APPENDIX E

Comparison of Surface Water Model Predictions with Actual Observed Data

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Powder River Oil and Gas Preliminary Final Environmental Impact Statement
By: Joe Meyer – U.S. Bureau of Land Management – Casper Field Office

Introduction:

The Powder River Oil and Gas Preliminary Final Environmental Impact Statement (PFEIS) utilized a spreadsheet based mass balance model developed by the United States Environmental Protection Agency (EPA) to analyze potential surface water impacts resulting from the discharge of coalbed methane (CBM) produced water. The surface water mass balance model predicts potentially significant changes in water quality for some watersheds at maximum predicted development (Figures 1,2,3). Given the relatively simplistic nature of the mass balance model, concern has been raised regarding the ability of the model to accurately predict stream water quality.

Model Predictions:

As previously mentioned, the EPA spreadsheet based model utilizes a simple mass balance approach to impact analysis. Using a mass balance technique completely ignores geochemical processes that occur as produced water moves from the point of discharge to the mainstem streams. Since much of the water discharge in the Powder River Basin passes through impoundments, or flows down ephemeral channels, the effect of transport chemistry on resultant water quality can be significant.

To evaluate the ability of the mass balance model to predict resultant water quality, CBM produced water discharge was computed for Powder River at Moorhead, MT (06324500)(Wyoming production only), Little Powder River above Dry Creek near Weston, WY (06324970), and the Belle Fourche River below Moorcroft, WY (06426500) for the entire period of CBM produced water discharge in those watersheds (Table 1).

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Figure 1. EPA Mass Balance Model Predictions Powder River Moorhead, PFEIS Alt. 2B.

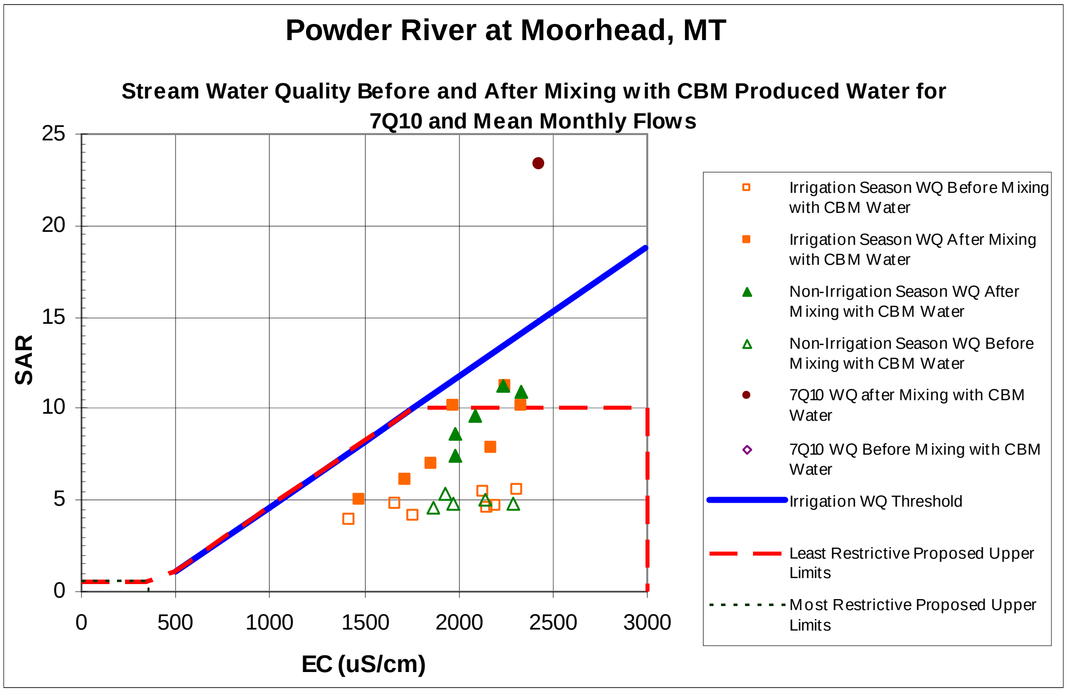

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Figure 2. EPA Mass Balance Model Prediction Little Powder River Weston, PFEIS Alt. 2B.

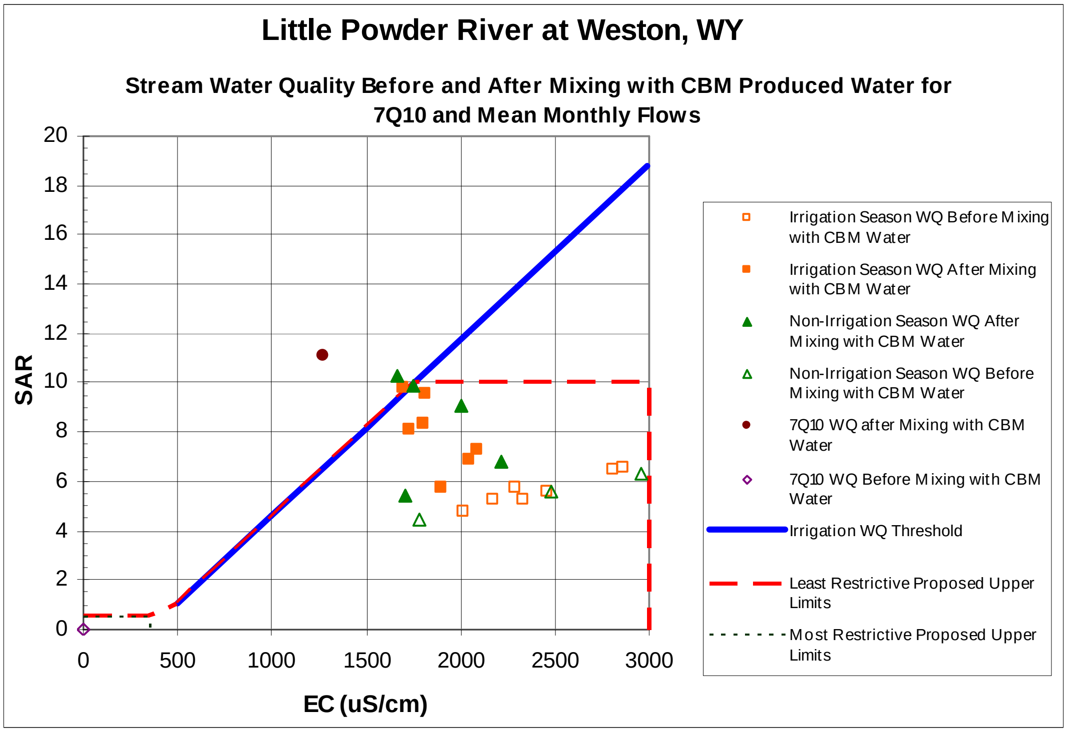

Figure 3. EPA Mass Balance Model Predictions Belle Fourche Moorcroft, PFEIS Alt. 2A.

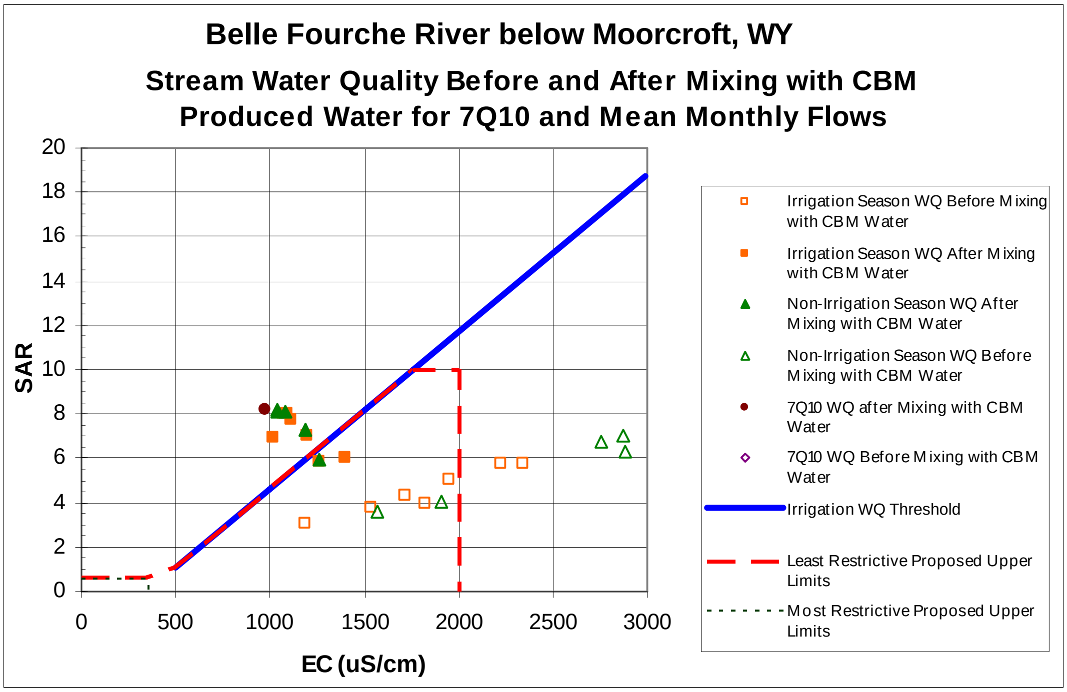

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Table 1 lists CBM water production values for the three basins for 2001. These values were input into the EPA mass balance model, and resultant stream water quality was predicted for each of the basins for the year 2001. There was too little CBM production in the Powder River Basin above Moorhead to show any significant change in resultant stream water quality with either the model predictions, or actual observed data (Figure 4, 5,6)

The mass balance model predictions for the Little Powder River using 2001 actual CBM produced water volumes indicate a significant change in resultant stream water quality (Figures 7,8,9). Graphical comparison of actual water quality samples collected by the United States Geological Survey (USGS) to the ambient mean monthly water quality at this station do not indicate any change in ambient stream water quality despite the fact that CBM produced water has been discharged in the Little Powder watershed since 1993, and the 2001 reported CBM produced water is equivalent to approximately 37 percent of the PFEIS predicted maximum CBM produced water discharge for this basin (Table 1).

A similar pattern is obvious in the model predictions for the Belle Fourche River below Moorcroft, WY (Figures 10,11,12). The mass balance model predicts a significant change in stream water quality as a result of CBM produced water discharge, and four months are predicted to exceed the Ayres – Westcott Line. Graphical comparison of actual water quality samples collected by the USGS to the ambient mean monthly water quality at this station do not indicate any change in ambient stream water quality despite the fact that CBM produced water has been discharged in the Belle Fourche watershed since 1993, and the 2001 reported CBM produced water is equivalent to approximately 33 percent of the PFEIS predicted maximum CBM produced water discharge for this basin (Table 1).

An attempt was made to conduct a more quantitative analysis of changes in ambient stream quality beyond the graphical comparison evident in Figures 7-12. Water quality data from USGS stations on the Belle Fourche River below Moorcroft, WY and Little Powder River Near Weston, WY were analyzed for two time periods, 1980 to 1992, and 1993 to 2001. These time periods correspond to the period of record available before and after CBM discharge in the basins. A plot of EC versus SAR was made for each station utilizing samples from the period prior to CBM discharge (Figures 13, 14). A linear trend line was then fitted to the pre CBM production samples. Using the equation of the trend line, SAR values were predicted for each EC value in the data set, both pre and post CBM development. A residual value was computed by subtracting the predicted value of SAR from the actual measured water quality. A positive residual value indicates that the predicted value of SAR is less than the actual measured value, and a negative residual indicates the predicted SAR is greater than the actual measured value. Most residual values for samples collected during the post 1993 period are negative (Figures 15,16), indicating that the EC / SAR relationship which existed prior to CBM production over predicts the SAR at any given EC value after CBM produced water has been discharged.

Residual values of predicted SAR for both stations (Table 2) seem to indicate that since the onset of CBM produced water discharge, SAR values at any given EC in the stream have actually decreased. This trend in EC / SAR does not follow the mass balance model which predicts increases in SAR in receiving streams as a result of CBM produced water discharge.

Further analysis of the measured water quality data was conducted to attempt to explain the apparent change in the EC / SAR relationship from 1993 to 2001. Samples collected during the period of 1993 to 2001 on average appear to have been collected at higher streamflow rates than the samples collected during the period of 1980 to 1992 (Table 3). USGS streamflow data from Powder River Moorhead, Belle Fourche Moorcroft and Little Powder Weston also indicate that mean annual streamflow was greater for water years 1993 to 2001 than they were during the water year 1980 to 1992 (Table 4). Precipitation records from Gillette, WY indicate that the average annual precipitation during the period of 1980 to 1992 was lower than the period of 1993 to 2001 (Table 5).

Comparison of streamflow records from stations with unequal periods of record, or comparison of two periods of record from the same station of unequal length can be difficult. Large variations in climate and streamflow in ephemeral systems can make statistical comparisons suspect. Streamflow rates obtained with water quality samples, annual mean streamflow records, and precipitation data all seem to support the trend of higher streamflow during the period of 1993 to 2001. It is likely that this higher streamflow is a result of greater precipitation rather than CBM produced water. Periods of higher precipitation and streamflow could account for a change in the EC / SAR relationship and account for the apparent lower SAR values during this period.

There is however, no evidence to support an increase in SAR in ambient water quality on the Belle Fourche River below Moorcroft, WY, or on the Little Powder River near Weston, WY despite significant CBM discharges during the period of 1993 to 2001. This is contrary to what is predicted by the EPA mass balance model.

Conclusions:

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. Samples collected since the onset of CBM production in the Belle Fourche and Little Powder River Basins 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.

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Table 1. Average Number of Producing CBM Wells and Rate by Basin.

Basin	Year	Average Number of Producing CBM Wells	Average Rate (gpm)	CBM Discharge as % of Predicted Maximum
Belle Fourche River Below Moorcroft (06426500)	1993	32	8.08	0.48
	1994	53	9.56	0.96
	1995	65	13.84	1.69
	1996	87	11.93	1.94
	1997	164	15.15	4.64
	1998	287	12.99	6.99
	1999	566	10.88	11.52
	2000	1557	9.05	26.38
	2001	2818	6.28	33.11
Little Powder River above Dry Creek near Weston, WY (06324970)	1993	13	4.71	0.38
	1994	7	4.92	0.21
	1995	7	10.76	0.49
	1996	10	15.41	1.01
	1997	24	13.73	2.10
	1998	45	12.73	3.67
	1999	116	14.30	10.50
	2000	525	9.23	30.74
	2001	1050	5.57	37.07
Powder River at Moorhead, MT (06324500)	1993	0		
(Wyoming Production Only)	1994	0		
	1995	0		
	1996	0		
	1997	0		
	1998	0		
	1999	46	25.15	0.89
	2000	357	9.66	2.64
	2001	1243	6.49	6.18

Figure 4. Mass Balance Prediction Using 2001 Actual CBM Production.

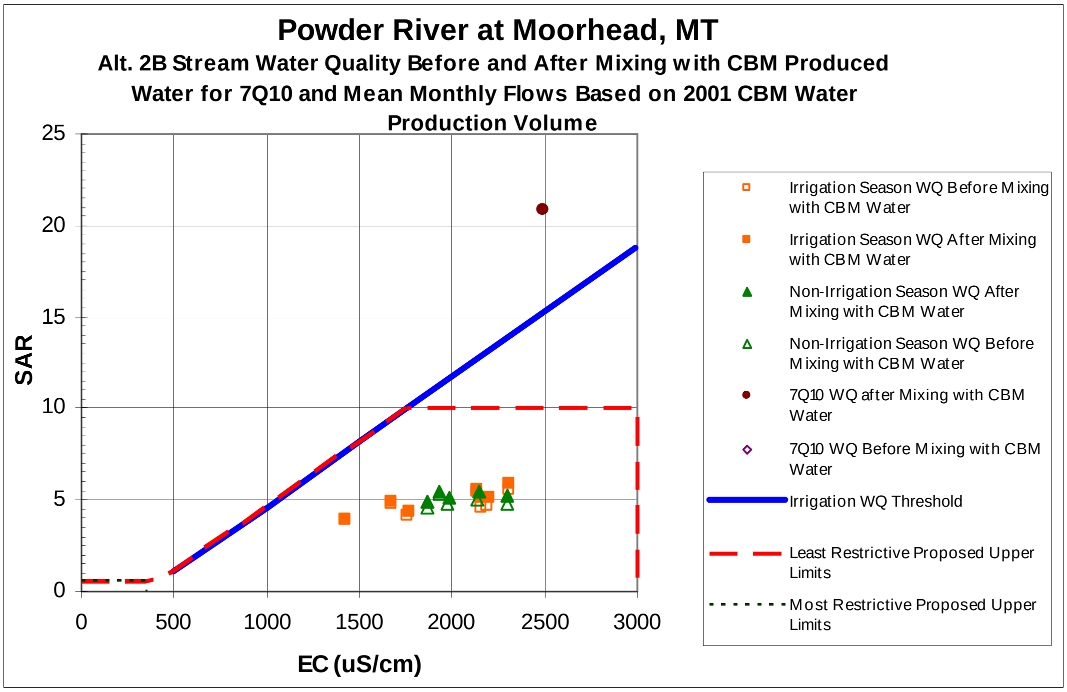

Figure 5. Mass Balance Prediction With Measured QW Samples.

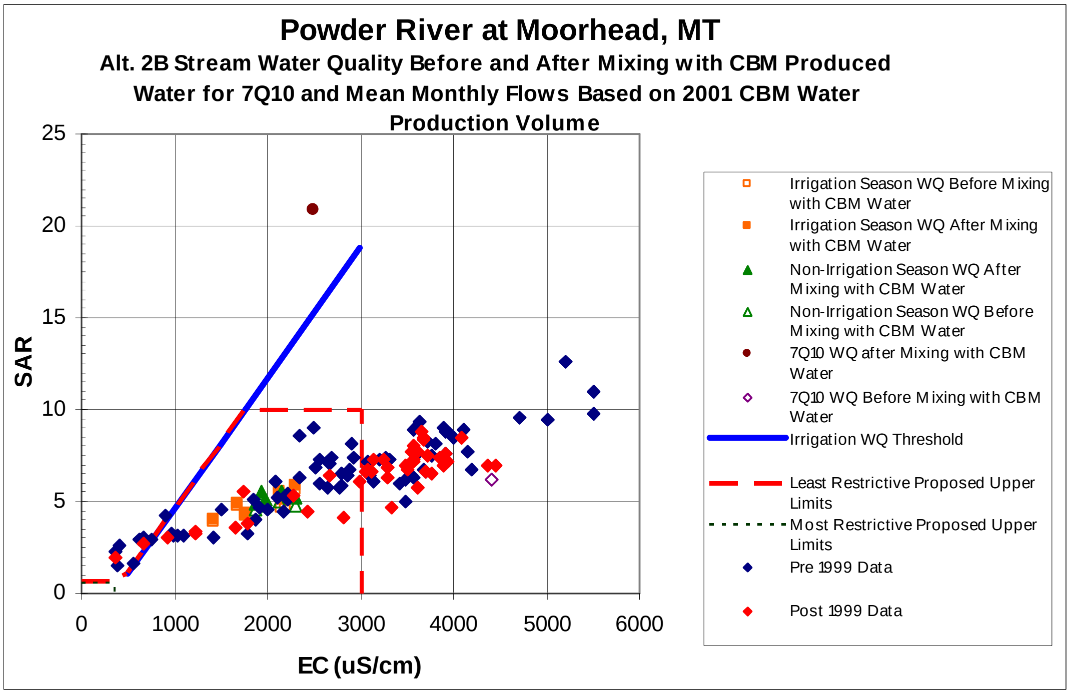

Figure 6. Mass Balance Prediction With 2001 Measured QW Samples Only.

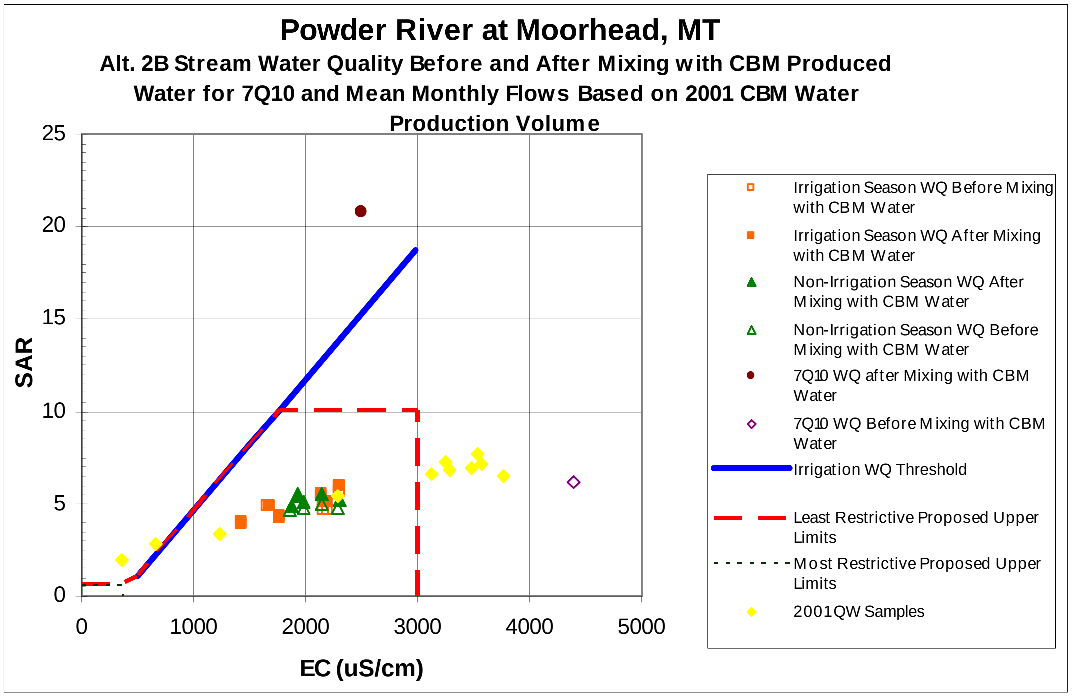

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Figure 7. Mass Balance Model Prediction Using Actual 2001 CBM Produced Water Volumes.

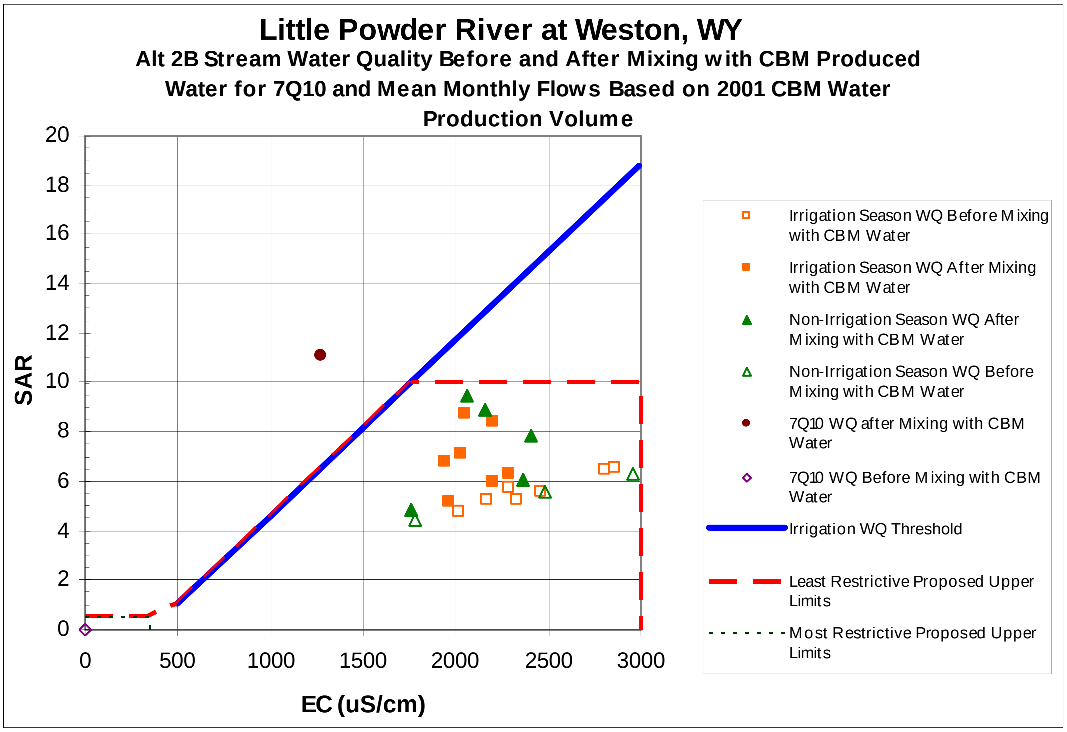

Figure 8. Mass Balance Model Prediction for 2001 With Actual QW Samples.

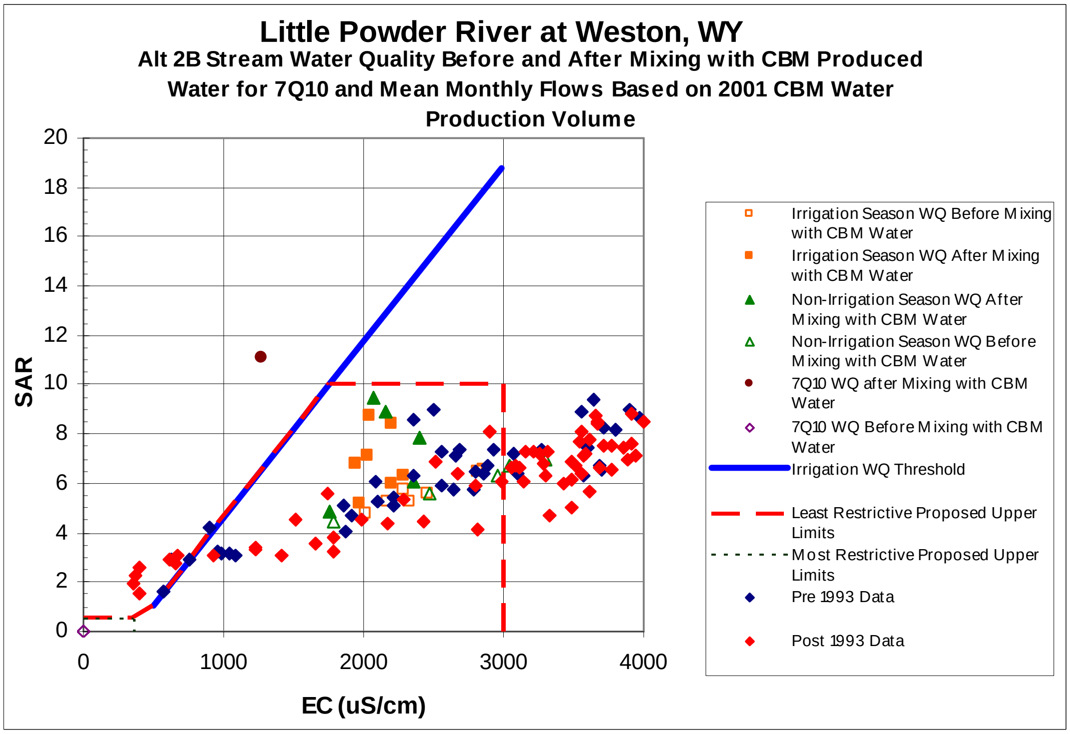

Figure 9. Mass Balance Prediction With 2001 Actual QW Samples.

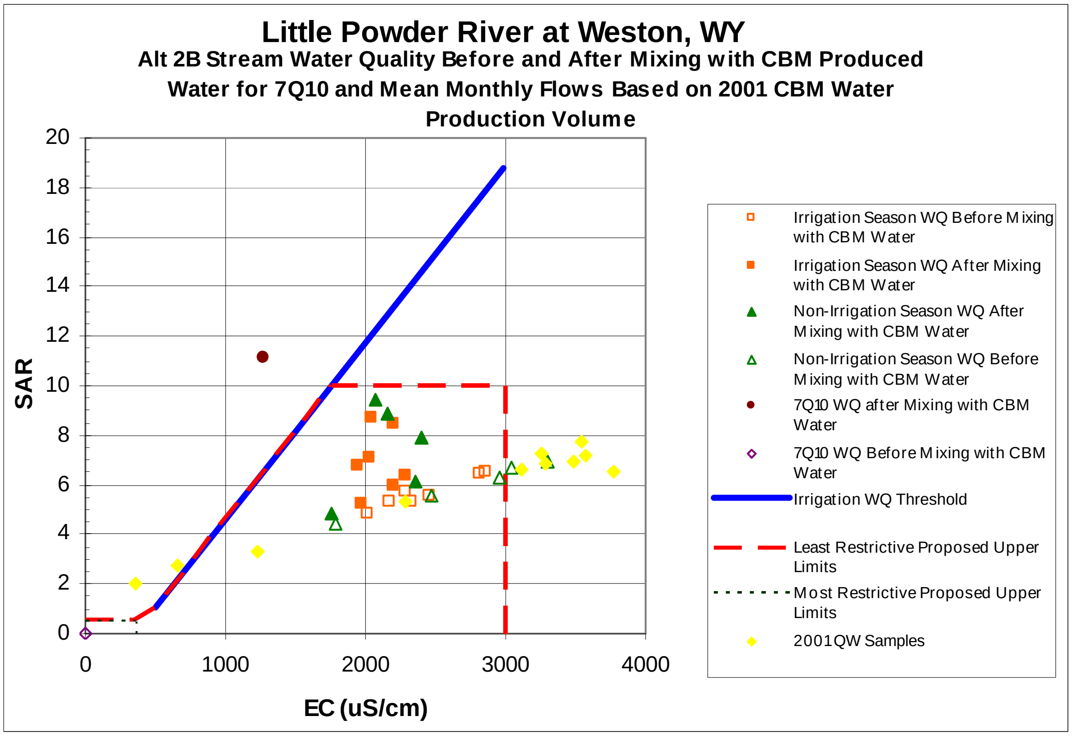

Figure 10. Mass Balance Model Prediction River Using 2001 Actual CBM Produced Water Volumes.

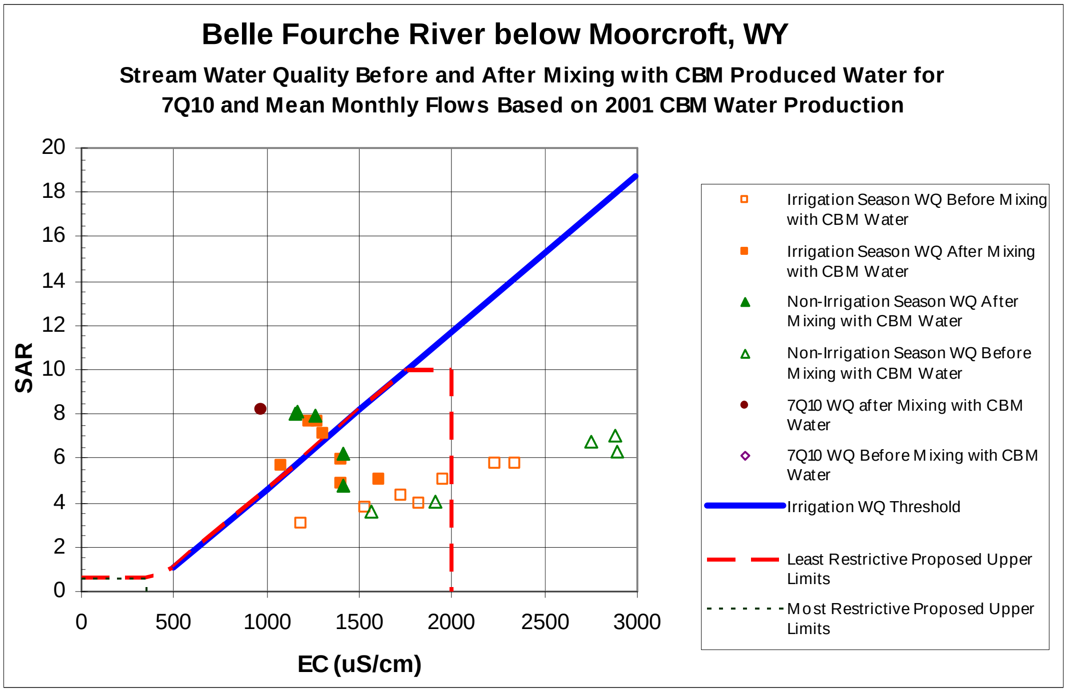

Figure 11. Mass Balance Model Predictions With Actual QW Samples.

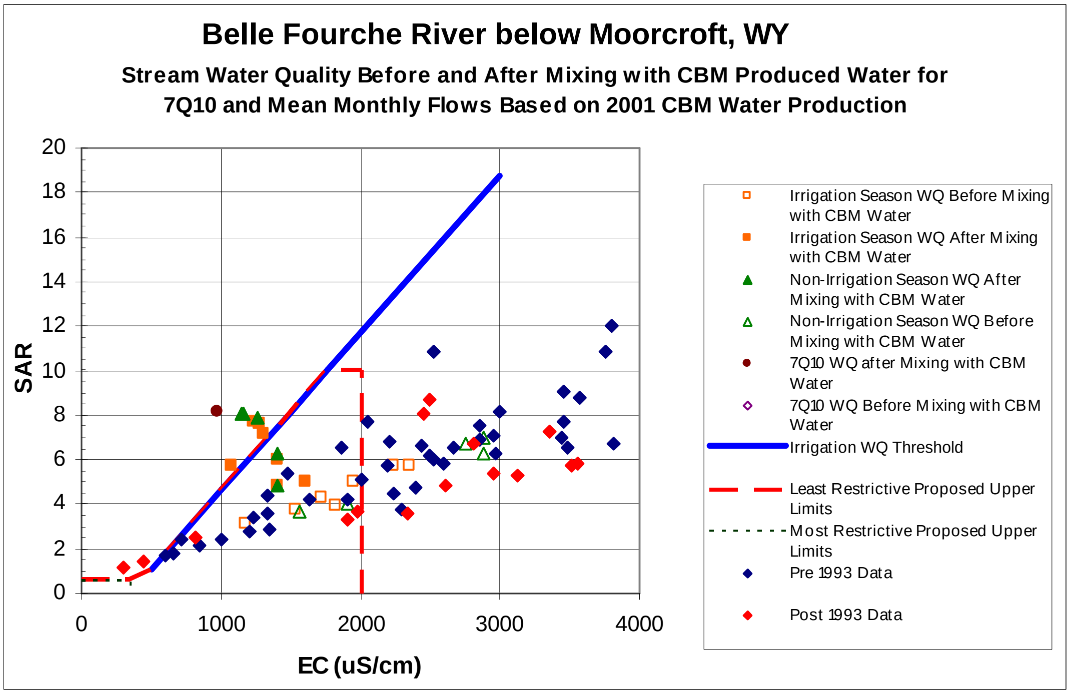

Figure 12. Mass Balance Model Predictions With 2001 Actual QW Samples.

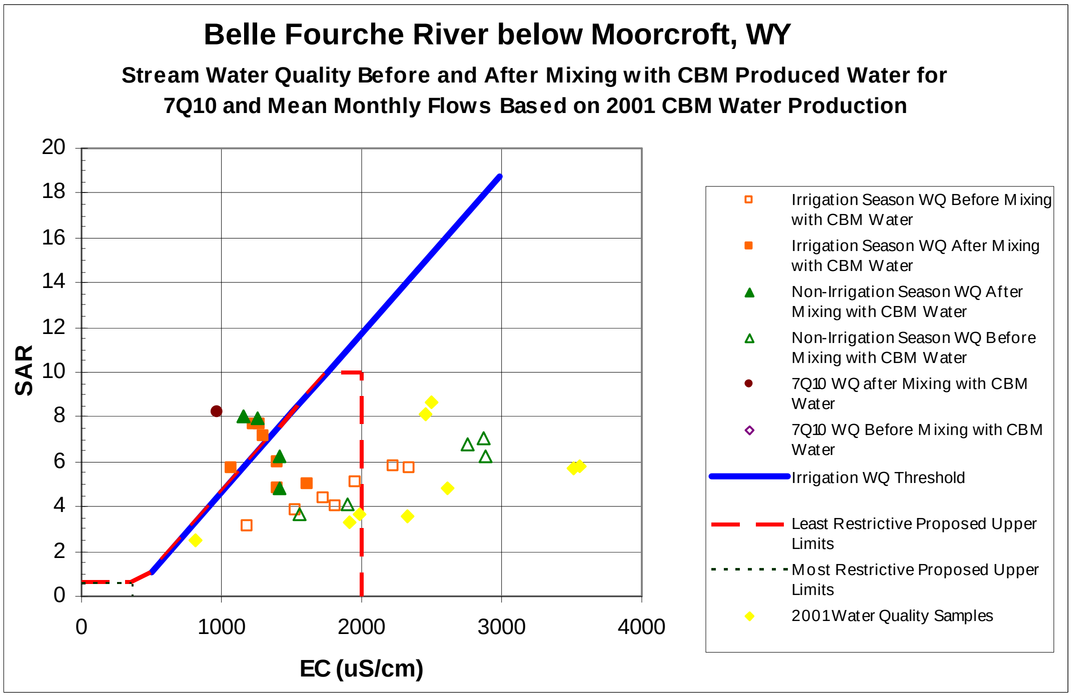

Figure 13. EC - SAR Relationship for Little Powder Weston.

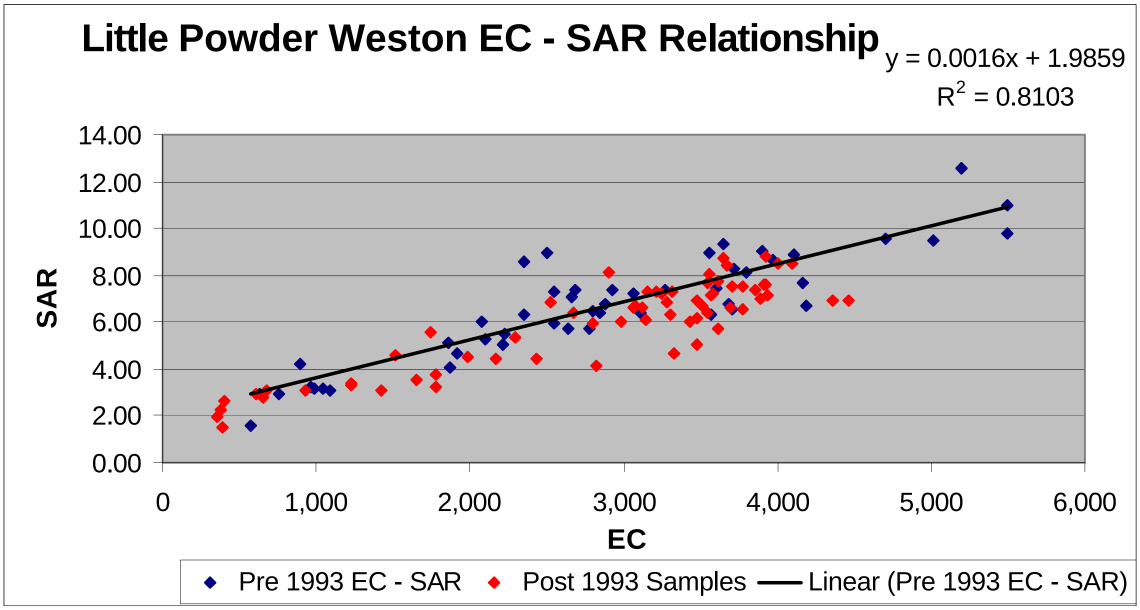

Figure 14. EC - SAR Relationship for Belle Fourche River Below Moorcroft.

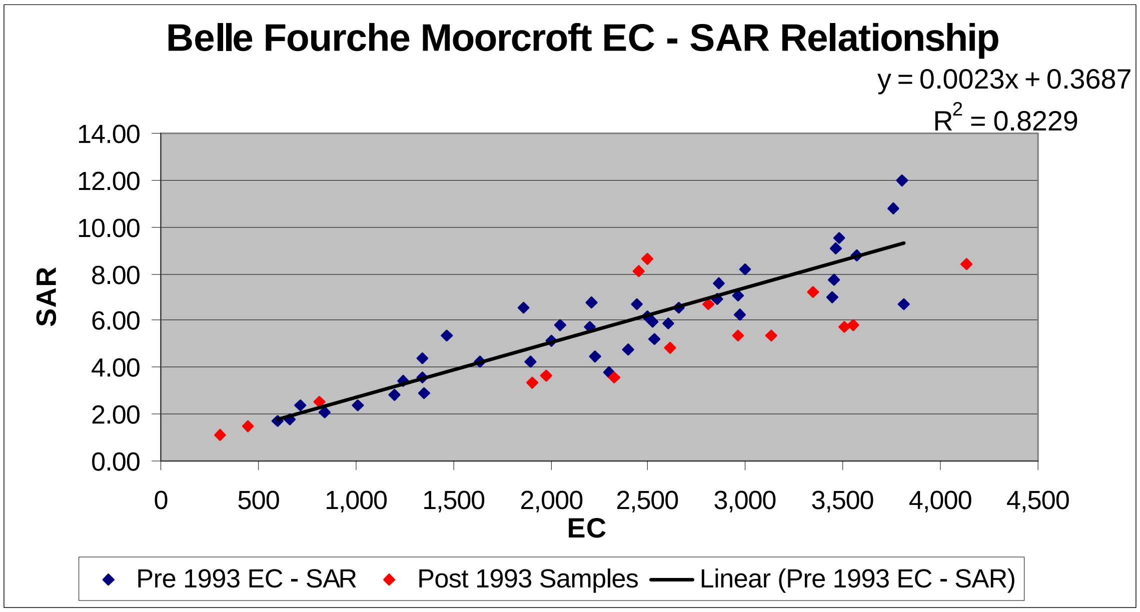

Figure 15. Residual Values For Predicted SAR.

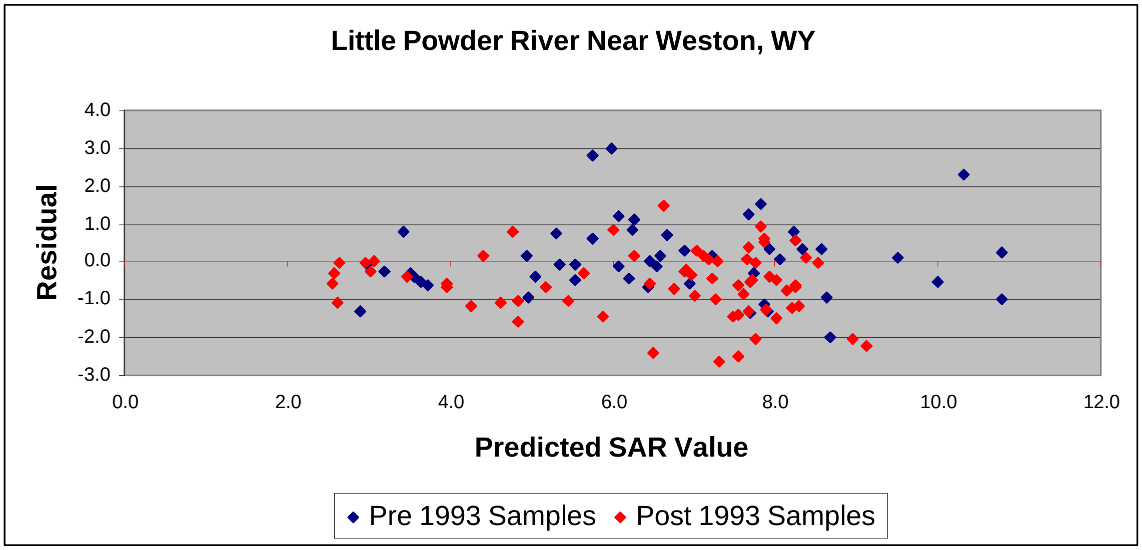

Figure 16. Residual Values for Predicted SAR.

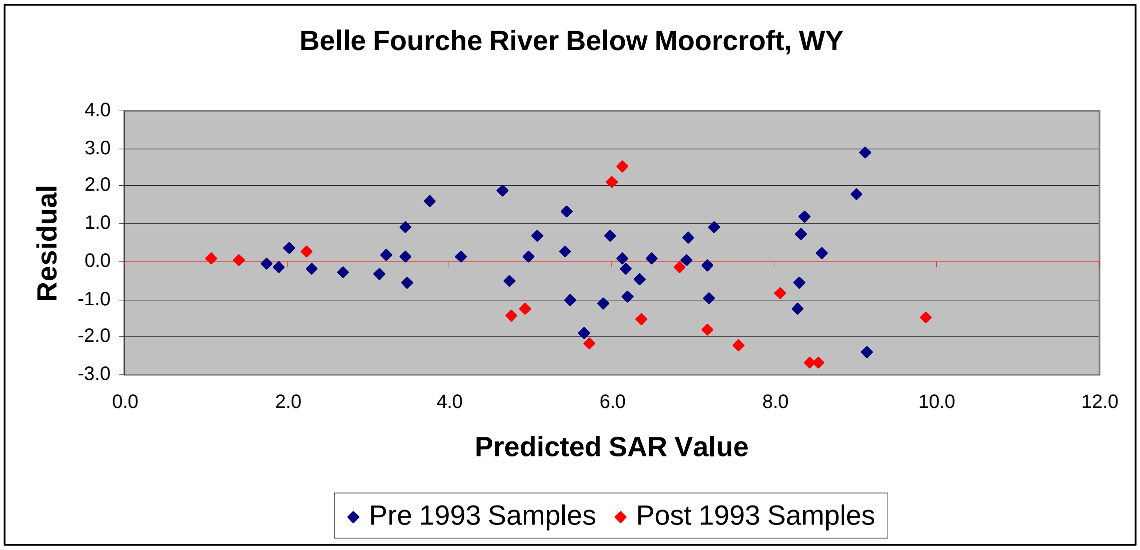

Table 2. Residual Values of Predicted SAR.

Station	Period	Standard Deviation of Residuals	Average Of Residuals
Belle Fourche Moorcroft	1980 to 1992	1.02	0.10
Belle Fourche Moorcroft	1993 to 2001	1.55	-0.82
Little Powder Weston	1980 to 1992	1.01	0.08
Little Powder Weston	1993 to 2001	0.85	-0.58

Table 3. Measured Streamflow of QW Samples.

Period	Belle Fourche Moorcroft	Little Powder Weston
Pre 1993 Average QW Sample Discharge	21.55	32.43
Pre 1993 Median QW Sample Discharge	1.50	1.20
Post 1993 Average QW Sample Discharge	114.07	46.97
Post 1993 Median QW Sample Discharge	8.50	7.30

Table 4. Mean of Annual Mean Discharge.

	Station 06324500 Powder River at Moorhead, MT	Station 06324970 Little Powder River above Dry Creek near Weston, WY	Station 06426500 Belle Fourche River below Moorcroft, WY
Mean - Annual Mean Discharge 1980 to 1992 Water Year	372.6	12.7	16.9
Median - Annual Mean Discharge 1980 to 1992 Water Year	359.1	9.6	16.5
Mean - Annual Mean Discharge 1993 to 2001 Water Year	492.8	30.0	28.5
Median - Annual Mean Discharge 1993 to 2001 Water Year	503.9	26.6	32.1

Table 5. Average Annual Precipitation - Gillette, WY

Station: Gillette 9 ESE, Wyoming	
Year	Precipitation (Inches)
1980	14.77
1981	13.45
1982	26.37
1983	12.75
1984	14.25
1985	14.07
1986	17.35
1987	16.50
1988	12.56
1989	15.31
1990	12.72
1991	14.88
1992	11.67
1993	25.34
1994	18.79
1995	19.80
1996	19.48
1997	19.67
1998	23.56
1999	18.41
2000	14.62
2001	15.87
Average Annual Precipitation 1980 to 1992	15.13
Average Annual Precipitation 1993 to 2001	19.50

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Please reference the following files for detailed data:

Powder_Little_Powder_2001_Model_Prediction.xls - Re-run of the EPA mass balance model using actual 2001 CBM production for Powder and Little Powder River stations.

Belle_Fourche_2001_Model_Prediction.xls - Re-run of the EPA mass balance model using actual 2001 CBM production for the Belle Fourche Moorcroft Station.

Belle_Fourche_Little_Powder_EC_SAR_Analysis.xls – Contains QW data, analysis of EC / SAR relationships, CBM produced water volumes, streamflow volumes and precipitation data.