5.0 IMPACTS PROJECTED BY THE SURFACE WATER MODEL

The projected impacts of CBM development on surface water quality in each sub-watershed were derived with the use of four graphs, which are described below. The four graphs included in this document for each sub-watershed depict the preferred alternative, which for the Wyoming streams is Alternative 2A and for the Montana streams is Alternative E. The first graph plots ambient and projected EC for mean monthly and 7Q10 flows. The second graph plots ambient and projected SAR for mean monthly and 7Q10 flows. Both these graphs include lines showing the LRPL and MRPL to facilitate evaluation of the impacts. The next two graphs plot ambient and projected water quality for both EC and SAR in relation to the Ayers-Westcott EC-SAR threshold that represents no reduction in the rate of infiltration" as well as to the LRPL and MRPL. Water quality that meets the proposed EC and SAR limits as well as the Ayers-Westcott threshold should fall to the left of the proposed EC limit, below the proposed SAR limit and below and to the right of the diagonal line on the graphs. The first of these graphs plots ambient and projected EC and SAR for mean monthly and 7Q10 flows. The second plots the projected EC and SAR for incremental proportions of CBM discharge. The input parameters used in developing the graphs are summarized in Appendices C and D.

When considering the potential impacts to surface water resources discussed below for each sub-watershed under the various alternatives, the reader should be aware that the mass balance model used in this analysis is a tool for comparison of alternatives, and analysis of relative contributions of cumulative impacts. However, due to a lack of data regarding chemical transport relationships and conveyance loss it may not accurately predict likely impacts on resultant water quality (See Appendix E). Samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge.

5.1 Wyoming Streams

5.1.1 Belle Fourche River

Results of the impact analysis in the Upper Belle Fourche River sub-watershed under each alternative are presented in Table 5-1. Potential impacts are discussed below.

5.1.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Belle Fourche River sub-watershed would occur in year 2006, when 7,630 wells would be producing at an average rate of 7.0 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 49 cfs (35,479 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Belle Fourche River currently exceed the MRPL and LRPL for EC during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL for

SAR under similar flow conditions. After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero, so that the resulting water quality under these flow conditions would be represented by the quality of CBM produced water, if discharges were to occur during critical low flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Belle Fourche River at Moorcroft, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season (April, and July through October), as well as during 7Q10 flow conditions. Only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow.

5.1.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1 primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments for water handling. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 61 cfs (44,168 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Table 5-1
Impact Analysis for Surface Water of the Upper Belle Fourche River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	2.3	6.8	2755	51	8.1	1051	0.0	--	--	49	8.2	970
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				64	8.1	1034				62	8.2	970
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				64	8.1	1034				62	8.2	970
3	10 (1)	2000 (1)	10 (2)	2500 (2)				37	8.1	1081				35	8.2	970

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standards.

After they have mixed, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-1 and 5-2 illustrate the months during the year under Alternative 2A when the existing stream water quality and resulting mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Upper Belle Fourche River sub-watershed. Under modeled conditions, the resulting water quality in the Belle Fourche River at Moorcroft, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Figure 5-3 illustrates the relationship between EC and SAR in the Belle Fourche River before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season, as well as during 7Q10 flow conditions. Figure 5-4 illustrates the relationship between EC and SAR in the Belle Fourche River after the water mixes with varying proportions of CBM produced water discharges under various stream flow conditions. Only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow.

Based on modeled results, impacts to the suitability for irrigation of the Upper Belle Fourche River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River sub-watershed have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Belle Fourche River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-1 Stream EC Before and After Mixing-Upper Belle Fourche River Sub-Watershed

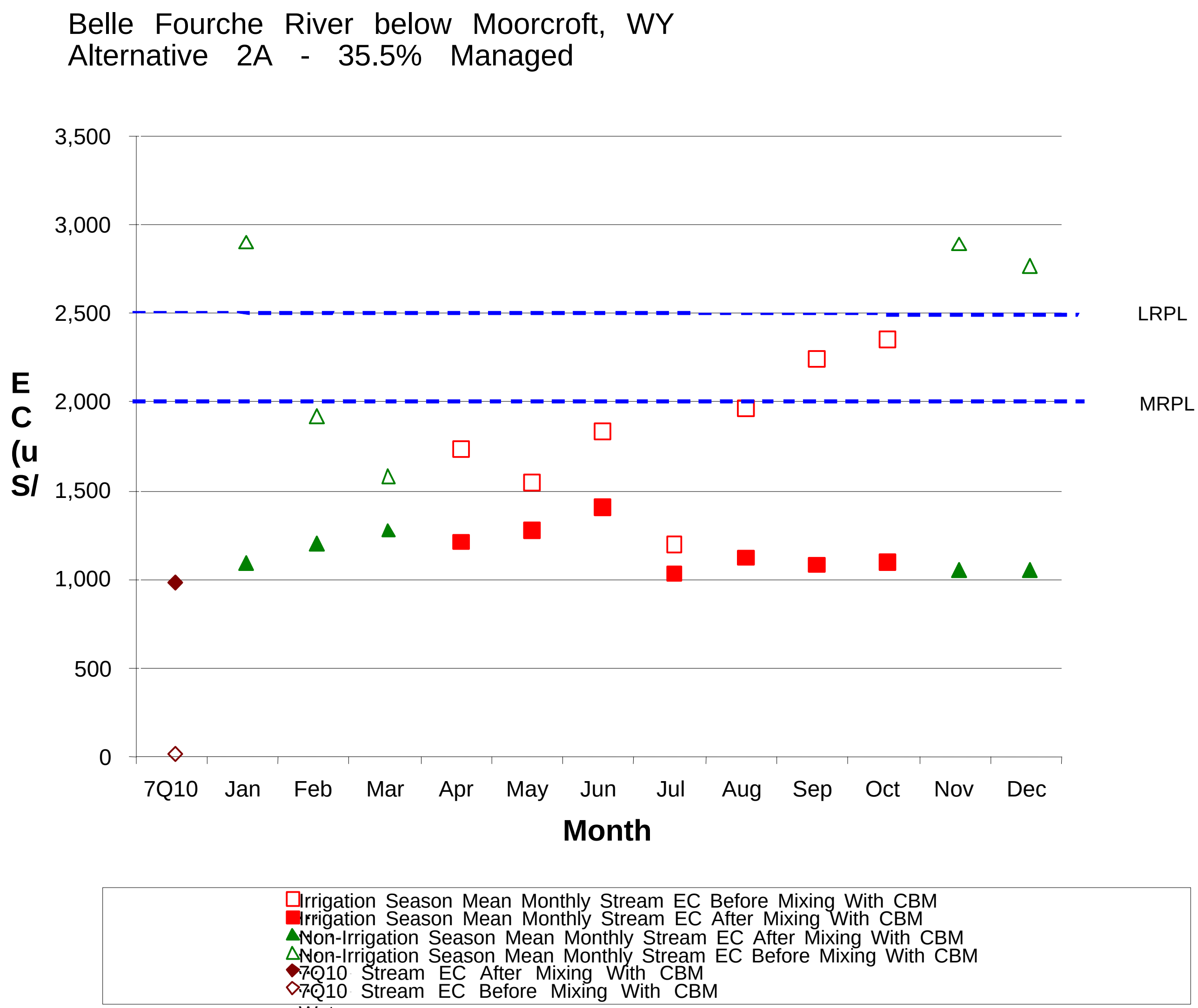


Figure 5-2 **Stream SAR Before and After Mixing-Upper Belle Fourche River Sub-Watershed**

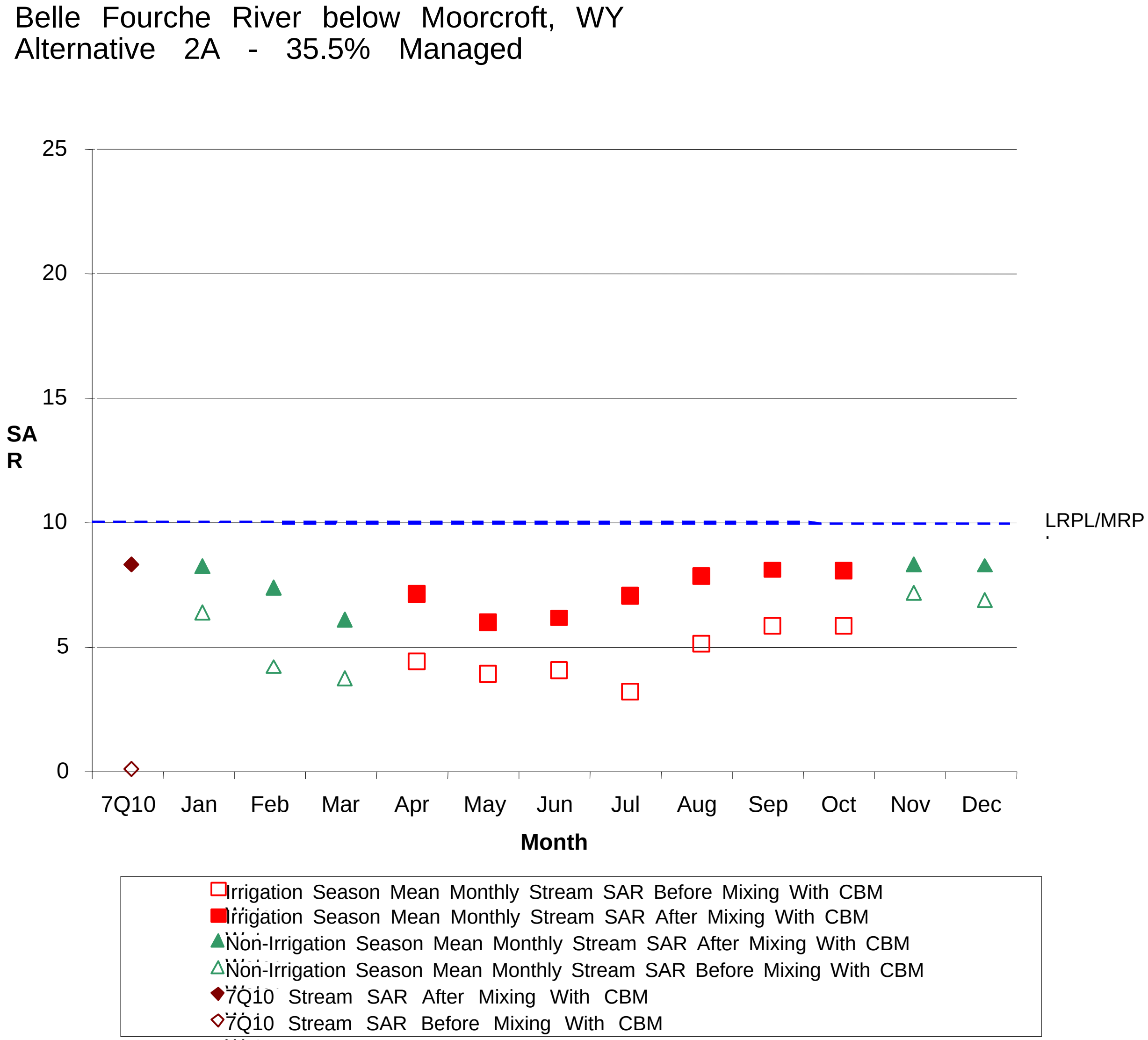


Figure 5-3 Irrigation Suitability Before and After Mixing – Upper Belle Fourche River Sub-Watershed

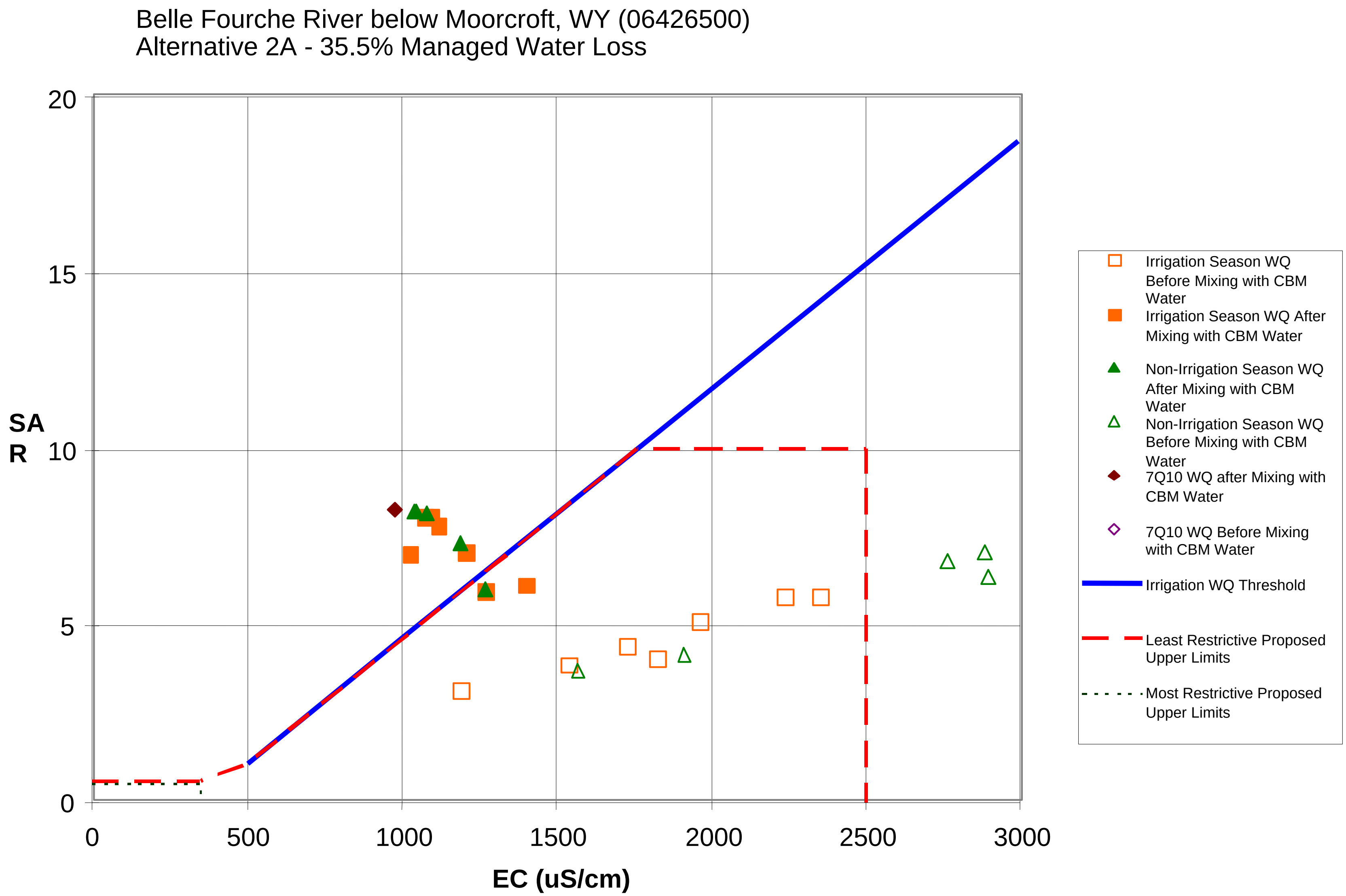
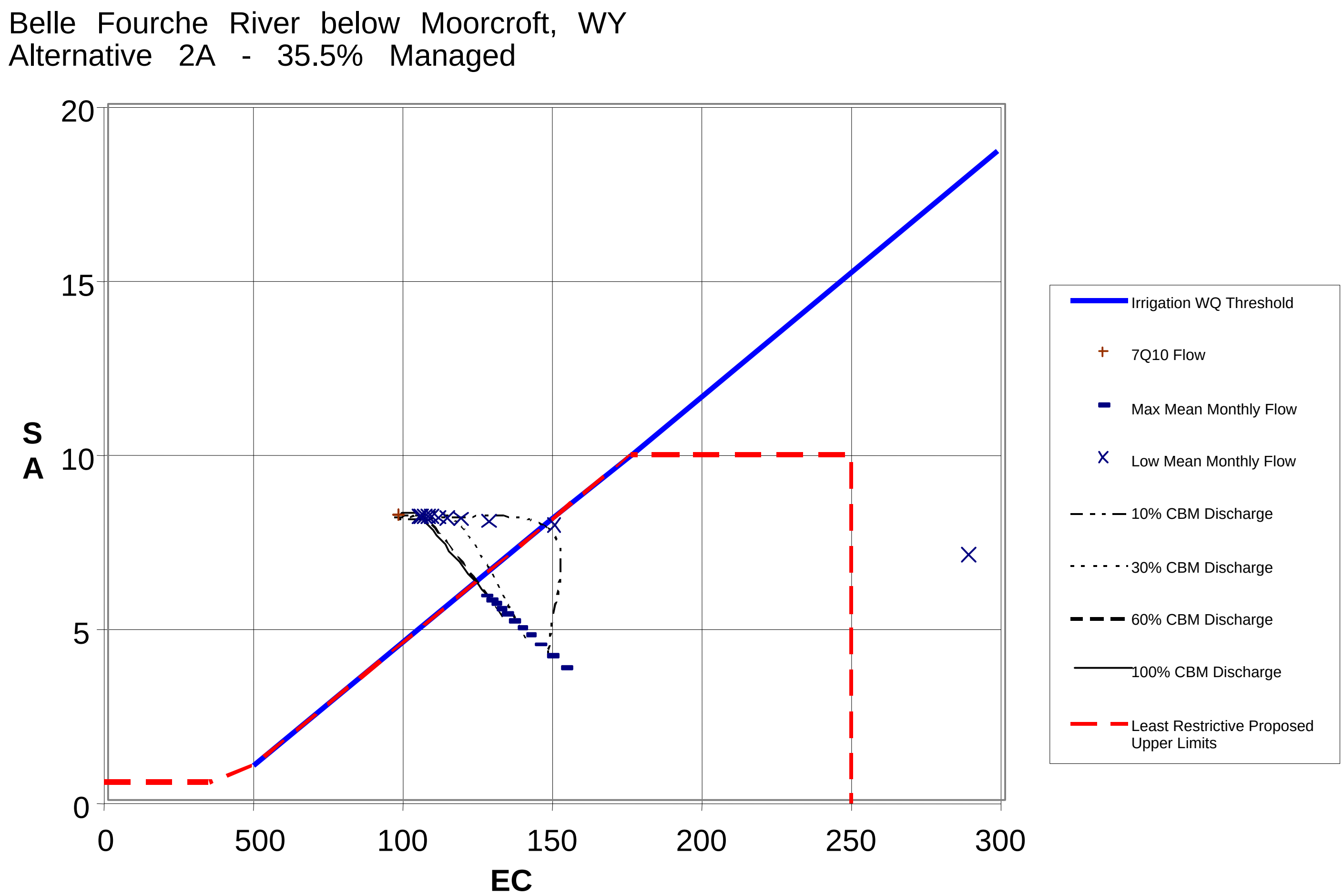


Figure 5-4 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Belle Fourche River Sub-Watershed



5.1.1.3 Alternative 2B

There is no difference between Alternatives 2A and 2B that would affect the modeled output in the Upper Belle Fourche River sub-watershed. Thus, potential impacts described above for Alternative 2A would be the same under Alternative 2B.

5.1.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Belle Fourche River sub-watershed would occur in year 2005, when 6,160 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 35 cfs (25,342 acre-feet per year). Impacts to surface water quality in the Upper Belle Fourche River sub-watershed would be similar to Alternative 1.

5.1.2 Cheyenne River

5.1.2.1 Antelope Creek

Results of the impact analysis in the Antelope Creek sub-watershed under each alternative are presented in Table 5-2. Potential impacts are discussed below.

5.1.2.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Antelope Creek sub-watershed would occur in year 2004, when 925 wells would be producing at an average rate of 11.9 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Antelope Creek currently exceed the MRPL, but are less than the LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL under similar flow conditions. After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow could not be computed because of a lack of data; therefore, the resultant water quality under these flow conditions is assumed to be represented by the quality of CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Antelope Creek near Teckla, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.

- Ayers and Westcot diagram: Irrigation with the mixed water indicates some effects to infiltration, primarily during the lowest flow months of September through February, and during 7Q10 flow conditions. During the low monthly flow, only a small fraction (less than 10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Table 5-2
Surface Water Impact Analysis of the Antelope Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	0.2	2.6	2354	12	7.0	924	NC	--	--	12	7.1	905
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				13	7.0	923				13	7.1	905
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				13	7.0	923				13	7.1	905
3	10 (1)	2000 (1)	10 (2)	2500 (2)				7	7.0	937				7	7.1	905

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
NC=Not calculated based on insufficient record
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota’s existing water quality standards

5.1.2.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1, primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 13 cfs (9,413 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-5 and 5-6 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Antelope Creek sub-watershed. Under modeled conditions, the resultant water quality in Antelope Creek near Teckla, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Figure 5-7 illustrates the relationship between EC and SAR in Antelope Creek before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates some effects to infiltration, primarily during the lowest flow months of September through February, and during 7Q10 flow conditions. Figure 5-8 illustrates the relationship between EC and SAR in Antelope Creek after mixing with varying proportions of CBM produced water discharges under various stream flow conditions. During the low monthly flow, only a small fraction (less than 10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of Antelope Creek from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of Antelope Creek from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-5 Stream EC Before and After Mixing-Antelope Creek Sub-Watershed

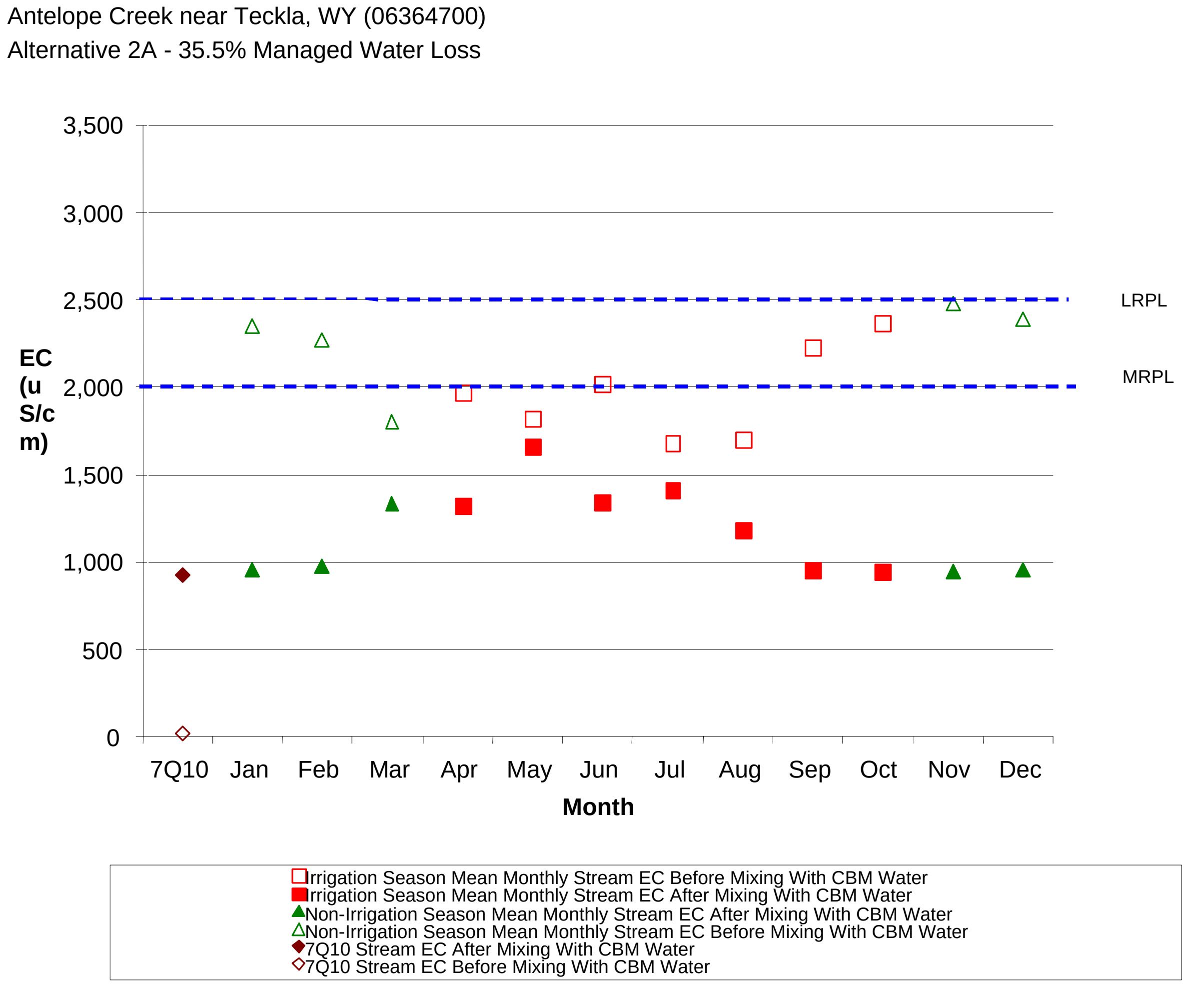


Figure 5-6 Stream SAR Before and After Mixing- Antelope Creek Sub-Watershed

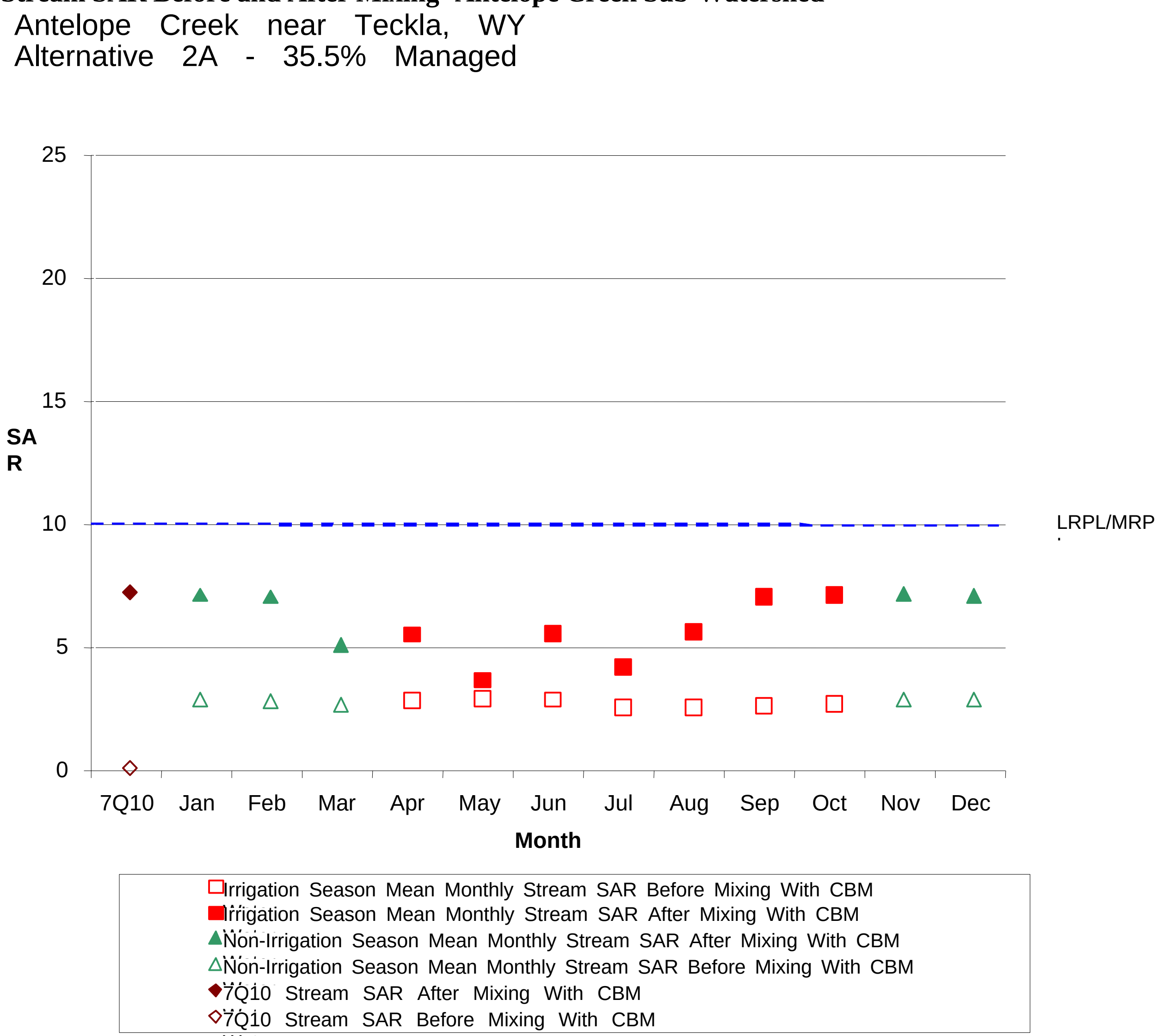


Figure 5-7 Irrigation Suitability Before and After Mixing – Antelope Creek Sub-Watershed

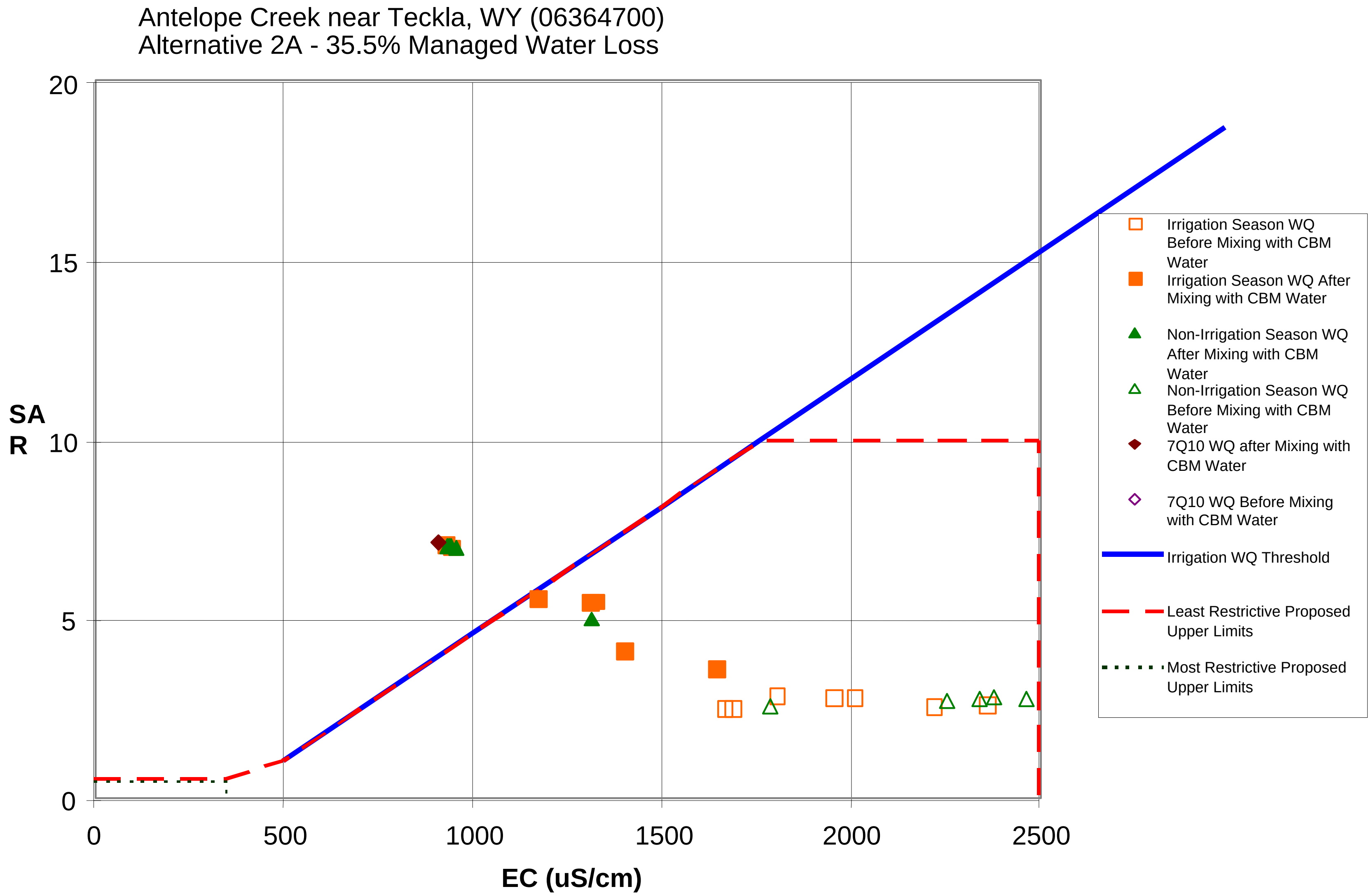
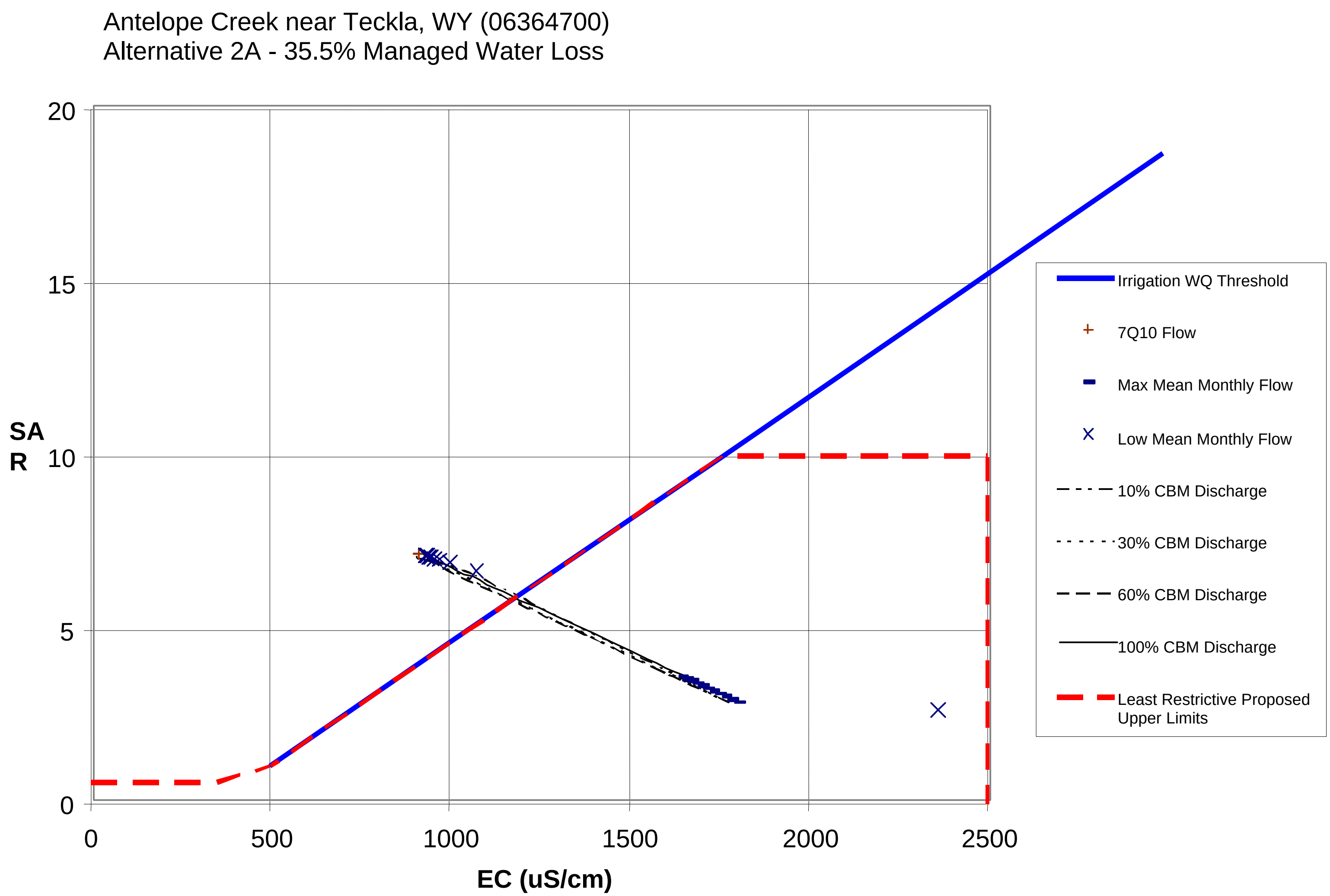


Figure 5-8 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Antelope Creek Sub-Watershed



5.1.2.1.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because active treatment would be implemented. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). Impacts to surface water quality in the Antelope Creek sub-watershed would be similar to Alternative 1. Additional water would be available to support beneficial use because of the proportion of water to undergo active treatment.

5.1.2.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Antelope Creek sub-watershed would occur in year 2005, when 561 wells would be producing at an average rate of 11.9 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 7 cfs (5,068 acre-feet per year). Impacts to surface water quality in the Antelope Creek sub-watershed would be similar to Alternative 1.

5.1.2.2 Cheyenne River

The impact analysis of surface water in the Upper Cheyenne River sub-watershed incorporates the discharges of CBM produced water from the Antelope Creek sub-watershed under each of the alternatives to predict water quality conditions at the USGS gauging station on the Cheyenne River at Riverview, Wyoming.

Results of the impact analysis in the Upper Cheyenne River sub-watershed under each alternative are presented in Table 5-3. Potential impacts are discussed below.

5.1.2.2.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Cheyenne River sub-watershed would occur in year 2003, when 1,471 wells would be producing at an average rate of 11.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 18 cfs (13,033 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Cheyenne River currently exceed the MRPL and LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL under similar flow conditions. After they mix, the resulting stream flow under low-flow conditions would consist almost entirely of CBM produced water. Stream water quality would improve with the addition of CBM produced water. The resulting EC and SAR would decrease from existing conditions. The existing 7Q10 flow could not be computed because of a lack of data; however, the 7Q10 flow is zero calculated at the USGS station on the Cheyenne River at Edgemont, South Dakota; therefore, it is assumed that the resultant water quality under these flow conditions at the station in Riverview, Wyoming, would be represented by the quality of CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

Table 5-3
Surface Water Impact Analysis of the Upper Cheyenne River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	0.4	8.7	4127	18	6.9	881	NC	--	--	18	6.9	806
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				19	6.9	876				19	6.9	806
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				19	6.9	877				19	6.9	806
3	10 (1)	2000 (1)	10 (2)	2500 (2)				12	6.9	896				12	6.9	806

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
NC=Not calculated based on insufficient record
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standards

- MRPL: Under modeled conditions, with the exception of during the highest flow months of September through December, and during 7Q10 flow conditions, the resultant water quality in the Upper Cheyenne River near Riverview, Wyoming would be adequate to meet the MRPL for EC that the WDEQ has adopted in their NPDES permitting process to be protective of downstream irrigation uses. The resultant SAR would be adequate to meet the MRPL during all months.
- LRPL: With the exception during October and November, the LRPL for EC would be met under similar flow conditions. The LRPL for SAR would be met during all months.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates some effects to infiltration during the irrigation season, primarily during low flow in April, and during 7Q10 flow conditions. During the low monthly flow, only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

5.1.2.2.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1, primarily due to the increase in surface discharge and less use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 19 cfs (13,757 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Following mixing, the resultant stream flow under low flow conditions would consist almost entirely of CBM produced water. Stream water quality would improve with the addition of CBM produced water. The resultant EC and SAR would decrease from existing conditions. The resultant stream water quality can be compared to the following criteria:

- MRPL: Figures 5-9 and 5-10 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Upper Cheyenne River sub-watershed. Under modeled conditions, the resultant water quality in the Upper Cheyenne River near Riverview, Wyoming, would be adequate to meet the MRPL for EC that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses. The exception would occur during the highest flow months of September through December and during 7Q10 flow conditions. The resulting SAR would be adequate to meet the MRPL during all months.
- LRPL: With the exception during October and November, the LRPL for EC would be met under similar flow conditions. The LRPL for SAR could be met during all months.
- Ayers and Westcot diagram: Figure 5-11 illustrates the relationship between EC and SAR in the Upper Cheyenne River before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates some effects to infiltration during the irrigation season, primarily during low flow in April and during 7Q10 flow conditions. Figure 5-12 illustrates the relationship between EC and SAR in the Upper Cheyenne River after the water mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Upper Cheyenne River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Cheyenne River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-9 Stream EC Before and After Mixing- the Upper Cheyenne River Sub-Watershed

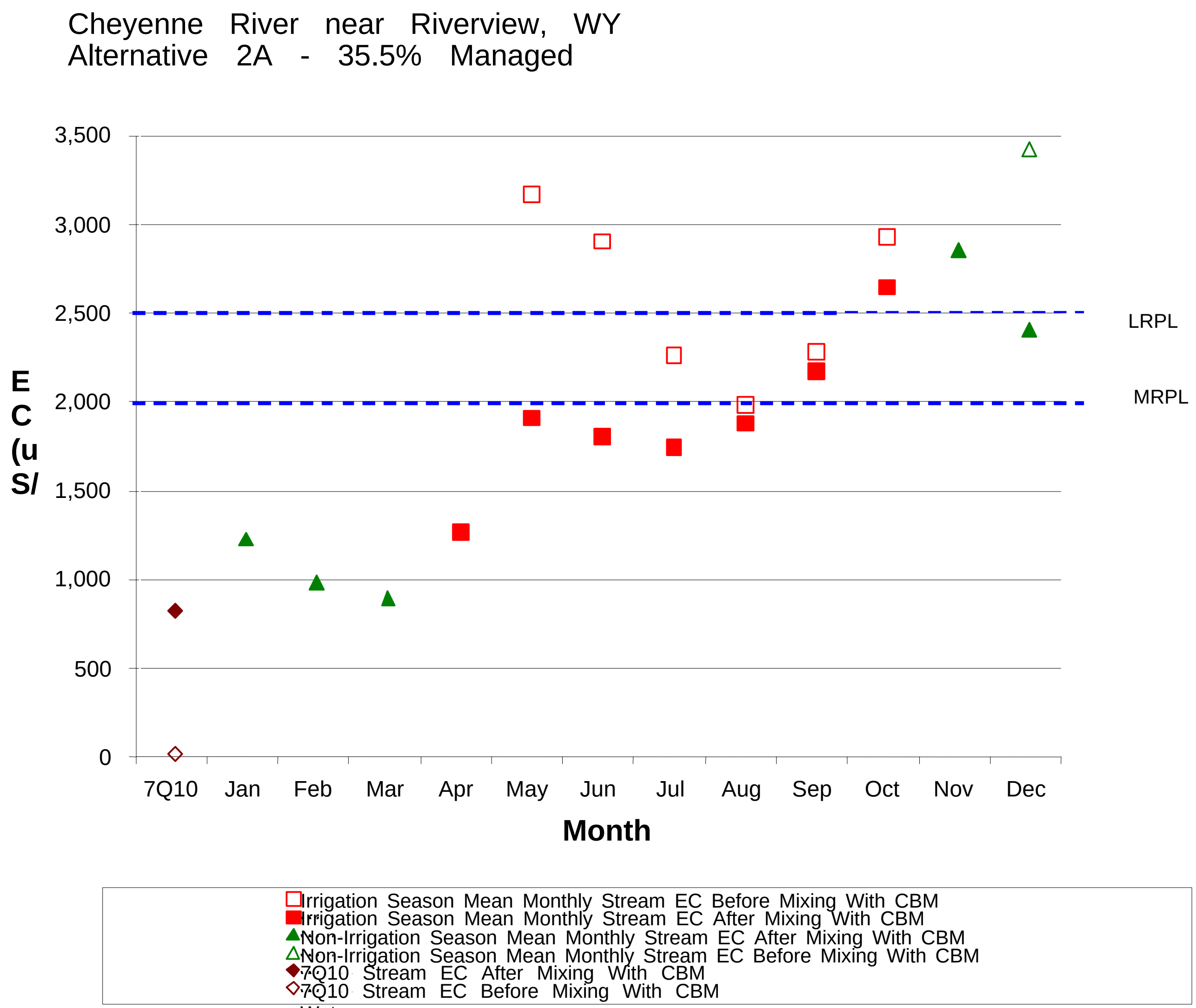


Figure 5-10 Stream SAR Before and After Mixing- the Upper Cheyenne River Sub-Watershed

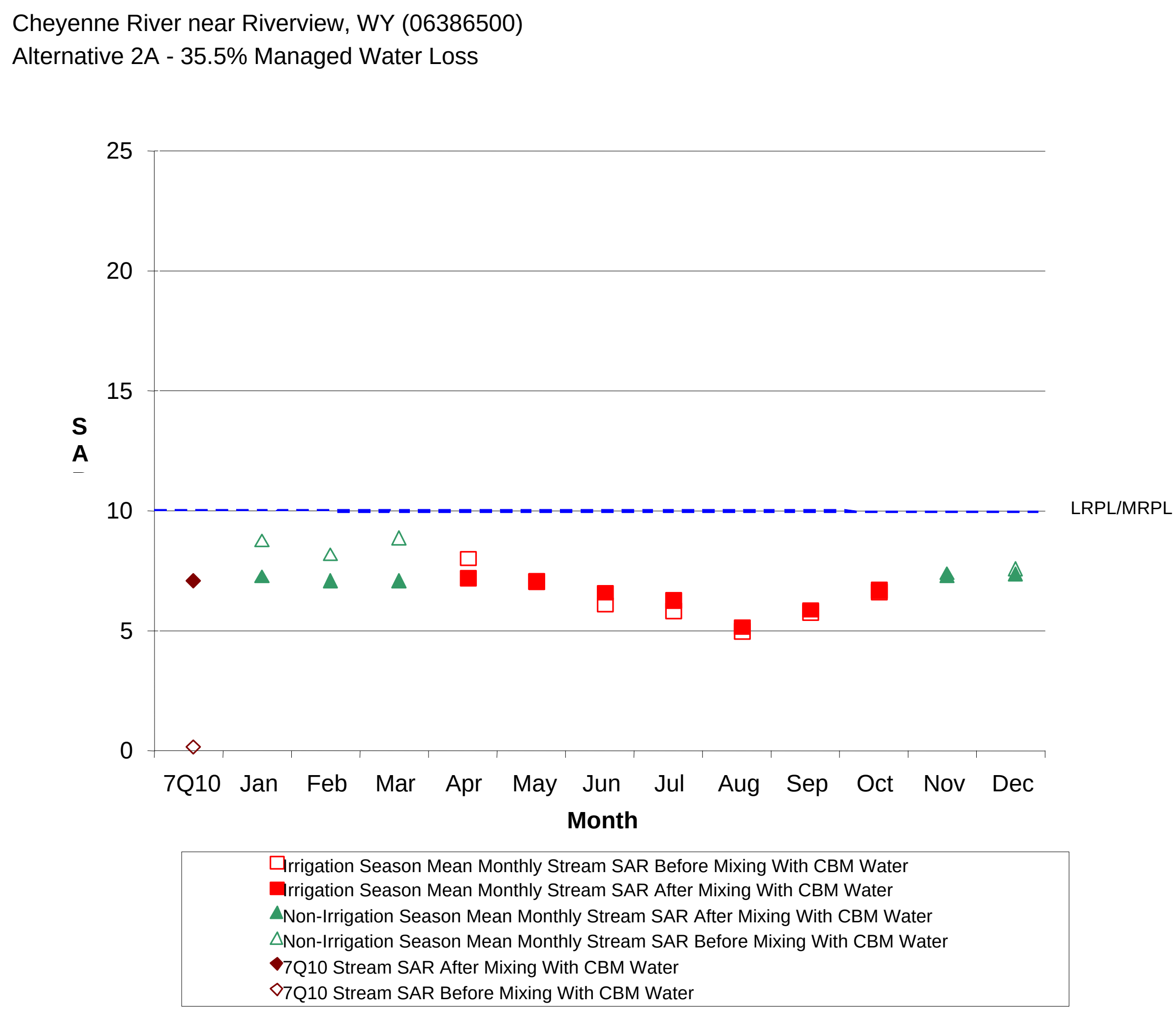


Figure 5-11 Irrigation Suitability Before and After Mixing – the Upper Cheyenne River Sub-Watershed

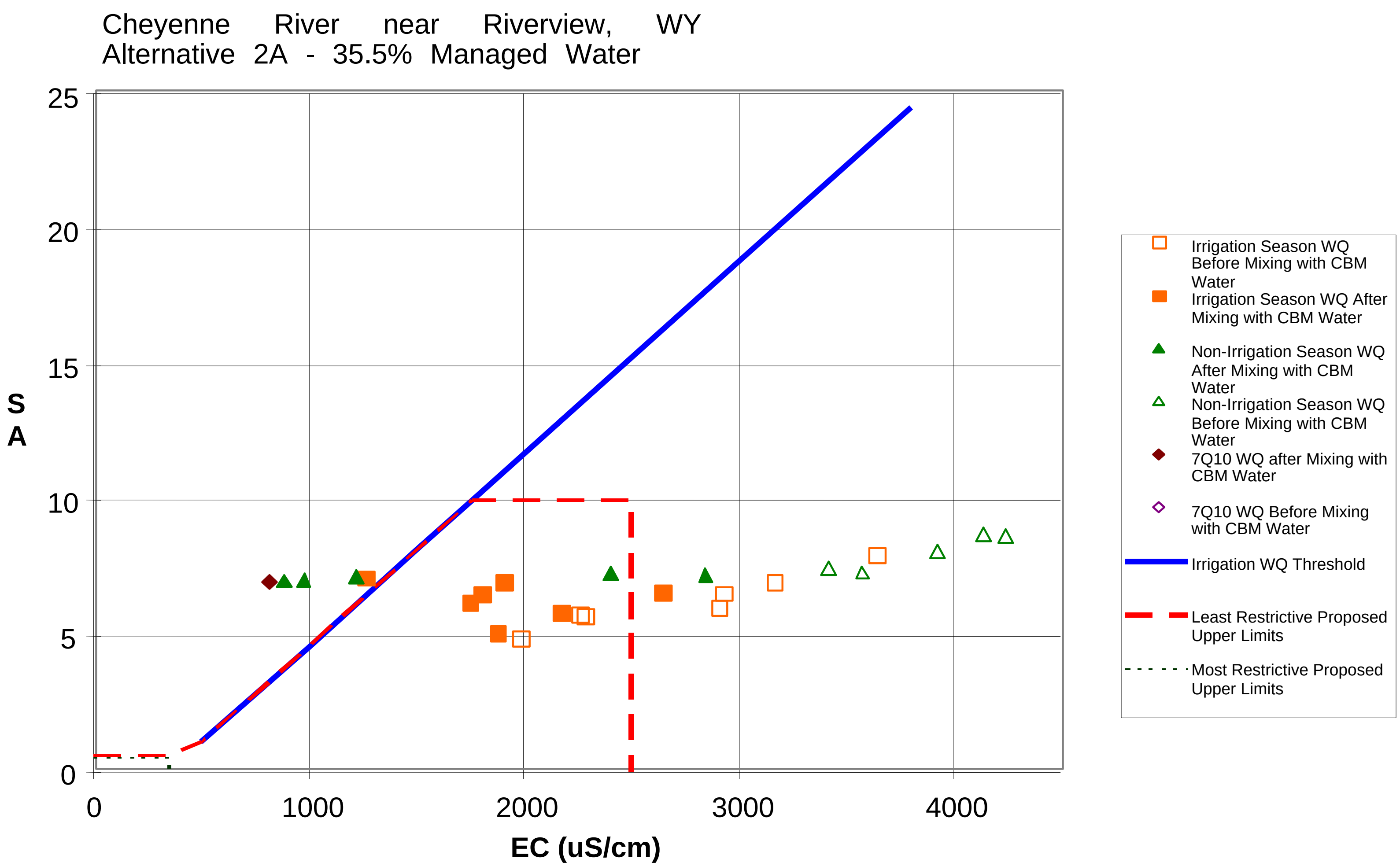
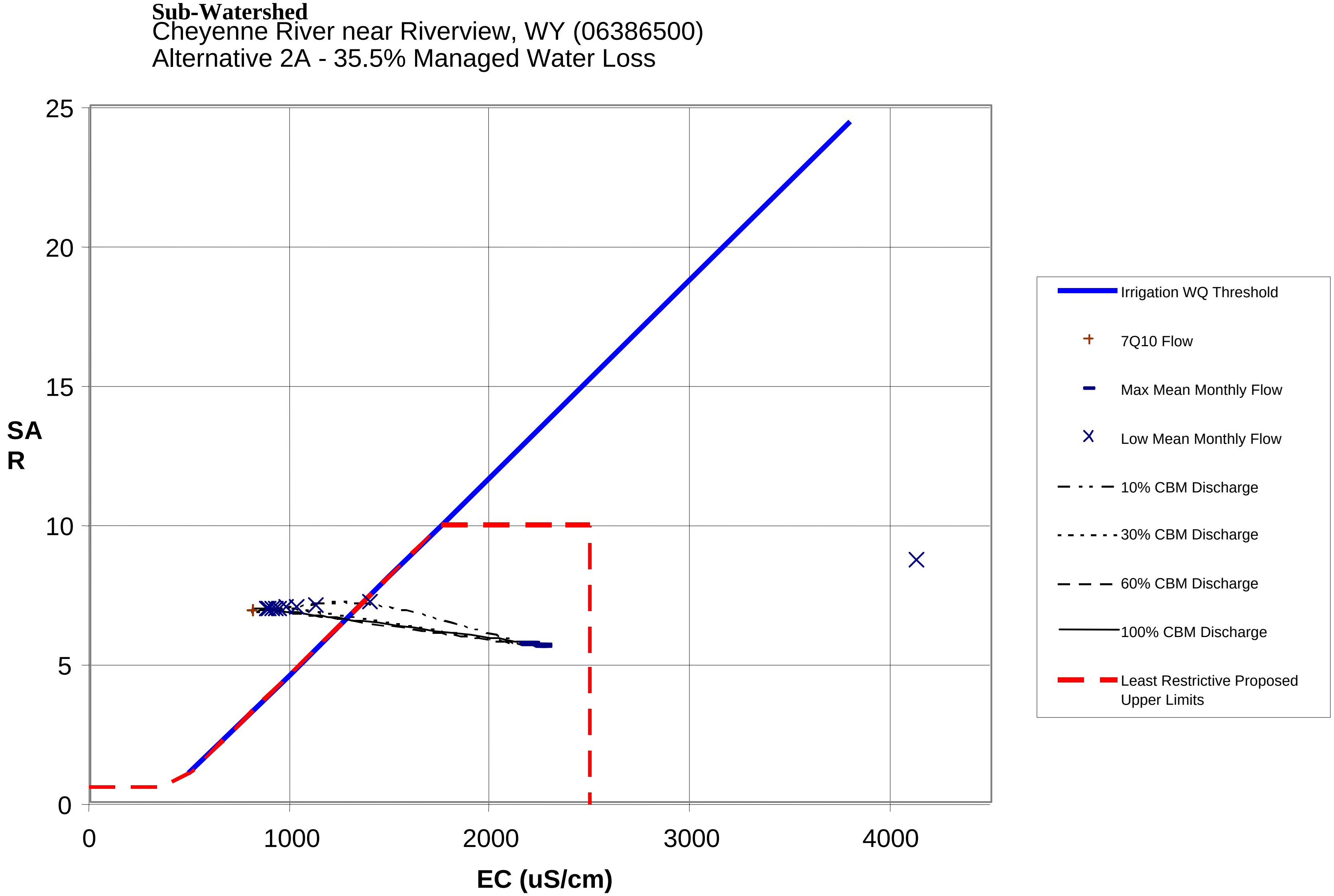


Figure 5-12 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – the Upper Cheyenne River Sub-Watershed



5.1.2.2.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 18 cfs (13,033 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1. Additional water would be available to support beneficial use because of the proportion of water to undergo active treatment.

5.1.2.2.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Cheyenne River sub-watershed would occur in Year 2003, when 1,030 wells would be producing at an average rate of 11.0 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). A comparison of the resultant mixed water quality with the Ayers-Westcot line indicates no effects to infiltration except for during 7Q10 flow conditions. Under Alternative 3, the resultant EC would not be adequate to meet the LRPL during several months of the irrigation season as well as during 7Q10 flow.

5.1.3 Upper Powder River

Results of the impact analysis in the Upper Powder River sub-watershed under each alternative are presented in Table 5-4. Potential impacts are discussed below.

Table 5-4
Surface Water Impact Analysis of the Upper Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	75	7.8	3400	211	15.3	2606	0.0	--	--	135	19.5	2163
2A	2.0	1000	10	3200				144	13.4	2812				68	19.5	2163
2B	2.0	1000	10	3200				138	13.1	2837				63	19.5	2163
3	2.0	1000	10	3200				121	12.2	2934				46	19.5	2163

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.3.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Powder River sub-watershed would occur in year 2006, when 15,822 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 135 cfs (97,749 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Powder River currently exceed the MRPL and LRPL under low-flow conditions. Mean monthly SAR values currently exceed the MRPL, but are less than the LRPL under similar flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would nearly triple from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero; therefore, it is assumed that the resulting water quality under these flow conditions would be represented by the quality of CBM produced water if discharges were to occur during critical low flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Powder River sub-watershed at Arvada, Wyoming, would not be adequate to meet the MRPL for EC and SAR at any time if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months as well as during 7Q10 flow conditions. The resulting water quality would not be adequate to meet the LRPL for SAR during the irrigation months of July through October or during 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration during the irrigation months; however, some reduction in infiltration would be likely during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.3.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 68 cfs (49,237 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would nearly triple from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The resulting stream water quality can be compared with the following criteria:

- MRPL: Figures 5-13 and 5-14 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Upper Powder River sub-watershed. Under modeled conditions, the resultant water quality in the Upper Powder River at Arvada, Wyoming, would not be adequate to meet the MRPL for EC and SAR at any time if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months as well as during 7Q10 flow conditions. The resulting water quality would not be adequate to meet the LRPL for SAR during the irrigation months of August through October or during 7Q10 flow conditions.
- Ayers and Westcot diagram: Figure 5-15 illustrates the relationship between EC and SAR in the Upper Powder River before and after the river mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration during the irrigation months; however, some reduction in infiltration would be likely during 7Q10 flow conditions. Figure 5-16 illustrates the relationship between EC and SAR in the Upper Powder River after the water mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without affecting infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, under certain flow conditions, impacts to irrigated agriculture in the Upper Powder River sub-watershed from CBM development in Wyoming under Alternative 2A may occur. Although the resultant impacts fall outside the boundaries of the LRPL during some months, BLM recognizes the uncertainty concerning the determination of water quality standards for EC and SAR. If a standard at the low end of the range of proposed values is selected, additional mitigation may be necessary for CBM discharges to this sub-watershed to occur. Potential mitigation measures that could be implemented in order to meet the ultimate regulatory standards for EC and SAR once those standards have been identified include CBM produced water storage during the irrigation months and surface discharge during the non-irrigation months. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Powder River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-13 Stream EC Before and After Mixing-Upper Powder River Sub-Watershed

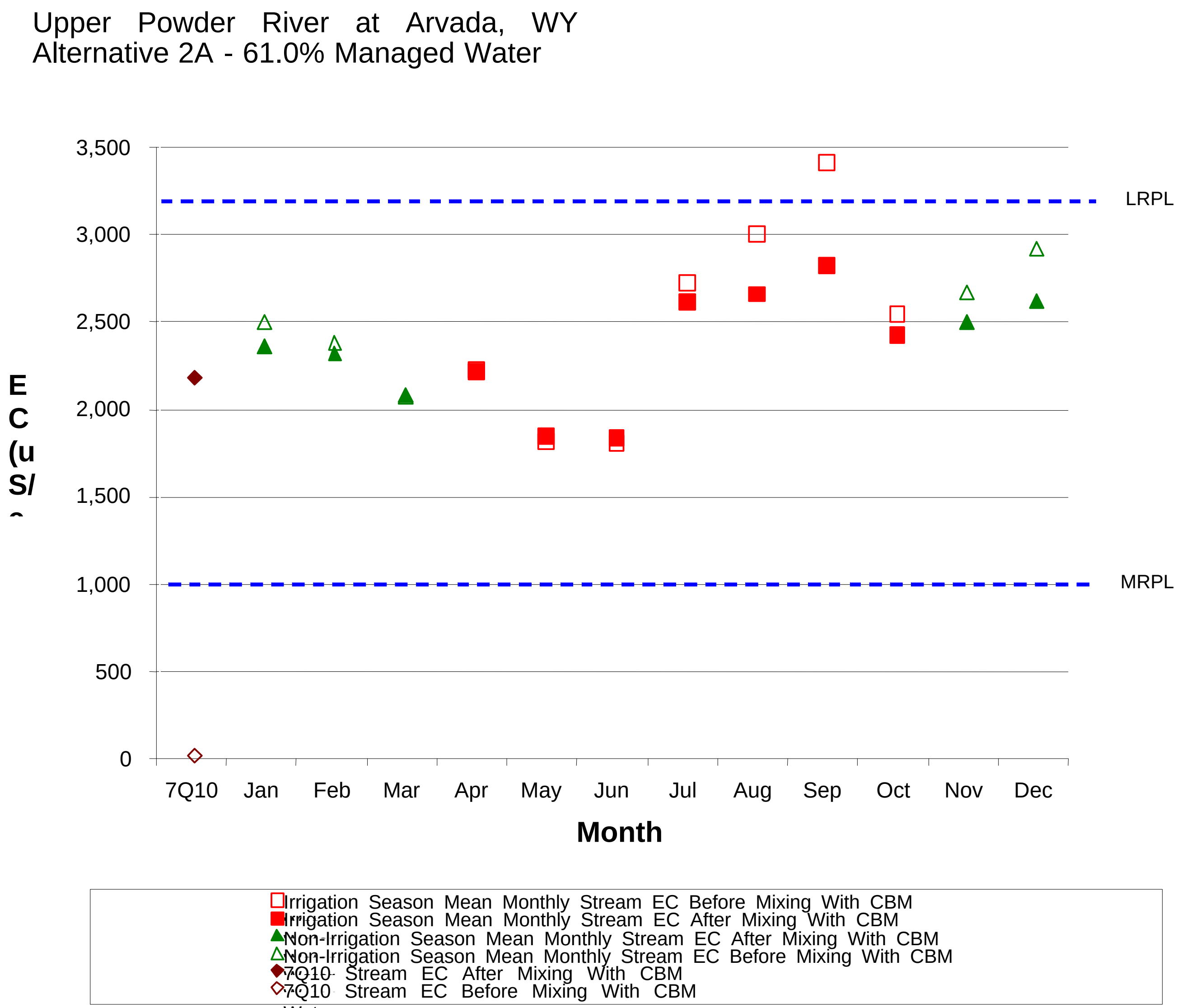


Figure 5-14 Stream SAR Before and After Mixing-Upper Powder River Sub-Watershed

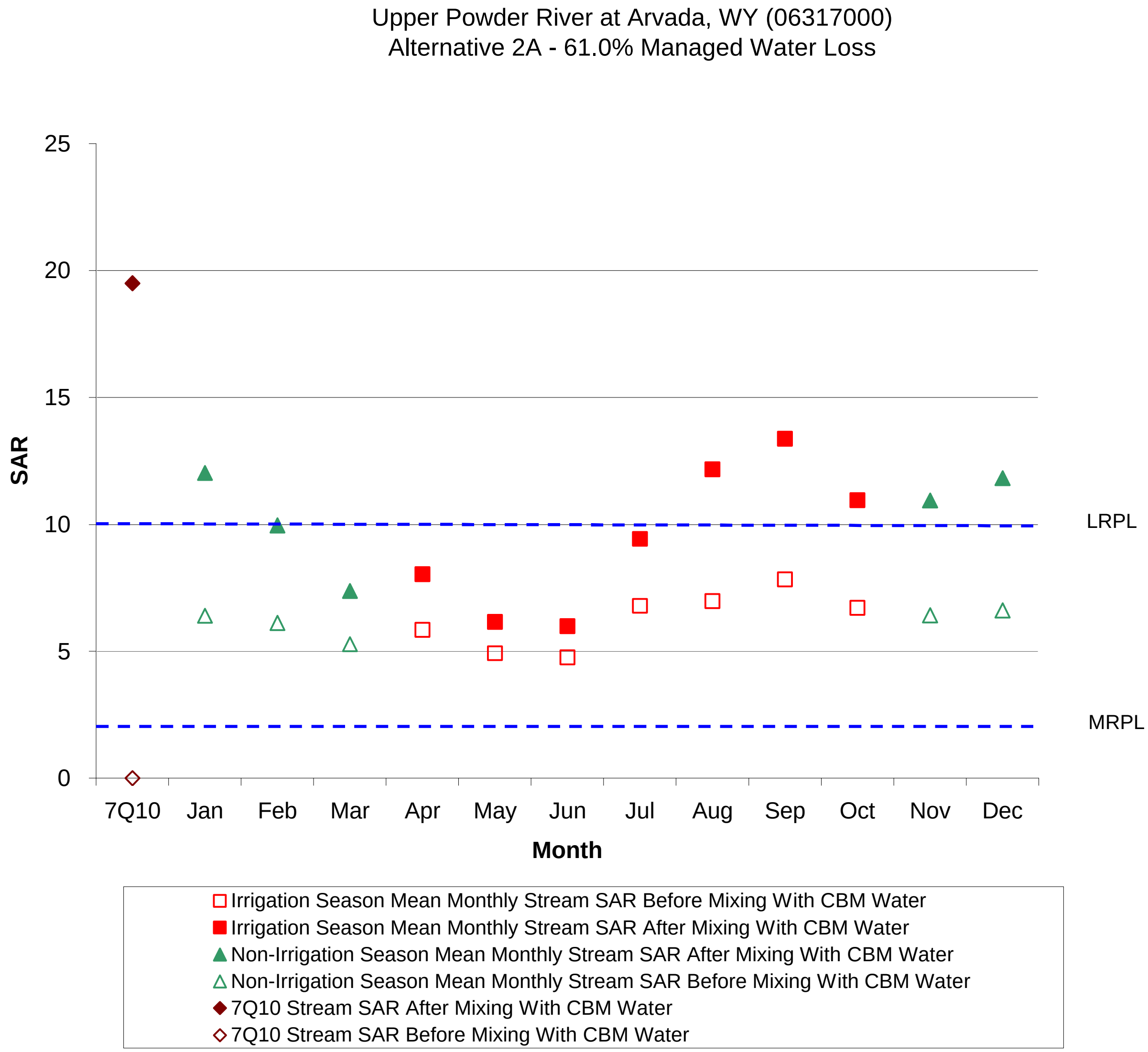


Figure 5-15 Irrigation Suitability Before and After Mixing – Upper Powder River Sub-Watershed

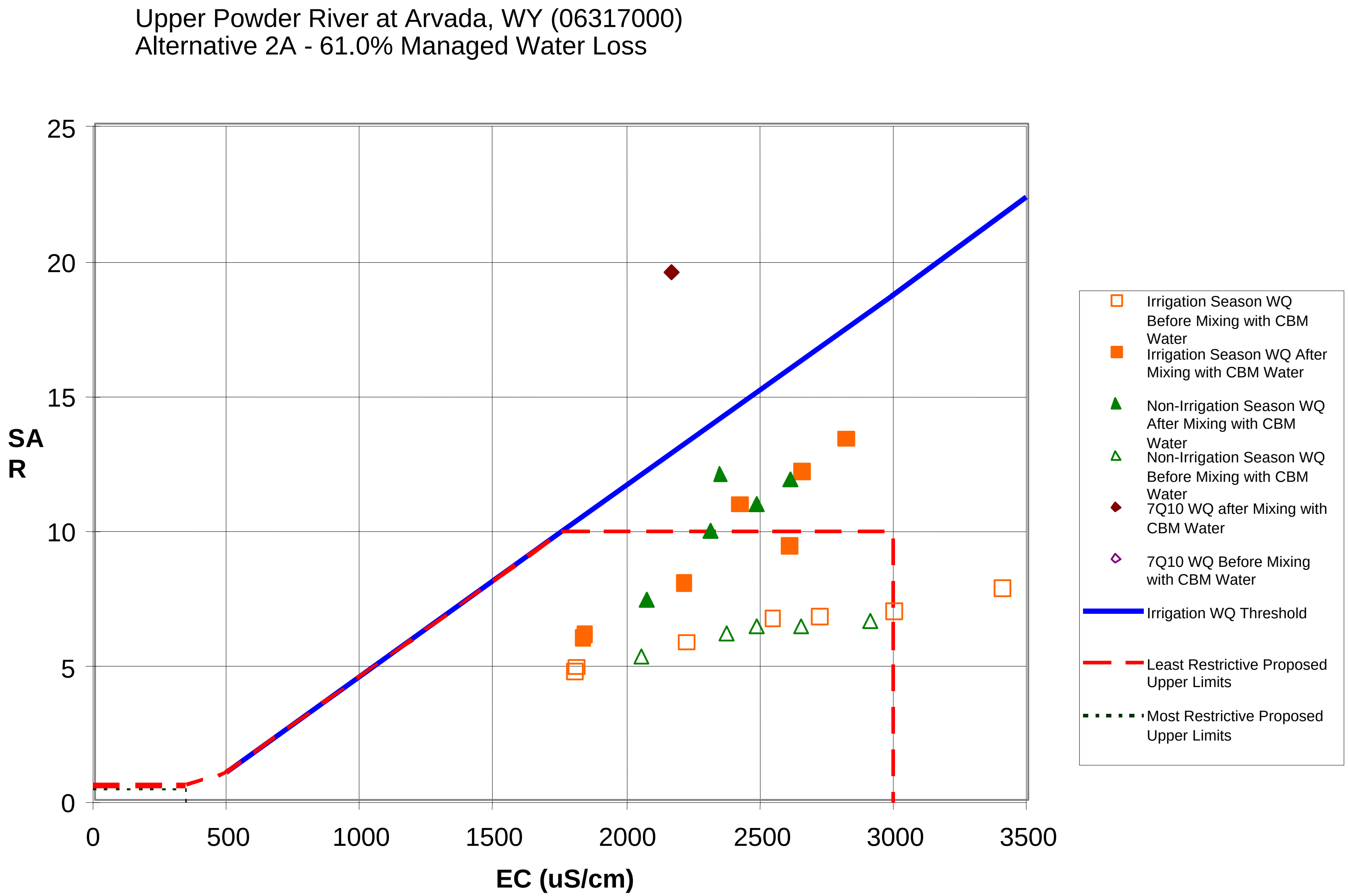
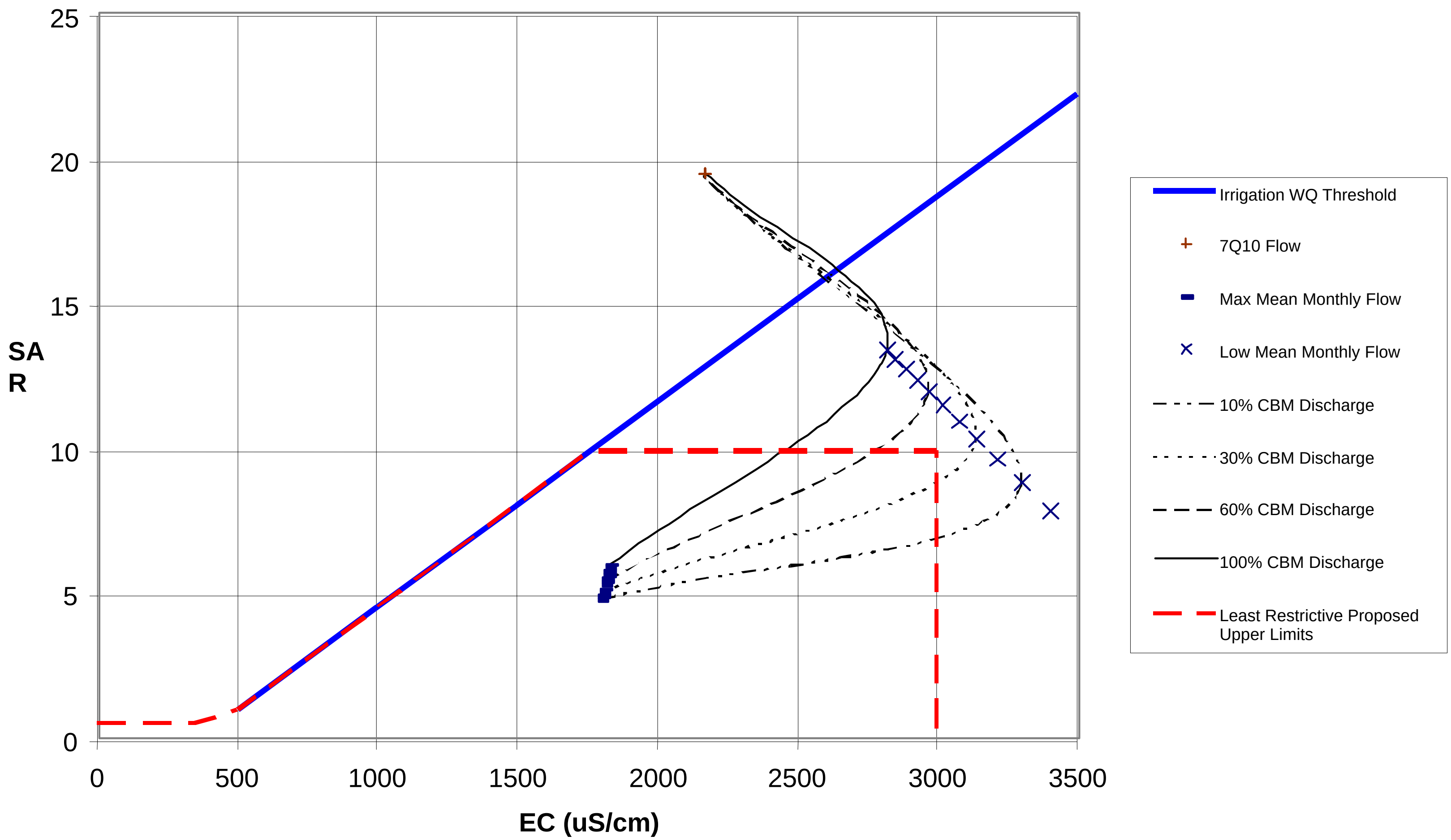


Figure 5-16 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Powder River Sub-Watershed

Upper Powder River at Arvada, WY (06317000)
Alternative 2A - 61.0% Managed Water Loss



5.1.3.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 63 cfs (45,616 acre-feet per year). The resultant flow and water quality would be similar to Alternative 1, but the magnitude of change from existing water quality would be less because of the reduced CBM discharges. Impacts to surface water quality would be similar to Alternative 1. Additional water would be available to support beneficial use as a result of the proportion of water that would undergo active treatment.

5.1.3.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Powder River sub-watershed would occur in year 2005, when 5,332 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 45 cfs (32,583 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.1.4 Clear Creek

Results of the impact analysis in the Clear Creek sub-watershed under each alternative are presented in Table 5-5. Potential impacts are discussed below.

Table 5-5
Surface Water Impact Analysis of the Clear Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	62	1.5	1276	73	5.4	1522	0.1	3.96	3879	10	29.0	3030
2A	2.0	1000	10	3200				66	3.1	1378				4	28.6	3044
2B	2.0	1000	10	3200				65	2.8	1359				3	28.4	3049
3	2.0	1000	10	3200				70	4.5	1469				8	28.9	3033

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.4.1 Alternative 1

Under Alternative 1, the peak of water production in the Clear Creek sub-watershed would occur in year 2006, when 2,257 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 10 cfs (7,241 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Clear Creek currently exceed the MRPL but are less than the LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL under similar flow conditions and are less than the LRPL during 7Q10 flow.
After the water mixes, the resultant stream flow under low-flow conditions would increase moderately from natural stream flow. The resulting EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Clear Creek near Arvada, Wyoming, would not be adequate to meet the MRPL for both EC and SAR, if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses. The only exception occurs during high flow in June,
- LRPL: The resultant water quality would be adequate to meet the LRPL for both constituents.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.4.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 4 cfs (2,896 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would increase moderately from natural stream flow. The resulting EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-17 and 5-18 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Clear Creek sub-watershed. Under modeled conditions, the resultant water quality in Clear Creek near Arvada, Wyoming, would not be adequate to meet the MRPL for both EC and SAR if it should be determined that the MRPL/LRPL criteria are protective of downstream irrigation uses. The only exception occurs during high flow in June.

- LRPL: The resultant water quality would be adequate to meet the LRPL for both constituents during all months, but not during 7Q10 flow conditions.
- Ayers and Westcot diagram: Figure 5-19 illustrates the relationship between EC and SAR in Clear Creek before and after the creek mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. Figure 5-20 illustrates the relationship between EC and SAR in Clear Creek after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on the higher water quality of the stream and its value as a source of irrigation water in the Clear Creek sub-watershed, WDEQ would not allow any new discharge permits under Alternatives 1 or 2A that would result in any decrease in baseline water quality. Because of WDEQ's policy, it is expected that water quality in Clear Creek would be preserved at near current levels.

Figure 5-17 Stream EC Before and After Mixing-Clear Creek Sub-Watershed

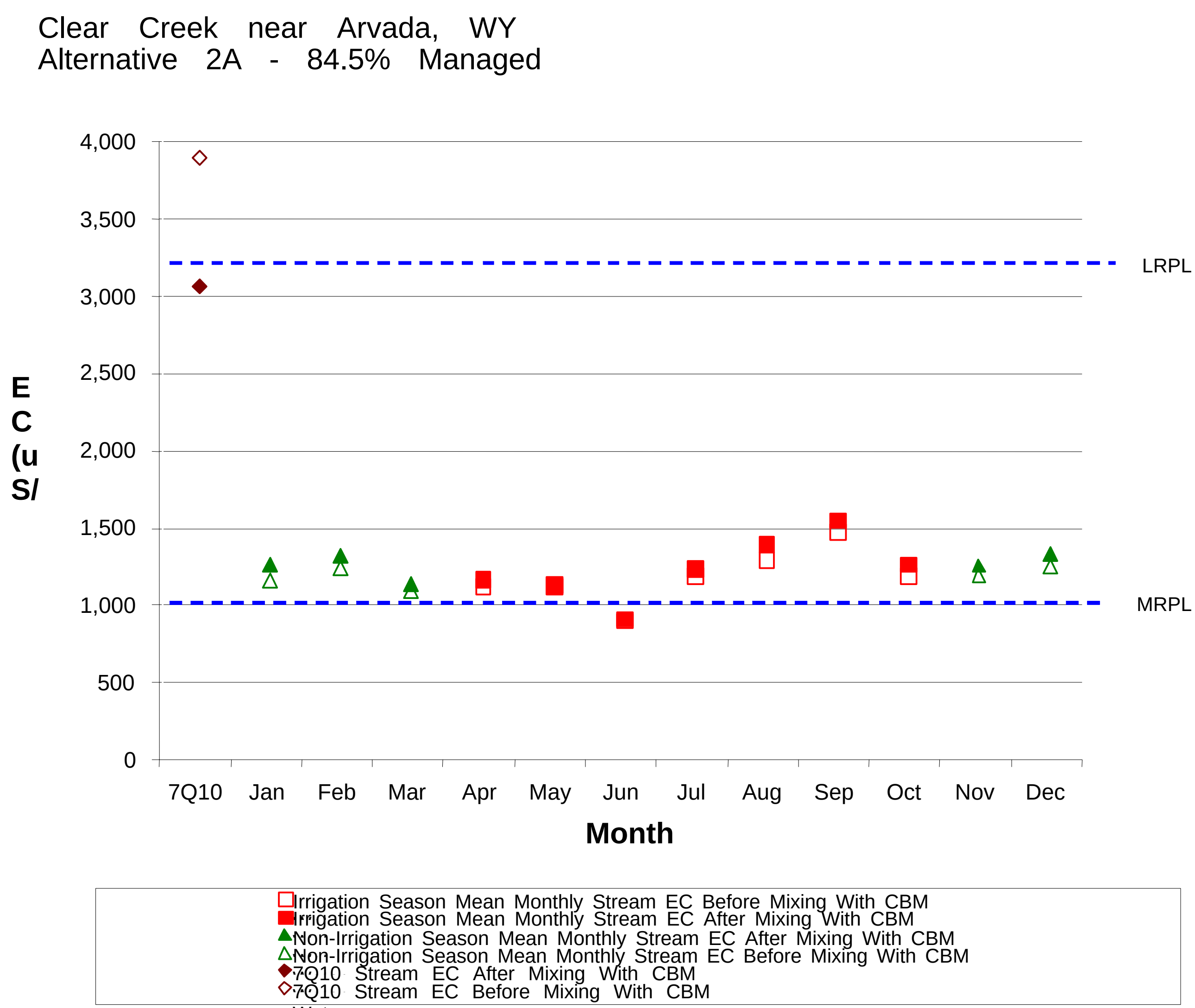


Figure 5-18 Stream SAR Before and After Mixing- Clear Creek Sub-Watershed

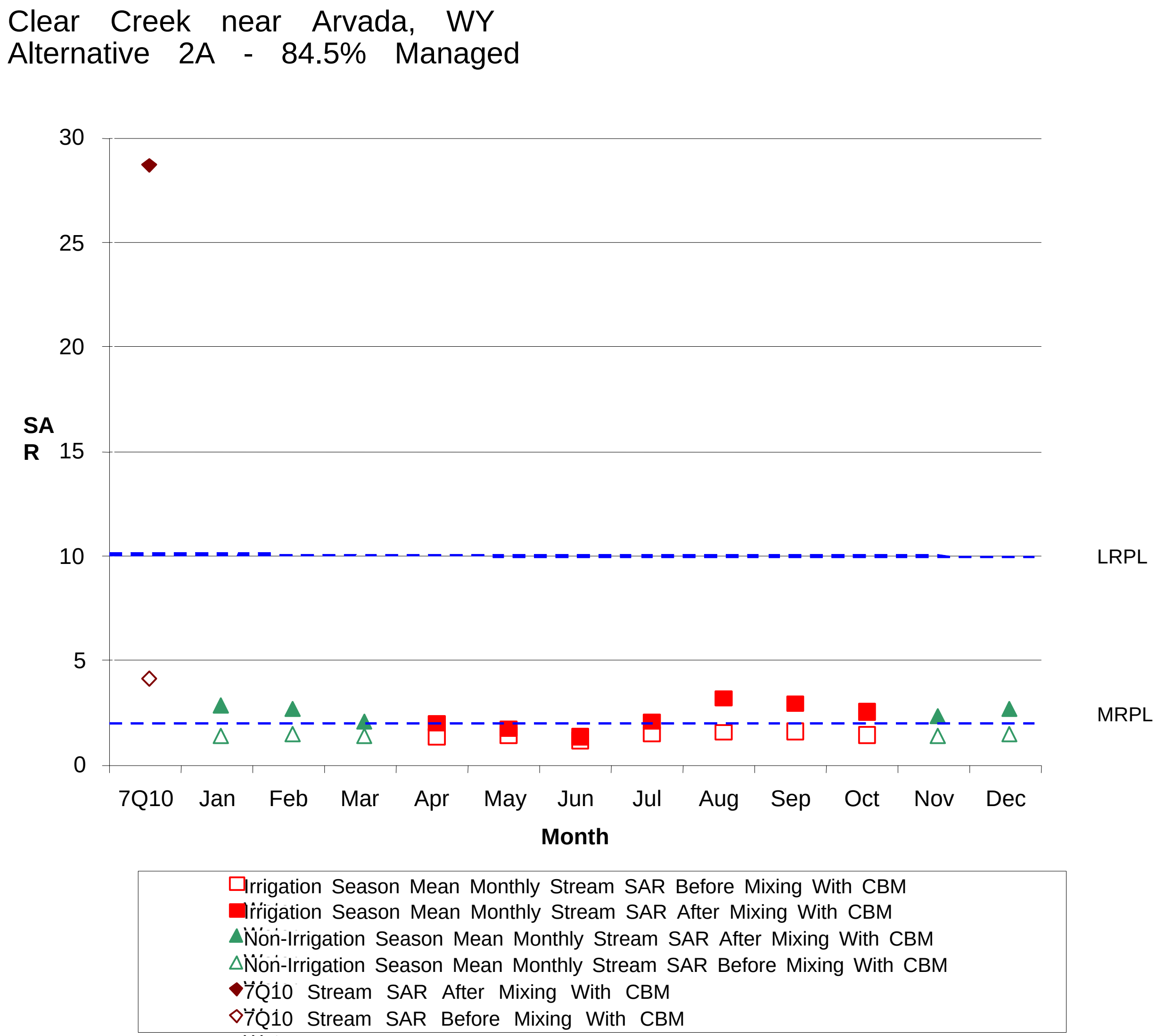


Figure 5-19 Irrigation Suitability Before and After Mixing – Clear Creek Sub-Watershed

Clear Creek near Arvada, WY (06324000)
Alternative 2A - 84.5% Managed Water Loss

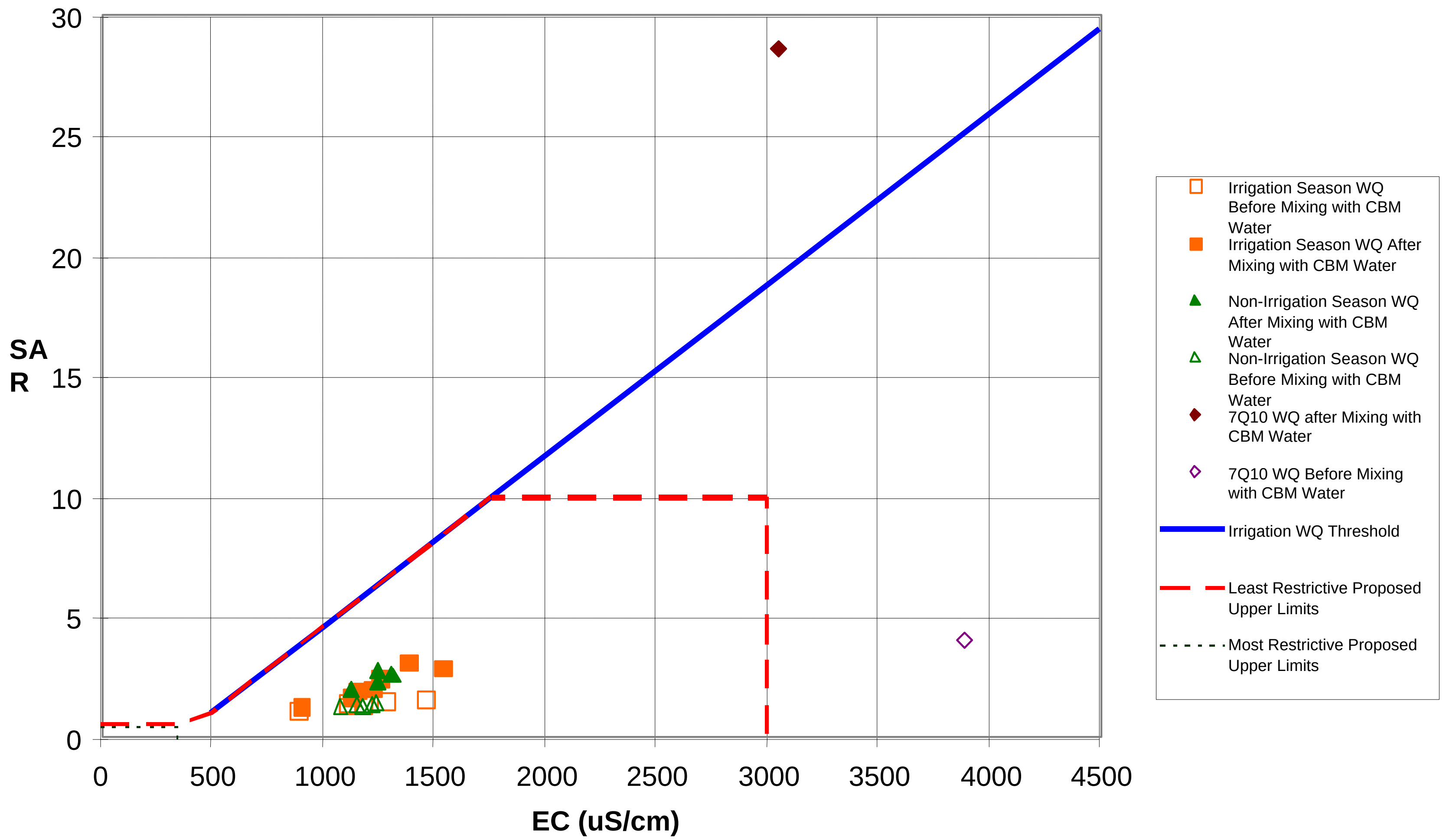
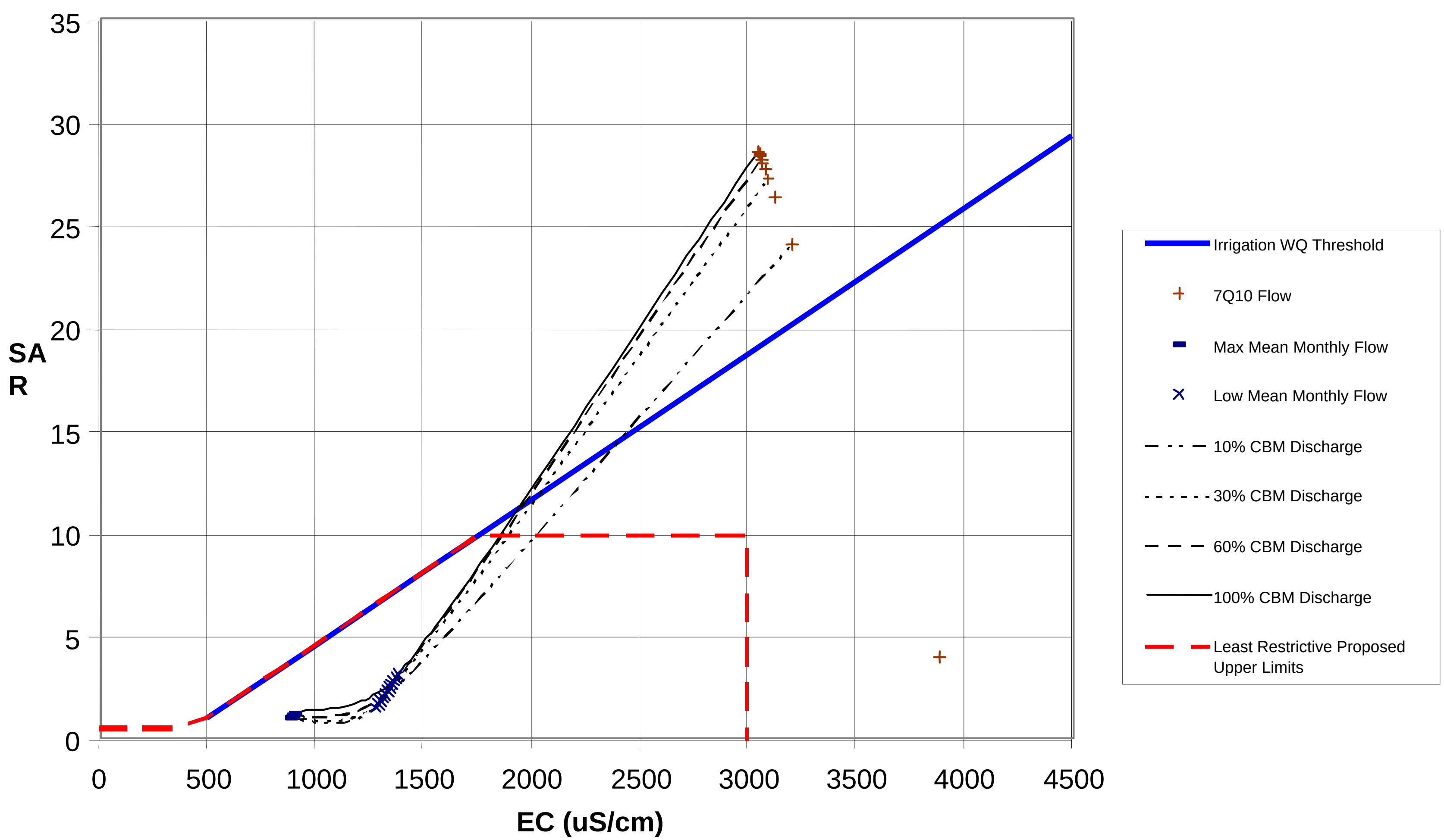


Figure 5-20 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Clear Creek Sub-Watershed

Clear Creek near Arvada, WY (06324000)
Alternative 2A - 84.5% Managed Water Loss



5.1.4.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and implementation of active treatment, along with lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 3 cfs (2,172 acre-feet per year). Under Alternative 2B, the resultant SAR would be adequate to meet the MRPL during high flows in April through June but not during the remainder of the irrigation season, when natural stream flow decreases. Remaining impacts to surface water quality would be similar to the results obtained under Alternative 1. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.4.4 Alternative 3

Under Alternative 3, the peak of water production in the Clear Creek sub-watershed would occur in year 2006, when 1,705 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 8 cfs (5,793 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.1.5 Crazy Woman Creek

Results of the impact analysis in the Crazy Woman Creek sub-watershed under each alternative are presented in Table 5-6. Potential impacts are discussed below.

Table 5-6
Surface Water Impact Analysis of the Crazy Woman Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	14	2.3	1937	28	13.8	2545	0.0	--	--	14	24.8	3129
2A	2.0	1000	10	3200				17	6.5	2159				3	24.8	3129
2B	2.0	1000	10	3200				16	5.6	2112				2	24.8	3129
3	2.0	1000	10	3200				19	8.0	2240				5	24.8	3129

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.5.1 Alternative 1

Under Alternative 1, the peak of water production in the Crazy Woman Creek sub-watershed would occur in year 2006, when 1,853 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 14 cfs (10,137 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Crazy Woman Creek currently exceed the MRPL but are less than the LRPL under low-flow conditions. Mean monthly SAR values currently are about equal to the MRPL under similar flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would nearly double from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero; therefore, it is assumed that the resultant water quality under this flow would be represented by the quality of the CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months, but not during 7Q10 flow conditions. With the exception of during low flows from August through February and during 7Q10 flow conditions, the resultant water quality would be adequate to meet the LRPL for SAR.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration, except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.5.1 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 3 cfs (2,172 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would nearly double from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-21 and 5-22 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Crazy Woman Creek sub-watershed. Under modeled conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months, but not during 7Q10 flow conditions. With the exception of low flows during August through February and during 7Q10 flow conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, would be adequate to meet the LRPL for SAR.
- Ayers and Westcot diagram: Figure 5-23 illustrates the relationship between EC and SAR in Crazy Woman Creek before and after the creek mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. Figure 5-24 illustrates the relationship between EC and SAR in Crazy Woman Creek after the creek mixes with varying proportions of CBM produced water discharges under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on the higher water quality and its value as a source of irrigation water in the sub-watershed, WDEQ would not allow any new discharge permits in this sub-watershed under Alternatives 1 or 2A that would result in any decrease in baseline water quality. Because of WDEQ's policy, it is expected that water quality in Crazy Woman Creek would be preserved at near current levels.

Figure 5-21 Stream EC Before and After Mixing-Crazy Woman Creek Sub-Watershed

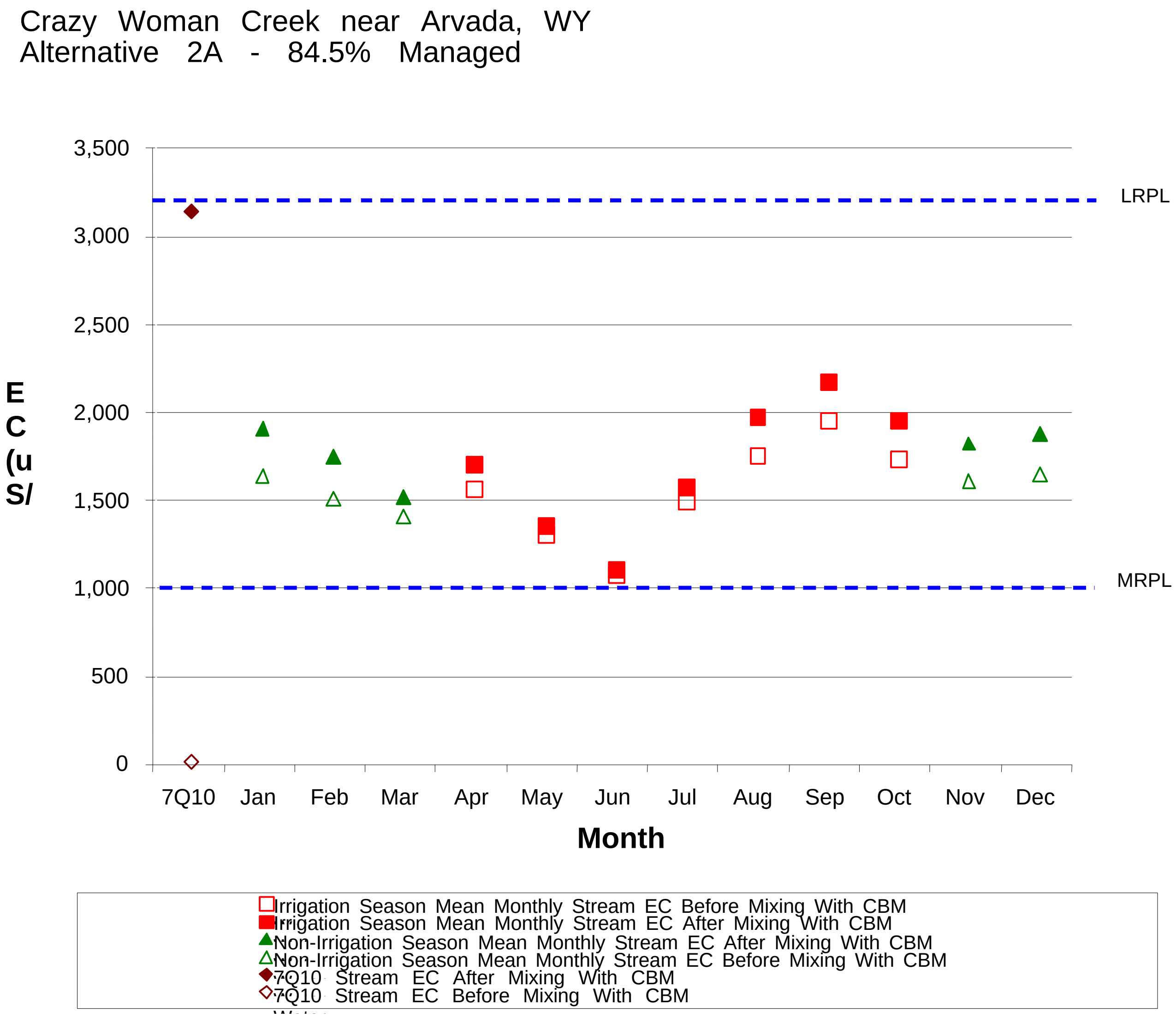


Figure 5-22 Stream SAR Before and After Mixing- Crazy Woman Creek Sub-Watershed

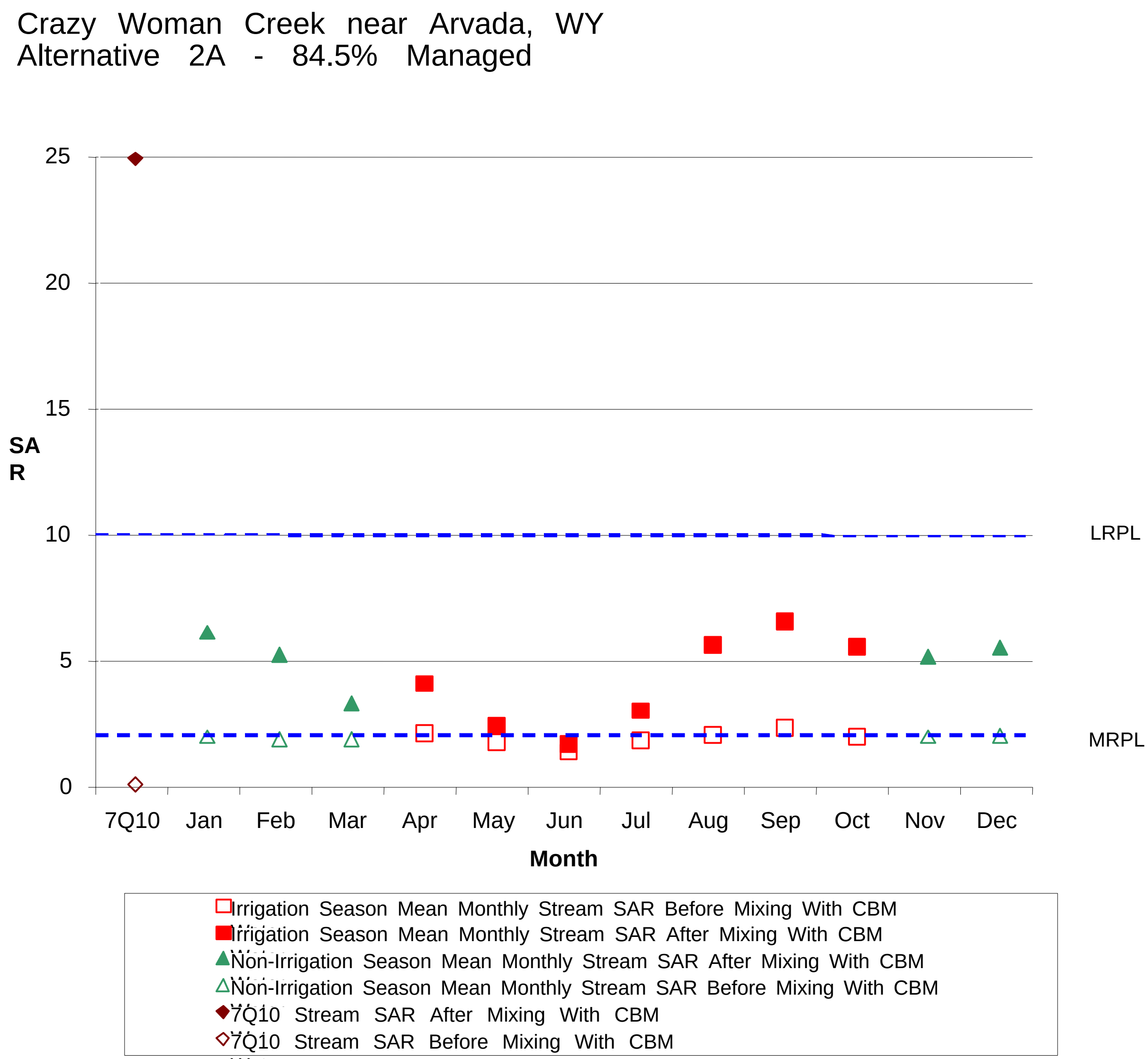


Figure 5-23 Irrigation Suitability Before and After Mixing – Crazy Woman Creek Sub-Watershed

Crazy Woman Creek near Arvada, WY (06316400)
Alternative 2A - 84.5% Managed Water Loss

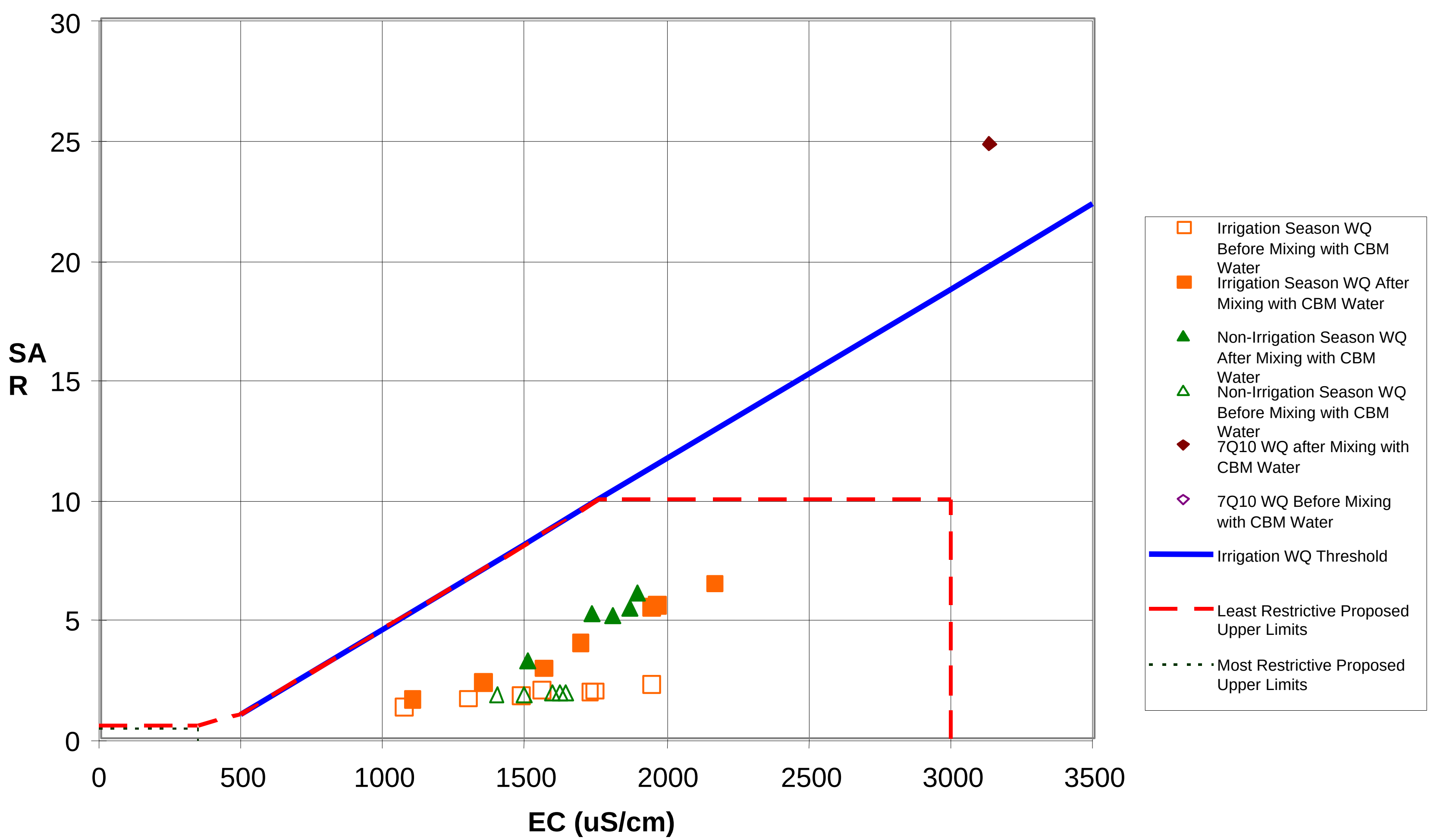
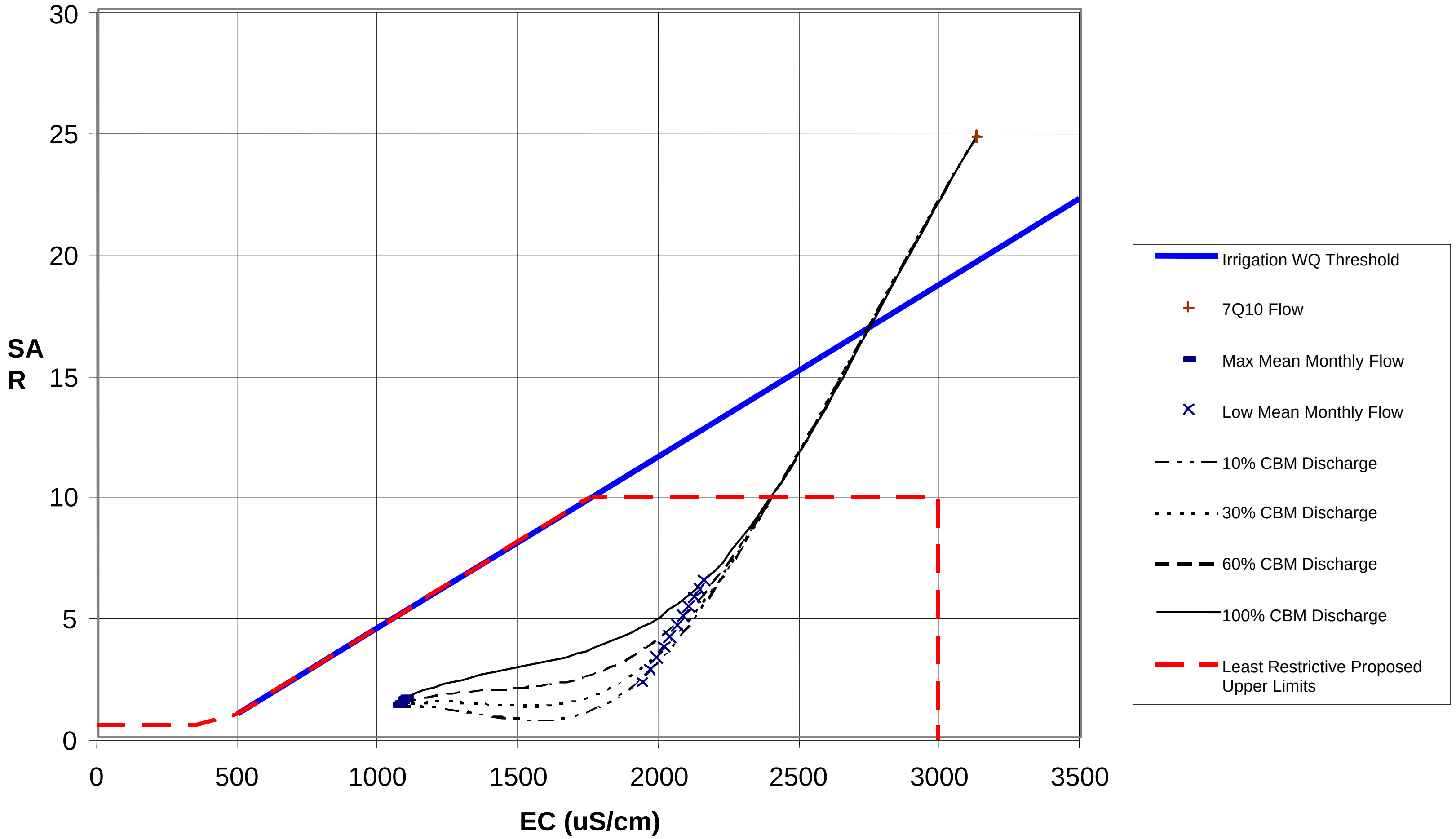


Figure 5-24 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Crazy Woman Creek Sub-Watershed

Crazy Woman Creek near Arvada, WY (06316400)
Alternative 2A - 84.5% Managed Water Loss



5.1.5.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treat1212ment, along with lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 2 cfs (1,448 acre-feet per year). Impacts to surface water quality would be similar to Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.5.4 Alternative 3

Under Alternative 3, the peak of water production in the Crazy Woman Creek sub-watershed would occur in year 2005, when 606 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 5 cfs (3,620 acre-feet per year). Impacts to surface water quality would be similar to Alternative 2A.

5.1.6 Salt Creek

Results of the impact analysis for the Salt Creek sub-watershed under each alternative are presented in Table 5-7. Potential impacts are discussed below.

Table 5-7
Surface Water Impact Analysis of the Salt Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	27	26.1	5750	27	25.9	5711	8.4	25.1	6741	8.6	24.7	6588
2A	2.0	1000	10	3200				27	26.0	5743				8.4	25.0	6714
2B	2.0	1000	10	3200				27	26.1	5750				8.4	25.0	6721
3	2.0	1000	10	3200				27	26.0	5730				8.5	24.9	6662

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.6.1 Alternative 1

Under Alternative 1, the peak of water production in the Salt Creek sub-watershed would occur in year 2006, when 37 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Salt Creek sub-watershed during the peak year of CBM water production is about 0.2 cfs (145 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

The water quality in Salt Creek currently exceeds the MRPL or LRPL for both EC and SAR under low-flow conditions. After the water mixes, the resultant stream flow under low monthly flow conditions would be similar to the natural stream flow. The resultant EC and SAR would decrease slightly from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Salt Creek near Sussex, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for both EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: The resultant water quality would not be adequate to meet the LRPL for both EC and SAR under similar flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration under similar flow conditions. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.6.2 Alternative 2A

Under Alternative 2A, there would be no surface discharge to the Salt Creek sub-watershed. Minimal amounts of subsurface flow from infiltration impoundments would resurface in stream channels but are not likely to reach the main stem of the Salt Creek sub-watershed. Under Alternative 2A, impacts to surface water quality would be similar to the results obtained under Alternative 1.

5.1.6.3 Alternative 2B

Under Alternative 2B, there would be no untreated surface discharge to the Salt Creek sub-watershed. Minimal amounts of subsurface flow from infiltration impoundments would resurface in stream channels but are not likely to reach the main stem of the Salt Creek sub-watershed. Under Alternative 2B, impacts to surface water quality would be similar to the results obtained under Alternative 1. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.6.4 Alternative 3

Under Alternative 3, the peak of water production in the Salt Creek sub-watershed would occur in year 2006, when 19 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Salt Creek sub-watershed during the peak year of CBM water production is about 0.1 cfs (72 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.2 Wyoming/Montana Streams

5.2.1 Upper Tongue River

The impact analysis of surface water in the Upper Tongue River sub-watershed incorporates current and forecast future development of CBM resources in the Montana portion of the Upper Tongue River sub-watershed. These flows are likely to contribute to flows of CBM produced water upstream of the USGS gauging station on the Tongue River at the state line near Decker, Wyoming.

This analysis assumed that the Montana Preferred Alternative E would be adopted. Montana's Alternative E emphasizes beneficial uses of produced water from CBM wells. Alternative E could include discharges of produced water that involve both treated and untreated water, so long as MPDES permit requirements are met. This impact analysis includes existing discharges of CBM produced water in the Upper Tongue River sub-watershed from Montana's CX Ranch field. Montana's existing permitted discharge incorporated in this modeling effort includes produced water from 120 wells at a discharge rate of 50 percent of the permitted maximum discharge (Langhus 2002).

Results of the impact analysis in the Upper Tongue River sub-watershed under each alternative are presented in Table 5-8. Potential impacts are discussed below.

Table 5-8
Surface Water Impact Analysis of the Upper Tongue River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	0.5	500	10	2500	178	0.9	731	189	3.1	826	43	1.29	1179	54	8.98	1423
2A	0.5	500	10	2500				183	1.9	776				48	5.38	1304
2B	0.5	500	10	2500				183	1.8	770				48	4.92	1288
3	0.5	500	10	2500				188	2.9	820				53	8.56	1409

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Tongue River sub-watershed would occur in year 2006, when 1,948 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 11 cfs (7,965 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

The Tongue River is an important source of irrigation water in and downstream of the Project Area. With the exception of the highest flow months of May and June, the water quality in the Tongue River currently exceeds the MRPL for EC and SAR; thus, any additional discharge that would reach the main stem would likely cause further degradation in terms of suitability irrigation if the states and EPA conclude that the MRPL is protective of irrigation uses. The water quality in the Tongue River currently is below the LRPL for both EC and SAR during all months and during 7Q10 flow conditions.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Tongue River would not meet the MRPL for EC, with the exception during high flows in May and June. The resultant water quality would not be adequate to meet the MRPL for SAR during all months and during 7Q10 flow conditions.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for both EC and SAR during all months of the year and during 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that some reduction in infiltration would be likely during some months of the irrigation season. During the low monthly flow, about 70 percent of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Upper Tongue River sub-watershed from CBM development in Wyoming and Montana under Alternative 1 would be expected to occur at the state line station near Decker, Wyoming, using the MRPL and LRPL criteria if the states and EPA conclude that the proposed limits would be protective of irrigation uses. However, surface discharge to the Upper Tongue River sub-watershed from CBM development in Wyoming would be controlled by WDEQ's interim "no new discharge" policy. Thus, the percentage of untreated surface discharge to the Upper Tongue River sub-watershed under Alternative 1 would not be authorized by WDEQ unless the quality of the discharged water was at or near the existing quality in the Tongue River. Potential impacts from Montana's existing CBM discharges from the CX Ranch field to the Upper Tongue River sub-watershed would be controlled by the current MPDES permit. Therefore, impacts to water quality would be more likely to result from CBM produced waters that resurface from infiltration impoundments or from migration of salts beneath LAD systems than from surface discharge. Impacts to water quality from CBM development in Wyoming to downstream uses on the Northern Cheyenne Reservation would be limited by the state's discharge policy.

5.2.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 5 cfs (3,620 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-25 and 5-26 are used to illustrate the months during the year when the existing water quality and resultant mixed water quality under mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Upper Tongue River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions exceeds the MRPL for EC and SAR when CBM produced water discharges from both states are mixed, except during the highest flow months of May and June.
- LRPL: Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is less than the LRPL for both constituents when CBM produced water discharges from both states are mixed.
- Ayers and Westcot diagram: Figure 5-27 illustrates the relationship between EC and SAR in the Upper Tongue River before and after the river mixes with discharges of CBM produced water under Wyoming’s Alternative 2A and Montana’s Alternative E. Under modeled conditions, a comparison of the resultant quality of the mixed water with the Ayers-Westcot diagram in Figure 5-27 indicates that a reduction in infiltration is not likely under mean monthly or 7Q10 flow conditions. Figure 5-28 illustrates the relationship between EC and SAR in the Upper Tongue River after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially all of the CBM discharge to the Upper Tongue River sub-watershed from both states could occur during the low monthly flow and during 7Q10 flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Figure 5-25 Stream EC Before and After Mixing-Upper Tongue River Sub-Watershed

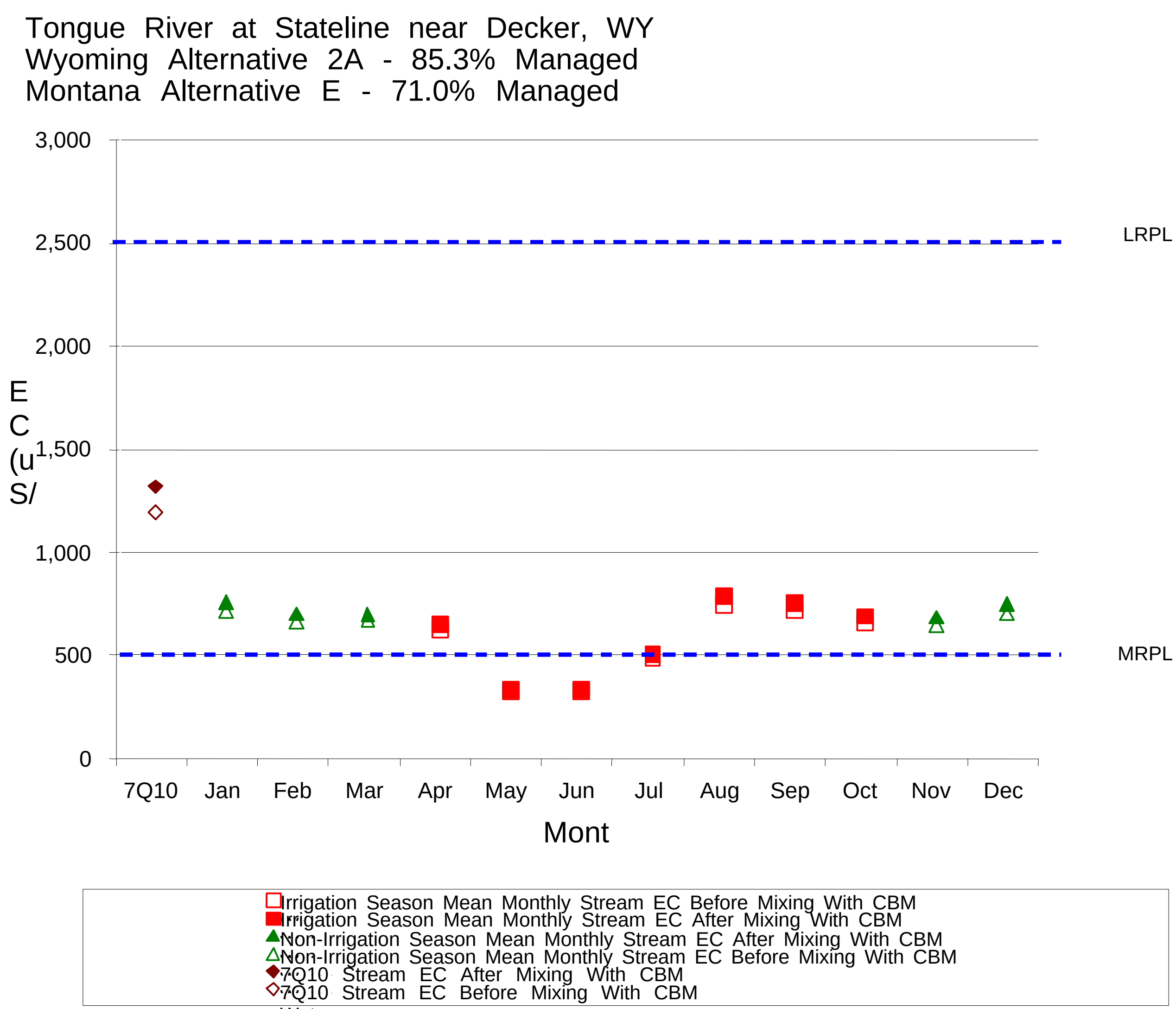


Figure 5-26 Stream SAR Before and After Mixing-Upper Tongue River Sub-Watershed

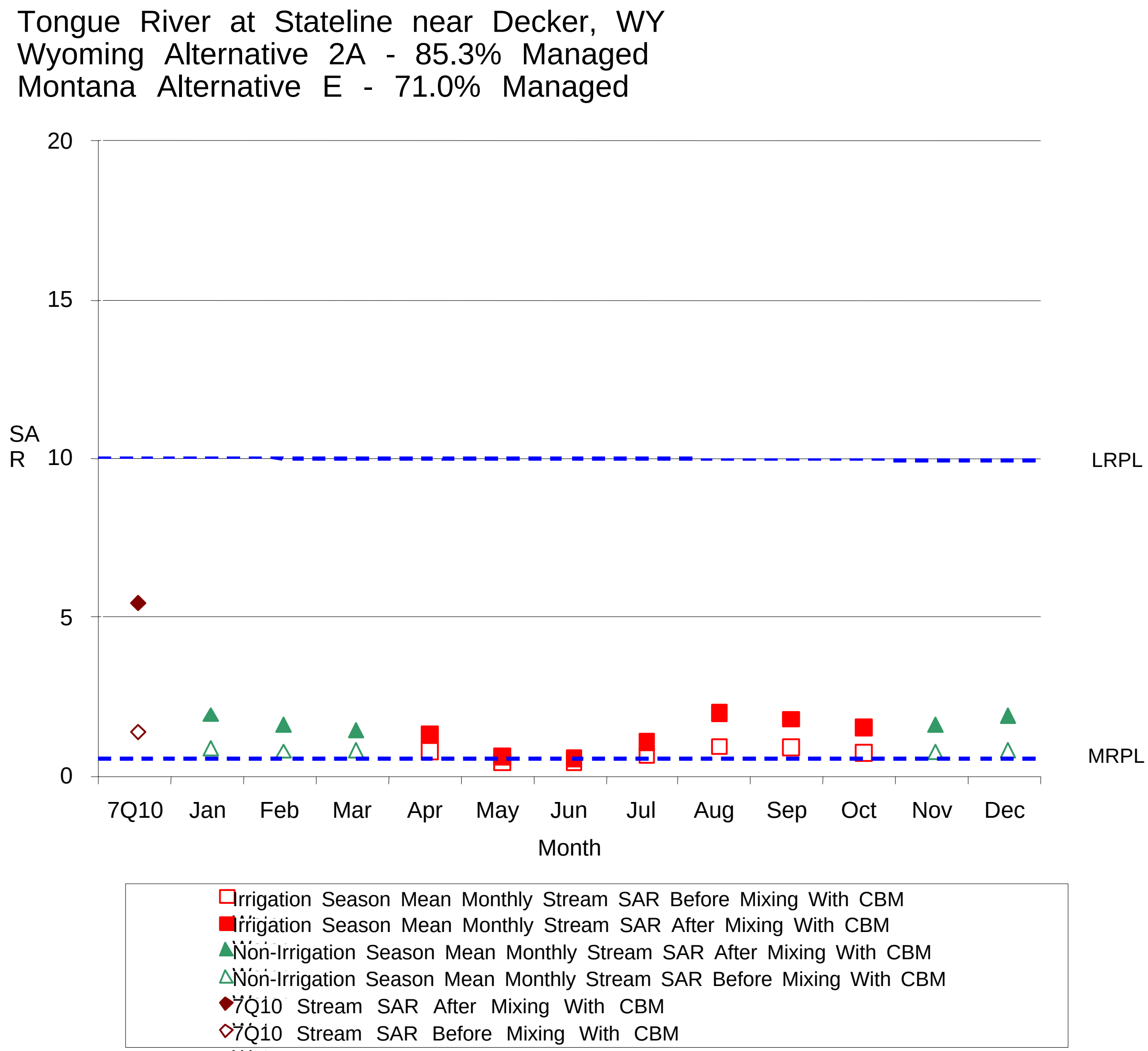


Figure 5-27 Irrigation Suitability Before and After Mixing – Upper Tongue River Sub-Watershed

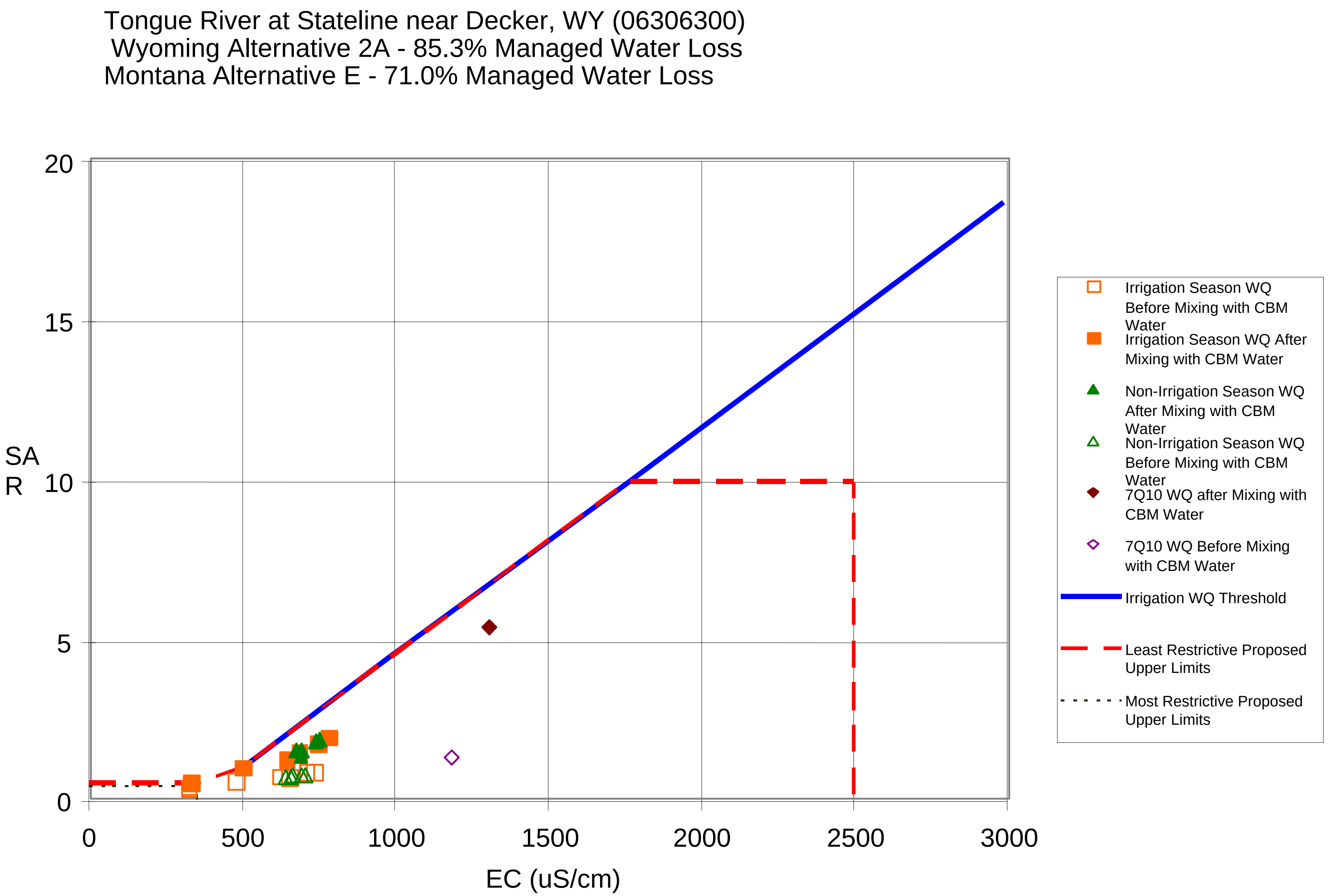
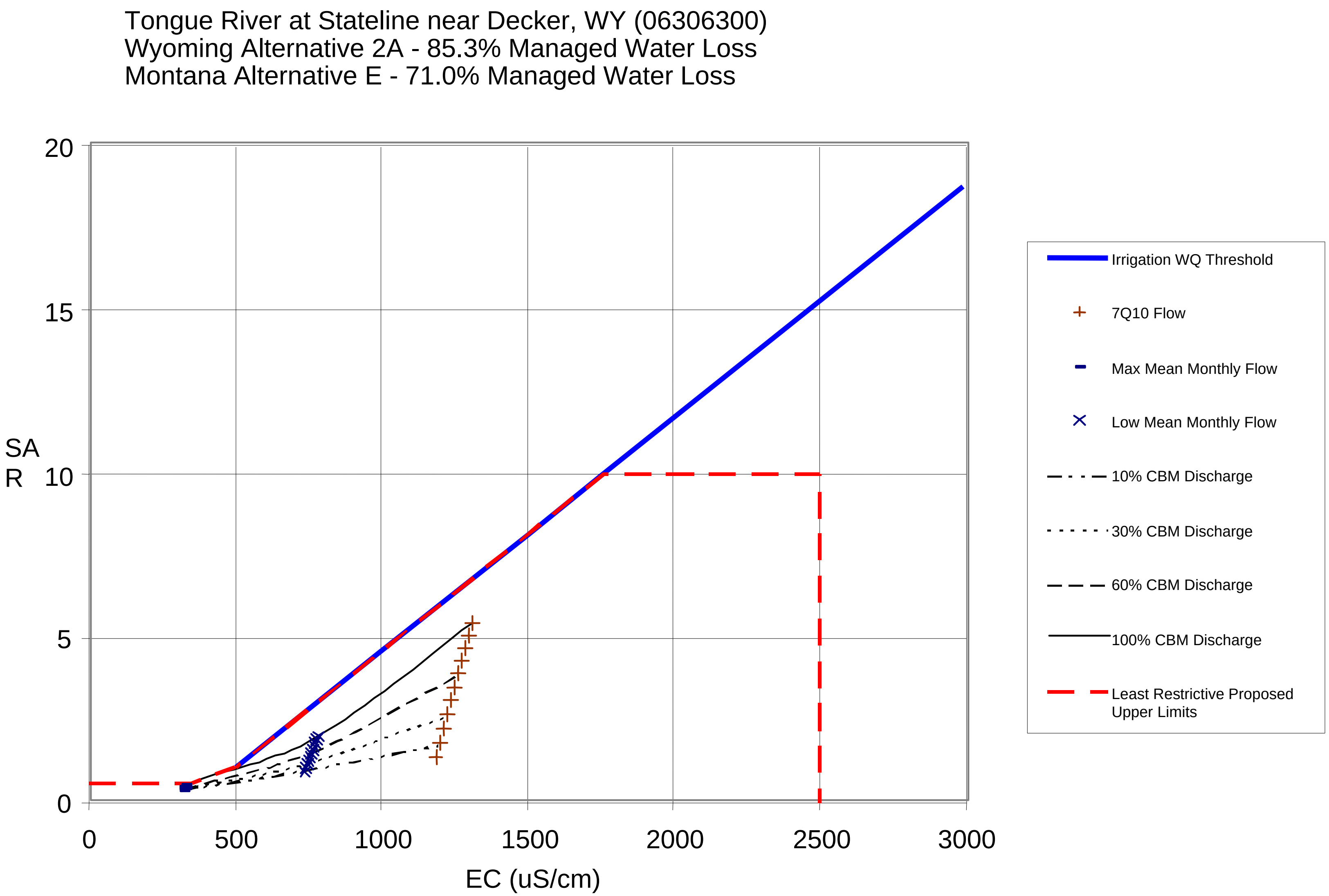


Figure 5-28 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Tongue River Sub-Watershed



Based on modeled results, impacts to the suitability for irrigation of the Tongue River from CBM development in Wyoming and Montana under Alternative 2A would not be expected to occur.

5.2.1.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in LAD for water handling and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 4 cfs (2,896 acre-feet per year). Impacts to surface water quality in the Upper Tongue River sub-watershed would be less than were described under Alternative 1 and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Tongue River sub-watershed would occur in year 2006, when 1,786 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 10 cfs (7,241 acre-feet per year). Impacts to surface water quality in the Upper Tongue River sub-watershed would be similar to Alternative 1.

5.2.2 Powder River

The impact analysis of surface water in the Middle Powder River sub-watershed incorporates the cumulative discharges of CBM produced water from the Clear Creek, Crazy Woman Creek, Salt Creek, and Upper Powder River sub-watersheds. The analysis also includes current and future forecast development of CBM resources in the Montana portion of the Middle Powder River sub-watershed that would be likely to contribute flows of CBM produced water upstream of the USGS gauging station on the Powder River at Moorhead, Montana.

This analysis assumed that Montana Preferred Alternative E would be adopted. Under Alternative E, Montana would not allow untreated surface discharge from CBM wells to the Middle Powder River sub-watershed (in other words, managed water losses would equal 100 percent) if Wyoming were to implement Alternative 1. Montana would, however, allow unlimited (100 percent) surface discharge, assuming MPDES permit requirements were met, if Wyoming were to implement one of Alternatives 2A, 2B, or 3. Results of the impact analysis for the Middle Powder river sub-watershed under each alternative are presented in Table 5-9. Potential impacts to water quality are discussed below.

Table 5-9
Surface Water Impact Analysis of the Middle Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	145	4.6	2154	312	13.8	2270	0.3	6.15	4400	167	21.8	2374
2A	2.0	1000	10	3200				230	11.6	2253				85	23.2	2426
2B	2.0	1000	10	3200				223	11.2	2249				78	23.3	2431
3	2.0	1000	10	3200				218	11.3	2270				73	24.4	2505

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.2.1 Alternative 1

Under Alternative 1, the peak of water production in the Middle Powder River sub-watershed would occur in year 2005, when 21,047 wells would be producing at an average rate of 6.2 gpm per well. The peak year of water production in the Salt Creek, Clear Creek, Crazy Woman Creek, and Upper Powder River sub-watersheds would occur in 2006; however, this analysis used the number of wells that would be producing in those watersheds during 2006 for the analysis of cumulative impacts in the Middle Powder River sub-watershed for 2005 to predict the impacts during the peak year. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 167 cfs (120,920 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC and SAR values in the Middle Powder River currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. With the exception of the EC under 7Q10 flow conditions, the water quality currently is less than the LRPL for both EC and SAR under similar flow conditions. After the water mixes, natural stream flow would increase by approximately twofold during low-flow conditions. The resultant EC and SAR would increase from existing conditions. The resulting stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Middle Powder River sub-watershed would not meet the MRPL for both EC and SAR during all months and during 7Q10 flow conditions.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC during all months of the year but would not be adequate to meet the LRPL for SAR during the lowest flow months, or during 7Q10 flow conditions. The lowest flow months include the irrigation season from August through October.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would not be a reduction in infiltration except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Middle Powder River from CBM development in Wyoming and Montana would be expected to occur at the Moorhead, Montana station, using the MRPL and LRPL criteria if the states and EPA conclude that the proposed limits would be protective of irrigation uses.

Modeling indicates that the suitability of the Powder River for irrigation may be compromised by surface discharge of CBM produced water during maximum CBM development in both states. However, enhanced monitoring of CBM discharges and an evaluation of downstream irrigation practices would be necessary to assess whether there would be a measurable decrease in crop production. State permitting procedures in Wyoming require CBM operators to include an irrigation use protection plan with the NPDES permit application that specifies necessary measures to prevent violating the narrative standards for protection of irrigated agriculture in the Powder River drainage. Mitigation measures would be implemented based on the site-specific analysis of existing irrigation practices. CBM operators could be required to increase the amount of storage of CBM water during the irrigation months, and proceed with more surface discharge during the non-irrigation months, to meet the needs of downstream irrigators. As the state develops a better understanding of the effects of CBM discharges through the enhanced monitoring required by the MOC, Wyoming can adjust its permitting approach to allow more or less discharges to the Powder River drainage. Through the implementation of instream monitoring and adaptive management, water quality standards and agreements with bordering states can be met.

5.2.2.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 86 cfs (62,270 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-29 and 5-30 illustrate the months during the year when the existing water quality and resultant quality of mixed water under mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Middle Powder River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is greater than the MRPL for EC and SAR during all months of the year when CBM produced water discharges from both states are mixed.
- LRPL: Under modeled conditions, the resultant EC is less than the LRPL under similar flow conditions when CBM produced water discharges from both states are mixed. The resultant SAR would not be adequate to meet the LRPL during the lowest flow months or during 7Q10 flow.
- Ayers and Westcot diagram: Figure 5-31 illustrates the suitability for irrigation of the Powder River before and after the river mixes with discharges of CBM produced water. Under modeled conditions, a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-31 indicates that a reduction in infiltration is not likely except under 7Q10 flow conditions. Figure 5-32 illustrates the relationship between EC and SAR in the Middle Powder River sub-watershed after the river mixes with varying proportions of CBM produced water discharges under various stream flow conditions. Under modeled conditions, essentially all of the CBM discharge to the Middle Powder River sub-watershed from both states could occur without causing effects to infiltration, with the exception of 7Q10 flow conditions. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, under certain flow conditions, impacts to irrigated agriculture in the Powder River sub-watershed from CBM development in Wyoming and Montana under Alternative 2A may occur. Although the resultant impacts fall outside the boundaries of the LRPL during some months, BLM recognizes the uncertainty concerning the determination of water quality standards for EC and SAR. If a standard at the low end of the range of proposed values is selected, additional mitigation may be necessary for CBM discharges to this sub-watershed to occur. Potential mitigation measures that could be implemented in order to meet the ultimate regulatory standards for EC and SAR once those standards have been identified include CBM produced water storage during the irrigation months and surface discharge during the non-irrigation months. In addition, discharge permits issued by the WDEQ and MDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Powder River from CBM development in Wyoming and Montana under Alternative 2A may not occur.

Figure 5-29 Stream EC Before and After Mixing- Middle Powder River Sub-Watershed

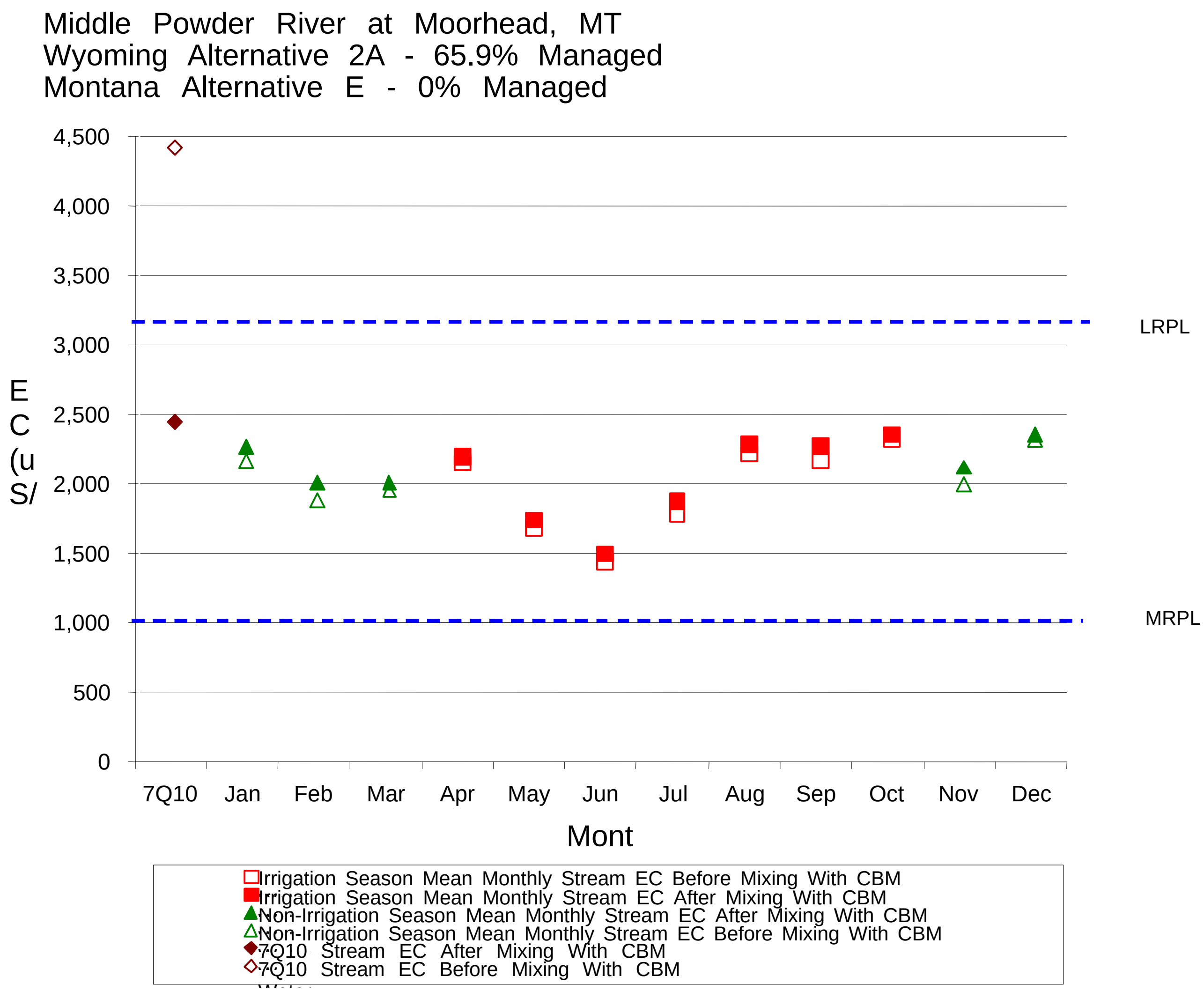


Figure 5-30 Stream SAR Before and After Mixing- Middle Powder River Sub-Watershed

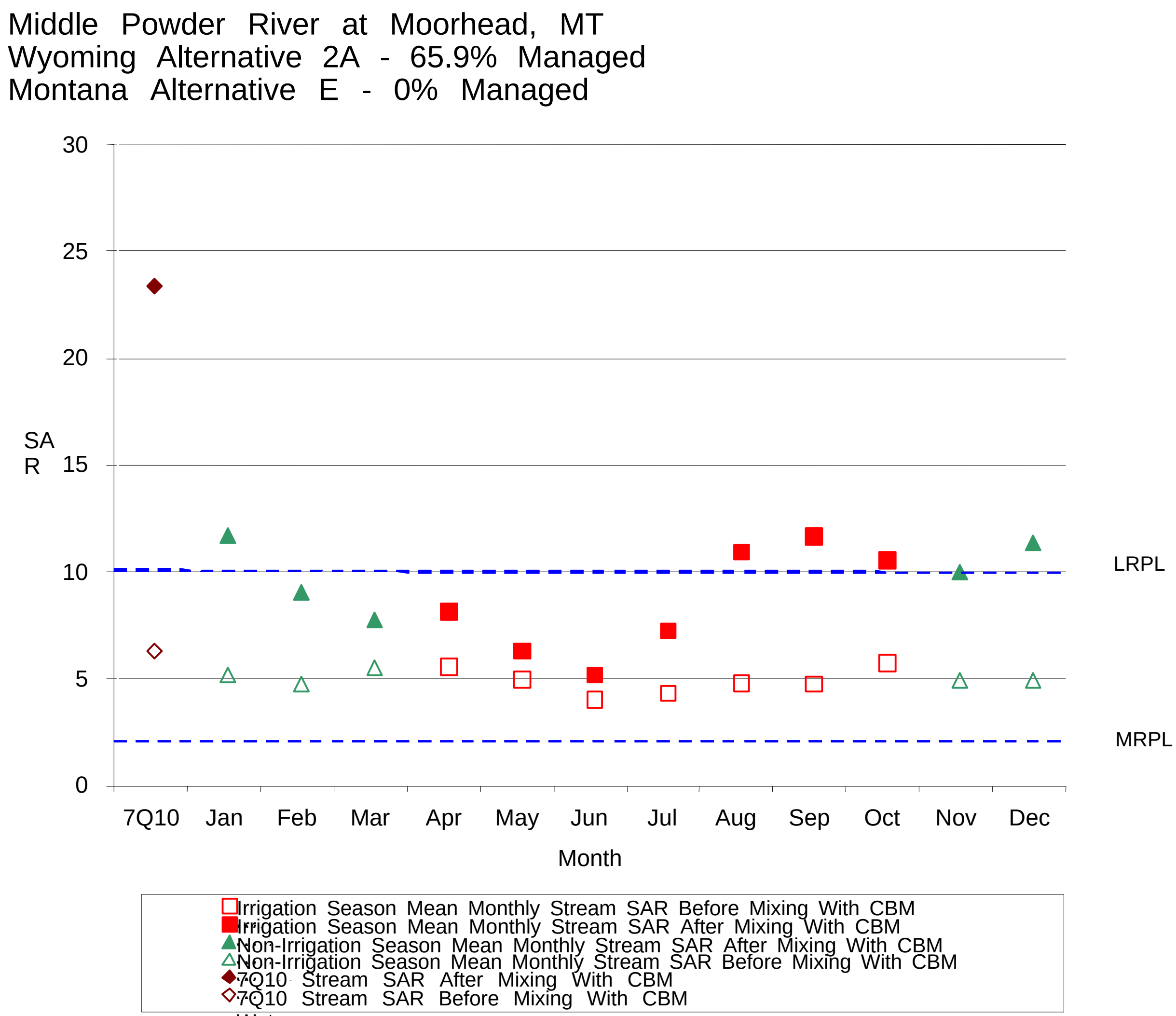


Figure 5-31 Irrigation Suitability Before and After Mixing – Middle Powder River Sub-Watershed

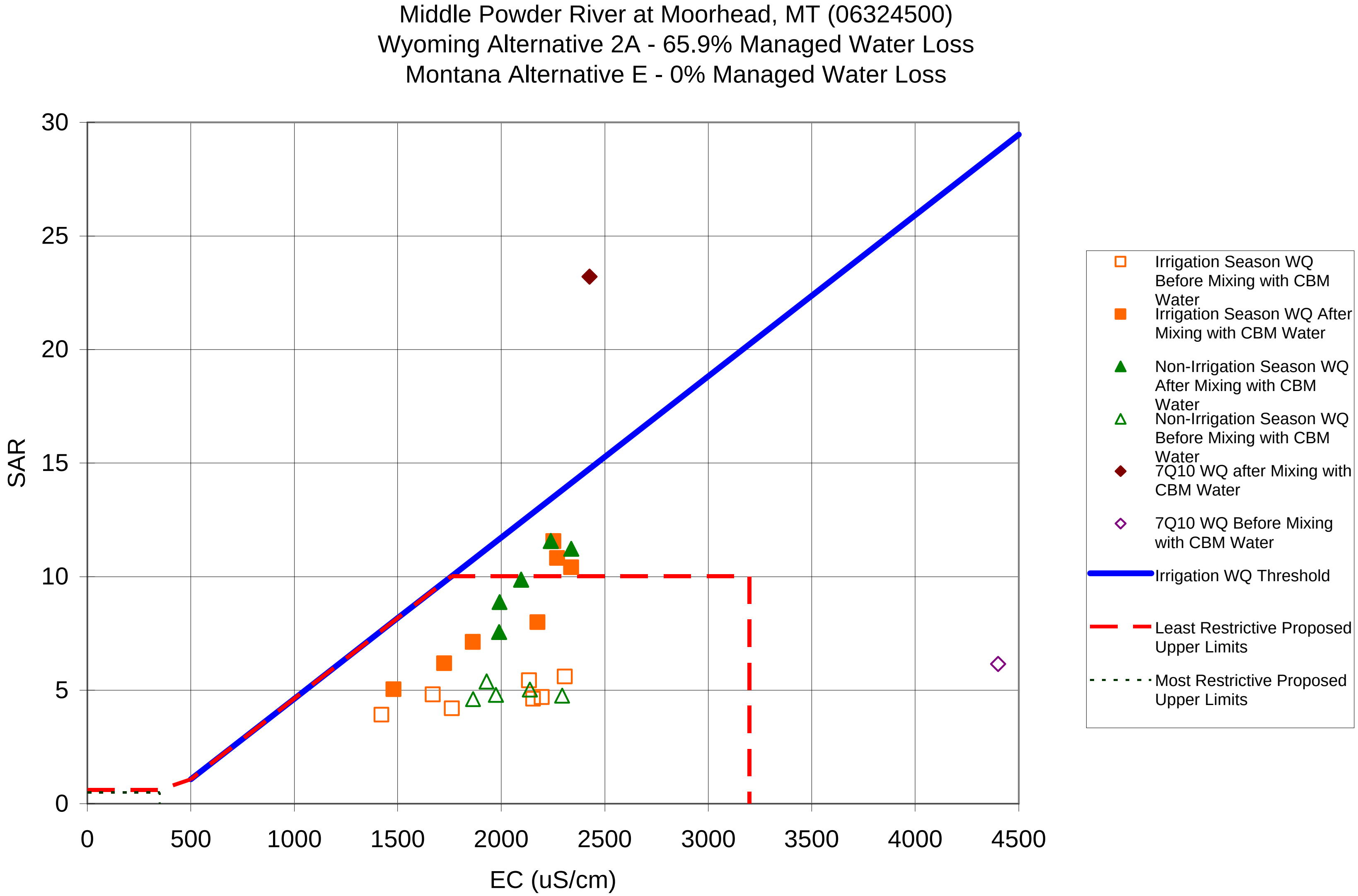
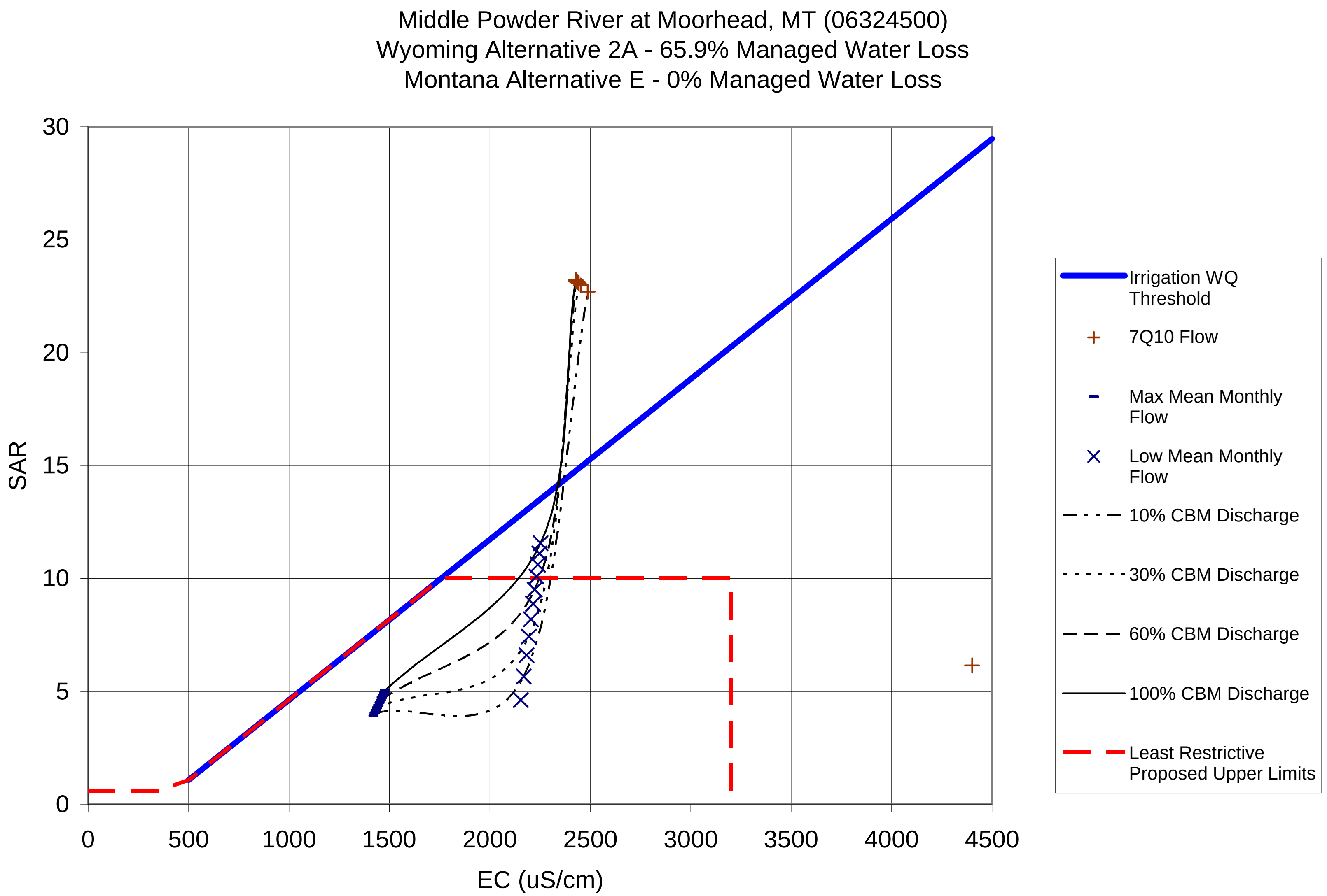


Figure 5-32 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Middle Powder River Sub-Watershed



5.2.2.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 79 cfs (57,200 acre-feet per year). Impacts to surface water quality in the Middle Powder River sub-watershed would be less than were described under Alternative 1, and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.2.4 Alternative 3

Under Alternative 3, the peak of water production in the Middle Powder River sub-watershed would occur in year 2005, when 8,469 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 74 cfs (53,581 acre-feet per year). Impacts to the quality of surface water in the Middle Powder River sub-watershed would be similar to Alternative 1.

5.2.3 Little Powder River

Development of CBM resources in Montana would not contribute flows upstream of the USGS gauging station on the Little Powder River near Weston, Wyoming. However, CBM development in Wyoming has the potential to cause impacts to water quality in this drainage. Therefore, future forecast development of CBM resources downstream in Montana may be limited in the amount of surface discharge to this drainage under the Montana preferred alternative.

Results of the impact analysis in the Little Powder River sub-watershed under each alternative are presented in Table 5-10. Potential water quality impacts are discussed below.

Table 5-10
Surface Water Impact Analysis of the Little Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	3.0	1000	10	3000	3	6.9	3300	21	10.6	1519	0.0	--	--	18	11.1	1271
2A	3.0	1000	10	3000				16	10.4	1606				13	11.1	1271
2B	3.0	1000	10	3000				15	10.4	1625				12	11.1	1271
3	3.0	1000	10	3000				18	10.5	1564				15	11.1	1271

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.3.1 Alternative 1

Under Alternative 1, the peak of water production in the Little Powder River sub-watershed would occur in year 2005, when 2,543 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 19 cfs (13,757 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC and SAR values in the Little Powder River currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents, except during low-flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would increase. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero. Therefore, the resultant water quality under these flow conditions would be represented by the quality of CBM produced water, if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Little Powder River during all months and during 7Q10 flow conditions would not meet the MRPL for both EC and SAR.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC during all months of the year but would not be adequate to meet the LRPL for SAR during the lowest flow months. These low-flow months include the irrigation season during August and September.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season and during 7Q10 flow conditions. During the low monthly flow, about 40 percent of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, under certain flow conditions, impacts to the suitability for irrigation of the Little Powder River from CBM development in Wyoming would be expected to occur at the Weston, Wyoming station using the Ayers-Westcot diagram and MRPL and LRPL criteria for EC and SAR, if the states and EPA conclude that the proposed limit would be protective of irrigation uses.

Modeling indicates that the suitability of the Little Powder River for irrigation may be compromised by the surface discharge of CBM produced water during maximum CBM development in both states. However, enhanced monitoring of CBM discharges and an evaluation of downstream irrigation practices would be necessary to assess whether there would be a measurable decrease in crop production. State permitting procedures in Wyoming require CBM operators to include an irrigation use protection plan with the NPDES permit application that specifies measures necessary to prevent violations of the narrative standards for protection of irrigated agriculture in the Powder River drainage. Mitigation measures would be implemented based on the site-specific analysis of existing irrigation practices. CBM operators could be required to increase the amount of storage of CBM water during the irrigation months, and proceed with more surface discharge during the non-irrigation months, to meet the needs of downstream irrigators. As the state develops a better understanding of the effects of CBM discharges through the enhanced monitoring required by the MOC, Wyoming can adjust its permitting approach to allow more or less discharges to the Little Powder River drainage so that water quality standards and agreements with bordering states can be met.

5.2.3.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 13 cfs (9,143 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-33 and 5-34 are used to illustrate the months during the year when the existing water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Little Powder River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is greater than the MRPL for EC and SAR during all months of the year.
- LRPL: Under modeled conditions, the resultant EC is less than the LRPL under both mean monthly and 7Q10 flow conditions. The resultant SAR is less than the LRPL, except during the lowest flow months, and during 7Q10 flow.
- Ayers and Westcot diagram: Figure 5-35 illustrates the suitability for irrigation of the Little Powder River before and after the river mixes with discharges of CBM produced water under Wyoming’s Alternative 2A. Under modeled conditions, a comparison of the resultant quality of the mixed water with the Ayers-Westcot diagram in Figure 5-35 indicates that there would be some reduction in infiltration during some months of the irrigation season and under 7Q10 flow conditions. Figure 5-36 illustrates the relationship between EC and SAR in the Little Powder River after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 50 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Based on modeled results, under certain flow conditions, impacts to the suitability for irrigation of the Little Powder River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Little Powder River from CBM development in Wyoming under Alternative 2A may not occur.

Figure 5-33 Stream EC Before and After Mixing-Little Powder River Sub-Watershed

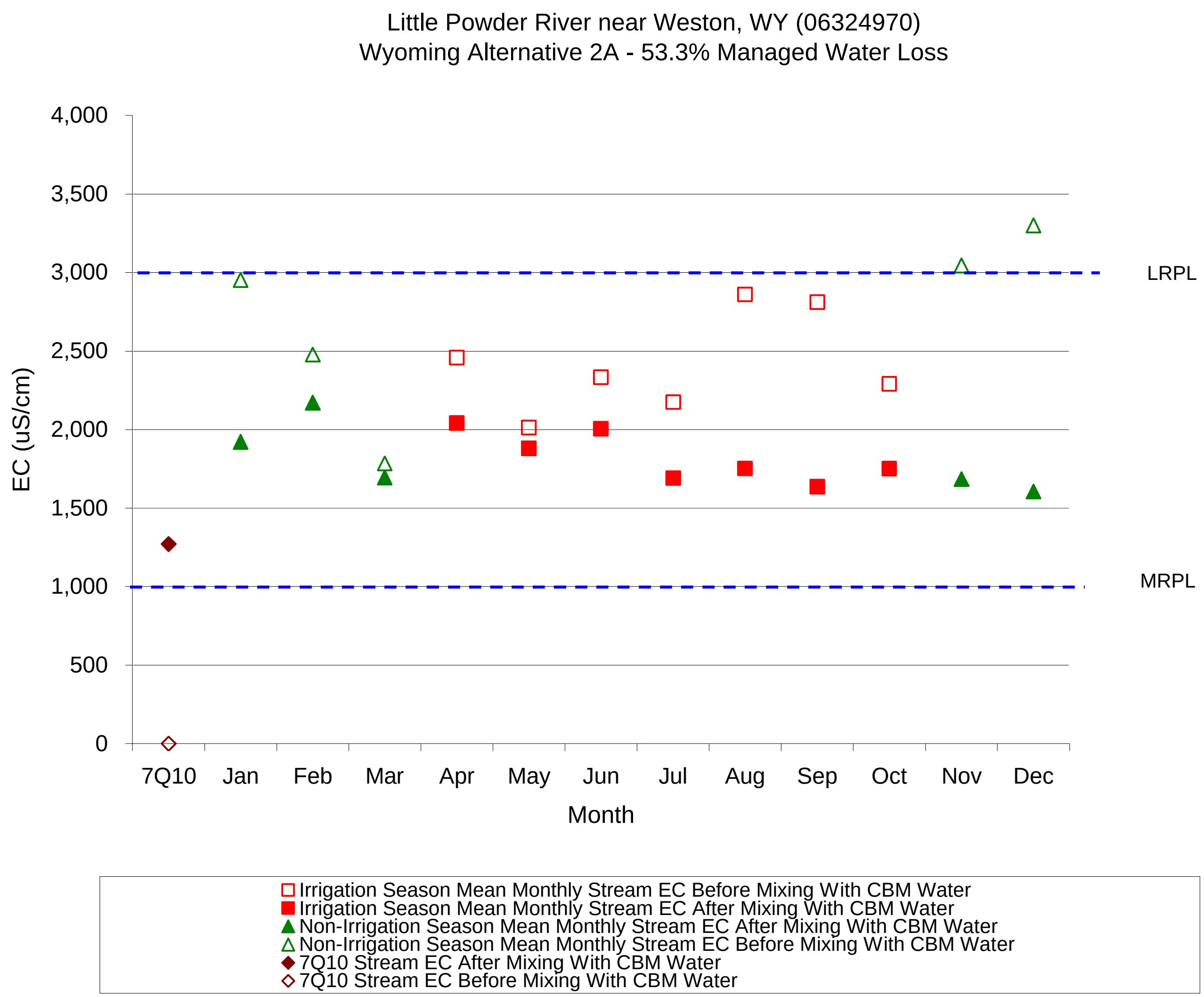


Figure 5-34 Stream SAR Before and After Mixing-Little Powder River Sub-Watershed

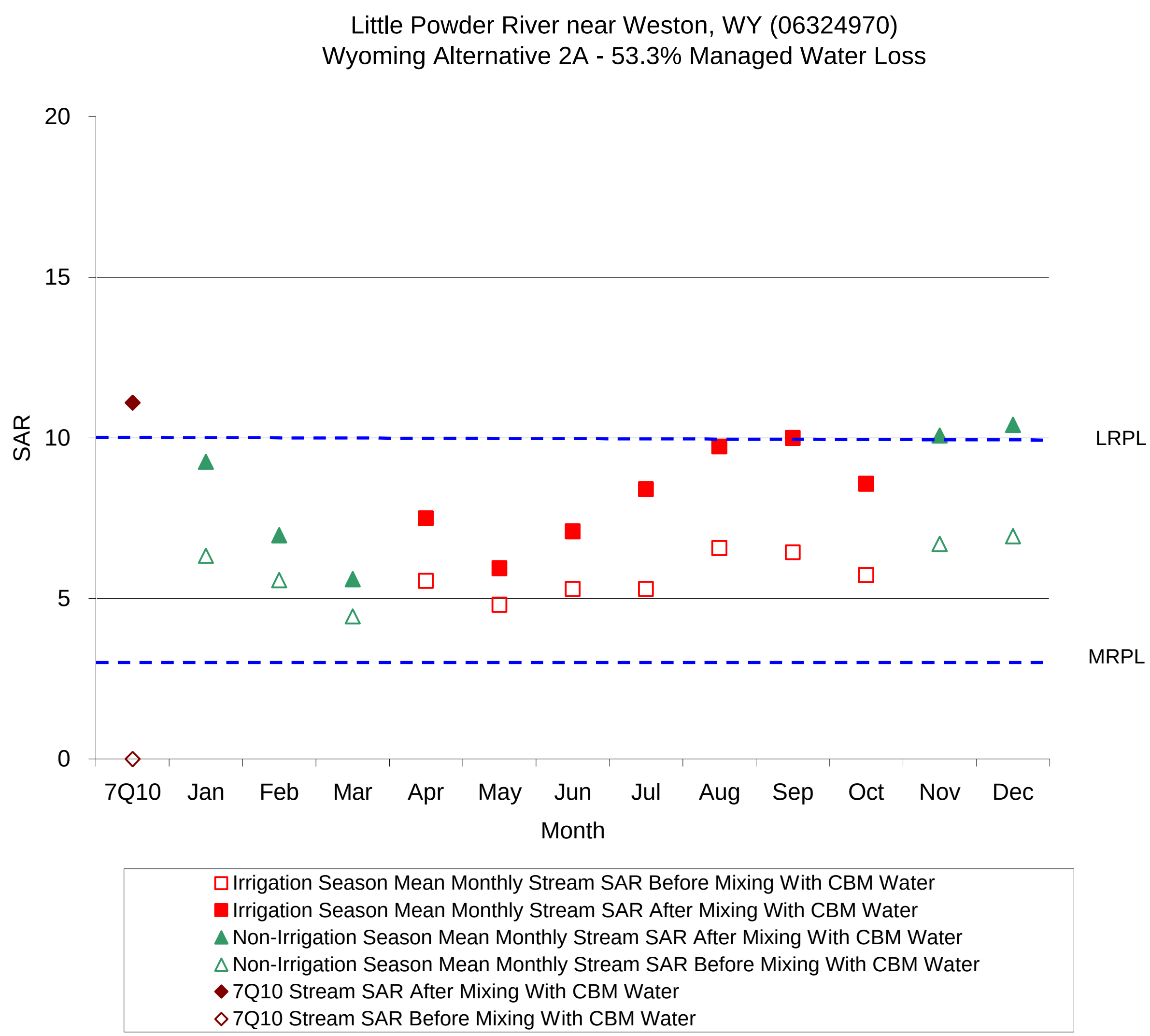


Figure 5-35 Irrigation Suitability Before and After Mixing - Little Powder River Sub-Watershed

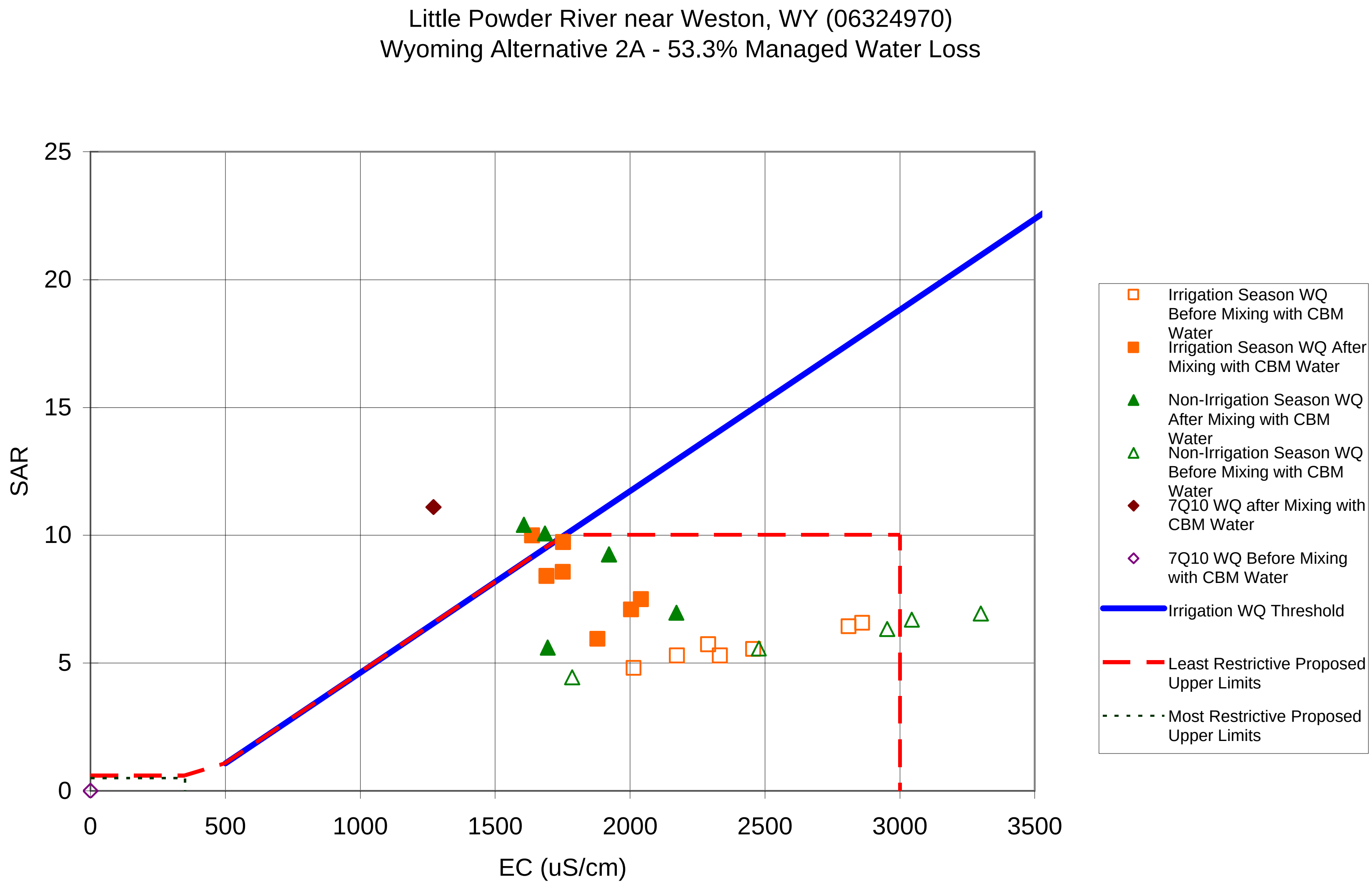
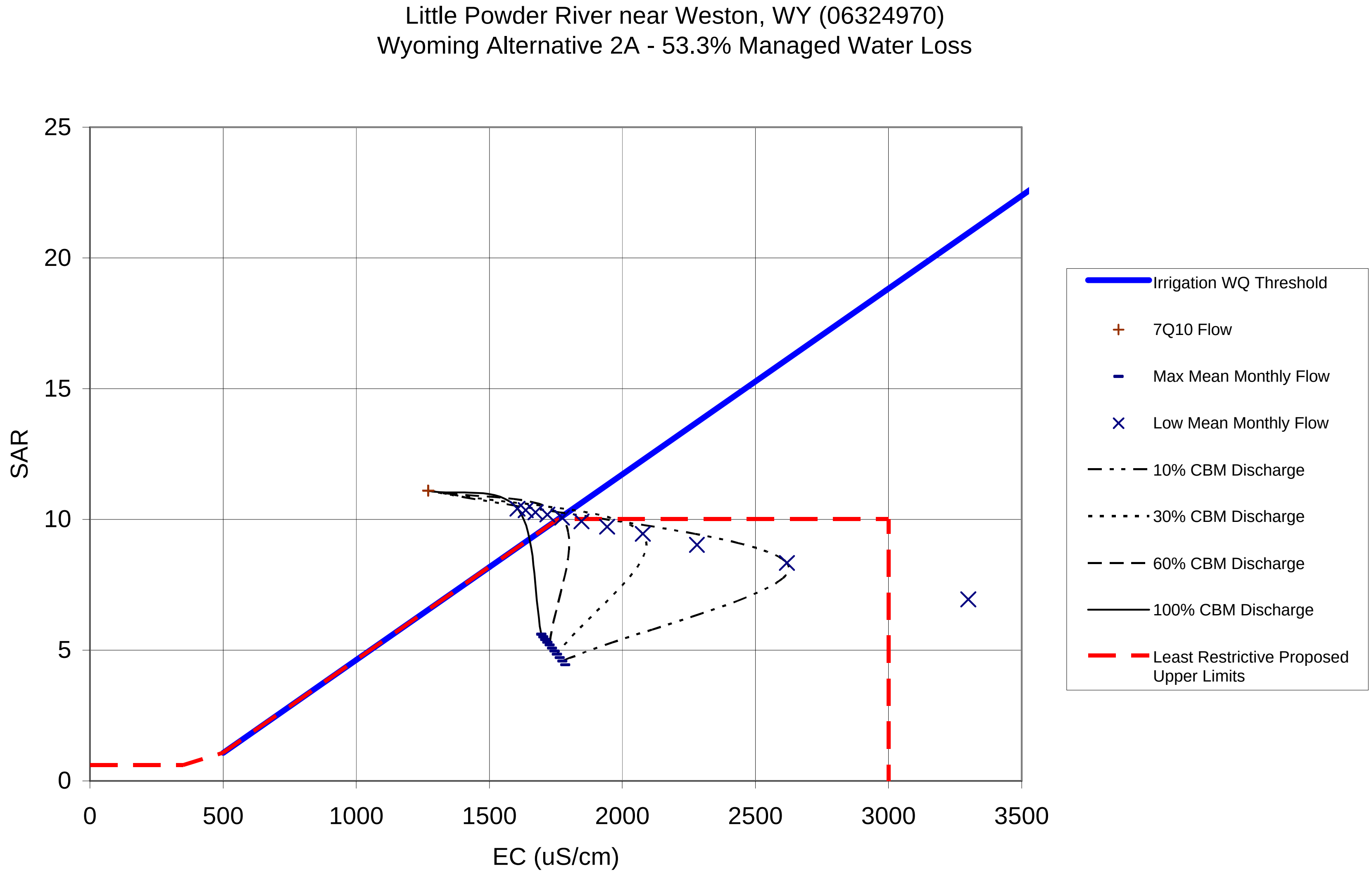


Figure 5-36 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Little Powder River Sub-Watershed



5.2.3.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). Impacts to surface water quality in the Little Powder River sub-watershed would be less than were described under Alternative 1, and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.3.4 Alternative 3

Under Alternative 3, the peak of water production in the Little Powder River sub-watershed would occur in year 2005, when 2,093 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 15 cfs (10,861 acre-feet per year). Impacts to surface water quality in the Little Powder River sub-watershed would be similar to Alternative 1.

5.3 Montana Streams

Potential impacts to the water quality in Montana streams were analyzed assuming Wyoming Alternative 2A would be implemented and potential impacts to water quality identified from CBM development under Alternative 2A in Wyoming would persist in Montana. Potential water quality impacts identified in Wyoming streams that flow into Montana were assumed to be present under all five management alternatives considered in the Montana FEIS.

5.3.1 Tongue River

The headwaters of the Tongue River are in the Bighorn Mountains southwest of the point where it crosses the state line near Decker, Montana; it can receive CBM discharges from current and future development in both the Wyoming and Montana portions of the PRB. Table 5-11 below summarizes the impacts for the three stream stations along the Tongue River in Montana.

The Tongue River is not expected to be affected by direct discharges of CBM produced water from Wyoming based on WDEQ’s “no new discharge” policy. It was assumed, however, that 15 percent of the Managed Water Loss from CBM discharges in Wyoming would reach the Tongue River and contribute to existing surface flows before it reaches the state line station. Additional impacts to water quality could be anticipated from the surface discharge of 240 CBM wells in the CX Ranch field, as well as additional CBM wells under other management alternatives.

Table 5-11
Surface Water Impact Analysis of the Upper/Lower Tongue River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	183	1.93	773	43	1.29	1179	48	5.34-5.09	1295-1304
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	190	2.52	912	45	1.60	1159	51	6.26-6.79	1316-1303
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	214	2.50	1058	70	1.82	1281	76	4.95-5.31	1377-1368
C	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	187	2.68-2.94	806-812	43	1.29	1179	52	7.76-8.70	1369-1391
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	213	6.38-7.43	1055-1080	45	1.60	1159	75	16.43-19.4	1586-1658
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	265	9.51-11.22	1278-1319	70	1.82	1281	128	18.49-22.04	1705-1790
D	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	187	1.49	747	43	1.29	1179	52	3.46	1157

Table 5-11
Surface Water Impact Analysis of the Upper/Lower Tongue River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	213	1.59	824	45	1.60	1159	75	6.79	1303
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	265	1.67	904	70	1.82	1281	128	2.26	929
E	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	183	1.93	773	43	1.29	1179	48	5.34	1295
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	190	2.52	912	45	1.60	1159	51	6.26-6.79	1303-1316
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	214	2.50	1058	70	1.82	1281	76	4.95-5.31	1368-1377

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.1.1 Alternative A

Under this alternative, no further CBM development would occur, except at the existing CX Ranch field. Mean monthly EC and SAR values in the Tongue River at the three gauging stations currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents under similar flow conditions. After the water mixes, the resultant flow under low monthly conditions would increase slightly at the three locations. The resultant EC and SAR would increase from existing stream conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Tongue River at the three locations would not be adequate to meet the MRPL for both EC and SAR; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast would further exceed these limits.
- LRPL: Under modeled conditions, the resulting water quality would be adequate to meet the LRPL for EC and SAR during the minimum mean monthly and 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that no reduction in infiltration would be likely during the irrigation season. Essentially 100 percent of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.3.1.2 Alternative C

Under this alternative, CBM discharges from maximum development would result in moderate increases in EC and flow and significant increases in SAR. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Tongue River at the three locations would not be adequate to meet the MRPL for both EC and SAR; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The forecast impacts from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: Under modeled conditions, the resultant water quality during the minimum mean monthly flow would exceed the LRPL for SAR at the Ashland station in Montana. The resultant water quality during other months would be below the proposed limits for both constituents. The resultant water quality during the 7Q10 flow would exceed the LRPL for SAR.
- Ayers and Westcot diagram: Irrigation with the mixed water at the station in Decker, Wyoming, indicates that there would not be a reduction in infiltration, except during 7Q10 flow conditions. The resultant water quality at the Birney Day School and Ashland stations would result in some reduction in infiltration. Texture and permeability, especially of clayey soils, could be reduced if the mixed Tongue River water from these locations were to be used for irrigation. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA. Irrigators may need to alter management schemes to avoid these impacts.

Under this alternative, the surface water quality of the Tongue River would be reduced, requiring changes in irrigation management practices by downstream users during part or all of the year. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.1.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used, and the remaining 80 percent would be treated to achieve the pre-development quality of surface water before discharge.

The increases in surface water quality shown in Table 5-11 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. The volume of flow would change as a result of treated and untreated discharges in both Montana and Wyoming. The effects to water quality that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water conditions from CBM development in Montana would be caused by the increases in base flow.

5.3.1.4 Preferred Alternative E

Under Preferred Alternative E, the Tongue River could receive CBM discharges from current and future development in both the Wyoming and Montana portions of the PRB. The discharges forecast under this alternative would result in the same water quality described for Alternative A. The resultant stream water quality near Birney, Montana, can be compared with the following criteria:

- MRPL: Figures 5-37 and 5-38 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Upper Tongue River sub-watershed. This quality was modeled at the USGS gauging station near Birney, Montana. The water quality in the Tongue River near Birney naturally exceeds the MRPL for both EC and SAR for all but 2 months out of the average year; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly or 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-39 illustrates the suitability for irrigation of the Upper Tongue River near Birney before and after the river mixes with discharges of CBM produced water. a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-39 indicates that there would be some reduction in infiltration during some months of the irrigation season under modeled conditions. Figure 5-40 illustrates the relationship between EC and SAR in the Upper Tongue River near Birney after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow and 7Q10 flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Figure 5-37 Stream EC Before and After Mixing-Upper Tongue River Sub-Watershed

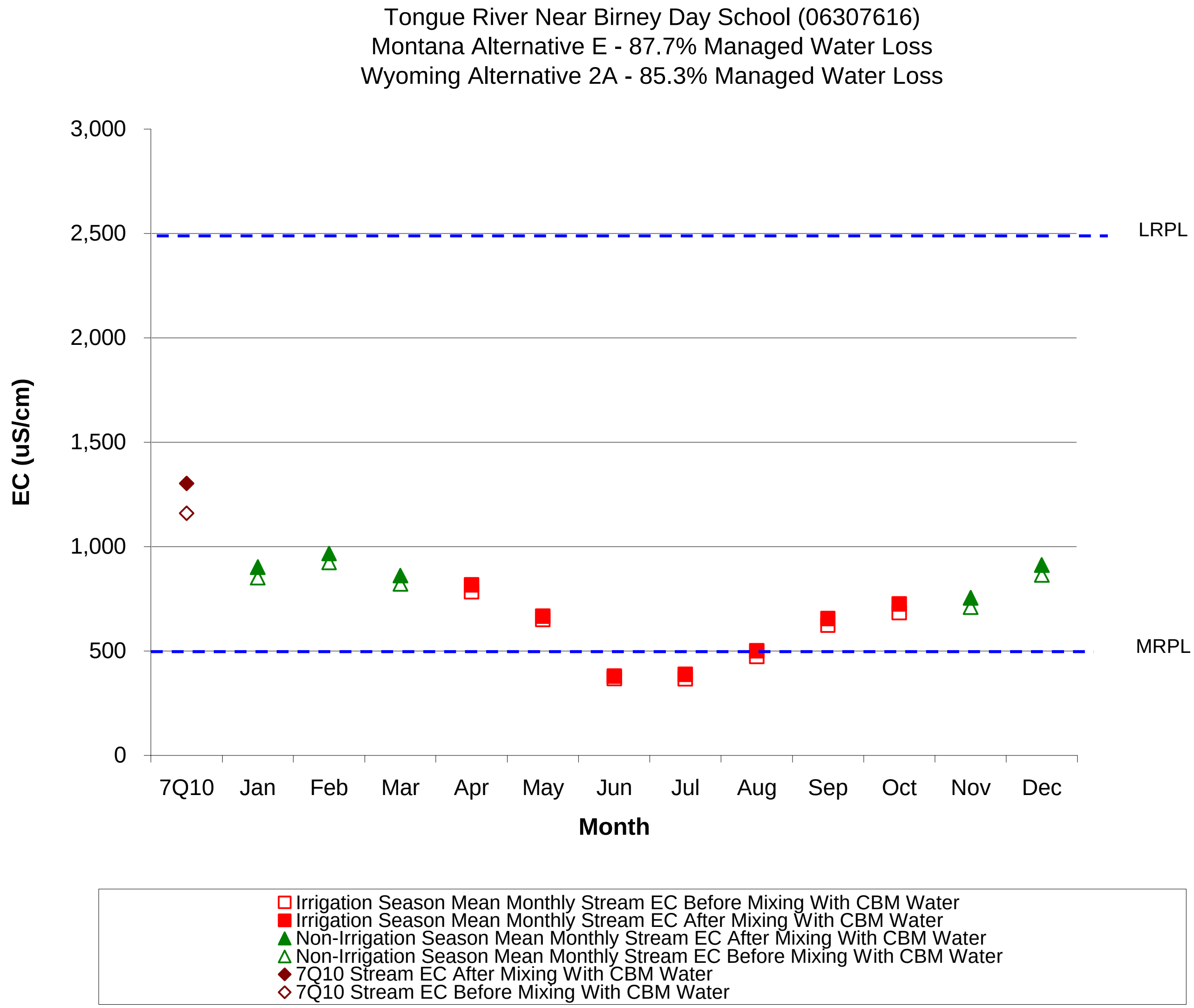


Figure 5-38 Stream SAR Before and After Mixing-Upper Tongue River Sub-Watershed

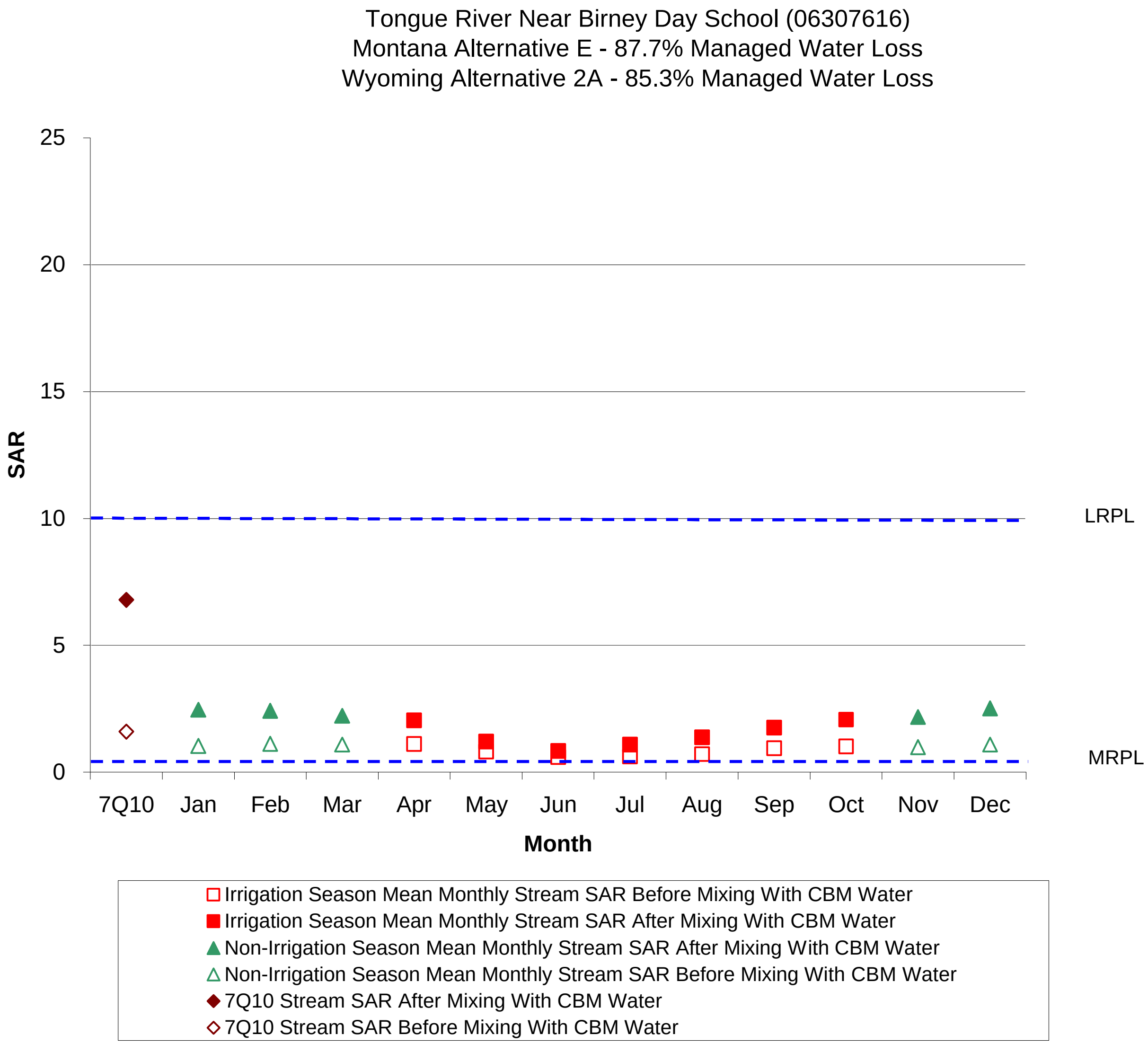


Figure 5-39 Irrigation Suitability Before and After Mixing – Upper Tongue River Sub-Watershed

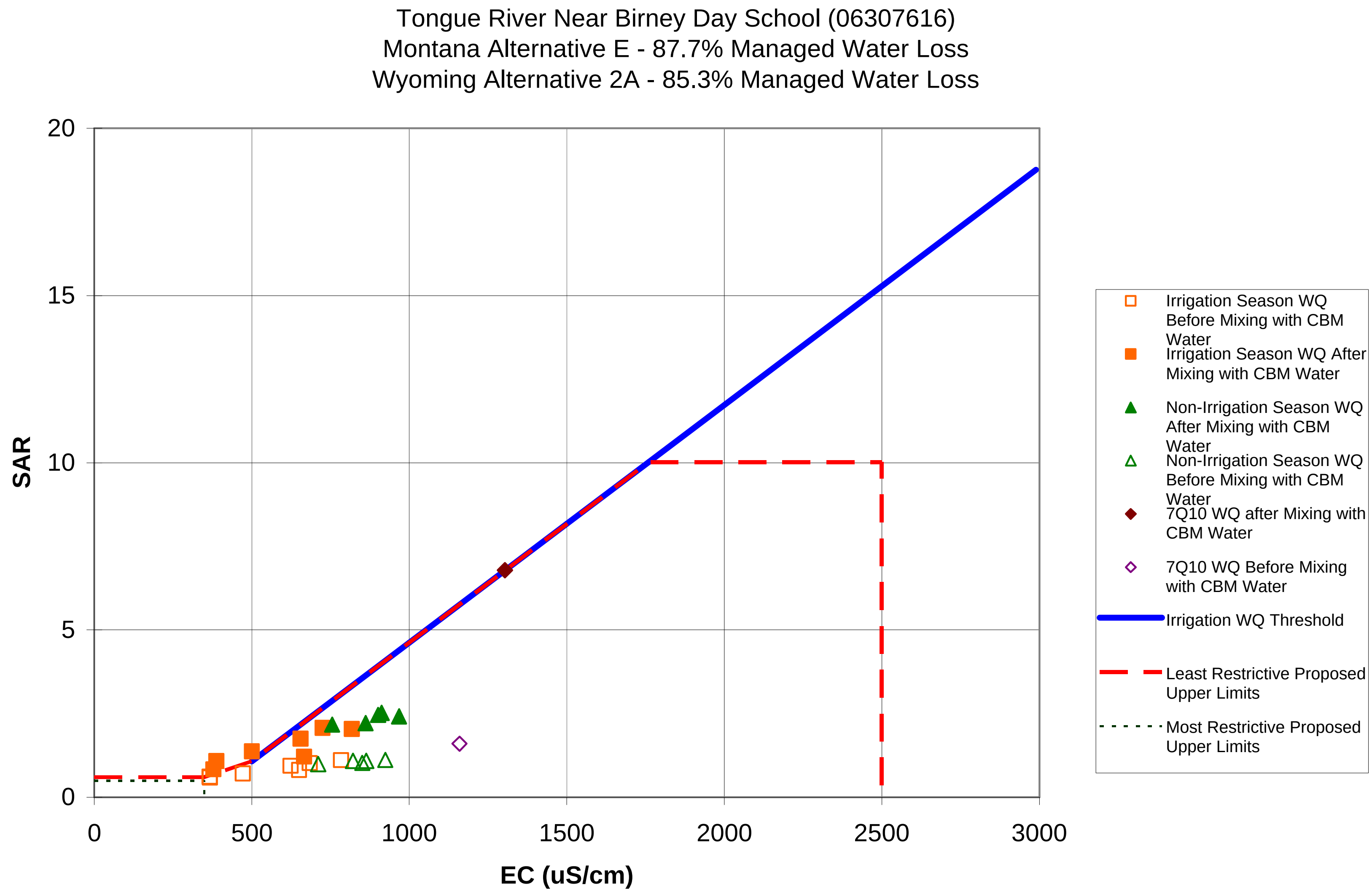
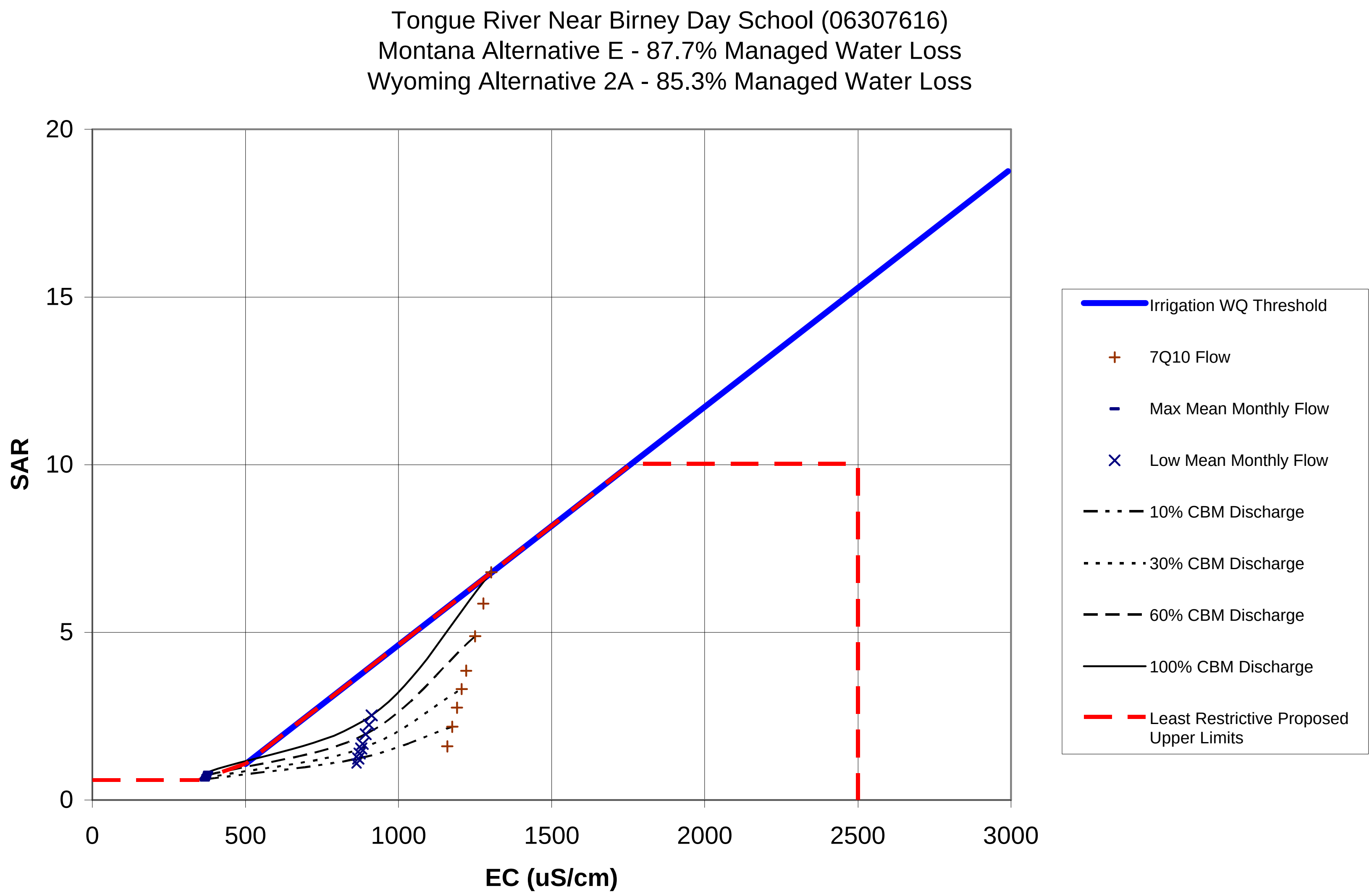


Figure 5-40 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Tongue River Sub-Watershed



Under Alternative E, the resultant stream water quality near Ashland, Montana, can be compared with the following criteria:

- MRPL: Figures 5-41 and 5-41 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Upper Tongue River sub-watershed, as modeled at the USGS gauging station near Ashland, Montana. The water quality in the Tongue River near Ashland naturally exceeds the MRPL for both EC and SAR for all but 2 months out of the average year; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly or 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-43 illustrates the suitability for irrigation of the Upper Tongue River near Ashland before and after the river mixes with discharges of CBM produced water.A comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-43 indicates that there would be some reduction in infiltration during some months of the irrigation season under modeled conditions. Figure 5-44 illustrates the relationship between EC and SAR in the Upper Tongue River near Ashland after the river mixes with varying proportions of Discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

The Tongue River is an important source of irrigation water in the PRB. The effects to the Tongue River under this alternative would be the same as for Alternative A. No additional discharge from Montana to the Tongue River sub-watershed would be allowed under this alternative, except for discharge in accordance with the current CX Ranch MPDES permit. This permit currently allows a discharge of 3.3 cfs of CBM water. Of the 41 cfs of water predicted to be produced in year 6 of development, 3 cfs would be managed by surface discharge, and the remaining 38 cfs would need to be managed by other approved means.

Figure 5-41 Stream EC Before and After Mixing-Lower Tongue River Sub-Watershed

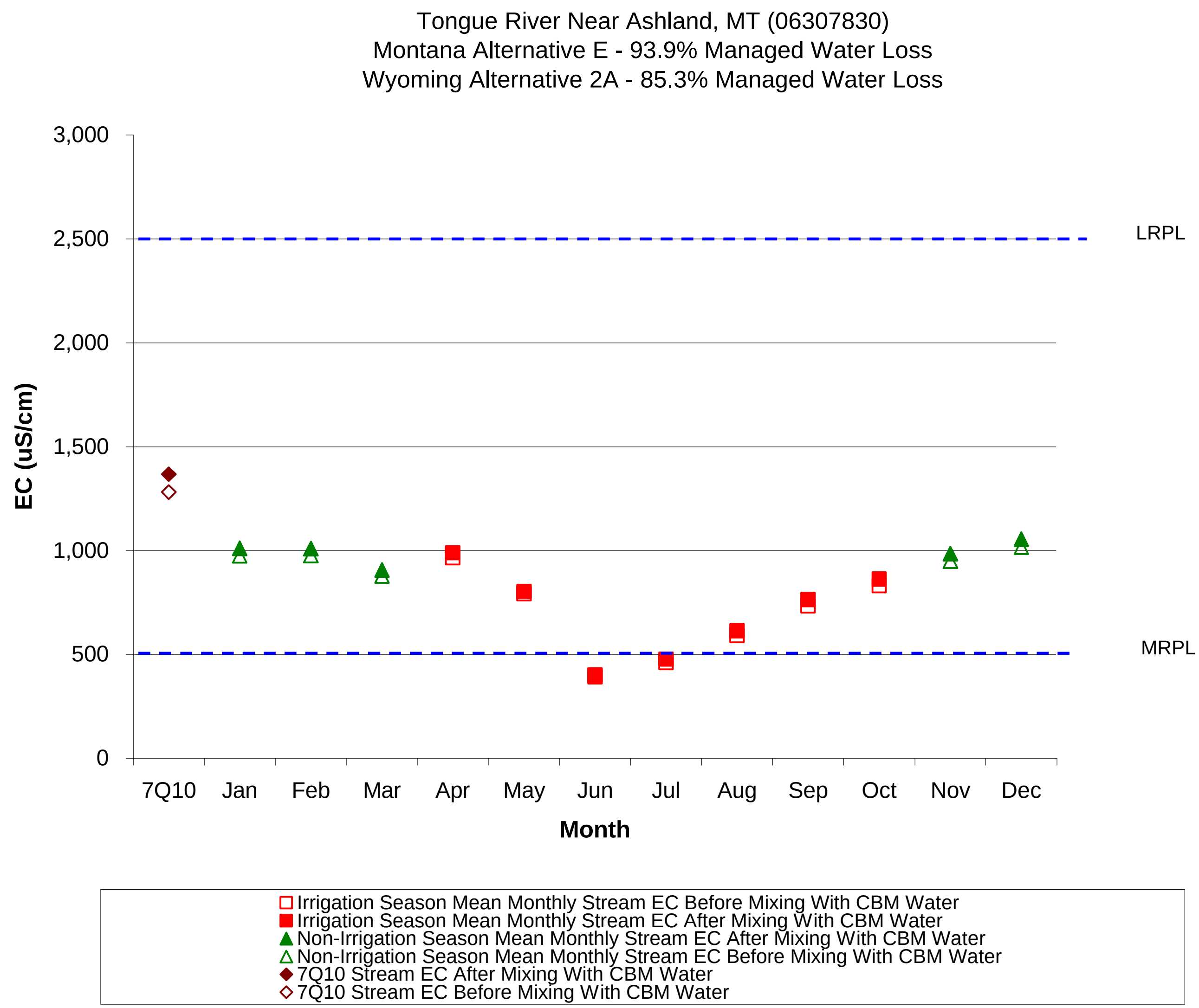


Figure 5-42 Stream SAR Before and After Mixing-Lower Tongue River Sub-Watershed

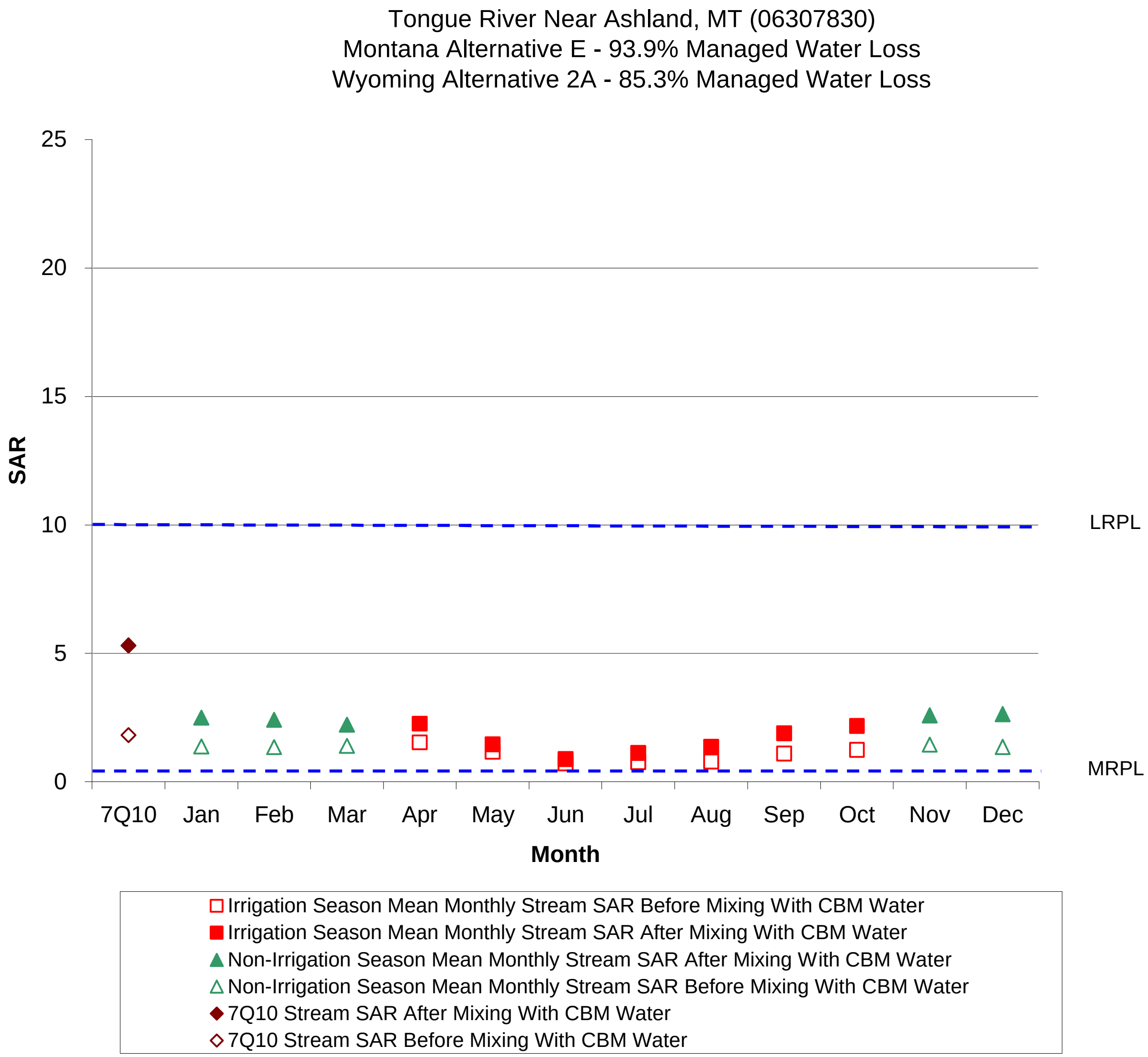


Figure 5-43 Irrigation Suitability Before and After Mixing – Lower Tongue River Sub-Watershed

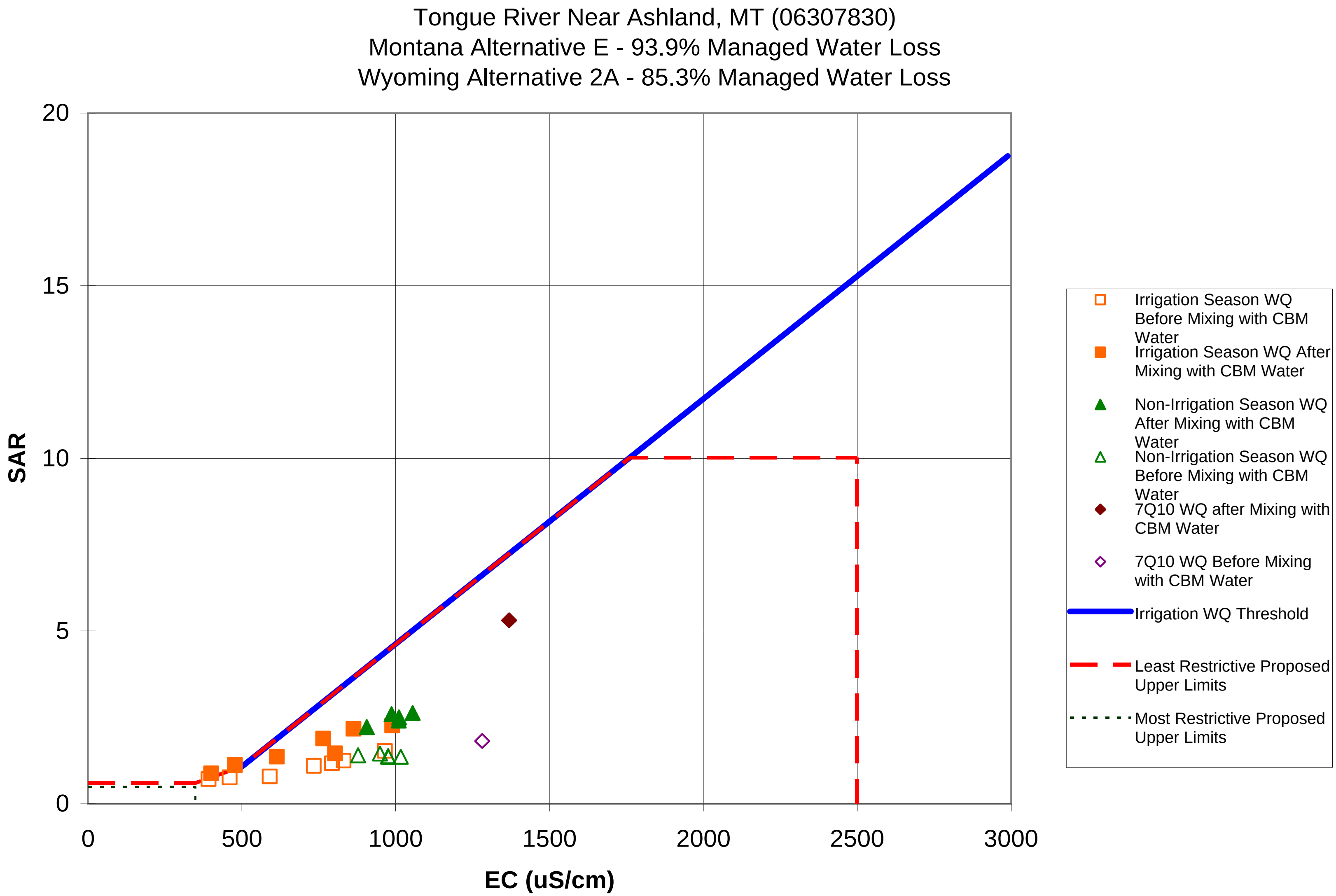
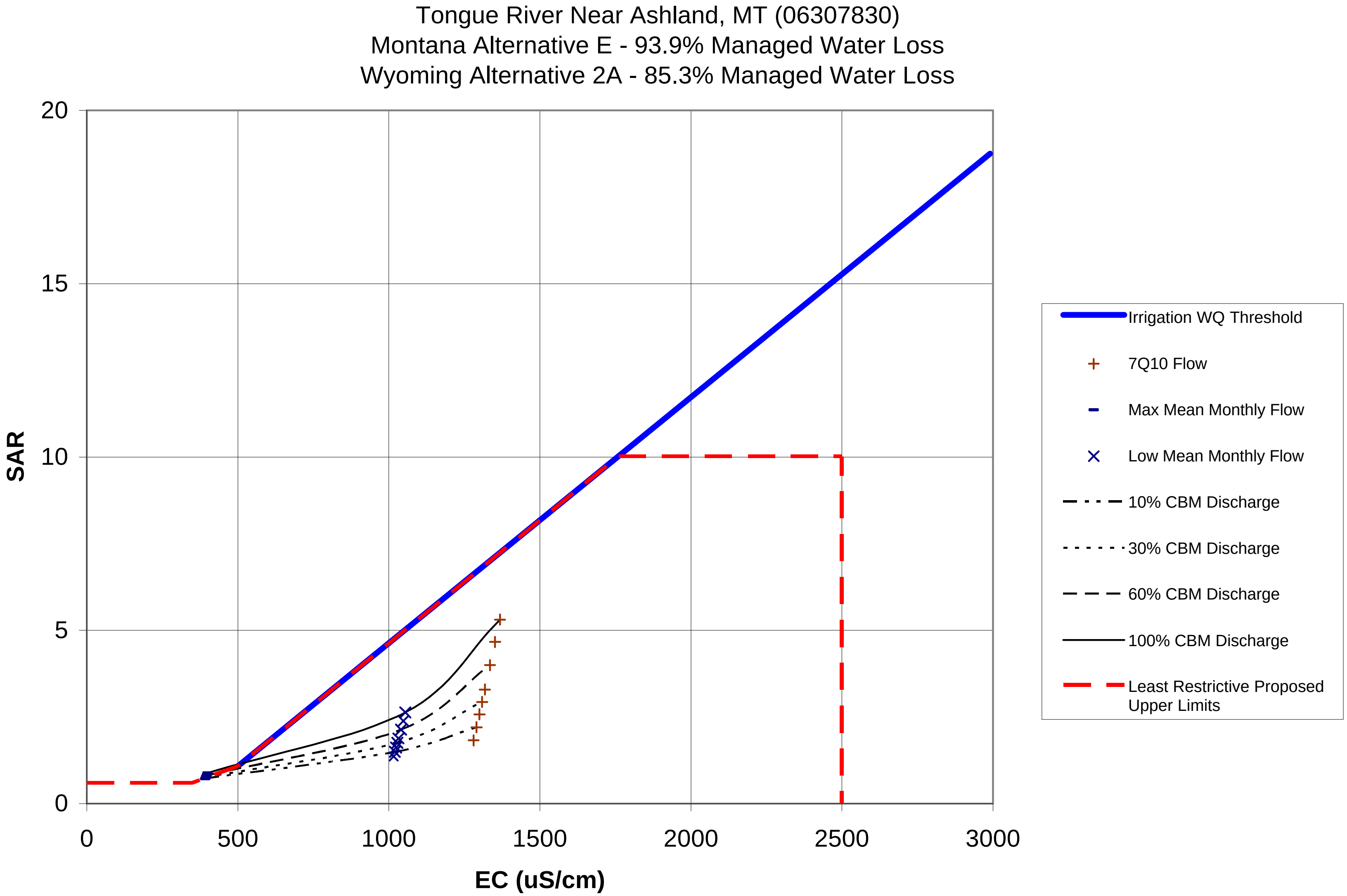


Figure 5-44 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Tongue River Sub-Watershed



5.3.2 Powder River

The Powder River would receive CBM water from development in Wyoming. Since no Montana CBM wells would be allowed to discharge into the Powder River under Alternative A, all forecast alterations in water quality would be caused by CBM development in Wyoming. The analysis conducted at the station in Locate, Montana, includes the combined CBM discharges into the Powder, Little Powder, and Mizpah sub-watersheds. Table 5-12 summarizes these impacts:

Table 5-12
Surface Water Impact Analysis of the Middle/Lower Powder River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	224	10.7	2230	0.1	6.15	4400	79	21.8	2370
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	236	11.36	2320	1.6	6.87	3313	95	21.6	2586
C	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08-11.56	2226-2253	0.1	6.15	4400	86	22.0-23.2	2349-2426
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	11.97-13.13	2323-2361	1.6	6.87	3313	109	21.6-24.3	2384-2473
D	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08	2226	0.1	6.15	4400	86	20.5	2300
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	10.89	2268	1.6	6.87	3313	109	19.1	2259

Table 5-12
Surface Water Impact Analysis of the Middle/Lower Powder River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08-11.56	2226-2253	0.1	6.15	4400	86	22.0-23.2	2349-2426
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	11.97-13.13	2323-2361	1.6	6.87	3313	109	21.6-24.3	2384-2473

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.2.1 Alternative A

Under this alternative, the Powder River is expected to be affected only by CBM development in Wyoming, resulting in an appreciable alteration of surface water quality. Mean monthly EC and SAR values in the Powder River at the two gauging stations currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents under similar flow conditions. After the water mixes, the resultant flow under low monthly flow conditions would increase at the two locations. The resultant EC and SAR would increase from existing stream conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: The Powder River naturally exceeds the MRPL for SAR and EC; therefore, the Powder River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast under Alternative A would cause the Powder River to exceed these proposed limits even more.
- LRPL: Except during 7Q10 flow conditions, the resultant water quality would be adequate to meet the LRPL for EC and SAR at both locations.
- Ayers and Westcot diagram: Except during 7Q10 flows, the resultant water quality would not cause impacts to infiltration in soils being irrigated. During the low monthly flow, essentially 100 percent of the CBM discharge could occur without causing potential effects to infiltration.

The volume and quality of surface water in the Powder River would be affected by discharges from Wyoming CBM development under Alternative A. Changes in water quality of the Powder River are expected to have minor impacts that may require downstream users to alter management practices.

5.3.2.2 Alternative C

The Powder River would receive CBM discharges from development in Wyoming and Montana and is expected to be affected by CBM development in both Wyoming and Montana under this alternative. After the water mixes, the resultant water quality would be altered by slight changes in EC; however, changes in SAR may be significant. Flow rate would also be expected to increase. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The Powder River contains water that naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharge if these limits were adopted. The effects forecast from CBM water in Wyoming and Montana would further exceed these proposed limits.
- LRPL: The resultant quality of mixed water at the Moorhead station would exceed the proposed SAR limit for half the months analyzed and for the 7Q10 flow. The LRPL for EC would be exceeded only at the Moorhead station during 7Q10 flow. The resultant water quality during minimum mean monthly and 7Q10 flows would exceed the LRPL for SAR at the Locate station. During other months, the mixed water at the Locate station would be below these limits.
- Ayers and Westcot diagram: Irrigation with the mixed water at the Powder River stations would be likely to cause impacts to infiltration in soils being irrigated during 7Q10 flow. Under modeled conditions, 100 percent of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the

Ayers-Westcot diagram indicates no reduction in infiltration. The surface water quality in the Powder River would be reduced under Alternative C. These effects would likely require changes in management practices by downstream irrigators if this alternative were adopted. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.2.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used and the remaining 80 percent would be treated to reflect the pre-development quality of surface water before discharge.

The increases in the quality of surface water shown in Table 5-12 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow would result from treated and untreated discharges in both Montana and Wyoming. The effects that would originate from Wyoming would be the same as were detailed above under Alternative A. Effects on surface water from CBM development in Montana would result from increases in base flow.

5.3.2.4 Preferred Alternative E

The Powder River is expected to be affected by CBM development in both Wyoming and Montana, resulting in an appreciable alteration of surface water quality. Under Preferred Alternative E, volume of flows and SAR and EC values are forecast to increase. The resultant water quality in streams can be compared with the following criteria:

- MRPL: Figures 5-45 and 5-46 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Lower Powder River sub-watershed, as modeled at the USGS gauging station at Locate, Montana. The Powder River naturally exceeds the MRPL for EC and SAR; therefore, it could not receive any CBM discharge if these limits were adopted. The Powder River would exceed these proposed limits even further as a result of the impacts forecast under this alternative.
- LRPL: The LRPL for both EC and SAR would be exceeded during an average of five months of each year as well as during 7Q10 flows.
- Ayers and Westcot diagram: Figure 5-47 illustrates the suitability for irrigation of the Lower Powder River at Locate before and after the river mixes with Discharges of CBM produced water.A comparison of the resultant quality of mixed water with the Ayers-Westcot diagram in Figure 5-47 indicates that the mixed water would not cause impacts on infiltration to irrigated soils under modeled conditions except during 7Q10 flow. Figure 5-48 illustrates the relationship between EC and SAR in the Lower Powder River at Locate after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Of course site-specific conditions and the actual surface water standards adopted by the MBER will be the most important factors in determining the actual water management practices within the Montana portion of the PRB. The MDEQ cannot allow discharges of CBM water to impact surface water conditions in excess of prevailing regulations and standards. CBM producers in the Wyoming portion of this watershed will be held to the same standards if the Montana standards are approved by the EPA and given CWA standing.

Figure 5-45 Stream EC Before and After Mixing-Lower Powder River Sub-Watershed

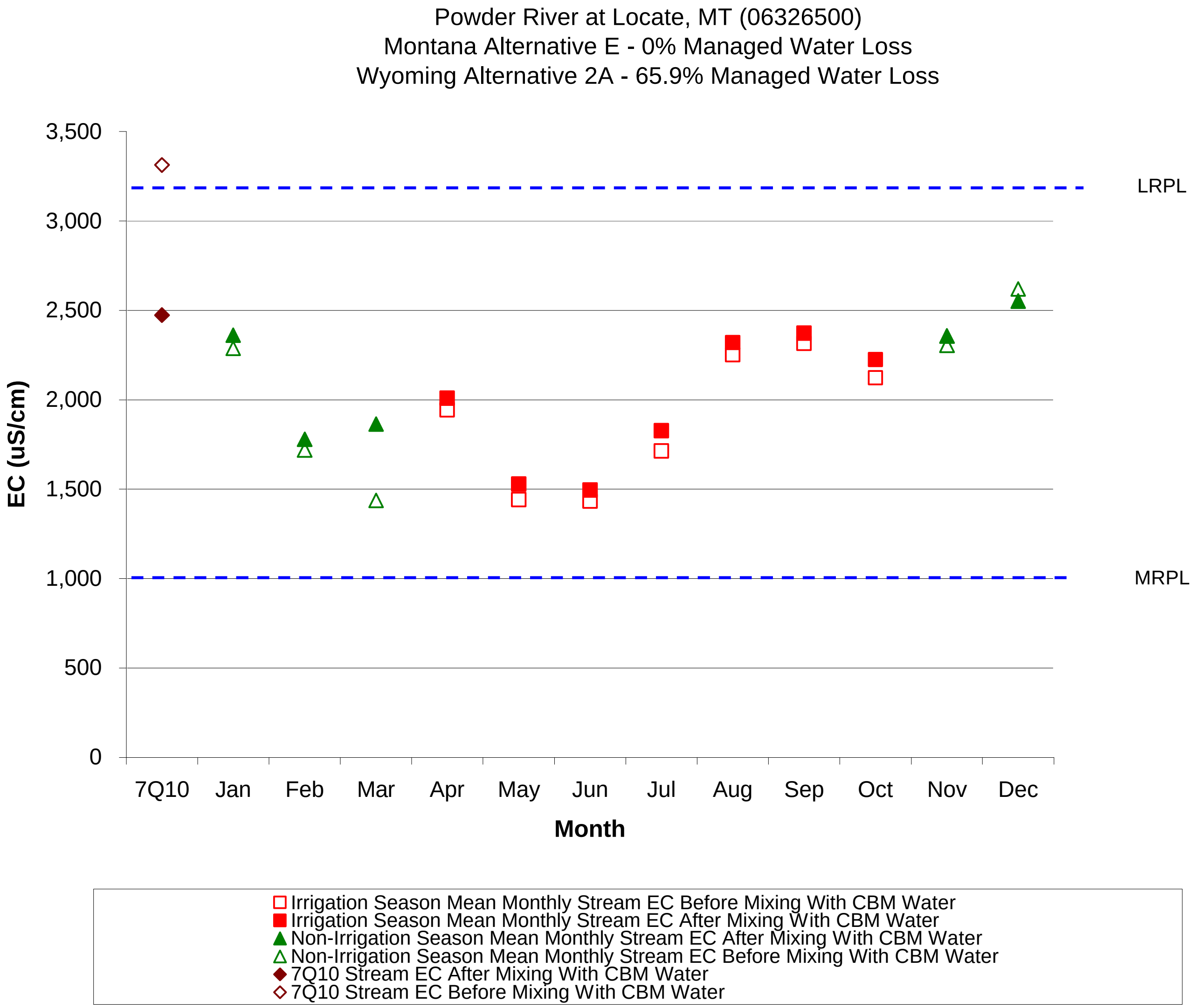


Figure 5-46 Stream SAR Before and After Mixing-Lower Powder River Sub-Watershed

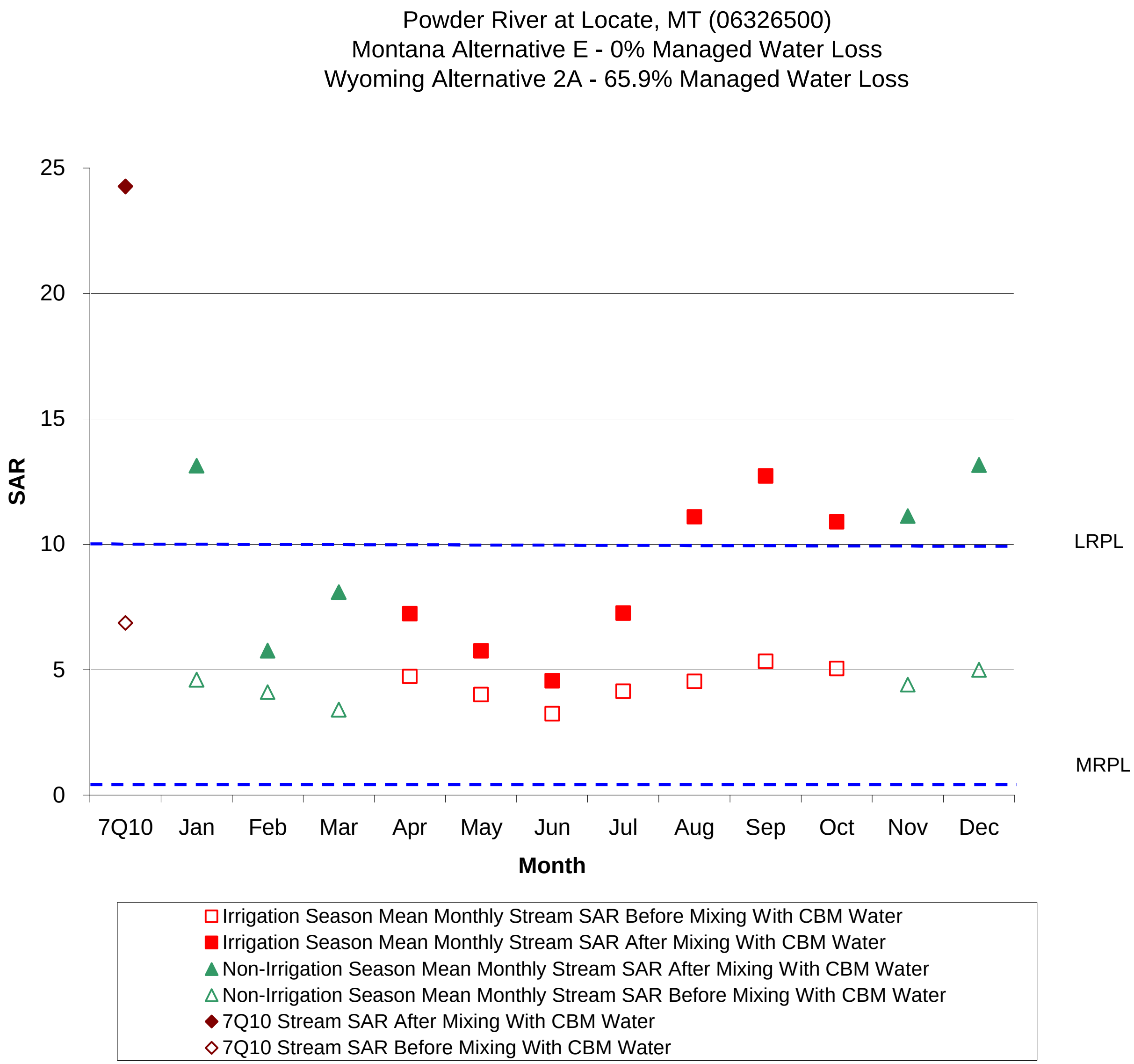


Figure 5-47 Irrigation Suitability Before and After Mixing – Lower Powder River Sub-Watershed

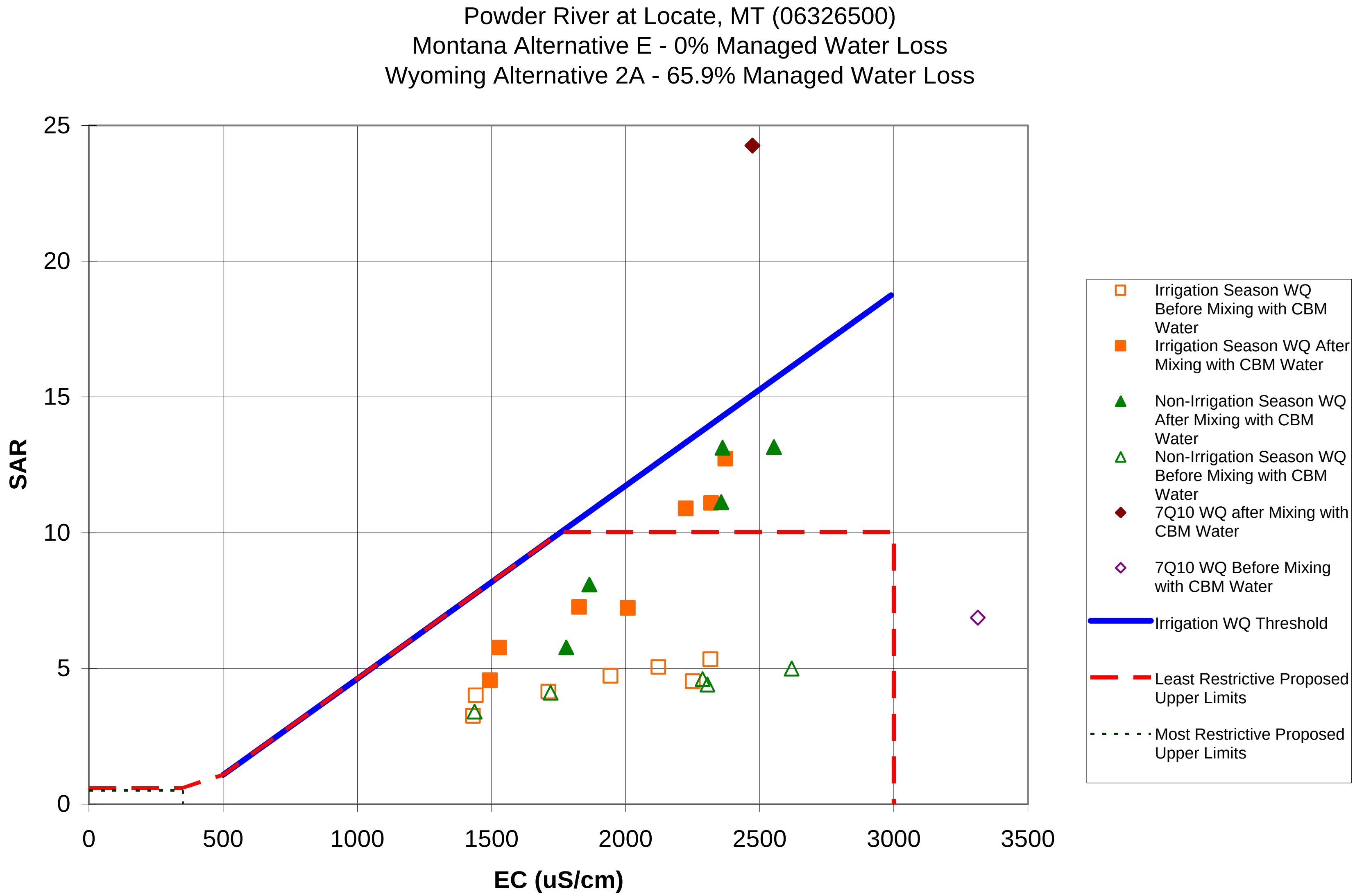
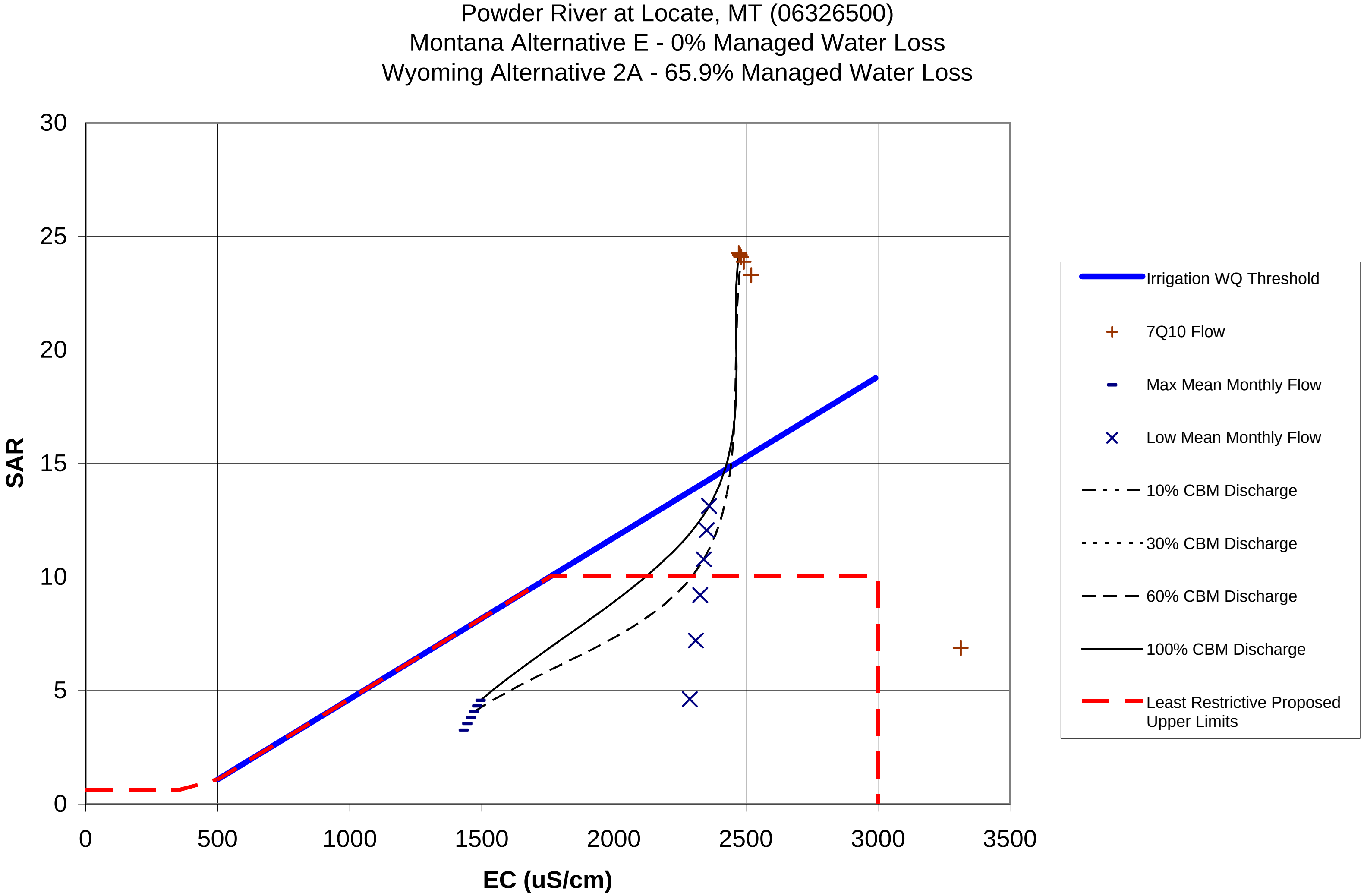


Figure 5-48 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Powder River Sub-Watershed



The Powder River contains variable amounts of water that naturally exceeds the MRPL for EC and SAR. The resultant quality of mixed water during the irrigation and non-irrigation seasons would generally be below the LRPL for both constituents, as well as below the Ayers-Westcot threshold. Therefore, Preferred Alternative E would allow for the possibility of 100 percent discharge of CBM water into the Powder River sub-watershed, and effects to surface water would be the same as were described for Alternative C. However, local conditions would dictate the actual discharge permits for individual CBM projects. No changes in management practices are foreseen by downstream irrigators.

5.3.3 Little Powder River

The Little Powder River has its headwaters in the Wyoming portion of the PRB and as such, it is expected to receive CBM water from development in Wyoming. The analysis for this stream is conducted at the station in Weston, Wyoming, near the state line. No effects would result from CBM development in Montana under any alternative at this station. The impacts from wells in Montana downstream of this station are discussed in the analysis for the Powder River at Locate station.

5.3.4 Mizpah Creek

Mizpah Creek carries water into the Powder River in Montana. No CBM wells in Wyoming could affect this sub-watershed. Instead, effects to Mizpah Creek would result from the discharge of CBM produced water in Montana only. Table 5-13 summarizes changes predicted in water quality in Mizpah Creek just upstream from its junction with the Powder River.

Table 5-13
Surface Water Impact Analysis of the Mizpah Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	0.26	16.6	3503	0.0	--	--	--	--	--
C	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.26	20.43-35.26	2663-3163	0.0	--	--	1.0	11.1-22.6	1271-2451
D	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.26	16.6	3503	0.0	--	--	1.0	8.17	1131
E	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.0	20.43-35.26	2663-3163	0.0	--	--	1.0	11.1-22.6	1271-2451

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.3.1 Alternative A

Mizpah Creek contains low-quality water that has limited use for irrigation but can be used for stock watering and by wildlife. This sub-watershed is not expected to experience effects from CBM development under Alternative A. The water quality in streams can be compared with the following criteria:

- MRPL: Mean monthly EC and SAR values in Mizpah Creek currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions.
- LRPL: Except for 2 months out of the year, the existing water quality in Mizpah Creek would exceed the LRPL for SAR but would be adequate to meet the LRPL for EC for 11 months of the year.
- Ayers and Westcot diagram: Except for 3 months out of the year, the existing water quality would reduce infiltration to irrigated soils.

5.3.3.2 Alternative C

Mizpah Creek contains water that naturally exceeds the LRPL for EC and SAR. CBM discharges would decrease the EC from existing conditions and would increase the SAR. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The water quality in Mizpah Creek naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits are adopted. The impacts forecast under Alternative C would further exceeds these proposed limits.
- LRPL: The water quality in Mizpah Creek exceeds the LRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted.
- Ayers and Westcot diagram: The quality of mixed water at the Mizpah station would likely cause impacts to infiltration in irrigated soils during all flows, except for 1 or 2 high-flow months per year.

The surface water quality of Mizpah Creek would be reduced under Alternative C, requiring changes in management practices of downstream users. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.3.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used and the remaining 80 percent would be treated to reflect the pre-development quality of before discharge.

The increases in surface water quality shown in Table 5-13 for Alternative D are a result of the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow are caused by treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as those were described under Alternative A. Effects on surface water conditions from CBM development in Montana are a result of the increases in base flow.

5.3.3.4 Preferred Alternative E

In Montana, 125 CBM wells are projected to be productive in this sub-watershed, but no CBM wells in Wyoming will produce. Under Preferred Alternative E, impacts to water quality are expected to be the same as under Alternative C, since all CBM produced water could be discharged under this alternative. The resultant water quality in streams can be compared with the following criteria:

- MRPL: Figures 5-49 and 5-50 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Mizpah Creek sub-watershed, as modeled at the USGS gauging station near Mizpah, Montana. The water quality in Mizpah Creek naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted. The impacts forecast under Alternative C further exceed these proposed limits.
- LRPL: The water quality in Mizpah Creek exceeds the LRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted.
- Ayers and Westcot diagram: Figure 5-51 illustrates the suitability for irrigation of Mizpah Creek at Mizpah before and after the creek mixes with discharges of CBM produced water.A comparison of the resultant quality of mixed water with the Ayers-Westcot diagram under modeled conditions in Figure 5-51 indicates that the quality of the mixed water at the Mizpah station would likely cause impacts to infiltration in irrigated soils during all flows except for 1 or 2 high-flow months a year. Figure 5-52 illustrates the relationship between EC and SAR in Mizpah Creek after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 10 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-49 Stream EC Before and After Mixing- Mizpah Creek Sub-Watershed

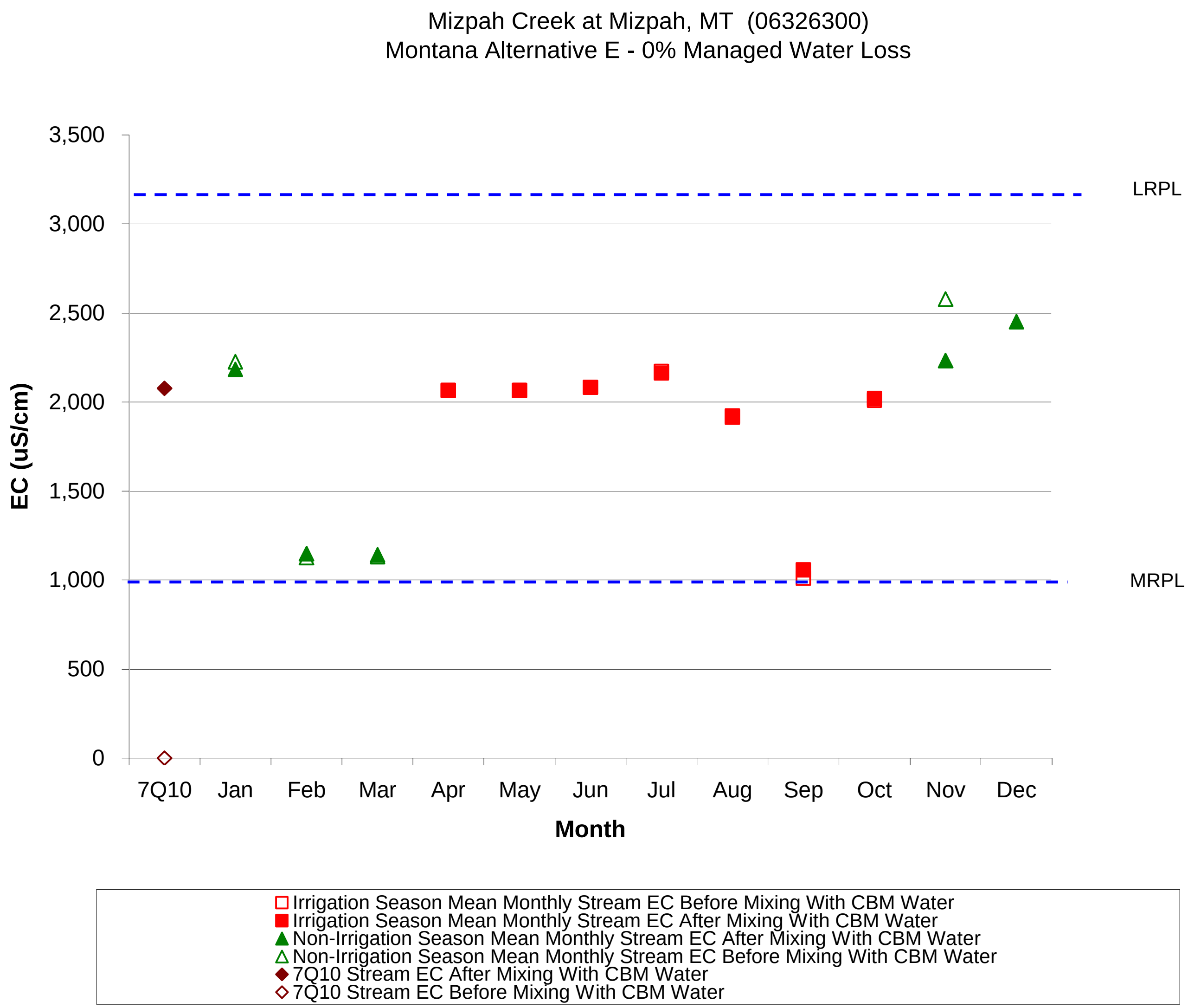


Figure 5-50 Stream SAR Before and After Mixing- Mizpah Creek Sub-Watershed

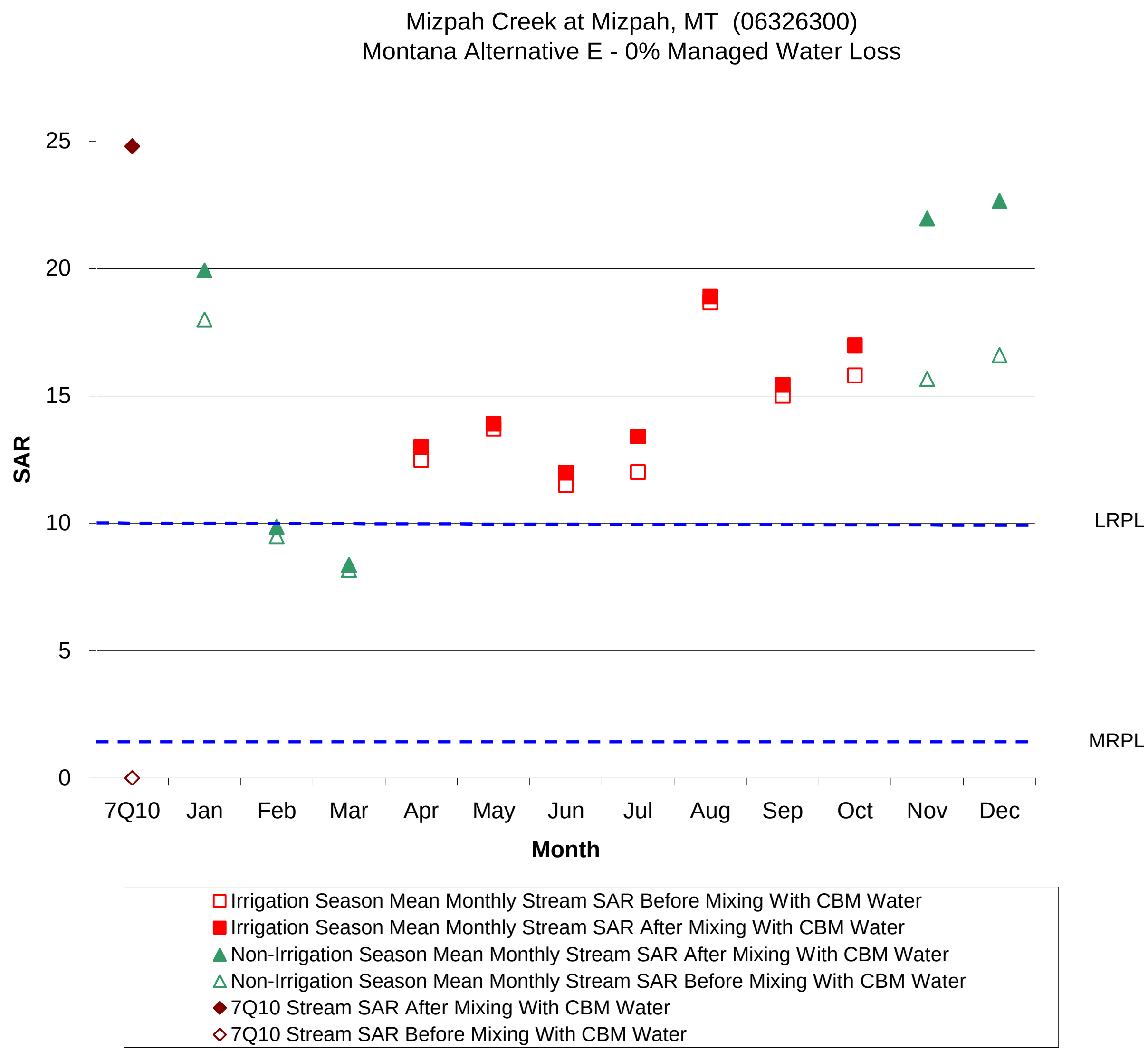


Figure 5-51 Irrigation Suitability Before and After Mixing – Mizpah Creek Sub-Watershed

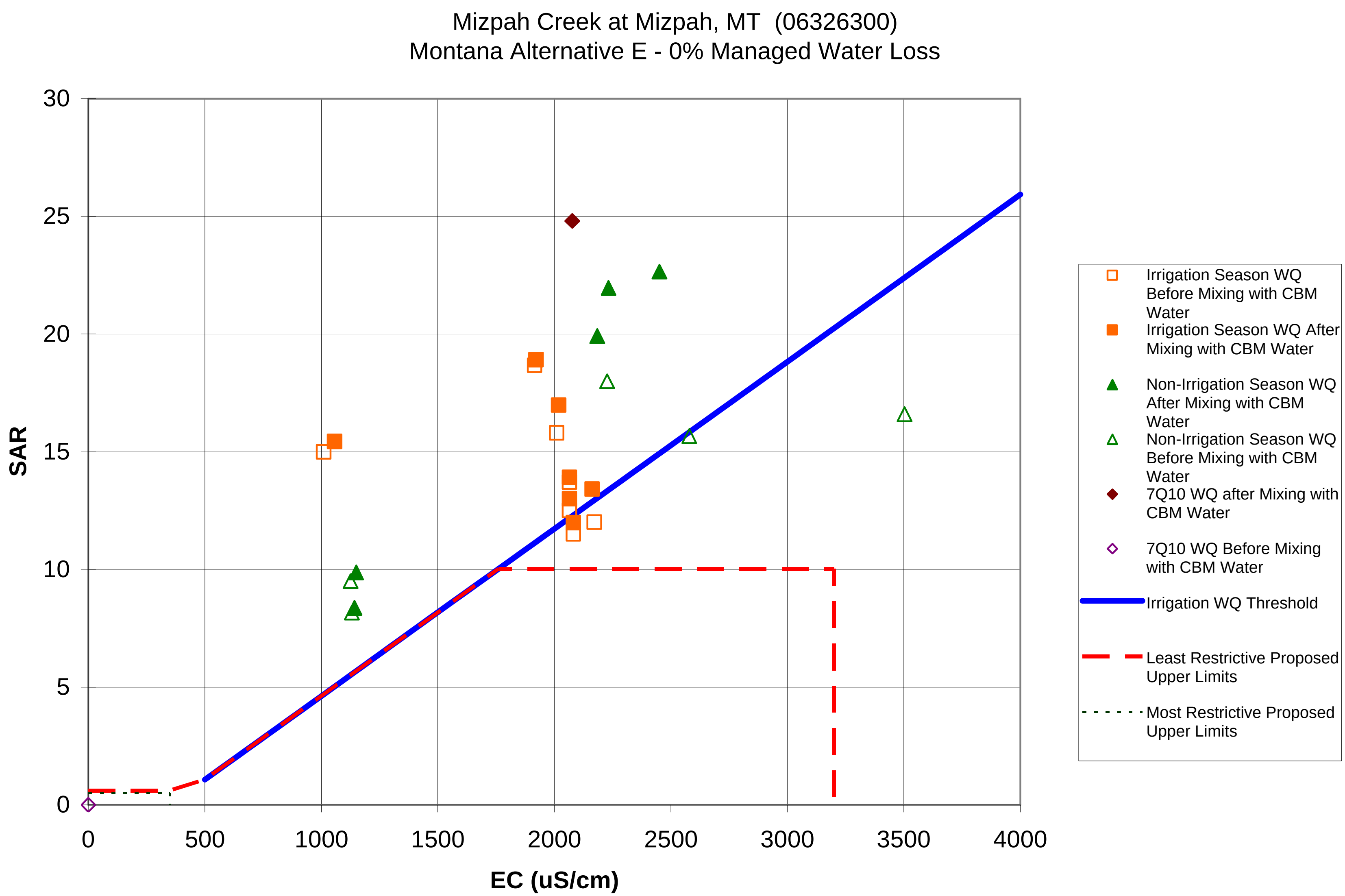
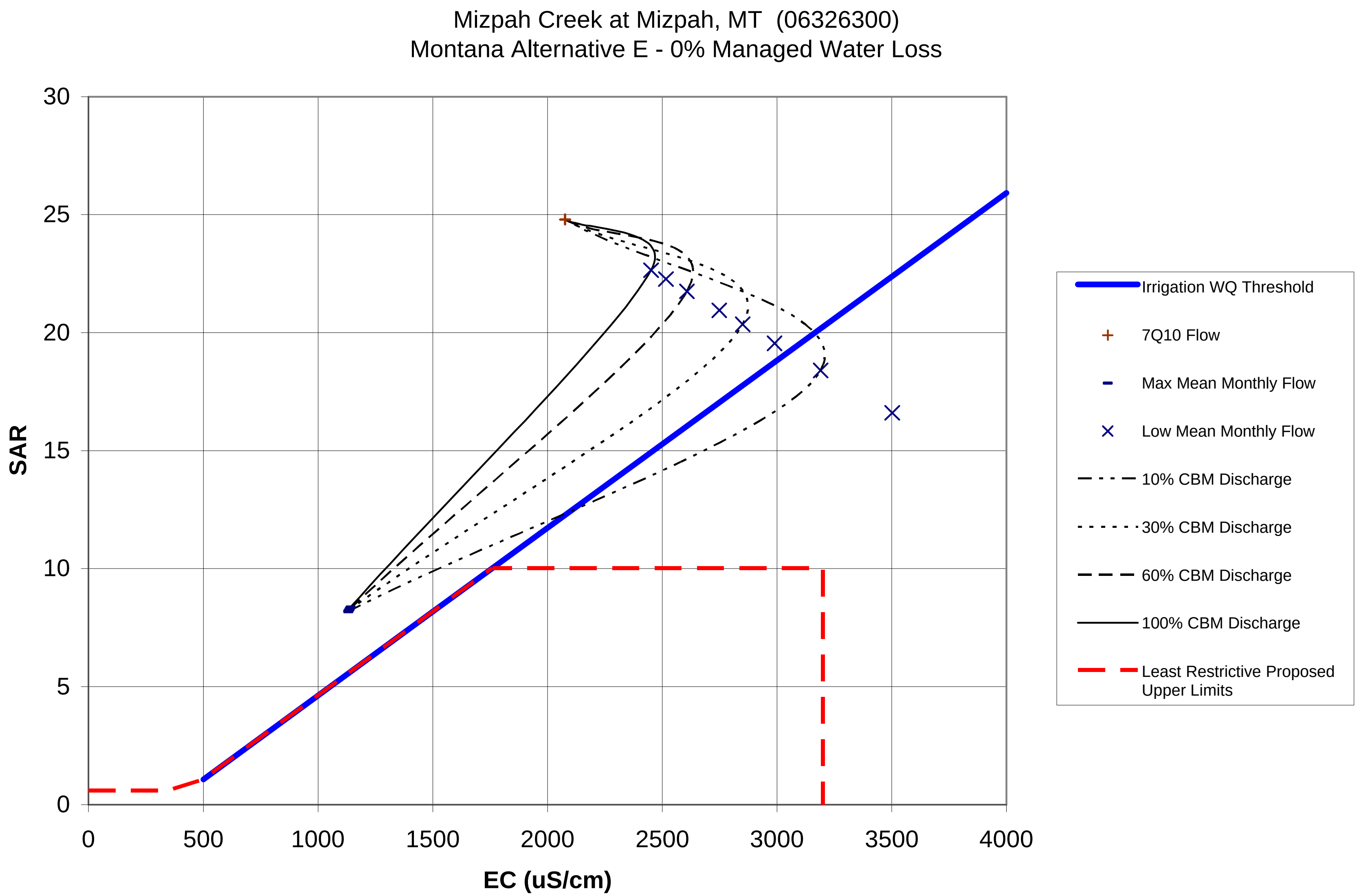


Figure 5-52 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Mizpah Creek Sub-Watershed



Both the existing and the resultant quality of mixed water in the Mizpah Creek sub-watershed exceed the proposed limits for EC and SAR for some portion of the year. Nonetheless, beneficial uses for the existing low volumes of low-quality water from Mizpah Creek would not be reduced. Therefore, the Preferred Alternative E allows 100 percent of the produced water to be discharged.

5.3.4 Bighorn/Little Bighorn Rivers

These rivers carry water from the Bighorn Mountains north from Wyoming into Montana. No CBM wells in Wyoming are expected to affect these rivers. Table 5-14 below summarizes the effects to water quality for two stations along the Little Bighorn River and one on the Bighorn River, just upstream from its confluence with the Yellowstone River.

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	110	0.53	548	47	0.8	629	47	0.8	629
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	123	0.99	768	21	1.6	830	21	1.6	830
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1523	2.08	952	870	2.8	989	870	2.8	989

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
C	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	549	115	2.26-2.64	623-632	47	0.8	629	52	4.59-5.42	787-807
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	3.94-4.59	881-896	21	1.6	830	31	13.9-16.7	1287-1353
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1542	2.54-2.64	968-970	870	2.8	989	889	3.58-3.76	1015-1020

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
D	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	115	0.53	548	47	0.8	629	52	0.8	605
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	0.99	768	21	1.6	830	31	1.53	784
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1542	2.08	952	870	2.8	989	889	2.78	986

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	115	2.64-3.26	623-632	47	0.8	629	52	4.59-5.42	787-807
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	3.94-4.59	881-896	21	1.6	830	31	13.9-16.7	1287-1353
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	962	1542	2.54-2.64	968-970	870	2.8	989	889	3.58-3.76	1015-1020

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.4.1 Alternative A

No CBM wells in Wyoming or Montana are expected to affect these rivers under Alternative A. Water quality and volume of flow in streams are expected to remain unchanged. The existing water quality in streams can be compared with the following criteria:

- MRPL: Existing water monthly averages in streams at Wyola except during 2 months of the year exceed the MRPL for SAR; likewise, the existing stream water exceeds the MRPL for EC for all but 3 months of the year. Water quality at the other two stations exceeds these limits throughout the year. The streams could not receive CBM discharges unless the produced water was of better quality than the streams.
- LRPL: The existing water monthly averages for the streams do not exceed the LRPL for both constituents during the year at any of the three stations.
- Ayers and Westcot diagram: Irrigation with the existing stream water at the three stations would not likely reduce infiltration to irrigated soils.

All current uses of these waters would be maintained under Alternative A.

5.3.4.2 Alternative C

Under Alternative C, the effects to the Little Bighorn and Lower Bighorn Rivers would result from CBM discharges in Montana only. The resultant impacts to water quality for these rivers would include increases in EC and SAR. Flows would increase slightly. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The water quality in these streams naturally exceeds the MRPL for EC and SAR during several months; therefore, these streams could not receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Hardin station only during 7Q10 flow conditions is above the LRPL for SAR. The resultant water quality would be adequate to meet these limits for the remaining stations.
- Ayers and Westcot diagram: Irrigation with the mixed water at the Wyola and Hardin stations would be likely to cause impacts to infiltration in irrigated soils during several months of the year. The resultant water quality represents a low EC-to-SAR relationship; thus, the water would likely alter clayey soils if it is used for irrigation. Water quality at the station near Bighorn would likely cause no impacts to infiltration and would be adequate for use for irrigation. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

The water quality in the Bighorn Rivers in Montana will be slightly reduced under Alternative C, resulting in minor changes to management practices by downstream users for continued use in irrigation. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA. The flows in these rivers are of sufficient quality and quantity to dilute any CBM discharges without affected irrigation use with the mixed stream water.

5.3.4.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses and the remaining 80 percent would be treated to the quality of pre-development water before discharge.

The increases in the quality of surface water shown in Table 5-14 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow are a result of treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water from CBM development in Montana are a result of the increases in base flow.

5.3.4.4 Preferred Alternative E

The Bighorn River and its tributary the Little Bighorn River would not likely be affected by CBM development in Wyoming but would likely be affected by CBM wells on Indian Lands and state and fee lands in Montana.

Under Preferred Alternative E, potential impacts to water quality in the Bighorn and Little Bighorn Rivers would be the same as were described under Alternative C. Preferred Alternative E would allow for discharge of 100 percent of the CBM water. Actual discharge from future CBM projects would depend on site-specific conditions and approval of a water management plan. The WMP would need to show minimal impacts to beneficial use to be approved. In Table 5-14, discharges located within the upper segments of the sub-watershed (upstream of the Wyola and Hardin stations) would cause major impacts and would likely be restricted in number and volume. The impact of discharges near the downstream segments of the sub-watershed would be less, however, and could be approved in larger numbers. Cumulative discharges of the entire volume of CBM water would be minor at the downstream end and would not require changes in management by end users. The resultant water quality in streams near Hardin, Montana, can be compared with the following criteria:

- MRPL: Figures 5-53 and 5-54 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Little Bighorn River sub-watershed, as modeled at the USGS gauging station near Hardin, Montana. The water quality in this stream naturally exceeds the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Hardin station is expected to be adequate to meet the LRPL for EC 2nd SAR during all months, but at the 7Q10 flow, the LRPL for SAR would be exceeded.
- Ayers-Westcot diagram: Figure 5-55 illustrates the suitability for irrigation of the Little Bighorn River near Hardin before and after the river mixes with discharges of CBM produced water.A comparison of the resultant mixed water quality under modeled conditions with the Ayers-Westcot diagram in Figure 5-55 indicates that there would be some reduction in infiltration during some months of the irrigation season and under 7Q10 flow conditions. The resultant water quality represents a low EC–to-SAR relationship; thus, the water would likely impact clayey soils if it is used for irrigation. Figure 5-56 illustrates the relationship between EC and SAR in the Little Bighorn River near Hardin after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 60

percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-53 Stream EC Before and After Mixing-Little Bighorn River Sub-Watershed

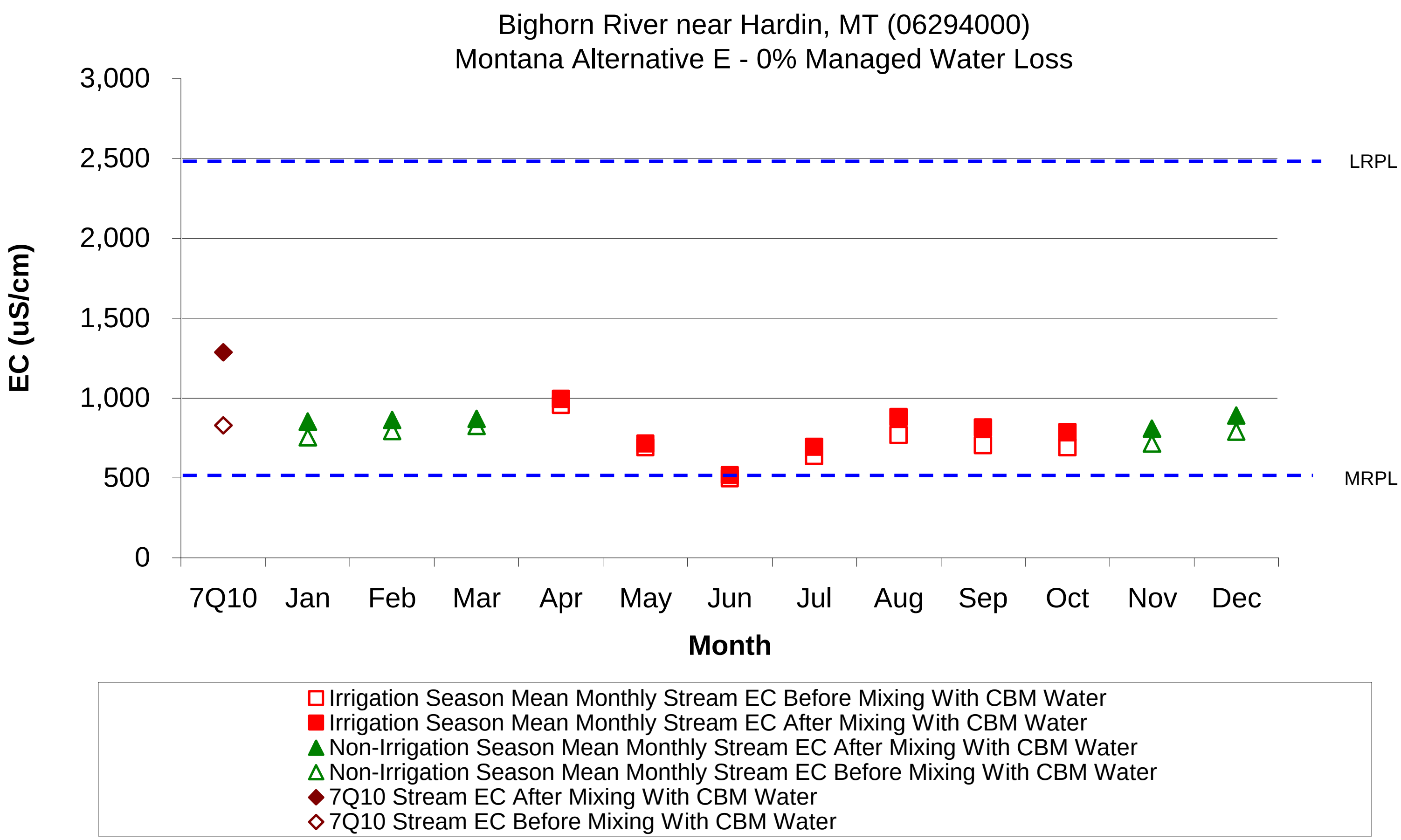


Figure 5-54 Stream SAR Before and After Mixing- Little Bighorn River Sub-Watershed

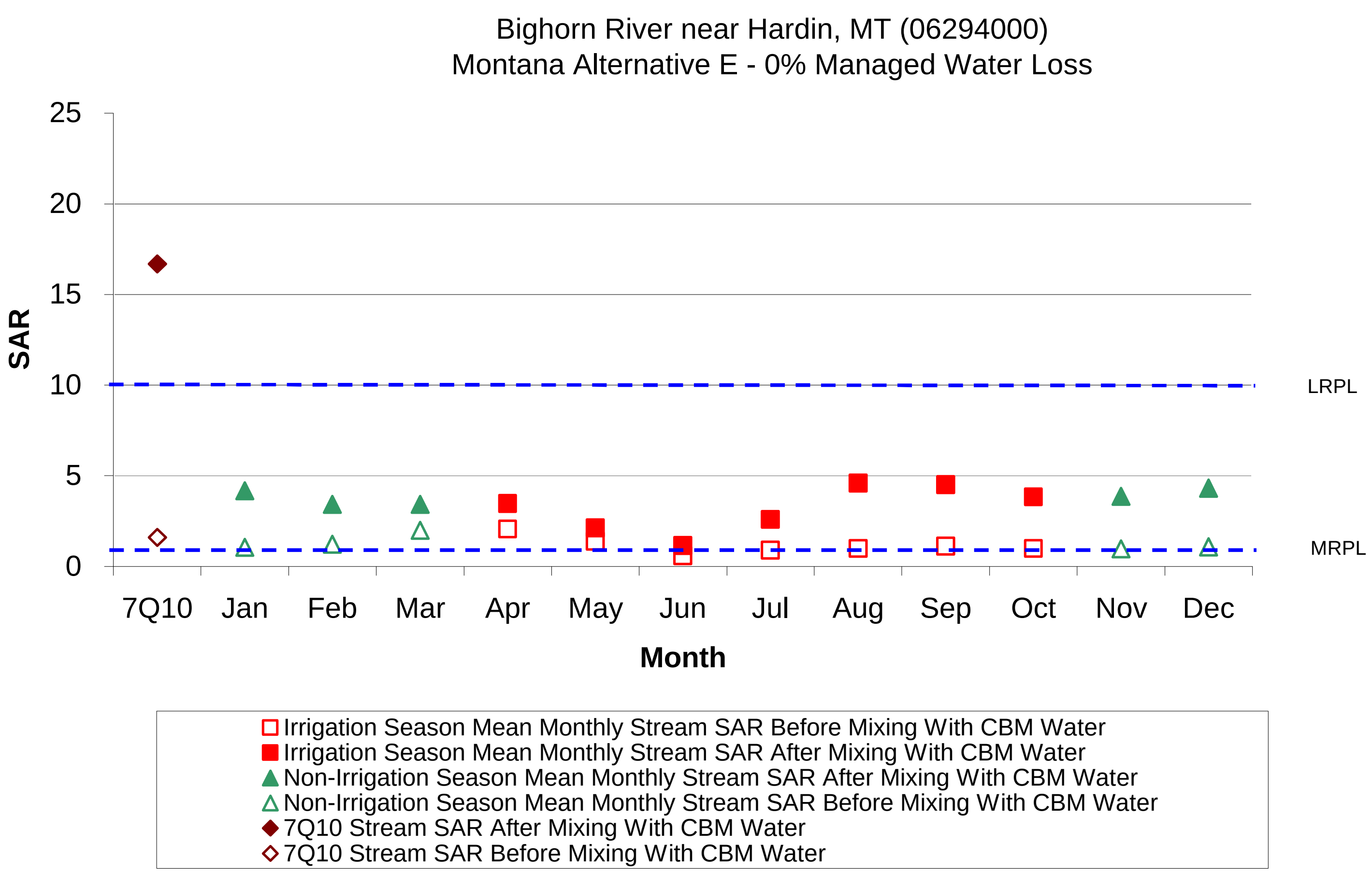


Figure 5-55 Irrigation Suitability Before and After Mixing – Little Bighorn River Sub-Watershed

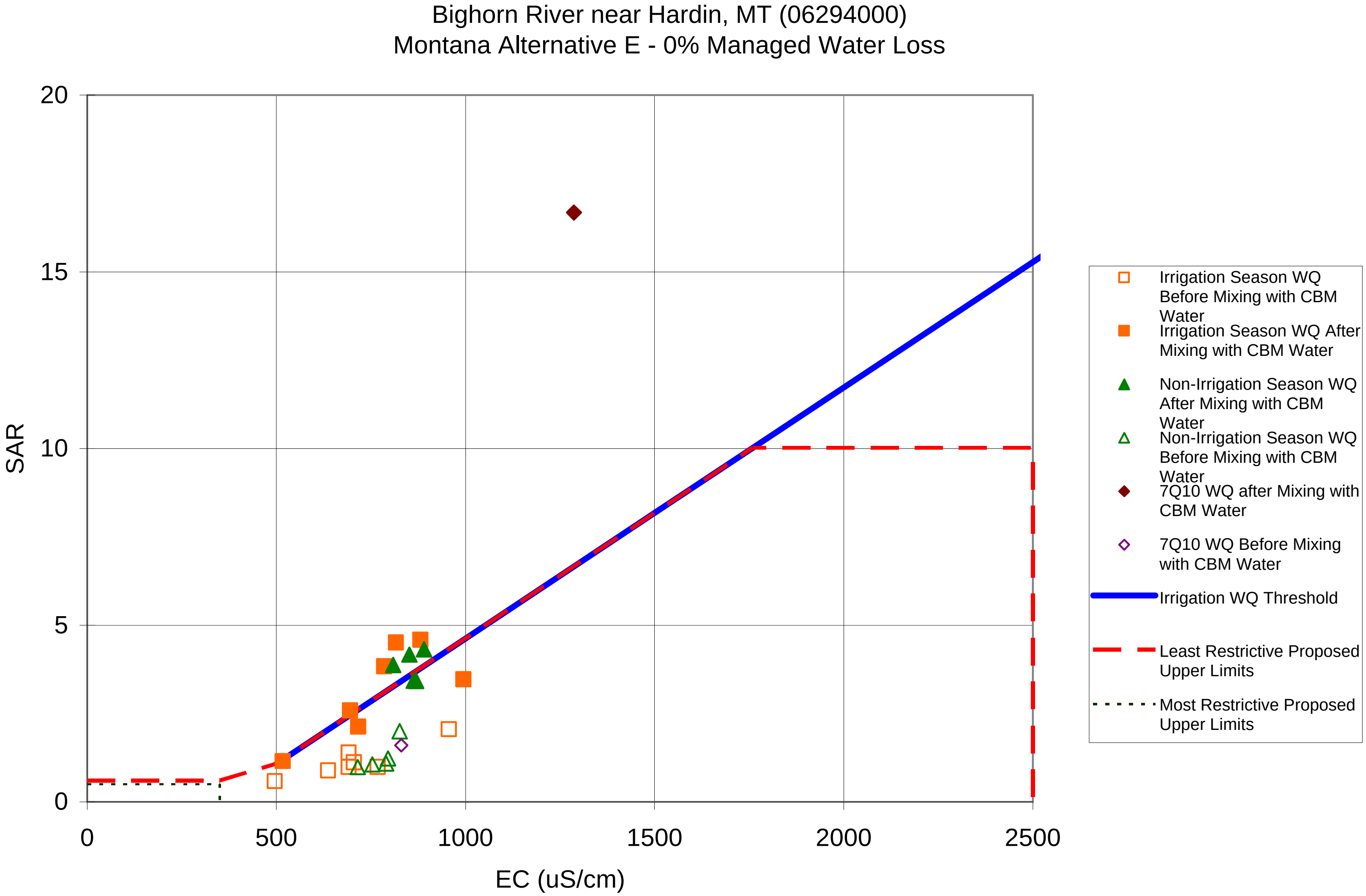
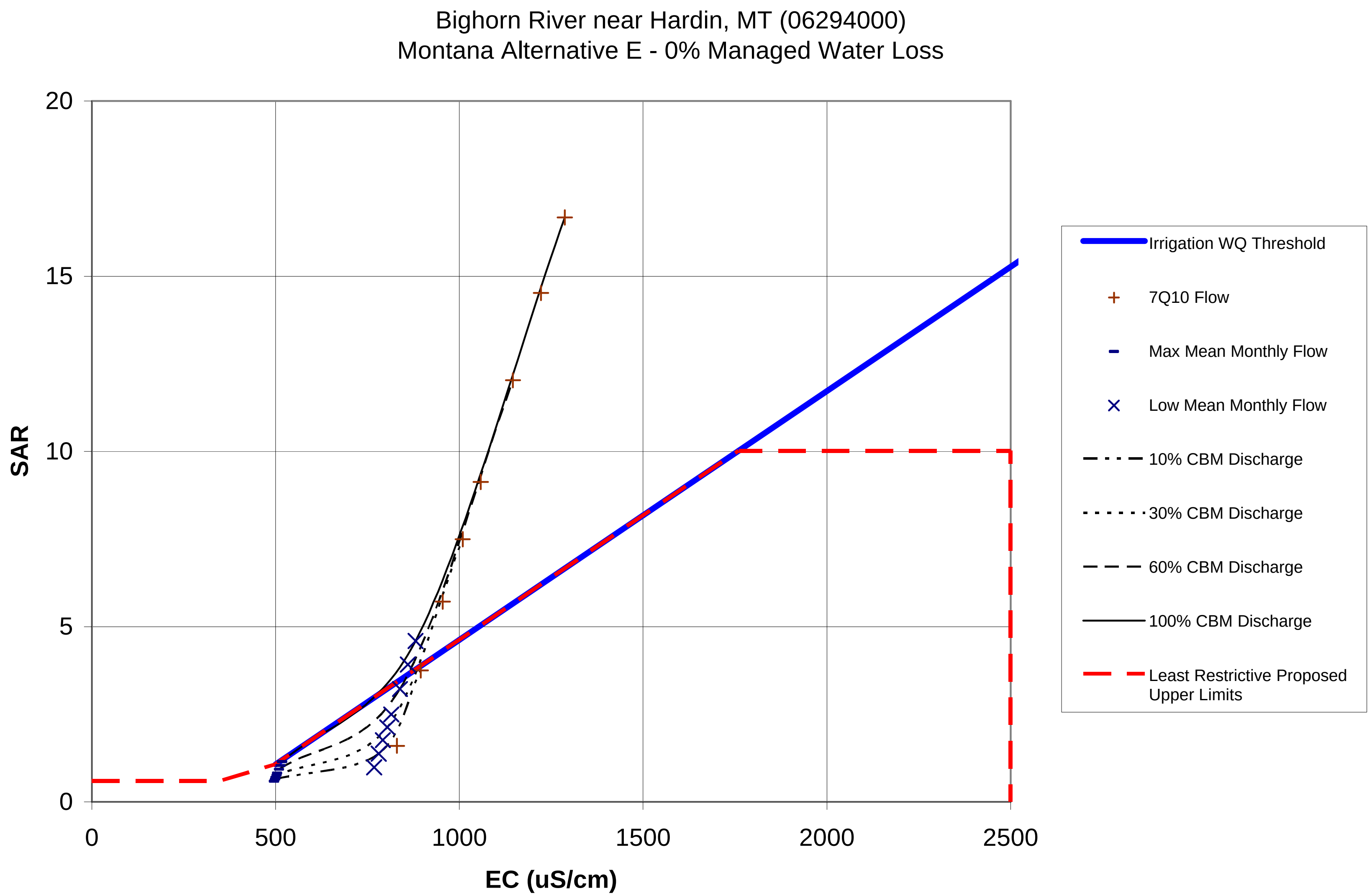


Figure 5-56 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Little Bighorn River Sub-Watershed



Under Alternative E, the resultant water quality in streams near Bighorn, Montana, can be compared with the following criteria:

- MRPL: Figures 5-57 and 5-58 are used to illustrate at which months during the year the existing water quality and resultant mixed water quality during mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Lower Bighorn River sub-watershed, as modeled at the USGS gauging station near Bighorn, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months, and therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The forecast effects from CBM development would further be in excess of these proposed limits.
- LRPL: The LRPL for EC and SAR would not be exceeded during either the minimum mean monthly flow or during 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-59 illustrates the suitability for irrigation of the Lower Bighorn River near Bighorn before and after mixing with Discharges of CBM produced water. Under modeled conditions, a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-59 indicates that there would be no infiltration impacts and the mixed water would be adequate for use for irrigation. Figure 5-60 illustrates the relationship between EC and SAR in the Lower Bighorn River near Bighorn after mixing with varying proportions of Discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-57 Stream EC Before and After Mixing-Lower Bighorn River Sub-Watershed

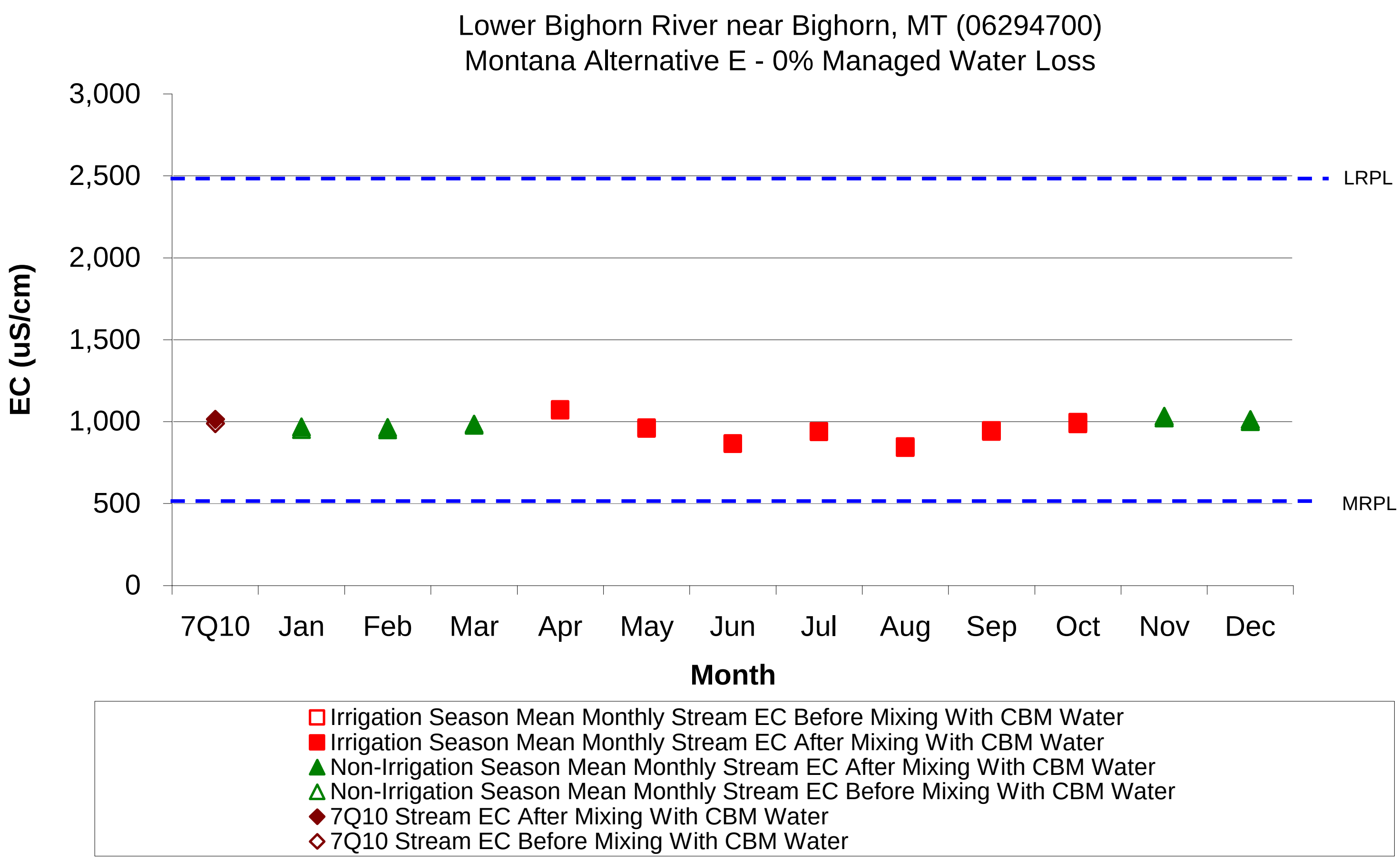


Figure 5-58 Stream SAR Before and After Mixing-Lower Bighorn River Sub-Watershed

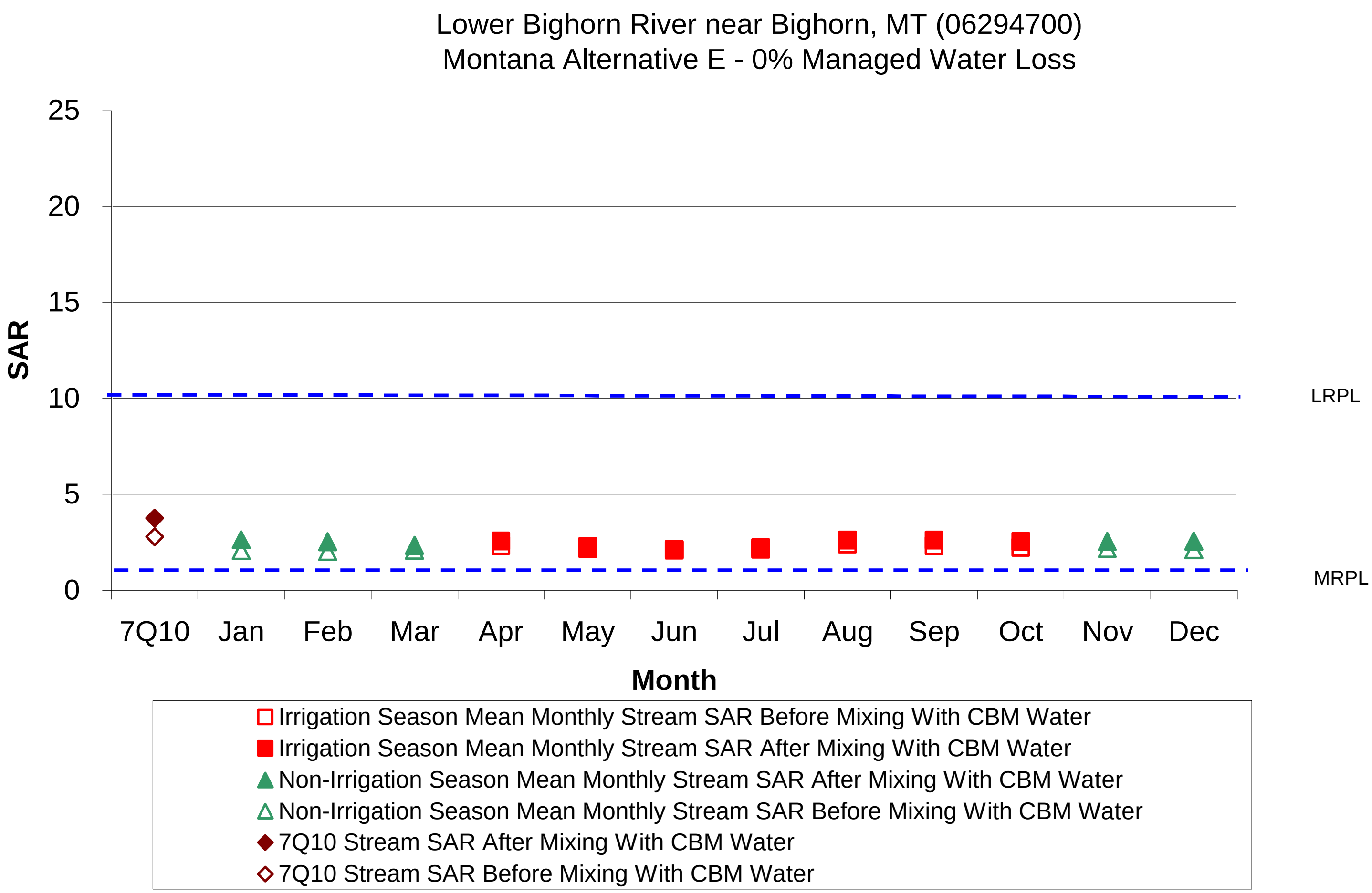


Figure 5-59 Irrigation Suitability Before and After Mixing – Lower Bighorn River Sub-Watershed

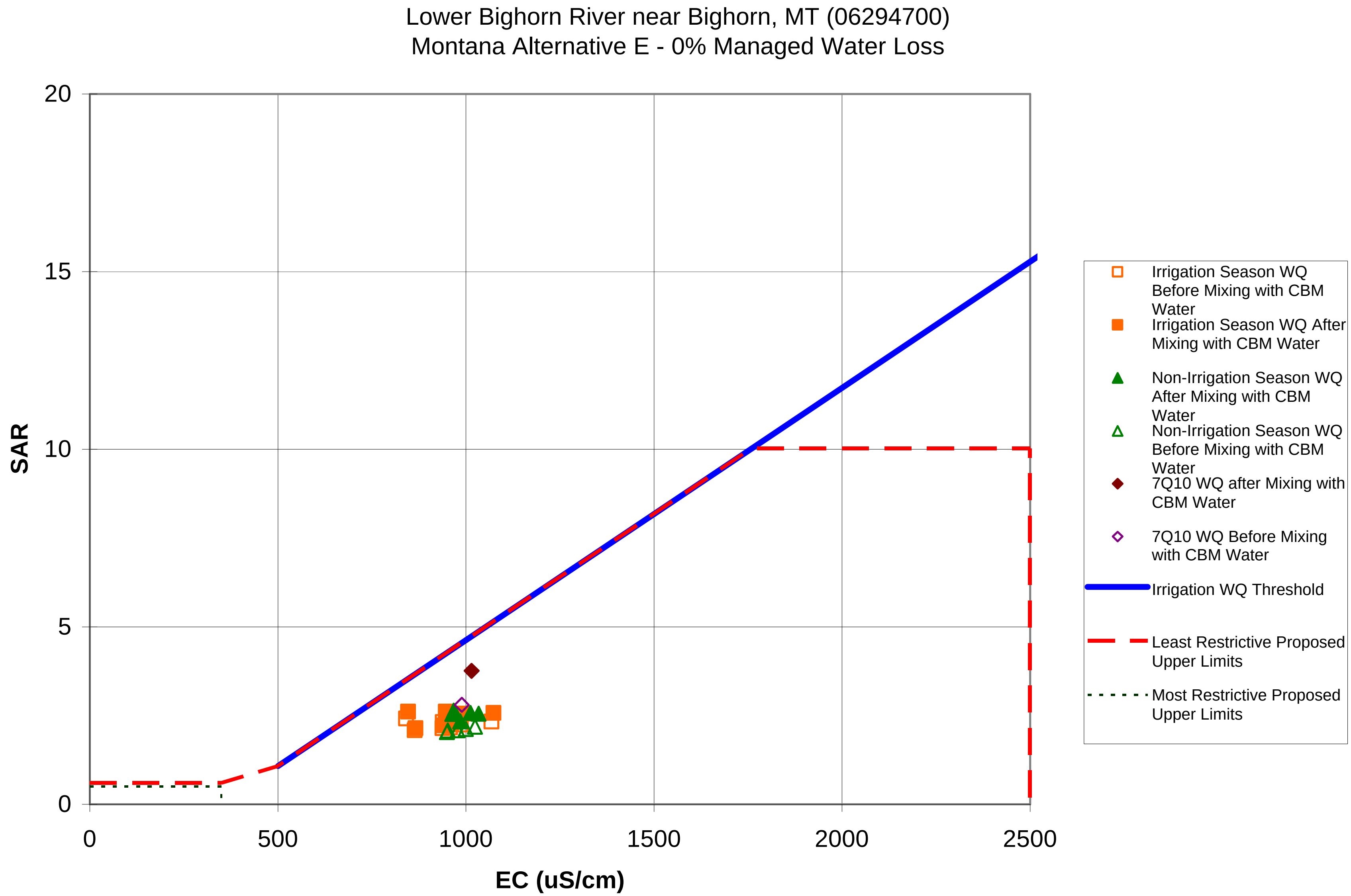
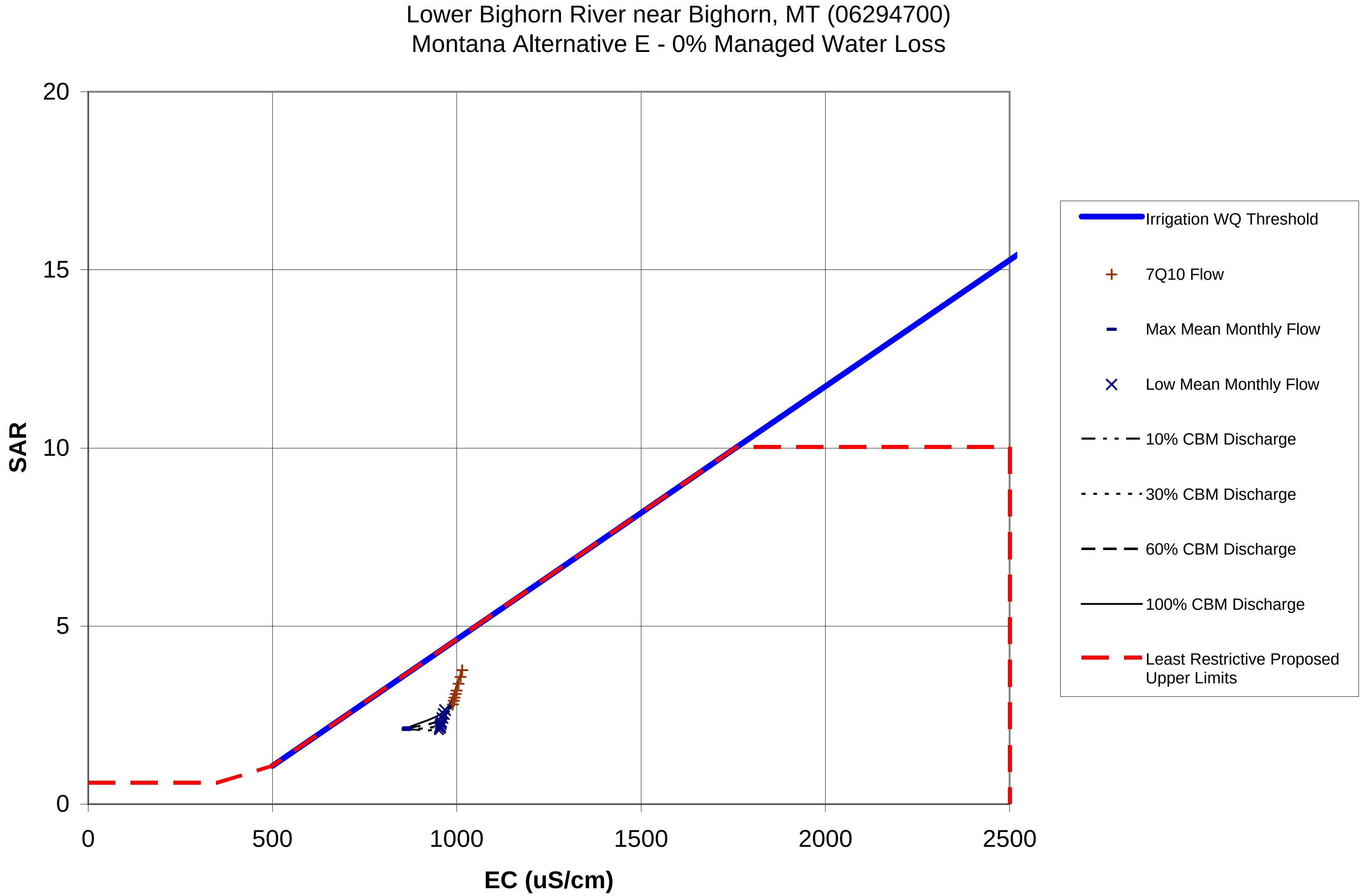


Figure 5-60 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Bighorn River Sub-Watershed



5.3.5 Rosebud Creek

This stream drains part of the area of the PRB in Montana. This stream begins on the Crow Reservation, flows through a portion of Montana and through the Northern Cheyenne Reservation, then through another portion of Montana before it joins the Yellowstone River near Rosebud, Montana. No CBM wells in Wyoming could affect the Rosebud Creek sub-watershed. Table 5-15 below summarizes the predicted effects to water quality for the two stations along Rosebud Creek in Montana.

Table 5-15
Surface Water Impact Analysis of the Rosebud Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (μS/cm)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)
A	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	1.78	0.77	1016	0.1	1.16	1123	0.1	1.16	1123
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	8.42	4.84	1780	0.0	--	--	0.0	--	--
C	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	22	35.62-43.25	2110-2293	0.1	1.16	1123	20	38.5-46.8	2202-2400
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	49	32.85-39.32	2133-2298	0.0	--	--	40	38.7-47.0	2207-2406

Table 5-15
Surface Water Impact Analysis of the Rosebud Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
D	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	22	0.77	1016	0.1	1.16	1123	20	0.54	913
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	48	4.84	1780	0.0	--	--	40	1.76	1071
E	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	1.78	0.77	1016	0.1	1.16	1123	0.1	1.16	1123
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	8.42	4.84	1780	0.0	--	--	0.0	--	--

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.5.1 Alternative A

Under this alternative, no CBM water would be discharged into this sub-watershed; therefore, stream water quality and flow will be unchanged. The existing stream water quality can be compared with the following criteria:

- MRPL: Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive discharges of CBM produced water unless it was of better quality than the stream.
- LRPL: The existing water monthly averages for streams are adequate to meet the LRPL for both constituents throughout the year at both stations.
- Ayers and Westcot diagram: Irrigation with the stream water would not likely cause a reduction in infiltration to soils being irrigated.

All current uses of these waters would be maintained under Alternative A.

5.3.5.2 Alternative C

Under Alternative C, effects to this stream would result from CBM discharges on the reservations or in Montana. Flows would increase by an order of magnitude with CBM discharge, and water quality would be more representative of the CBM discharged water than of the existing stream water quality because there is so little water in the Rosebud Creek naturally. The resultant stream water quality near Kirby, Montana, can be compared with the following criteria:

- MRPL: Figures 5-61 and 5-62 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Kirby, Montana. Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive CBM discharges unless the water was of better quality than the stream.
- LRPL: The resultant stream water quality at Kirby would exceed the LRPL for SAR but would be below the LRPL for EC.
- Ayers-Westcot diagram: Figure 5-63 illustrates the suitability for irrigation of Rosebud Creek near Kirby before and after the creek mixes with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-63 indicates some reduction in infiltration during all months of the irrigation season and under 7Q10 flow conditions. Figure 5-64 illustrates the relationship between EC and SAR in Rosebud Creek near Kirby after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, a small fraction of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-61 Stream EC Before and After Mixing-Rosebud Creek Sub-Watershed

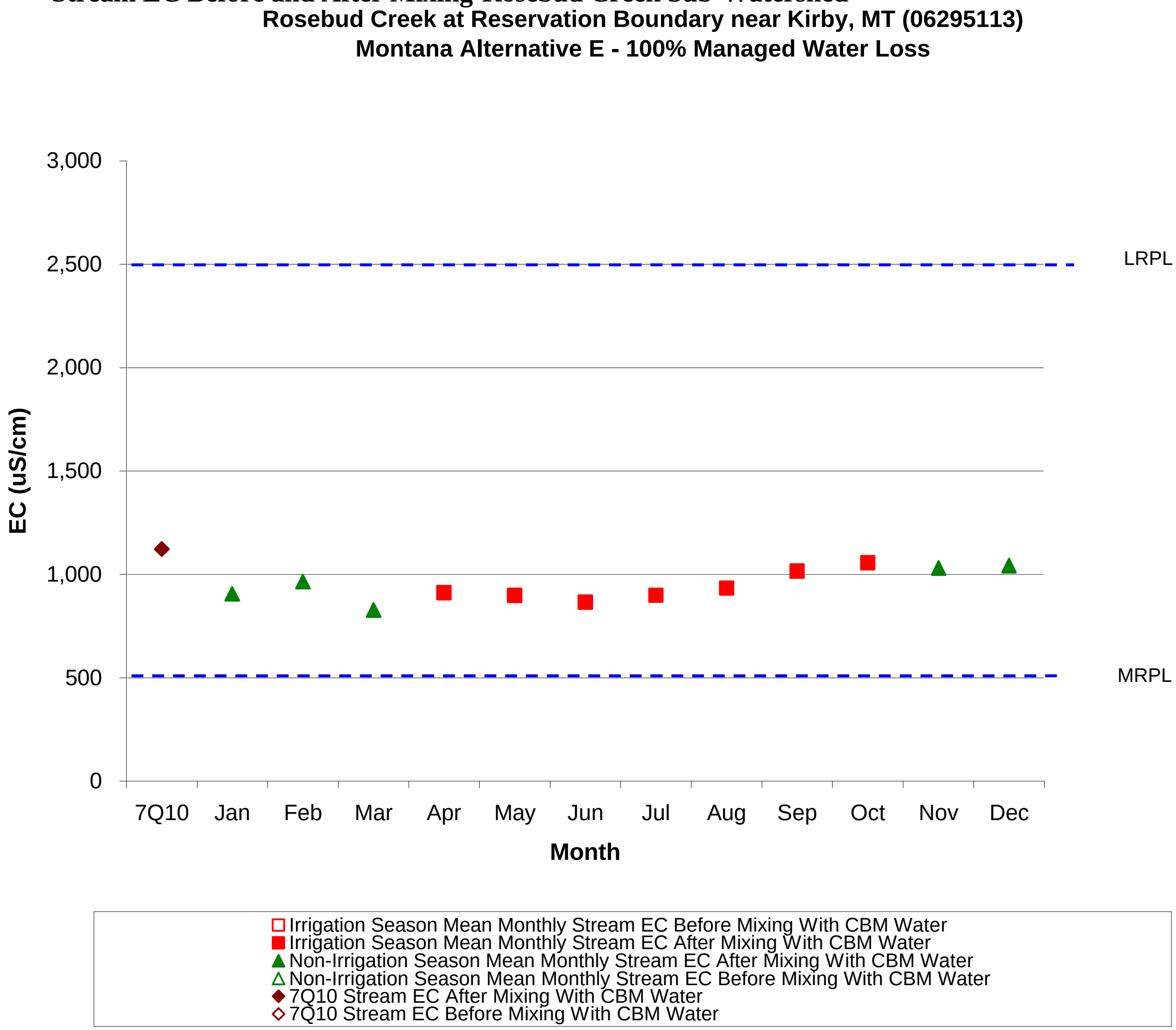


Figure 5-62 Stream SAR Before and After Mixing- Rosebud Creek Sub-Watershed

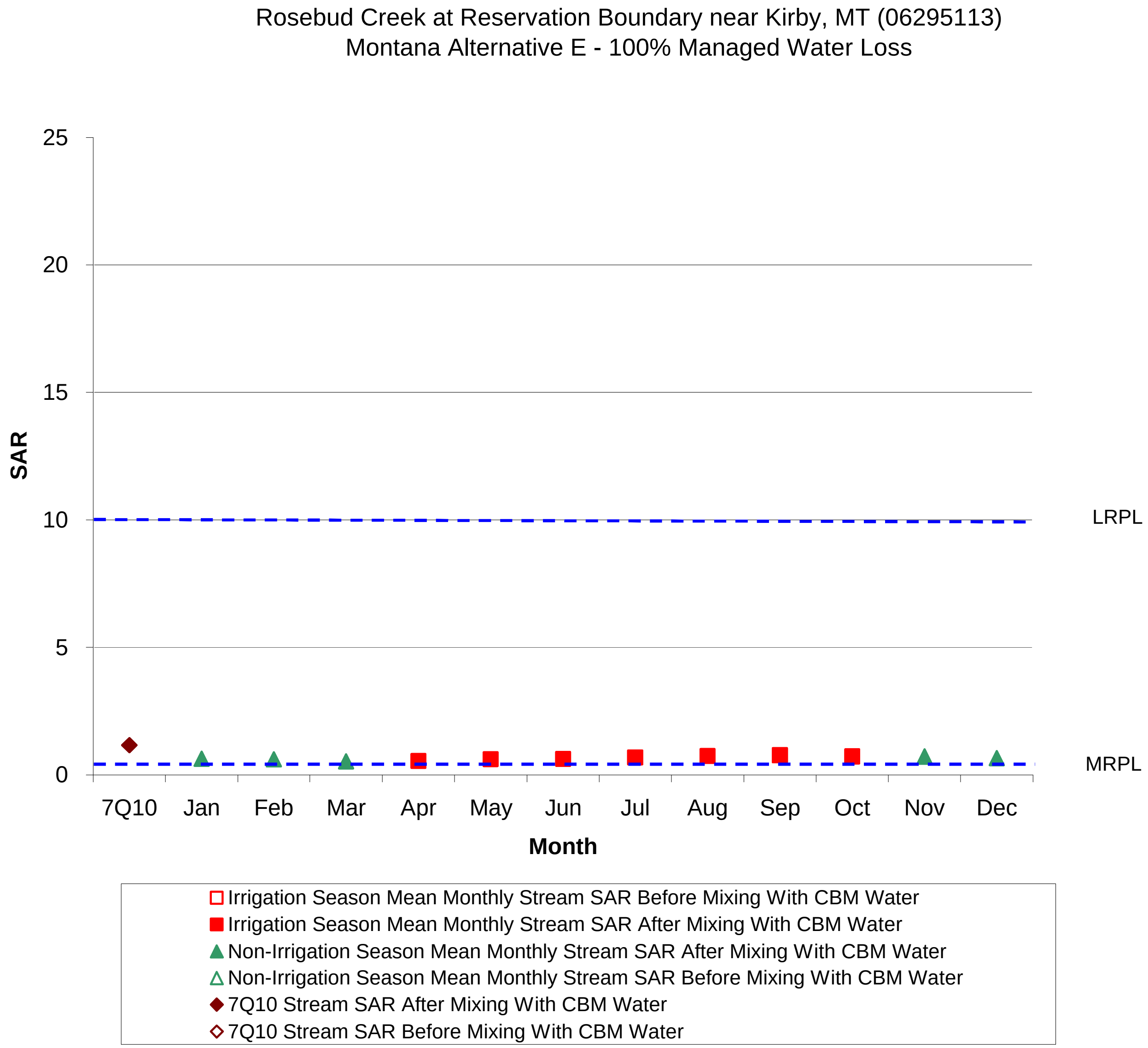


Figure 5-63 Irrigation Suitability Before and After Mixing – Rosebud Creek Sub-Watershed

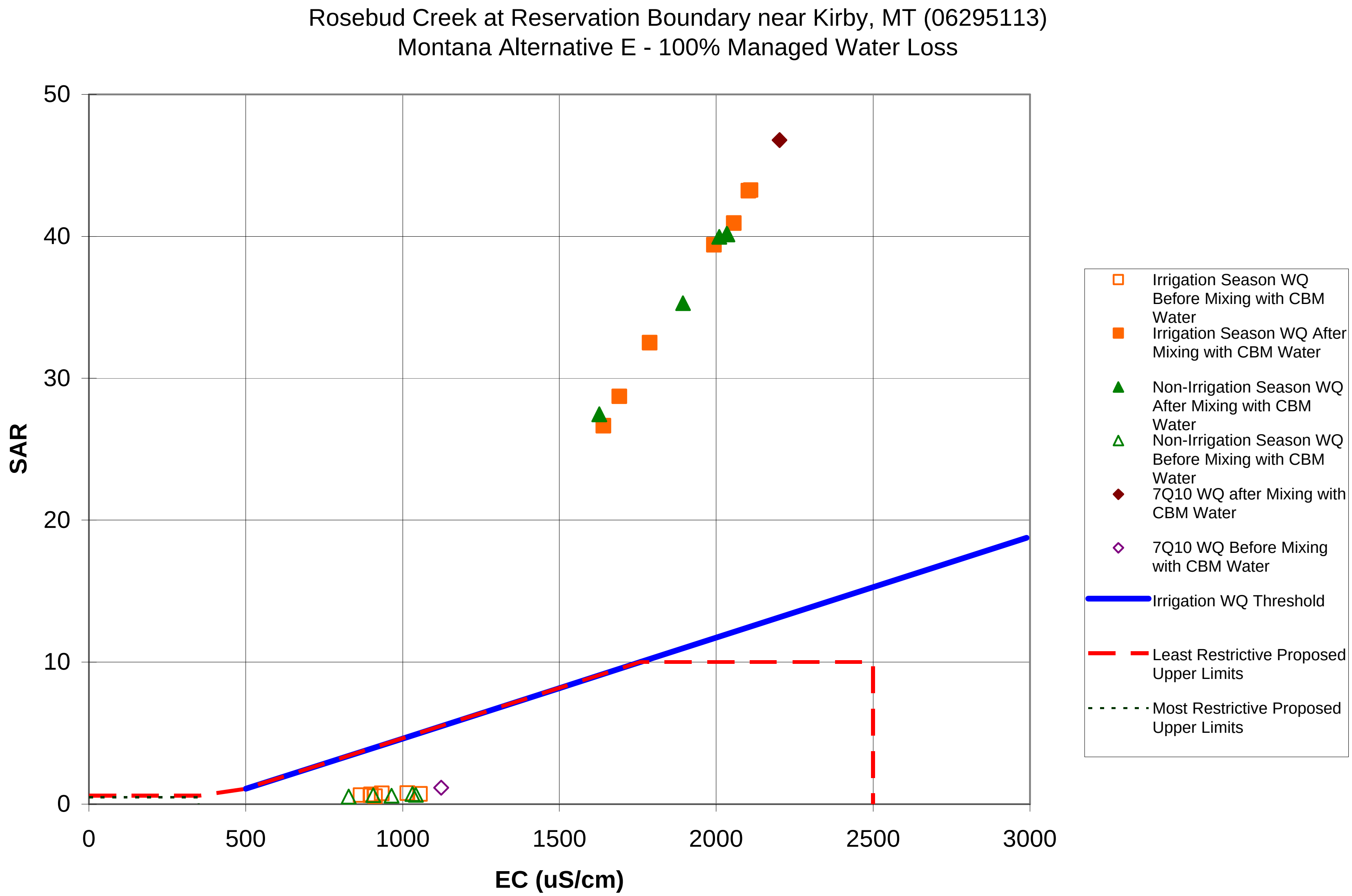
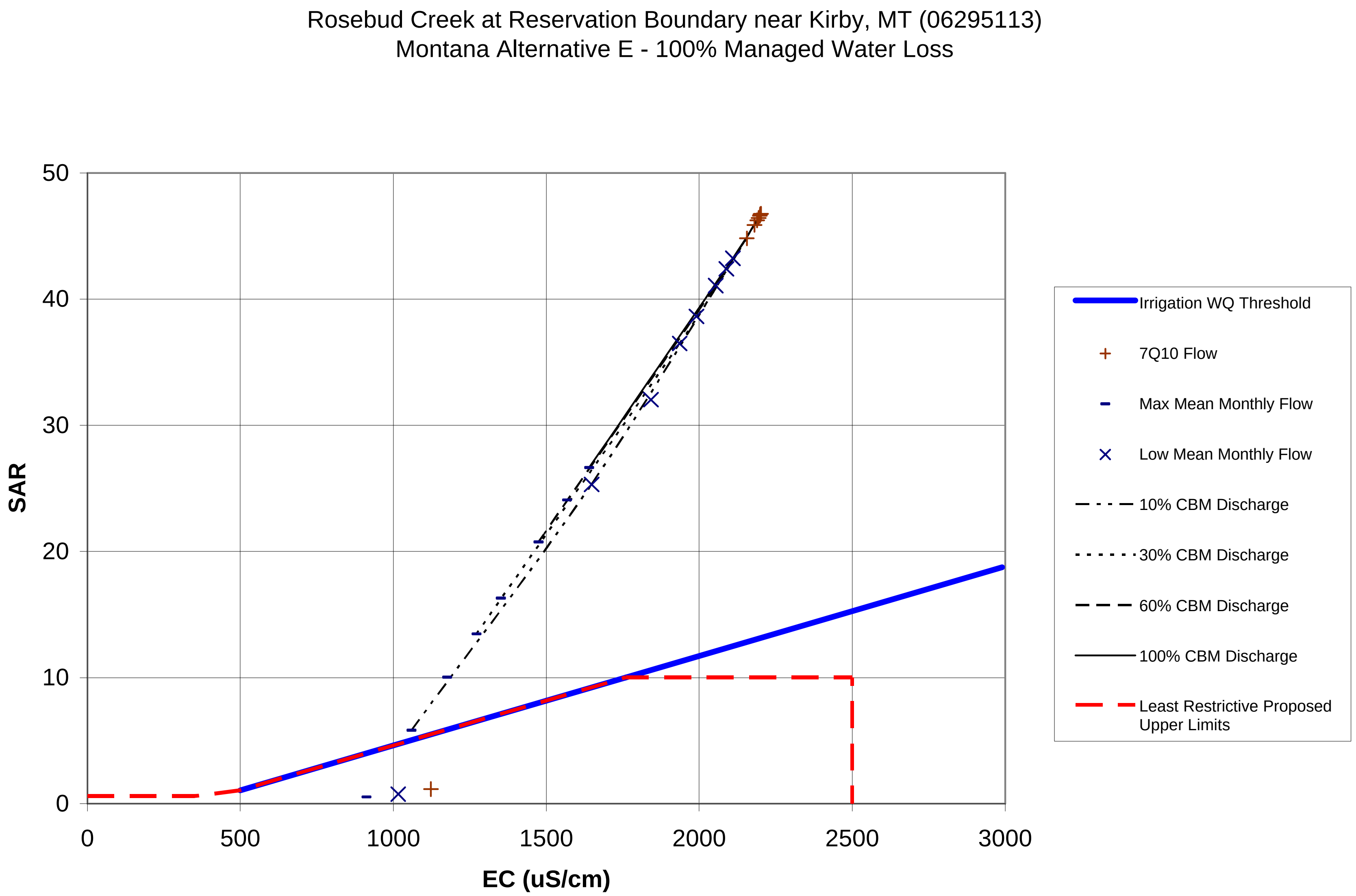


Figure 5-64 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Rosebud Creek Sub-Watershed



Under Alternative C, the resultant stream water quality near Rosebud, Montana can be compared with the following criteria:

- MRPL: Figures 5-65 and 5-66 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Rosebud, Montana. Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive CBM discharges unless the water was of better quality than the stream.
- LRPL: The resultant water quality in the stream at Rosebud would exceed the LRPL for SAR but would be below the LRPL for EC.
- Ayers-Westcot diagram: Figure 5-67 illustrates the suitability for irrigation of the Rosebud Creek near Rosebud before and after mixing with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-67 indicates that the quality of the mixed water at Rosebud would likely cause severe infiltration impacts to irrigated soils during all months of the year. Figure 5-68 illustrates the relationship between EC and SAR in Rosebud Creek near Rosebud after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, only as small traction (<10 percent) of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-65 Stream EC Before and After Mixing- Rosebud Creek Sub-Watershed

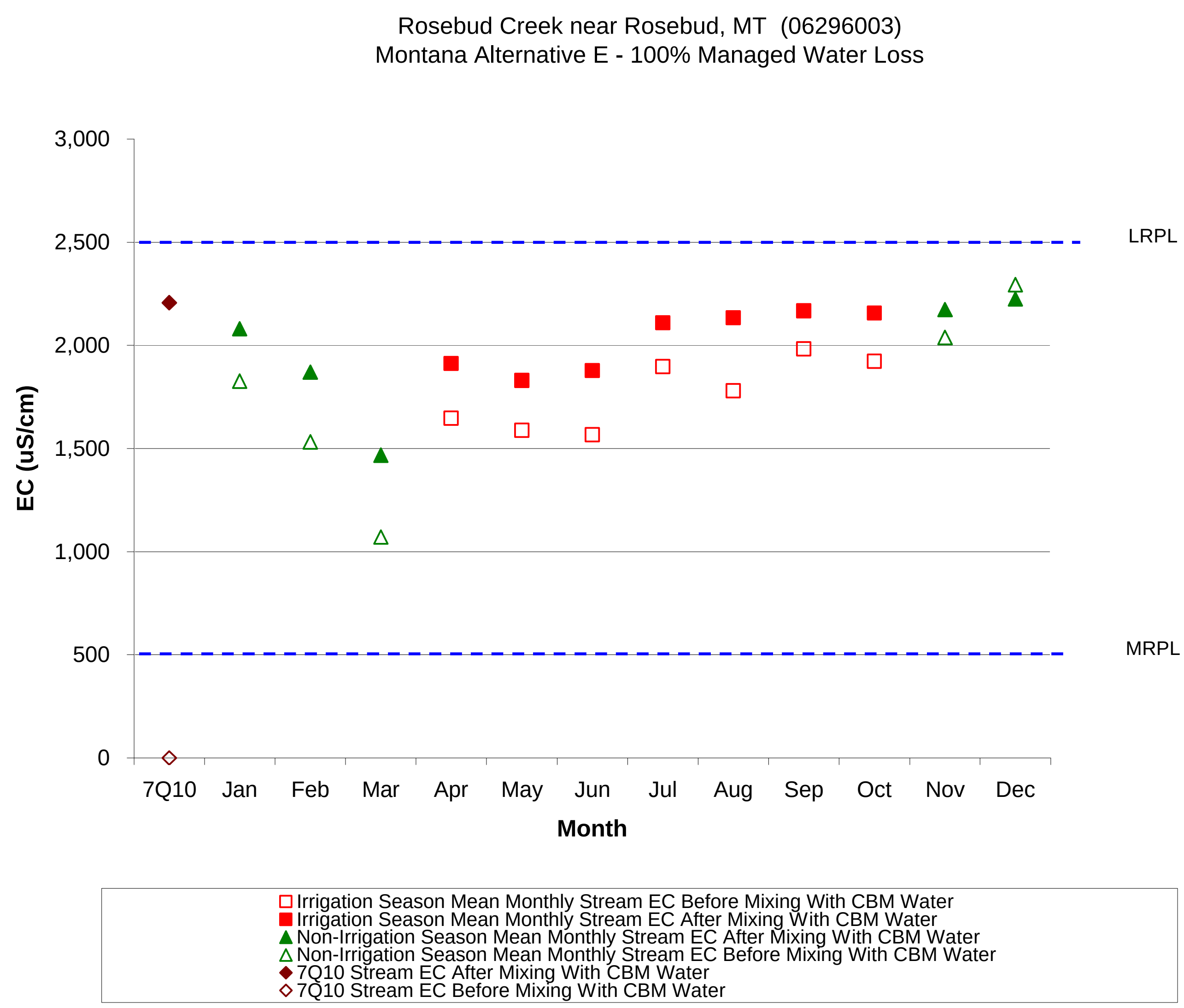


Figure 5-66 Stream SAR Before and After Mixing- Rosebud Creek Sub-Watershed

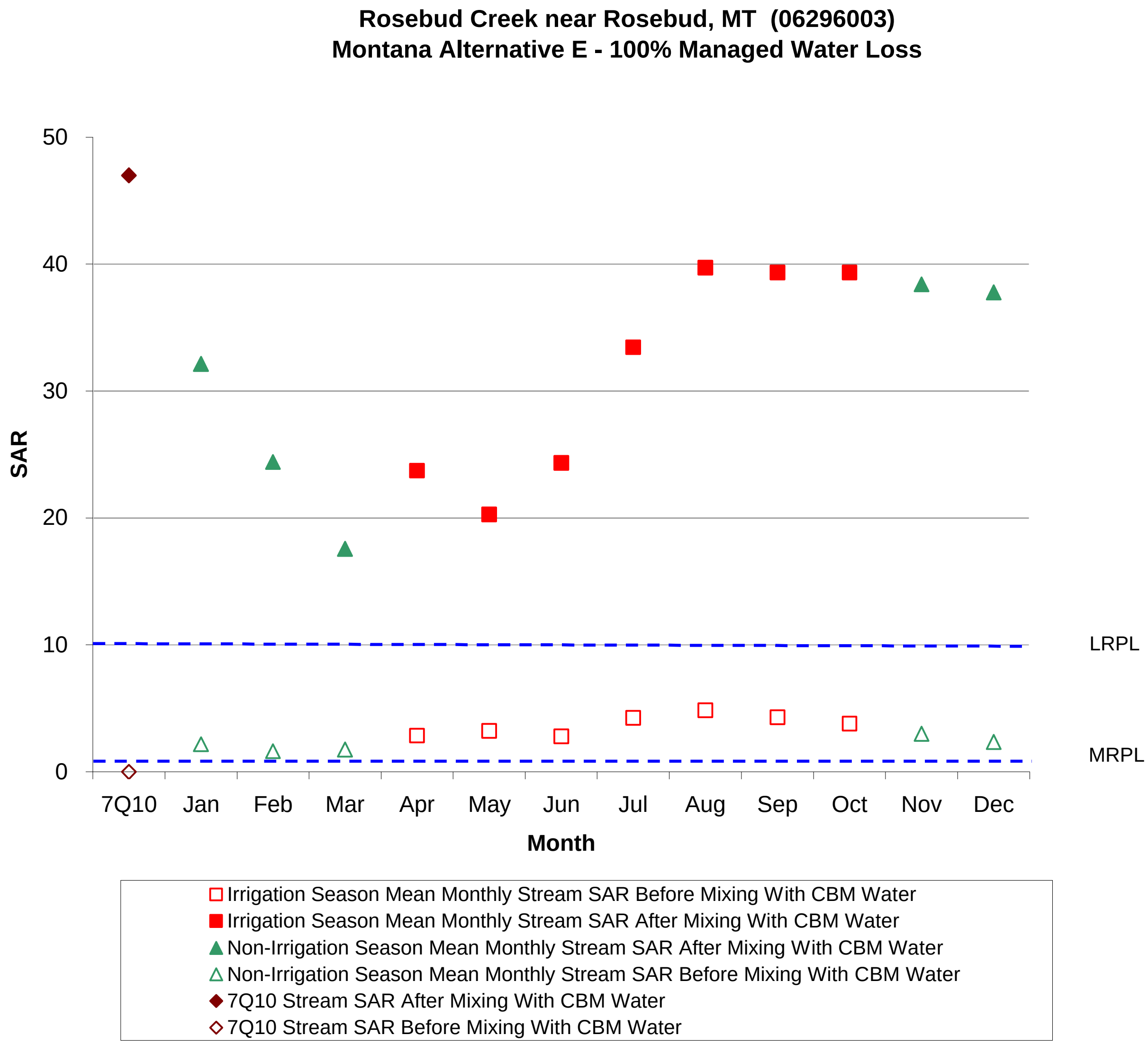


Figure 5-67 Irrigation Suitability Before and After Mixing – Rosebud Creek Sub-Watershed

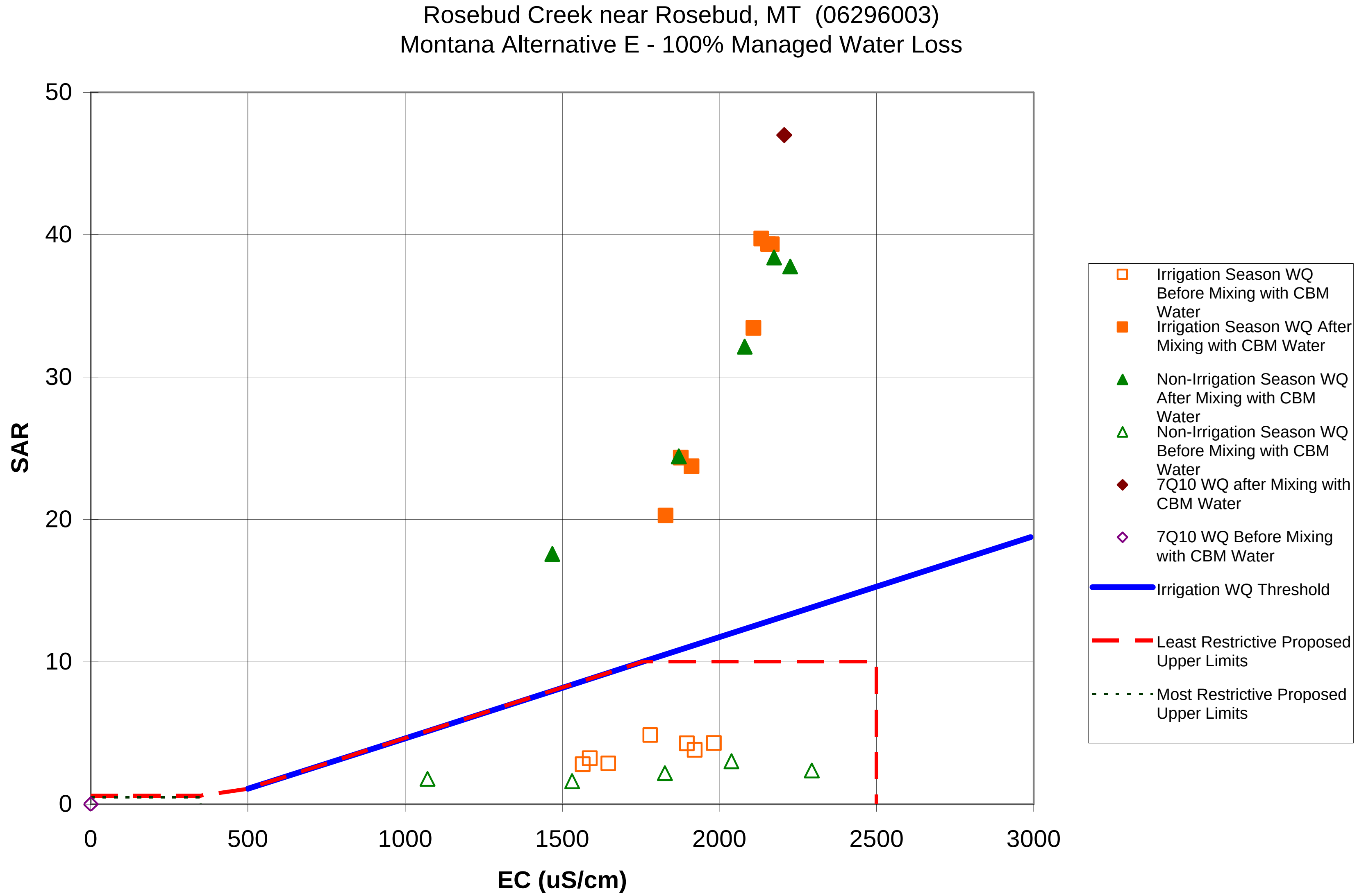
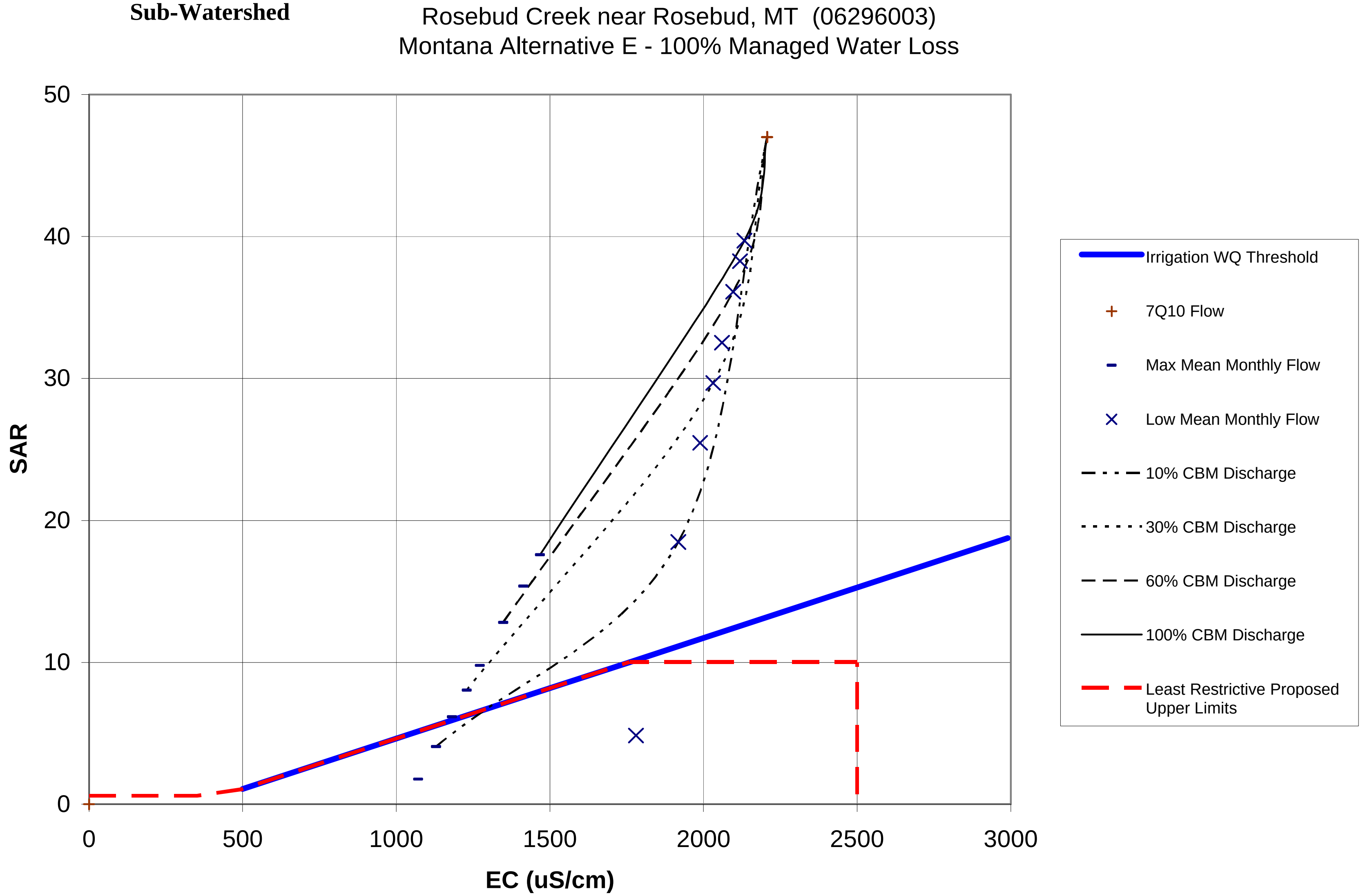


Figure 5-68 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Rosebud Creek Sub-Watershed



Under Alternative C the surface water quality in Rosebud Creek in Montana would be reduced, resulting in severe curtailment of use of this water for irrigation.

5.3.5.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses, and the remaining 80 percent would be treated to the pre-development quality of the surface water before discharge.

Changes in volume of flow are a result of treated and untreated discharges in Montana. Effects on surface water from Montana CBM development are caused by the increases in base flow.

5.3.5.4 Preferred Alternative E

Rosebud Creek is not expected to be affected by CBM wells in Wyoming, and because Rosebud Creek contains high-quality water at low flow rates, there is expected to be no discharge of CBM water from Montana into Rosebud Creek under the Preferred Alternative E.

The effects to the Rosebud Creek under this alternative would be the same as were described for Alternative A since no additional CBM discharge in Montana to Rosebud Creek would be allowed. One hundred percent of the CBM produced water would be managed by other methods in the Rosebud Creek sub-watershed.

5.3.6 Yellowstone River

The Yellowstone River drains all of the Montana watersheds in the PRB. It provides a predictor of the cumulative effects forecast from CBM development in Montana and Wyoming in the Bighorn, Rosebud, Tongue, and Powder watersheds. The Forsyth station would be affected by CBM discharges into the Bighorn, Little Bighorn, and Rosebud watersheds. The Sidney station would be affected by all CBM development in Montana, and from CBM development in Wyoming that occurs in the Tongue, Powder, and Little Powder watersheds. Table 5-16 below summarizes the impacts for two stations along the Lower Yellowstone River in Montana.

Table 5-16
Surface Water Impact Analysis of the Lower Yellowstone-Sunday/Lower Yellowstone Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5820	1.99	745	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5805	2.26	881	2240	2.52	809	2281	3.17	838
C	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	2.06-2.08	748	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5945	3.12-3.31	912-917	2240	2.52	809	2421	5.22-5.70	917-928
D	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	1.99	745	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5805	2.23	870	2240	2.52	809	2421	3.06	814

Table 5-16
Surface Water Impact Analysis of the Lower Yellowstone-Sunday/Lower Yellowstone Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	2.06	748	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5850	2.54	893	2240	2.52	809	2421	5.22-5.70	917-928

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
NA = Not Applicable

5.3.6.1 Alternative A

Only the station at Sidney is expected to receive CBM-related effects under Alternative A. These effects would result from discharges from CX Ranch wells in Montana and CBM wells in Wyoming. After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing stream conditions. The resultant water quality in the stream can be compared with the following criteria:

- MRPL: The water quality in the Yellowstone River naturally exceeds the MRPL for SAR; and therefore could not receive additional CBM discharges if these limits were adopted. The effects forecast under this alternative would cause the stream water to further exceed these limits.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC and SAR during even the lowest flow periods.
- Ayers and Westcot diagram: Irrigation with the mixed water would not cause infiltration impacts to irrigated soils.

The volume and quality of surface water in the Yellowstone River would not be appreciably affected by discharges from Montana and Wyoming under Alternative A. Discharges of CBM water would only slightly increase surface water flow in the Yellowstone River, causing negligible changes to water quality, even during historically low-flow periods.

5.3.6.2 Alternative C

Because of the significant volume of water in the Yellowstone River to dilute the water that would be discharged by CBM production in both Montana and Wyoming, the resultant water quality would show only slight changes in both EC and SAR. The resultant water quality can be compared with the following criteria:

- MRPL: The existing water quality in the Yellowstone River naturally exceeds the MRPL for EC and SAR during all months of the year and would not be able to receive additional CBM discharges if these limits were adopted. The impacts forecast from Wyoming and Montana CBM water under Alternative C would also exceed these limits.
- LRPL: The resultant water quality would be adequate to meet these limits.
- Ayers and Westcot diagram: Irrigation with the mixed water would not cause infiltration impacts to irrigated soils at any time. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Under Alternative C, the quality of surface water in the Yellowstone River in Montana would be slightly reduced; however, no changes should be required in irrigation management practices by downstream users for continued use of this water. The resultant water quality in the Lower Yellowstone River is sufficient for irrigation even during the months with the lowest flows.

5.3.6.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses, and the remaining 80 percent would be treated to the pre-development quality of the surface water before discharge.

The increases in the quality of surface water for Alternative D would result from discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow would result from treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water from CBM development in Montana would be caused by the increases in base flow.

5.3.6.4 Preferred Alternative E

The Yellowstone River receives the combined flows of the other watersheds in the PRB. The Forsyth Station is upstream, which receives no contribution from discharges in Wyoming but will receive some CBM discharge from Montana. The Sidney station is the downstream station and receives discharges from all CBM wells in the Montana portion of the PRB. It also receives discharges from 25,538 CBM wells in Wyoming. The resultant stream water quality near Forsyth, Montana, can be compared with the following criteria:

- MRPL: Figures 5-69 and 5-70 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Lower Yellowstone sub-watershed, as modeled at the USGS gauging station near Forsyth, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Forsyth station during 7Q10 flow conditions is above the LRPL for SAR.
- Ayers-Westcot diagram: Figure 5-71 illustrates the suitability for irrigation of the Yellowstone River near Forsyth before and after the river mixes with Discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-71 indicates no reduction in infiltration. Figure 5-72 illustrates the relationship between EC and SAR in Rosebud Creek near Kirby after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-69 Stream EC Before and After Mixing-Lower Yellowstone River Sub-Watershed

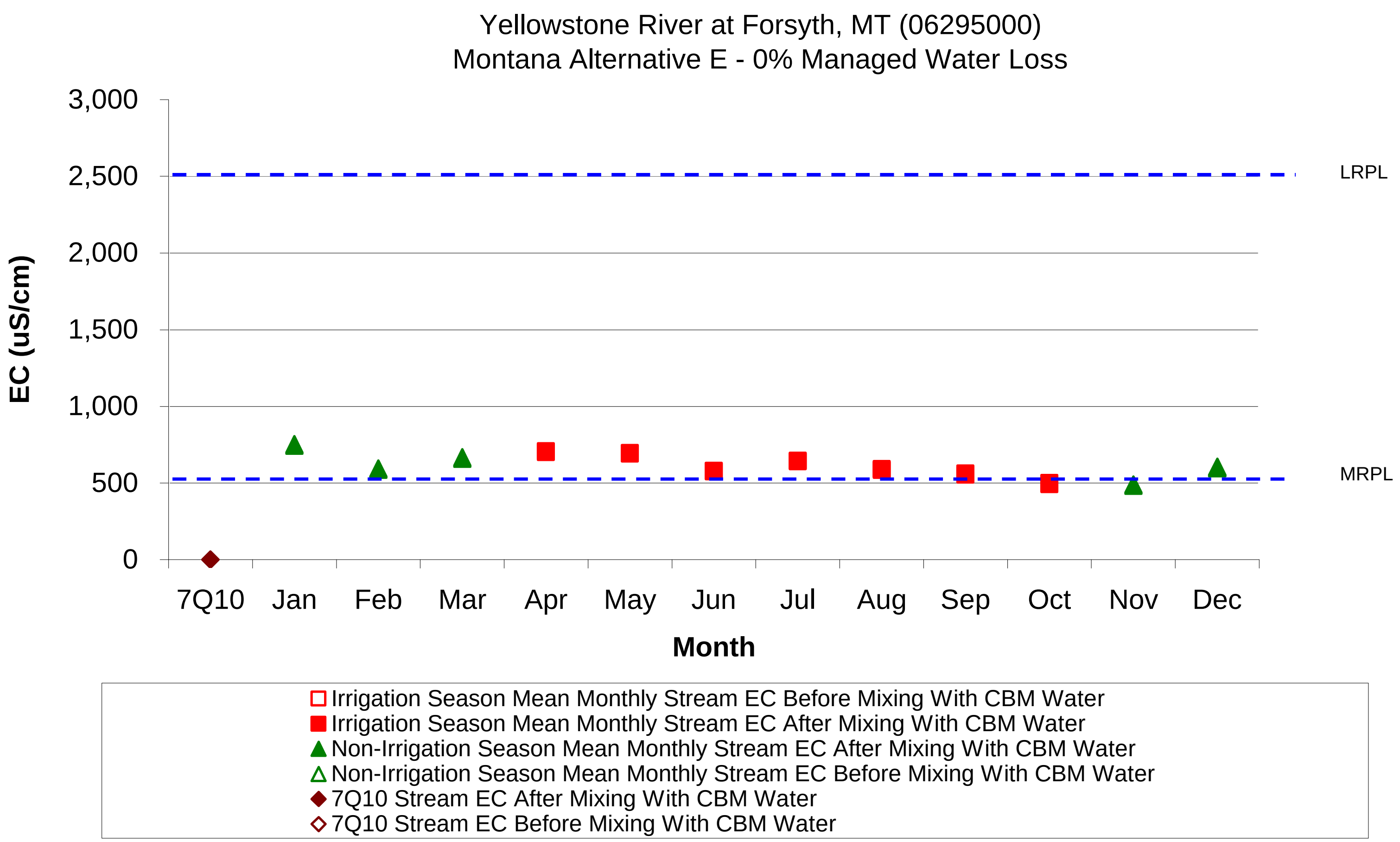


Figure 5-70 Stream SAR Before and After Mixing- Lower Yellowstone River Sub-Watershed

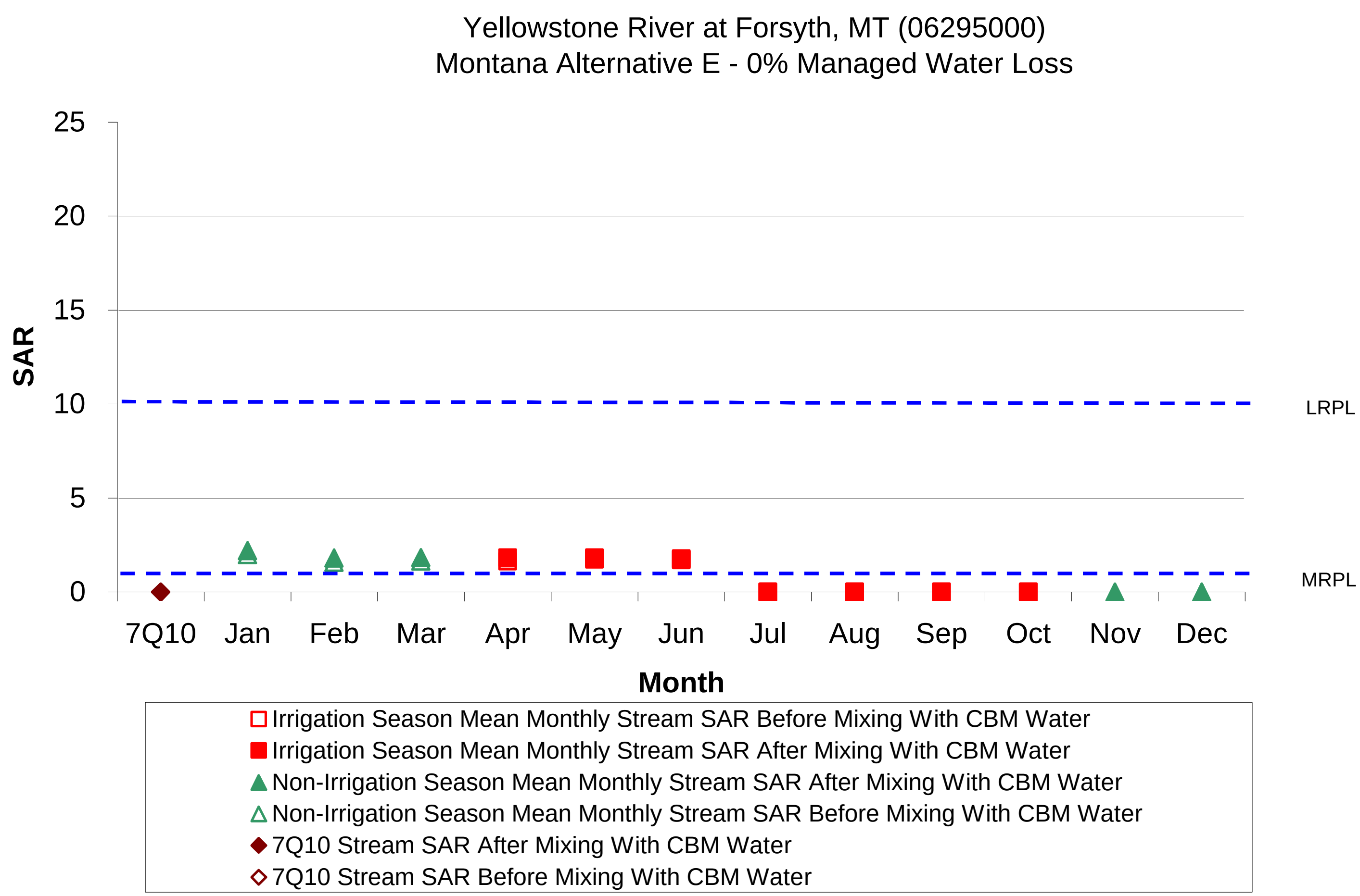


Figure 5-71 Irrigation Suitability Before and After Mixing – Lower Yellowstone River Sub-Watershed

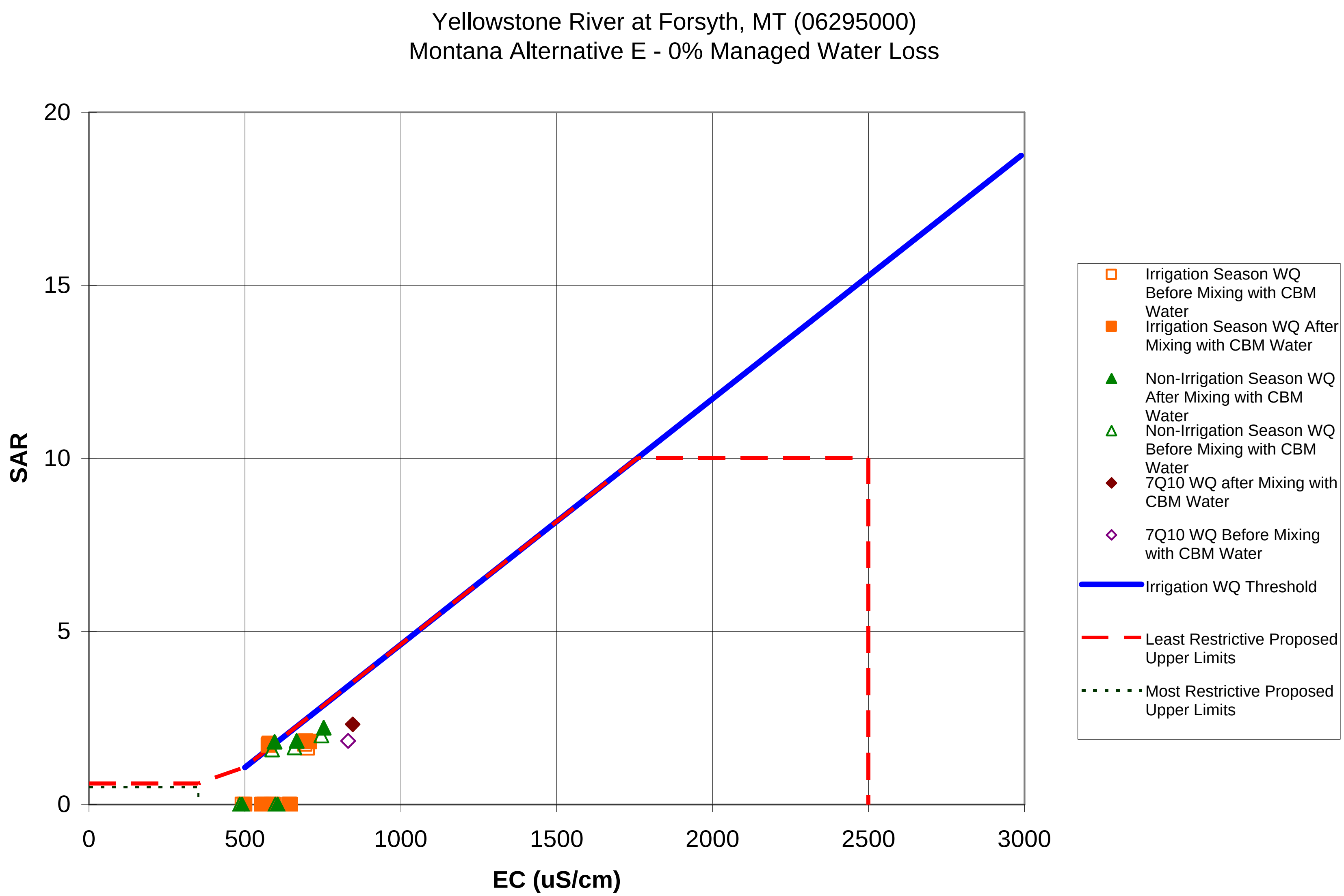
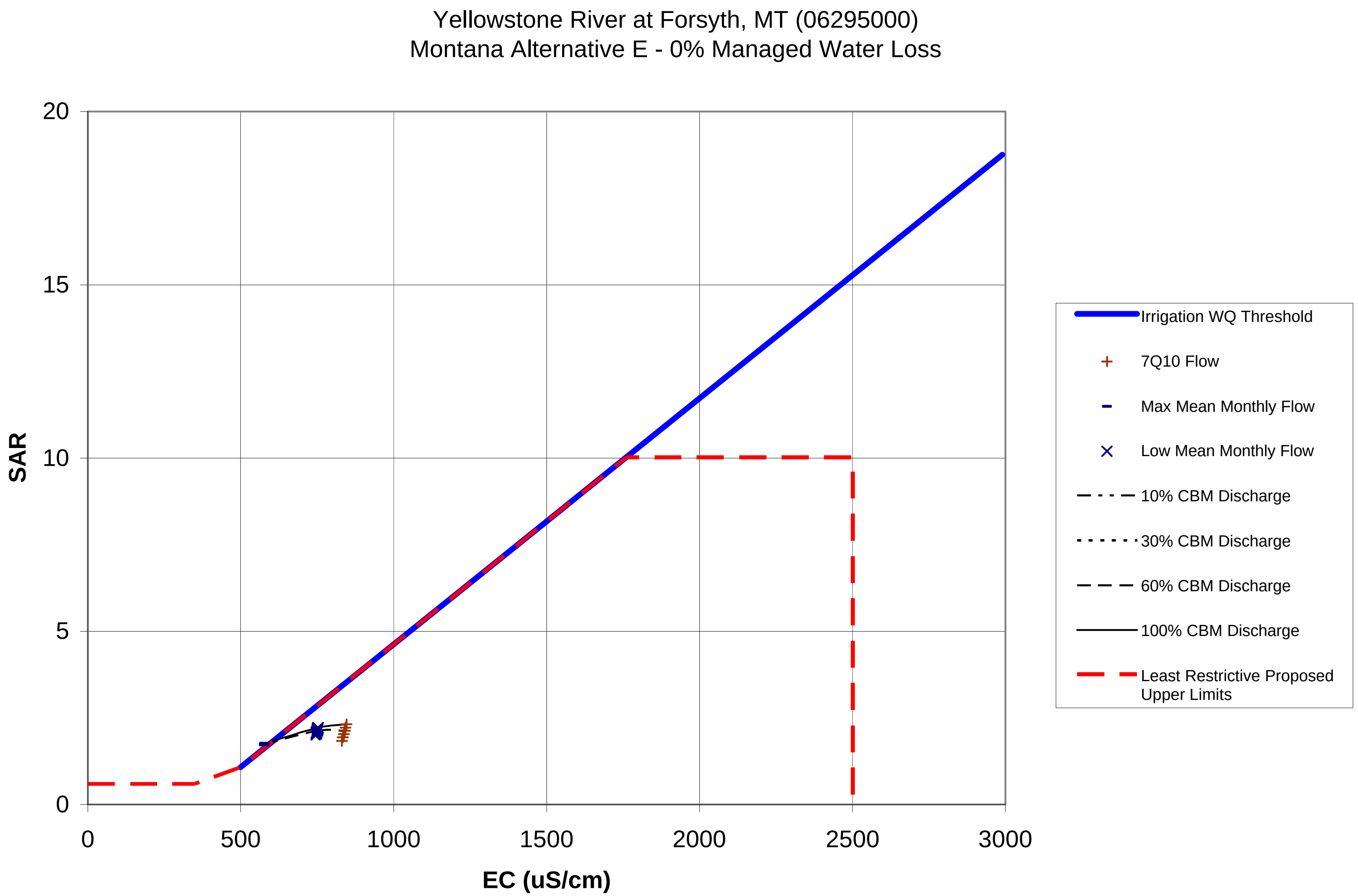


Figure 5-72 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Yellowstone River Sub-Watershed



Under Alternative E, the resultant stream water quality near Sydney, Montana can be compared with the following criteria:

- MRPL: Figures 5-73 and 5-74 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Sydney, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly flow or during 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-75 illustrates the suitability for irrigation of the Lower Yellowstone River near Sydney before and after the river mixes with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-75 indicates no impacts to infiltration during the low monthly flow and that the mixed water would be adequate for use for irrigation. Figure 5-76 illustrates the relationship between EC and SAR in the Lower Yellowstone River near Sydney after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-73 Stream EC Before and After Mixing- Lower Yellowstone River Sub-Watershed

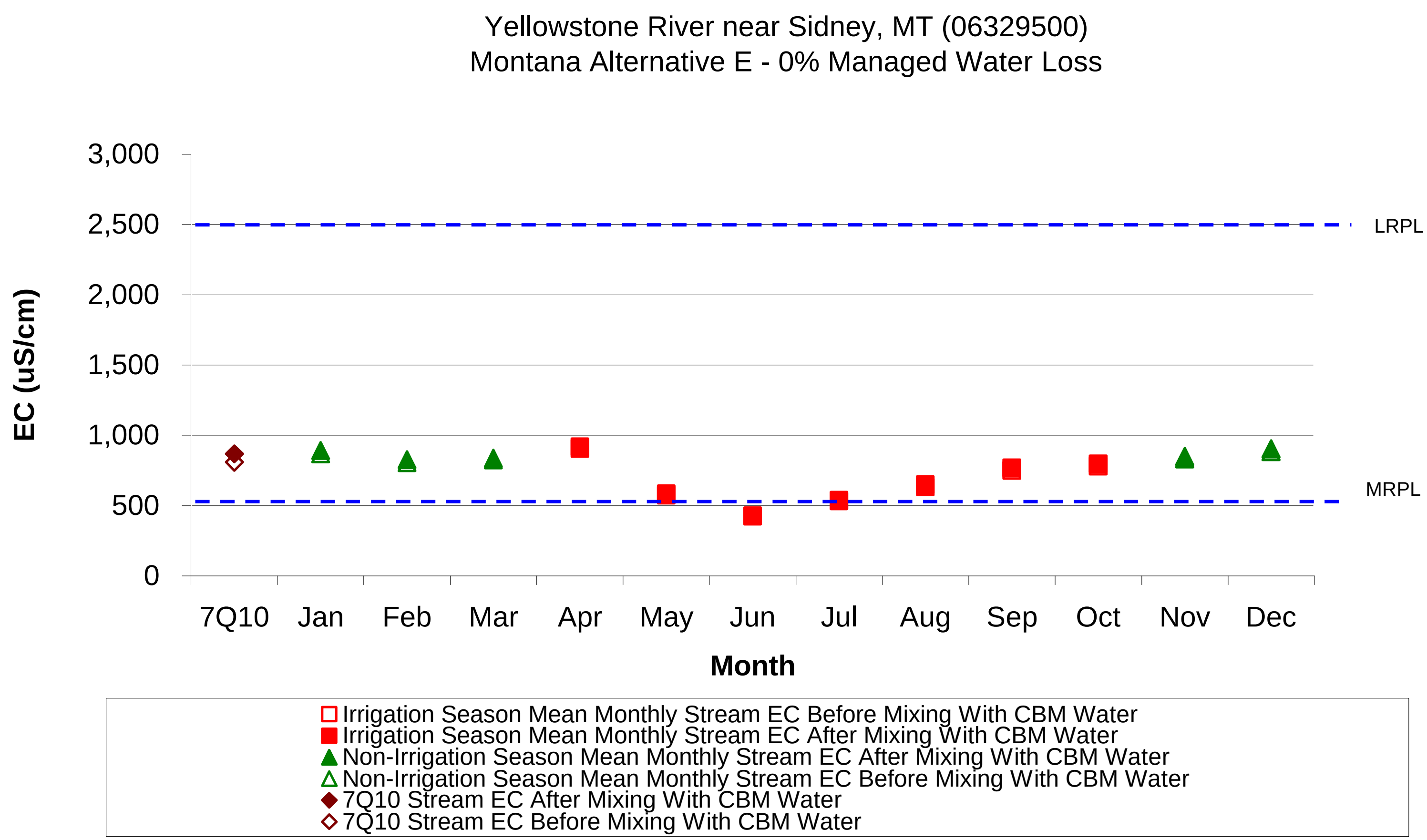


Figure 5-74 Stream SAR Before and After Mixing- Lower Yellowstone River Sub-Watershed

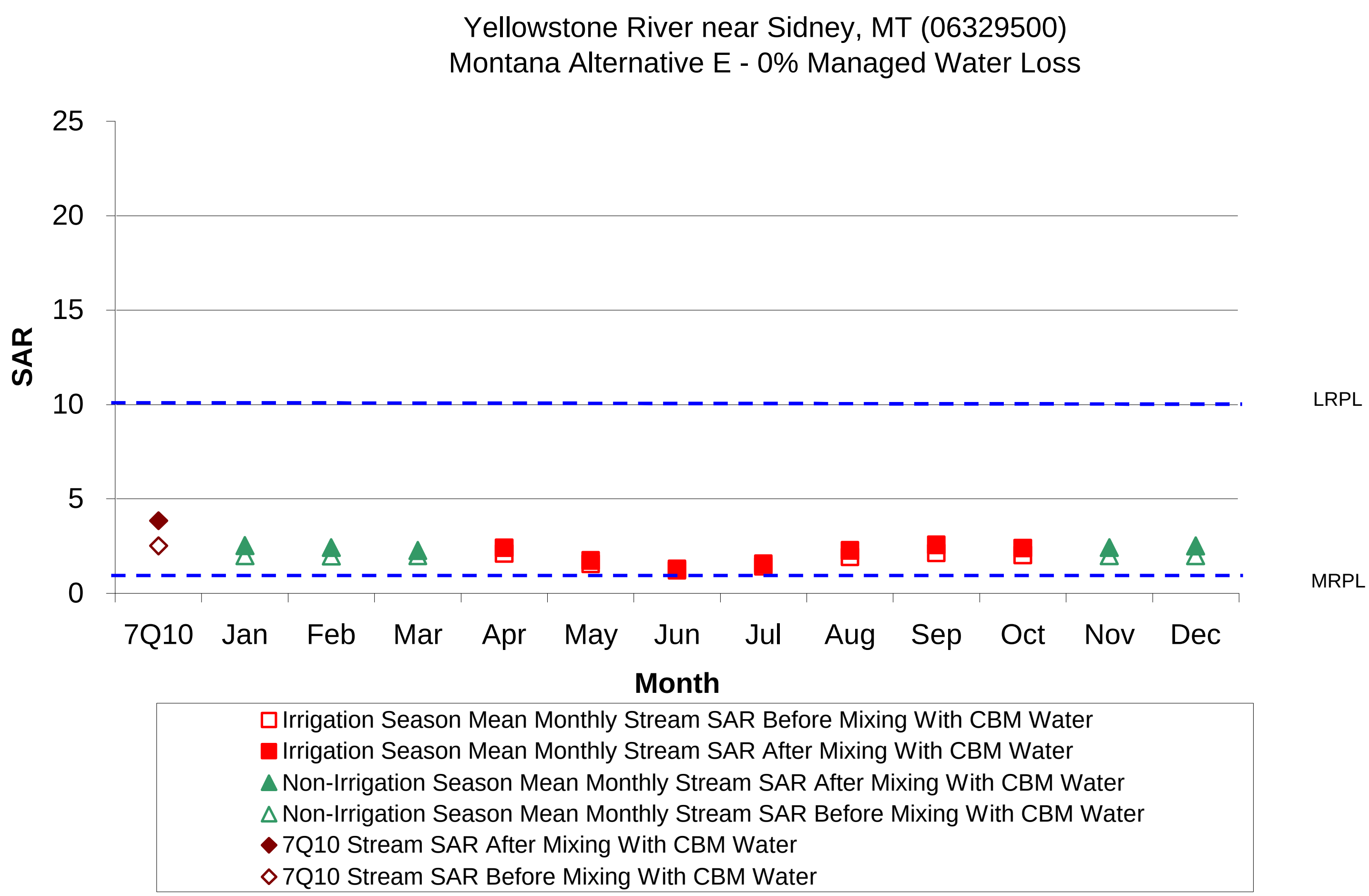


Figure 5-75 Irrigation Suitability Before and After Mixing – Lower Yellowstone River Sub-Watershed

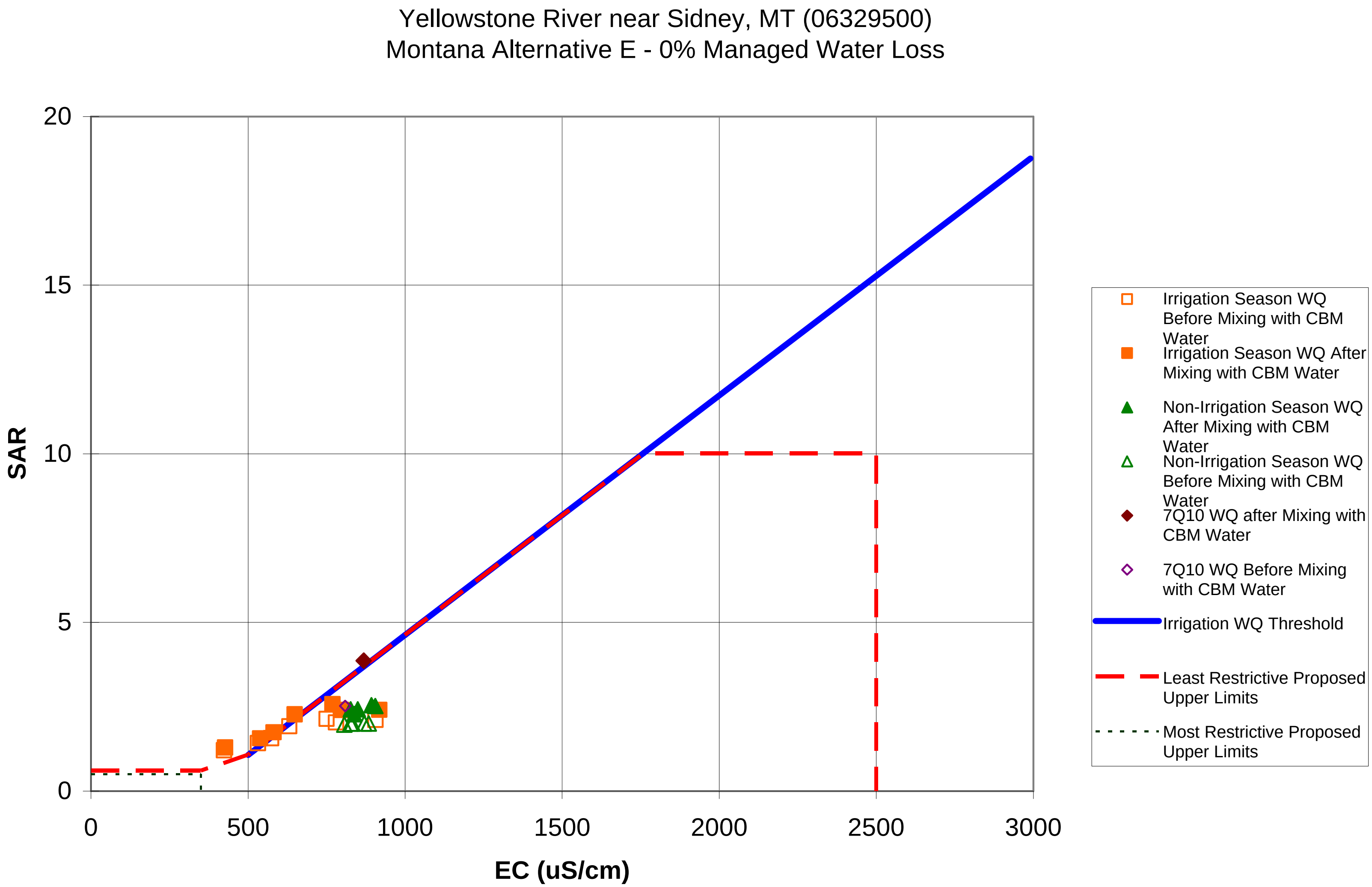
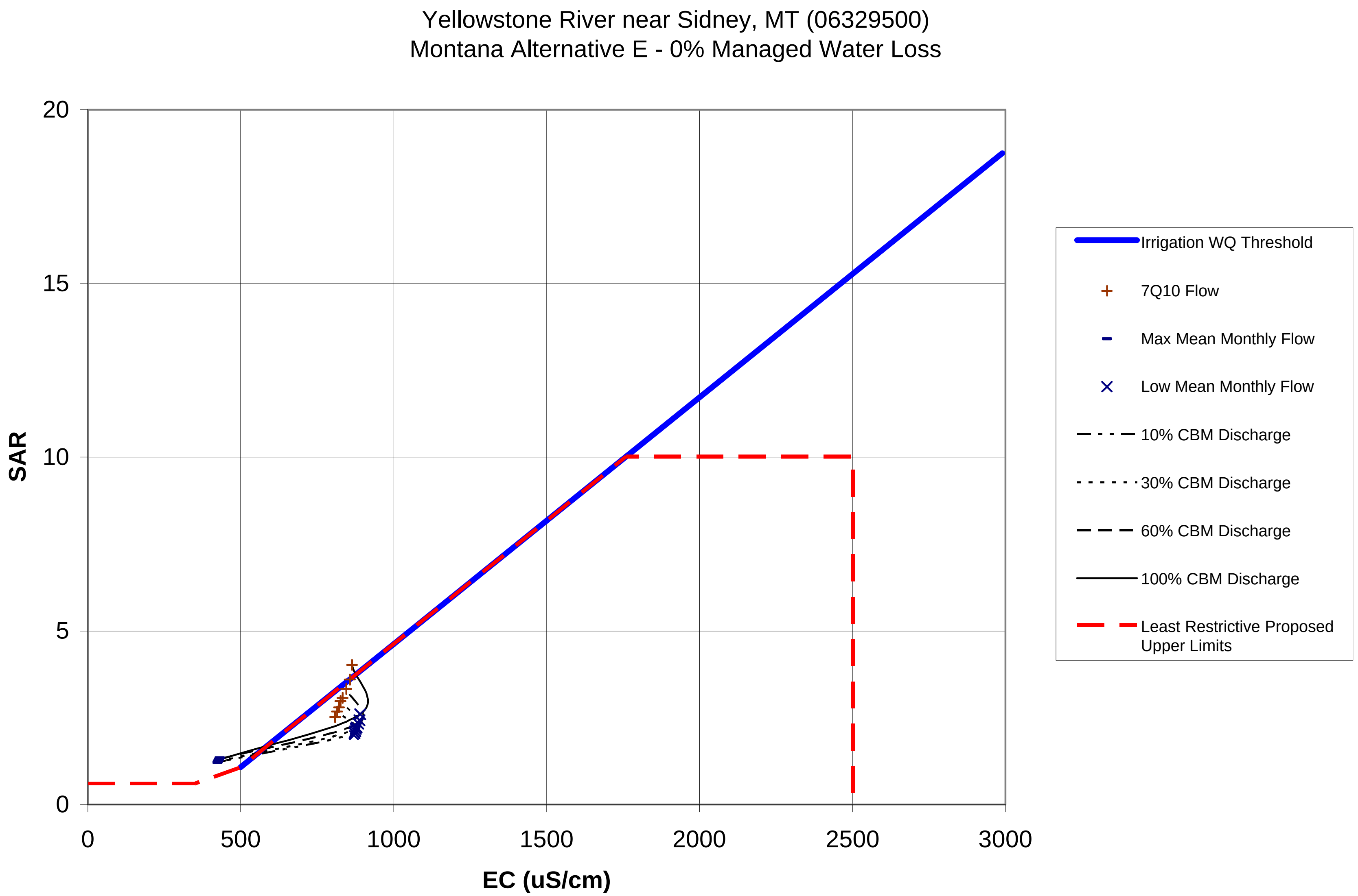


Figure 5-76 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Yellowstone River Sub-Watershed



Although discernable effects may be seen at Forsyth and Sidney, beneficial uses would not be reduced under Preferred Alternative E.