223	304	402	1672	2815	713	1529	1765	879	253	11141
1999	3997	1375	695	574	382	1752	7105	1310	4897	849	273	349	23557
2000	358	276	315	368	468	781	1148	1328	334	528	21	33	5959
2001	163	137	211	223	243	2324	1773	904	1690	445	157	146	8416
2002	309	365	387	148	261	867	2333	1470	1315	232	965	356	9007
2003	316	433	301	317	381	6155	845	861	4742	614	136	293	15394
2004	291	360	342	222	742	732	400	261	99	1002	143	86	4680
2005	154	381	211	269	416	571	1232	3283	519	96	267	63	7463
2006	286	214	339	400	309	584	420	978	180	11	176	215	4110
2007	237	304	197	115	544	2287	2553	7139	3529	236	174	192	17508
2008	261	174	191	175	493	3068	774	10662	6016	935	362	397	23507

NOTE: See Keyhole vs Belle Fourche Analysis spreadsheet
Keyhole reservoir inflow was used to estimate Belle Fourche missing months.
Monthly regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06395000 CHEYENNE R AT EDGEMONT,SD

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	1,015	1,261	732	263	282	15,685	7,021	1,992	4,635	8,959	18,705	1,131	61681
1980	658	1,065	398	523	6,851	8,061	2,154	978	4,540	384	7,046	320	32977
1981	399	435	732	1,820	2,077	1,174	179	627	1,386	14,536	4,347	146	27859
1982	531	672	615	295	5,248	10,889	1,547	2,773	20,350	8,645	6,893	4,296	62755
1983	5,294	3,035	1,986	1,912	7,853	3,861	3,731	3,068	2,868	3,615	2,300	226	39749
1984	1,008	946	266	1,857	8,985	18,145	5,224	26,224	7,634	1,808	2,140	288	74526
1985	953	1,137	610	544	828	6,635	1,398	387	238	9	13	82	12833
1986	119	136	49	615	2,460	14,075	8,860	9,555	22,451	6,536	959	7,355	73170
1987	12,420	1,714	1,488	1,617	2,099	23,292	6,266	6,001	7,521	1,328	285	225	64257
1988	183	503	341	425	518	2,908	857	538	922	173	1,199	154	8723
1989	149	50	63	71	9	1,709	857	3,991	244	713	11	9,211	17080
1990	251	708	480	842	1,288	5,823	1,874	3,579	1,172	4,894	1,506	463	22882
1991	996	564	298	25	48	1,310	1,386	60,940	61,765	4,353	990	340	133016
1992	676	649	520	621	1,202	2,041	530	361	702	1,679	363	68	9413
1993	28	342	215	215	127	12,783	6,284	11,824	12,781	10,969	11,178	1,416	68163
1994	2,017	1,214	403	475	1,422	31,100	3,201	3,191	375	2,127	93	6	45626
1995	1,623	274	873	2,127	4,476	4,316	1,125	14,191	10,681	3,283	304	128	43404
1996	824	314	235	290	8,703	14,628	6,040	12,470	6,682	805	448	696	52134
1997	1,648	1,446	750	1,291	16,789	16,559	8,206	7,163	4,582	5,343	4,384	1,018	69178
1998	1,586	1,357	1,894	2,023	5,987	6,727	5,760	2,466	11,044	7,323	6,616	1,440	54222
1999	17,868	15,852	3,105	2,293	3,999	4,193	7,337	8,860	33,537	3,948	2,041	1,827	104860
2000	1,728	1,684	1,371	1,611	2,479	3,419	11,895	4,144	1,012	1,414	391	300	31448
2001	1,254	1,053	836	1,150	1,977	12,254	4,677	1,482	6,855	8,295	411	221	40466
2002	354	797	504	424	722	2,109	1,785	536	143	51	683	1,059	9167
2003	279	881	1,273	1,125	955	15,575	1,696	1,716	6,147	701	91	613	31051
2004	320	655	873	830	1,334	1,660	296	544	76	17	1	0	6607
2005	37	590	658	738	1,244	461	576	1,316	4,130	305	1,574	409	12037
2006	425	197	237	990	616	1,174	607	652	113	8	824	2	5846
2007	1	136	363	419	466	805	359	3,406	468	68	24	1	6517
2008	0	1	0	5	54	1,580	593	28,782	7,152	6,671	984	278	46101

NOTE: Complete data record was available

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06386500 CHEYENNE RIVER NEAR SPENCER, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	527	860	633	370	143	2,909	1,671	15,005	6,194	1,623	8,685	122	38741
1980	262	427	315	184	71	1,446	831	7,461	3,080	807	4,318	61	19262
1981	215	350	258	151	58	1,186	681	6,115	2,525	661	3,540	50	15789
1982	537	876	645	376	146	2,964	1,702	15,287	6,311	1,653	8,848	124	39470
1983	325	529	390	228	88	1,791	1,029	9,240	3,815	999	5,348	75	23858
1984	646	1,053	776	453	175	3,564	2,046	18,381	7,588	1,988	10,639	149	47457
1985	76	124	91	53	21	420	241	2,166	894	234	1,254	18	5593
1986	634	1,033	761	444	172	3,494	2,007	18,024	7,441	1,949	10,432	147	46537
1987	551	899	662	386	149	3,040	1,746	15,682	6,474	1,696	9,077	127	40489
1988	38	62	46	27	10	211	121	1,086	448	117	628	9	2804
1989	115	188	139	81	31	636	365	3,282	1,355	355	1,900	27	8474
1990	169	275	203	118	46	932	535	4,807	1,985	520	2,782	39	12412
1991	1,186	1,934	1,425	831	322	6,544	3,758	33,753	13,934	3,650	19,537	274	87149
1992	45	73	53	31	12	246	141	1,267	523	137	733	10	3272
1993	587	957	705	411	159	3,239	1,860	16,708	6,898	1,807	9,671	136	43140
1994	379	618	455	266	103	2,091	1,201	10,785	4,452	1,166	6,242	88	27846
1995	359	584	431	251	97	1,978	1,136	10,201	4,211	1,103	5,904	83	26338
1996	439	716	527	308	119	2,423	1,391	12,496	5,158	1,351	7,232	102	32262
1997	597	973	716	418	162	3,291	1,890	16,975	7,008	1,836	9,825	138	43828
1998	459	747	551	321	124	2,529	1,452	13,044	5,385	1,411	7,550	106	33679
1999	926	1,510	1,112	649	251	5,109	2,934	26,353	10,879	2,850	15,253	214	68042
2000	248	404	298	174	67	1,369	786	7,059	2,914	763	4,086	57	18225
2001	331	540	398	232	90	1,828	1,050	9,429	3,892	1,020	5,457	77	24344
2002	42	69	51	30	11	233	134	1,202	496	130	696	10	3105
2003	244	398	294	171	66	1,348	774	6,954	2,871	752	4,025	57	17955
2004	4	6	5	3	1	18	8	13	4	0	0	0	62
2005	0	1	2	0	3	9	109	491	1,702	267	391	41	3017
2006	17	33	3	1	0	0	9	4	64	0	1,709	3	1843
2007	1	3	13	8	2	351	173	3,456	95	57	233	1	4393
2008	2	37	11	0	3	48	16	16,393	2,321	2,164	230	8	21231

NOTE: See Cheyenne River Analysis spreadsheet
Cheyenne River at Edgemont, SD data was used to estimate Cheyenne River nr Spencer missing months (annual regression)
Annual regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06324000 CLEAR CREEK NEAR ARVADA, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	6,579	5,302	2,607	1,623	1,611	3,247	4,594	6,598	5,254	5,829	9,807	4,326	57376
1980	3,861	2,725	2,121	1,402	1,627	3,499	2,475	5,472	9,372	12,254	12,451	12,698	69959
1981	15,120	17,024	18,182	17,936	7,609	6,450	3,261	15,710	30,895	5,749	3,560	2,112	143607
1982	3,013	3,094	2,244	1,746	1,910	2,287	2,612	1,728	6,486	6,942	3,431	7,271	42766
1983	6,699	6,506	5,312	4,998	4,560	7,337	7,804	15,596	19,205	8,990	5,858	7,204	100068
1984	9,597	9,321	7,610	7,160	6,532	10,510	11,180	22,342	27,512	12,878	8,393	10,320	143356
1985	2,484	2,413	1,970	1,853	1,691	2,720	2,894	5,783	7,121	3,333	2,172	2,671	37106
1986	5,121	4,973	4,061	3,821	3,485	5,608	5,966	11,921	14,680	6,872	4,478	5,507	76492
1987	6,816	6,619	5,405	5,085	4,639	7,464	7,940	15,867	19,539	9,146	5,960	7,329	101810
1988	3,316	3,221	2,630	2,474	2,257	3,632	3,864	7,721	9,507	4,450	2,900	3,566	49539
1989	1,512	1,469	1,199	1,128	1,029	1,656	1,762	3,520	4,335	2,029	1,322	1,626	22588
1990	4,651	4,517	3,688	3,470	3,166	5,094	5,418	10,828	13,334	6,242	4,068	5,002	69477
1991	6,898	6,699	5,470	5,146	4,695	7,554	8,036	16,058	19,774	9,256	6,032	7,418	103036
1992	4,573	4,441	3,626	3,412	3,113	5,008	5,327	10,646	13,110	6,137	3,999	4,918	68309
1993	8,400	8,158	6,661	6,267	5,717	9,199	9,786	19,555	24,081	11,272	7,346	9,033	125474
1994	3,972	3,858	3,150	2,963	2,703	4,350	4,627	9,247	11,387	5,330	3,474	4,271	59332
1995	11,865	11,524	9,409	8,853	8,076	12,995	13,823	27,623	34,016	15,923	10,377	12,760	177241
1996	6,411	6,227	5,084	4,783	4,364	7,022	7,469	14,926	18,380	8,604	5,607	6,895	95772
1997	8,801	8,548	6,979	6,566	5,990	9,639	10,253	20,490	25,231	11,811	7,697	9,465	131470
1998	7,104	6,900	5,633	5,300	4,835	7,780	8,276	16,539	20,366	9,533	6,213	7,640	106120
1999	10,321	10,024	8,184	7,700	7,025	11,303	12,024	24,028	29,588	13,850	9,026	11,099	154170
2000	4,128	4,010	3,274	3,080	2,810	4,521	4,809	9,611	11,835	5,540	3,610	4,440	61668
2001	1,364	1,325	1,082	1,018	929	1,494	1,589	3,176	3,911	1,831	1,193	1,467	20380
2002	1,593	1,547	1,263	1,188	1,084	1,744	1,856	3,708	4,566	2,138	1,393	1,713	23794
2003	3,514	3,413	2,787	2,622	2,716	7,176	8,420	12,009	13,978	3,720	1,267	3,207	64826
2004	3,240	3,975	3,462	2,982	3,349	4,569	4,231	345	59	2,607	941	3,189	32949
2005	5,331	3,731	4,304	3,671	4,171	3,855	4,213	39,985	30,419	9,752	7,096	2,707	119235
2006	5,737	5,492	3,954	5,620	3,599	5,405	8,146	5,405	1,488	100	47	1,142	46134
2007	2,988	3,523	3,240	2,779	2,460	6,339	6,075	30,412	41,897	5,706	1,273	6,016	112709
2008	6,530	5,605	4,452	3,849	4,032	10,275	5,683	55,425	87,233	29,391	1,531	4,260	218266

NOTE: See Clear Creek Analysis spreadsheet
Powder River at Moorhead, MT data was used to estimate Clear Creek missing months (annual regression)
Monthly regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06316400 CRAZY WOMAN CREEK AT UPPER STA, NEAR ARVADA, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	1,998	1,815	1,740	1,617	1,570	2,773	4,260	6,106	6,718	732	1,728	578	31635
1980	799	881	1,371	1,224	933	707	458	4,015	4,671	1,113	233	54	16459
1981	637	779	773	674	754	1,751	1,383	2,873	4,607	1,729	472	290	16723
1982	1,375	1,680	1,668	1,453	1,628	3,777	2,984	6,199	9,939	3,729	1,019	625	36076
1983	1,540	1,882	1,868	1,627	1,823	4,230	3,342	6,942	11,132	4,176	1,141	700	40403
1984	1,797	2,196	2,179	1,899	2,127	4,935	3,899	8,100	12,988	4,873	1,331	817	47141
1985	502	614	609	531	595	1,380	1,090	2,264	3,631	1,362	372	228	13178
1986	1,001	1,223	1,214	1,058	1,185	2,748	2,172	4,511	7,234	2,714	742	455	26255
1987	1,573	1,922	1,907	1,662	1,862	4,320	3,413	7,090	11,369	4,265	1,165	715	41264
1988	607	741	736	641	718	1,666	1,316	2,734	4,384	1,645	449	276	15913
1989	460	563	558	487	545	1,265	999	2,076	3,328	1,249	341	209	12080
1990	786	960	953	830	930	2,157	1,705	3,541	5,678	2,130	582	357	20609
1991	1,061	1,297	1,287	1,122	1,256	2,915	2,303	4,784	7,672	2,878	786	483	27845
1992	669	818	811	707	792	1,838	1,452	3,016	4,836	1,814	496	304	17553
1993	1,791	2,188	2,172	1,892	2,120	4,918	3,886	8,073	12,944	4,856	1,327	814	46982
1994	747	912	905	789	884	2,050	1,620	3,365	5,396	2,024	553	339	19583
1995	3,168	3,872	3,842	3,348	3,750	8,701	6,875	14,281	22,900	8,591	2,348	1,441	83117
1996	1,126	1,376	1,365	1,190	1,333	3,092	2,443	5,075	8,138	3,053	834	512	29539
1997	1,434	1,752	1,739	1,515	1,697	3,938	3,112	6,464	10,364	3,888	1,063	652	37618
1998	1,455	1,778	1,764	1,537	1,722	3,995	3,157	6,558	10,516	3,945	1,078	662	38167
1999	2,061	2,519	2,499	2,178	2,439	5,660	4,473	9,291	14,897	5,589	1,527	937	54070
2000	504	607	996	1,058	694	2,263	744	527	392	4,556	18	4	12362
2001	6	190	530	345	441	898	1,220	436	249	497	885	111	5807
2002	249	726	701	615	722	1,863	3,160	5,220	7,420	1,949	148	250	23023
2003	320	756	941	532	886	1,691	521	338	106	756	58	7	6912
2004	242	643	855	627	744	689	1,226	10,687	9,991	2,349	701	82	28834
2005	627	791	537	910	628	1,144	827	475	122	0	1	1	6064
2006	3	27	64	39	194	953	655	1,808	2,880	867	240	7	7736
2007	264	549	398	466	1,012	1,734	774	15,870	25,212	5,460	849	756	53343
2008	1,094	1,363	824	879	1,966	3,216	3,457	2,066	6,081	3,228	1,765	708	26648

NOTE: See Crazy Woman Analysis spreadsheet
Powder River at Arvada, WY data was used to estimate Crazy Woman Creek missing months (annual regression)
Monthly regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06365300 DRY FORK CHEYENNE RIVER NEAR BILL, WYO

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	2	14	19	1	8	49	36	44	3	18	85	1	282
1980	5	11	9	1	74	32	16	83	24	0	0	1	254
1981	3	7	11	8	9	13	16	53	2	0	0	0	122
1982	6	14	16	9	41	56	43	68	61	8	21	1	345
1983	4	9	10	5	26	36	27	43	39	5	13	1	217
1984	7	16	19	10	49	67	51	81	73	10	25	1	410
1985	1	3	3	2	8	11	9	14	12	2	4	0	69
1986	5	8	7	13	72	30	35	26	325	19	0	2	542
1987	8	11	6	6	21	100	68	7	49	4	0	1	282
1988	1	2	2	1	6	8	6	9	8	1	3	0	47
1989	2	4	4	2	11	15	12	18	16	2	6	0	92
1990	2	5	6	3	15	20	16	25	22	3	8	0	124
1991	13	29	34	18	88	121	93	146	131	17	45	3	737
1992	1	2	2	1	6	8	6	10	9	1	3	0	51
1993	7	15	17	9	45	61	47	74	67	9	23	1	375
1994	4	10	11	6	30	41	31	49	44	6	15	1	250
1995	4	9	11	6	28	39	30	47	42	6	14	1	237
1996	5	11	13	7	34	47	36	56	51	7	17	1	286
1997	7	15	17	9	46	62	48	75	68	9	23	1	380
1998	5	12	14	7	36	49	37	59	53	7	18	1	297
1999	10	23	26	14	69	95	73	114	103	14	35	2	580
2000	3	7	8	4	21	28	21	34	30	4	10	1	171
2001	4	9	10	5	26	36	28	44	39	5	13	1	221
2002	1	2	2	1	6	8	6	10	9	1	3	0	49
2003	3	7	8	4	20	28	21	33	30	4	10	1	169
2004	1	1	2	1	4	6	4	7	6	1	2	0	35
2005	1	3	3	2	8	11	8	13	12	2	4	0	65
2006	1	1	1	1	4	5	4	6	6	1	2	0	31
2007	1	1	2	1	4	6	4	7	6	1	2	0	35
2008	5	10	12	6	30	41	32	50	45	6	15	1	252

NOTE: See Dry Fork Analysis spreadsheet
Cheyenne River at Edgemont, SD data was used to estimate Dry Fork Cheyenne River nr Bill missing months (annual regression)
Annual regression analysis recommended in HKM Report

Annual Total Estimated from Regression Relationship

Monthly Flows Estimated from Distribution of Monthly Data in Measured

USGS 06324970 LITTLE POWDER RIVER AB DRY CREEK, NEAR WESTON, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	113	186	216	159	147	4,501	1,345	695	295	258	34	4	7953
1980	1	6	66	79	1,777	707	211	160	482	3	658	1	4151
1981	1	2	52	79	92	82	45	713	431	1,949	965	1	4412
1982	1	1	13	15	388	462	210	6,960	4,076	4,230	1,740	1,119	19216
1983	1,107	191	213	1,961	5,404	2,183	1,256	521	176	232	376	1	13619
1984	26	67	98	247	1,035	1,039	558	9,266	11,157	510	488	44	24536
1985	156	183	133	138	583	4,599	516	349	258	24	11	1	6950
1986	36	140	68	108	944	1,691	797	5,122	1,244	89	30	3,618	13885
1987	2,238	1,214	346	210	519	1,838	1,523	2,134	418	965	299	177	11882
1988	117	133	134	18	742	1,943	358	355	126	78	1	2	4006
1989	45	38	51	77	26	707	240	972	400	361	0	2	2919
1990	3	193	69	157	3,732	1,888	1,440	2,373	172	29	1	0	10058
1991	1	13	26	6	76	114	613	1,617	380	56	0	0	2902
1992	1	58	51	22	118	100	56	64	371	235	7	0	1083
1993	1	45	40	25	59	2,367	1,261	3,554	5,034	2,177	2,755	333	17650
1994	234	184	205	183	7,986	8,485	934	1,347	587	683	57	143	21029
1995	10,551	851	613	367	911	4,710	720	14,978	5,326	1,051	744	269	41091
1996	388	489	464	495	14,737	16,669	2,452	2,626	1,458	476	142	140	40535
1997	217	379	227	3,665	18,683	7,729	5,010	935	791	1,273	264	133	39305
1998	193	287	290	261	320	1,420	2,100	334	1,613	344	333	284	7780
1999	1,992	1,511	331	274	1,377	2,835	5,909	2,072	2,339	409	106	92	19246
2000	122	169	189	218	326	560	696	996	231	43	1	1	3550
2001	159	129	88	95	91	2,054	994	240	316	1,500	62	1	5729
2002	11	46	53	37	53	181	578	167	53	12	6	8	1206
2003	1	11	66	60	154	3,634	726	732	537	24	1	1	5945
2004	1	13	39	19	536	400	55	71	14	246	13	17	1425
2005	35	101	60	95	106	237	809	3,997	310	103	52	1	5905
2006	337	59	58	97	83	145	412	1,058	95	153	3,886	550	6932
2007	170	151	100	61	3,182	2,373	2,678	14,234	12,317	490	261	152	36170
2008	195	310	201	207	1,357	2,662	940	11,812	9,300	965	366	224	28541

NOTE: Complete data record was available

USGS 06317000 POWDER RIVER AT ARVADA, WY

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	12,064	10,520	8,338	5,583	7,336	36,856	33,816	40,779	31,728	16,153	6,223	2,612	212007
1980	10,385	9,170	5,116	5,977	15,732	18,674	17,827	22,818	14,852	3,222	6,419	3,362	133554
1981	6,671	9,229	8,528	9,789	11,030	12,556	9,181	25,739	12,871	8,750	2,134	714	117191
1982	5,202	7,968	4,901	4,181	8,469	17,850	12,912	20,900	46,544	46,589	14,782	26,860	217158
1983	15,913	13,555	9,229	11,209	19,310	20,568	22,344	43,945	59,272	12,562	9,752	1,851	239510
1984	7,428	7,789	5,688	8,055	13,195	32,342	24,706	95,060	58,618	12,445	5,429	3,558	274313
1985	7,551	7,521	7,040	7,046	5,287	15,999	12,835	19,430	5,230	3,271	4,667	3,005	98884
1986	8,141	5,576	7,188	8,098	13,807	21,109	23,338	32,920	27,658	3,333	941	14,323	166429
1987	26,452	13,549	7,157	8,079	16,839	41,166	37,083	32,435	32,656	12,740	7,631	8,170	243957
1988	8,584	10,616	6,007	4,894	6,143	24,023	17,107	26,077	6,629	1,691	130	1,107	113008
1989	4,593	6,956	6,432	5,786	3,810	15,968	11,841	14,566	13,174	4,249	612	5,224	93212
1990	7,194	10,288	6,468	7,200	8,647	20,992	13,740	24,146	18,244	2,896	15,132	2,321	137268
1991	5,491	7,039	4,027	2,546	8,747	10,969	15,667	55,966	55,601	5,214	1,131	2,243	174643
1992	5,509	7,617	5,847	5,079	7,926	9,783	9,330	5,688	26,926	27,534	6,493	3,749	121481
1993	6,069	7,194	5,085	5,177	5,054	25,235	19,012	70,649	87,769	25,112	12,802	4,332	273488
1994	8,073	8,235	9,389	8,891	18,611	24,755	15,007	18,465	3,767	13,417	2,890	469	131969
1995	53,205	11,889	13,982	10,969	16,683	17,506	15,846	109,140	169,111	34,187	4,138	3,481	460138
1996	10,465	7,741	5,817	5,245	17,751	35,909	23,558	44,037	27,461	3,720	563	1,125	183391
1997	5,565	8,360	4,421	4,999	11,057	22,830	22,147	41,141	48,960	25,892	21,361	8,390	225125
1998	10,600	9,687	6,389	6,985	9,302	25,007	34,489	51,133	31,240	17,352	9,149	16,625	227959
1999	28,512	24,938	14,333	11,135	14,467	16,331	32,947	98,626	51,257	9,481	3,124	4,951	310103
2000	9,143	9,830	9,377	8,934	10,135	12,261	12,478	40,883	10,223	3,443	112	246	127066
2001	5,860	5,457	6,585	7,280	5,587	25,056	11,246	8,590	3,642	14,277	148	0	93728
2002	2,349	5,486	4,015	3,431	4,254	12,132	16,292	11,547	2,029	3,726	8,528	6,599	80389
2003	5,878	11,776	5,362	6,013	6,220	22,129	22,308	21,152	17,917	4,722	633	1,012	125123
2004	2,515	5,320	6,253	4,015	6,276	15,028	8,717	8,024	1,880	4,784	510	30	63352
2005	3,941	6,789	6,733	9,285	10,635	8,135	10,497	41,984	22,790	4,347	2,595	16	127746
2006	4,968	6,629	4,980	8,270	6,987	16,682	13,192	16,596	5,040	904	210	1,476	85933
2007	5,140	5,790	4,821	3,984	4,460	16,436	20,344	42,310	26,176	12,777	5,214	1,535	148987
2008	6,382	8,081	5,780	6,032	7,610	19,535	10,955	95,982	78,605	19,584	3,117	4,136	265798

NOTE: Complete data record was available

USGS 06324500 Powder River at Moorhead MT

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	16,682	9,414	9,260	8,147	6,481	35,257	31,043	38,098	32,573	19,018	15,649	8,003	229624
1980	11,959	12,912	7,022	7,126	17,377	20,537	19,113	31,685	28,056	14,124	19,301	15,174	204386
1981	20,875	25,557	20,014	27,350	19,338	19,934	12,305	40,385	53,066	14,898	5,995	2,684	262402
1982	8,313	11,199	7,409	5,761	8,031	20,057	14,055	21,023	54,446	50,783	18,090	40,808	259974
1983	31,254	12,329	9,371	14,044	38,032	23,568	26,729	47,548	99,669	25,917	11,861	5,034	345357
1984	14,388	15,560	5,110	11,283	21,559	40,668	31,983	147,878	138,526	28,733	12,347	8,604	476639
1985	19,295	18,916	8,965	8,885	6,842	24,939	24,932	21,262	6,992	6,167	7,391	4,237	158824
1986	14,376	7,295	7,409	9,303	14,917	37,477	26,920	41,725	72,774	9,752	6,124	28,288	276360
1987	34,070	17,232	11,344	10,828	27,541	53,629	40,451	38,073	50,977	31,580	14,394	20,809	350930
1988	15,704	16,816	5,829	6,229	10,135	37,729	29,574	51,459	15,608	4,034	1,156	2,005	196277
1989	6,671	7,724	5,829	7,231	3,860	20,660	15,031	14,708	15,965	7,668	3,437	6,718	115501
1990	13,244	16,471	6,278	9,906	17,155	35,866	21,451	36,001	58,701	13,140	20,186	7,027	255427
1991	12,328	13,490	8,412	6,468	21,582	24,644	28,056	103,607	113,355	12,574	3,548	6,736	354800
1992	10,299	15,959	12,974	14,837	18,729	18,065	17,964	11,012	51,531	58,542	13,749	8,926	252587
1993	11,818	15,423	8,282	6,733	6,903	38,362	26,783	97,765	129,719	47,511	23,525	9,705	422531
1994	18,157	15,102	13,927	12,574	23,503	43,127	31,281	41,012	4,713	15,317	3,652	2,785	225151
1995	55,161	18,934	9,838	10,730	38,904	24,700	18,292	109,632	216,238	60,774	6,204	6,218	575624
1996	18,170	17,768	11,320	8,657	30,756	43,004	36,565	65,300	88,423	10,219	2,035	2,737	334956
1997	10,785	14,293	7,108	15,077	21,637	47,032	32,614	68,866	115,260	49,461	44,517	13,775	440424
1998	20,555	16,941	13,902	13,011	17,555	32,718	39,535	79,934	51,043	33,050	25,247	21,285	364774
1999	38,190	39,297	13,257	13,349	16,978	21,748	48,454	146,402	128,112	23,285	7,120	11,365	507558
2000	16,755	15,822	14,302	16,104	16,267	19,719	23,070	63,086	31,882	6,616	2,527	6,534	232684
2001	14,290	9,794	8,867	8,571	7,975	18,047	13,698	10,883	5,534	10,637	158	455	108909
2002	3,394	7,569	8,233	12,021	13,168	11,363	18,565	11,148	3,999	3,308	15,347	10,984	119099
2003	9,826	11,330	8,030	9,463	11,185	36,124	34,399	35,263	39,648	9,555	1,617	3,808	210248
2004	4,858	5,433	9,623	3,480	4,395	22,652	12,585	7,618	1,851	7,206	2,048	3,457	85205
2005	9,979	13,186	8,719	8,332	8,786	12,224	14,388	85,406	57,987	13,964	9,309	2,815	245095
2006	10,029	10,431	6,604	12,021	9,619	20,838	19,208	19,356	7,498	615	60	2,725	119003
2007	7,231	10,717	5,319	5,128	3,988	17,690	25,420	72,740	68,787	17,272	9,912	8,206	252408
2008	12,211	13,888	11,185	5,774	9,083	33,197	17,357	154,580	190,651	63,332	5,669	8,813	525740

NOTE: Complete data record was available

USGS 06307616 Tongue R at Birney Day School Br nr Birney MT

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1979	14629	13157	11317	10930	10348	13537	16421	38530	66046	35529	23866	17602	271913
1980	14253	16596	13392	10324	11849	13859	17298	26679	56190	29170	24570	19589	253769
1981	14462	13680	12119	9512	8769	7348	5986	33099	97468	28358	23949	20606	275357
1982	14486	11466	12476	11701	11085	12175	16274	20549	37232	45698	24681	22064	239888
1983	22246	19761	10871	17641	19455	18858	11098	17911	96813	36825	26827	18071	316378
1984	12439	11978	11892	11394	11395	13195	18500	108772	173812	42137	28579	23540	467632
1985	13337	16185	14259	12949	9836	8418	17685	20654	21648	20039	12740	12115	179863
1986	10398	11395	12359	12753	16978	19522	21183	25357	88364	31795	26409	16203	292716
1987	14757	20642	15968	14191	8508	4796	4957	24798	33233	24380	21681	21243	209154
1988	18735	16899	10078	9143	9640	12328	11074	58413	49317	20414	15593	8354	239990
1989	5208	3903	3904	5614	8114	13251	19285	18661	15656	21847	19123	13359	147924
1990	8282	4493	4685	7526	11685	22984	25355	48452	75749	46964	25991	23314	305480
1991	13620	15519	9026	9936	8786	10619	24670	70834	67299	31057	28844	14269	304479
1992	8209	8610	14124	13607	12764	9844	3921	21398	36125	65730	39303	30728	264363
1993	21146	16429	13607	13386	11424	14941	11746	42918	78248	34027	37901	19934	315708
1994	20568	12454	13171	12537	10274	21232	34262	57374	21362	19707	16577	11389	250907
1995	13835	10508	11424	10926	11169	13810	15644	78520	149891	78028	26317	25985	446057
1996	23433	15554	9832	9660	19292	26655	34685	60135	86460	28327	24632	14091	352755
1997	19215	9907	9260	10133	9602	21760	32876	59907	108714	54533	41590	31311	408810
1998	19129	14281	11861	11922	11224	17100	19934	26809	31073	32176	31771	41266	268546
1999	20199	19529	12543	14062	10036	9863	7271	41867	123352	38989	25567	16780	340058
2000	15409	12758	11799	9801	9341	12728	10889	36696	54232	25917	21324	18720	239614
2001	17549	10604	9008	8897	8531	8534	7123	16374	13377	14376	10318	8229	132919
2002	6438	6022	6149	5872	4998	5239	5022	8830	15495	15962	9758	6736	96520
2003	6210	6456	6364	5891	5032	17352	7962	34439	75273	31285	21613	12817	230693
2004	7071	5457	5319	5829	5367	8756	10128	13478	12811	16122	12863	6272	109472
2005	5860	5599	5472	4304	3888	4728	5123	65361	83246	35159	23906	15531	258178
2006	13398	11472	12537	10828	6070	6180	5498	7790	12103	17967	11492	4100	119436
2007	6419	8872	8153	5872	4921	13927	31412	100717	128945	24810	22172	16506	372728
2008	11670	11359	8848	7993	7478	13269	24230	40281	178691	72740	24478	19952	420989

NOTE: See Tongue River Analysis spreadsheet
Tongue River at Tongue River Dam data was used to estimate Tongue River at Birney Day School missing months (annual regression)
Gage not used in previous HKM reports

APPENDIX 2C

SURFACE WATER QUALITY DATABASE

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm	Sodium Adsorption Ratio	Specific Conductance, laboratory, unfiltered uS/cm
5s	15s	10d	4d	8s	p00095 12s	p00931 12s	p90095 12s
USGS	06316400	11/14/1966			3660	3.7	
USGS	06316400	12/12/1966			2270	2.2	
USGS	06316400	1/3/1967			2070	2.3	
USGS	06316400	2/7/1967			1550	2.1	
USGS	06316400	3/6/1967			1260	1.6	
USGS	06316400	4/3/1967			1980	2.7	
USGS	06316400	5/11/1967			1780	2.6	
USGS	06316400	6/9/1967			845	1	
USGS	06316400	7/15/1967			988	1.4	
USGS	06316400	8/1/1967			1240	1.6	
USGS	06316400	9/12/1967			1980	2.2	
USGS	06316400	10/10/1967	08:05		1620	1.9	
USGS	06316400	11/28/1967	13:30		1710	1.9	
USGS	06316400	1/23/1968	12:00		1540	1.7	
USGS	06316400	2/21/1968	10:30		973	1.3	
USGS	06316400	3/15/1968	15:30		1450	1.7	
USGS	06316400	4/12/1968	14:45		1470	1.7	
USGS	06316400	5/2/1968	09:30		1890	2.5	
USGS	06316400	6/10/1968	14:15		917	1.1	
USGS	06316400	7/2/1968	13:10		923	1.2	
USGS	06316400	8/8/1968	14:30		1780	2.3	
USGS	06316400	9/12/1968	13:50		1180	1.7	
USGS	06316400	10/24/1968	14:30		1320	1.8	
USGS	06316400	11/29/1968	14:00		1770	2	
USGS	06316400	12/19/1968	13:45		1600	1.5	
USGS	06316400	1/24/1969	15:15		1730	2.1	
USGS	06316400	2/19/1969	16:00		1250	1.5	
USGS	06316400	3/24/1969	15:00		1390	1.8	
USGS	06316400	4/30/1969	11:35		2220	2.9	
USGS	06316400	5/28/1969	12:05		3040	3.5	
USGS	06316400	7/1/1969	16:25		1490	1.7	
USGS	06316400	8/1/1969	08:00		2390	2.4	
USGS	06316400	9/3/1969	11:30		3300	3.8	
USGS	06316400	10/3/1969	17:45		3230	3.6	
USGS	06316400	11/12/1969	13:15		1840	1.6	
USGS	06316400	12/10/1969	13:20		2100	1.8	
USGS	06316400	1/23/1970	13:45		2690	2.4	
USGS	06316400	2/24/1970	10:00		1210	1.3	
USGS	06316400	3/24/1970	13:20		1590	2	
USGS	06316400	4/20/1970	14:00		2510	2.5	
USGS	06316400	5/27/1970	12:00		1060	1.6	
USGS	06316400	7/1/1970	11:15		1360	1.8	
USGS	06316400	7/29/1970	14:00		2260	2.3	
USGS	06316400	8/25/1970	09:30		3320	3.8	
USGS	06316400	10/12/1970	14:50		4170	3.6	
USGS	06316400	11/30/1970	10:00		2010	2.3	
USGS	06316400	1/11/1971	11:30		2530	2.2	
USGS	06316400	5/27/1971	14:00		1030	1.5	

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	6/24/1971	10:30		590	0.9	
USGS	06316400	7/28/1971	11:00		2220	2.5	
USGS	06316400	9/9/1971	12:00		2780	2.9	
USGS	06316400	10/5/1971	13:30		3340	2.7	
USGS	06316400	11/2/1971	13:30		1440	1.7	
USGS	06316400	11/30/1971	11:45		1520	1.7	
USGS	06316400	1/17/1972	12:30		1440	1.6	
USGS	06316400	1/31/1972	14:45		1580	1.8	
USGS	06316400	2/29/1972	08:30		443	0.4	
USGS	06316400	4/4/1972	13:20		1540	1.9	
USGS	06316400	5/15/1972	13:15		1070	1.5	
USGS	06316400	6/20/1972	12:20		1400	0.8	
USGS	06316400	7/17/1972	15:00		1120	1.4	
USGS	06316400	8/15/1972	16:00		2350	2.4	
USGS	06316400	9/11/1972	13:30		1480	1.6	
USGS	06316400	10/18/1972	09:05		1440	1.7	
USGS	06316400	11/16/1972	10:00		1420	1.7	
USGS	06316400	12/19/1972	16:10		2220	2.1	
USGS	06316400	1/23/1973	10:40		1460	1.6	
USGS	06316400	2/22/1973	16:00		1540	1.6	
USGS	06316400	3/27/1973	16:30		1340	1.8	
USGS	06316400	5/1/1973	17:20		2360	2.7	
USGS	06316400	5/29/1973	18:45		1080	1.4	
USGS	06316400	7/16/1973	12:00		1970	2.1	
USGS	06316400	8/14/1973	12:50		1240	1.4	
USGS	06316400	9/20/1973	09:40		935	1.3	
USGS	06316400	10/11/1973	08:15		1440	1.5	
USGS	06316400	11/6/1973	09:35		1380	1.6	
USGS	06316400	12/18/1973	10:55		1380	1.7	
USGS	06316400	1/22/1974	10:45		1440	1.6	
USGS	06316400	2/26/1974	15:15		1430	1.8	
USGS	06316400	4/6/1974	14:45		1800	2	
USGS	06316400	4/30/1974	11:40		508	0.9	
USGS	06316400	5/29/1974	13:00		1670	1.9	
USGS	06316400	7/11/1974	18:45		1790	2.2	
USGS	06316400	8/7/1974	11:00		2670	2.9	
USGS	06316400	9/5/1974	14:35		2100	2.5	
USGS	06316400	10/8/1974	12:15			2.1	
USGS	06316400	11/20/1974	12:35			1.4	
USGS	06316400	12/9/1974	16:05			1.6	
USGS	06316400	1/10/1975	10:40			1.5	
USGS	06316400	2/19/1975	15:30			1.6	
USGS	06316400	3/24/1975	16:30			1.6	
USGS	06316400	4/18/1975	17:00			2.1	
USGS	06316400	5/2/1975	18:20			1.2	
USGS	06316400	6/11/1975	12:15			0.7	
USGS	06316400	7/16/1975	17:30			1.1	
USGS	06316400	8/6/1975	15:00			1.4	
USGS	06316400	9/10/1975	15:30			2.4	

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	10/1/1975	10:00			2	
USGS	06316400	11/5/1975	09:10			1.9	
USGS	06316400	12/4/1975	16:00			1.9	
USGS	06316400	1/14/1976	13:00			2	
USGS	06316400	2/12/1976	15:30			1.5	
USGS	06316400	3/4/1976	16:10			1.9	
USGS	06316400	4/9/1976	14:10			2.3	
USGS	06316400	5/5/1976	16:30			2.5	
USGS	06316400	6/9/1976	15:10			1	
USGS	06316400	6/30/1976	11:00			1.6	
USGS	06316400	8/4/1976	09:30			0.8	
USGS	06316400	8/10/1976	12:00		1060	1.4	
USGS	06316400	9/16/1976	20:00			2.2	
USGS	06316400	10/5/1976	13:45			1.4	
USGS	06316400	11/5/1976	12:45			1.8	
USGS	06316400	12/10/1976	10:20			1.7	
USGS	06316400	2/15/1977	17:20			2.3	
USGS	06316400	3/15/1977	18:50			1.7	
USGS	06316400	4/15/1977	15:15			1.3	
USGS	06316400	5/26/1977	10:15			2.1	
USGS	06316400	6/17/1977	11:50			1.6	
USGS	06316400	7/19/1977	15:30		2100	2.4	
USGS	06316400	7/20/1977	14:45			2.1	
USGS	06316400	8/15/1977	17:20			0.8	
USGS	06316400	9/12/1977	13:30			3.2	
USGS	06316400	11/3/1977	12:30		1720	2	
USGS	06316400	11/29/1977	15:45		2200	2.2	
USGS	06316400	12/21/1977	14:00		1620	1.9	
USGS	06316400	1/20/1978	13:45		1530	1.6	
USGS	06316400	2/8/1978	11:30		1420	1.7	
USGS	06316400	3/7/1978	10:00		1750	1.9	
USGS	06316400	4/11/1978	11:00		1610	2	
USGS	06316400	5/25/1978	16:00		525	1.1	
USGS	06316400	6/13/1978	11:30	USGS-WRD	445	0.9	
USGS	06316400	7/11/1978	08:35	USGS-WRD	1280	1.6	
USGS	06316400	8/1/1978	15:30	USGS-WRD	1920	2.6	
USGS	06316400	8/31/1978	16:00	USGS-WRD	2350	2.4	
USGS	06316400	10/17/1978	09:10	USGS-WRD	1480	1.7	
USGS	06316400	11/28/1978	12:00	USGS-WRD	1340	1.8	
USGS	06316400	12/8/1978	10:00	USGS-WRD	1460	2.1	
USGS	06316400	1/16/1979	10:55	USGS-WRD	1840	2.2	
USGS	06316400	2/16/1979	10:15	USGS-WRD	1560	2	
USGS	06316400	3/6/1979	12:15	USGS-WRD	1630	2	
USGS	06316400	3/21/1979	11:30	USGS-WRD	1400	2	
USGS	06316400	4/26/1979	09:50	USGS-WRD	1530	2.4	
USGS	06316400	5/24/1979	09:30	USGS-WRD	1120	2	
USGS	06316400	6/27/1979	09:35	USGS-WRD	945	1.4	
USGS	06316400	7/24/1979	09:45	USGS-WRD	1880	2.3	
USGS	06316400	8/15/1979	09:10	USGS-WRD	2450	2.8	

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	9/19/1979	14:40	USGS-WRD	1620	2	
USGS	06316400	10/9/1979	15:00	USGS-WRD	1510	1.8	
USGS	06316400	11/8/1979	09:50	USGS-WRD	1440	2	
USGS	06316400	12/5/1979	15:15	USGS-WRD	1950	2.1	
USGS	06316400	1/11/1980	11:00	USGS-WRD	2050	2.3	
USGS	06316400	2/15/1980	12:50	USGS-WRD	1620	2	
USGS	06316400	3/20/1980	10:00	USGS-WRD	1400	2	
USGS	06316400	4/9/1980	11:15	USGS-WRD	2410	5.4	
USGS	06316400	5/15/1980	08:55	USGS-WRD	993	1.6	
USGS	06316400	6/18/1980	12:15	USGS-WRD	930	1.3	
USGS	06316400	7/15/1980	16:30	USGS-WRD	2090	2.5	
USGS	06316400	8/19/1980	17:15	USGS-WRD	1340	1.3	
USGS	06316400	9/5/1980	12:30	USGS-WRD	2150	1.7	
USGS	06316400	9/26/1980	09:20	USGS-WRD	1980	2.1	
USGS	06316400	10/8/1980	13:30	USGS-WRD	2600	2.3	2190
USGS	06316400	11/12/1980	11:15	USGS-WRD	1980	2.1	1940
USGS	06316400	12/11/1980	12:30	USGS-WRD	1600	2.2	1790
USGS	06316400	1/6/1981	10:15	USGS-WRD	1400	2.1	1520
USGS	06316400	2/6/1981	10:30	USGS-WRD	1800	2.4	2100
USGS	06316400	3/4/1981	10:15	USGS-WRD	1750	2.5	1740
USGS	06316400	4/9/1981	11:15	USGS-WRD	2800	3.2	2700
USGS	06316400	5/14/1981	14:15	USGS-WRD	2800	2.9	2750
USGS	06316400	6/1/1981	10:45	USGS-WRD	700	1.1	669
USGS	06316400	7/8/1981	12:30	USGS-WRD	1930	2.5	1960
USGS	06316400	8/6/1981	12:30	USGS-WRD	1650	2.2	1680
USGS	06316400	9/3/1981	17:00	USGS-WRD	2700	2.7	2760
USGS	06316400	7/26/1988	12:55	USGS-WRD	2980	3.72	2890
USGS	06316400	9/6/1988	14:20	USGS-WRD	3100	4.26	2910
USGS	06316400	10/18/1988	10:45	USGS-WRD	2630	2.9	2670
USGS	06316400	11/29/1988	15:10	USGS-WRD	3130	2.98	2850
USGS	06316400	1/12/1989	17:40	USGS-WRD	2340	2.22	2210
USGS	06316400	2/27/1989	17:15	USGS-WRD	1820	1.84	1640
USGS	06316400	4/11/1989	18:40	USGS-WRD	1980	2.47	2130
USGS	06316400	4/27/1989	14:00	USGS-WRD	2650	2.7	2640
USGS	06316400	6/26/1989	17:30	USGS-WRD	1400	1.23	1310
USGS	06316400	8/8/1989	13:00	USGS-WRD	2750	3.71	2750
USGS	06316400	9/22/1989	11:35	USGS-WRD	2860	3.86	2950
USGS	06316400	11/2/1989	12:15	USGS-WRD	1550	1.63	1430
USGS	06316400	5/30/1990	10:05	USGS-WRD	1950	2.44	1940
USGS	06316400	3/28/2001	14:30	USGS-WRD	1460	1.83	1470
USGS	06316400	5/9/2001	13:20	USGS-WRD	1760	2.24	1770
USGS	06316400	6/7/2001	15:00	USGS-WRD	2820	3.05	2760
USGS	06316400	7/12/2001	18:55	USGS-WRD	684	0.45	690
USGS	06316400	8/14/2001	11:45	USGS-WRD	2850	3.43	2800
USGS	06316400	9/11/2001	14:30	USGS-WRD	3140	4.05	3080
USGS	06316400	10/11/2001	12:30	USGS-WRD	2940	3.59	2890
USGS	06316400	11/21/2001	08:25	USGS-WRD	2860	2.88	2900
USGS	06316400	12/12/2001	12:50	USGS-WRD	2030	2.2	2090
USGS	06316400	1/9/2002	11:20	USGS-WRD	2030	2.17	2080

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	2/13/2002	15:20	USGS-WRD	1420	1.6	1470
USGS	06316400	3/18/2002	14:40	USGS-WRD	1260	1.53	1290
USGS	06316400	4/10/2002	11:20	USGS-WRD	1110	1.67	1130
USGS	06316400	5/8/2002	11:45	USGS-WRD	1930	2.31	1920
USGS	06316400	6/11/2002	14:15	USGS-WRD	2620	2.88	2620
USGS	06316400	7/9/2002	12:55	USGS-WRD	3150	3.49	2980
USGS	06316400	8/13/2002	15:20	USGS-WRD	2460	2.43	2440
USGS	06316400	9/11/2002	10:55	USGS-WRD	1840	1.93	1800
USGS	06316400	10/8/2002	11:15	USGS-WRD	2140	2.66	E 2180
USGS	06316400	10/24/2002	09:50	USGS-WRD	2440	2.52	2430
USGS	06316400	11/5/2002	10:25	USGS-WRD	2000	1.99	1920
USGS	06316400	11/18/2002	11:15	USGS-WRD	1510	1.76	1510
USGS	06316400	12/5/2002	10:15	USGS-WRD	1740	1.91	1630
USGS	06316400	12/18/2002	12:30	USGS-WRD	1780	2.05	1760
USGS	06316400	12/31/2002	14:00	USGS-WRD	2100	2.34	2030
USGS	06316400	1/16/2003	16:15	USGS-WRD	1630	1.71	1600
USGS	06316400	1/29/2003	14:00	USGS-WRD	1550	1.76	1500
USGS	06316400	2/12/2003	17:15	USGS-WRD	1470	1.82	1450
USGS	06316400	37678	09:50	USGS-WRD	1440	1.69	1460
USGS	06316400	37690	12:00	USGS-WRD	1590	1.73	1510
USGS	06316400	37704	13:30	USGS-WRD	1210	1.5	1140
USGS	06316400	37719	17:45	USGS-WRD	2150	2.55	2090
USGS	06316400	37735	14:45	USGS-WRD	1170	1.71	1150
USGS	06316400	37748	14:15	USGS-WRD	1470	1.84	1470
USGS	06316400	37763	13:45	USGS-WRD	923	1.41	882
USGS	06316400	37778	09:20	USGS-WRD	488	0.85	430
USGS	06316400	37788	14:55	USGS-WRD	852	1.2	823
USGS	06316400	37803	08:50	USGS-WRD	570	0.88	538
USGS	06316400	37818	16:10	USGS-WRD	1180	1.58	1130
USGS	06316400	37832	17:35	USGS-WRD	1670	2.16	1600
USGS	06316400	37845	13:55	USGS-WRD	2150	2.5	2050
USGS	06316400	37859	14:10	USGS-WRD	2480	2.68	2360
USGS	06316400	37873	13:40	USGS-WRD	2930	3.58	2700
USGS	06316400	37887	12:15	USGS-WRD	1830	2.02	1730
USGS	06316400	37901	15:00	USGS-WRD	1640	2.02	1610
USGS	06316400	37916	14:00	USGS-WRD	1860	2.21	1760
USGS	06316400	37932	13:30	USGS-WRD	1780	1.93	1800
USGS	06316400	37945	16:00	USGS-WRD	1190	1.41	1140
USGS	06316400	37960	12:20	USGS-WRD	1510	1.44	1520
USGS	06316400	37973	14:30	USGS-WRD	1370	1.55	1390
USGS	06316400	37995	12:55	USGS-WRD	1680	1.78	1640
USGS	06316400	38008	16:30	USGS-WRD	1600	1.62	1560
USGS	06316400	38023	13:00	USGS-WRD	1350	1.53	1330
USGS	06316400	38036	18:10	USGS-WRD	1100	1.4	1060
USGS	06316400	38056	16:00	USGS-WRD	1100	1.46	1060
USGS	06316400	38069	17:45	USGS-WRD	1450	1.95	E 1420
USGS	06316400	38083	17:45	USGS-WRD	2260	2.6	2170
USGS	06316400	38098	09:25	USGS-WRD	2200	2.58	2160
USGS	06316400	38111	15:00	USGS-WRD	2430	2.68	2390

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	38124	18:30	USGS-WRD	2660	3	2410
USGS	06316400	38147	12:50	USGS-WRD	2650	3.12	2740
USGS	06316400	38161	17:55	USGS-WRD	2980	3.43	2880
USGS	06316400	38183	13:15	USGS-WRD	2710	2.75	2630
USGS	06316400	38196	13:00	USGS-WRD	1270	1.09	1320
USGS	06316400	38209	12:00	USGS-WRD	1970	2.34	1960
USGS	06316400	38223	15:05	USGS-WRD	2860	3.63	2750
USGS	06316400	38238	10:45	USGS-WRD	2130	3.06	2180
USGS	06316400	38250	14:45	USGS-WRD	3030	4.38	3030
USGS	06316400	38266	17:10	USGS-WRD	2840	3.1	2760
USGS	06316400	38278	17:25	USGS-WRD	2690	2.87	2560
USGS	06316400	38296	11:25	USGS-WRD	1670	1.95	1620
USGS	06316400	38315	07:55	USGS-WRD		1.62	1320
USGS	06316400	38330	12:30	USGS-WRD	1810	1.83	1790
USGS	06316400	38342	08:35	USGS-WRD	1460	1.71	1400
USGS	06316400	38365	14:00	USGS-WRD	1560	1.65	1520
USGS	06316400	38378	14:00	USGS-WRD	1280	1.48	1250
USGS	06316400	38393	12:10	USGS-WRD	1420	1.63	1260
USGS	06316400	38407	14:20	USGS-WRD	1380	1.64	1270
USGS	06316400	38419	16:00	USGS-WRD	1220	1.66	1140
USGS	06316400	38439	14:20	USGS-WRD	2160	2.33	2090
USGS	06316400	38456	17:40	USGS-WRD	940	1.36	901
USGS	06316400	38470	09:00	USGS-WRD	1640	1.99	1600
USGS	06316400	38481	19:15	USGS-WRD	1650	1.78	1620
USGS	06316400	38496	10:15	USGS-WRD	442	1.08	506
USGS	06316400	38511	12:30	USGS-WRD	587	1.02	552
USGS	06316400	38525	10:40	USGS-WRD	508	0.89	462
USGS	06316400	38546	16:15	USGS-WRD	956	1.33	926
USGS	06316400	38560	11:30	USGS-WRD	1520	1.64	1470
USGS	06316400	38574	12:50	USGS-WRD	1390	1.74	1390
USGS	06316400	38588	15:40	USGS-WRD	1630	1.8	1590
USGS	06316400	38603	15:50	USGS-WRD	1990	2.31	1980
USGS	06316400	38616	16:05	USGS-WRD	2380	2.85	2360
USGS	06316400	38637	17:15	USGS-WRD	1990	2.03	1970
USGS	06316400	38653	08:50	USGS-WRD	1500	1.75	1460
USGS	06316400	38665	13:25	USGS-WRD	1630	2.01	1600
USGS	06316400	38678	11:00	USGS-WRD	1510	1.79	1480
USGS	06316400	38695	13:20	USGS-WRD	1570	1.69	1520
USGS	06316400	38705	10:15	USGS-WRD	1760	1.78	1750
USGS	06316400	38729	12:35	USGS-WRD	1200	1.51	1240
USGS	06316400	38741	14:25	USGS-WRD	1370	1.64	1430
USGS	06316400	38757	12:30	USGS-WRD	1280	1.6	1320
USGS	06316400	38770	08:40	USGS-WRD	1850	2.47	1940
USGS	06316400	38785	11:30	USGS-WRD	1130	1.6	1070
USGS	06316400	38797	15:15	USGS-WRD	1570	2.01	1660
USGS	06316400	38820	11:35	USGS-WRD	1590	2.13	1580
USGS	06316400	38832	15:40	USGS-WRD	1670	2.31	1760
USGS	06316400	38847	17:20	USGS-WRD	2130	2.64	2140
USGS	06316400	38860	09:00	USGS-WRD	2330	2.77	2410

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	38874	18:30	USGS-WRD	1890	2.38	1890
USGS	06316400	38890	15:10	USGS-WRD	2340	2.77	2280
USGS	06316400	38911	15:45	USGS-WRD	3390	4.81	3380
USGS	06316400	38923	15:15	USGS-WRD	3660	5.73	3620
USGS	06316400	38981	12:20	USGS-WRD	3580	5.28	3570
USGS	06316400	39001	13:50	USGS-WRD	2710	3.74	2810
USGS	06316400	39013	13:20	USGS-WRD	2610	3.18	2620
USGS	06316400	39028	16:15	USGS-WRD	2580	3.3	2660
USGS	06316400	39050	14:15	USGS-WRD	3150	3.09	3380
USGS	06316400	39063	15:35	USGS-WRD	3600	3.24	3610
USGS	06316400	39078	15:45	USGS-WRD	2430	2.39	2500
USGS	06316400	39092	12:20	USGS-WRD	2340	2.42	2380
USGS	06316400	39107	15:25	USGS-WRD	3180	3.03	3160
USGS	06316400	39121	12:20	USGS-WRD	2770	2.81	2800
USGS	06316400	39135	09:25	USGS-WRD	2480	2.55	2510
USGS	06316400	39148	17:10	USGS-WRD	1030	1.33	1050
USGS	06316400	39161	16:00	USGS-WRD	1110	1.52	1130
USGS	06316400	39183	17:10	USGS-WRD	1950	2.29	2000
USGS	06316400	39197	15:00	USGS-WRD	2270	2.7	2300
USGS	06316400	39213	12:35	USGS-WRD	1330	1.63	1360
USGS	06316400	39225	15:35	USGS-WRD	1070	1.52	1100
USGS	06316400	39239	17:50	USGS-WRD	1360	1.55	1370
USGS	06316400	39252	15:50	USGS-WRD	1190	1.59	1200
USGS	06316400	39274	15:10	USGS-WRD	2230	2.54	2250
USGS	06316400	39287	15:35	USGS-WRD	2810	3.56	2780
USGS	06316400	39302	14:45	USGS-WRD	1050	1.43	1050
USGS	06316400	39315	15:25	USGS-WRD	1980	2.76	2110
USGS	06316400	39343	16:50	USGS-WRD	3010	4.07	3010
USGS	06316400	39365	14:50	USGS-WRD	2830	3.1	2830
USGS	06316400	39378	15:55	USGS-WRD	1760	2.13	1800
USGS	06316400	39393	10:00	USGS-WRD	1680	1.93	1730
USGS	06316400	39405	14:15	USGS-WRD	1560	1.74	1570
USGS	06316400	39422	16:25	USGS-WRD	1590	1.83	1630
USGS	06316400	39433	10:55	USGS-WRD	1560	1.68	1570
USGS	06316400	39457	13:15	USGS-WRD	1570	1.76	1580
USGS	06316400	39470	16:40	USGS-WRD	1280	1.39	1330
USGS	06316400	39485	13:10	USGS-WRD	1580	E 1.84	1600
USGS	06316400	39498	15:30	USGS-WRD	1390	1.48	1370
USGS	06316400	39511	15:15	USGS-WRD	924	1.22	933
USGS	06316400	39525	15:55	USGS-WRD	1300	1.63	1300
USGS	06316400	39547	15:45	USGS-WRD	1770	2.15	1770
USGS	06316400	39560	16:45	USGS-WRD	2010	2.29	2020
USGS	06316400	39575	17:00	USGS-WRD	1560	1.97	1560
USGS	06316400	39589	16:50	USGS-WRD	1280	1.46	1290
USGS	06316400	39611	15:50	USGS-WRD	409	0.84	418
USGS	06316400	39623	17:35	USGS-WRD	386	0.69	386
USGS	06316400	39638	16:00	USGS-WRD	711	1.08	708
USGS	06316400	39651	15:40	USGS-WRD	997	1.39	993
USGS	06316400	39666	14:00	USGS-WRD	1730	2.03	1720

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	39679	14:20	USGS-WRD	1900	2.36	1920
USGS	06316400	39701	17:00	USGS-WRD	1830	2.39	1860
USGS	06316400	39714	16:05	USGS-WRD	1430	1.86	1440
USGS	06316400	39728	15:30	USGS-WRD	1680	2.19	1740
USGS	06316400	39741	15:45	USGS-WRD	1450	1.77	1460
USGS	06316400	39762	13:00	USGS-WRD	1360	1.67	1380
USGS	06316400	39770	13:50	USGS-WRD	1390	1.76	1390
USGS	06316400	39785	16:00	USGS-WRD	1260	1.61	1260
USGS	06316400	39798	15:40	USGS-WRD	1690	1.96	1660
USGS	06316400	39821	12:35	USGS-WRD	1850	1.82	1830
USGS	06316400	39840	15:30	USGS-WRD	1120	1.41	1130
USGS	06316400	39856	11:55	USGS-WRD	873	1.52	932
USGS	06316400	39869	11:20	USGS-WRD	1050	1.63	1030
USGS	06316400	39884	14:05	USGS-WRD	1390	1.97	1420
USGS	06316400	39903	15:05	USGS-WRD	1260	1.86	1280
USGS	06316400	39910	14:00	USGS-WRD	1760	2.26	1810
USGS	06316400	39924	16:00	USGS-WRD	1020	1.45	1040
USGS	06316400	39945	13:30	USGS-WRD	1600	2.1	1620
USGS	06316400	39960	15:10	USGS-WRD	1090	1.6	1090
USGS	06316400	39974	13:15	USGS-WRD	634	0.91	658
USGS	06316400	39987	15:45	USGS-WRD	616	1.01	631
USGS	06316400	40002	13:30	USGS-WRD	685	1.26	694
USGS	06316400	40029	12:30	USGS-WRD	1040	1.59	1060
USGS	06316400	40065	13:05	USGS-WRD	1570	1.93	1580
USGS	06316400	40092	14:05	USGS-WRD	1660	2.12	1680
USGS	06316400	40121	13:35	USGS-WRD	1310	1.75	1360
USGS	06316400	40150	13:45	USGS-WRD	1670	2.04	1700
USGS	06316400	40191	15:00	USGS-WRD	1740	1.85	1720
USGS	06316400	40213	16:00	USGS-WRD	1650	1.85	1640
USGS	06316400	40240	14:00	USGS-WRD	1520	1.89	1520
USGS	06316400	40282	13:00	USGS-WRD	2140	2.77	2180
USGS	06316400	40311	14:40	USGS-WRD	1420	1.96	1470
USGS	06316400	40337	13:25	USGS-WRD	335	0.74	344
USGS	06316400	40367	12:55	USGS-WRD	564	0.92	565
USGS	06316400	40401	13:30	USGS-WRD	1430	1.83	1440
USGS	06316400	40429	12:30	USGS-WRD	2200	2.85	2230
USGS	06316400	40457	13:35	USGS-WRD	2590	3.21	2590
USGS	06316400	40491	13:10	USGS-WRD	1310	1.6	1290
USGS	06316400	40520	13:25	USGS-WRD	1400	1.59	1400
USGS	06316400	40548	15:30	USGS-WRD	1340	1.69	1320
USGS	06316400	40584	15:30	USGS-WRD	1670	2.17	1650
USGS	06316400	40611	14:10	USGS-WRD	1270	1.75	1260
USGS	06316400	40639	13:55	USGS-WRD	1790	2.32	1810
USGS	06316400	40667	08:20	USGS-WRD	1910	2.52	1930
USGS	06316400	40702	17:20	USGS-WRD	365	0.84	378
USGS	06316400	40736	14:10	USGS-WRD	631	1.08	624
USGS	06316400	40765	12:55	USGS-WRD	1350	1.79	1320
USGS	06316400	40794	13:00	USGS-WRD	2070	2.5	2050
USGS	06316400	40821	14:15	USGS-WRD	1690	2.17	1690

Crazy Woman Creek near Arvada, WY

6316400

Agency	Gage Number	Sample Date	Sample Time	Collecting Entity	Specific Conductance, unfiltered uS/cm p00095	Sodium Adsorption Ratio p00931	Specific Conductance, laboratory, unfiltered uS/cm p90095
USGS	06316400	40855	14:00	USGS-WRD	1380	1.77	1450
USGS	06316400	40883	13:25	USGS-WRD	1430	1.86	1380
USGS	06316400	40919	14:30	USGS-WRD	1220	1.47	1260
USGS	06316400	40946	17:00	USGS-WRD	1230	1.61	1210
USGS	06316400	40975	13:50	USGS-WRD	561	1.14	562
USGS	06316400	41010	14:30	USGS-WRD	1360	1.94	1390

APPENDIX 2D

CBNG WATER PUMPAGE-DISCHARGE-RECHARGE

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2003	Antelope Creek	224	1,205.6	0.0	1,085.0	120.6	0.0	1,205.6	0.0	0.0	868.0
2003	Clear Creek	139	435.3	100.1	113.2	222.0	396.1	0.0	0.0	39.2	316.9
2003	Crazy Woman Creek	2	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.1
2003	Dry Fork Cheyenne River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Lightning Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Little Powder River	2043	2,731.4	0.0	1,830.0	901.4	87.4	2,586.6	8.2	49.2	1,925.3
2003	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Middle North Platte River	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Middle Powder River	665	1,156.0	0.0	358.4	797.7	0.0	1,156.0	0.0	0.0	832.3
2003	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Upper Belle Fourche River	4957	7,264.6	0.0	7,119.3	145.3	7.3	7,257.3	0.0	0.0	5,230.5
2003	Upper Cheyenne River	470	1,015.8	0.0	1,015.8	0.0	0.0	428.7	587.1	0.0	308.6
2003	Upper Powder River	2449	5,739.1	57.4	4,706.1	975.7	86.1	5,555.5	11.5	86.1	4,061.9
2003	Upper Tongue River	1212	2,467.6	0.0	2,146.8	320.8	1,974.1	404.7	39.5	49.4	1,879.2
2004	Antelope Creek	436	1,280.3	0.0	1,152.3	128.0	0.0	1,280.3	0.0	0.0	921.8
2004	Clear Creek	179	367.1	84.4	95.5	187.2	334.1	0.0	0.0	33.0	267.3
2004	Crazy Woman Creek	39	25.3	0.5	9.9	15.0	14.6	3.6	0.0	7.1	14.2
2004	Dry Fork Cheyenne River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Lightning Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Little Powder River	2214	2,366.6	0.0	1,585.6	781.0	75.7	2,241.2	7.1	42.6	1,668.2
2004	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Middle North Platte River	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Middle Powder River	723	913.5	0.0	283.2	630.3	0.0	913.5	0.0	0.0	657.7
2004	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Salt Creek	2	3.9	0.0	3.9	0.0	0.0	0.0	0.0	3.9	0.0
2004	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	Upper Belle Fourche River	5351	5,829.8	0.0	5,713.2	116.6	5.8	5,824.0	0.0	0.0	4,197.4
2004	Upper Cheyenne River	530	870.5	0.0	870.5	0.0	0.0	367.4	503.2	0.0	264.5
2004	Upper Powder River	3031	6,089.0	60.9	4,993.0	1,035.1	91.3	5,894.2	12.2	91.3	4,309.6
2004	Upper Tongue River	1534	2,248.1	0.0	1,955.8	292.2	1,798.4	368.7	36.0	45.0	1,712.0
2005	Antelope Creek	883	1,547.5	0.0	1,392.7	154.7	0.0	1,547.5	0.0	0.0	1,114.2
2005	Clear Creek	250	403.7	92.9	105.0	205.9	367.4	0.0	0.0	36.3	293.9
2005	Crazy Woman Creek	100	24.6	0.5	9.6	14.5	14.1	3.5	0.0	6.9	13.8
2005	Dry Fork Cheyenne River	2	46.8	0.0	0.0	46.8	0.0	46.8	0.0	0.0	33.7
2005	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Little Powder River	2388	2,454.6	0.0	1,644.6	810.0	78.5	2,324.5	7.4	44.2	1,730.2
2005	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Middle Powder River	888	1,227.0	0.0	380.4	846.6	0.0	1,227.0	0.0	0.0	883.4
2005	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Salt Creek	1	3.5	0.0	3.5	0.0	0.0	0.0	0.0	3.5	0.0
2005	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	Upper Belle Fourche River	5375	4,035.1	0.0	3,954.4	80.7	4.0	4,031.1	0.0	0.0	2,905.3
2005	Upper Cheyenne River	540	615.7	0.0	615.7	0.0	0.0	259.8	355.9	0.0	187.1
2005	Upper Powder River	4037	8,113.5	81.1	6,653.1	1,379.3	121.7	7,853.9	16.2	121.7	5,742.4
2005	Upper Tongue River	2073	2,798.3	0.0	2,434.6	363.8	2,238.7	458.9	44.8	56.0	2,131.1
2006	Antelope Creek	1152	1,697.4	0.0	1,527.6	169.7	0.0	1,697.4	0.0	0.0	1,222.1
2006	Clear Creek	303	240.6	55.3	62.6	122.7	219.0	0.0	0.0	21.7	175.2
2006	Crazy Woman Creek	144	124.5	2.5	48.5	73.4	71.7	17.8	0.0	35.0	69.8
2006	Dry Fork Cheyenne River	13	68.9	0.0	0.0	68.9	0.0	68.9	0.0	0.0	49.6
2006	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Little Powder River	2547	2,390.2	0.0	1,601.4	788.8	76.5	2,263.5	7.2	43.0	1,684.8
2006	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Middle Powder River	1097	1,748.1	0.0	541.9	1,206.2	0.0	1,748.1	0.0	0.0	1,258.6
2006	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Salt Creek	1	2.3	0.0	2.3	0.0	0.0	0.0	0.0	2.3	0.0
2006	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	Upper Belle Fourche River	5438	3,646.3	0.0	3,573.4	72.9	3.6	3,642.7	0.0	0.0	2,625.3
2006	Upper Cheyenne River	502	431.6	0.0	431.6	0.0	0.0	182.1	249.5	0.0	131.1
2006	Upper Powder River	5520	12,044.5	120.4	9,876.5	2,047.6	180.7	11,659.1	24.1	180.7	8,524.6
2006	Upper Tongue River	2282	3,244.2	0.0	2,822.5	421.8	2,595.4	532.1	51.9	64.9	2,470.7
2007	Antelope Creek	1168	719.4	0.0	647.4	71.9	0.0	719.4	0.0	0.0	517.9
2007	Clear Creek	341	204.9	47.1	53.3	104.5	186.4	0.0	0.0	18.4	149.2
2007	Crazy Woman Creek	223	130.0	2.6	50.7	76.7	74.9	18.6	0.0	36.5	72.9
2007	Dry Fork Cheyenne River	21	103.6	0.0	0.0	103.6	0.0	103.6	0.0	0.0	74.6
2007	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Little Powder River	2748	2,309.6	0.0	1,547.4	762.2	73.9	2,187.2	6.9	41.6	1,628.0
2007	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Middle Powder River	1267	2,074.8	0.0	643.2	1,431.6	0.0	2,074.8	0.0	0.0	1,493.9
2007	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Salt Creek	1	0.8	0.0	0.8	0.0	0.0	0.0	0.0	0.8	0.0
2007	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	Upper Belle Fourche River	5531	2,924.4	0.0	2,865.9	58.5	2.9	2,921.5	0.0	0.0	2,105.6
2007	Upper Cheyenne River	466	317.3	0.0	317.3	0.0	0.0	133.9	183.4	0.0	96.4
2007	Upper Powder River	7008	13,563.2	135.6	11,121.8	2,305.7	203.4	13,129.2	27.1	203.4	9,599.5
2007	Upper Tongue River	2509	3,625.2	0.0	3,153.9	471.3	2,900.2	594.5	58.0	72.5	2,760.8
2008	Antelope Creek	1193	594.4	0.0	534.9	59.4	0.0	594.4	0.0	0.0	427.9

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2008	Clear Creek	350	509.2	117.1	132.4	259.7	463.4	0.0	0.0	45.8	370.7
2008	Crazy Woman Creek	264	211.5	4.2	82.5	124.8	121.8	30.2	0.0	59.4	118.6
2008	Dry Fork Cheyenne River	22	100.2	0.0	0.0	100.2	0.0	100.2	0.0	0.0	72.1
2008	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Little Powder River	2731	2,403.5	0.0	1,610.4	793.2	76.9	2,276.2	7.2	43.3	1,694.2
2008	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Middle Powder River	1434	2,340.9	0.0	725.7	1,615.2	0.0	2,340.9	0.0	0.0	1,685.5
2008	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Salt Creek	1	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.9	0.0
2008	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	Upper Belle Fourche River	5479	2,354.6	0.0	2,307.5	47.1	2.4	2,352.2	0.0	0.0	1,695.3
2008	Upper Cheyenne River	438	243.8	0.0	243.8	0.0	0.0	102.9	140.9	0.0	74.1
2008	Upper Powder River	8104	14,693.6	146.9	12,048.7	2,497.9	220.4	14,223.4	29.4	220.4	10,399.5
2008	Upper Tongue River	2790	4,222.4	0.0	3,673.5	548.9	3,377.9	692.5	67.6	84.4	3,215.6
2009	Antelope Creek	1473	2,244.0	0.0	2,954.0	1,315.5	0.0	2,244.0	0.0	0.0	1,615.7
2009	Clear Creek	134	341.0	0.0	31.3	617.5	310.3	0.0	0.0	30.7	248.3
2009	Crazy Woman Creek	69	247.7	0.0	97.3	373.9	142.7	35.4	0.0	69.6	138.9
2009	Dry Fork Cheyenne River	17	61.8	0.0	0.0	117.6	0.0	61.8	0.0	0.0	44.5
2009	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Little Powder River	2125	1,807.2	0.0	1,989.7	1,448.6	57.8	1,711.4	5.4	32.5	1,273.8
2009	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Middle Powder River	1404	2,105.6	0.0	478.6	3,527.5	0.0	2,105.6	0.0	0.0	1,516.1
2009	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	Upper Belle Fourche River	3944	2,290.8	0.0	4,282.2	76.3	2.3	2,288.5	0.0	0.0	1,649.4
2009	Upper Cheyenne River	346	265.1	0.0	504.4	0.0	0.0	111.9	153.2	0.0	80.6
2009	Upper Powder River	8098	17,003.2	161.3	23,468.7	8,720.1	255.0	16,459.1	34.0	255.0	12,034.2
2009	Upper Tongue River	2549	4,692.6	0.0	8,205.7	722.4	3,754.1	769.6	75.1	93.9	3,573.7
2010	Antelope Creek	1412	1,793.7	0.0	2,168.4	1,244.2	0.0	1,793.7	0.0	0.0	1,291.5
2010	Clear Creek	147	346.7	26.0	75.7	558.0	315.5	0.0	0.0	31.2	252.4
2010	Crazy Woman Creek	95	373.1	2.1	183.3	524.4	214.9	53.3	0.0	104.8	209.2
2010	Dry Fork Cheyenne River	15	55.0	0.0	0.0	104.6	0.0	55.0	0.0	0.0	39.6
2010	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Little Powder River	2028	1,949.9	0.0	2,219.4	1,490.5	62.4	1,846.6	5.8	35.1	1,374.5
2010	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Middle Powder River	1261	1,911.5	0.0	439.9	3,197.0	0.0	1,911.5	0.0	0.0	1,376.3
2010	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	Upper Belle Fourche River	3687	2,428.0	0.0	4,511.8	107.6	2.4	2,425.6	0.0	0.0	1,748.2
2010	Upper Cheyenne River	315	284.3	0.0	540.9	0.0	0.0	120.0	164.3	0.0	86.4
2010	Upper Powder River	7815	17,692.8	173.6	24,797.5	8,691.0	265.4	17,126.6	35.4	265.4	12,522.3
2010	Upper Tongue River	2304	4,314.9	0.0	7,529.4	680.0	3,451.9	707.6	69.0	86.3	3,286.1
2011	Antelope Creek	1417	1,898.5	0.0	2,313.1	1,298.9	0.0	1,898.5	0.0	0.0	1,366.9
2011	Clear Creek	161	395.6	41.3	100.5	610.8	360.0	0.0	0.0	35.6	288.0
2011	Crazy Woman Creek	116	443.2	3.3	224.7	615.2	255.3	63.4	0.0	124.5	248.5
2011	Dry Fork Cheyenne River	13	48.1	0.0	0.0	91.5	0.0	48.1	0.0	0.0	34.6
2011	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Little Powder River	1865	1,833.0	0.0	2,098.7	1,388.8	58.7	1,735.9	5.5	33.0	1,292.1
2011	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Middle Powder River	1225	2,048.6	0.0	518.5	3,379.1	0.0	2,048.6	0.0	0.0	1,475.0
2011	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	Upper Belle Fourche River	3430	2,430.0	0.0	4,497.2	126.1	2.4	2,427.6	0.0	0.0	1,749.6
2011	Upper Cheyenne River	283	286.9	0.0	545.8	0.0	0.0	121.1	165.8	0.0	87.2
2011	Upper Powder River	7328	16,524.4	165.7	23,173.5	8,099.9	247.9	15,995.6	33.0	247.9	11,695.3
2011	Upper Tongue River	2059	3,901.1	0.0	6,790.1	632.0	3,120.9	639.8	62.4	78.0	2,970.9
2012	Antelope Creek	1296	1,431.2	0.0	1,583.1	1,139.8	0.0	1,431.2	0.0	0.0	1,030.4
2012	Clear Creek	174	432.3	52.0	116.8	653.8	393.4	0.0	0.0	38.9	314.7
2012	Crazy Woman Creek	138	505.4	4.1	258.6	698.7	291.1	72.3	0.0	142.0	283.4
2012	Dry Fork Cheyenne River	11	41.2	0.0	0.0	78.4	0.0	41.2	0.0	0.0	29.7
2012	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Little Powder River	1702	1,710.8	0.0	1,970.3	1,284.7	54.7	1,620.1	5.1	30.8	1,205.9
2012	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Middle Powder River	1268	2,331.3	0.0	651.7	3,783.8	0.0	2,331.3	0.0	0.0	1,678.6
2012	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	Upper Belle Fourche River	3192	2,436.5	0.0	4,499.0	136.6	2.4	2,434.0	0.0	0.0	1,754.3
2012	Upper Cheyenne River	252	277.8	0.0	528.6	0.0	0.0	117.2	160.6	0.0	84.4
2012	Upper Powder River	6813	15,207.0	157.2	21,351.9	7,423.6	228.1	14,720.4	30.4	228.1	10,762.9
2012	Upper Tongue River	1814	3,466.1	0.0	6,014.3	580.2	2,772.9	568.4	55.5	69.3	2,639.6
2013	Antelope Creek	1245	1,583.6	0.0	1,470.1	1,542.7	0.0	1,583.6	0.0	0.0	1,140.2
2013	Clear Creek	188	462.7	60.0	128.5	691.7	421.0	0.0	0.0	41.6	336.8

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2013	Crazy Woman Creek	159	562.5	4.9	288.2	777.2	324.0	80.4	0.0	158.1	315.5
2013	Dry Fork Cheyenne River	9	34.4	0.0	0.0	65.4	0.0	34.4	0.0	0.0	24.7
2013	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Little Powder River	1552	1,611.1	0.0	1,871.6	1,193.7	51.6	1,525.7	4.8	29.0	1,135.6
2013	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Middle Powder River	1124	1,909.2	0.0	525.9	3,106.6	0.0	1,909.2	0.0	0.0	1,374.6
2013	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Salt Creek	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	Upper Belle Fourche River	2935	2,290.9	0.0	4,217.5	141.2	2.3	2,288.6	0.0	0.0	1,649.5
2013	Upper Cheyenne River	220	260.5	0.0	495.7	0.0	0.0	109.9	150.6	0.0	79.2
2013	Upper Powder River	6374	14,186.4	152.2	20,011.7	6,826.9	212.8	13,732.4	28.4	212.8	10,040.5
2013	Upper Tongue River	1569	3,016.2	0.0	5,213.5	525.1	2,413.0	494.7	48.3	60.3	2,297.0
2014	Antelope Creek	1136	1,354.0	0.0	1,153.0	1,423.0	0.0	1,354.0	0.0	0.0	974.9
2014	Clear Creek	201	489.0	66.4	137.4	726.6	445.0	0.0	0.0	44.0	356.0
2014	Crazy Woman Creek	180	615.9	5.5	314.6	851.8	354.8	88.1	0.0	173.1	345.4
2014	Dry Fork Cheyenne River	8	27.5	0.0	0.0	52.3	0.0	27.5	0.0	0.0	19.8
2014	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Little Powder River	1389	1,460.5	0.0	1,702.3	1,076.5	46.7	1,383.1	4.4	26.3	1,029.5
2014	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Middle Powder River	981	1,565.3	0.0	429.4	2,548.7	0.0	1,565.3	0.0	0.0	1,127.0
2014	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	Upper Belle Fourche River	2678	2,141.5	0.0	3,933.2	141.1	2.1	2,139.3	0.0	0.0	1,541.9
2014	Upper Cheyenne River	189	237.2	0.0	451.3	0.0	0.0	100.1	137.1	0.0	72.1
2014	Upper Powder River	5867	12,714.4	141.1	17,971.3	6,078.0	190.7	12,307.6	25.4	190.7	8,998.8
2014	Upper Tongue River	1385	2,776.9	0.0	4,759.3	523.9	2,221.5	455.4	44.4	55.5	2,114.7
2015	Antelope Creek	1026	1,190.8	0.0	933.9	1,331.6	0.0	1,190.8	0.0	0.0	857.4
2015	Clear Creek	215	512.7	71.8	144.4	759.3	466.6	0.0	0.0	46.1	373.2
2015	Crazy Woman Creek	395	1,506.6	21.1	883.3	1,961.9	867.8	215.4	0.0	423.3	844.9
2015	Dry Fork Cheyenne River	6	20.6	0.0	0.0	39.2	0.0	20.6	0.0	0.0	14.8
2015	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Little Powder River	1231	1,316.1	0.0	1,539.0	965.1	42.1	1,246.4	3.9	23.7	927.7
2015	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Middle Powder River	937	1,562.4	0.0	455.7	2,516.9	0.0	1,562.4	0.0	0.0	1,124.9
2015	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	Upper Belle Fourche River	2421	1,977.2	0.0	3,624.7	137.1	2.0	1,975.3	0.0	0.0	1,423.6
2015	Upper Cheyenne River	157	209.3	0.0	398.3	0.0	0.0	88.3	121.0	0.0	63.6
2015	Upper Powder River	5138	10,351.1	120.7	14,588.7	4,984.4	155.3	10,019.8	20.7	155.3	7,326.1
2015	Upper Tongue River	1140	2,255.2	0.0	3,836.7	453.9	1,804.1	369.8	36.1	45.1	1,717.4
2016	Antelope Creek	933	1,153.5	0.0	821.1	1,373.6	0.0	1,153.5	0.0	0.0	830.5
2016	Clear Creek	244	587.2	89.4	171.2	856.6	534.4	0.0	0.0	52.8	427.5
2016	Crazy Woman Creek	417	1,397.4	18.8	788.3	1,851.5	804.9	199.8	0.0	392.7	783.7
2016	Dry Fork Cheyenne River	4	13.7	0.0	0.0	26.1	0.0	13.7	0.0	0.0	9.9
2016	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Little Powder River	1068	1,151.0	0.0	1,349.3	840.7	36.8	1,090.0	3.5	20.7	811.3
2016	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Middle Powder River	880	1,453.3	0.0	443.4	2,321.6	0.0	1,453.3	0.0	0.0	1,046.3
2016	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	Upper Belle Fourche River	2173	1,829.2	0.0	3,350.3	129.9	1.8	1,827.3	0.0	0.0	1,317.0
2016	Upper Cheyenne River	126	177.6	0.0	338.0	0.0	0.0	75.0	102.7	0.0	54.0
2016	Upper Powder River	4785	9,891.3	119.0	14,161.9	4,538.1	148.4	9,574.8	19.8	148.4	7,000.7
2016	Upper Tongue River	903	1,777.1	0.0	2,992.2	388.8	1,421.7	291.4	28.4	35.5	1,353.4
2017	Antelope Creek	856	1,297.7	0.0	607.7	1,861.3	0.0	1,297.7	0.0	0.0	934.3
2017	Clear Creek	258	599.7	91.1	171.4	878.5	545.7	0.0	0.0	54.0	436.6
2017	Crazy Woman Creek	438	1,353.2	17.6	741.3	1,815.6	779.4	193.5	0.0	380.2	758.9
2017	Dry Fork Cheyenne River	2	6.9	0.0	0.0	13.1	0.0	6.9	0.0	0.0	4.9
2017	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Little Powder River	905	981.5	0.0	1,152.9	714.5	31.4	929.5	2.9	17.7	691.8
2017	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Middle Powder River	736	1,063.5	0.0	327.2	1,696.3	0.0	1,063.5	0.0	0.0	765.7
2017	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	Upper Belle Fourche River	1916	1,625.8	0.0	2,973.5	119.7	1.6	1,624.2	0.0	0.0	1,170.6
2017	Upper Cheyenne River	94	142.3	0.0	270.7	0.0	0.0	60.0	82.2	0.0	43.2
2017	Upper Powder River	4406	8,895.3	114.4	12,843.1	3,966.6	133.4	8,610.7	17.8	133.4	6,295.8
2017	Upper Tongue River	734	1,519.7	0.0	2,515.6	375.7	1,215.7	249.2	24.3	30.4	1,157.3
2018	Antelope Creek	822	1,718.4	0.0	1,341.4	1,927.9	0.0	1,718.4	0.0	0.0	1,237.2
2018	Clear Creek	271	614.1	93.3	172.5	902.7	558.9	0.0	0.0	55.3	447.1
2018	Crazy Woman Creek	459	1,334.5	16.9	713.1	1,809.0	768.7	190.8	0.0	375.0	748.4

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2018	Dry Fork Cheyenne River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Little Powder River	742	821.4	0.0	969.4	593.4	26.3	777.9	2.5	14.8	579.0
2018	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Middle Powder River	593	731.0	0.0	231.5	1,159.4	0.0	731.0	0.0	0.0	526.4
2018	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	Upper Belle Fourche River	1676	1,505.7	0.0	2,757.6	107.1	1.5	1,504.2	0.0	0.0	1,084.1
2018	Upper Cheyenne River	63	102.6	0.0	195.3	0.0	0.0	43.3	59.3	0.0	31.2
2018	Upper Powder River	4192	8,549.9	110.4	12,501.9	3,654.8	128.2	8,276.3	17.1	128.2	6,051.3
2018	Upper Tongue River	489	966.5	0.0	1,560.8	278.0	773.2	158.5	15.5	19.3	736.0
2019	Antelope Creek	593	1,674.2	0.0	776.0	2,409.3	0.0	1,674.2	0.0	0.0	1,205.4
2019	Clear Creek	359	914.5	169.8	304.1	1,265.9	832.2	0.0	0.0	82.3	665.7
2019	Crazy Woman Creek	430	1,148.6	14.7	600.4	1,570.2	661.6	164.2	0.0	322.7	644.1
2019	Dry Fork Cheyenne River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Little Powder River	624	650.4	0.0	758.0	479.4	20.8	615.9	2.0	11.7	458.4
2019	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Middle Powder River	648	801.7	0.0	256.5	1,268.8	0.0	801.7	0.0	0.0	577.2
2019	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	Upper Belle Fourche River	1370	1,010.0	0.0	1,836.9	84.7	1.0	1,009.0	0.0	0.0	727.2
2019	Upper Cheyenne River	56	75.2	0.0	143.0	0.0	0.0	31.7	43.4	0.0	22.8
2019	Upper Powder River	4343	8,621.9	104.0	12,544.0	3,755.9	129.3	8,346.0	17.2	129.3	6,102.3
2019	Upper Tongue River	451	818.2	0.0	1,308.6	248.1	654.5	134.2	13.1	16.4	623.1
2020	Antelope Creek	588	1,678.8	0.0	981.6	2,212.4	0.0	1,678.8	0.0	0.0	1,208.7
2020	Clear Creek	330	777.0	141.2	244.2	1,092.9	707.1	0.0	0.0	69.9	565.7
2020	Crazy Woman Creek	396	997.5	12.9	511.8	1,373.2	574.6	142.6	0.0	280.3	559.4
2020	Dry Fork Cheyenne River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Little Powder River	531	558.0	0.0	652.9	408.7	17.9	528.4	1.7	10.0	393.3
2020	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Middle Powder River	692	757.1	0.0	243.4	1,197.0	0.0	757.1	0.0	0.0	545.1
2020	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	Upper Belle Fourche River	1277	943.8	0.0	1,728.2	67.4	0.9	942.9	0.0	0.0	679.5
2020	Upper Cheyenne River	79	199.3	0.0	379.2	0.0	0.0	84.1	115.2	0.0	60.6
2020	Upper Powder River	4226	8,361.0	108.9	12,183.4	3,615.1	125.4	8,093.4	16.7	125.4	5,917.6
2020	Upper Tongue River	528	1,052.7	0.0	1,682.9	319.9	842.1	172.6	16.8	21.1	801.7
2021	Antelope Creek	520	1,520.0	0.0	701.7	2,190.3	0.0	1,520.0	0.0	0.0	1,094.4
2021	Clear Creek	302	670.3	120.9	202.2	952.1	610.0	0.0	0.0	60.3	488.0
2021	Crazy Woman Creek	367	861.3	11.4	434.4	1,193.0	496.1	123.2	0.0	242.0	483.1
2021	Dry Fork Cheyenne River	20	162.9	0.0	0.0	309.9	0.0	162.9	0.0	0.0	117.3
2021	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Little Powder River	599	735.4	0.0	886.7	512.5	23.5	696.4	2.2	13.2	518.4
2021	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Middle Powder River	726	972.7	0.0	328.6	1,522.1	0.0	972.7	0.0	0.0	700.4
2021	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	Upper Belle Fourche River	1228	997.9	0.0	1,845.4	53.2	1.0	996.9	0.0	0.0	718.5
2021	Upper Cheyenne River	76	165.8	0.0	315.4	0.0	0.0	69.9	95.8	0.0	50.4
2021	Upper Powder River	4403	8,815.9	117.9	12,895.2	3,759.9	132.2	8,533.7	17.6	132.2	6,239.5
2021	Upper Tongue River	490	876.4	0.0	1,380.5	286.9	701.1	143.7	14.0	17.5	667.4
2022	Antelope Creek	744	2,560.8	0.0	1,548.6	3,323.6	0.0	2,560.8	0.0	0.0	1,843.8
2022	Clear Creek	396	1,018.3	214.8	367.3	1,355.3	926.7	0.0	0.0	91.6	741.3
2022	Crazy Woman Creek	338	734.9	10.0	364.5	1,023.6	423.3	105.1	0.0	206.5	412.1
2022	Dry Fork Cheyenne River	20	136.4	0.0	0.0	259.6	0.0	136.4	0.0	0.0	98.2
2022	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Little Powder River	532	599.0	0.0	711.0	428.6	19.2	567.2	1.8	10.8	422.2
2022	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Middle Powder River	578	918.9	0.0	309.2	1,439.2	0.0	918.9	0.0	0.0	661.6
2022	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	Upper Belle Fourche River	1076	776.1	0.0	1,435.6	41.0	0.8	775.3	0.0	0.0	558.8
2022	Upper Cheyenne River	73	142.0	0.0	270.1	0.0	0.0	59.9	82.1	0.0	43.1
2022	Upper Powder River	4668	9,517.1	124.1	13,970.0	4,013.1	142.8	9,212.6	19.0	142.8	6,735.8
2022	Upper Tongue River	482	833.7	0.0	1,299.7	286.5	666.9	136.7	13.3	16.7	634.9
2023	Antelope Creek	668	1,794.8	0.0	800.9	2,613.8	0.0	1,794.8	0.0	0.0	1,292.2
2023	Clear Creek	462	1,223.8	276.8	466.1	1,585.6	1,113.7	0.0	0.0	110.1	891.0
2023	Crazy Woman Creek	420	1,075.1	16.9	606.9	1,421.8	619.3	153.7	0.0	302.1	603.0
2023	Dry Fork Cheyenne River	47	340.9	0.0	0.0	648.5	0.0	340.9	0.0	0.0	245.4

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2023	Lightning Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Little Powder River	467	510.8	0.0	603.4	368.4	16.3	483.7	1.5	9.2	360.0
2023	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Middle Powder River	565	733.6	0.0	241.6	1,154.1	0.0	733.6	0.0	0.0	528.2
2023	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	Upper Belle Fourche River	1119	1,143.7	0.0	2,145.5	30.5	1.1	1,142.6	0.0	0.0	823.5
2023	Upper Cheyenne River	66	103.3	0.0	196.5	0.0	0.0	43.6	59.7	0.0	31.4
2023	Upper Powder River	4731	9,293.7	127.1	13,624.2	3,930.8	139.4	8,996.3	18.6	139.4	6,577.7
2023	Upper Tongue River	608	1,181.2	0.0	1,876.9	370.5	945.0	193.7	18.9	23.6	899.6
2024	Antelope Creek	649	1,528.1	0.0	560.0	2,347.3	0.0	1,528.1	0.0	0.0	1,100.2
2024	Clear Creek	614	1,752.3	422.5	715.0	2,196.5	1,594.6	0.0	0.0	157.7	1,275.7
2024	Crazy Woman Creek	618	1,605.0	29.1	1,012.3	2,012.3	924.5	229.5	0.0	451.0	900.1
2024	Dry Fork Cheyenne River	74	514.0	0.0	0.0	978.0	0.0	514.0	0.0	0.0	370.1
2024	Lightning Creek	17	138.5	0.0	0.0	263.4	0.0	138.5	0.0	0.0	99.7
2024	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Little Powder River	400	413.8	0.0	483.3	303.9	13.2	391.8	1.2	7.4	291.6
2024	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Middle Powder River	553	547.6	0.0	178.7	863.1	0.0	547.6	0.0	0.0	394.3
2024	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	Upper Belle Fourche River	956	748.3	0.0	1,402.3	21.3	0.7	747.5	0.0	0.0	538.7
2024	Upper Cheyenne River	59	75.0	0.0	142.7	0.0	0.0	31.6	43.3	0.0	22.8
2024	Upper Powder River	4893	9,201.5	133.9	13,536.5	3,836.3	138.0	8,907.1	18.4	138.0	6,512.5
2024	Upper Tongue River	671	1,530.7	0.0	2,424.8	487.5	1,224.5	251.0	24.5	30.6	1,165.7
2025	Antelope Creek	679	1,654.9	0.0	573.8	2,574.7	0.0	1,654.9	0.0	0.0	1,191.5
2025	Clear Creek	781	2,248.9	565.3	950.1	2,763.2	2,046.5	0.0	0.0	202.4	1,637.2
2025	Crazy Woman Creek	413	1,355.1	24.4	851.9	1,701.7	780.5	193.8	0.0	380.8	759.9
2025	Dry Fork Cheyenne River	74	448.9	0.0	0.0	854.0	0.0	448.9	0.0	0.0	323.2
2025	Lightning Creek	17	116.0	0.0	0.0	220.6	0.0	116.0	0.0	0.0	83.5
2025	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Little Powder River	327	324.1	0.0	375.9	240.8	10.4	306.9	1.0	5.8	228.5
2025	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Middle Powder River	440	405.5	0.0	131.6	639.8	0.0	405.5	0.0	0.0	291.9
2025	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	Upper Belle Fourche River	794	558.2	0.0	1,048.7	13.3	0.6	557.6	0.0	0.0	401.9
2025	Upper Cheyenne River	52	53.9	0.0	102.6	0.0	0.0	22.7	31.2	0.0	16.4
2025	Upper Powder River	5411	10,488.5	142.6	15,507.6	4,305.2	157.3	10,152.9	21.0	157.3	7,423.4
2025	Upper Tongue River	774	1,743.2	0.0	2,743.2	573.4	1,394.6	285.9	27.9	34.9	1,327.5
2026	Antelope Creek	645	1,437.9	0.0	403.8	2,331.9	0.0	1,437.9	0.0	0.0	1,035.3
2026	Clear Creek	1155	3,634.7	941.8	1,594.7	4,378.8	3,307.6	0.0	0.0	327.1	2,646.1
2026	Crazy Woman Creek	713	2,645.9	54.4	1,752.2	3,227.4	1,524.0	378.4	0.0	743.5	1,483.9
2026	Dry Fork Cheyenne River	97	593.5	0.0	0.0	1,129.2	0.0	593.5	0.0	0.0	427.3
2026	Lightning Creek	37	265.7	0.0	0.0	505.5	0.0	265.7	0.0	0.0	191.3
2026	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Little Powder River	260	249.4	0.0	287.6	186.9	8.0	236.2	0.7	4.5	175.8
2026	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Middle Powder River	342	325.3	0.0	104.0	514.9	0.0	325.3	0.0	0.0	234.2
2026	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	Upper Belle Fourche River	621	410.9	0.0	775.6	6.2	0.4	410.5	0.0	0.0	295.9
2026	Upper Cheyenne River	45	37.7	0.0	71.8	0.0	0.0	15.9	21.8	0.0	11.5
2026	Upper Powder River	4991	8,204.9	121.8	11,998.8	3,490.0	123.1	7,942.4	16.4	123.1	5,807.1
2026	Upper Tongue River	889	1,946.8	0.0	3,064.5	639.4	1,557.4	319.3	31.1	38.9	1,482.6
2027	Antelope Creek	595	1,133.7	0.0	351.4	1,805.7	0.0	1,133.7	0.0	0.0	816.3
2027	Clear Creek	1324	3,878.2	1,020.6	1,675.3	4,682.7	3,529.2	0.0	0.0	349.0	2,823.3
2027	Crazy Woman Creek	978	3,498.6	75.0	2,350.3	4,231.2	2,015.2	500.3	0.0	983.1	1,962.1
2027	Dry Fork Cheyenne River	97	530.8	0.0	0.0	1,009.9	0.0	530.8	0.0	0.0	382.2
2027	Lightning Creek	37	229.9	0.0	0.0	437.4	0.0	229.9	0.0	0.0	165.5
2027	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Little Powder River	192	183.4	0.0	212.0	137.0	5.9	173.7	0.6	3.3	129.3
2027	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Middle Powder River	407	501.9	0.0	169.0	786.0	0.0	501.9	0.0	0.0	361.4
2027	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	Upper Belle Fourche River	458	311.7	0.0	593.1	0.0	0.3	311.4	0.0	0.0	224.5
2027	Upper Cheyenne River	38	24.7	0.0	47.1	0.0	0.0	10.4	14.3	0.0	7.5
2027	Upper Powder River	4526	6,575.3	98.7	9,599.4	2,812.0	98.6	6,364.9	13.2	98.6	4,653.7
2027	Upper Tongue River	1003	2,442.7	0.0	3,828.5	818.9	1,954.2	400.6	39.1	48.9	1,860.3
2028	Antelope Creek	508	1,012.8	0.0	250.1	1,676.8	0.0	1,012.8	0.0	0.0	729.2
2028	Clear Creek	1386	3,442.2	904.0	1,443.8	4,201.3	3,132.4	0.0	0.0	309.8	2,505.9
2028	Crazy Woman Creek	1004	2,962.0	68.5	1,951.4	3,615.6	1,706.1	423.6	0.0	832.3	1,661.1
2028	Dry Fork Cheyenne River	97	487.0	0.0	0.0	926.5	0.0	487.0	0.0	0.0	350.6
2028	Lightning Creek	37	207.1	0.0	0.0	394.1	0.0	207.1	0.0	0.0	149.1

HTSD Table G-1 Wyoming PRB Actual and Projected CBNG Water Production, Disposal, and Related Groundwater Recharge

See footnotes to right

			CBNG Water Production 1,2 (mmgpy)				CBNG Groundwater Disposal by Method 1 (mmgpy)				
Year	Subwatershed1	Total Number of Producing Wells for Year	Total Groundwater Production for Year	Groundwater Production from Shallow Coals (GW Model Layer 1)	Groundwater Production from Wyodak Coals (GW Model Layer 3)	Groundwater Production from Deep Coals (GW Model Layer 4)	Headwater Reservoir or Unlined Off-channel Impoundment	Unlined On-channel Impoundment or Direct Discharge to Drainage	Playa Lake Containment	Injection	Total CBNG-related Groundwater Recharge 3 (GW Model Layer 1) (mmgpy)
2028	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Little Powder River	211	212.1	0.0	249.2	154.5	6.8	200.9	0.6	3.8	149.5
2028	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Middle Powder River	425	414.6	0.0	140.6	648.3	0.0	414.6	0.0	0.0	298.5
2028	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	Upper Belle Fourche River	446	280.0	0.0	532.7	0.0	0.3	279.7	0.0	0.0	201.6
2028	Upper Cheyenne River	38	17.2	0.0	32.8	0.0	0.0	7.3	10.0	0.0	5.2
2028	Upper Powder River	4137	5,747.6	87.2	8,455.9	2,392.2	86.2	5,563.7	11.5	86.2	4,067.9
2028	Upper Tongue River	1437	3,638.5	0.0	5,732.8	1,189.7	2,910.8	596.7	58.2	72.8	2,770.9
2029	Antelope Creek	402	661.6	0.0	195.1	1,063.7	0.0	661.6	0.0	0.0	476.4
2029	Clear Creek	1522	4,083.7	1,072.7	1,706.3	4,990.7	3,716.2	0.0	0.0	367.5	2,973.0
2029	Crazy Woman Creek	1004	2,492.2	60.0	1,607.7	3,074.0	1,435.5	356.4	0.0	700.3	1,397.7
2029	Dry Fork Cheyenne River	97	452.5	0.0	0.0	860.9	0.0	452.5	0.0	0.0	325.8
2029	Lightning Creek	41	222.8	0.0	0.0	423.9	0.0	222.8	0.0	0.0	160.4
2029	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Little Powder River	211	189.5	0.0	217.0	143.6	6.1	179.5	0.6	3.4	133.6
2029	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Middle Powder River	357	301.4	0.0	100.3	473.1	0.0	301.4	0.0	0.0	217.0
2029	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	Upper Belle Fourche River	429	237.2	0.0	451.4	0.0	0.2	237.0	0.0	0.0	170.8
2029	Upper Cheyenne River	38	3.8	0.0	7.3	0.0	0.0	1.6	2.2	0.0	1.2
2029	Upper Powder River	3723	4,536.1	70.4	6,676.4	1,883.5	68.0	4,390.9	9.1	68.0	3,210.5
2029	Upper Tongue River	1728	3,945.6	0.0	6,188.4	1,318.4	3,156.5	647.1	63.1	78.9	3,004.8
2030	Antelope Creek	341	584.4	0.0	140.4	971.5	0.0	584.4	0.0	0.0	420.8
2030	Clear Creek	1710	4,350.9	1,142.4	1,778.6	5,357.0	3,959.3	0.0	0.0	391.6	3,167.4
2030	Crazy Woman Creek	1250	3,315.0	77.4	2,157.0	4,072.6	1,909.4	474.0	0.0	931.5	1,859.1
2030	Dry Fork Cheyenne River	97	348.9	0.0	0.0	663.8	0.0	348.9	0.0	0.0	251.2
2030	Lightning Creek	41	204.0	0.0	0.0	388.1	0.0	204.0	0.0	0.0	146.9
2030	Little Bighorn River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Little Missouri River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Little Powder River	171	227.4	0.0	279.8	152.8	7.3	215.3	0.7	4.1	160.3
2030	Middle Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Middle North Platte River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Middle Powder River	301	177.2	0.0	60.7	276.4	0.0	177.2	0.0	0.0	127.6
2030	North Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Salt Creek	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	South Fork Powder River	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	Upper Belle Fourche River	359	185.9	0.0	353.8	0.0	0.2	185.8	0.0	0.0	133.9
2030	Upper Cheyenne River	8	1.6	0.0	3.0	0.0	0.0	0.7	0.9	0.0	0.5
2030	Upper Powder River	3236	3,604.0	54.1	5,338.5	1,464.3	54.1	3,488.6	7.2	54.1	2,550.8
2030	Upper Tongue River	1613	3,221.1	0.0	4,909.7	1,218.8	2,576.9	528.3	51.5	64.4	2,453.1

Footnotes and reference:

Footnote 1 - for GW Production and Disposal Columns: Based on Task 2 data (AECOM 2011a).

Footnote 2 - for GW Production column: Groundwater production by coal zone for 2003-2008 based on the actual total groundwater pumpage volume and the percent allocation rates per coal zone as identified in Appendix D of the Task 2 report (AECOM 2011a); 2009-2030 data based on Crockett (2011).

Footnote 3 - for Recharge Column: As discussed in the Groundwater Model Protocol (AECOM 2011b), the only CBNG-related discharges with potential to contribute recharge to the Wasatch (Layer 1) are the discharges to impoundments (on-channel and off-channel) and direct discharges to ephemeral drainages. CBNG-related recharge was calculated based on total discharge to impoundments and ephemeral drainages and the following subwatershed-specific recharge rates: 80 percent for Clear Creek, 78 percent for Crazy Woman Creek, 79 percent for Upper Tongue River, and 72 percent for all other subwatersheds.

Reference: Crockett, F. 2011. Projected CBNG water production data through 2030 provided by F. Crockett, Bureau of Land Management Reservoir Management Group, to M. Giere, AECOM. December 2011.

APPENDIX 2E

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

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:

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

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

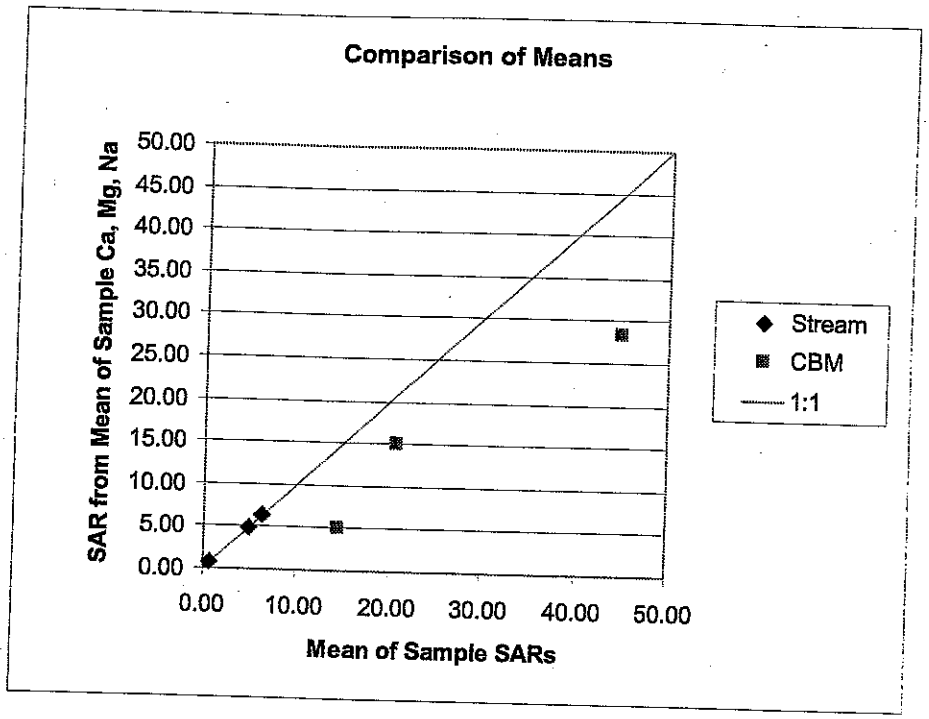


Figure A-1. Comparison of mean values of individual sample SARs and SARs estimated from mean values of sample Ca, Mg, and Na concentrations.

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

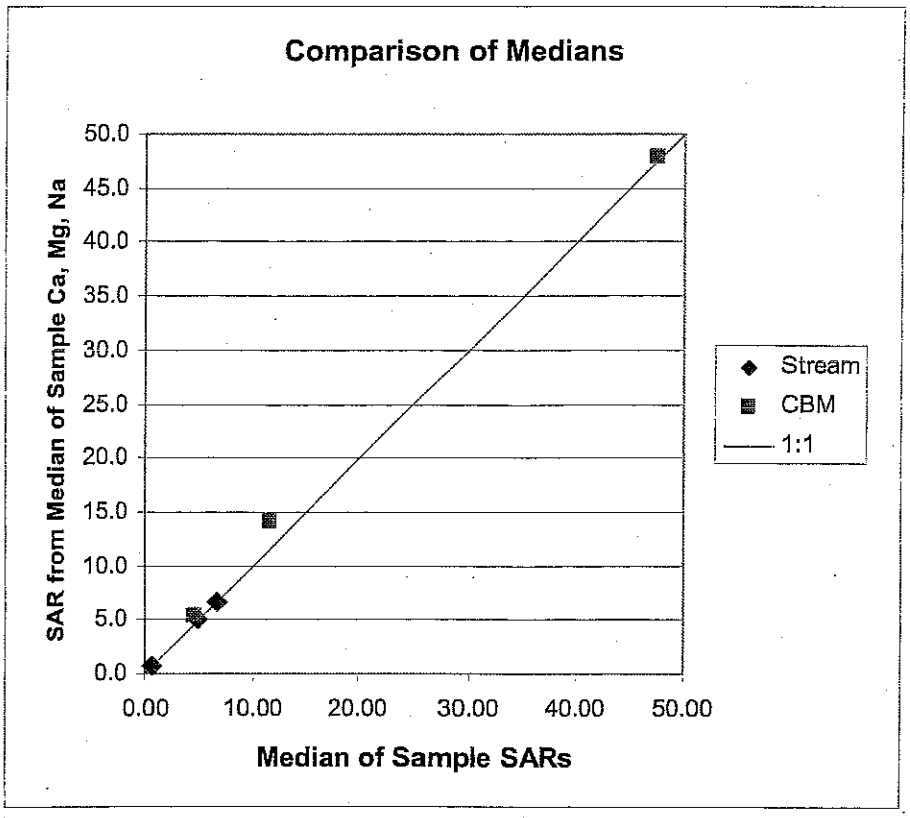


Figure A-2. Comparison of median values of sample SARs and SARs calculated from median values of sample Ca, Mg, and Na concentrations.

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

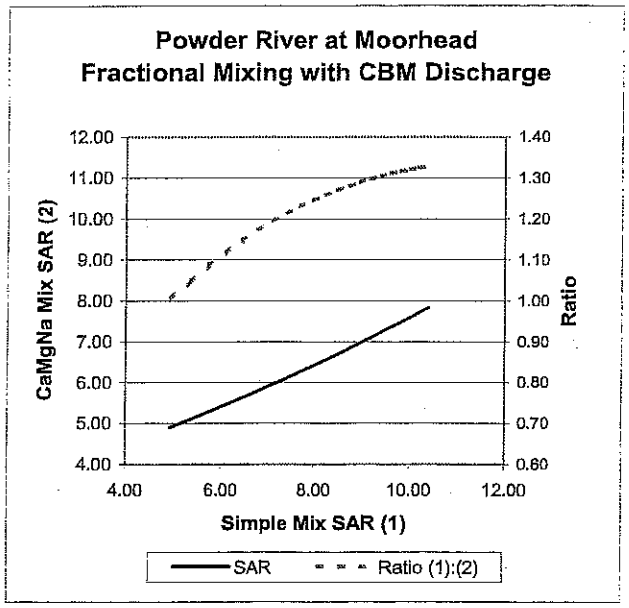


Figure A-3. Fractional mixing of stream water and CBM discharge. Comparison of SAR values calculated using (1) simple mixing as in equation [4] and (2) flow-weighted mixing of Ca, Mg, and Na as in equation [3].

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.*

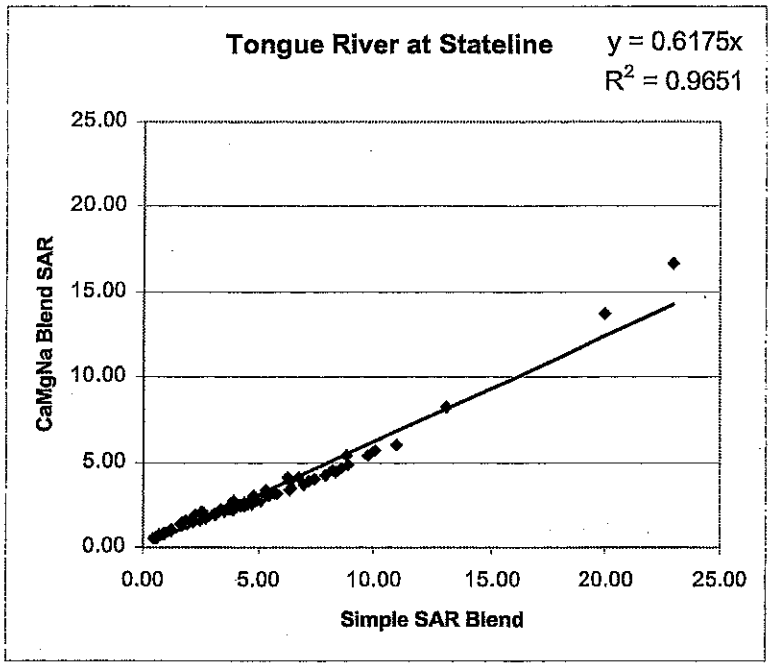


Figure 4. Tongue River at Stateline (USGS data) mixed with CX Ranch CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].

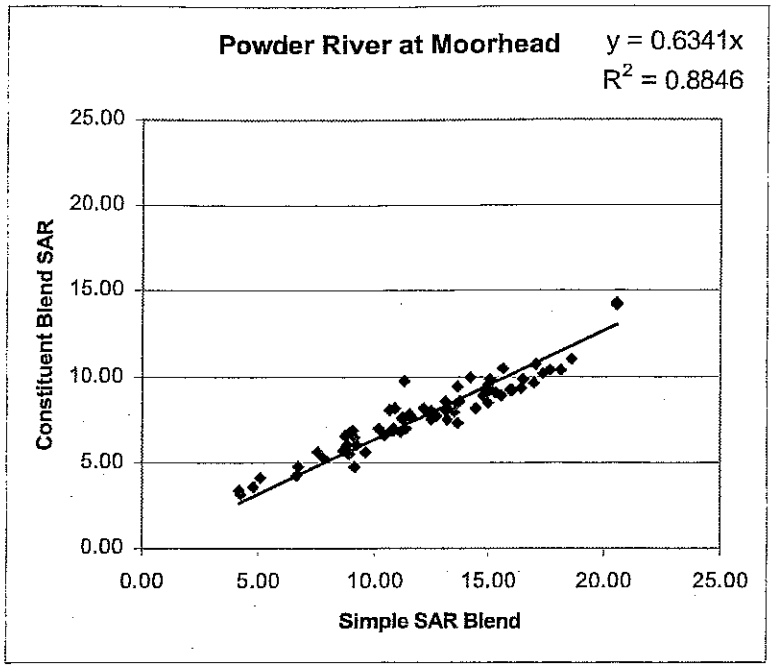


Figure 5. **Powder River at Moorhead (USGS data) mixed with Powder River Basin CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].**

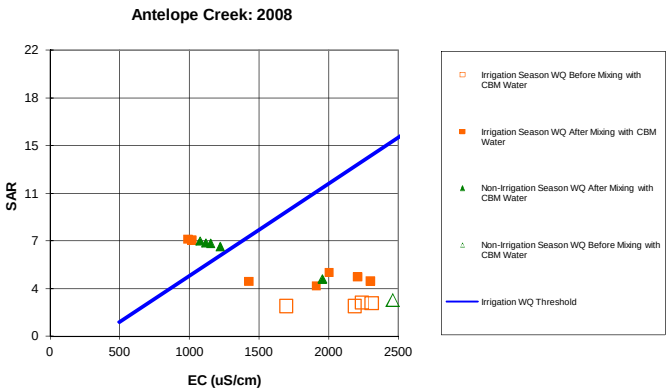
APPENDIX 3A

WATER QUALITY MODELING RESULTS DRY YEAR

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93



		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 (--)	Resulting stream Flow (CBM + Streamflow) (cfs)
Non-Irrigation Season	Nov	0.8	0.06	1067	1075	1084	7.11	7.34	7.57	2789	2.95	0.86
	Dec	0.8	0.10	1143	1152	1160	6.95	7.17	7.38	2841	2.98	0.90
	Jan	0.8	0.09	1108	1117	1125	6.98	7.20	7.42	2708	2.79	0.89
	Feb	0.8	0.15	1211	1219	1227	6.70	6.91	7.12	2684	2.82	0.95
	Mar	0.8	1.60	1950	1953	1957	4.34	4.43	4.51	2459	2.80	2.40
Irrigation Season	Apr	0.8	1.66	2202	2205	2208	4.51	4.59	4.67	2814	3.11	2.46
	May	0.8	2.70	2294	2297	2299	4.22	4.28	4.33	2698	3.27	3.50
	Jun	0.8	1.23	1998	2002	2005	4.83	4.92	5.02	2689	3.13	2.03
	Jul	0.8	2.37	1908	1910	1913	3.83	3.89	3.95	2238	2.61	3.17
	Aug	0.8	1.45	1423	1426	1429	4.16	4.25	4.33	1693	2.35	2.25
	Sep	0.8	0.03	978	987	996	7.25	7.49	7.73	2185	2.35	0.83
	Oct	0.8	0.05	1007	1016	1024	7.18	7.41	7.64	2307	2.57	0.85

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	2.52	70%	0.8	0.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2.8	31	0.05
Nov	3.7	30	0.06
Dec	6.1	31	0.10
Jan	5.4	31	0.09
Feb	8.4	28	0.15
Mar	98.5	31	1.60
Apr	98.8	30	1.66
May	166.1	31	2.70
Jun	73.4	30	1.23
Jul	145.5	31	2.37
Aug	89.2	31	1.45
Sep	1.8	30	0.03

Irrigation Suitability Threshold Analysis

Nov	5.16	Exceeded
Dec	5.70	Exceeded
Jan	5.45	Exceeded
Feb	6.18	Exceeded
Mar	11.39	
Apr	13.18	
May	13.83	
Jun	11.74	
Jul	11.09	
Aug	7.65	
Sep	4.53	Exceeded
Oct	4.74	Exceeded

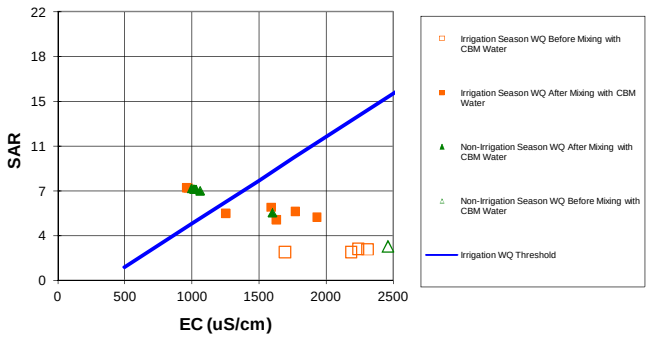
Irrigation WQ Threshold Line	
EC	SAR
500	1.07
1000	4.62
1500	8.17
2990	18.75

6364700 2020

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Antelope Creek: 2020



Antelope Creek

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows

(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	2.1	0.06	986	995	1004	7.31	7.55	7.79	2789	2.95	2.16
	Dec	2.1	0.10	1019	1028	1037	7.24	7.47	7.71	2841	2.98	2.20
	Jan	2.1	0.09	1004	1013	1022	7.25	7.49	7.72	2708	2.79	2.19
	Feb	2.1	0.15	1050	1059	1068	7.13	7.36	7.59	2684	2.82	2.25
	Mar	2.1	1.60	1593	1598	1604	5.43	5.57	5.71	2459	2.80	3.70
Irrigation Season	Apr	2.1	1.66	1763	1769	1774	5.53	5.66	5.80	2814	3.11	3.76
	May	2.1	2.70	1926	1930	1934	5.09	5.20	5.31	2698	3.27	4.80
	Jun	2.1	1.23	1583	1589	1594	5.85	6.00	6.16	2689	3.13	3.33
	Jul	2.1	2.37	1624	1628	1633	4.88	5.00	5.11	2238	2.61	4.47
	Aug	2.1	1.45	1243	1249	1254	5.36	5.50	5.65	1693	2.35	3.55
	Sep	2.1	0.03	950	960	969	7.37	7.61	7.85	2185	2.35	2.13
	Oct	2.1	0.05	962	971	980	7.34	7.58	7.82	2307	2.57	2.15

[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	7.1	70%	2.1	2.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2.80	31	0.05
Nov	3.70	30	0.06
Dec	6.10	31	0.10
Jan	5.40	31	0.09
Feb	8.40	28	0.15
Mar	98.50	31	1.60
Apr	98.80	30	1.66
May	166.10	31	2.70
Jun	73.40	30	1.23
Jul	145.50	31	2.37
Aug	89.20	31	1.45
Sep	1.80	30	0.03

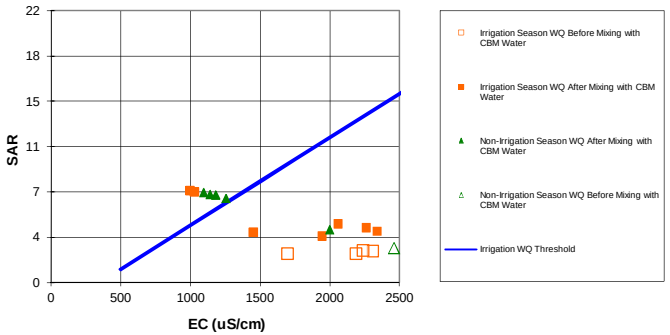
Irrigation Suitability Threshold Analysis

Nov	4.59	Exceeded
Dec	4.82	Exceeded
Jan	4.72	Exceeded
Feb	5.04	Exceeded
Mar	8.87	
Apr	10.08	
May	11.23	
Jun	8.80	
Jul	9.09	
Aug	6.39	
Sep	4.34	Exceeded
Oct	4.42	Exceeded

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

Antelope Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	0.7	0.06	1084	1093	1101	7.07	7.30	7.52	2789	2.95	0.76
	Dec	0.7	0.10	1170	1178	1186	6.89	7.10	7.32	2841	2.98	0.80
	Jan	0.7	0.09	1131	1139	1147	6.92	7.14	7.36	2708	2.79	0.79
	Feb	0.7	0.15	1244	1252	1259	6.62	6.82	7.02	2684	2.82	0.85
	Mar	0.7	1.60	1995	1997	2000	4.21	4.29	4.36	2459	2.80	2.30
Irrigation Season	Apr	0.7	1.66	2256	2259	2262	4.39	4.46	4.54	2814	3.11	2.36
	May	0.7	2.70	2334	2336	2338	4.12	4.18	4.23	2698	3.27	3.40
	Jun	0.7	1.23	2053	2057	2060	4.69	4.78	4.87	2689	3.13	1.93
	Jul	0.7	2.37	1940	1942	1944	3.71	3.77	3.82	2238	2.61	3.07
	Aug	0.7	1.45	1445	1448	1452	4.01	4.09	4.17	1693	2.35	2.15
	Sep	0.7	0.03	985	994	1003	7.23	7.46	7.70	2185	2.35	0.73
	Oct	0.7	0.05	1017	1025	1034	7.14	7.37	7.60	2307	2.57	0.75

[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)
Antelope	Antelope Creek near Teckla, WY	2.5	70%	0.7	0.7

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2.8	31	0.05
Nov	3.7	30	0.06
Dec	6.1	31	0.10
Jan	5.4	31	0.09
Feb	8.4	28	0.15
Mar	98.5	31	1.60
Apr	98.8	30	1.66
May	166.1	31	2.70
Jun	73.4	30	1.23
Jul	145.5	31	2.37
Aug	89.2	31	1.45
Sep	1.8	30	0.03

Table of Plotting Positions for graph

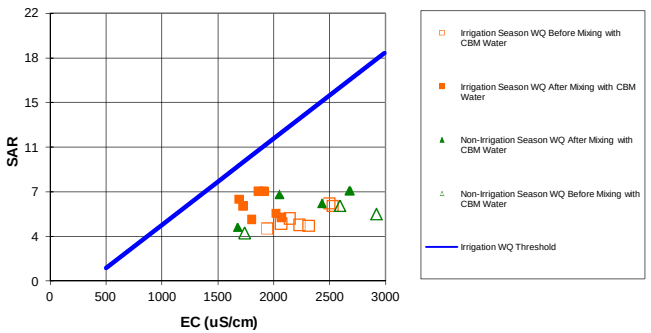
	Irrigation Suitability Threshold Analysis	
Nov	5.28	Exceeded
Dec	5.89	Exceeded
Jan	5.61	Exceeded
Feb	6.41	Exceeded
Mar	11.71	
Apr	13.56	
May	14.11	
Jun	12.13	
Jul	11.31	
Aug	7.81	
Sep	4.58	Exceeded
Oct	4.81	Exceeded

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Upper Belle Fourche River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow	StreamFlow	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
		(cfs)	(cfs)	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	3.0	5.28	2049	2050	2051	7.08	7.16	7.23	2592	6.21	8.28
	Dec	3.0	6.33	2680	2681	2682	7.38	7.44	7.51	3433	6.78	9.33
	Jan	3.0	5.30	2672	2674	2675	7.38	7.46	7.53	3567	6.68	8.30
	Feb	3.0	8.22	2428	2429	2430	6.36	6.41	6.47	2916	5.53	11.22
	Mar	3.0	28.39	1676	1677	1677	4.43	4.45	4.47	1738	3.98	31.39
Irrigation Season	Apr	3.0	17.97	2065	2066	2066	5.23	5.26	5.29	2228	4.67	20.97
	May	3.0	15.20	1801	1801	1802	5.06	5.09	5.13	1941	4.36	18.20
	Jun	3.0	9.51	2017	2018	2019	5.54	5.59	5.64	2310	4.57	12.51
	Jul	3.0	5.53	1722	1723	1724	6.12	6.19	6.26	2063	4.76	8.53
	Aug	3.0	3.91	1686	1687	1689	6.67	6.76	6.85	2142	5.17	6.91
	Sep	3.0	4.18	1909	1910	1912	7.34	7.42	7.51			
	Oct	3.0	3.45	1858	1860	1862	7.33	7.43	7.52			

[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	10.0	70%	3.0	3.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	212.2	31	3.45
Nov	314.1	30	5.28
Dec	389.1	31	6.33
Jan	325.9	31	5.30
Feb	456.5	28	8.22
Mar	1745.4	31	28.39
Apr	1069.2	30	17.97
May	934.8	31	15.20
Jun	565.6	30	9.51
Jul	340.2	31	5.53
Aug	240.3	31	3.91
Sep	248.6	30	4.18

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

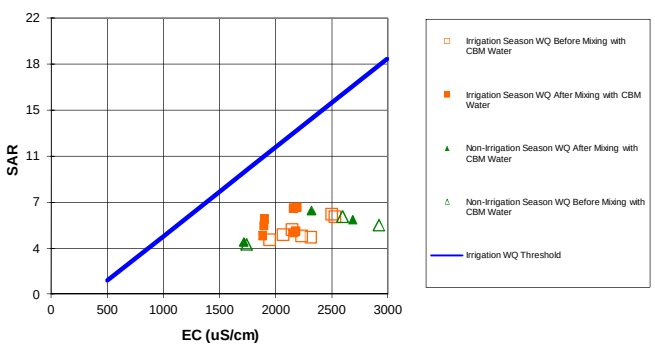
Nov	12.08	
Dec	16.56	
Jan	16.51	
Feb	14.77	
Mar	9.43	
	-2.48	Exceeded
Apr	12.19	
May	10.31	
Jun	11.85	
Jul	9.76	
Aug	9.50	
Sep	11.09	
Oct	10.73	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Upper Belle Fourche River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow	StreamFlow	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
		(cfs)	(cfs)	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	1.2	5.28	2314	2315	2316	6.66	6.69	6.73	2592	6.21	6.48
	Dec	1.2	6.33	3060	3061	3061	7.08	7.11	7.14	3433	6.78	7.53
	Jan	1.2	5.30	3110	3111	3111	7.04	7.08	7.12	3567	6.68	6.50
	Feb	1.2	8.22	2684	2684	2684	5.92	5.95	5.98	2916	5.53	9.42
	Mar	1.2	28.39	1712	1712	1712	4.17	4.18	4.19	1738	3.98	29.59
Irrigation Season	Apr	1.2	17.97	2157	2157	2157	4.91	4.93	4.94	2228	4.67	19.17
	May	1.2	15.20	1879	1879	1879	4.67	4.68	4.70	1941	4.36	16.40
	Jun	1.2	9.51	2173	2173	2174	5.03	5.05	5.07	2310	4.57	10.71
	Jul	1.2	5.53	1890	1891	1891	5.44	5.48	5.52	2063	4.76	6.73
	Aug	1.2	3.91	1895	1896	1897	5.98	6.03	6.08	2142	5.17	5.11
	Sep	1.2	4.18	2183	2183	2184	6.91	6.95	7.00	2496	6.41	5.38
	Oct	1.2	3.45	2155	2156	2157	6.83	6.88	6.94	2525	6.20	4.65

[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	4.0	70%	1.2	1.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	212.2	31	3.45
Nov	314.1	30	5.28
Dec	389.1	31	6.33
Jan	325.9	31	5.30
Feb	456.5	28	8.22
Mar	1745.4	31	28.39
Apr	1069.2	30	17.97
May	934.8	31	15.20
Jun	565.6	30	9.51
Jul	340.2	31	5.53
Aug	240.3	31	3.91
Sep	248.6	30	4.18

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

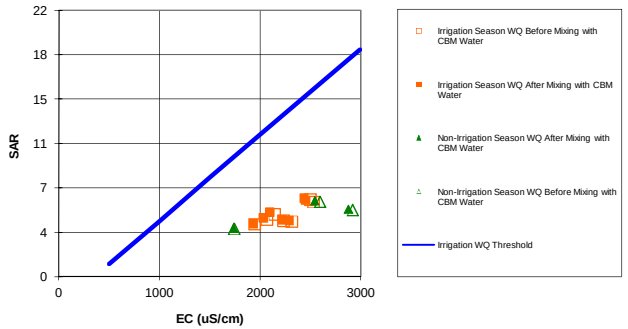
Nov	13.96	
Dec	19.26	
Jan	19.61	
Feb	16.58	
Mar	9.68	
	-2.48	Exceeded
Apr	12.84	
May	10.86	
Jun	12.96	
Jul	10.95	
Aug	10.98	
Sep	13.03	
Oct	12.83	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Upper Belle Fourche River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow	StreamFlow	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
		(cfs)	(cfs)	95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	0.2	5.28	2537	2538	2538	6.30	6.30	6.31	2592	6.21	5.48
	Dec	0.2	6.33	3362	3362	3362	6.84	6.85	6.85	3433	6.78	6.53
	Jan	0.2	5.30	3477	3477	3477	6.75	6.76	6.77	3567	6.68	5.50
	Feb	0.2	8.22	2873	2873	2873	5.60	5.61	5.61	2916	5.53	8.42
	Mar	0.2	28.39	1734	1734	1734	4.02	4.02	4.02	1738	3.98	28.59
Irrigation Season	Apr	0.2	17.97	2215	2216	2216	4.71	4.71	4.71	2228	4.67	18.17
	May	0.2	15.20	1930	1930	1930	4.41	4.42	4.42	1941	4.36	15.40
	Jun	0.2	9.51	2284	2284	2285	4.66	4.66	4.67	2310	4.57	9.71
	Jul	0.2	5.53	2029	2030	2030	4.89	4.90	4.90	2063	4.76	5.73
	Aug	0.2	3.91	2090	2091	2091	5.34	5.35	5.36	2142	5.17	4.11
	Sep	0.2	4.18	2432	2432	2432	6.51	6.52	6.53	2496	6.41	4.38
	Oct	0.2	3.45	2446	2446	2447	6.34	6.35	6.36	2525	6.20	3.65

[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	0.8	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	212.2	31	3.45
Nov	314.1	30	5.28
Dec	389.1	31	6.33
Jan	325.9	31	5.30
Feb	456.5	28	8.22
Mar	1745.4	31	28.39
Apr	1069.2	30	17.97
May	934.8	31	15.20
Jun	565.6	30	9.51
Jul	340.2	31	5.53
Aug	240.3	31	3.91
Sep	248.6	30	4.18

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	15.54	
Dec	21.39	
Jan	22.21	
Feb	17.92	
Mar	9.83	
	-2.48	Exceeded
Apr	13.25	
May	11.22	
Jun	13.74	
Jul	11.93	
Aug	12.37	
Sep	14.79	
Oct	14.89	

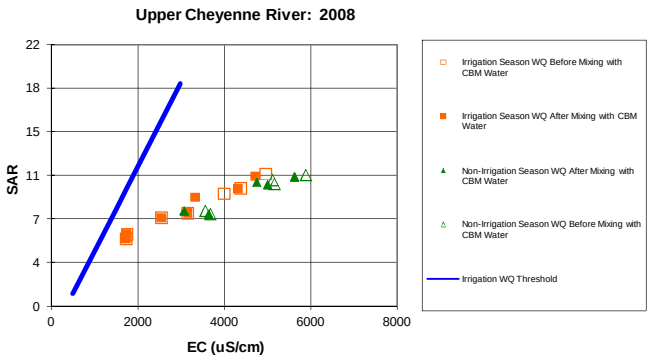
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
796	804	812	6.90	8.08	9.27



		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 SAR (--) 95% lower	Mixed SAR mean	Mixed SAR 95% upper	Background Water Quality EC (uS/cm)	Background SAR (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.1	2.69	5001	5002	5002	10.20	10.24	10.29	5158	10.32	2.79
	Dec	0.1	1.86	5624	5625	5625	10.84	10.90	10.96	5884	11.05	1.96
	Jan	0.1	1.08	4748	4749	4750	10.32	10.42	10.52	5113	10.64	1.18
	Feb	0.1	0.46	3067	3068	3070	7.83	8.04	8.25	3558	8.03	0.56
	Mar	0.1	8.50	3641	3641	3641	7.76	7.77	7.79	3674	7.77	8.60
Irrigation Season	Apr	0.1	5.06	4307	4307	4307	9.88	9.90	9.93	4376	9.94	5.16
	May	0.1	43.63	3147	3147	3147	7.85	7.86	7.86	3152	7.86	43.73
	Jun	0.1	18.78	2534	2534	2534	7.45	7.46	7.47	2544	7.46	18.88
	Jul	0.1	4.71	1730	1730	1730	6.10	6.12	6.15	1749	6.08	4.81
	Aug	0.1	29.86	1719	1719	1719	5.69	5.70	5.70	1722	5.69	29.96
	Sep	0.1	0.37	3319	3321	3323	8.94	9.19	9.44	3993	9.49	0.47
	Oct	0.1	1.59	4707	4707	4708	10.90	10.97	11.04	4953	11.15	1.69

[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	0.4	70%	0.1	0.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	97.60	31	1.59
Nov	160.00	30	2.69
Dec	114.40	31	1.86
Jan	66.60	31	1.08
Feb	25.70	28	0.46
Mar	522.60	31	8.50
Apr	301.30	30	5.06
May	2682.80	31	43.63
Jun	1117.70	30	18.78
Jul	289.90	31	4.71
Aug	1836.00	31	29.86
Sep	22.30	30	0.37

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	33.04	
Dec	37.46	
Jan	31.24	
Feb	19.31	
Mar	23.37	
	-2.48	Exceeded
Apr	28.11	
May	19.87	
Jun	15.52	
Jul	9.81	
Aug	9.73	
Sep	21.10	
Oct	30.95	

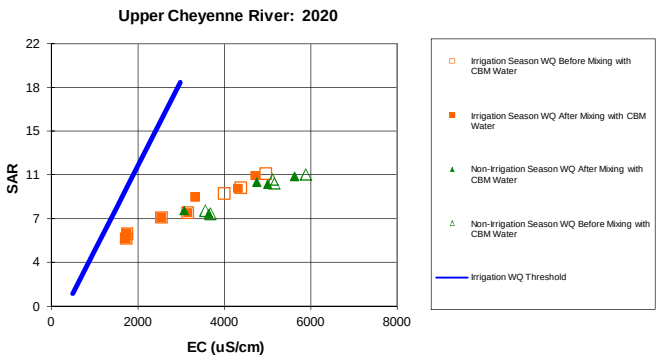
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
796	804	812	6.90	8.08	9.27



		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.1	2.69	5001	5002	5002	10.20	10.24	10.29	5158	10.32	2.79
	Dec	0.1	1.86	5624	5625	5625	10.84	10.90	10.96	5884	11.05	1.96
	Jan	0.1	1.08	4748	4749	4750	10.32	10.42	10.52	5113	10.64	1.18
	Feb	0.1	0.46	3067	3068	3070	7.83	8.04	8.25	3558	8.03	0.56
	Mar	0.1	8.50	3641	3641	3641	7.76	7.77	7.79	3674	7.77	8.60
Irrigation Season	Apr	0.1	5.06	4307	4307	4307	9.88	9.90	9.93	4376	9.94	5.16
	May	0.1	43.63	3147	3147	3147	7.85	7.86	7.86	3152	7.86	43.73
	Jun	0.1	18.78	2534	2534	2534	7.45	7.46	7.47	2544	7.46	18.88
	Jul	0.1	4.71	1730	1730	1730	6.10	6.12	6.15	1749	6.08	4.81
	Aug	0.1	29.86	1719	1719	1719	5.69	5.70	5.70	1722	5.69	29.96
	Sep	0.1	0.37	3319	3321	3323	8.94	9.19	9.44	3993	9.49	0.47
	Oct	0.1	1.59	4707	4707	4708	10.90	10.97	11.04	4953	11.15	1.69

[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	0.4	70%	0.1	0.1

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	97.60	31	1.59
Nov	160.00	30	2.69
Dec	114.40	31	1.86
Jan	66.60	31	1.08
Feb	25.70	28	0.46
Mar	522.60	31	8.50
Apr	301.30	30	5.06
May	2682.80	31	43.63
Jun	1117.70	30	18.78
Jul	289.90	31	4.71
Aug	1836.00	31	29.86
Sep	22.30	30	0.37

Irrigation Suitability Threshold Analysis

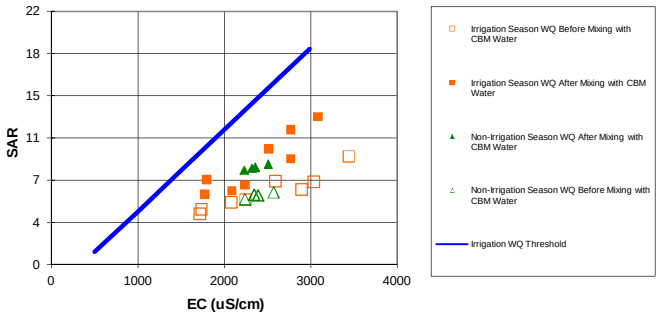
Nov	33.04	
Dec	37.46	
Jan	31.24	
Feb	19.31	
Mar	23.37	
	-2.48	Exceeded
Apr	28.11	
May	19.87	
Jun	15.52	
Jul	9.81	
Aug	9.73	
Sep	21.10	
Oct	30.95	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Upper Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	18.1	104.67	2318	2319	2321	8.32	8.39	8.46	2343	6.09	122.77
	Dec	18.1	95.70	2507	2508	2510	8.67	8.74	8.82	2570	6.29	113.80
	Jan	18.1	97.12	2354	2356	2358	8.41	8.49	8.56	2388	6.02	115.22
	Feb	18.1	96.63	2227	2229	2231	8.14	8.21	8.29	2237	5.69	114.73
Irrigation Season	Mar	18.1	273.40	2085	2086	2086	6.41	6.44	6.47	2079	5.43	291.50
	Apr	18.1	207.62	2238	2239	2240	6.91	6.95	6.99	2244	5.66	225.72
	May	18.1	213.47	1768	1769	1770	6.11	6.15	6.19	1734	4.83	231.57
	Jun	18.1	86.82	1793	1795	1797	7.33	7.41	7.50	1714	4.44	104.92
	Jul	18.1	84.60	2765	2767	2770	9.14	9.23	9.31	2893	6.56	102.70
	Aug	18.1	39.78	2764	2767	2771	11.59	11.75	11.90	3033	7.22	57.88
	Sep	18.1	45.75	3079	3082	3086	12.76	12.90	13.04	3438	9.42	63.85
	Oct	18.1	75.45	2509	2511	2513	9.97	10.07	10.16	2590	7.28	93.55

[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	60.3	70%	18.1	18.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4639.20	31	75.45
Nov	6228.10	30	104.67
Dec	5884.40	31	95.70
Jan	5971.50	31	97.12
Feb	5366.70	28	96.63
Mar	16810.70	31	273.40
Apr	12354.00	30	207.62
May	13125.60	31	213.47
Jun	5166.00	30	86.82
Jul	5201.90	31	84.60
Aug	2445.80	31	39.78
Sep	2722.40	30	45.75

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

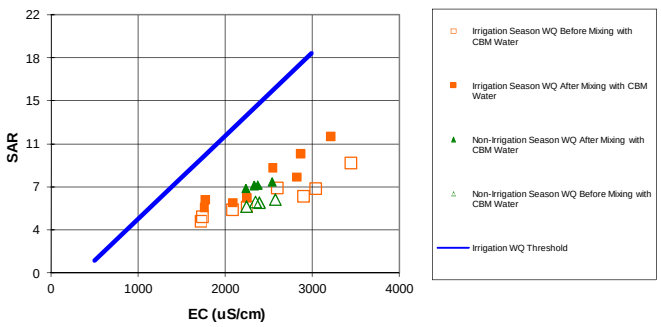
Nov	13.99	
Dec	15.33	
Jan	14.25	
Feb	13.35	
Mar	-2.48	Exceeded
	12.33	
Apr	13.42	
May	10.08	
Jun	10.27	
Jul	17.17	
Aug	17.17	
Sep	19.41	
Oct	15.35	

Irrigation WQ Threshold Line

500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Upper Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	10.3	104.67	2328	2329	2330	7.44	7.49	7.53	2343	6.09	114.97
	Dec	10.3	95.70	2531	2532	2534	7.74	7.79	7.84	2570	6.29	106.00
	Jan	10.3	97.12	2367	2368	2370	7.48	7.53	7.57	2388	6.02	107.42
	Feb	10.3	96.63	2231	2232	2233	7.18	7.23	7.28	2237	5.69	106.93
Irrigation Season	Mar	10.3	273.40	2082	2083	2083	6.00	6.02	6.04	2079	5.43	283.70
	Apr	10.3	207.62	2241	2241	2242	6.40	6.42	6.44	2244	5.66	217.92
	May	10.3	213.47	1754	1755	1755	5.58	5.61	5.63	1734	4.83	223.77
	Jun	10.3	86.82	1763	1764	1765	6.21	6.27	6.32	1714	4.44	97.12
	Jul	10.3	84.60	2814	2816	2817	8.15	8.20	8.26	2893	6.56	94.90
	Aug	10.3	39.78	2856	2858	2861	10.10	10.20	10.30	3033	7.22	50.08
	Sep	10.3	45.75	3206	3208	3210	11.59	11.68	11.77	3438	9.42	56.05
	Oct	10.3	75.45	2539	2541	2542	8.95	9.01	9.07	2590	7.28	85.75

[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 Powder	Upper Powder River	34.3	70%	10.3	10.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4639.2	31	75.45
Nov	6228.1	30	104.67
Dec	5884.4	31	95.70
Jan	5971.5	31	97.12
Feb	5366.7	28	96.63
Mar	16810.7	31	273.40
Apr	12354.0	30	207.62
May	13125.6	31	213.47
Jun	5166.0	30	86.82
Jul	5201.9	31	84.60
Aug	2445.8	31	39.78
Sep	2722.4	30	45.75

Table of Plotting Positions for graph

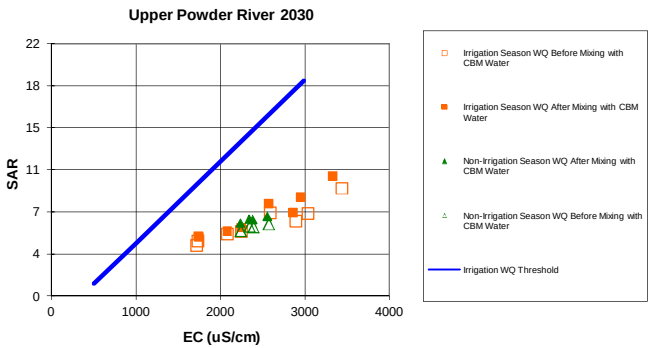
Irrigation Suitability Threshold Analysis

Nov	14.06	
Dec	15.50	
Jan	14.34	
Feb	13.37	
Mar	-2.48	Exceeded
	12.31	
Apr	13.44	
May	9.98	
Jun	10.05	
Jul	17.51	
Aug	17.82	
Sep	20.30	
Oct	15.56	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	4.4	104.67	2336	2337	2337	6.70	6.72	6.74	2343	6.09	109.07
	Dec	4.4	95.70	2552	2553	2553	6.95	6.97	6.99	2570	6.29	100.10
	Jan	4.4	97.12	2379	2379	2380	6.68	6.70	6.72	2388	6.02	101.52
	Feb	4.4	96.63	2235	2235	2236	6.36	6.39	6.41	2237	5.69	101.03
Irrigation Season	Mar	4.4	273.40	2081	2081	2081	5.68	5.69	5.69	2079	5.43	277.80
	Apr	4.4	207.62	2242	2243	2243	5.98	5.99	6.00	2244	5.66	212.02
	May	4.4	213.47	1743	1743	1743	5.16	5.17	5.18	1734	4.83	217.87
	Jun	4.4	86.82	1736	1737	1737	5.25	5.27	5.29	1714	4.44	91.22
	Jul	4.4	84.60	2857	2857	2858	7.28	7.31	7.33	2893	6.56	89.00
	Aug	4.4	39.78	2947	2949	2950	8.61	8.66	8.71	3033	7.22	44.18
	Sep	4.4	45.75	3327	3328	3329	10.46	10.50	10.54	3438	9.42	50.15
	Oct	4.4	75.45	2567	2567	2568	8.04	8.07	8.10	2590	7.28	79.85

[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	14.8	70%	4.4	4.4

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4639.20	31	75.45
Nov	6228.10	30	104.67
Dec	5884.40	31	95.70
Jan	5971.50	31	97.12
Feb	5366.70	28	96.63
Mar	16810.70	31	273.40
Apr	12354.00	30	207.62
May	13125.60	31	213.47
Jun	5166.00	30	86.82
Jul	5201.90	31	84.60
Aug	2445.80	31	39.78
Sep	2722.40	30	45.75

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

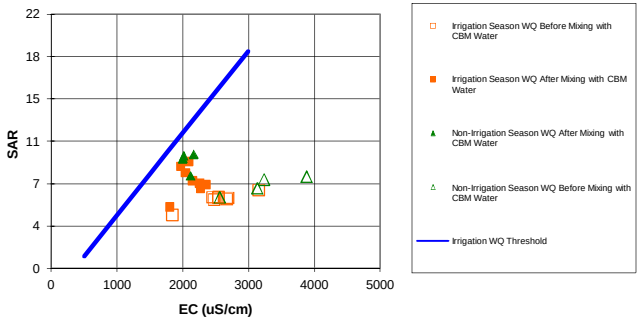
Nov	14.11	
Dec	15.65	
Jan	14.42	
Feb	13.39	
Mar	-2.48	Exceeded
	12.30	
Apr	13.45	
May	9.90	
Jun	9.86	
Jul	17.81	
Aug	18.46	
Sep	21.15	
Oct	15.75	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Little Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	2.9	1.31	1988	1993	1998	9.26	9.50	9.75	3125	6.95	4.21
	Dec	2.9	1.14	2153	2158	2164	9.64	9.89	10.15	3874	7.96	4.04
	Jan	2.9	1.26	2005	2010	2015	9.52	9.77	10.02	3229	7.71	4.16
	Feb	2.9	4.12	2110	2113	2115	7.88	8.02	8.17	2557	6.17	7.02
Irrigation Season	Mar	2.9	21.92	1793	1794	1795	5.31	5.35	5.40	1836	4.65	24.82
	Apr	2.9	7.83	2343	2345	2347	7.17	7.27	7.36	2664	6.01	10.73
	May	2.9	7.74	2248	2250	2252	7.31	7.41	7.51	2538	6.19	10.64
	Jun	2.9	3.18	2031	2034	2037	8.13	8.30	8.47	2537	6.15	6.08
	Jul	2.9	6.23	2139	2141	2143	7.49	7.60	7.71	2448	6.18	9.13
	Aug	2.9	10.78	2259	2261	2262	6.88	6.96	7.03	2470	5.96	13.68
	Sep	2.9	1.62	2075	2079	2084	9.04	9.27	9.50	3147	6.79	4.52
	Oct	2.9	1.92	1957	1961	1965	8.64	8.85	9.07	2684	6.13	4.82

[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	9.6	70%	2.9	2.9

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	118.10	31	1.92
Nov	77.80	30	1.31
Dec	70.30	31	1.14
Jan	77.20	31	1.26
Feb	228.60	28	4.12
Mar	1347.70	31	21.92
Apr	465.90	30	7.83
May	476.10	31	7.74
Jun	189.40	30	3.18
Jul	382.80	31	6.23
Aug	663.00	31	10.78
Sep	96.50	30	1.62

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

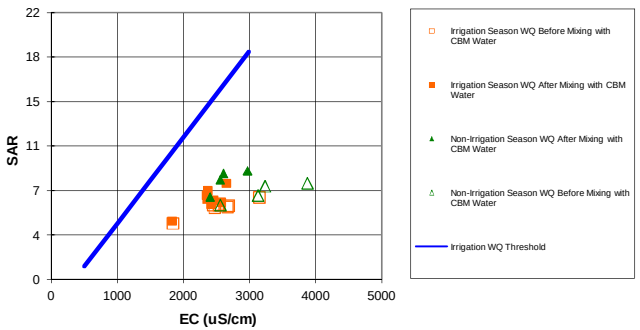
Nov	11.67	
Dec	12.85	
Jan	11.80	
Feb	12.52	
Mar	-2.48	Exceeded
	10.26	
Apr	14.17	
May	13.50	
Jun	11.97	
Jul	12.73	
Aug	13.58	
Sep	12.29	
Oct	11.45	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Little Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow	StreamFlow	EC (uS/cm)			SAR (--)			EC	SAR	
		(cfs)	(cfs)	95% lower	mean	95% upper	95% lower	mean	95% upper	(uS/cm)	(--)	(cfs)
Non-Irrigation Season	Nov	0.7	1.31	2550	2552	2555	8.12	8.24	8.37	3125	6.95	2.01
	Dec	0.7	1.14	2963	2966	2968	8.85	8.98	9.12	3874	7.96	1.84
	Jan	0.7	1.26	2601	2604	2606	8.64	8.76	8.89	3229	7.71	1.96
	Feb	0.7	4.12	2399	2401	2402	6.77	6.82	6.87	2557	6.17	4.82
Irrigation Season	Mar	0.7	21.92	1824	1825	1825	4.83	4.84	4.85	1836	4.65	22.62
	Apr	0.7	7.83	2567	2567	2568	6.36	6.39	6.42	2664	6.01	8.53
	May	0.7	7.74	2450	2450	2451	6.53	6.56	6.59	2538	6.19	8.44
	Jun	0.7	3.18	2345	2347	2348	6.90	6.96	7.03	2537	6.15	3.88
	Jul	0.7	6.23	2350	2350	2351	6.59	6.63	6.67	2448	6.18	6.93
	Aug	0.7	10.78	2409	2410	2410	6.23	6.25	6.27	2470	5.96	11.48
	Sep	0.7	1.62	2643	2645	2647	7.85	7.96	8.06	3147	6.79	2.32
	Oct	0.7	1.92	2361	2363	2365	7.24	7.34	7.43	2684	6.13	2.62

[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	2.2	70%	0.7	0.7

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	118.10	31	1.92
Nov	77.80	30	1.31
Dec	70.30	31	1.14
Jan	77.20	31	1.26
Feb	228.60	28	4.12
Mar	1347.70	31	21.92
Apr	465.90	30	7.83
May	476.10	31	7.74
Jun	189.40	30	3.18
Jul	382.80	31	6.23
Aug	663.00	31	10.78
Sep	96.50	30	1.62

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

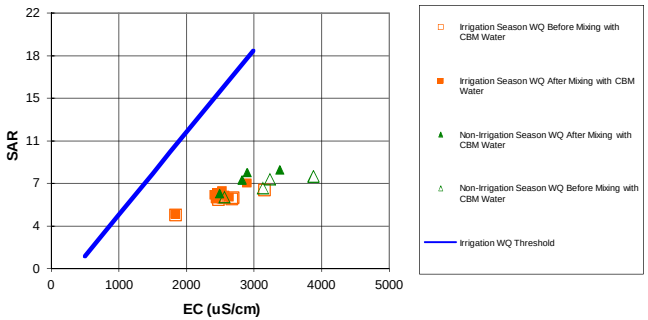
Nov	15.64	
Dec	18.58	
Jan	16.01	
Feb	14.57	
Mar	-2.48	Exceeded
	10.48	
Apr	15.75	
May	14.92	
Jun	14.19	
Jul	14.21	
Aug	14.63	
Sep	16.31	
Oct	14.30	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Little Powder River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.3	1.31	2817	2818	2820	7.57	7.64	7.71	3125	6.95	1.61
	Dec	0.3	1.14	3375	3377	3378	8.45	8.52	8.59	3874	7.96	1.44
	Jan	0.3	1.26	2891	2892	2894	8.21	8.28	8.35	3229	7.71	1.56
	Feb	0.3	4.12	2483	2484	2484	6.45	6.47	6.50	2557	6.17	4.42
Irrigation Season	Mar	0.3	21.92	1831	1831	1831	4.73	4.73	4.74	1836	4.65	22.22
	Apr	0.3	7.83	2620	2621	2621	6.17	6.18	6.20	2664	6.01	8.13
	May	0.3	7.74	2498	2499	2499	6.35	6.36	6.37	2538	6.19	8.04
	Jun	0.3	3.18	2445	2446	2446	6.51	6.54	6.57	2537	6.15	3.48
	Jul	0.3	6.23	2403	2404	2404	6.37	6.38	6.40	2448	6.18	6.53
	Aug	0.3	10.78	2443	2443	2444	6.08	6.09	6.10	2470	5.96	11.08
	Sep	0.3	1.62	2886	2887	2888	7.34	7.39	7.45	3147	6.79	1.92
	Oct	0.3	1.92	2521	2522	2523	6.69	6.74	6.79	2684	6.13	2.22

[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	0.9	70%	0.3	0.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	118.10	31	1.92
Nov	77.80	30	1.31
Dec	70.30	31	1.14
Jan	77.20	31	1.26
Feb	228.60	28	4.12
Mar	1347.70	31	21.92
Apr	465.90	30	7.83
May	476.10	31	7.74
Jun	189.40	30	3.18
Jul	382.80	31	6.23
Aug	663.00	31	10.78
Sep	96.50	30	1.62

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

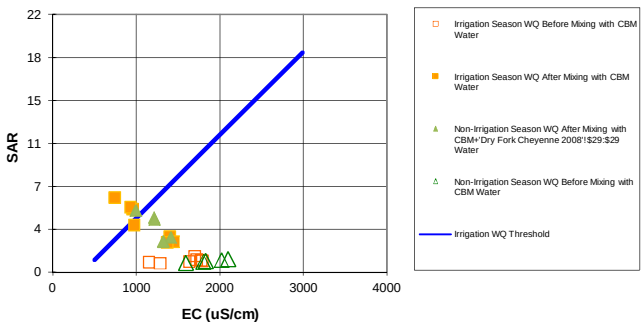
Nov	17.54	
Dec	21.50	
Jan	18.06	
Feb	15.16	
Mar	-2.48	Exceeded
	10.52	
Apr	16.13	
May	15.26	
Jun	14.89	
Jul	14.59	
Aug	14.87	
Sep	18.02	
Oct	15.43	

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Dry Fork Cheyenne River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--) Not Applicable			Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.1	0.06	1187	1212	1236	4.64	4.70	4.77	2098	1.14	0.16
	Dec	0.1	0.06	1193	1217	1240	4.47	4.53	4.59	2020	1.05	0.16
	Jan	0.1	0.03	964	993	1021	5.20	5.28	5.36	1830	0.98	0.13
	Feb	0.1	0.18	1398	1412	1426	2.95	2.99	3.02	1800	0.92	0.28
	Mar	0.1	0.22	1309	1321	1332	2.61	2.65	2.68	1592	0.82	
												0.00
Irrigation Season	Apr	0.1	0.17	1385	1399	1413	3.03	3.07	3.10	1788	1.00	0.27
	May	0.1	0.27	1439	1449	1460	2.60	2.63	2.66	1723	1.11	0.37
	Jun	0.1	0.25	1360	1371	1381	2.54	2.57	2.60	1632	0.92	0.35
	Jul	0.1	0.03	922	951	980	5.35	5.43	5.51	1699	1.40	0.13
	Aug	0.1	0.08	953	974	994	3.98	4.04	4.10	1285	0.80	0.18
	Sep	0.1	0.01	705	741	777	6.30	6.40	6.50	1150	0.90	0.11
	Oct	0.1	0.02	897	927	957	5.49	5.58	5.66	1775	1.05	0.12

[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)
Normal Fork Cheyenne	Dry Fork Cheyenne River	0.4	70%	0.1	0.1

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	1.500	31	0.02
Nov	3.300	30	0.06
Dec	3.800	31	0.06
Jan	2.000	31	0.03
Feb	9.900	28	0.18
Mar	13.600	31	0.22
Apr	10.400	30	0.17
May	16.400	31	0.27
Jun	14.800	30	0.25
Jul	1.900	31	0.03
Aug	5.000	31	0.08
Sep	0.300	30	0.01

Irrigation Suitability Threshold Analysis

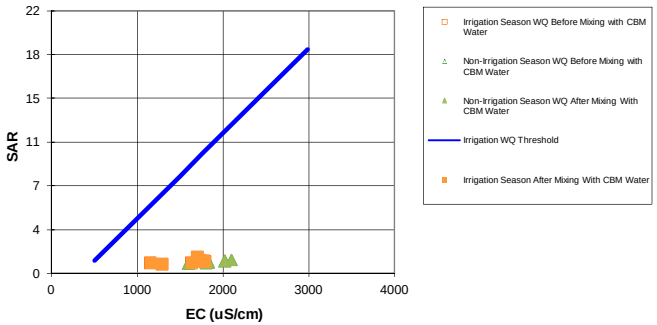
Nov	6.13	
Dec	6.16	
Jan	4.57	Exceeded
Feb	7.55	
Mar	6.90	
Apr	7.46	
May	7.81	
Jun	7.26	
Jul	4.28	Exceeded
Aug	4.44	
Sep	2.78	Exceeded
Oct	4.11	Exceeded

Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

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

Dry Fork Cheyenne River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.00	0.06	2098	2098	2098	1.14	1.14	1.14	2098	1.14	0.06
	Dec	0.00	0.06	2020	2020	2020	1.05	1.05	1.05	2020	1.05	0.06
	Jan	0.00	0.03	1830	1830	1830	0.98	0.98	0.98	1830	0.98	0.03
	Feb	0.00	0.18	1800	1800	1800	0.92	0.92	0.92	1800	0.92	0.18
	Mar	0.00	0.22	1592	1592	1592	0.82	0.82	0.82	1592	0.82	0.22
Irrigation Season	Apr	0.00	0.17	1788	1788	1788	1.00	1.00	1.00	1788	1.00	0.17
	May	0.00	0.27	1723	1723	1723	1.11	1.11	1.11	1723	1.11	0.27
	Jun	0.00	0.25	1632	1632	1632	0.92	0.92	0.92	1632	0.92	0.25
	Jul	0.00	0.03	1699	1699	1699	1.40	1.40	1.40	1699	1.40	0.03
	Aug	0.00	0.08	1285	1285	1285	0.80	0.80	0.80	1285	0.80	0.08
	Sep	0.00	0.01	1150	1150	1150	0.90	0.90	0.90	1150	0.90	0.01
	Oct	0.00	0.02	1775	1775	1775	1.05	1.05	1.05	1775	1.05	0.02

[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	70%	0.0	0.0

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	1.50	31	0.02
Nov	3.30	30	0.06
Dec	3.80	31	0.06
Jan	2.00	31	0.03
Feb	9.90	28	0.18
Mar	13.60	31	0.22
Apr	10.40	30	0.17
May	16.40	31	0.27
Jun	14.80	30	0.25
Jul	1.90	31	0.03
Aug	5.00	31	0.08
Sep	0.30	30	0.01

Irrigation Suitability Threshold Analysis

Nov	12.42	
Dec	11.87	
Jan	10.52	
Feb	10.30	
Mar	8.83	
	-2.48	Exceeded
Apr	10.22	
May	9.75	
Jun	9.11	
Jul	9.59	
Aug	6.65	
Sep	5.69	
Oct	10.13	

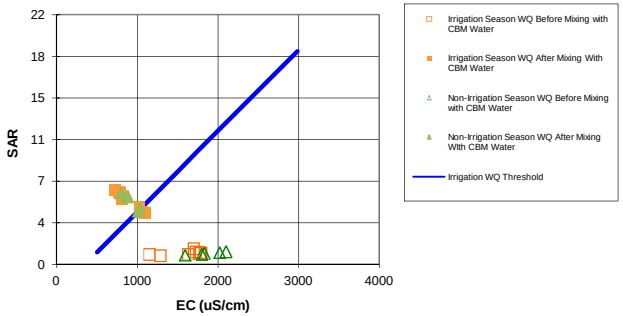
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Dry Fork Cheyenne River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.4	0.06	841	874	908	5.97	6.06	6.15	2098	1.14	0.50
	Dec	0.4	0.06	847	880	913	5.90	5.99	6.08	2020	1.05	0.50
	Jan	0.4	0.03	761	797	832	6.19	6.29	6.38	1830	0.98	0.47
	Feb	0.4	0.18	1005	1032	1058	4.94	5.02	5.09	1800	0.92	0.62
	Mar	0.4	0.22	987	1012	1037	4.65	4.72	4.79	1592	0.82	0.66
Irrigation Season	Apr	0.4	0.17	997	1024	1051	4.99	5.07	5.14	1788	1.00	0.61
	May	0.4	0.27	1075	1099	1122	4.51	4.58	4.64	1723	1.11	0.71
	Jun	0.4	0.25	1025	1050	1074	4.53	4.60	4.67	1632	0.92	0.69
	Jul	0.4	0.03	749	784	820	6.24	6.33	6.43	1699	1.40	0.47
	Aug	0.4	0.08	776	808	840	5.67	5.76	5.85	1285	0.80	0.52
	Sep	0.4	0.01	688	725	763	6.51	6.61	6.72	1150	0.90	0.45
	Oct	0.4	0.02	740	776	811	6.29	6.38	6.48	1775	1.05	0.46

[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)
Dry Fork Cheyenne	Dry Fork Cheyenne River	1.5	70%	0.4	0.4

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	1.50	31	0.02
Nov	3.30	30	0.06
Dec	3.80	31	0.06
Jan	2.00	31	0.03
Feb	9.90	28	0.18
Mar	13.60	31	0.22
Apr	10.40	30	0.17
May	16.40	31	0.27
Jun	14.80	30	0.25
Jul	1.90	31	0.03
Aug	5.00	31	0.08
Sep	0.30	30	0.01

Irrigation Suitability Threshold Analysis

Nov	3.73	Exceeded
Dec	3.77	Exceeded
Jan	3.18	Exceeded
Feb	4.85	Exceeded
Mar	4.71	Exceeded
	-2.48	Exceeded
Apr	4.79	Exceeded
May	5.32	
Jun	4.98	
Jul	3.09	Exceeded
Aug	3.26	Exceeded
Sep	2.67	Exceeded
Oct	3.03	Exceeded

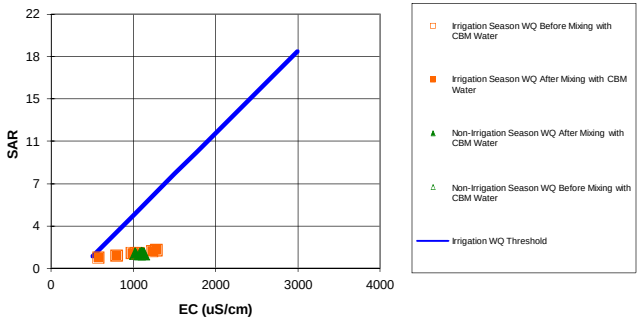
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.0	45.43	1122	1122	1122	1.27	1.27	1.27	1122	1.27	45.43
	Dec	0.0	35.05	1109	1109	1109	1.30	1.30	1.30	1109	1.30	35.05
	Jan	0.0	37.38	1074	1074	1074	1.29	1.29	1.29	1074	1.29	37.38
	Feb	0.0	35.05	1092	1092	1092	1.35	1.35	1.35	1092	1.35	35.05
	Mar	0.0	35.05	1018	1018	1018	1.30	1.30	1.30	1018	1.30	35.05
Irrigation Season	Apr	0.0	57.36	1024	1024	1024	1.32	1.32	1.32	1024	1.32	57.36
	May	0.0	59.46	789	789	789	1.13	1.13	1.13	789	1.13	59.46
	Jun	0.0	60.17	568	568	568	0.96	0.96	0.96	568	0.96	60.17
	Jul	0.0	32.63	976	976	976	1.36	1.36	1.36	976	1.36	32.63
	Aug	0.0	19.16	1274	1274	1274	1.62	1.62	1.62	1274	1.62	19.16
	Sep	0.0	33.08	1221	1221	1221	1.51	1.51	1.51	1221	1.51	33.08
	Oct	0.0	43.18	1055	1055	1055	1.34	1.34	1.34	1055	1.34	43.18

[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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2655.1	31	43.18
Nov	2703.4	30	45.43
Dec	2154.9	31	35.05
Jan	2298.3	31	37.38
Feb	1946.7	28	35.05
Mar	2931.4	31	47.67
Apr	3412.9	30	57.36
May	3656.3	31	59.46
Jun	3580.2	30	60.17
Jul	2006.4	31	32.63
Aug	1178.1	31	19.16
Sep	1968.2	30	33.08

Irrigation Suitability Threshold Analysis

Nov	5.49	
Dec	5.40	
Jan	5.15	
Feb	5.28	
Mar	4.75	
	-2.48	Exceeded
Apr	4.80	
May	3.13	
Jun	1.55	
Jul	4.45	
Aug	6.57	
Sep	6.19	
Oct	5.01	

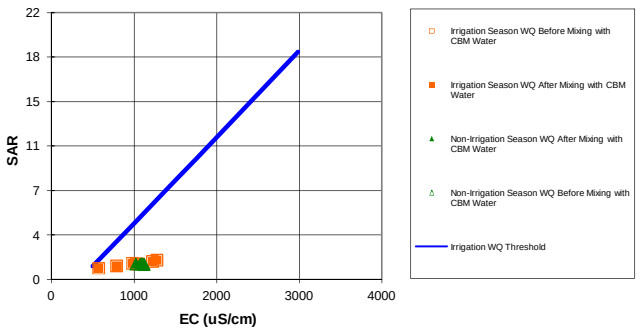
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2010



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.0	45.43	1122	1122	1122	1.27	1.27	1.27	1122	1.27	45.43
	Dec	0.0	35.05	1109	1109	1109	1.30	1.30	1.30	1109	1.30	35.05
	Jan	0.0	37.38	1074	1074	1074	1.29	1.29	1.29	1074	1.29	37.38
	Feb	0.0	35.05	1092	1092	1092	1.35	1.35	1.35	1092	1.35	35.05
	Mar	0.0	47.67	1018	1018	1018	1.30	1.30	1.30	1018	1.30	47.67
Irrigation Season	Apr	0.0	57.36	1024	1024	1024	1.32	1.32	1.32	1024	1.32	57.36
	May	0.0	59.46	789	789	789	1.13	1.13	1.13	789	1.13	59.46
	Jun	0.0	60.17	568	568	568	0.96	0.96	0.96	568	0.96	60.17
	Jul	0.0	32.63	976	976	976	1.36	1.36	1.36	976	1.36	32.63
	Aug	0.0	19.16	1274	1274	1274	1.62	1.62	1.62	1274	1.62	19.16
	Sep	0.0	33.08	1221	1221	1221	1.51	1.51	1.51	1221	1.51	33.08
	Oct	0.0	43.18	1055	1055	1055	1.34	1.34	1.34	1055	1.34	43.18

[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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2655.1	31	43.18
Nov	2703.4	30	45.43
Dec	2154.9	31	35.05
Jan	2298.3	31	37.38
Feb	1946.7	28	35.05
Mar	2931.4	31	47.67
Apr	3412.9	30	57.36
May	3656.3	31	59.46
Jun	3580.2	30	60.17
Jul	2006.4	31	32.63
Aug	1178.1	31	19.16
Sep	1968.2	30	33.08

Irrigation Suitability Threshold Analysis

Nov	5.49	
Dec	5.40	
Jan	5.15	
Feb	5.28	
Mar	4.75	
	-2.48	Exceeded
Apr	4.80	
May	3.13	
Jun	1.55	
Jul	4.45	
Aug	6.57	
Sep	6.19	
Oct	5.01	

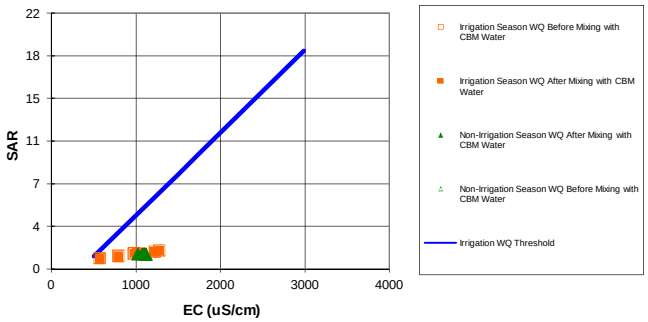
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.0	45.43	1122	1122	1122	1.27	1.27	1.27	1122	1.27	45.43
	Dec	0.0	35.05	1109	1109	1109	1.30	1.30	1.30	1109	1.30	35.05
	Jan	0.0	37.38	1074	1074	1074	1.29	1.29	1.29	1074	1.29	37.38
	Feb	0.0	35.05	1092	1092	1092	1.35	1.35	1.35	1092	1.35	35.05
	Mar	0.0	47.67	1018	1018	1018	1.30	1.30	1.30	1018	1.30	47.67
Irrigation Season	Apr	0.0	57.36	1024	1024	1024	1.32	1.32	1.32	1024	1.32	57.36
	May	0.0	59.46	789	789	789	1.13	1.13	1.13	789	1.13	59.46
	Jun	0.0	60.17	568	568	568	0.96	0.96	0.96	568	0.96	60.17
	Jul	0.0	32.63	976	976	976	1.36	1.36	1.36	976	1.36	32.63
	Aug	0.0	19.16	1274	1274	1274	1.62	1.62	1.62	1274	1.62	19.16
	Sep	0.0	33.08	1221	1221	1221	1.51	1.51	1.51	1221	1.51	33.08
	Oct	0.0	43.18	1055	1055	1055	1.34	1.34	1.34	1055	1.34	43.18

[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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	2655.1	31	43.18
Nov	2703.4	30	45.43
Dec	2154.9	31	35.05
Jan	2298.3	31	37.38
Feb	1946.7	28	35.05
Mar	2931.4	31	47.67
Apr	3412.9	30	57.36
May	3656.3	31	59.46
Jun	3580.2	30	60.17
Jul	2006.4	31	32.63
Aug	1178.1	31	19.16
Sep	1968.2	30	33.08

Irrigation Suitability Threshold Analysis

Nov	5.49	
Dec	5.40	
Jan	5.15	
Feb	5.28	
Mar	4.75	
	-2.48	Exceeded
Apr	4.80	
May	3.13	
Jun	1.55	
Jul	4.45	
Aug	6.57	
Sep	6.19	
Oct	5.01	

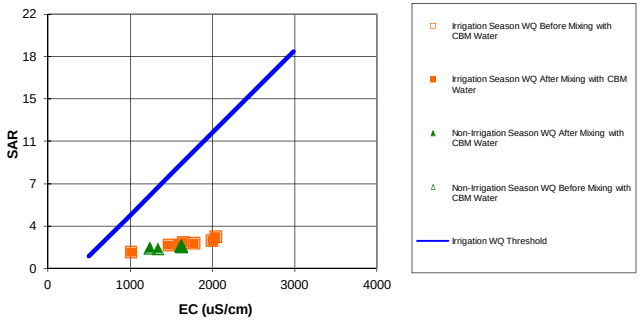
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.0	7.74	1621	1621	1621	2.00	2.00	2.00	1621	2.00	7.74
	Dec	0.0	8.99	1612	1612	1612	1.92	1.92	1.92	1612	1.92	8.99
	Jan	0.0	7.17	1623	1623	1623	1.86	1.86	1.86	1623	1.86	7.17
	Feb	0.0	9.73	1334	1334	1334	1.71	1.71	1.71	1334	1.71	9.73
	Mar	0.0	19.10	1234	1234	1234	1.76	1.76	1.76	1234	1.76	19.10
Irrigation Season	Apr	0.0	23.38	1641	1641	1641	2.28	2.28	2.28	1641	2.28	23.38
	May	0.0	60.96	1467	1467	1467	2.04	2.04	2.04	1467	2.04	60.96
	Jun	0.0	77.02	1007	1007	1007	1.43	1.43	1.43	1007	1.43	77.02
	Jul	0.0	22.42	1593	1593	1593	2.07	2.07	2.07	1593	2.07	22.42
	Aug	0.0	7.29	1774	1774	1774	2.20	2.20	2.20	1774	2.20	7.29
	Sep	0.0	2.49	2036	2036	2036	2.76	2.76	2.76	2036	2.76	2.49
	Oct	0.0	3.97	1994	1994	1994	2.42	2.42	2.42	1994	2.42	3.97

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)
Crazy Woman Creek	Crazy Woman Creek	0.1	70%	0.0	0.0

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	243.90	31	3.97
Nov	460.30	30	7.74
Dec	552.90	31	8.99
Jan	440.60	31	7.17
Feb	540.20	28	9.73
Mar	1174.40	31	19.10
Apr	1391.50	30	23.38
May	3748.40	31	60.96
Jun	4583.10	30	77.02
Jul	1378.80	31	22.42
Aug	448.00	31	7.29
Sep	147.90	30	2.49

Irrigation Suitability Threshold Analysis

Nov	9.03	
Dec	8.97	
Jan	9.05	
Feb	7.00	
Mar	6.28	
	-2.48	Exceeded
Apr	9.18	
May	7.94	
Jun	4.67	
Jul	8.84	
Aug	10.12	
Sep	11.98	
Oct	11.68	

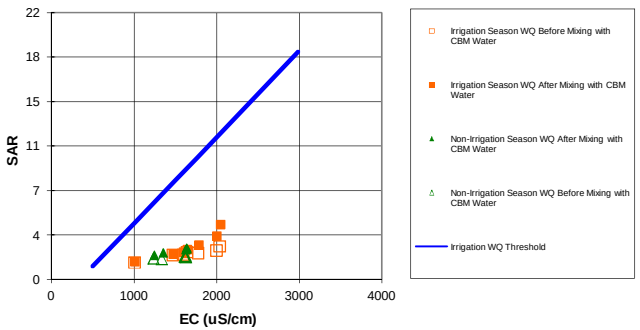
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.2	7.74	1629	1635	1642	2.56	2.63	2.70	1621	2.00	7.94
	Dec	0.2	8.99	1618	1624	1630	2.40	2.46	2.53	1612	1.92	9.19
	Jan	0.2	7.17	1631	1638	1645	2.47	2.55	2.62	1623	1.86	7.37
	Feb	0.2	9.73	1346	1351	1356	2.16	2.22	2.27	1334	1.71	9.93
	Mar	0.2	19.10	1241	1243	1246	2.00	2.02	2.05	1234	1.76	19.30
Irrigation Season	Apr	0.2	23.38	1644	1646	1648	2.47	2.49	2.51	1641	2.28	23.58
	May	0.2	60.96	1469	1470	1470	2.12	2.13	2.13	1467	2.04	61.16
	Jun	0.2	77.02	1009	1010	1010	1.49	1.50	1.51	1007	1.43	77.22
	Jul	0.2	22.42	1596	1599	1601	2.27	2.29	2.32	1593	2.07	22.62
	Aug	0.2	7.29	1778	1785	1792	2.79	2.87	2.94	1774	2.20	7.49
	Sep	0.2	2.49	2028	2047	2066	4.35	4.56	4.77	2036	2.76	2.69
	Oct	0.2	3.97	1990	2003	2015	3.46	3.60	3.73	1994	2.42	4.17

[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)
Crazy Woman Creek	Crazy Woman Creek	0.6	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	243.90	31	3.97
Nov	460.30	30	7.74
Dec	552.90	31	8.99
Jan	440.60	31	7.17
Feb	540.20	28	9.73
Mar	1174.40	31	19.10
Apr	1391.50	30	23.38
May	3748.40	31	60.96
Jun	4583.10	30	77.02
Jul	1378.80	31	22.42
Aug	448.00	31	7.29
Sep	147.90	30	2.49

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	9.13	
Dec	9.05	
Jan	9.15	
Feb	7.12	
Mar	6.35	
	-2.48	Exceeded
Apr	9.21	
May	7.96	
Jun	4.69	
Jul	8.87	
Aug	10.20	
Sep	12.06	
Oct	11.74	

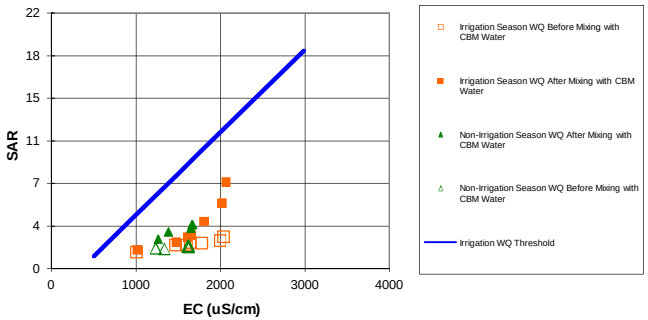
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.6	7.74	1643	1661	1680	3.60	3.80	4.00	1621	2.00	8.34
	Dec	0.6	8.99	1631	1647	1663	3.31	3.49	3.66	1612	1.92	9.59
	Jan	0.6	7.17	1646	1666	1686	3.59	3.80	4.02	1623	1.86	7.77
	Feb	0.6	9.73	1368	1383	1398	3.01	3.18	3.34	1334	1.71	10.33
	Mar	0.6	19.10	1255	1262	1270	2.45	2.53	2.62	1234	1.76	19.70
Irrigation Season	Apr	0.6	23.38	1648	1655	1661	2.83	2.90	2.97	1641	2.28	23.98
	May	0.6	60.96	1472	1474	1477	2.26	2.29	2.31	1467	2.04	61.56
	Jun	0.6	77.02	1014	1016	1018	1.61	1.63	1.65	1007	1.43	77.62
	Jul	0.6	22.42	1602	1609	1615	2.65	2.72	2.79	1593	2.07	23.02
	Aug	0.6	7.29	1785	1805	1825	3.88	4.09	4.30	1774	2.20	7.89
	Sep	0.6	2.49	2014	2064	2114	6.92	7.47	8.01	2036	2.76	3.09
	Oct	0.6	3.97	1984	2018	2052	5.28	5.64	6.01	1994	2.42	4.57

[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)
Crazy Woman Creek	Crazy Woman Creek	2.0	70%	0.6	0.6

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	243.90	31	3.97
Nov	460.30	30	7.74
Dec	552.90	31	8.99
Jan	440.60	31	7.17
Feb	540.20	28	9.73
Mar	1174.40	31	19.10
Apr	1391.50	30	23.38
May	3748.40	31	60.96
Jun	4583.10	30	77.02
Jul	1378.80	31	22.42
Aug	448.00	31	7.29
Sep	147.90	30	2.49

Irrigation Suitability Threshold Analysis

Nov	9.32	
Dec	9.22	
Jan	9.35	
Feb	7.34	
Mar	6.49	
	-2.48	Exceeded
Apr	9.27	
May	7.99	
Jun	4.74	
Jul	8.95	
Aug	10.34	
Sep	12.18	
Oct	11.85	

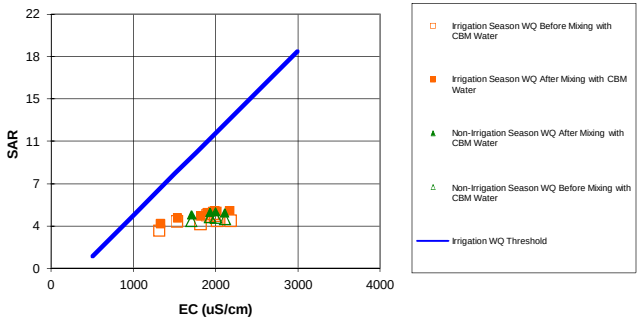
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	3.0	167.68	1924	1925	1925	4.82	4.87	4.91	1925	4.46	170.68
	Dec	3.0	130.43	2104	2104	2105	4.77	4.82	4.88	2108	4.30	133.43
	Jan	3.0	141.52	1993	1993	1994	4.87	4.93	4.98	1995	4.44	144.52
	Feb	3.0	137.62	1703	1703	1703	4.60	4.65	4.70	1698	4.15	140.62
Irrigation Season	Mar	3.0	321.20	1891	1891	1891	4.81	4.83	4.86	1891	4.62	324.20
	Apr	3.0	291.35	1961	1961	1961	4.94	4.97	4.99	1961	4.73	294.35
	May	3.0	230.33	1529	1530	1530	4.37	4.41	4.44	1524	4.10	233.33
	Jun	3.0	117.18	1323	1323	1324	3.84	3.90	3.96	1308	3.29	120.18
	Jul	3.0	96.50	1810	1811	1811	4.50	4.57	4.65	1807	3.85	99.50
	Aug	3.0	77.09	2165	2166	2167	4.95	5.04	5.14	2175	4.16	80.09
	Sep	3.0	80.04	2009	2010	2010	4.89	4.98	5.07	2013	4.13	83.04
	Oct	3.0	158.67	1984	1985	1985	4.97	5.02	5.07	1986	4.59	161.67

[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)
Middle Powder	Powder River at Moorhead	9.9	70%	3.0	3.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9756.00	31	158.67
Nov	9977.90	30	167.68
Dec	8020.00	31	130.43
Jan	8701.50	31	141.52
Feb	7643.10	28	137.62
Mar	19749.80	31	321.20
Apr	17336.50	30	291.35
May	14162.60	31	230.33
Jun	6972.90	30	117.18
Jul	5933.60	31	96.50
Aug	4740.10	31	77.09
Sep	4762.80	30	80.04

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	11.19	
Dec	12.46	
Jan	11.68	
Feb	9.62	
Mar	-2.48	Exceeded
	10.95	
Apr	11.45	
May	8.38	
Jun	6.92	
Jul	10.38	
Aug	12.90	
Sep	11.79	
Oct	11.62	

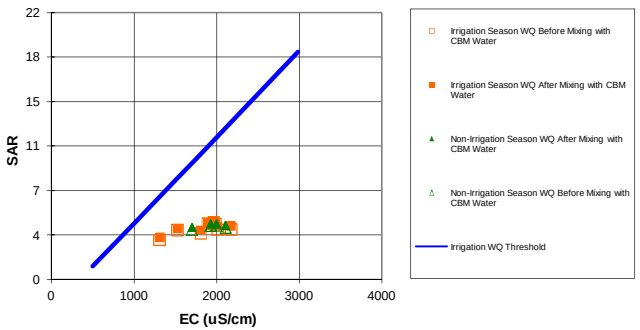
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	1.0	167.68	1925	1925	1925	4.58	4.60	4.61	1925	4.46	168.68
	Dec	1.0	130.43	2107	2107	2107	4.46	4.48	4.50	2108	4.30	131.43
	Jan	1.0	141.52	1994	1994	1994	4.59	4.61	4.62	1995	4.44	142.52
	Feb	1.0	137.62	1700	1700	1700	4.30	4.32	4.33	1698	4.15	138.62
Irrigation Season	Mar	1.0	321.20	1891	1891	1891	4.68	4.69	4.70	1891	4.62	322.20
	Apr	1.0	291.35	1961	1961	1961	4.80	4.81	4.82	1961	4.73	292.35
	May	1.0	230.33	1526	1526	1526	4.19	4.21	4.22	1524	4.10	231.33
	Jun	1.0	117.18	1313	1313	1313	3.48	3.50	3.52	1308	3.29	118.18
	Jul	1.0	96.50	1808	1808	1809	4.07	4.10	4.12	1807	3.85	97.50
	Aug	1.0	77.09	2172	2172	2172	4.43	4.46	4.49	2175	4.16	78.09
	Sep	1.0	80.04	2012	2012	2012	4.39	4.42	4.45	2013	4.13	81.04
	Oct	1.0	158.67	1985	1985	1986	4.72	4.73	4.75	1986	4.59	159.67

[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)
Middle Powder	Powder River at Moorhead	3.2	70%	1.0	1.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9756.0	31	158.67
Nov	9977.9	30	167.68
Dec	8020.0	31	130.43
Jan	8701.5	31	141.52
Feb	7643.1	28	137.62
Mar	19749.8	31	321.20
Apr	17336.5	30	291.35
May	14162.6	31	230.33
Jun	6972.9	30	117.18
Jul	5933.6	31	96.50
Aug	4740.1	31	77.09
Sep	4762.8	30	80.04

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	11.19	
Dec	12.48	
Jan	11.68	
Feb	9.59	
Mar	-2.48	Exceeded
	10.95	
Apr	11.45	
May	8.36	
Jun	6.85	
Jul	10.36	
Aug	12.95	
Sep	11.81	
Oct	11.62	

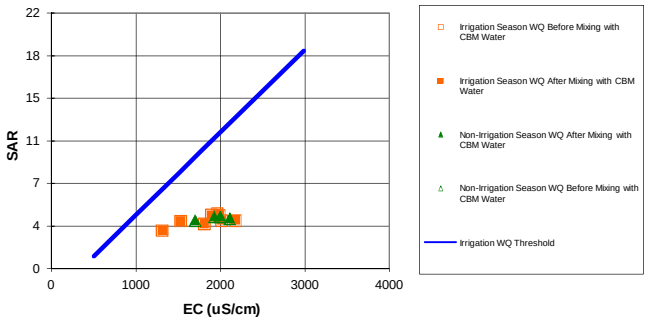
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.2	167.68	1925	1925	1925	4.48	4.49	4.49	1925	4.46	167.88
	Dec	0.2	130.43	2108	2108	2108	4.33	4.33	4.34	2108	4.30	130.63
	Jan	0.2	141.52	1994	1994	1995	4.47	4.47	4.48	1995	4.44	141.72
	Feb	0.2	137.62	1698	1699	1699	4.18	4.18	4.18	1698	4.15	137.82
	Mar	0.2	321.20	1891	1891	1891	4.63	4.63	4.64	1891	4.62	321.40
Irrigation Season	Apr	0.2	291.35	1961	1961	1961	4.75	4.75	4.75	1961	4.73	291.55
	May	0.2	230.33	1525	1525	1525	4.12	4.12	4.13	1524	4.10	230.53
	Jun	0.2	117.18	1309	1309	1309	3.33	3.33	3.34	1308	3.29	117.38
	Jul	0.2	96.50	1807	1807	1807	3.90	3.90	3.91	1807	3.85	96.70
	Aug	0.2	77.09	2174	2175	2175	4.21	4.22	4.23	2175	4.16	77.29
	Sep	0.2	80.04	2013	2013	2013	4.18	4.19	4.19	2013	4.13	80.24
	Oct	0.2	158.67	1986	1986	1986	4.62	4.62	4.62	1986	4.59	158.87

[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)
Middle Powder	Powder River at Moorhead	0.8	70%	0.2	0.2

Table of Plotting Positions for graph

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9756.00	31	158.67
Nov	9977.90	30	167.68
Dec	8020.00	31	130.43
Jan	8701.50	31	141.52
Feb	7643.10	28	137.62
Mar	19749.80	31	321.20
Apr	17336.50	30	291.35
May	14162.60	31	230.33
Jun	6972.90	30	117.18
Jul	5933.60	31	96.50
Aug	4740.10	31	77.09
Sep	4762.80	30	80.04

Irrigation Suitability Threshold Analysis

Nov	11.19	
Dec	12.49	
Jan	11.69	
Feb	9.58	
Mar	-2.48	Exceeded
	10.95	
Apr	11.45	
May	8.35	
Jun	6.82	
Jul	10.36	
Aug	12.96	
Sep	11.81	
Oct	11.62	

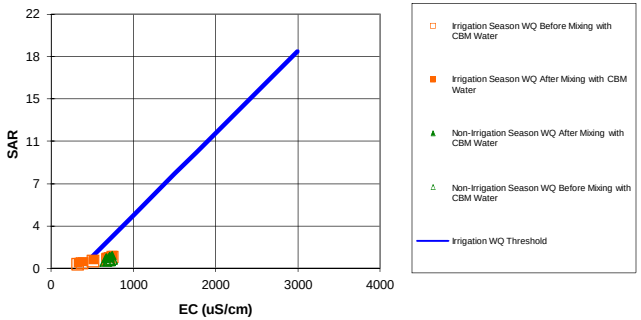
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.8	150.25	710	710	710	0.96	0.96	0.97	703	0.75	151.05
	Dec	0.8	138.72	700	700	700	0.97	0.98	0.98	693	0.75	139.52
	Jan	0.8	135.50	666	666	666	0.92	0.93	0.93	659	0.70	136.30
	Feb	0.8	128.79	705	705	705	1.03	1.03	1.04	697	0.79	129.59
	Mar	0.8	136.55	735	735	735	1.12	1.12	1.13	728	0.90	137.35
Irrigation Season	Apr	0.8	181.33	705	705	705	1.01	1.01	1.02	699	0.84	182.13
	May	0.8	232.53	373	373	373	0.60	0.61	0.61	368	0.47	233.33
	Jun	0.8	255.13	323	323	323	0.52	0.52	0.53	318	0.40	255.93
	Jul	0.8	288.17	508	508	508	0.77	0.78	0.78	504	0.67	288.97
	Aug	0.8	206.80	744	744	745	1.16	1.17	1.17	740	1.02	207.60
	Sep	0.8	142.32	689	689	689	1.03	1.04	1.04	682	0.82	143.12
	Oct	0.8	170.77	684	684	684	0.93	0.94	0.94	678	0.75	171.57

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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	2.7	70%	0.8	0.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10500.00	31	170.77
Nov	8940.50	30	150.25
Dec	8529.40	31	138.72
Jan	8331.60	31	135.50
Feb	7152.60	28	128.79
Mar	8396.10	31	136.55
Apr	10790.10	30	181.33
May	14297.90	31	232.53
Jun	15181.50	30	255.13
Jul	17718.70	31	288.17
Aug	12715.60	31	206.80
Sep	8468.40	30	142.32

Table of Plotting Positions for graph

Irrigation Suitability Threshold Analysis

Nov	2.52	
Dec	2.44	
Jan	2.20	
Feb	2.48	
Mar	2.69	
Apr	2.49	
May	0.14	Exceeded
Jun	-0.22	Exceeded
Jul	1.11	
Aug	2.78	
Sep	2.37	
Oct	2.34	

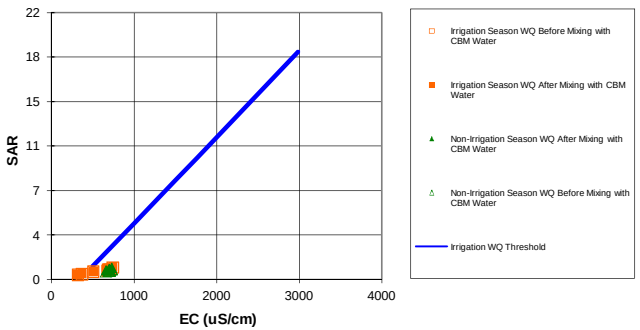
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		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 (--)	Resulting stream Flow (cfs)
Non-Irrigation Season	Nov	0.2	150.25	705	705	705	0.80	0.81	0.81	703	0.75	150.45
	Dec	0.2	138.72	695	695	695	0.80	0.81	0.81	693	0.75	138.92
	Jan	0.2	135.50	661	661	661	0.75	0.75	0.76	659	0.70	135.70
	Feb	0.2	128.79	699	699	699	0.85	0.85	0.85	697	0.79	128.99
	Mar	0.2	136.55	730	730	730	0.95	0.95	0.95	728	0.90	136.75
Irrigation Season	Apr	0.2	181.33	701	701	701	0.88	0.88	0.89	699	0.84	181.53
	May	0.2	232.53	369	369	369	0.50	0.51	0.51	368	0.47	232.73
	Jun	0.2	255.13	319	319	319	0.43	0.43	0.43	318	0.40	255.33
	Jul	0.2	288.17	505	505	505	0.69	0.69	0.70	504	0.67	288.37
	Aug	0.2	206.80	741	741	741	1.05	1.05	1.06	740	1.02	207.00
	Sep	0.2	142.32	684	684	684	0.87	0.87	0.88	682	0.82	142.52
	Oct	0.2	170.77	680	680	680	0.80	0.80	0.80	678	0.75	170.97

[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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	0.7	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10500.00	31	170.77
Nov	8940.50	30	150.25
Dec	8529.40	31	138.72
Jan	8331.60	31	135.50
Feb	7152.60	28	128.79
Mar	8396.10	31	136.55
Apr	10790.10	30	181.33
May	14297.90	31	232.53
Jun	15181.50	30	255.13
Jul	17718.70	31	288.17
Aug	12715.60	31	206.80
Sep	8468.40	30	142.32

Table of Plotting Positions for graph

	Irrigation Suitability Threshold Analysis	
Nov	2.53	
Dec	2.46	
Jan	2.22	
Feb	2.49	
Mar	2.71	
Apr	2.50	
May	0.15	Exceeded
Jun	-0.21	Exceeded
Jul	1.11	
Aug	2.79	
Sep	2.38	
Oct	2.35	

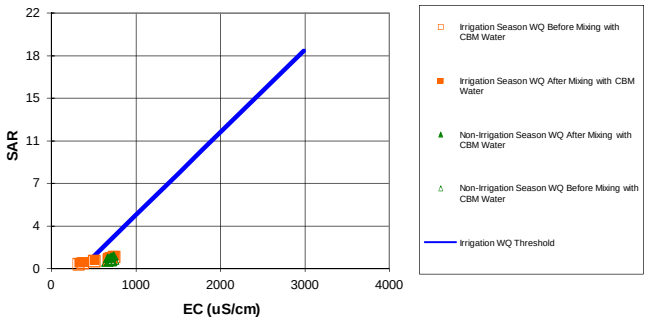
Irrigation WQ Threshold Line

EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream Flow
		CBM Flow	StreamFlow	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
		(cfs)	(cfs)	95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	0.7	150.25	709	709	709	0.93	0.94	0.94	703	0.75	150.95
	Dec	0.7	138.72	699	699	699	0.94	0.95	0.95	693	0.75	139.42
	Jan	0.7	135.50	665	665	665	0.89	0.90	0.90	659	0.70	136.20
	Feb	0.7	128.79	704	704	704	1.00	1.00	1.01	697	0.79	129.49
	Mar	0.7	136.55	734	734	734	1.09	1.10	1.10	728	0.90	137.25
Irrigation Season	Apr	0.7	181.33	704	704	704	0.99	0.99	1.00	699	0.84	182.03
	May	0.7	232.53	372	373	373	0.59	0.59	0.59	368	0.47	233.23
	Jun	0.7	255.13	322	322	322	0.51	0.51	0.51	318	0.40	255.83
	Jul	0.7	288.17	508	508	508	0.76	0.76	0.77	504	0.67	288.87
	Aug	0.7	206.80	744	744	744	1.15	1.15	1.15	740	1.02	207.50
	Sep	0.7	142.32	688	688	688	1.01	1.01	1.02	682	0.82	143.02
	Oct	0.7	170.77	683	683	683	0.91	0.92	0.92	678	0.75	171.47

[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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	2.2	70%	0.7	0.7

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10500.00	31	170.77
Nov	8940.50	30	150.25
Dec	8529.40	31	138.72
Jan	8331.60	31	135.50
Feb	7152.60	28	128.79
Mar	8396.10	31	136.55
Apr	10790.10	30	181.33
May	14297.90	31	232.53
Jun	15181.50	30	255.13
Jul	17718.70	31	288.17
Aug	12715.60	31	206.80
Sep	8468.40	30	142.32

Table of Plotting Positions for graph

Irrigation Threshold Suitability Analysis

Nov	2.56	
Dec	2.49	
Jan	2.25	
Feb	2.52	
Mar	2.74	
Apr	2.52	
May	0.17	Exceeded
Jun	-0.19	Exceeded
Jul	1.13	
Aug	2.81	
Sep	2.41	
Oct	2.38	

Irrigation WQ Threshold Line

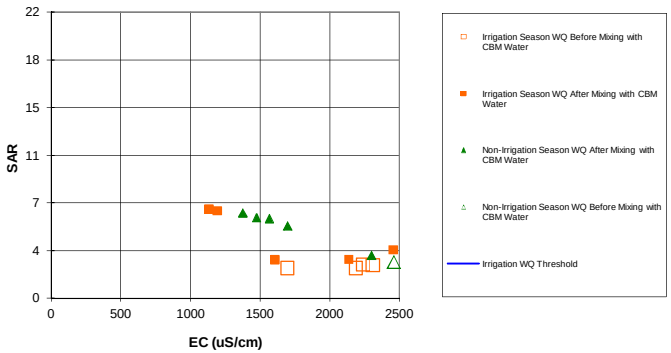
EC	SAR
500	1.0746
1000	4.62
1500	8.17
2990	18.75

APPENDIX 3A

WATER QUALITY MODELING RESULTS NORMAL YEAR

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

Antelope Creek: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93

		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 (--)	Resulting stream Flow (CBM (cfs)
Non-Irrigation Season	Nov	0.8	0.24	1367	1374	1381	6.39	6.58	6.77	2789	2.95	1.04
	Dec	0.8	0.39	1559	1565	1572	5.98	6.14	6.31	2841	2.98	1.19
	Jan	0.8	0.34	1466	1472	1479	6.04	6.21	6.39	2708	2.79	1.14
	Feb	0.8	0.61	1690	1696	1701	5.44	5.58	5.72	2684	2.82	1.41
	Mar	0.8	6.77	2297	2298	2299	3.29	3.32	3.34	2459	2.80	7.57
Irrigation Season	Apr	0.8	7.28	2628	2629	2630	3.54	3.56	3.58	2814	3.11	8.08
	May	0.8	9.86	2565	2566	2567	3.58	3.60	3.62	2698	3.27	10.66
	Jun	0.8	5.12	2452	2453	2454	3.71	3.75	3.78	2689	3.13	5.92
	Jul	0.8	9.30	2134	2135	2136	2.99	3.01	3.03	2238	2.61	10.10
	Aug	0.8	5.90	1602	1603	1604	2.96	2.99	3.02	1693	2.35	6.70
	Sep	0.8	0.14	1122	1130	1138	6.67	6.88	7.09	2185	2.35	0.94
	Oct	0.8	0.18	1182	1190	1197	6.55	6.76	6.96	2307	2.57	0.98

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	2.52	70%	0.8	0.8

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

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10.9	31	0.18
Nov	14.5	30	0.24
Dec	24.0	31	0.39
Jan	21.1	31	0.34
Feb	33.9	28	0.61
Mar	416.3	31	6.77
Apr	433.0	30	7.28
May	606.1	31	9.86
Jun	304.4	30	5.12
Jul	571.8	31	9.30
Aug	362.9	31	5.90
Sep	8.5	30	0.14

Irrigation Suitability Threshold Analysis		
Nov	7.28	Suitable
Dec	8.64	Suitable
Jan	7.98	Suitable
Feb	9.56	Suitable
Mar	13.84	Suitable
		Suitable
Apr	16.19	Suitable
May	15.74	Suitable
Jun	14.94	Suitable
Jul	12.68	Suitable
Aug	8.91	Suitable
Sep	5.55	Not Suitable
Oct	5.97	Not Suitable

SAR values are based upon ambient EC

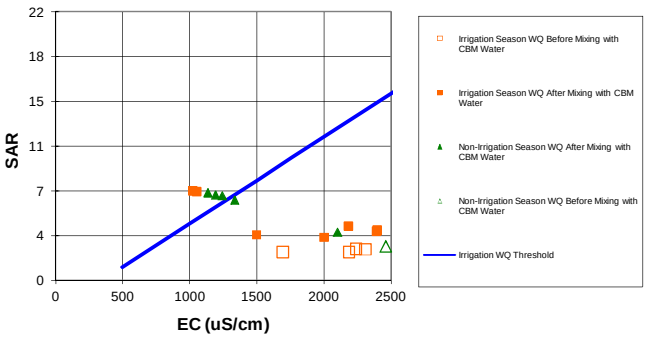
2990	18.75

6364700 2020

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Antelope Creek: 2020



Antelope Creek

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows

(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	2.1	0.24	1126	1134	1143	6.97	7.19	7.41	2789	2.95	2.34
	Dec	2.1	0.39	1232	1240	1248	6.74	6.95	7.15	2841	2.98	2.49
	Jan	2.1	0.34	1182	1190	1198	6.79	7.00	7.21	2708	2.79	2.44
	Feb	2.1	0.61	1327	1334	1341	6.40	6.59	6.78	2684	2.82	2.71
	Mar	2.1	6.77	2097	2100	2102	3.90	3.96	4.01	2459	2.80	8.87
Irrigation Season	Apr	2.1	7.28	2393	2395	2397	4.08	4.13	4.19	2814	3.11	9.38
	May	2.1	9.86	2388	2389	2391	4.00	4.04	4.09	2698	3.27	11.96
	Jun	2.1	5.12	2178	2181	2183	4.39	4.46	4.53	2689	3.13	7.22
	Jul	2.1	9.30	1997	1999	2001	3.50	3.54	3.59	2238	2.61	11.40
	Aug	2.1	5.90	1493	1496	1498	3.69	3.75	3.81	1693	2.35	8.00
	Sep	2.1	0.14	1012	1021	1030	7.12	7.35	7.58	2185	2.35	2.24
	Oct	2.1	0.18	1040	1048	1057	7.06	7.29	7.51	2307	2.57	2.28

[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	7.1	70%	2.1	2.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10.90	31	0.18
Nov	14.52	30	0.24
Dec	24.03	31	0.39
Jan	21.12	31	0.34
Feb	33.86	28	0.61
Mar	416.35	31	6.77
Apr	432.99	30	7.28
May	606.11	31	9.86
Jun	304.44	30	5.12
Jul	571.81	31	9.30
Aug	362.91	31	5.90
Sep	8.48	30	0.14

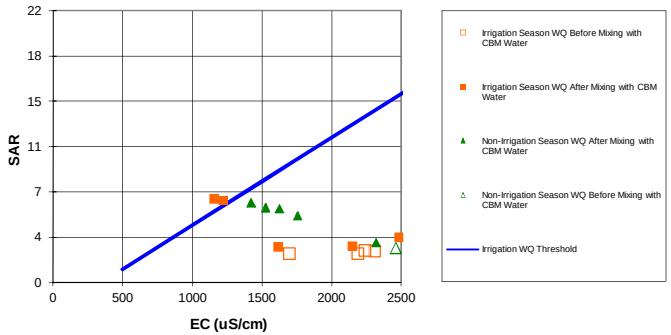
Irrigation Suitability Threshold Analysis		
Nov	5.58	Not Suitable
Dec	6.33	Not Suitable
Jan	5.98	Not Suitable
Feb	7.00	Suitable
Mar	12.43	Suitable
		Suitable
Apr	14.53	Suitable
May	14.49	Suitable
Jun	13.01	Suitable
Jul	11.72	Suitable
Aug	8.14	Suitable
Sep	4.77	Not Suitable
Oct	4.97	Not Suitable

SAR values are based upon ambient EC

2990	18.75

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

Antelope Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
933	942	951	7.44	7.68	7.93

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.7	0.24	1413	1419	1426	6.28	6.46	6.64	2789	2.95	0.94
	Dec	0.7	0.39	1616	1622	1629	5.84	6.00	6.16	2841	2.98	1.09
	Jan	0.7	0.34	1517	1523	1530	5.91	6.07	6.24	2708	2.79	1.04
	Feb	0.7	0.61	1748	1753	1758	5.29	5.42	5.55	2684	2.82	1.31
	Mar	0.7	6.77	2316	2316	2317	3.23	3.26	3.28	2459	2.80	7.47
Irrigation Season	Apr	0.7	7.28	2649	2650	2651	3.49	3.51	3.53	2814	3.11	7.98
	May	0.7	9.86	2581	2581	2582	3.54	3.56	3.58	2698	3.27	10.56
	Jun	0.7	5.12	2478	2479	2480	3.65	3.68	3.71	2689	3.13	5.82
	Jul	0.7	9.30	2146	2147	2147	2.95	2.97	2.98	2238	2.61	10.00
	Aug	0.7	5.90	1612	1613	1614	2.89	2.92	2.94	1693	2.35	6.60
	Sep	0.7	0.14	1144	1152	1160	6.58	6.78	6.99	2185	2.35	0.84
	Oct	0.7	0.18	1210	1218	1225	6.45	6.65	6.85	2307	2.57	0.88

[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	2.5	70%	0.7	0.7

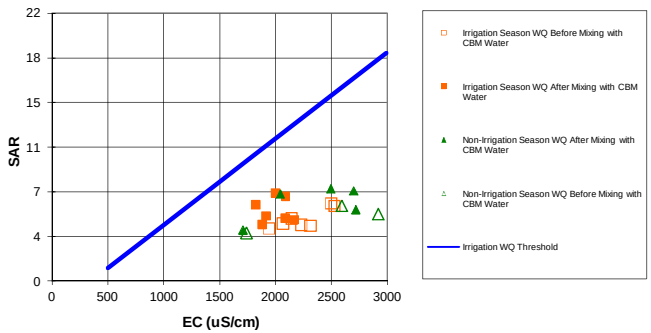
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	10.9	31	0.18
Nov	14.5	30	0.24
Dec	24.0	31	0.39
Jan	21.1	31	0.34
Feb	33.9	28	0.61
Mar	416.3	31	6.77
Apr	433.0	30	7.28
May	606.1	31	9.86
Jun	304.4	30	5.12
Jul	571.8	31	9.30
Aug	362.9	31	5.90
Sep	8.5	30	0.14

Irrigation Suitability Threshold Analysis		
Nov	7.60	Suitable
Dec	9.04	Suitable
Jan	8.34	Suitable
Feb	9.97	Suitable
Mar	13.97	Suitable
		Suitable
Apr	16.34	Suitable
May	15.85	Suitable
Jun	15.12	Suitable
Jul	12.77	Suitable
Aug	8.98	Suitable
Sep	5.71	Not Suitable
Oct	6.17	Not Suitable

SAR values are based upon ambient EC

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

Upper Belle Fourche River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	3.0	5.14	2040	2041	2042	7.10	7.17	7.25	2592	6.21	8.14
	Dec	3.0	4.45	2491	2492	2493	7.52	7.61	7.69	3433	6.78	7.45
	Jan	3.0	5.53	2696	2698	2699	7.37	7.44	7.51	3567	6.68	8.53
	Feb	3.0	24.21	2715	2715	2716	5.87	5.89	5.92	2916	5.53	27.21
	Mar	3.0	58.98	1707	1707	1707	4.21	4.22	4.23	1738	3.98	61.98
Irrigation Season	Apr	3.0	20.64	2084	2084	2085	5.17	5.19	5.22	2228	4.67	23.64
	May	3.0	37.55	1878	1878	1878	4.67	4.69	4.70	1941	4.36	40.55
	Jun	3.0	22.40	2166	2166	2166	5.05	5.08	5.10	2310	4.57	25.40
	Jul	3.0	16.39	1913	1914	1914	5.35	5.39	5.42	2063	4.76	19.39
	Aug	3.0	6.73	1818	1819	1820	6.24	6.30	6.37	2142	5.17	9.73
	Sep	3.0	5.43	1996	1998	1999	7.20	7.27	7.35	2496	6.41	8.43
	Oct	3.0	6.82	2087	2088	2089	6.94	7.01	7.07	2525	6.20	9.82

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	10.0	70%	3.0	3.0

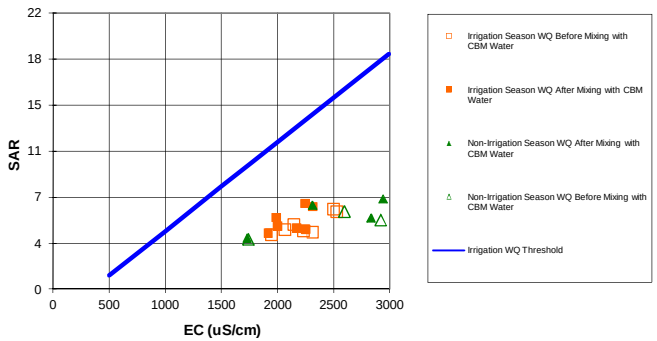
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	419.1	31	6.82
Nov	306.1	30	5.14
Dec	273.8	31	4.45
Jan	340.0	31	5.53
Feb	1344.8	28	24.21
Mar	3626.8	31	58.98
Apr	1228.1	30	20.64
May	2308.8	31	37.55
Jun	1332.9	30	22.40
Jul	1007.9	31	16.39
Aug	414.0	31	6.73
Sep	323.2	30	5.43

Irrigation Suitability Threshold Analysis		
Nov	12.01	Suitable
Dec	15.22	Suitable
Jan	16.68	Suitable
Feb	16.80	Suitable
Mar	9.64	Suitable
		Suitable
Apr	12.32	Suitable
May	10.86	Suitable
Jun	12.90	Suitable
Jul	11.11	Suitable
Aug	10.44	Suitable
Sep	11.71	Suitable
Oct	12.35	Suitable

SAR values are based upon ambient EC

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

Upper Belle Fourche River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	1.2	5.14	2308	2309	2310	6.67	6.70	6.74	2592	6.21	6.34
	Dec	1.2	4.45	2936	2937	2938	7.17	7.22	7.26	3433	6.78	5.65
	Jan	1.2	5.53	3126	3126	3127	7.03	7.07	7.10	3567	6.68	6.73
	Feb	1.2	24.21	2830	2830	2830	5.68	5.69	5.70	2916	5.53	25.41
	Mar	1.2	58.98	1725	1725	1725	4.08	4.08	4.09	1738	3.98	60.18
Irrigation Season	Apr	1.2	20.64	2166	2166	2166	4.88	4.89	4.91	2228	4.67	21.84
	May	1.2	37.55	1914	1914	1915	4.49	4.50	4.50	1941	4.36	38.75
	Jun	1.2	22.40	2248	2248	2248	4.78	4.79	4.80	2310	4.57	23.60
	Jul	1.2	16.39	1997	1997	1997	5.02	5.03	5.05	2063	4.76	17.59
	Aug	1.2	6.73	1983	1983	1984	5.70	5.73	5.76	2142	5.17	7.93
	Sep	1.2	5.43	2242	2242	2243	6.81	6.85	6.89	2496	6.41	6.63
	Oct	1.2	6.82	2310	2311	2311	6.57	6.60	6.63	2525	6.20	8.02

[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	4.0	70%	1.2	1.2

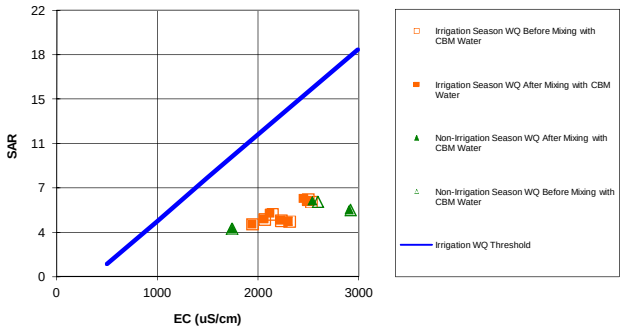
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	419.1	31	6.82
Nov	306.1	30	5.14
Dec	273.8	31	4.45
Jan	340.0	31	5.53
Feb	1344.8	28	24.21
Mar	3626.8	31	58.98
Apr	1228.1	30	20.64
May	2308.8	31	37.55
Jun	1332.9	30	22.40
Jul	1007.9	31	16.39
Aug	414.0	31	6.73
Sep	323.2	30	5.43

Irrigation Suitability Threshold Analysis		
Nov	13.92	Suitable
Dec	18.38	Suitable
Jan	19.72	Suitable
Feb	17.62	Suitable
Mar	9.77	Suitable
		Suitable
Apr	12.90	Suitable
May	11.12	Suitable
Jun	13.48	Suitable
Jul	11.71	Suitable
Aug	11.61	Suitable
Sep	13.45	Suitable
Oct	13.93	Suitable

SAR values are based upon ambient EC

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

Upper Belle Fourche River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

CBNG Discharge Quality					
EC (uS/cm)			SAR (--)		
1092	1095	1099	8.62	8.83	9.04

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% Lower	Mean	95% upper	95% Lower	Mean	95% upper			
Non-Irrigation Season	Nov	0.2	5.14	2536	2536	2536	6.30	6.31	6.31	2592	6.21	5.34
	Dec	0.2	4.45	3333	3333	3333	6.86	6.87	6.88	3433	6.78	4.65
	Jan	0.2	5.53	3480	3481	3481	6.75	6.76	6.77	3567	6.68	5.73
	Feb	0.2	24.21	2901	2901	2901	5.56	5.56	5.56	2916	5.53	24.41
	Mar	0.2	58.98	1736	1736	1736	4.00	4.00	4.00	1738	3.98	59.18
Irrigation Season	Apr	0.2	20.64	2217	2217	2217	4.70	4.70	4.71	2228	4.67	20.84
	May	0.2	37.55	1936	1936	1936	4.38	4.38	4.38	1941	4.36	37.75
	Jun	0.2	22.40	2299	2299	2299	4.61	4.61	4.61	2310	4.57	22.60
	Jul	0.2	16.39	2052	2052	2052	4.80	4.80	4.81	2063	4.76	16.59
	Aug	0.2	6.73	2111	2111	2111	5.27	5.28	5.29	2142	5.17	6.93
	Sep	0.2	5.43	2446	2446	2446	6.49	6.50	6.51	2496	6.41	5.63
	Oct	0.2	6.82	2484	2484	2484	6.27	6.28	6.28	2525	6.20	7.02

[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	0.8	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	419.1	31	6.82
Nov	306.1	30	5.14
Dec	273.8	31	4.45
Jan	340.0	31	5.53
Feb	1344.8	28	24.21
Mar	3626.8	31	58.98
Apr	1228.1	30	20.64
May	2308.8	31	37.55
Jun	1332.9	30	22.40
Jul	1007.9	31	16.39
Aug	414.0	31	6.73
Sep	323.2	30	5.43

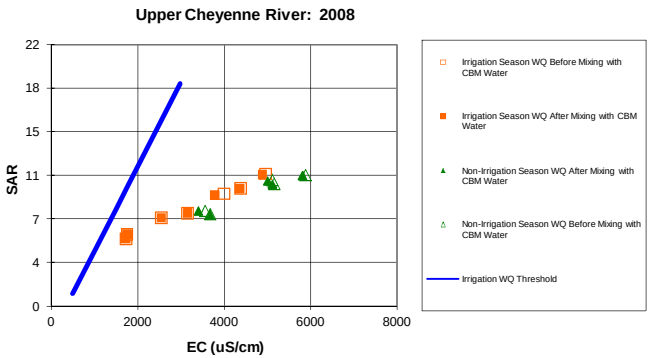
Irrigation Suitability Threshold Analysis		
Nov	15.53	Suitable
Dec	21.19	Suitable
Jan	22.24	Suitable
Feb	18.12	Suitable
Mar	9.85	Suitable
		Suitable
Apr	13.27	Suitable
May	11.27	Suitable
Jun	13.85	Suitable
Jul	12.09	Suitable
Aug	12.52	Suitable
Sep	14.89	Suitable
Oct	15.16	Suitable

SAR values are based upon ambient EC

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
796	804	812	6.90	8.08	9.27



		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.1	9.53	5112	5113	5113	10.29	10.30	10.31	5158	10.32	9.63
	Dec	0.1	6.80	5810	5810	5811	10.99	11.01	11.03	5884	11.05	6.90
	Jan	0.1	3.97	5007	5007	5008	10.54	10.57	10.60	5113	10.64	4.07
	Feb	0.1	1.70	3404	3405	3405	7.97	8.03	8.10	3558	8.03	1.80
	Mar	0.1	31.52	3665	3665	3665	7.76	7.77	7.77	3674	7.77	31.62
Irrigation Season	Apr	0.1	18.77	4357	4357	4357	9.92	9.93	9.94	4376	9.94	18.87
	May	0.1	164.45	3150	3150	3150	7.86	7.86	7.86	3152	7.86	164.55
	Jun	0.1	70.31	2541	2541	2541	7.46	7.46	7.46	2544	7.46	70.41
	Jul	0.1	17.69	1744	1744	1744	6.08	6.09	6.10	1749	6.08	17.79
	Aug	0.1	93.68	1721	1721	1721	5.69	5.69	5.69	1722	5.69	93.78
	Sep	0.1	1.39	3778	3779	3779	9.31	9.39	9.47	3993	9.49	1.49
	Oct	0.1	5.66	4881	4881	4881	11.08	11.10	11.12	4953	11.15	5.76

[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	0.4	70%	0.1	0.1

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	347.80	31	5.66
Nov	567.05	30	9.53
Dec	418.34	31	6.80
Jan	244.07	31	3.97
Feb	94.53	28	1.70
Mar	1937.95	31	31.52
Apr	1117.12	30	18.77
May	10111.72	31	164.45
Jun	4183.73	30	70.31
Jul	1087.77	31	17.69
Aug	5760.45	31	93.68
Sep	82.73	30	1.39

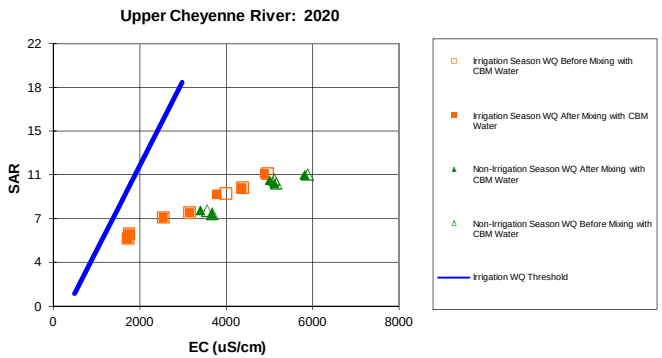
Irrigation Suitability Threshold Analysis		
Nov	33.82	Suitable
Dec	38.78	Suitable
Jan	33.08	Suitable
Feb	21.70	Suitable
Mar	23.55	Suitable
		Suitable
Apr	28.46	Suitable
May	19.89	Suitable
Jun	15.57	Suitable
Jul	9.91	Suitable
Aug	9.75	Suitable
Sep	24.35	Suitable
Oct	32.18	Suitable

SAR values are based upon ambient EC

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
796	804	812	6.90	8.08	9.27



		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.1	9.53	5112	5113	5113	10.29	10.30	10.31	5158	10.32	9.63
	Dec	0.1	6.80	5810	5810	5811	10.99	11.01	11.03	5884	11.05	6.90
	Jan	0.1	3.97	5007	5007	5008	10.54	10.57	10.60	5113	10.64	4.07
	Feb	0.1	1.70	3404	3405	3405	7.97	8.03	8.10	3558	8.03	1.80
	Mar	0.1	31.52	3665	3665	3665	7.76	7.77	7.77	3674	7.77	31.62
Irrigation Season	Apr	0.1	18.77	4357	4357	4357	9.92	9.93	9.94	4376	9.94	18.87
	May	0.1	164.45	3150	3150	3150	7.86	7.86	7.86	3152	7.86	164.55
	Jun	0.1	70.31	2541	2541	2541	7.46	7.46	7.46	2544	7.46	70.41
	Jul	0.1	17.69	1744	1744	1744	6.08	6.09	6.10	1749	6.08	17.79
	Aug	0.1	93.68	1721	1721	1721	5.69	5.69	5.69	1722	5.69	93.78
	Sep	0.1	1.39	3778	3779	3779	9.31	9.39	9.47	3993	9.49	1.49
	Oct	0.1	5.66	4881	4881	4881	11.08	11.10	11.12	4953	11.15	5.76

[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	0.4	70%	0.1	0.1

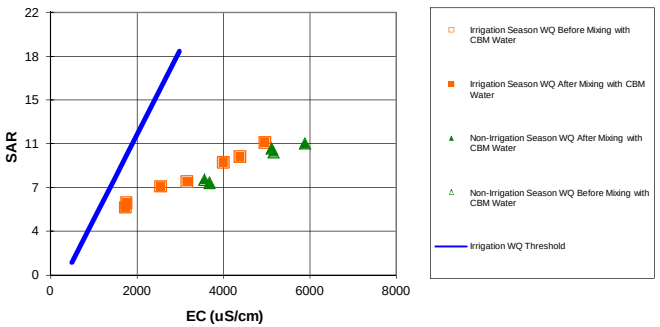
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	347.80	31	5.66
Nov	567.05	30	9.53
Dec	418.34	31	6.80
Jan	244.07	31	3.97
Feb	94.53	28	1.70
Mar	1937.95	31	31.52
Apr	1117.12	30	18.77
May	10111.72	31	164.45
Jun	4183.73	30	70.31
Jul	1087.77	31	17.69
Aug	5760.45	31	93.68
Sep	82.73	30	1.39

Irrigation Suitability Threshold Analysis		
Nov	33.82	Suitable
Dec	38.78	Suitable
Jan	33.08	Suitable
Feb	21.70	Suitable
Mar	23.55	Suitable
		Suitable
Apr	28.46	Suitable
May	19.89	Suitable
Jun	15.57	Suitable
Jul	9.91	Suitable
Aug	9.75	Suitable
Sep	24.35	Suitable
Oct	32.18	Suitable

SAR values are based upon ambient EC

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

Upper Cheyenne River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
796	804	812	6.90	8.08	9.27

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.0	9.53	5158	5158	5158	10.32	10.32	10.32	5158	10.32	9.53
	Dec	0.0	6.80	5884	5884	5884	11.05	11.05	11.05	5884	11.05	6.80
	Jan	0.0	3.97	5113	5113	5113	10.64	10.64	10.64	5113	10.64	3.97
	Feb	0.0	1.70	3558	3558	3558	8.03	8.03	8.03	3558	8.03	1.70
	Mar	0.0	31.52	3674	3674	3674	7.77	7.77	7.77	3674	7.77	31.52
Irrigation Season	Apr	0.0	18.77	4376	4376	4376	9.94	9.94	9.94	4376	9.94	18.77
	May	0.0	164.45	3152	3152	3152	7.86	7.86	7.86	3152	7.86	164.45
	Jun	0.0	70.31	2544	2544	2544	7.46	7.46	7.46	2544	7.46	70.31
	Jul	0.0	17.69	1749	1749	1749	6.08	6.08	6.08	1749	6.08	17.69
	Aug	0.0	93.68	1722	1722	1722	5.69	5.69	5.69	1722	5.69	93.68
	Sep	0.0	1.39	3993	3993	3993	9.49	9.49	9.49	3993	9.49	1.39
	Oct	0.0	5.66	4953	4953	4953	11.15	11.15	11.15	4953	11.15	5.66

[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	0.0	70%	0.0	0.0

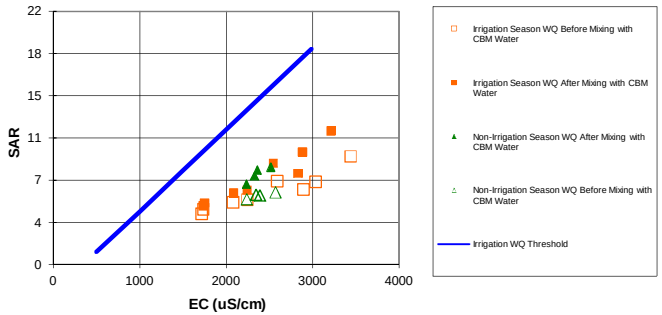
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	347.80	31	5.66
Nov	567.05	30	9.53
Dec	418.34	31	6.80
Jan	244.07	31	3.97
Feb	94.53	28	1.70
Mar	1937.95	31	31.52
Apr	1117.12	30	18.77
May	10111.72	31	164.45
Jun	4183.73	30	70.31
Jul	1087.77	31	17.69
Aug	5760.45	31	93.68
Sep	82.73	30	1.39

Irrigation Suitability Threshold Analysis		
Nov	34.14	Suitable
Dec	39.30	Suitable
Jan	33.83	Suitable
Feb	22.78	Suitable
Mar	23.61	Suitable
		Suitable
Apr	28.60	Suitable
May	19.90	Suitable
Jun	15.58	Suitable
Jul	9.94	Suitable
Aug	9.75	Suitable
Sep	25.87	Suitable
Oct	32.69	Suitable

SAR values are based upon ambient EC

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

Upper Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	18.1	154.03	2325	2326	2327	7.68	7.73	7.78	2343	6.09	172.13
	Dec	18.1	109.05	2513	2515	2517	8.42	8.49	8.56	2570	6.29	127.15
	Jan	18.1	110.21	2358	2359	2361	8.17	8.24	8.30	2388	6.02	128.31
	Feb	18.1	201.17	2232	2233	2234	6.97	7.01	7.05	2237	5.69	219.27
Irrigation Season	Mar	18.1	342.59	2084	2084	2085	6.22	6.25	6.27	2079	5.43	0.00
	Apr	18.1	327.73	2240	2241	2241	6.48	6.50	6.53	2244	5.66	360.69
	May	18.1	534.32	1748	1749	1749	5.37	5.38	5.40	1734	4.83	345.83
	Jun	18.1	441.19	1732	1733	1733	5.10	5.12	5.14	1714	4.44	552.42
	Jul	18.1	181.12	2827	2828	2829	7.89	7.94	7.98	2893	6.56	459.29
	Aug	18.1	83.05	2879	2881	2883	9.72	9.81	9.90	3033	7.22	199.22
	Sep	18.1	82.48	3210	3212	3214	11.54	11.63	11.72	3438	9.42	101.15
	Oct	18.1	148.94	2544	2546	2547	8.79	8.84	8.89	2590	7.28	100.58
												167.04

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	60.3	70%	18.1	18.1

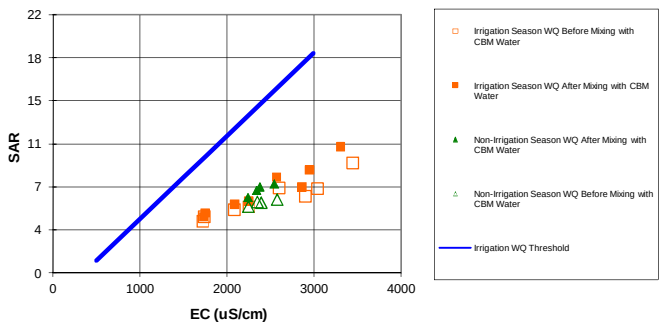
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9158.24	31	148.94
Nov	9165.29	30	154.03
Dec	6705.22	31	109.05
Jan	6776.28	31	110.21
Feb	11172.29	28	201.17
Mar	21065.31	31	342.59
Apr	19501.49	30	327.73
May	32854.19	31	534.32
Jun	26252.89	30	441.19
Jul	11136.77	31	181.12
Aug	5106.82	31	83.05
Sep	4907.75	30	82.48

Irrigation Suitability Threshold Analysis		
Nov	14.04	Suitable
Dec	15.38	Suitable
Jan	14.28	Suitable
Feb	13.38	Suitable
Mar		Suitable
	12.32	Suitable
Apr	13.43	Suitable
May	9.94	Suitable
Jun	9.83	Suitable
Jul	17.60	Suitable
Aug	17.98	Suitable
Sep	20.33	Suitable
Oct	15.60	Suitable

SAR values are based upon ambient EC

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

Upper Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	10.3	154.03	2332	2333	2334	7.03	7.07	7.10	2343	6.09	164.33
	Dec	10.3	109.05	2536	2537	2538	7.58	7.62	7.67	2570	6.29	119.35
	Jan	10.3	110.21	2370	2371	2372	7.32	7.36	7.41	2388	6.02	120.51
	Feb	10.3	201.17	2234	2235	2235	6.44	6.47	6.49	2237	5.69	211.47
Irrigation Season	Mar	10.3	342.59	2082	2082	2082	5.89	5.90	5.92	2079	5.43	352.89
	Apr	10.3	327.73	2242	2242	2242	6.14	6.15	6.17	2244	5.66	338.03
	May	10.3	534.32	1742	1742	1743	5.14	5.15	5.16	1734	4.83	544.62
	Jun	10.3	441.19	1725	1725	1725	4.82	4.83	4.84	1714	4.44	451.49
	Jul	10.3	181.12	2854	2854	2855	7.35	7.37	7.40	2893	6.56	191.42
	Aug	10.3	83.05	2938	2939	2941	8.76	8.82	8.87	3033	7.22	93.35
	Sep	10.3	82.48	3298	3299	3300	10.73	10.78	10.84	3438	9.42	92.78
	Oct	10.3	148.94	2563	2563	2564	8.18	8.21	8.24	2590	7.28	159.24

[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	34.3	70%	10.3	10.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9158.2	31	148.94
Nov	9165.3	30	154.03
Dec	6705.2	31	109.05
Jan	6776.3	31	110.21
Feb	11172.3	28	201.17
Mar	21065.3	31	342.59
Apr	19501.5	30	327.73
May	32854.2	31	534.32
Jun	26252.9	30	441.19
Jul	11136.8	31	181.12
Aug	5106.8	31	83.05
Sep	4907.7	30	82.48

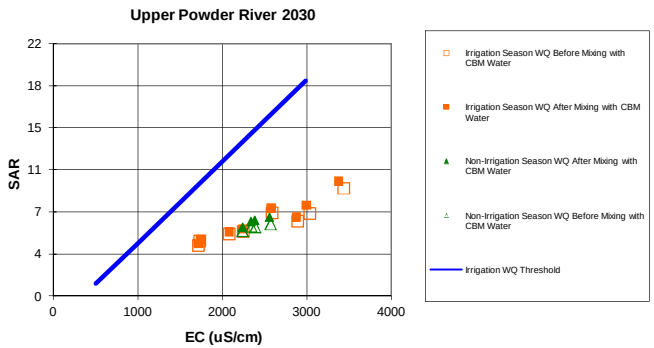
Irrigation Suitability Threshold Analysis		
Nov	14.09	Suitable
Dec	15.53	Suitable
Jan	14.36	Suitable
Feb	13.39	Suitable
Mar		Suitable
	12.31	Suitable
Apr	13.44	Suitable
May	9.90	Suitable
Jun	9.77	Suitable
Jul	17.79	Suitable
Aug	18.39	Suitable
Sep	20.95	Suitable
Oct	15.72	Suitable

SAR values are based upon ambient EC

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

Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
2172	2183	2194	21.21	21.70	22.19



		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	4.4	154.03	2338	2339	2339	6.51	6.52	6.53	2343	6.09	158.43
	Dec	4.4	109.05	2555	2555	2555	6.87	6.89	6.91	2570	6.29	113.45
	Jan	4.4	110.21	2380	2380	2381	6.61	6.63	6.64	2388	6.02	114.61
	Feb	4.4	201.17	2236	2236	2236	6.02	6.03	6.04	2237	5.69	205.57
Irrigation Season	Mar	4.4	342.59	2080	2080	2081	5.63	5.64	5.64	2079	5.43	346.99
	Apr	4.4	327.73	2243	2243	2243	5.87	5.87	5.88	2244	5.66	332.13
	May	4.4	534.32	1738	1738	1738	4.96	4.97	4.97	1734	4.83	538.72
	Jun	4.4	441.19	1719	1719	1719	4.60	4.61	4.61	1714	4.44	445.59
	Jul	4.4	181.12	2875	2876	2876	6.91	6.92	6.93	2893	6.56	185.52
	Aug	4.4	83.05	2990	2990	2991	7.92	7.95	7.97	3033	7.22	87.45
	Sep	4.4	82.48	3374	3375	3375	10.02	10.04	10.07	3438	9.42	86.88
	Oct	4.4	148.94	2578	2578	2578	7.68	7.69	7.70	2590	7.28	153.34

[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	14.8	70%	4.4	4.4

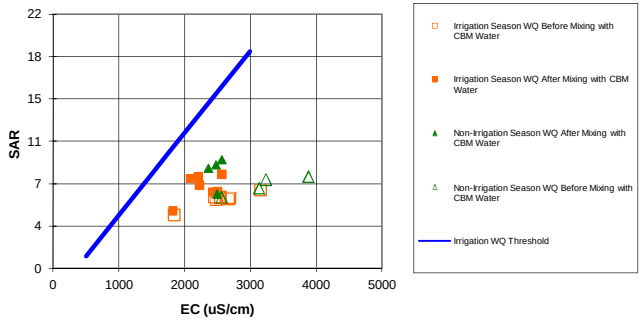
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	9158.24	31	148.94
Nov	9165.29	30	154.03
Dec	6705.22	31	109.05
Jan	6776.28	31	110.21
Feb	11172.29	28	201.17
Mar	21065.31	31	342.59
Apr	19501.49	30	327.73
May	32854.19	31	534.32
Jun	26252.89	30	441.19
Jul	11136.77	31	181.12
Aug	5106.82	31	83.05
Sep	4907.75	30	82.48

Irrigation Suitability Threshold Analysis		
Nov	14.13	Suitable
Dec	15.67	Suitable
Jan	14.42	Suitable
Feb	13.40	Suitable
Mar		Suitable
	12.30	Suitable
Apr	13.45	Suitable
May	9.86	Suitable
Jun	9.73	Suitable
Jul	17.94	Suitable
Aug	18.76	Suitable
Sep	21.49	Suitable
Oct	15.83	Suitable

SAR values are based upon ambient EC

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

Little Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	2.9	3.29	2352	2356	2359	8.52	8.68	8.85	3125	6.95	6.19
	Dec	2.9	2.37	2555	2559	2563	9.25	9.44	9.64	3874	7.96	5.27
	Jan	2.9	3.78	2468	2471	2474	8.83	8.99	9.14	3229	7.71	6.68
	Feb	2.9	40.76	2485	2485	2486	6.44	6.47	6.49	2557	6.17	43.66
Irrigation Season	Mar	2.9	44.17	1813	1814	1814	5.00	5.02	5.04	1836	4.65	47.07
	Apr	2.9	17.04	2491	2492	2493	6.63	6.69	6.74	2664	6.01	19.94
	May	2.9	40.64	2467	2468	2468	6.47	6.49	6.51	2538	6.19	43.54
	Jun	2.9	23.55	2420	2421	2422	6.61	6.65	6.69	2537	6.15	26.45
	Jul	2.9	9.29	2217	2218	2220	7.16	7.24	7.33	2448	6.18	12.19
	Aug	2.9	4.48	2079	2082	2085	7.67	7.81	7.95	2470	5.96	7.38
	Sep	2.9	5.27	2554	2556	2559	8.04	8.16	8.29	3147	6.79	8.17
	Oct	2.9	4.30	2197	2200	2203	7.81	7.95	8.09	2684	6.13	7.20

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	9.6	70%	2.9	2.9

[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

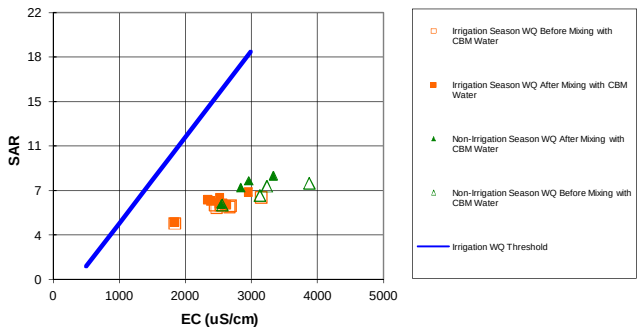
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	264.54	31	4.30
Nov	195.91	30	3.29
Dec	145.96	31	2.37
Jan	232.58	31	3.78
Feb	2263.91	28	40.76
Mar	2716.04	31	44.17
Apr	1013.81	30	17.04
May	2498.86	31	40.64
Jun	1401.26	30	23.55
Jul	571.44	31	9.29
Aug	275.45	31	4.48
Sep	313.71	30	5.27

Irrigation Suitability Threshold Analysis		
Nov	14.25	Suitable
Dec	15.69	Suitable
Jan	15.07	Suitable
Feb	15.17	Suitable
Mar		Suitable
	10.40	Suitable
Apr	15.22	Suitable
May	15.05	Suitable
Jun	14.71	Suitable
Jul	13.27	Suitable
Aug	12.31	Suitable
Sep	15.67	Suitable
Oct	13.15	Suitable

SAR values are based upon ambient EC

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

Little Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.7	3.29	2836	2837	2838	7.54	7.60	7.66	3125	6.95	3.99
	Dec	0.7	2.37	3328	3329	3331	8.49	8.57	8.65	3874	7.96	3.07
	Jan	0.7	3.78	2955	2956	2957	8.11	8.17	8.23	3229	7.71	4.48
	Feb	0.7	40.76	2538	2539	2539	6.24	6.24	6.25	2557	6.17	41.46
Irrigation Season	Mar	0.7	44.17	1830	1830	1830	4.74	4.75	4.75	1836	4.65	44.87
	Apr	0.7	17.04	2617	2618	2618	6.18	6.19	6.21	2664	6.01	17.74
	May	0.7	40.64	2520	2520	2520	6.26	6.27	6.27	2538	6.19	41.34
	Jun	0.7	23.55	2506	2506	2506	6.27	6.28	6.29	2537	6.15	24.25
	Jul	0.7	9.29	2380	2380	2381	6.47	6.49	6.52	2448	6.18	9.99
	Aug	0.7	4.48	2336	2337	2338	6.55	6.60	6.65	2470	5.96	5.18
	Sep	0.7	5.27	2951	2952	2953	7.20	7.24	7.29	3147	6.79	5.97
	Oct	0.7	4.30	2515	2516	2517	6.71	6.76	6.81	2684	6.13	5.00

[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	2.2	70%	0.7	0.7

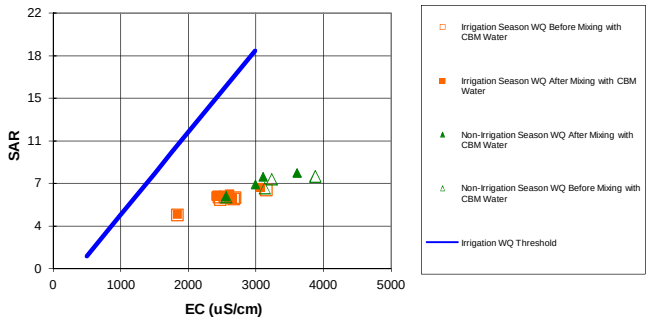
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	264.54	31	4.30
Nov	195.91	30	3.29
Dec	145.96	31	2.37
Jan	232.58	31	3.78
Feb	2263.91	28	40.76
Mar	2716.04	31	44.17
Apr	1013.81	30	17.04
May	2498.86	31	40.64
Jun	1401.26	30	23.55
Jul	571.44	31	9.29
Aug	275.45	31	4.48
Sep	313.71	30	5.27

Irrigation Suitability Threshold Analysis		
Nov	17.67	Suitable
Dec	21.16	Suitable
Jan	18.51	Suitable
Feb	15.55	Suitable
Mar		Suitable
	10.52	Suitable
Apr	16.11	Suitable
May	15.42	Suitable
Jun	15.32	Suitable
Jul	14.42	Suitable
Aug	14.11	Suitable
Sep	18.48	Suitable
Oct	15.39	Suitable

SAR values are based upon ambient EC

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

Little Powder River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
1475	1482	1489	10.30	10.66	11.01

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	0.3	3.29	2987	2988	2988	7.23	7.26	7.29	3125	6.95	3.59
	Dec	0.3	2.37	3605	3606	3607	8.22	8.26	8.30	3874	7.96	2.67
	Jan	0.3	3.78	3100	3101	3101	7.90	7.93	7.95	3229	7.71	4.08
	Feb	0.3	40.76	2549	2549	2549	6.20	6.20	6.20	2557	6.17	41.06
Irrigation Season	Mar	0.3	44.17	1833	1833	1833	4.69	4.69	4.70	1836	4.65	44.47
	Apr	0.3	17.04	2644	2644	2644	6.09	6.09	6.10	2664	6.01	17.34
	May	0.3	40.64	2530	2530	2530	6.22	6.23	6.23	2538	6.19	40.94
	Jun	0.3	23.55	2523	2523	2523	6.20	6.21	6.21	2537	6.15	23.85
	Jul	0.3	9.29	2418	2418	2418	6.31	6.32	6.33	2448	6.18	9.59
	Aug	0.3	4.48	2408	2408	2409	6.24	6.26	6.28	2470	5.96	4.78
	Sep	0.3	5.27	3057	3057	3058	6.98	7.00	7.02	3147	6.79	5.57
	Oct	0.3	4.30	2605	2606	2606	6.40	6.42	6.44	2684	6.13	4.60

[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	0.9	70%	0.3	0.3

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	264.54	31	4.30
Nov	195.91	30	3.29
Dec	145.96	31	2.37
Jan	232.58	31	3.78
Feb	2263.91	28	40.76
Mar	2716.04	31	44.17
Apr	1013.81	30	17.04
May	2498.86	31	40.64
Jun	1401.26	30	23.55
Jul	571.44	31	9.29
Aug	275.45	31	4.48
Sep	313.71	30	5.27

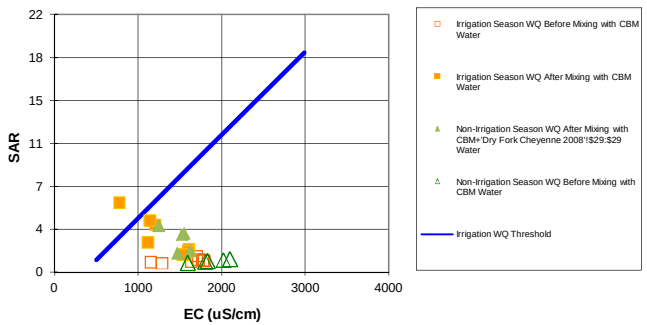
Irrigation Suitability Threshold Analysis		
Nov	18.74	Suitable
Dec	23.13	Suitable
Jan	19.54	Suitable
Feb	15.62	Suitable
Mar		Suitable
	10.54	Suitable
Apr	16.29	Suitable
May	15.49	Suitable
Jun	15.44	Suitable
Jul	14.69	Suitable
Aug	14.62	Suitable
Sep	19.23	Suitable
Oct	16.03	Suitable

SAR values are based upon ambient EC

Normal Year Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Dry Fork Cheyenne River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--) Not Applicable			Background Water Quality EC (uS/cm)	Background Water Quality SAR (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.1	0.15	1534	1549	1564	3.31	3.35	3.39	2098	1.14	0.25
	Dec	0.1	0.16	1509	1524	1538	3.16	3.20	3.24	2020	1.05	0.26
	Jan	0.1	0.09	1224	1244	1264	3.93	3.99	4.04	1830	0.98	0.19
	Feb	0.1	0.52	1619	1625	1631	1.83	1.85	1.86	1800	0.92	0.62
	Mar	0.1	0.62	1465	1470	1475	1.63	1.64	1.65	1592	0.82	
												0.00
Irrigation Season	Apr	0.1	0.49	1599	1606	1612	1.95	1.97	1.99	1788	1.00	0.59
	May	0.1	0.69	1591	1596	1601	1.80	1.82	1.83	1723	1.11	0.79
	Jun	0.1	0.84	1531	1535	1539	1.52	1.53	1.54	1632	0.92	0.94
	Jul	0.1	0.10	1183	1202	1221	4.03	4.08	4.13	1699	1.40	0.20
	Aug	0.1	0.23	1103	1114	1126	2.54	2.57	2.61	1285	0.80	0.33
	Sep	0.1	0.01	741	774	807	5.87	5.96	6.05	1150	0.90	0.11
	Oct	0.1	0.07	1117	1140	1162	4.38	4.44	4.50	1775	1.05	0.17

[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)
Normal Fork Cheyenne	Dry Fork Cheyenne River	0.4	70%	0.1	0.1

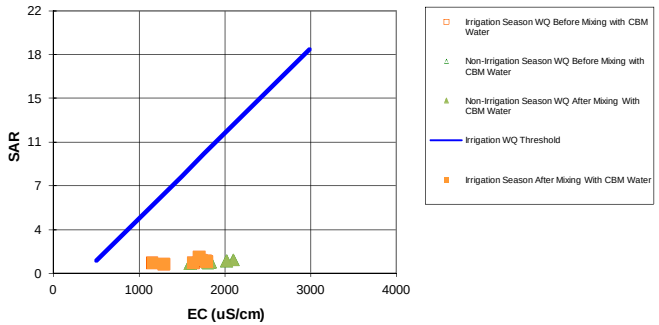
Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4.059	31	0.07
Nov	8.984	30	0.15
Dec	9.949	31	0.16
Jan	5.497	31	0.09
Feb	28.787	28	0.52
Mar	37.862	31	0.62
Apr	28.973	30	0.49
May	42.484	31	0.69
Jun	49.914	30	0.84
Jul	5.967	31	0.10
Aug	14.186	31	0.23
Sep	0.852	30	0.01

Irrigation Suitability Threshold Analysis		
Nov	8.52	Suitable
Dec	8.34	Suitable
Jan	6.36	Suitable
Feb	9.06	Suitable
Mar	7.96	Suitable
		Suitable
Apr	8.92	Suitable
May	8.85	Suitable
Jun	8.42	Suitable
Jul	6.06	Suitable
Aug	5.44	Suitable
Sep	3.02	Not Suitable
Oct	5.62	Suitable

SAR values are based upon ambient EC

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

Dry Fork Cheyenne River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows
(Normal Year Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.00	0.15	2098	2098	2098	1.14	1.14	1.14	2098	1.14	0.15
	Dec	0.00	0.16	2020	2020	2020	1.05	1.05	1.05	2020	1.05	0.16
	Jan	0.00	0.09	1830	1830	1830	0.98	0.98	0.98	1830	0.98	0.09
	Feb	0.00	0.52	1800	1800	1800	0.92	0.92	0.92	1800	0.92	0.52
	Mar	0.00	0.62	1592	1592	1592	0.82	0.82	0.82	1592	0.82	0.62
Irrigation Season	Apr	0.00	0.49	1788	1788	1788	1.00	1.00	1.00	1788	1.00	0.49
	May	0.00	0.69	1723	1723	1723	1.11	1.11	1.11	1723	1.11	0.69
	Jun	0.00	0.84	1632	1632	1632	0.92	0.92	0.92	1632	0.92	0.84
	Jul	0.00	0.10	1699	1699	1699	1.40	1.40	1.40	1699	1.40	0.10
	Aug	0.00	0.23	1285	1285	1285	0.80	0.80	0.80	1285	0.80	0.23
	Sep	0.00	0.01	1150	1150	1150	0.90	0.90	0.90	1150	0.90	0.01
	Oct	0.00	0.07	1775	1775	1775	1.05	1.05	1.05	1775	1.05	0.07

[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	70%	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4.06	31	0.07
Nov	8.98	30	0.15
Dec	9.95	31	0.16
Jan	5.50	31	0.09
Feb	28.79	28	0.52
Mar	37.86	31	0.62
Apr	28.97	30	0.49
May	42.48	31	0.69
Jun	49.91	30	0.84
Jul	5.97	31	0.10
Aug	14.19	31	0.23
Sep	0.85	30	0.01

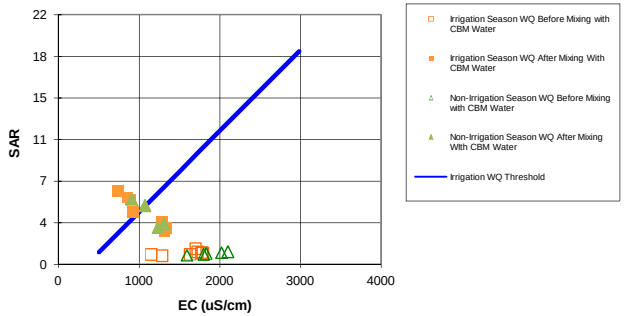
Irrigation Suitability Threshold Analysis		
Nov	12.42	Suitable
Dec	11.87	Suitable
Jan	10.52	Suitable
Feb	10.30	Suitable
Mar	8.83	Suitable
		Suitable
Apr	10.22	Suitable
May	9.75	Suitable
Jun	9.11	Suitable
Jul	9.59	Suitable
Aug	6.65	Suitable
Sep	5.69	Suitable
Oct	10.13	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Dry Fork Cheyenne River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
682	720	758	6.58	6.68	6.78

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.4	0.15	1044	1072	1100	5.19	5.26	5.34	2098	1.14	0.59
	Dec	0.4	0.16	1042	1070	1097	5.09	5.17	5.24	2020	1.05	0.60
	Jan	0.4	0.09	876	908	939	5.63	5.72	5.80	1830	0.98	0.53
	Feb	0.4	0.52	1287	1304	1322	3.51	3.56	3.61	1800	0.92	0.96
	Mar	0.4	0.62	1213	1229	1244	3.22	3.26	3.31	1592	0.82	1.06
Irrigation Season	Apr	0.4	0.49	1263	1281	1299	3.65	3.70	3.75	1788	1.00	0.93
	May	0.4	0.69	1318	1333	1347	3.24	3.28	3.32	1723	1.11	1.13
	Jun	0.4	0.84	1305	1318	1331	2.87	2.90	2.94	1632	0.92	1.28
	Jul	0.4	0.10	866	897	928	5.64	5.73	5.81	1699	1.40	0.54
	Aug	0.4	0.23	890	915	939	4.59	4.66	4.72	1285	0.80	0.67
	Sep	0.4	0.01	697	734	770	6.40	6.50	6.60	1150	0.90	0.45
	Oct	0.4	0.07	825	858	891	5.86	5.95	6.04	1775	1.05	0.51

[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	1.5	70%	0.4	0.4

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	4.06	31	0.07
Nov	8.98	30	0.15
Dec	9.95	31	0.16
Jan	5.50	31	0.09
Feb	28.79	28	0.52
Mar	37.86	31	0.62
Apr	28.97	30	0.49
May	42.48	31	0.69
Jun	49.91	30	0.84
Jul	5.97	31	0.10
Aug	14.19	31	0.23
Sep	0.85	30	0.01

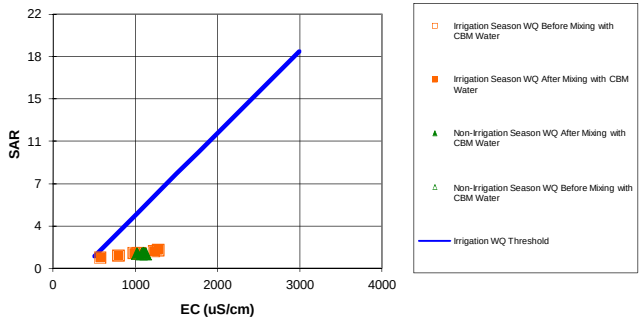
Irrigation Suitability Threshold Analysis		
Nov	5.14	Not Suitable
Dec	5.12	Not Suitable
Jan	3.97	Not Suitable
Feb	6.78	Suitable
Mar	6.25	Suitable
		Suitable
Apr	6.62	Suitable
May	6.99	Suitable
Jun	6.88	Suitable
Jul	3.89	Not Suitable
Aug	4.02	Not Suitable
Sep	2.73	Not Suitable
Oct	3.62	Not Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.0	90.36	1122	1122	1122	1.27	1.27	1.27	1122	1.27	90.36
	Dec	0.0	74.83	1109	1109	1109	1.30	1.30	1.30	1109	1.30	74.83
	Jan	0.0	68.95	1074	1074	1074	1.29	1.29	1.29	1074	1.29	68.95
	Feb	0.0	62.75	1092	1092	1092	1.35	1.35	1.35	1092	1.35	62.75
	Mar	0.0	62.75	1018	1018	1018	1.30	1.30	1.30	1018	1.30	62.75
Irrigation Season	Apr	0.0	94.47	1024	1024	1024	1.32	1.32	1.32	1024	1.32	94.47
	May	0.0	226.67	789	789	789	1.13	1.13	1.13	789	1.13	226.67
	Jun	0.0	288.88	568	568	568	0.96	0.96	0.96	568	0.96	288.88
	Jul	0.0	117.51	976	976	976	1.36	1.36	1.36	976	1.36	117.51
	Aug	0.0	82.30	1274	1274	1274	1.62	1.62	1.62	1274	1.62	82.30
	Sep	0.0	95.72	1221	1221	1221	1.51	1.51	1.51	1221	1.51	95.72
	Oct	0.0	90.44	1055	1055	1055	1.34	1.34	1.34	1055	1.34	90.44

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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	5560.8	31	90.44
Nov	5376.8	30	90.36
Dec	4601.0	31	74.83
Jan	4239.6	31	68.95
Feb	3485.0	28	62.75
Mar	5456.8	31	88.75
Apr	5621.5	30	94.47
May	13937.5	31	226.67
Jun	17189.8	30	288.88
Jul	7225.1	31	117.51
Aug	5060.3	31	82.30
Sep	5696.0	30	95.72

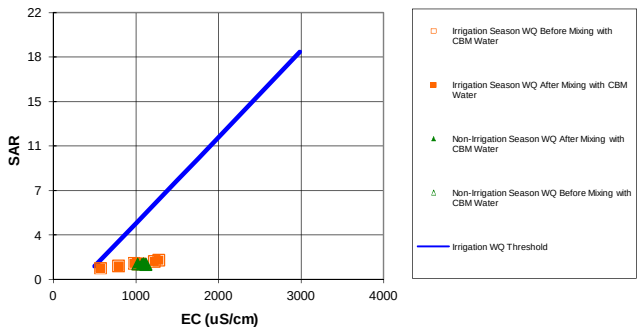
Irrigation Suitability Threshold Analysis		
Nov	5.49	Suitable
Dec	5.40	Suitable
Jan	5.15	Suitable
Feb	5.28	Suitable
Mar	4.75	Suitable
		Suitable
Apr	4.80	Suitable
May	3.13	Suitable
Jun	1.55	Suitable
Jul	4.45	Suitable
Aug	6.57	Suitable
Sep	6.19	Suitable
Oct	5.01	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2010



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.0	90.36	1122	1122	1122	1.27	1.27	1.27	1122	1.27	90.36
	Dec	0.0	74.83	1109	1109	1109	1.30	1.30	1.30	1109	1.30	74.83
	Jan	0.0	68.95	1074	1074	1074	1.29	1.29	1.29	1074	1.29	68.95
	Feb	0.0	62.75	1092	1092	1092	1.35	1.35	1.35	1092	1.35	62.75
	Mar	0.0	88.75	1018	1018	1018	1.30	1.30	1.30	1018	1.30	88.75
Irrigation Season	Apr	0.0	94.47	1024	1024	1024	1.32	1.32	1.32	1024	1.32	94.47
	May	0.0	226.67	789	789	789	1.13	1.13	1.13	789	1.13	226.67
	Jun	0.0	288.88	568	568	568	0.96	0.96	0.96	568	0.96	288.88
	Jul	0.0	117.51	976	976	976	1.36	1.36	1.36	976	1.36	117.51
	Aug	0.0	82.30	1274	1274	1274	1.62	1.62	1.62	1274	1.62	82.30
	Sep	0.0	95.72	1221	1221	1221	1.51	1.51	1.51	1221	1.51	95.72
	Oct	0.0	90.44	1055	1055	1055	1.34	1.34	1.34	1055	1.34	90.44

[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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	5560.8	31	90.44
Nov	5376.8	30	90.36
Dec	4601.0	31	74.83
Jan	4239.6	31	68.95
Feb	3485.0	28	62.75
Mar	5456.8	31	88.75
Apr	5621.5	30	94.47
May	13937.5	31	226.67
Jun	17189.8	30	288.88
Jul	7225.1	31	117.51
Aug	5060.3	31	82.30
Sep	5696.0	30	95.72

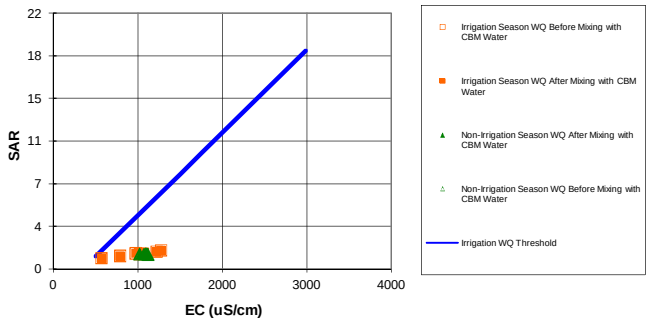
Irrigation Suitability Threshold Analysis		
Nov	5.49	Suitable
Dec	5.40	Suitable
Jan	5.15	Suitable
Feb	5.28	Suitable
Mar	4.75	Suitable
		Suitable
Apr	4.80	Suitable
May	3.13	Suitable
Jun	1.55	Suitable
Jul	4.45	Suitable
Aug	6.57	Suitable
Sep	6.19	Suitable
Oct	5.01	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Clear Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1688	1718	1747	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.0	90.36	1122	1122	1122	1.27	1.27	1.27	1122	1.27	90.36
	Dec	0.0	74.83	1109	1109	1109	1.30	1.30	1.30	1109	1.30	74.83
	Jan	0.0	68.95	1074	1074	1074	1.29	1.29	1.29	1074	1.29	68.95
	Feb	0.0	62.75	1092	1092	1092	1.35	1.35	1.35	1092	1.35	62.75
	Mar	0.0	88.75	1018	1018	1018	1.30	1.30	1.30	1018	1.30	88.75
Irrigation Season	Apr	0.0	94.47	1024	1024	1024	1.32	1.32	1.32	1024	1.32	94.47
	May	0.0	226.67	789	789	789	1.13	1.13	1.13	789	1.13	226.67
	Jun	0.0	288.88	568	568	568	0.96	0.96	0.96	568	0.96	288.88
	Jul	0.0	117.51	976	976	976	1.36	1.36	1.36	976	1.36	117.51
	Aug	0.0	82.30	1274	1274	1274	1.62	1.62	1.62	1274	1.62	82.30
	Sep	0.0	95.72	1221	1221	1221	1.51	1.51	1.51	1221	1.51	95.72
	Oct	0.0	90.44	1055	1055	1055	1.34	1.34	1.34	1055	1.34	90.44

[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)
Clear Creek	Clear Creek	0.0	70%	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	5560.8	31	90.44
Nov	5376.8	30	90.36
Dec	4601.0	31	74.83
Jan	4239.6	31	68.95
Feb	3485.0	28	62.75
Mar	5456.8	31	88.75
Apr	5621.5	30	94.47
May	13937.5	31	226.67
Jun	17189.8	30	288.88
Jul	7225.1	31	117.51
Aug	5060.3	31	82.30
Sep	5696.0	30	95.72

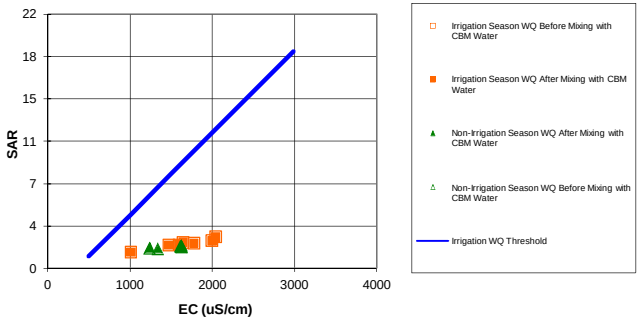
Irrigation Suitability Threshold Analysis		
Nov	5.49	Suitable
Dec	5.40	Suitable
Jan	5.15	Suitable
Feb	5.28	Suitable
Mar	4.75	Suitable
		Suitable
Apr	4.80	Suitable
May	3.13	Suitable
Jun	1.55	Suitable
Jul	4.45	Suitable
Aug	6.57	Suitable
Sep	6.19	Suitable
Oct	5.01	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.0	19.39	1621	1621	1621	2.00	2.00	2.00	1621	2.00	19.39
	Dec	0.0	19.19	1612	1612	1612	1.92	1.92	1.92	1612	1.92	19.19
	Jan	0.0	17.25	1623	1623	1623	1.86	1.86	1.86	1623	1.86	17.25
	Feb	0.0	20.62	1334	1334	1334	1.71	1.71	1.71	1334	1.71	20.62
	Mar	0.0	40.52	1234	1234	1234	1.76	1.76	1.76	1234	1.76	40.52
Irrigation Season	Apr	0.0	32.56	1641	1641	1641	2.28	2.28	2.28	1641	2.28	32.56
	May	0.0	75.92	1467	1467	1467	2.04	2.04	2.04	1467	2.04	75.92
	Jun	0.0	119.62	1007	1007	1007	1.43	1.43	1.43	1007	1.43	119.62
	Jul	0.0	42.21	1593	1593	1593	2.07	2.07	2.07	1593	2.07	42.21
	Aug	0.0	11.03	1774	1774	1774	2.20	2.20	2.20	1774	2.20	11.03
	Sep	0.0	6.65	2036	2036	2036	2.76	2.76	2.76	2036	2.76	6.65
	Oct	0.0	15.44	1994	1994	1994	2.42	2.42	2.42	1994	2.42	15.44

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)
Crazy Woman Creek	Crazy Woman Creek	0.1	70%	0.0	0.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	949.44	31	15.44
Nov	1153.68	30	19.39
Dec	1179.67	31	19.19
Jan	1060.87	31	17.25
Feb	1144.93	28	20.62
Mar	2491.67	31	40.52
Apr	1937.51	30	32.56
May	4667.84	31	75.92
Jun	7117.84	30	119.62
Jul	2595.59	31	42.21
Aug	678.08	31	11.03
Sep	395.42	30	6.65

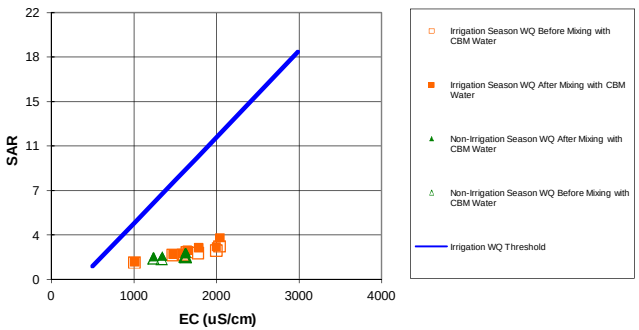
Irrigation Suitability Threshold Analysis		
Nov	9.03	Suitable
Dec	8.97	Suitable
Jan	9.05	Suitable
Feb	7.00	Suitable
Mar	6.28	Suitable
		Suitable
Apr	9.18	Suitable
May	7.94	Suitable
Jun	4.67	Suitable
Jul	8.84	Suitable
Aug	10.12	Suitable
Sep	11.98	Suitable
Oct	11.68	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.2	19.39	1624	1627	1629	2.23	2.25	2.28	1621	2.00	19.59
	Dec	0.2	19.19	1615	1617	1620	2.15	2.18	2.21	1612	1.92	19.39
	Jan	0.2	17.25	1626	1629	1632	2.12	2.15	2.18	1623	1.86	17.45
	Feb	0.2	20.62	1340	1342	1344	1.92	1.95	1.98	1334	1.71	20.82
	Mar	0.2	40.52	1237	1238	1239	1.87	1.89	1.90	1234	1.76	40.72
Irrigation Season	Apr	0.2	32.56	1643	1645	1646	2.41	2.43	2.45	1641	2.28	32.76
	May	0.2	75.92	1468	1469	1470	2.10	2.11	2.12	1467	2.04	76.12
	Jun	0.2	119.62	1008	1008	1009	1.47	1.47	1.48	1007	1.43	119.82
	Jul	0.2	42.21	1595	1596	1597	2.18	2.19	2.20	1593	2.07	42.41
	Aug	0.2	11.03	1777	1782	1786	2.60	2.65	2.70	1774	2.20	11.23
	Sep	0.2	6.65	2033	2040	2048	3.38	3.46	3.55	2036	2.76	6.85
	Oct	0.2	15.44	1993	1996	1999	2.70	2.73	2.77	1994	2.42	15.64

[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)
Crazy Woman Creek	Crazy Woman Creek	0.6	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	949.44	31	15.44
Nov	1153.68	30	19.39
Dec	1179.67	31	19.19
Jan	1060.87	31	17.25
Feb	1144.93	28	20.62
Mar	2491.67	31	40.52
Apr	1937.51	30	32.56
May	4667.84	31	75.92
Jun	7117.84	30	119.62
Jul	2595.59	31	42.21
Aug	678.08	31	11.03
Sep	395.42	30	6.65

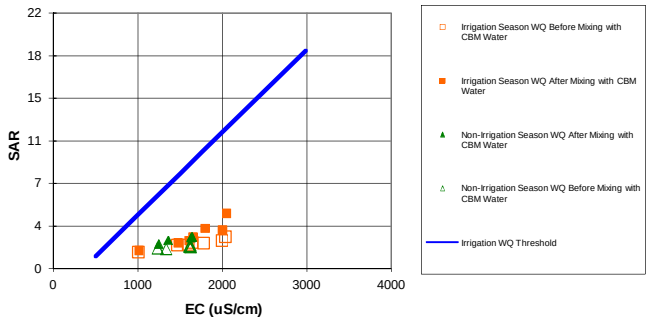
Irrigation Suitability Threshold Analysis		
Nov	9.07	Suitable
Dec	9.01	Suitable
Jan	9.09	Suitable
Feb	7.05	Suitable
Mar	6.32	Suitable
		Suitable
Apr	9.20	Suitable
May	7.96	Suitable
Jun	4.68	Suitable
Jul	8.86	Suitable
Aug	10.17	Suitable
Sep	12.01	Suitable
Oct	11.70	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Crazy Woman Creek: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1920	2178	2435	24.19	26.98	29.76

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.6	19.39	1630	1638	1646	2.66	2.75	2.83	1621	2.00	19.99
	Dec	0.6	19.19	1621	1629	1637	2.59	2.68	2.76	1612	1.92	19.79
	Jan	0.6	17.25	1633	1642	1650	2.61	2.71	2.80	1623	1.86	17.85
	Feb	0.6	20.62	1350	1358	1365	2.34	2.42	2.50	1334	1.71	21.22
	Mar	0.6	40.52	1244	1247	1251	2.09	2.13	2.17	1234	1.76	41.12
Irrigation Season	Apr	0.6	32.56	1646	1651	1656	2.68	2.73	2.78	1641	2.28	33.16
	May	0.6	75.92	1471	1473	1475	2.22	2.24	2.26	1467	2.04	76.52
	Jun	0.6	119.62	1011	1012	1014	1.55	1.56	1.57	1007	1.43	120.22
	Jul	0.6	42.21	1598	1602	1605	2.38	2.42	2.46	1593	2.07	42.81
	Aug	0.6	11.03	1782	1795	1808	3.34	3.48	3.63	1774	2.20	11.63
	Sep	0.6	6.65	2027	2048	2069	4.53	4.76	4.99	2036	2.76	7.25
	Oct	0.6	15.44	1991	2001	2010	3.23	3.34	3.44	1994	2.42	16.04

[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)
Crazy Woman Creek	Crazy Woman Creek	2.0	70%	0.6	0.6

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	949.44	31	15.44
Nov	1153.68	30	19.39
Dec	1179.67	31	19.19
Jan	1060.87	31	17.25
Feb	1144.93	28	20.62
Mar	2491.67	31	40.52
Apr	1937.51	30	32.56
May	4667.84	31	75.92
Jun	7117.84	30	119.62
Jul	2595.59	31	42.21
Aug	678.08	31	11.03
Sep	395.42	30	6.65

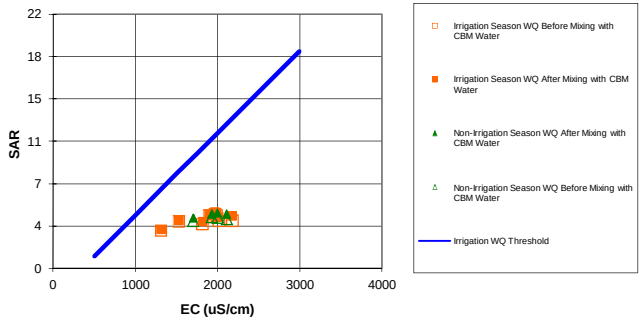
Irrigation Suitability Threshold Analysis		
Nov	9.15	Suitable
Dec	9.09	Suitable
Jan	9.18	Suitable
Feb	7.16	Suitable
Mar	6.38	Suitable
		Suitable
Apr	9.25	Suitable
May	7.98	Suitable
Jun	4.71	Suitable
Jul	8.90	Suitable
Aug	10.27	Suitable
Sep	12.07	Suitable
Oct	11.73	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	3.0	242.32	1925	1925	1925	4.71	4.74	4.78	1925	4.46	245.32
	Dec	3.0	163.39	2105	2105	2105	4.67	4.72	4.77	2108	4.30	166.39
	Jan	3.0	174.62	1993	1993	1994	4.79	4.84	4.88	1995	4.44	177.62
	Feb	3.0	311.46	1700	1700	1701	4.35	4.37	4.40	1698	4.15	314.46
Irrigation Season	Mar	3.0	480.11	1891	1891	1891	4.75	4.76	4.78	1891	4.62	483.11
	Apr	3.0	440.98	1961	1961	1961	4.87	4.89	4.91	1961	4.73	443.98
	May	3.0	816.21	1526	1526	1526	4.18	4.19	4.20	1524	4.10	819.21
	Jun	3.0	908.66	1310	1310	1310	3.36	3.37	3.38	1308	3.29	911.66
	Jul	3.0	325.59	1808	1808	1808	4.05	4.07	4.09	1807	3.85	328.59
	Aug	3.0	166.57	2170	2171	2171	4.53	4.58	4.62	2175	4.16	169.57
	Sep	3.0	180.81	2011	2011	2012	4.47	4.51	4.56	2013	4.13	183.81
	Oct	3.0	261.82	1985	1985	1985	4.82	4.85	4.88	1986	4.59	264.82

[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)
Middle Powder	Powder River at Moorhead	9.9	70%	3.0	3.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	16098.82	31	261.82
Nov	14418.84	30	242.32
Dec	10046.73	31	163.39
Jan	10737.10	31	174.62
Feb	17297.70	28	311.46
Mar	29520.54	31	480.11
Apr	26240.00	30	440.98
May	50186.52	31	816.21
Jun	54068.76	30	908.66
Jul	20019.68	31	325.59
Aug	10241.79	31	166.57
Sep	10759.01	30	180.81

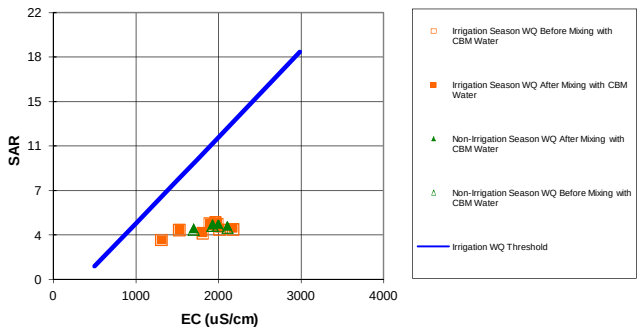
Irrigation Suitability Threshold Analysis		
Nov	11.19	Suitable
Dec	12.47	Suitable
Jan	11.68	Suitable
Feb	9.60	Suitable
Mar		Suitable
	10.95	Suitable
Apr	11.45	Suitable
May	8.36	Suitable
Jun	6.82	Suitable
Jul	10.36	Suitable
Aug	12.94	Suitable
Sep	11.81	Suitable
Oct	11.62	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	1.0	242.32	1925	1925	1925	4.54	4.56	4.57	1925	4.46	243.32
	Dec	1.0	163.39	2107	2107	2107	4.43	4.44	4.46	2108	4.30	164.39
	Jan	1.0	174.62	1994	1994	1994	4.56	4.57	4.59	1995	4.44	175.62
	Feb	1.0	311.46	1699	1699	1699	4.21	4.22	4.23	1698	4.15	312.46
Irrigation Season	Mar	1.0	480.11	1891	1891	1891	4.66	4.67	4.67	1891	4.62	481.11
	Apr	1.0	440.98	1961	1961	1961	4.78	4.78	4.79	1961	4.73	441.98
	May	1.0	816.21	1525	1525	1525	4.13	4.13	4.14	1524	4.10	817.21
	Jun	1.0	908.66	1308	1308	1308	3.31	3.32	3.32	1308	3.29	909.66
	Jul	1.0	325.59	1808	1808	1808	3.92	3.93	3.93	1807	3.85	326.59
	Aug	1.0	166.57	2174	2174	2174	4.28	4.30	4.31	2175	4.16	167.57
	Sep	1.0	180.81	2012	2012	2012	4.25	4.26	4.27	2013	4.13	181.81
	Oct	1.0	261.82	1985	1986	1986	4.67	4.68	4.69	1986	4.59	262.82

[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)
Middle Powder	Powder River at Moorhead	3.2	70%	1.0	1.0

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	16098.8	31	261.82
Nov	14418.8	30	242.32
Dec	10046.7	31	163.39
Jan	10737.1	31	174.62
Feb	17297.7	28	311.46
Mar	29520.5	31	480.11
Apr	26240.0	30	440.98
May	50186.5	31	816.21
Jun	54068.8	30	908.66
Jul	20019.7	31	325.59
Aug	10241.8	31	166.57
Sep	10759.0	30	180.81

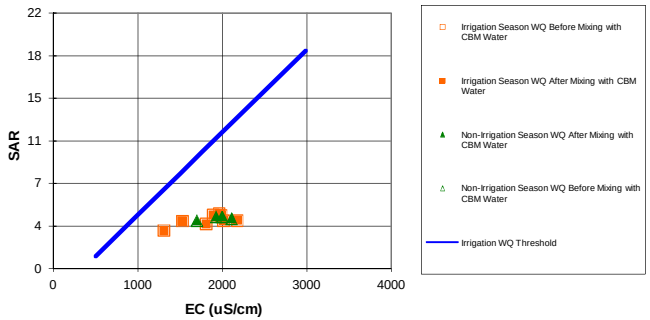
Irrigation Suitability Threshold Analysis		
Nov	11.19	Suitable
Dec	12.48	Suitable
Jan	11.68	Suitable
Feb	9.59	Suitable
Mar		Suitable
	10.95	Suitable
Apr	11.45	Suitable
May	8.35	Suitable
Jun	6.81	Suitable
Jul	10.36	Suitable
Aug	12.96	Suitable
Sep	11.81	Suitable
Oct	11.62	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Middle Powder River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1911	1929	1947	25.20	27.74	30.27

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.2	242.32	1925	1925	1925	4.48	4.48	4.48	1925	4.46	242.52
	Dec	0.2	163.39	2108	2108	2108	4.32	4.33	4.33	2108	4.30	163.59
	Jan	0.2	174.62	1994	1994	1995	4.47	4.47	4.47	1995	4.44	174.82
	Feb	0.2	311.46	1698	1698	1698	4.16	4.16	4.16	1698	4.15	311.66
	Mar	0.2	480.11	1891	1891	1891	4.63	4.63	4.63	1891	4.62	480.31
Irrigation Season	Apr	0.2	440.98	1961	1961	1961	4.74	4.74	4.74	1961	4.73	441.18
	May	0.2	816.21	1524	1524	1525	4.11	4.11	4.11	1524	4.10	816.41
	Jun	0.2	908.66	1308	1308	1308	3.30	3.30	3.30	1308	3.29	908.86
	Jul	0.2	325.59	1807	1807	1807	3.87	3.87	3.87	1807	3.85	325.79
	Aug	0.2	166.57	2175	2175	2175	4.18	4.19	4.19	2175	4.16	166.77
	Sep	0.2	180.81	2013	2013	2013	4.15	4.16	4.16	2013	4.13	181.01
	Oct	0.2	261.82	1986	1986	1986	4.61	4.61	4.61	1986	4.59	262.02

[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)
Middle Powder	Powder River at Moorhead	0.8	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	16098.82	31	261.82
Nov	14418.84	30	242.32
Dec	10046.73	31	163.39
Jan	10737.10	31	174.62
Feb	17297.70	28	311.46
Mar	29520.54	31	480.11
Apr	26240.00	30	440.98
May	50186.52	31	816.21
Jun	54068.76	30	908.66
Jul	20019.68	31	325.59
Aug	10241.79	31	166.57
Sep	10759.01	30	180.81

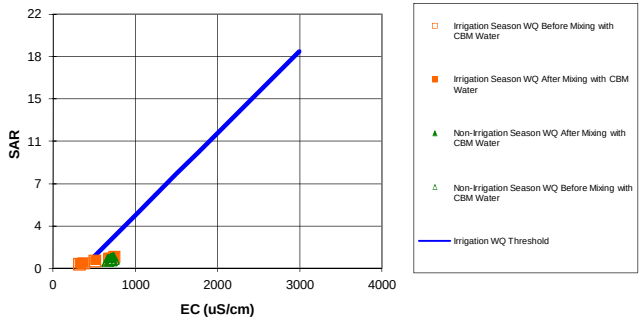
Irrigation Suitability Threshold Analysis		
Nov	11.19	Suitable
Dec	12.49	Suitable
Jan	11.69	Suitable
Feb	9.58	Suitable
Mar		Suitable
	10.95	Suitable
Apr	11.45	Suitable
May	8.35	Suitable
Jun	6.81	Suitable
Jul	10.36	Suitable
Aug	12.97	Suitable
Sep	11.82	Suitable
Oct	11.62	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2008



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.8	213.05	708	708	708	0.90	0.90	0.90	703	0.75	213.85
	Dec	0.8	174.44	698	699	699	0.92	0.93	0.93	693	0.75	175.24
	Jan	0.8	169.19	665	665	665	0.88	0.88	0.89	659	0.70	169.99
	Feb	0.8	193.90	703	703	703	0.95	0.95	0.96	697	0.79	194.70
	Mar	0.8	234.55	732	732	732	1.03	1.03	1.03	728	0.90	235.35
Irrigation Season	Apr	0.8	282.43	703	703	703	0.95	0.95	0.95	699	0.84	283.23
	May	0.8	693.50	370	370	370	0.52	0.52	0.52	368	0.47	694.30
	Jun	0.8	1105.83	319	319	319	0.43	0.43	0.43	318	0.40	1106.63
	Jul	0.8	536.06	507	507	507	0.72	0.73	0.73	504	0.67	536.86
	Aug	0.8	400.90	742	742	742	1.09	1.09	1.10	740	1.02	401.70
	Sep	0.8	319.64	685	685	685	0.91	0.92	0.92	682	0.82	320.44
	Oct	0.8	226.88	682	683	683	0.89	0.89	0.90	678	0.75	227.68

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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	2.7	70%	0.8	0.8

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	13950.24	31	226.88
Nov	12677.41	30	213.05
Dec	10726.01	31	174.44
Jan	10402.91	31	169.19
Feb	10768.86	28	193.90
Mar	14421.79	31	234.55
Apr	16805.81	30	282.43
May	42641.74	31	693.50
Jun	65801.47	30	1105.83
Jul	32961.21	31	536.06
Aug	24650.53	31	400.90
Sep	19020.19	30	319.64

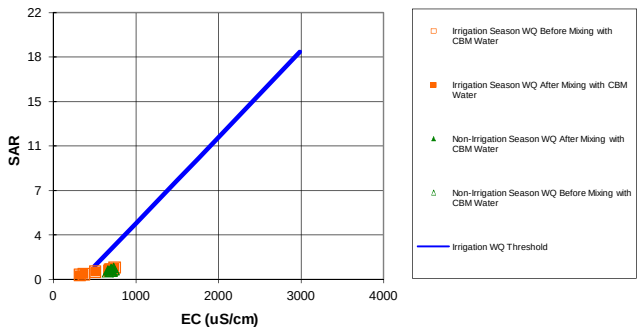
Irrigation Suitability Threshold Analysis		
Nov	2.55	Suitable
Dec	2.48	Suitable
Jan	2.25	Suitable
Feb	2.51	Suitable
Mar	2.72	Suitable
		Suitable
Apr	2.51	Suitable
May	0.15	Not Suitable
Jun	-0.21	Not Suitable
Jul	1.12	Suitable
Aug	2.79	Suitable
Sep	2.39	Suitable
Oct	2.37	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2020



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		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 (--)	Resulting stream (cfs)
Non-Irrigation Season	Nov	0.2	213.05	704	704	704	0.79	0.79	0.79	703	0.75	213.25
	Dec	0.2	174.44	694	694	694	0.79	0.79	0.80	693	0.75	174.64
	Jan	0.2	169.19	660	660	660	0.74	0.74	0.74	659	0.70	169.39
	Feb	0.2	193.90	699	699	699	0.83	0.83	0.83	697	0.79	194.10
	Mar	0.2	234.55	729	729	729	0.93	0.93	0.93	728	0.90	234.75
Irrigation Season	Apr	0.2	282.43	700	700	700	0.87	0.87	0.87	699	0.84	282.63
	May	0.2	693.50	368	368	368	0.48	0.48	0.48	368	0.47	693.70
	Jun	0.2	1105.83	318	318	318	0.41	0.41	0.41	318	0.40	1106.03
	Jul	0.2	536.06	505	505	505	0.68	0.68	0.68	504	0.67	536.26
	Aug	0.2	400.90	740	740	740	1.04	1.04	1.04	740	1.02	401.10
	Sep	0.2	319.64	683	683	683	0.84	0.84	0.84	682	0.82	319.84
	Oct	0.2	226.88	679	679	679	0.79	0.79	0.79	678	0.75	227.08

[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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	0.7	70%	0.2	0.2

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	13950.24	31	226.88
Nov	12677.41	30	213.05
Dec	10726.01	31	174.44
Jan	10402.91	31	169.19
Feb	10768.86	28	193.90
Mar	14421.79	31	234.55
Apr	16805.81	30	282.43
May	42641.74	31	693.50
Jun	65801.47	30	1105.83
Jul	32961.21	31	536.06
Aug	24650.53	31	400.90
Sep	19020.19	30	319.64

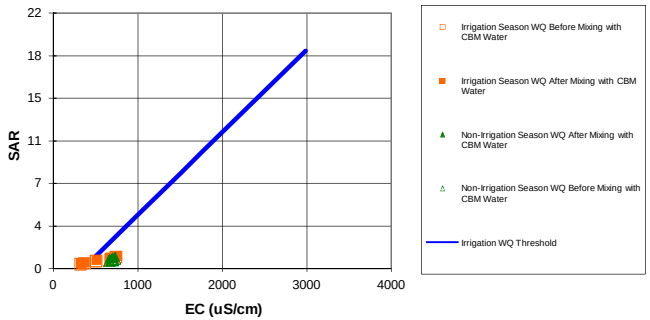
Irrigation Suitability Threshold Analysis		
Nov	2.52	Suitable
Dec	2.45	Suitable
Jan	2.21	Suitable
Feb	2.49	Suitable
Mar	2.70	Suitable
		Suitable
Apr	2.50	Suitable
May	0.14	Not Suitable
Jun	-0.22	Not Suitable
Jul	1.11	Suitable
Aug	2.78	Suitable
Sep	2.37	Suitable
Oct	2.35	Suitable

SAR values are based upon ambient EC

Normal Conditions

Impact of CBM Development on Surface Water in Powder River Basin

Tongue River: 2030



Stream Water Quality Before and After Mixing with CBM Produced Water for Mean Monthly Flows (Normal Hydrology)

EC (uS/cm)			SAR (--)		
1933	1948	1963	39.15	40.22	41.28

		Monthly Mean		Mixed Water Quality						Background Water Quality		Resulting stream
		CBM Flow (cfs)	StreamFlow (cfs)	EC (uS/cm)			SAR (--)			EC (uS/cm)	SAR (--)	(cfs)
				95% lower	mean	95% upper	95% lower	mean	95% upper			
Non-Irrigation Season	Nov	0.7	213.05	707	707	707	0.88	0.88	0.89	703	0.75	213.75
	Dec	0.7	174.44	698	698	698	0.90	0.91	0.91	693	0.75	175.14
	Jan	0.7	169.19	664	664	664	0.85	0.86	0.86	659	0.70	169.89
	Feb	0.7	193.90	702	702	702	0.93	0.93	0.93	697	0.79	194.60
	Mar	0.7	234.55	732	732	732	1.01	1.01	1.02	728	0.90	235.25
Irrigation Season	Apr	0.7	282.43	702	702	702	0.94	0.94	0.94	699	0.84	283.13
	May	0.7	693.50	369	369	369	0.51	0.51	0.51	368	0.47	694.20
	Jun	0.7	1105.83	319	319	319	0.42	0.42	0.43	318	0.40	1106.53
	Jul	0.7	536.06	506	506	506	0.72	0.72	0.72	504	0.67	536.76
	Aug	0.7	400.90	742	742	742	1.08	1.08	1.09	740	1.02	401.60
	Sep	0.7	319.64	685	685	685	0.90	0.90	0.91	682	0.82	320.34
	Oct	0.7	226.88	682	682	682	0.87	0.88	0.88	678	0.75	227.58

[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)
Tongue River	Tongue River near Birney Day School, near Birney, MT (USGS 06037616)	2.2	70%	0.7	0.7

Mean Monthly Discharge			
	Acre feet	Days	cfs
Oct	13950.24	31	226.88
Nov	12677.41	30	213.05
Dec	10726.01	31	174.44
Jan	10402.91	31	169.19
Feb	10768.86	28	193.90
Mar	14421.79	31	234.55
Apr	16805.81	30	282.43
May	42641.74	31	693.50
Jun	65801.47	30	1105.83
Jul	32961.21	31	536.06
Aug	24650.53	31	400.90
Sep	19020.19	30	319.64

Irrigation Suitability Threshold Analysis		
Nov	2.54	Suitable
Dec	2.48	Suitable
Jan	2.24	Suitable
Feb	2.51	Suitable
Mar	2.72	Suitable
		Suitable
Apr	2.51	Suitable
May	0.15	Not Suitable
Jun	-0.21	Not Suitable
Jul	1.12	Suitable
Aug	2.79	Suitable
Sep	2.39	Suitable
Oct	2.37	Suitable

SAR values are based upon ambient EC

APPENDIX 4A

CBNG DISCHARGE ANALYSIS RESULTS DRY YEAR

Antelope Creek Near Teckla, Wyoming (Station 06364700)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	0.0	2.5	0.8	NA	7.1	2.1	NA	2.5	0.7	NA
Nov	0.1	2.5	0.8	800.0%	7.1	2.1	2100.0%	2.5	0.7	700.0%
Dec	0.1	2.5	0.8	800.0%	7.1	2.1	2100.0%	2.5	0.7	700.0%
Jan	0.1	2.5	0.8	800.0%	7.1	2.1	2100.0%	2.5	0.7	700.0%
Feb	0.2	2.5	0.8	400.0%	7.1	2.1	1050.0%	2.5	0.7	350.0%
Mar	1.6	2.5	0.8	50.0%	7.1	2.1	131.3%	2.5	0.7	43.8%
Apr	1.7	2.5	0.8	47.1%	7.1	2.1	123.5%	2.5	0.7	41.2%
May	2.7	2.5	0.8	29.6%	7.1	2.1	77.8%	2.5	0.7	25.9%
Jun	1.2	2.5	0.8	66.7%	7.1	2.1	175.0%	2.5	0.7	58.3%
Jul	2.4	2.5	0.8	33.3%	7.1	2.1	87.5%	2.5	0.7	29.2%
Aug	1.5	2.5	0.8	53.3%	7.1	2.1	140.0%	2.5	0.7	46.7%
Sep	0.0	2.5	0.8	NA	7.1	2.1	NA	2.5	0.7	NA

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Little Powder River above Dry Creek Near Weston, Wyoming (Station 06324970)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	1.9	9.6	2.9	152.6%	2.2	0.7	36.8%	0.9	0.3	15.8%
Nov	1.3	9.6	2.9	223.1%	2.2	0.7	53.8%	0.9	0.3	23.1%
Dec	1.1	9.6	2.9	263.6%	2.2	0.7	63.6%	0.9	0.3	27.3%
Jan	1.3	9.6	2.9	223.1%	2.2	0.7	53.8%	0.9	0.3	23.1%
Feb	4.1	9.6	2.9	70.7%	2.2	0.7	17.1%	0.9	0.3	7.3%
Mar	21.9	9.6	2.9	13.2%	2.2	0.7	3.2%	0.9	0.3	1.4%
Apr	7.8	9.6	2.9	37.2%	2.2	0.7	9.0%	0.9	0.3	3.8%
May	7.7	9.6	2.9	37.7%	2.2	0.7	9.1%	0.9	0.3	3.9%
Jun	3.2	9.6	2.9	90.6%	2.2	0.7	21.9%	0.9	0.3	9.4%
Jul	6.2	9.6	2.9	46.8%	2.2	0.7	11.3%	0.9	0.3	4.8%
Aug	10.8	9.6	2.9	26.9%	2.2	0.7	6.5%	0.9	0.3	2.8%
Sep	1.6	9.6	2.9	181.3%	2.2	0.7	43.8%	0.9	0.3	18.8%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

(Upper) Belle Fourche River Below Moorcroft, Wyoming (Station 06426500)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	3.5	10.0	3.0	85.7%	4.0	1.2	34.3%	0.8	0.2	5.7%
Nov	5.3	10.0	3.0	56.6%	4.0	1.2	22.6%	0.8	0.2	3.8%
Dec	6.3	10.0	3.0	47.6%	4.0	1.2	19.0%	0.8	0.2	3.2%
Jan	5.3	10.0	3.0	56.6%	4.0	1.2	22.6%	0.8	0.2	3.8%
Feb	8.2	10.0	3.0	36.6%	4.0	1.2	14.6%	0.8	0.2	2.4%
Mar	28.4	10.0	3.0	10.6%	4.0	1.2	4.2%	0.8	0.2	0.7%
Apr	18.0	10.0	3.0	16.7%	4.0	1.2	6.7%	0.8	0.2	1.1%
May	15.2	10.0	3.0	19.7%	4.0	1.2	7.9%	0.8	0.2	1.3%
Jun	9.5	10.0	3.0	31.6%	4.0	1.2	12.6%	0.8	0.2	2.1%
Jul	5.5	10.0	3.0	54.5%	4.0	1.2	21.8%	0.8	0.2	3.6%
Aug	3.9	10.0	3.0	76.9%	4.0	1.2	30.8%	0.8	0.2	5.1%
Sep	4.2	10.0	3.0	71.4%	4.0	1.2	28.6%	0.8	0.2	4.8%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

(Upper) Cheyenne River Near Spencer, Wyoming (Station 06395000)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	1.6	0.4	0.1	6.3%	0.4	0.1	6.3%	0.0	0.0	0.0%
Nov	2.7	0.4	0.1	3.7%	0.4	0.1	3.7%	0.0	0.0	0.0%
Dec	1.9	0.4	0.1	5.3%	0.4	0.1	5.3%	0.0	0.0	0.0%
Jan	1.1	0.4	0.1	9.1%	0.4	0.1	9.1%	0.0	0.0	0.0%
Feb	0.5	0.4	0.1	20.0%	0.4	0.1	20.0%	0.0	0.0	0.0%
Mar	8.5	0.4	0.1	1.2%	0.4	0.1	1.2%	0.0	0.0	0.0%
Apr	5.1	0.4	0.1	2.0%	0.4	0.1	2.0%	0.0	0.0	0.0%
May	43.6	0.4	0.1	0.2%	0.4	0.1	0.2%	0.0	0.0	0.0%
Jun	18.8	0.4	0.1	0.5%	0.4	0.1	0.5%	0.0	0.0	0.0%
Jul	4.7	0.4	0.1	2.1%	0.4	0.1	2.1%	0.0	0.0	0.0%
Aug	29.9	0.4	0.1	0.3%	0.4	0.1	0.3%	0.0	0.0	0.0%
Sep	0.4	0.4	0.1	25.0%	0.4	0.1	25.0%	0.0	0.0	0.0%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

(Upper) Powder River at Arvada, Wyoming (Station 06317000)										
Month	Receiving Drainage Streamflow (cfs)	**Year**								
		2008			2020			2030		
		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)	(%)
Oct	75.4	60.3	18.1	24.0%	34.3	10.3	13.7%	14.8	4.4	5.8%
Nov	104.7	60.3	18.1	17.3%	34.3	10.3	9.8%	14.8	4.4	4.2%
Dec	95.7	60.3	18.1	18.9%	34.3	10.3	10.8%	14.8	4.4	4.6%
Jan	97.1	60.3	18.1	18.6%	34.3	10.3	10.6%	14.8	4.4	4.5%
Feb	96.6	60.3	18.1	18.7%	34.3	10.3	10.7%	14.8	4.4	4.6%
Mar	273.4	60.3	18.1	6.6%	34.3	10.3	3.8%	14.8	4.4	1.6%
Apr	207.6	60.3	18.1	8.7%	34.3	10.3	5.0%	14.8	4.4	2.1%
May	213.5	60.3	18.1	8.5%	34.3	10.3	4.8%	14.8	4.4	2.1%
Jun	86.8	60.3	18.1	20.9%	34.3	10.3	11.9%	14.8	4.4	5.1%
Jul	84.6	60.3	18.1	21.4%	34.3	10.3	12.2%	14.8	4.4	5.2%
Aug	39.8	60.3	18.1	45.5%	34.3	10.3	25.9%	14.8	4.4	11.1%
Sep	45.8	60.3	18.1	39.5%	34.3	10.3	22.5%	14.8	4.4	9.6%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Dry Fork Cheyenne River Near Bill, Wyoming (Station 0634700)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	0.0	0.42	0.13	0.0%	0.00	0.00	0.0%	1.48	0.44	0.0%
Nov	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Dec	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Jan	0.0	0.42	0.13	0.0%	0.00	0.00	0.0%	1.48	0.44	0.0%
Feb	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Mar	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Apr	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
May	0.3	0.42	0.13	43.3%	0.00	0.00	0.0%	1.48	0.44	146.7%
Jun	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Jul	0.0	0.42	0.13	0.0%	0.00	0.00	0.0%	1.48	0.44	0.0%
Aug	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Sep	0.0	0.42	0.13	0.0%	0.00	0.00	0.0%	1.48	0.44	0.0%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Clear Creek near Arvada, WY (USGS 06324000)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	43.2	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Nov	45.4	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Dec	35.0	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jan	37.4	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Feb	35.1	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Mar	47.7	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Apr	57.4	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
May	59.5	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jun	60.2	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jul	32.6	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Aug	19.2	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Sep	33.1	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Crazy Woman Creek near Arvada, WY (USGS 06316400)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	4.0	0.13	0.04	1.0%	0.61	0.18	4.5%	2.01	0.60	15.0%
Nov	7.7	0.13	0.04	0.5%	0.61	0.18	2.3%	2.01	0.60	7.8%
Dec	9.0	0.13	0.04	0.4%	0.61	0.18	2.0%	2.01	0.60	6.7%
Jan	7.2	0.13	0.04	0.6%	0.61	0.18	2.5%	2.01	0.60	8.3%
Feb	9.7	0.13	0.04	0.4%	0.61	0.18	1.9%	2.01	0.60	6.2%
Mar	19.1	0.13	0.04	0.2%	0.61	0.18	0.9%	2.01	0.60	3.1%
Apr	23.4	0.13	0.04	0.2%	0.61	0.18	0.8%	2.01	0.60	2.6%
May	61.0	0.13	0.04	0.1%	0.61	0.18	0.3%	2.01	0.60	1.0%
Jun	77.0	0.13	0.04	0.1%	0.61	0.18	0.2%	2.01	0.60	0.8%
Jul	22.4	0.13	0.04	0.2%	0.61	0.18	0.8%	2.01	0.60	2.7%
Aug	7.3	0.13	0.04	0.5%	0.61	0.18	2.5%	2.01	0.60	8.2%
Sep	2.5	0.13	0.04	1.6%	0.61	0.18	7.2%	2.01	0.60	24.0%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Powder River near Moorhead, MT (USGS 06324500)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	158.7	9.92	2.98	1.9%	3.21	0.96	0.6%	0.75	0.23	0.1%
Nov	167.7	9.92	2.98	1.8%	3.21	0.96	0.6%	0.75	0.23	0.1%
Dec	130.4	9.92	2.98	2.3%	3.21	0.96	0.7%	0.75	0.23	0.2%
Jan	141.5	9.92	2.98	2.1%	3.21	0.96	0.7%	0.75	0.23	0.2%
Feb	137.6	9.92	2.98	2.2%	3.21	0.96	0.7%	0.75	0.23	0.2%
Mar	321.2	9.92	2.98	0.9%	3.21	0.96	0.3%	0.75	0.23	0.1%
Apr	291.3	9.92	2.98	1.0%	3.21	0.96	0.3%	0.75	0.23	0.1%
May	230.3	9.92	2.98	1.3%	3.21	0.96	0.4%	0.75	0.23	0.1%
Jun	117.2	9.92	2.98	2.5%	3.21	0.96	0.8%	0.75	0.23	0.2%
Jul	96.5	9.92	2.98	3.1%	3.21	0.96	1.0%	0.75	0.23	0.2%
Aug	77.1	9.92	2.98	3.9%	3.21	0.96	1.2%	0.75	0.23	0.3%
Sep	80.0	9.92	2.98	3.7%	3.21	0.96	1.2%	0.75	0.23	0.3%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

Tongue River near Birney Day School, near Birney, MT (USGS 06037616)										
Month	Receiving Drainage Streamflow (cfs)	Year								
		2008			2020			2030		
		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)	(%)
Oct	170.8	2.67	0.80	0.5%	0.73	0.22	0.1%	2.24	0.67	0.4%
Nov	150.3	2.67	0.80	0.5%	0.73	0.22	0.1%	2.24	0.67	0.4%
Dec	138.7	2.67	0.80	0.6%	0.73	0.22	0.2%	2.24	0.67	0.5%
Jan	135.5	2.67	0.80	0.6%	0.73	0.22	0.2%	2.24	0.67	0.5%
Feb	128.8	2.67	0.80	0.6%	0.73	0.22	0.2%	2.24	0.67	0.5%
Mar	136.5	2.67	0.80	0.6%	0.73	0.22	0.2%	2.24	0.67	0.5%
Apr	181.3	2.67	0.80	0.4%	0.73	0.22	0.1%	2.24	0.67	0.4%
May	232.5	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.3%
Jun	255.1	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.3%
Jul	288.2	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.2%
Aug	206.8	2.67	0.80	0.4%	0.73	0.22	0.1%	2.24	0.67	0.3%
Sep	142.3	2.67	0.80	0.6%	0.73	0.22	0.2%	2.24	0.67	0.5%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow

APPENDIX 4A

CBNG DISCHARGE ANALYSIS RESULTS NORMAL YEAR

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

Antelope Creek Near Teckla, Wyoming (Station 06364700)										
Month	Receiving Drainage Streamflow (cfs)	**Alternative**								
		2008			2020			2030		
		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)	(%)
Oct	0.2	2.5	0.8	400.0%	7.1	2.1	1050.0%	2.5	0.7	350.0%
Nov	0.2	2.5	0.8	400.0%	7.1	2.1	1050.0%	2.5	0.7	350.0%
Dec	0.4	2.5	0.8	200.0%	7.1	2.1	525.0%	2.5	0.7	175.0%
Jan	0.3	2.5	0.8	266.7%	7.1	2.1	700.0%	2.5	0.7	233.3%
Feb	0.6	2.5	0.8	133.3%	7.1	2.1	350.0%	2.5	0.7	116.7%
Mar	6.8	2.5	0.8	11.8%	7.1	2.1	30.9%	2.5	0.7	10.3%
Apr	7.3	2.5	0.8	11.0%	7.1	2.1	28.8%	2.5	0.7	9.6%
May	9.9	2.5	0.8	8.1%	7.1	2.1	21.2%	2.5	0.7	7.1%
Jun	5.1	2.5	0.8	15.7%	7.1	2.1	41.2%	2.5	0.7	13.7%
Jul	9.3	2.5	0.8	8.6%	7.1	2.1	22.6%	2.5	0.7	7.5%
Aug	5.9	2.5	0.8	13.6%	7.1	2.1	35.6%	2.5	0.7	11.9%
Sep	0.1	2.5	0.8	800.0%	7.1	2.1	2100.0%	2.5	0.7	700.0%

(1) Source: AECOM, December 2011
(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**								
		2008			2020			2030		
		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)	(%)
Oct	4.3	9.6	2.9	67.4%	2.2	0.7	16.3%	0.9	0.3	7.0%
Nov	3.3	9.6	2.9	87.9%	2.2	0.7	21.2%	0.9	0.3	9.1%
Dec	2.4	9.6	2.9	120.8%	2.2	0.7	29.2%	0.9	0.3	12.5%
Jan	3.8	9.6	2.9	76.3%	2.2	0.7	18.4%	0.9	0.3	7.9%
Feb	40.8	9.6	2.9	7.1%	2.2	0.7	1.7%	0.9	0.3	0.7%
Mar	44.2	9.6	2.9	6.6%	2.2	0.7	1.6%	0.9	0.3	0.7%
Apr	17.0	9.6	2.9	17.1%	2.2	0.7	4.1%	0.9	0.3	1.8%
May	40.6	9.6	2.9	7.1%	2.2	0.7	1.7%	0.9	0.3	0.7%
Jun	23.5	9.6	2.9	12.3%	2.2	0.7	3.0%	0.9	0.3	1.3%
Jul	9.3	9.6	2.9	31.2%	2.2	0.7	7.5%	0.9	0.3	3.2%
Aug	4.5	9.6	2.9	64.4%	2.2	0.7	15.6%	0.9	0.3	6.7%
Sep	5.3	9.6	2.9	54.7%	2.2	0.7	13.2%	0.9	0.3	5.7%

(1) Source: AECOM, December 2011
(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**								
		2008			2020			2030		
		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)	(%)
Oct	6.8	10.0	3.0	44.1%	4.0	1.2	17.6%	0.8	0.2	2.9%
Nov	5.1	10.0	3.0	58.8%	4.0	1.2	23.5%	0.8	0.2	3.9%
Dec	4.5	10.0	3.0	66.7%	4.0	1.2	26.7%	0.8	0.2	4.4%
Jan	5.5	10.0	3.0	54.5%	4.0	1.2	21.8%	0.8	0.2	3.6%
Feb	24.2	10.0	3.0	12.4%	4.0	1.2	5.0%	0.8	0.2	0.8%
Mar	59.0	10.0	3.0	5.1%	4.0	1.2	2.0%	0.8	0.2	0.3%
Apr	20.6	10.0	3.0	14.6%	4.0	1.2	5.8%	0.8	0.2	1.0%
May	37.5	10.0	3.0	8.0%	4.0	1.2	3.2%	0.8	0.2	0.5%
Jun	22.4	10.0	3.0	13.4%	4.0	1.2	5.4%	0.8	0.2	0.9%
Jul	16.4	10.0	3.0	18.3%	4.0	1.2	7.3%	0.8	0.2	1.2%
Aug	6.7	10.0	3.0	44.8%	4.0	1.2	17.9%	0.8	0.2	3.0%
Sep	5.4	10.0	3.0	55.6%	4.0	1.2	22.2%	0.8	0.2	3.7%

(1) Source: AECOM, December 2011
(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**								
		2008			2020			2030		
		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)	(%)
Oct	5.7	0.4	0.1	1.8%	0.4	0.1	1.8%	0.0	0.0	0.0%
Nov	9.5	0.4	0.1	1.1%	0.4	0.1	1.1%	0.0	0.0	0.0%
Dec	6.8	0.4	0.1	1.5%	0.4	0.1	1.5%	0.0	0.0	0.0%
Jan	4.0	0.4	0.1	2.5%	0.4	0.1	2.5%	0.0	0.0	0.0%
Feb	1.7	0.4	0.1	5.9%	0.4	0.1	5.9%	0.0	0.0	0.0%
Mar	31.5	0.4	0.1	0.3%	0.4	0.1	0.3%	0.0	0.0	0.0%
Apr	18.8	0.4	0.1	0.5%	0.4	0.1	0.5%	0.0	0.0	0.0%
May	164.5	0.4	0.1	0.1%	0.4	0.1	0.1%	0.0	0.0	0.0%
Jun	70.3	0.4	0.1	0.1%	0.4	0.1	0.1%	0.0	0.0	0.0%
Jul	17.7	0.4	0.1	0.6%	0.4	0.1	0.6%	0.0	0.0	0.0%
Aug	93.7	0.4	0.1	0.1%	0.4	0.1	0.1%	0.0	0.0	0.0%
Sep	1.4	0.4	0.1	7.1%	0.4	0.1	7.1%	0.0	0.0	0.0%

(1) Source: AECOM, December 2011
(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**								
		2008			2020			2030		
		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)	(%)
Oct	148.9	60.3	18.1	12.2%	34.3	10.3	6.9%	14.8	4.4	3.0%
Nov	154.0	60.3	18.1	11.8%	34.3	10.3	6.7%	14.8	4.4	2.9%
Dec	109.1	60.3	18.1	16.6%	34.3	10.3	9.4%	14.8	4.4	4.0%
Jan	110.2	60.3	18.1	16.4%	34.3	10.3	9.3%	14.8	4.4	4.0%
Feb	201.2	60.3	18.1	9.0%	34.3	10.3	5.1%	14.8	4.4	2.2%
Mar	342.6	60.3	18.1	5.3%	34.3	10.3	3.0%	14.8	4.4	1.3%
Apr	327.7	60.3	18.1	5.5%	34.3	10.3	3.1%	14.8	4.4	1.3%
May	534.3	60.3	18.1	3.4%	34.3	10.3	1.9%	14.8	4.4	0.8%
Jun	441.2	60.3	18.1	4.1%	34.3	10.3	2.3%	14.8	4.4	1.0%
Jul	181.1	60.3	18.1	10.0%	34.3	10.3	5.7%	14.8	4.4	2.4%
Aug	83.1	60.3	18.1	21.8%	34.3	10.3	12.4%	14.8	4.4	5.3%
Sep	82.5	60.3	18.1	21.9%	34.3	10.3	12.5%	14.8	4.4	5.3%

(1) Source: AECOM, December 2011
(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**								
		2008			2020			2030		
		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)	(%)
Oct	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Nov	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Dec	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Jan	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Feb	0.5	0.42	0.13	26.0%	0.00	0.00	0.0%	1.48	0.44	88.0%
Mar	0.6	0.42	0.13	21.7%	0.00	0.00	0.0%	1.48	0.44	73.3%
Apr	0.5	0.42	0.13	26.0%	0.00	0.00	0.0%	1.48	0.44	88.0%
May	0.7	0.42	0.13	18.6%	0.00	0.00	0.0%	1.48	0.44	62.9%
Jun	0.8	0.42	0.13	16.3%	0.00	0.00	0.0%	1.48	0.44	55.0%
Jul	0.1	0.42	0.13	130.0%	0.00	0.00	0.0%	1.48	0.44	440.0%
Aug	0.2	0.42	0.13	65.0%	0.00	0.00	0.0%	1.48	0.44	220.0%
Sep	0.0	0.42	0.13	NA	0.00	0.00	NA	1.48	0.44	NA

(1) Source: AECOM, December 2011
(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

Clear Creek near Arvada, WY (USGS 06324000)										
Month	Receiving Drainage Streamflow (cfs)	**Alternative**								
		2008			2020			2030		
		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)	(%)
Oct	90.4	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Nov	90.4	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Dec	74.8	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jan	69.0	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Feb	62.8	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Mar	88.7	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Apr	94.5	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
May	226.7	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jun	288.9	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Jul	117.5	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Aug	82.3	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%
Sep	95.7	0.00	0.00	0.0%	0.00	0.00	0.0%	0.00	0.00	0.0%

(1) Source: AECOM, December 2011
(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

Crazy Woman Creek near Arvada, WY (USGS 06316400)										
Month	Receiving Drainage Streamflow (cfs)	**Alternative**								
		2008			2020			2030		
		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)	(%)
Oct	15.4	0.13	0.04	0.3%	0.61	0.18	1.2%	2.01	0.60	3.9%
Nov	19.4	0.13	0.04	0.2%	0.61	0.18	0.9%	2.01	0.60	3.1%
Dec	19.2	0.13	0.04	0.2%	0.61	0.18	0.9%	2.01	0.60	3.1%
Jan	17.3	0.13	0.04	0.2%	0.61	0.18	1.0%	2.01	0.60	3.5%
Feb	20.6	0.13	0.04	0.2%	0.61	0.18	0.9%	2.01	0.60	2.9%
Mar	40.5	0.13	0.04	0.1%	0.61	0.18	0.4%	2.01	0.60	1.5%
Apr	32.6	0.13	0.04	0.1%	0.61	0.18	0.6%	2.01	0.60	1.8%
May	75.9	0.13	0.04	0.1%	0.61	0.18	0.2%	2.01	0.60	0.8%
Jun	119.6	0.13	0.04	0.0%	0.61	0.18	0.2%	2.01	0.60	0.5%
Jul	42.2	0.13	0.04	0.1%	0.61	0.18	0.4%	2.01	0.60	1.4%
Aug	11.0	0.13	0.04	0.4%	0.61	0.18	1.6%	2.01	0.60	5.5%
Sep	6.6	0.13	0.04	0.6%	0.61	0.18	2.7%	2.01	0.60	9.1%

(1) Source: AECOM, December 2011
(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

Powder River near Moorhead, MT (USGS 06324500)										
Month	Receiving Drainage Streamflow (cfs)	**Alternative**								
		2008			2020			2030		
		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)	(%)
Oct	261.8	9.92	2.98	1.1%	3.21	0.96	0.4%	0.75	0.23	0.1%
Nov	242.3	9.92	2.98	1.2%	3.21	0.96	0.4%	0.75	0.23	0.1%
Dec	163.4	9.92	2.98	1.8%	3.21	0.96	0.6%	0.75	0.23	0.1%
Jan	174.6	9.92	2.98	1.7%	3.21	0.96	0.5%	0.75	0.23	0.1%
Feb	311.5	9.92	2.98	1.0%	3.21	0.96	0.3%	0.75	0.23	0.1%
Mar	480.1	9.92	2.98	0.6%	3.21	0.96	0.2%	0.75	0.23	0.0%
Apr	441.0	9.92	2.98	0.7%	3.21	0.96	0.2%	0.75	0.23	0.1%
May	816.2	9.92	2.98	0.4%	3.21	0.96	0.1%	0.75	0.23	0.0%
Jun	908.7	9.92	2.98	0.3%	3.21	0.96	0.1%	0.75	0.23	0.0%
Jul	325.6	9.92	2.98	0.9%	3.21	0.96	0.3%	0.75	0.23	0.1%
Aug	166.6	9.92	2.98	1.8%	3.21	0.96	0.6%	0.75	0.23	0.1%
Sep	180.8	9.92	2.98	1.6%	3.21	0.96	0.5%	0.75	0.23	0.1%

(1) Source: AECOM, December 2011
(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

Tongue River near Birney Day School, near Birney, MT (USGS 06037616)										
Month	Receiving Drainage Streamflow (cfs)	**Alternative**								
		2008			2020			2030		
		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)	(%)
Oct	226.9	2.67	0.80	0.4%	0.73	0.22	0.1%	2.24	0.67	0.3%
Nov	213.1	2.67	0.80	0.4%	0.73	0.22	0.1%	2.24	0.67	0.3%
Dec	174.4	2.67	0.80	0.5%	0.73	0.22	0.1%	2.24	0.67	0.4%
Jan	169.2	2.67	0.80	0.5%	0.73	0.22	0.1%	2.24	0.67	0.4%
Feb	193.9	2.67	0.80	0.4%	0.73	0.22	0.1%	2.24	0.67	0.3%
Mar	234.5	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.3%
Apr	282.4	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.2%
May	693.5	2.67	0.80	0.1%	0.73	0.22	0.0%	2.24	0.67	0.1%
Jun	1,105.8	2.67	0.80	0.1%	0.73	0.22	0.0%	2.24	0.67	0.1%
Jul	536.1	2.67	0.80	0.1%	0.73	0.22	0.0%	2.24	0.67	0.1%
Aug	400.9	2.67	0.80	0.2%	0.73	0.22	0.1%	2.24	0.67	0.2%
Sep	319.6	2.67	0.80	0.3%	0.73	0.22	0.1%	2.24	0.67	0.2%

(1) Source: AECOM, December 2011
(2) CBNG Flow reduced assuming 70% conveyance loss
(3) Reduced CBNG Flow divided by Receiving Drainage Streamflow