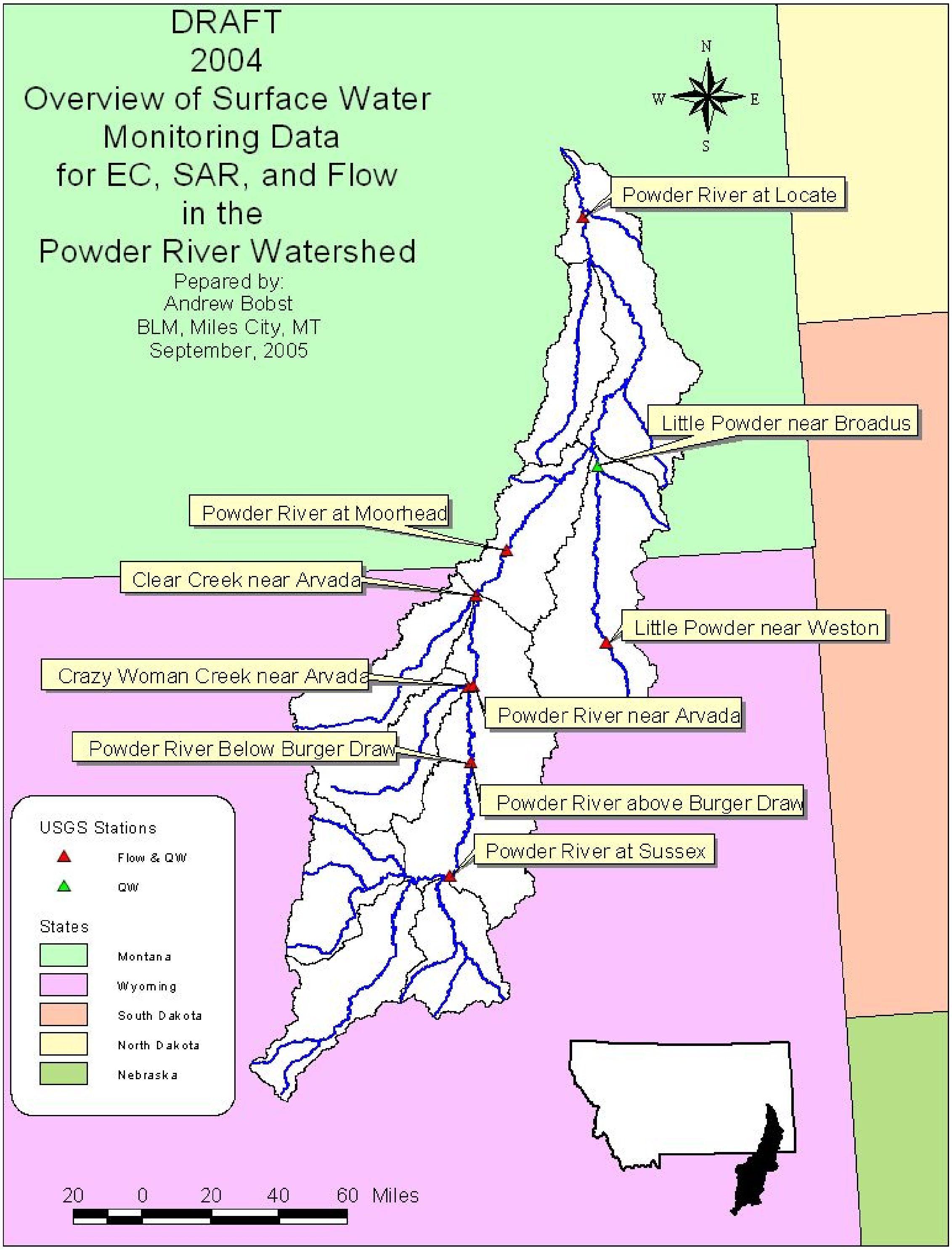


This cover map shows the Powder River Watershed as it extends from Wyoming into Montana. Also shown are major streams and the locations of the 10 surface water monitoring sites (7 in Wyoming, 3 in Montana), which are the subject of this report.

Introduction:

When Coal Bed Natural Gas (CBNG) is developed it is necessary to cause the methane to desorb from the coal, and flow to production wells. This is typically achieved by pumping groundwater from the coal bed aquifer being developed, since this reduces the hydrostatic pressure within the coal seam (allowing the methane to desorb) and creates a pressure gradient within the aquifer that causes methane to flow towards the pumping wells. The waters contained within the coal seams are rather variable, however in Montana they typically have high sodium adsorption ratios (SAR (a complex ratio of Na to Ca+Mg) typically between 30 and 60), very little sulfate, and are moderately saline (Electrical Conductivity (EC) on the order of 2,000 microSiemens per centimeter (uS/cm) (VanVoast, 2003).

One method which has been employed to manage this produced water is to discharge the co-produced water, either treated or untreated, into surface waters under a National Pollutant Discharge Elimination System (NPDES) permit. In Montana discharge permitting is conducted by the Montana Department of Environmental Quality (MDEQ) under its Montana Pollutant Discharge Elimination System (MPDES) permit program. No CBNG MPDES permits have been issued in the Montana portion of the Powder River watershed at this time. In Wyoming discharge permitting is conducted by the Wyoming Department of Environmental Quality (WDEQ). Within the Wyoming portion of the Powder River watershed CBNG development is well underway, and the produced water is commonly discharged to surface waters, or into impoundments. CBNG discharges could have noticeable effects on the quantity (flow) of surface waters; however, WDEQ, through the Wyoming Pollutant Discharge Elimination System (WYPDES) permitting process, regulates point-source discharges to protect Wyoming surface water quality standards and existing uses. The parameters most likely to be affected by CBNG discharges are EC and SAR (MDEQ, 2003), and so this report will focus on these. Impoundments could have impacts on surface waters if the water infiltrates, interacts with the underlying materials, and then flows to surface waters.

In response to the potential for CBNG development in the Powder River geologic basin the MDEQ have developed surface water quality standards for EC and SAR. These standards provide criteria against which to compare the monitoring data collected in Montana. These standards are summarized in Table 1. Numerical surface water standards have not been developed for Wyoming, so Wyoming monitoring data will only be compared to historical values.

Table 1. MDEQ Standards for EC and SAR in the Powder River Watershed

	Irrigation Season (March-October)				Non-Irrigation Season (November-February)			
Stream	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR
Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Little Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Tributaries	500	500	3	4.5	500	500	5	7.5

NTE = Not to Exceed

The Interagency working group for CBNG related issues has identified regional surface water monitoring stations for the Powder River watershed. These stations, with their status for water year 2004 (10/1/03-9/30/04) are listed on Table 2 below. Data collected at these stations included continuous flow, continuous specific conductance (SC), and analytical sampling. Although SC and EC are technically different parameters (SC accounts for temperature while EC does not), the SC results can be used for comparison to the EC standards. Analytical sampling includes measurement of flow, field parameters (SC, pH, temperature, etc.) and laboratory analysis of SC, SAR and other parameters. The monitoring at these stations was funded by the USGS, WDEQ, WSEO, MDEQ, and MDNRC.

Table 2: USGS Stations Identified for Regional Monitoring

Station #	Station Name	Status
06313500	Powder River at Sussex, WY	Flow and QW
06313590	Powder River above Burger Draw, near Buffalo, WY	Flow and QW
06313605	Powder River below Burger Draw, near Buffalo, WY	Flow and QW
06317000	Powder River at Arvada, WY	Flow and QW
06324500	Powder River near Moorhead, MT	Flow and QW
06324710	Powder River at Broadus, MT	Inactive
06325650	Powder River at Powderville, MT	Inactive
06326500	Powder River near Locate, MT	Flow and QW
06316400	Crazy Woman at Upper Station, near Arvada, WY	Flow and QW
06324000	Clear Creek near Arvada, WY	Flow and QW
06324970	Little Powder River above Dry Creek near Weston, WY	Flow and QW
06325500	Little Powder River near Broadus, MT	QW
06326300	Mizpah at Mizpah	Inactive

QW = Water Quality

The 2004 data summarized in this report is approved final USGS data. The USGS compiled, but did not interpret, this data under the USGS Rapid Response Program. All data used in this report are available from the USGS NWIS website (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata).

Data Review:

For all sites, please see the figures section for graphical display of the data. Tabulated summary statistics for the sites are provided in Appendix A. Where applicable, comparison is made to surface water standards. Comparison to the mean monthly EC standard is only performed when there is a continuous EC record available. Mean monthly values are calculated as the simple average of all the real time measurements recorded during each calendar month. Grab samples are compared to the NTE standards since analytical samples represent one moment in time.

Main Stem Sites:

Powder River at Sussex, WY: Flow and EC data were collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected twice a month. Recorded flow ranged from 6.8 to 1040 cubic feet per second (cfs), with the mean being 86 cfs (see Fig. 1). Peak flows occurred from February to early May, with a marked decrease in flow after this time, presumably due to the end of snow melt. One large flow occurred in late July. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region (see Appendix B). Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 real-time EC values recorded at this site ranged from 1050 to 6200 uS/cm, with the mean being 3316 uS/cm. Monthly mean EC values ranged from 1898 to 4502 uS/cm. Analytical SAR values at this site ranged from 4 to 21 with the mean being 8.2. (see Fig. 2).

The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 3 and 4).

Powder River above Burger Draw, WY: Flow data was collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected once a month. Recorded flow ranged from 1.9 to 724 cfs, with the mean being 92.3 cfs (see Fig. 5). Peak flows occurred from February to May, with a marked decrease in flow after this time, presumably due to the end of snow melt. One large flow occurred in late July. Historical flow data were not available for this station.

During water year 2004 analytical EC values recorded at this site ranged from 1960 to 4480 uS/cm, with the mean being 2960 uS/cm. Analytical SAR values at this site ranged from 4 to 12 with the mean being 7.1. (see Fig. 6).

The recorded EC and SAR values appear to follow the expected power curve declines with increases in flow, however no historical data was available for comparison (see Figs. 7 and 8).

Powder River below Burger Draw, WY: No real time data was collected at this station. Field measurements of flow, and analytical samples for EC and SAR were collected once a month. Recorded flow ranged from 8.8 to 171 cfs, with the mean being 71.8 cfs (see Fig. 9). Peak flows occurred from February to May, with a marked decrease in flow after this time, presumably due to the end of snow melt. One large flow occurred in late July. Historical flow data were not available for this station; however a comparison can be made to the station above Burger Draw. Based upon synoptic flow measurements between the two stations, it appears that Burger Draw contributes approximately 1-2 cfs of flow to the Powder River (1-11% of the flow below Burger Draw) (see Fig. 9).

During water year 2004 analytical EC values recorded at this site ranged from 2020 to 4400 uS/cm, with the mean being 2974 uS/cm. Analytical SAR values at this site ranged from 5 to 13 with the mean being 7.7. (see Fig. 10).

The recorded EC and SAR values appear to follow the expected power curve declines with increases in flow, however no historical data was available for comparison (see Figs. 11 and 12).

Since synoptic data has been collected above and below Burger Draw, the data can be used to assess the effects of Burger Draw inputs. It appears that when the Powder River above Burger Draw has an EC less than ~2500 uS/cm, input from Burger Draw causes the EC to increase. When the instream EC is between ~2500 and ~4000 uS/cm there is little observed change in EC. When instream EC is greater than ~4000 it appears that input from Burger Draw causes the EC to decrease. This is consistent with what would be expected if the input from Burger Draw had a relatively constant EC between 2500 and 4000 uS/cm (see Fig. 11). SAR values increase for all measurements, indicating that the input from Burger Draw has a higher SAR than any of the instream values (>13) (see Fig. 12).

Powder River at Arvada, WY: Flow data was collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected twice a month. Recorded flow ranged from 0 to 649 cfs, with the mean being 87.3 cfs (see Fig. 13). Peak flows occurred from February to May, with a marked decrease in flow after this time, presumably due to the end of snow melt. One large flow occurred in late July. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region (see Appendix B). Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 analytical EC values recorded at this site ranged from 1940 to 4430 uS/cm, with the mean being 2740 uS/cm. Analytical SAR values at this site ranged from 4 to 11 with the mean being 6.3. (see Fig. 14).

The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 15 and 16).

Powder River near Moorhead, MT: Flow and EC data were collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were also collected. Recorded flow ranged from 5.0 to 975 cfs, with the mean being 117 cfs (see Fig. 17). Peak flows occurred from March to May, with a marked decrease in flow after this time, presumably due to the end of snow melt. One large flow occurred in late July. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region (see Appendix B). Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 real-time EC values recorded at this site ranged from 902 to 3960 uS/cm, with the mean being 2000 uS/cm. Monthly mean EC values ranged from 1239 to 3451 uS/cm. Analytical SAR values at this site ranged from 1 to 8 with the mean being 4.1. (see Fig. 18).

The recorded EC and SAR values were sometimes above the MDEQ's standards (see Fig. 18). The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 19 and 20). Based upon this historical information, the MDEQ standards may not be attainable at this station during low flow years. This may be due to the quality of groundwater inflows, irrigation, or geology/soils (i.e. availability of soluble salts).

<u>Powder River near Locate, MT:</u> Flow data was collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were also collected. Recorded flow ranged from 2.0 to 704 cfs, with the mean being 79.1 cfs (see Fig. 21). Peak flows occurred from February to May. An increased flow event was recorded in early August. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region. Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are know to have occurred.

During water year 2004 analytical EC values recorded at this site ranged from 1270 to 3110 uS/cm, with the mean being 1277 uS/cm. Analytical SAR values at this site ranged from 2 to 9 with the mean being 5.6. (see Fig. 22).

The recorded EC and SAR values were often above the MDEQ's standards (see Fig. 22). The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 23 and 24). Based upon this historical information, the MDEQ standards may not be attainable at this station during low flow years. This may be due to the quality of groundwater inflows, irrigation, or geology/soils (i.e. availability of soluble salts).

<u>Tributary Sites:</u>

<u>Crazy Woman Creek near Arvada, WY</u>: Flow and EC data were collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected twice a month. Recorded flow ranged from 0.01 to 90 cfs, with the mean being 9.5 cfs (see Fig. 25). The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region (see Appendix B). Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 real-time EC values recorded at this site ranged from 1320 to 2970 uS/cm, with the mean being 2288 uS/cm. Monthly mean EC values ranged from 1691 to 2787 uS/cm. Analytical SAR values at this site ranged from 1 to 4 with the mean being 2.3. (see Fig. 26).

The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 27 and 28).

Clear Creek near Arvada, WY: Flow and EC data were collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected twice a month. Recorded flow ranged from 0.35 to 202 cfs, with the mean being 45.6 cfs (see Fig. 29). The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region (see Appendix B). Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 real-time EC values recorded at this site ranged from 716 to 2070 uS/cm, with the mean being 1341 uS/cm. Monthly mean EC values ranged from 924 to 1925 uS/cm. Analytical SAR values at this site ranged from 0.8 to 3 with the mean being 1.2. (see Fig. 30).

The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 31 and 32).

Little Powder River near Weston, WY: Flow data was collected in real time at this station. Field measurements of flow, and analytical samples for EC and SAR were collected once a month. Recorded flow ranged from 0 to 90 cfs, with the mean being 2.0 cfs (see Fig. 33). The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year. This reduction vs. the historical record is believed to be mainly attributable to the lack of snow pack during the winter of 2003-2004, and the continued drought throughout this region. Other factors such as new or changed irrigation, municipal, stock, or industrial use could also be affecting streamflow; however no changes in these activities are known to have occurred.

During water year 2004 analytical EC values recorded at this site ranged from 725 to 5250 uS/cm, with the mean being 3363 uS/cm. Analytical SAR values at this site ranged from 3 to 11 with the mean being 7.7. (see Fig. 34).

The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 35 and 36).

Little Powder River near Broadus, MT: No real time data was collected at this station. Field measurements of flow, and analytical samples for EC and SAR were collected.

Recorded flow ranged from 1.9 to 23 cfs, with the mean being 6.2 cfs (see Fig. 37). Historical flow data were not available for this station; however a comparison can be made to the station near Weston, WY. Based upon the relation of the measured flow values at this station to the real-time measurements made at the station near Weston it appears that there is a noticeable increase in flow between these two stations, particularly during low flows (see Fig. 37).

During water year 2004 analytical EC values recorded at this site ranged from 1250 to 2610 uS/cm, with the mean being 1890 uS/cm. Analytical SAR values at this site ranged from 4 to 14 with the mean being 10.4. (see Fig. 38).

One of the recorded EC values was above the MDEQ's standard for the Little Powder River. Most of the recorded SAR values were above the MDEQ's standards (see Fig. 38). The recorded EC and SAR values appear to be within the range of historical values during comparable flows (see Figs. 39 and 40). Based upon this historical information, the MDEQ standards may not be attainable at this station during low flow years. This may be due to the quality of groundwater inflows, irrigation, or geology/soils (i.e. availability of soluble salts).

Conclusions:
During Water year 2004, flows within the Powder River watershed were substantially less than historical values. As EC and SAR are both closely correlated with flow, EC and SAR values were also elevated; however overall values were in line with that expected based upon historical relationships between EC and SAR vs. Flow.

The main stem stations showed that the MDEQ surface water standards for EC and SAR are often exceeded by the instream values under current conditions. Since the EC and SAR values appear to be in line with historical trends, it is likely that these standards were also often exceeded in the past.

The tributaries for which data were collected showed that the MDEQ surface water standards for EC were typically exceeded by existing conditions. In some cases the existing conditions resulted in water quality values that were always in excess of the EC standards. The MDEQ standards for SAR were not exceeded in Crazy Woman or Clear Creek; however, the Little Powder River commonly exceeded the MDEQ's SAR standard. However, it should be noted the MDEQ’s standards are not applicable to Crazy Woman or Clear Creeks in Wyoming, nor that portion of the Little Powder River within Wyoming’s borders.

The results from water year 2004 monitoring, and historical monitoring indicate that the MDEQ's EC and SAR standards may not be achievable in the Powder River, particularly during low flow years. This may be due to the quality of groundwater inflows, irrigation, or geology/soils (i.e. availability of soluble salts). The MDEQ’s standards for EC and SAR on the Powder and Little Powder River watersheds may not be reflective of historical or ambient water quality conditions.

References:

MDEQ, 2003, ARM Title 17, Chapter 30, Section 17.30.670.

VanVoast, W.A., 2003, Geochemical signature of formation waters associated with coalbed methane, AAPG Bulletin, v. 87, no. 4 (April 2003), pp. 667–676.

Reviewed by:

Dan Hengel	
Watershed Modeler	WY-DEQ, Cheyenne, WY
Mike Philbin	
Hydrology, Wetland, Riparian, and Air Program Lead	BLM, Billings, MT
Mike McKinley	
Hydrologist	BLM, Buffalo, WY

Figures

Figure 1: Powder River at Sussex, WY

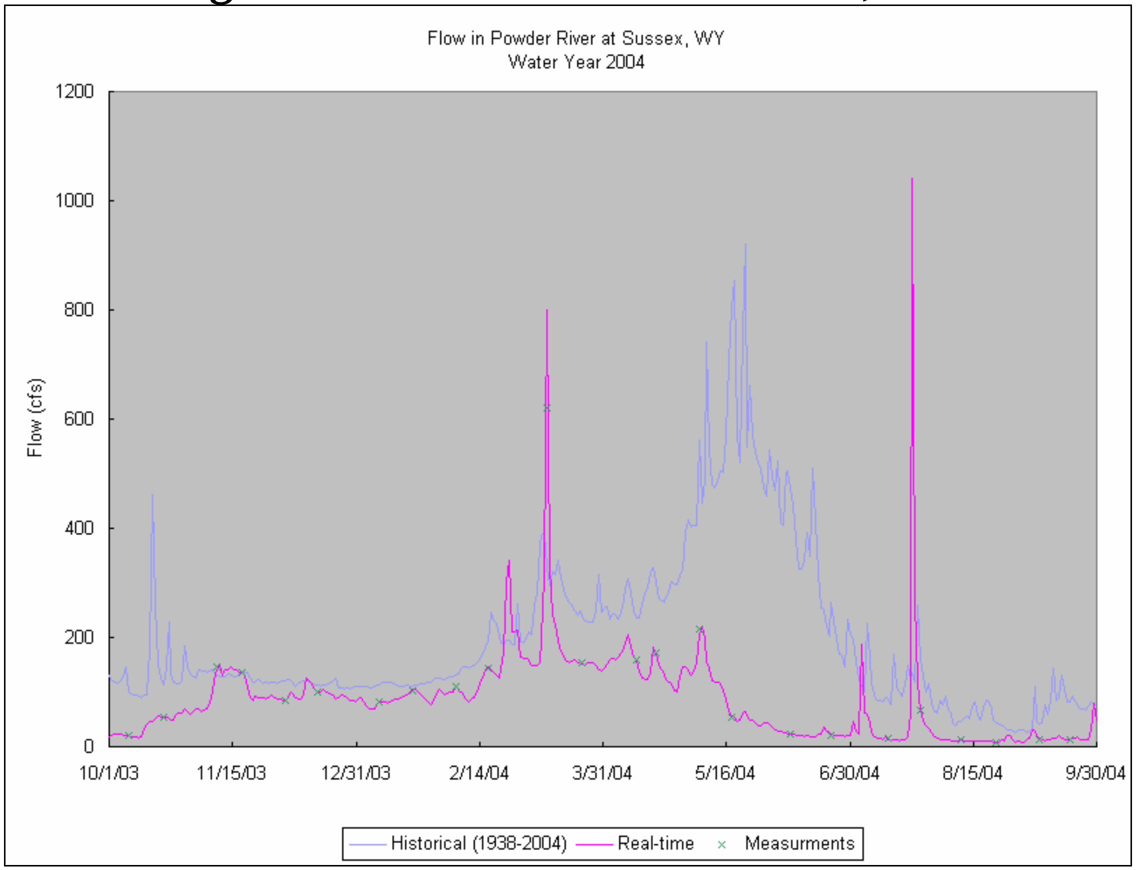


Figure 1 shows real time flow values in a time series plot for 2004 for the Powder River at Sussex, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 6.8 to 1040 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

Figure 2: Powder River at Sussex, WY

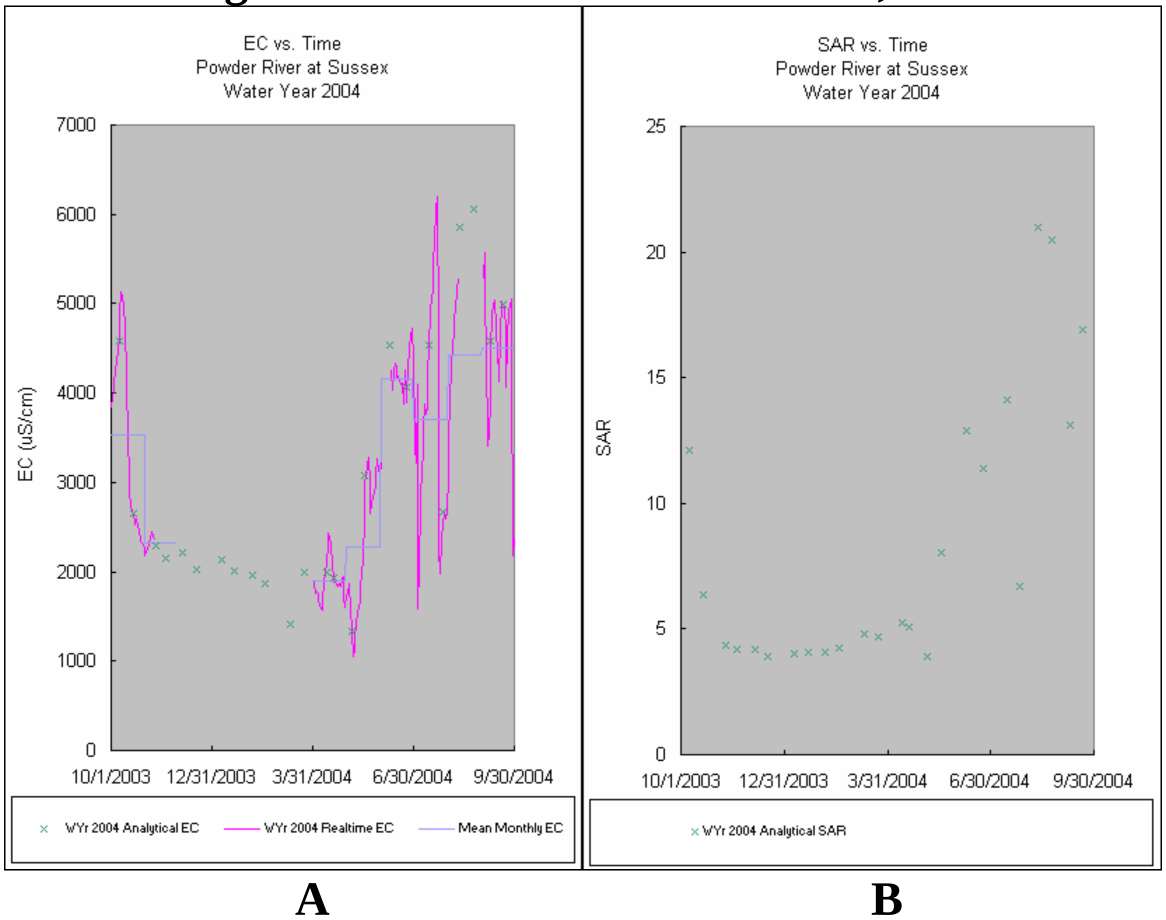


Figure 2 shows analytical and realtime EC (A) and analytical SAR (B) values in time series plots for 2004 for the Powder River at Sussex. Mean Monthly EC values are also shown. Realtime EC values during 2004 ranged from 1050 to 6200 uS/cm. Mean Monthly EC values ranged from 1898 to 4502 uS/cm. Analytical SAR values ranged from 3.9 to 21.

Figure 3: Powder River at Sussex, WY

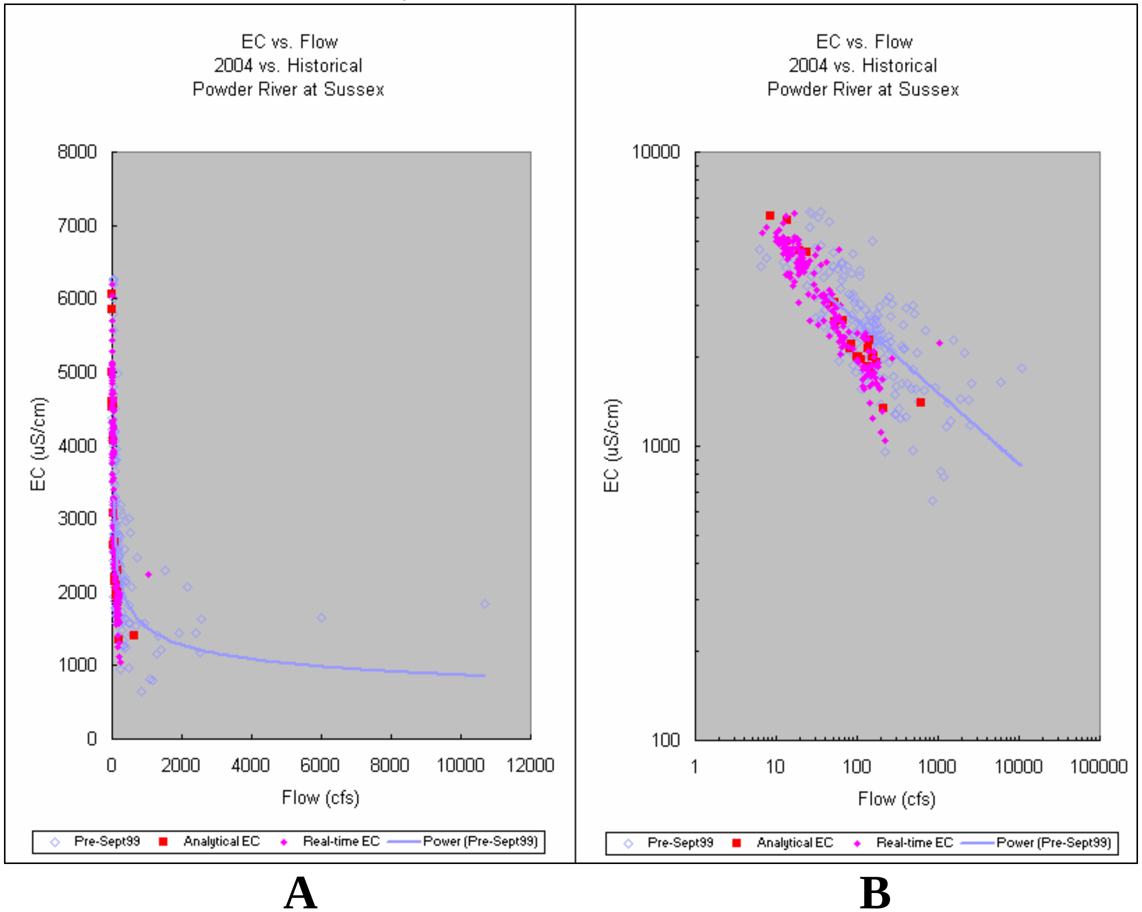
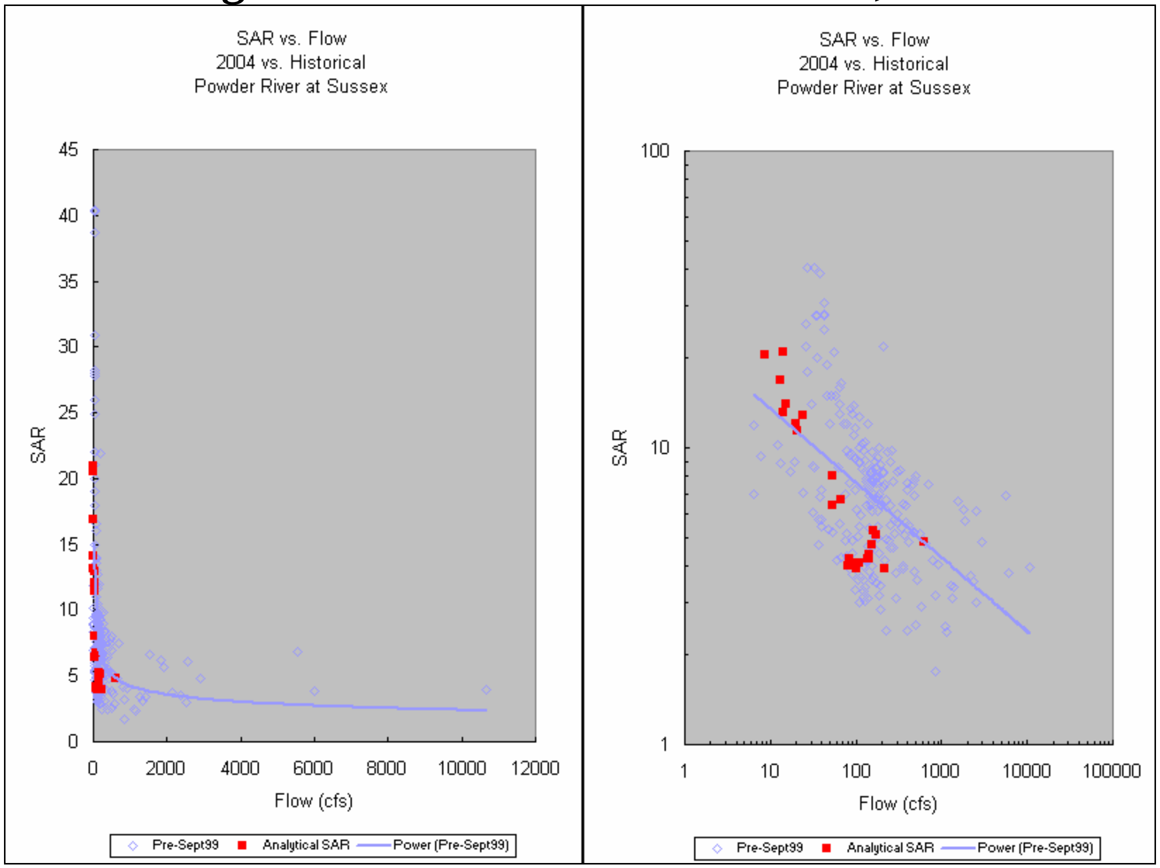


Figure 3 shows realtime and analytical EC values charted vs. Flow for 2004 for the Powder River at Sussex. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 4: Powder River at Sussex, WY



A **B**

Figure 4 shows analytical SAR values charted vs. Flow for 2004 for the Powder River at Sussex. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Figure 5: Powder River above Burger Draw, near Buffalo, WY

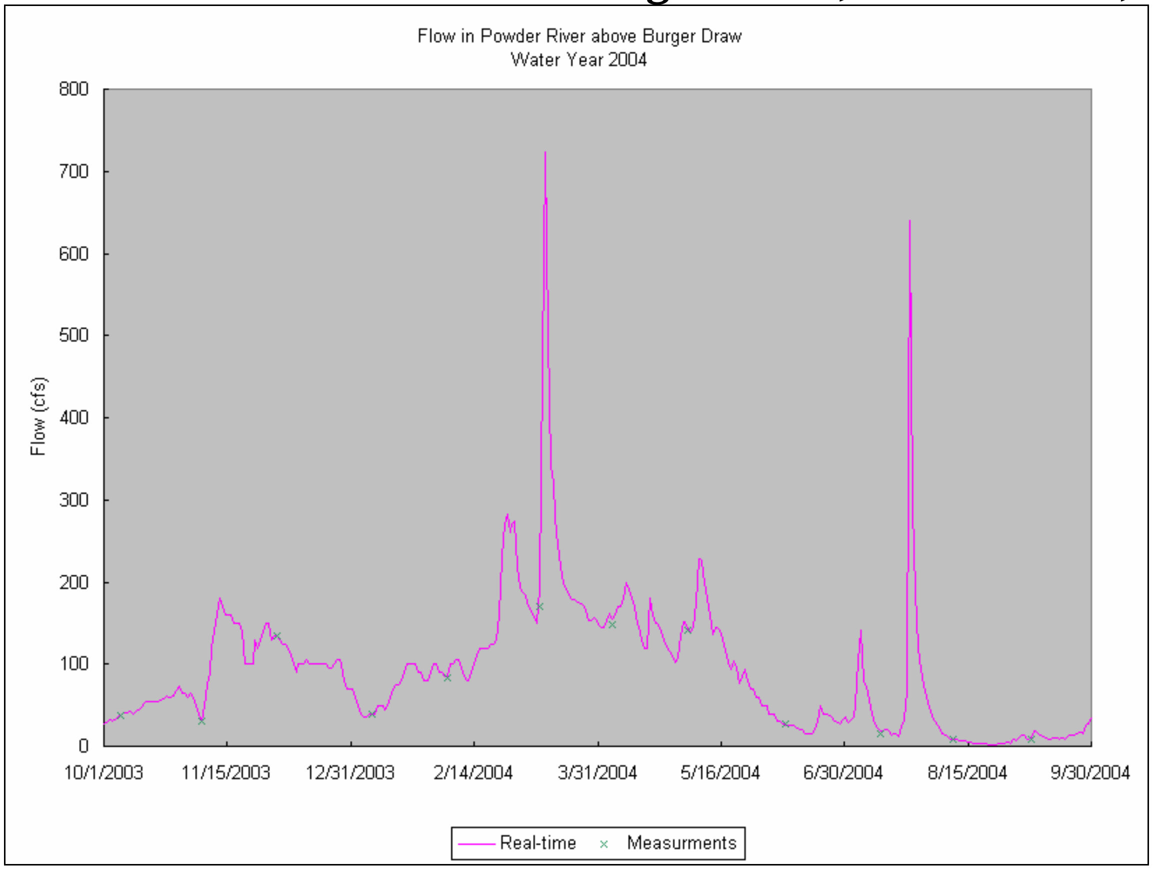
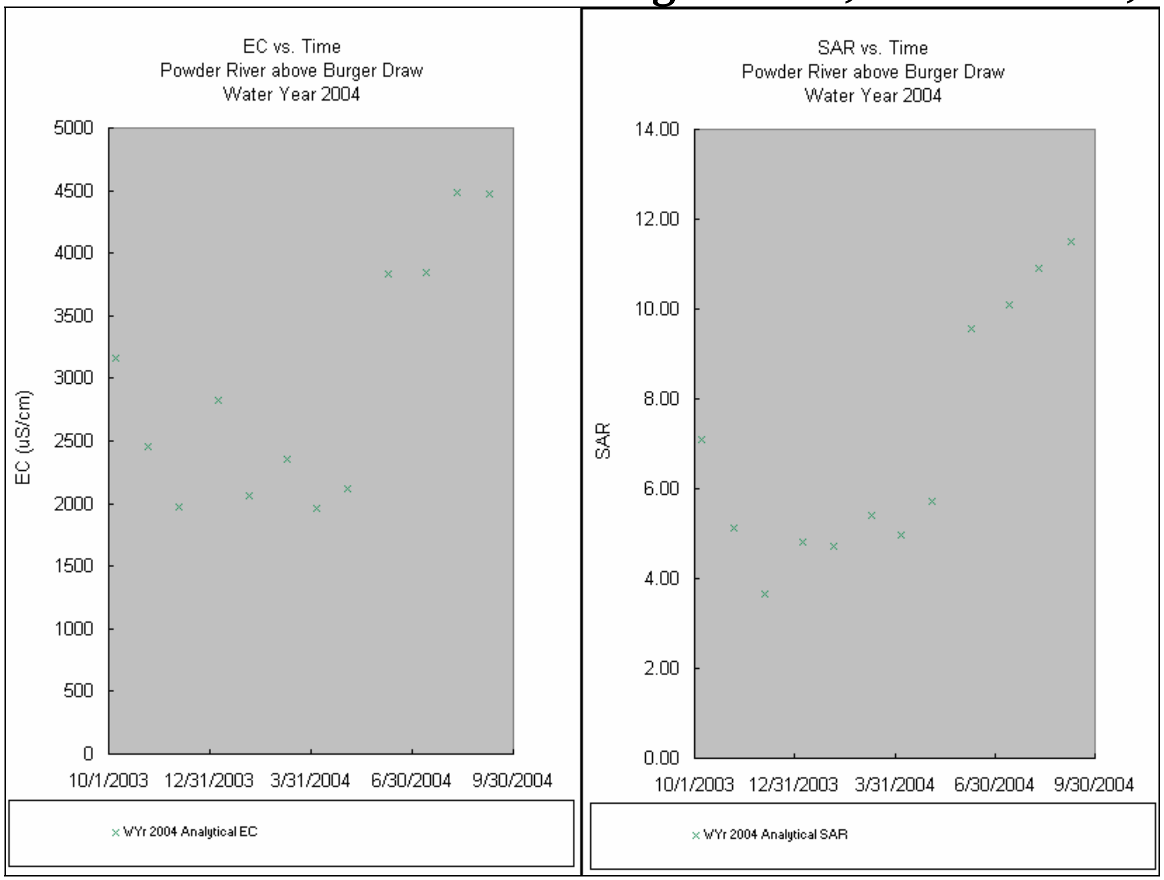


Figure 5 shows real time flow values in a time series plot for 2004 for the Powder River above Burger Draw, and field measurements of flow. No historical data area available for this station. Recorded flow values during 2004 ranged from 1.9 to 724 cfs.

Figure 6: Powder River above Burger Draw, near Buffalo, WY



A **B**

Figure 6 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Powder River above Burger Draw. Analytical EC values during 2004 ranged from 1960 to 4480 uS/cm. Analytical SAR values ranged from 3.7 to 11.5.

Figure 7: Powder River above Burger Draw, near Buffalo, WY

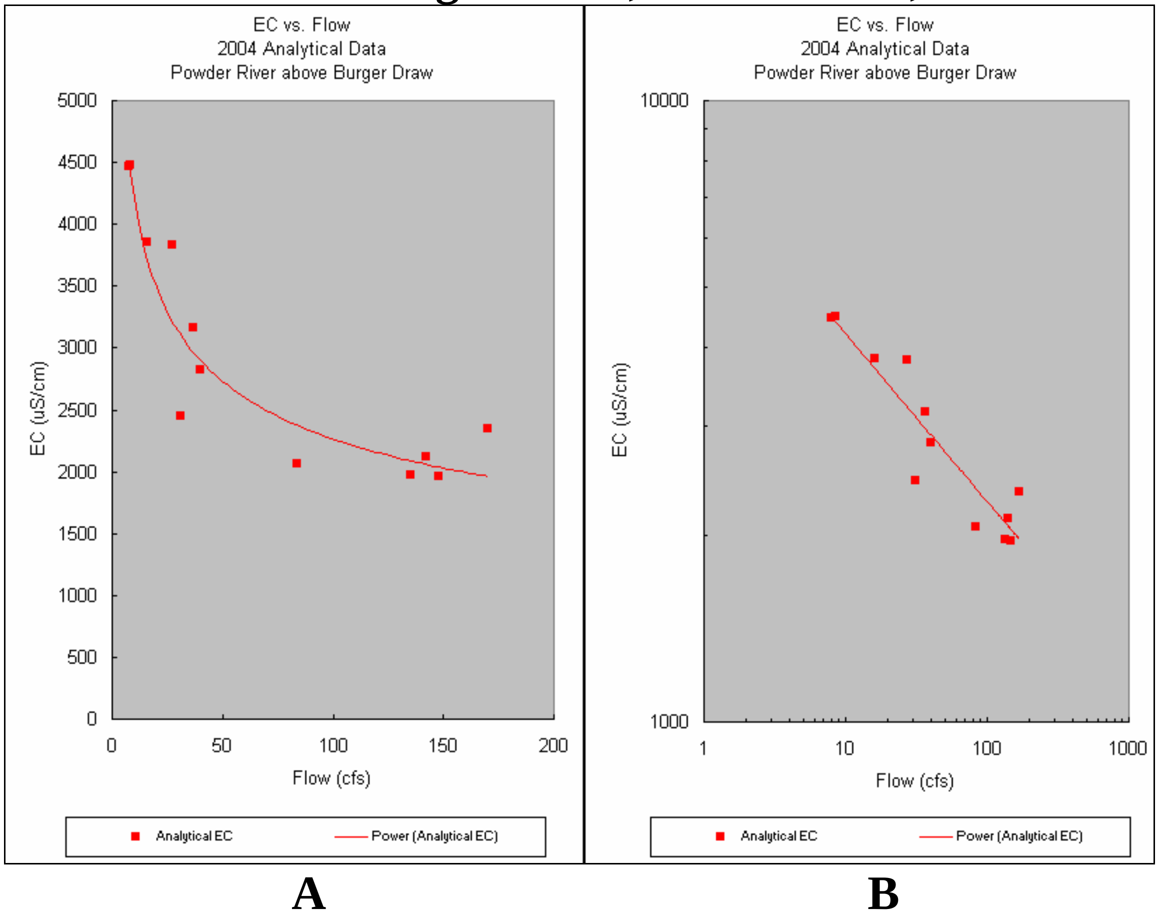
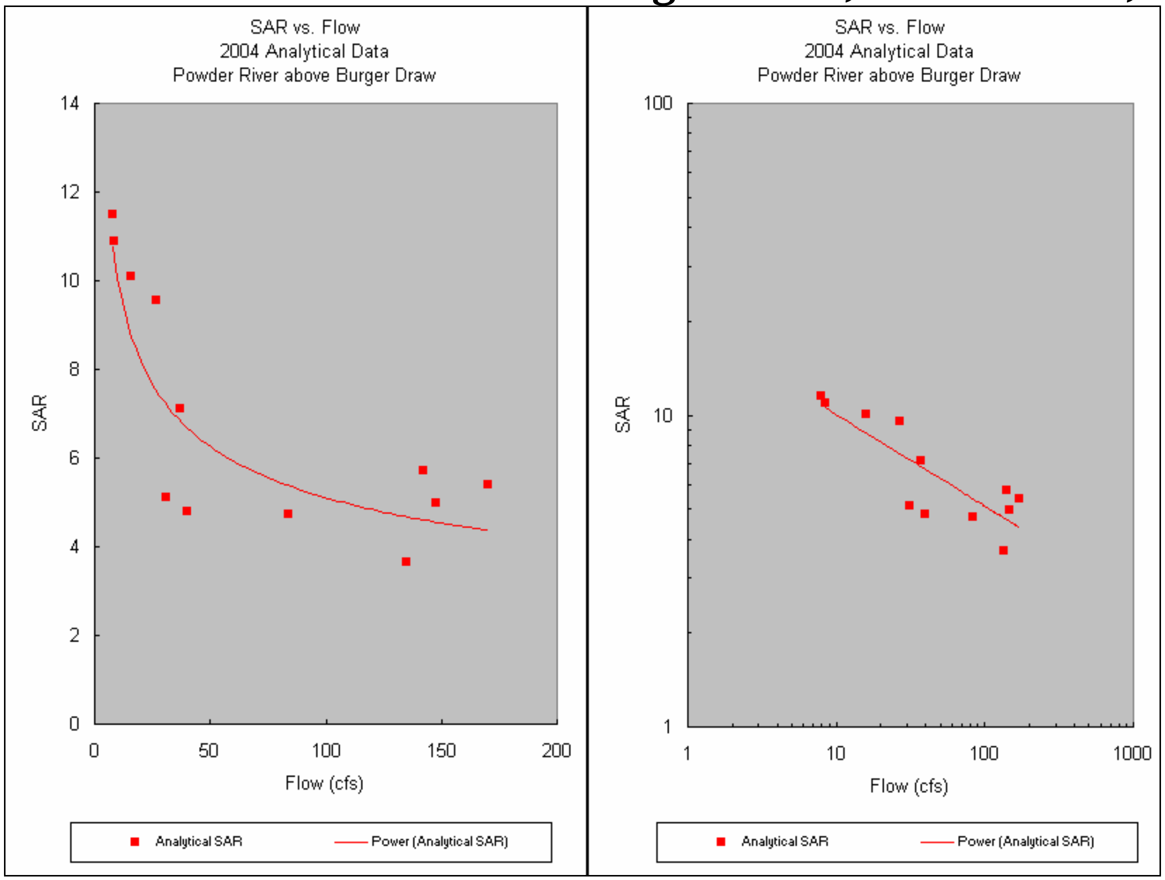


Figure 7 shows analytical EC values charted vs. Flow for 2004 for the Powder River below Burger Draw. These values are charted on both linier (A) and logarithmic (B) scales. Historical data are not available for comparison.

Figure 8: Powder River above Burger Draw, near Buffalo, WY



A **B**

Figure 8 shows analytical SAR values charted vs. Flow for 2004 for the Powder River above Burger Draw. These values are charted on both linier (A) and logarithmic (B) scales. Historical data are not available for comparison.

Figure 9: Powder River below Burger Draw, near Buffalo, WY

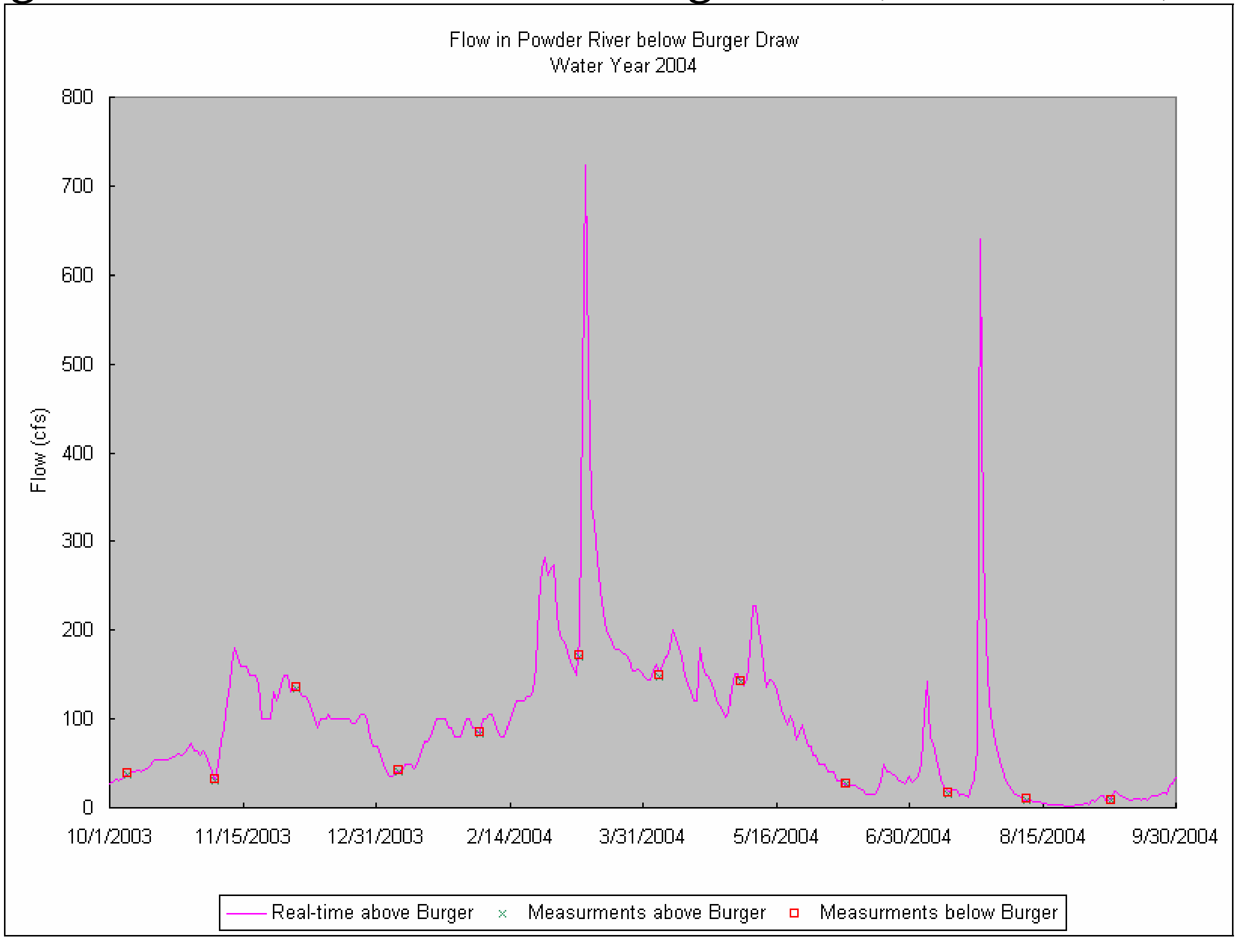


Figure 9 shows analytical flow values in a time series plot for 2004 for the Powder River below Burger Draw. No historical data area available for this station. Recorded flow values during 2004 ranged from 8.8 to 171 cfs. Realtime and analytical flow values from the station above Burger Draw are also shown for comparison. Burger Draw appears to contribute ~1-2 cfs of flow (1-11%) to the Powder River.

Figure 10: Powder River below Burger Draw, near Buffalo, WY

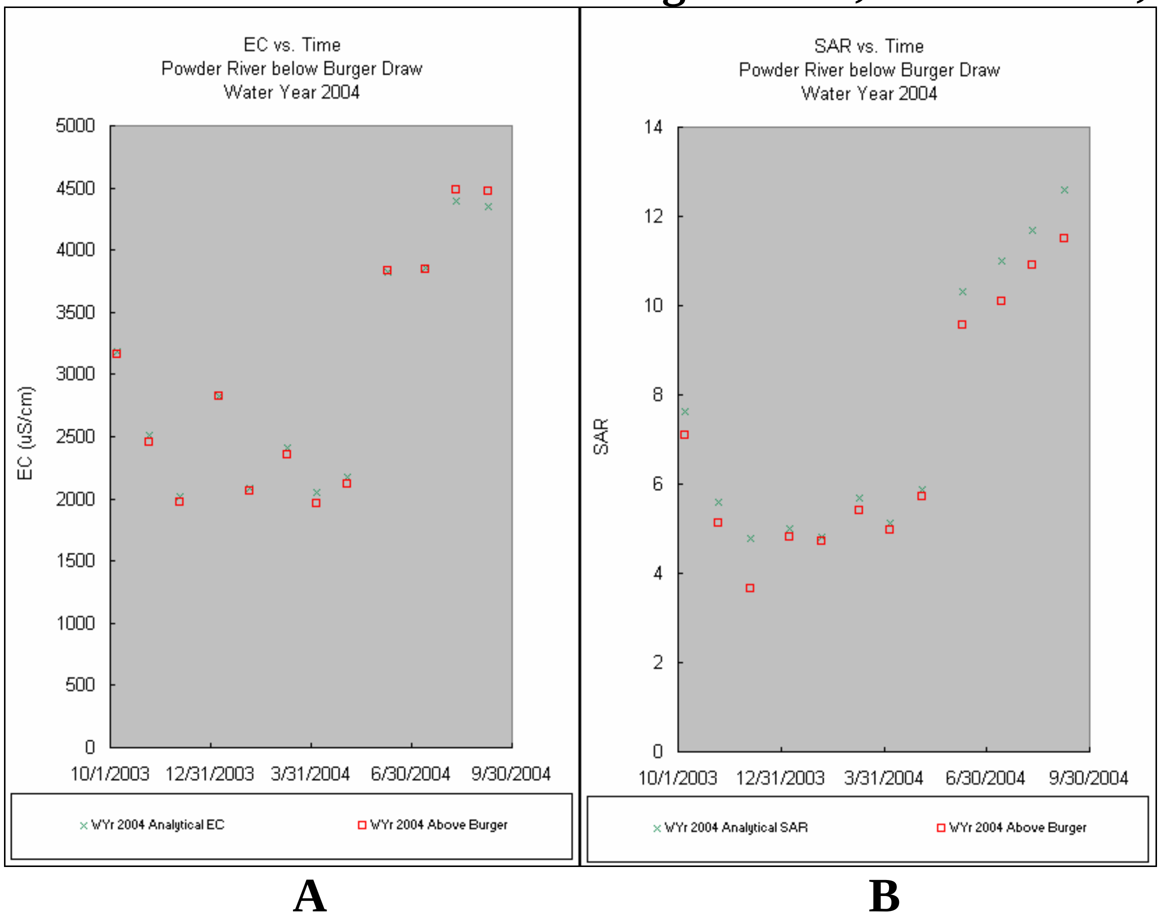
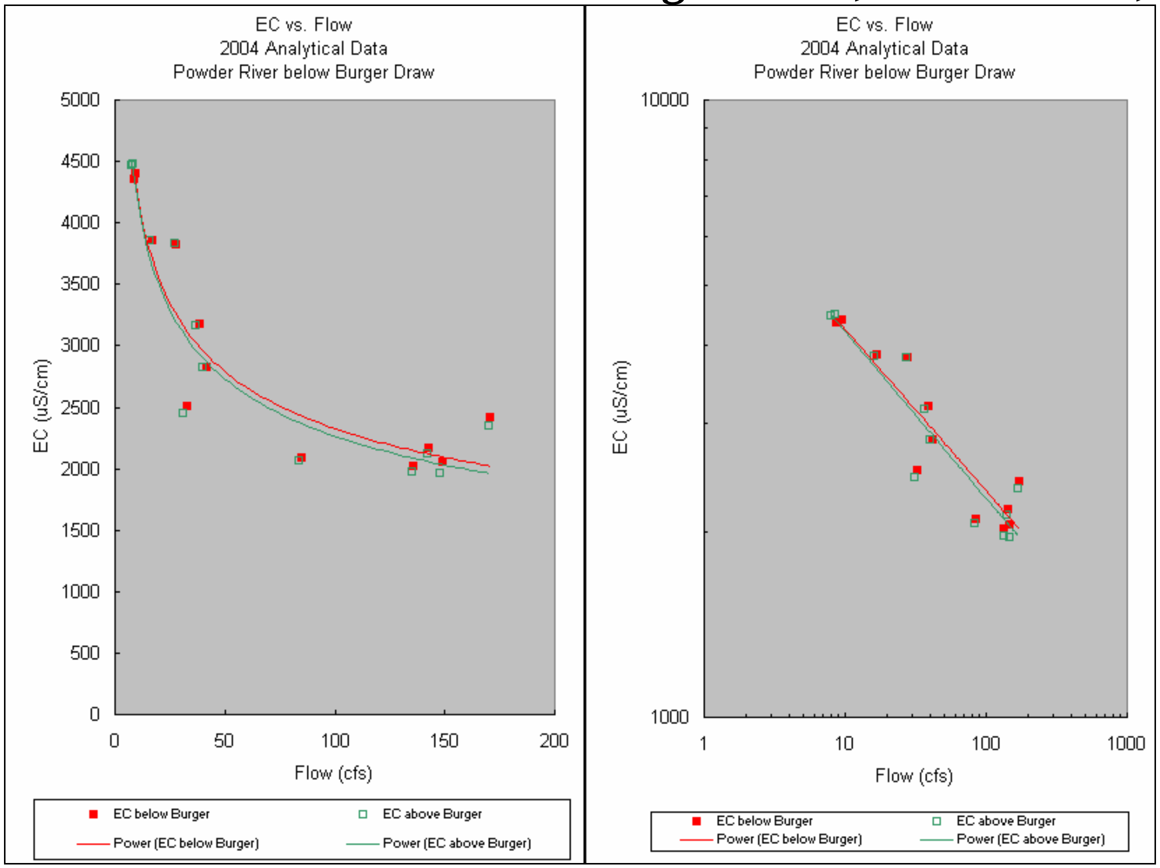


Figure 10 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Powder River below Burger Draw. Analytical EC values during 2004 ranged from 2020 to 4400 uS/cm. Analytical SAR values ranged from 4.8 to 12.6. Data from above Burger Draw are also shown for comparison. EC values appear to increase due to Burger draw when the instream EC is <~2500 uS/cm, show little change when instream EC is between ~2500 and ~4000 uS/cm, and decreases when instream EC is >~4000 uS/cm. SAR values appear to increase due to Burger Draw.

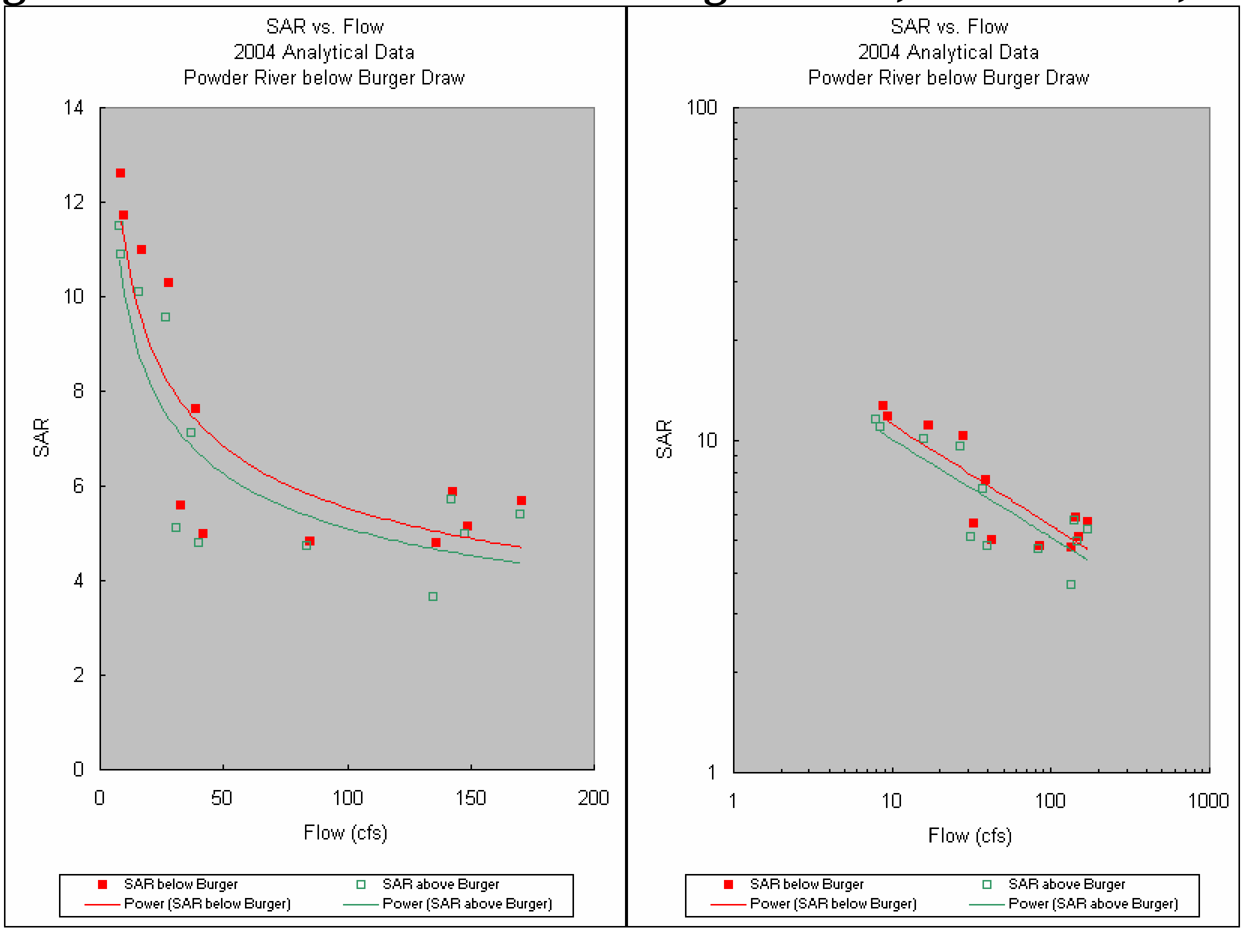
Figure 11: Powder River below Burger Draw, near Buffalo, WY



A **B**

Figure 11 shows analytical EC values charted vs. Flow for 2004 for the Powder River below Burger Draw. These values are charted on both linier (A) and logarithmic (B) scales. Historical data are not available for comparison. Data from the station above Burger Draw is included for comparison. EC values appear to increase due to Burger draw when the instream EC is <~2500 uS/cm, show little change when instream EC is between ~2500 and ~4000 uS/cm, and decreases when instream EC is >~4000 uS/cm.

Figure 12: Powder River below Burger Draw, near Buffalo, WY



A **B**

Figure 12 shows analytical SAR values charted vs. Flow for 2004 for the Powder River below Burger Draw. These values are charted on both linier (A) and logarithmic (B) scales. Historical data are not available for comparison. Data from the station above Burger Draw is included for comparison. SAR values appear to increase due to Burger draw.

Figure 13: Powder River at Arvada, WY

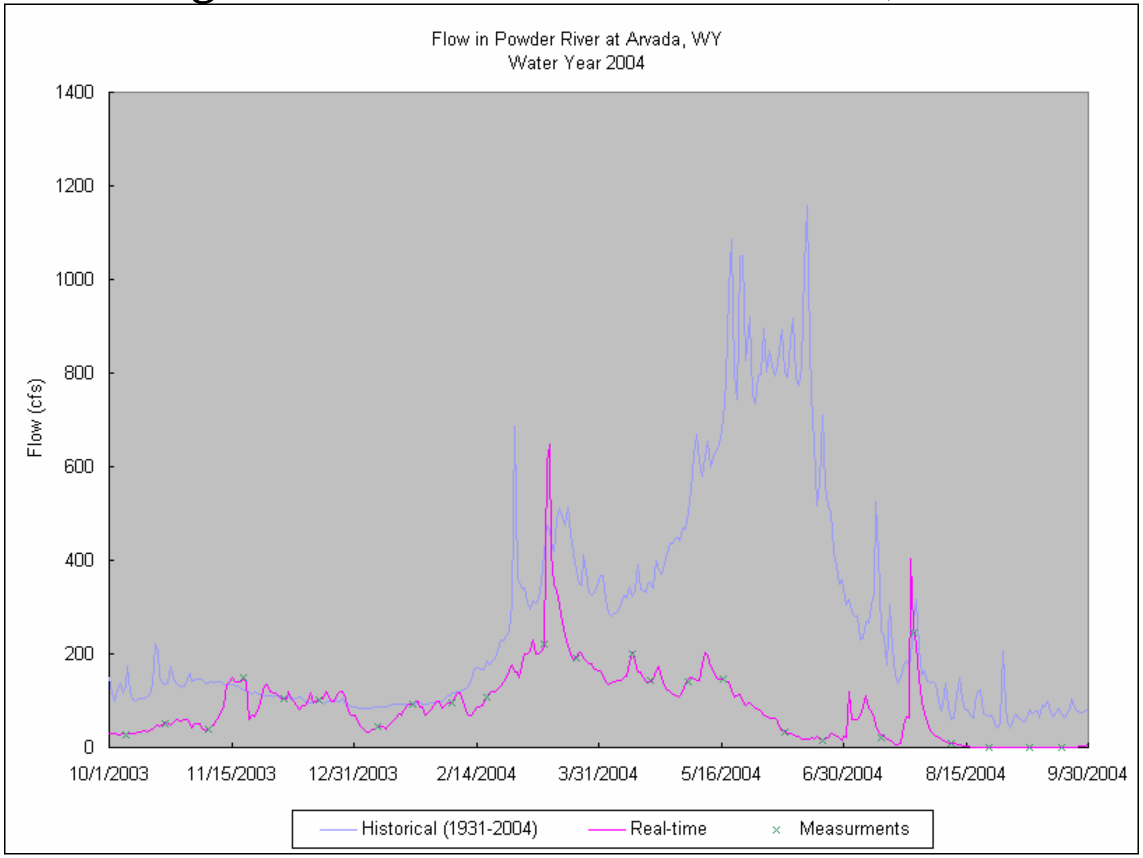
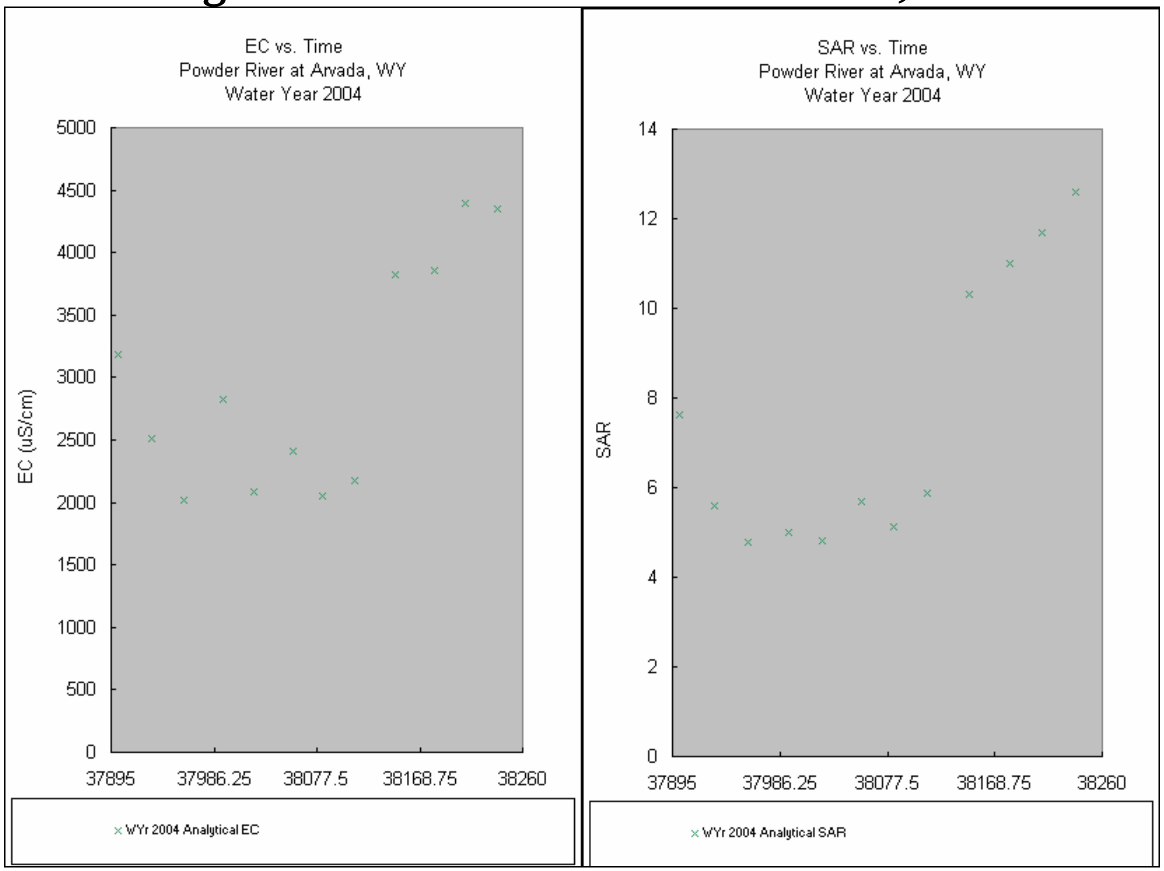


Figure 13 shows real time flow values in a time series plot for 2004 for the Powder River at Arvada, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 0 to 629 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

Figure 14: Powder River at Arvada, WY



A **B**

Figure 14 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Powder River at Arvada. Analytical EC values during 2004 ranged from 1940 to 4430 uS/cm. Analytical SAR values ranged from 4.0 to 10.9.

Figure 15: Powder River at Arvada, WY

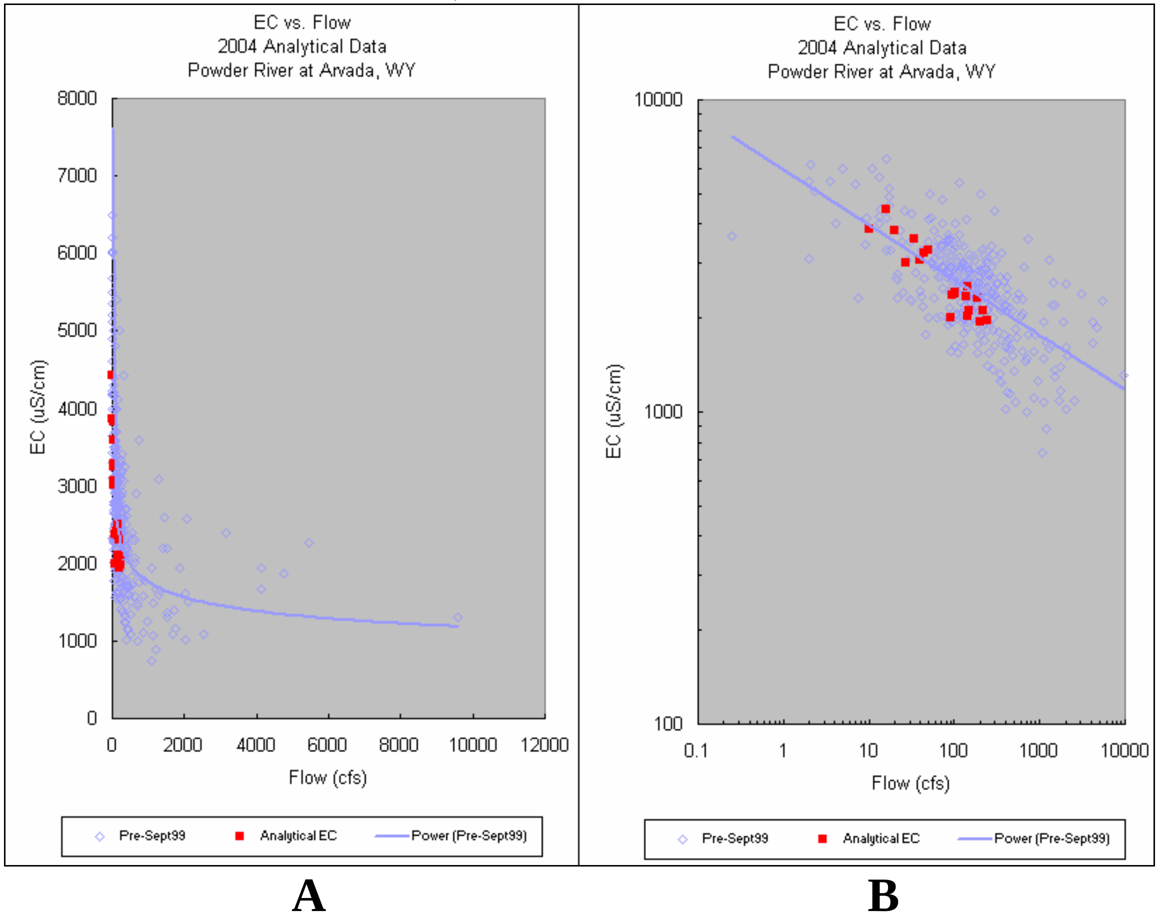


Figure 15 shows analytical EC values charted vs. Flow for 2004 for the Powder River at Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 16: Powder River at Arvada, WY

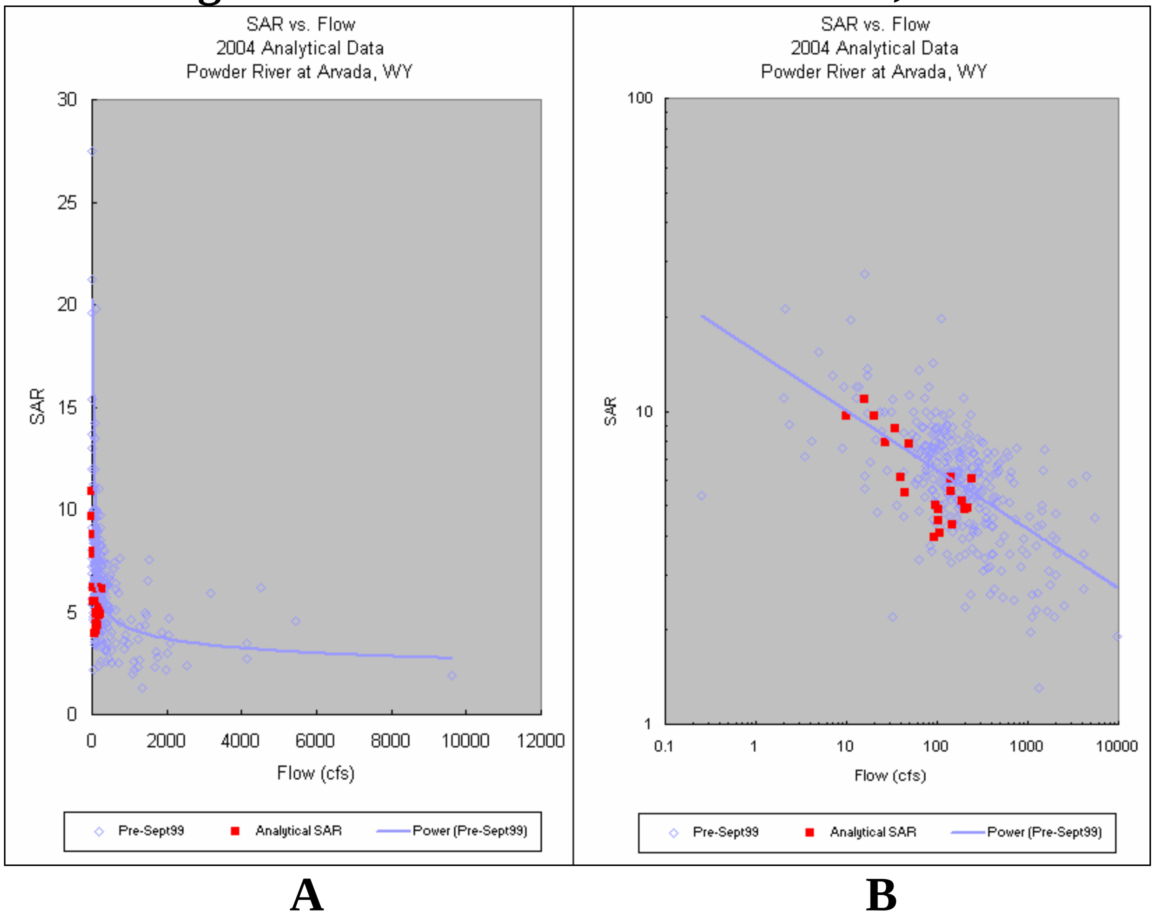


Figure 16 shows analytical SAR values charted vs. Flow for 2004 for the Powder River at Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 17: Powder River near Moorhead, MT

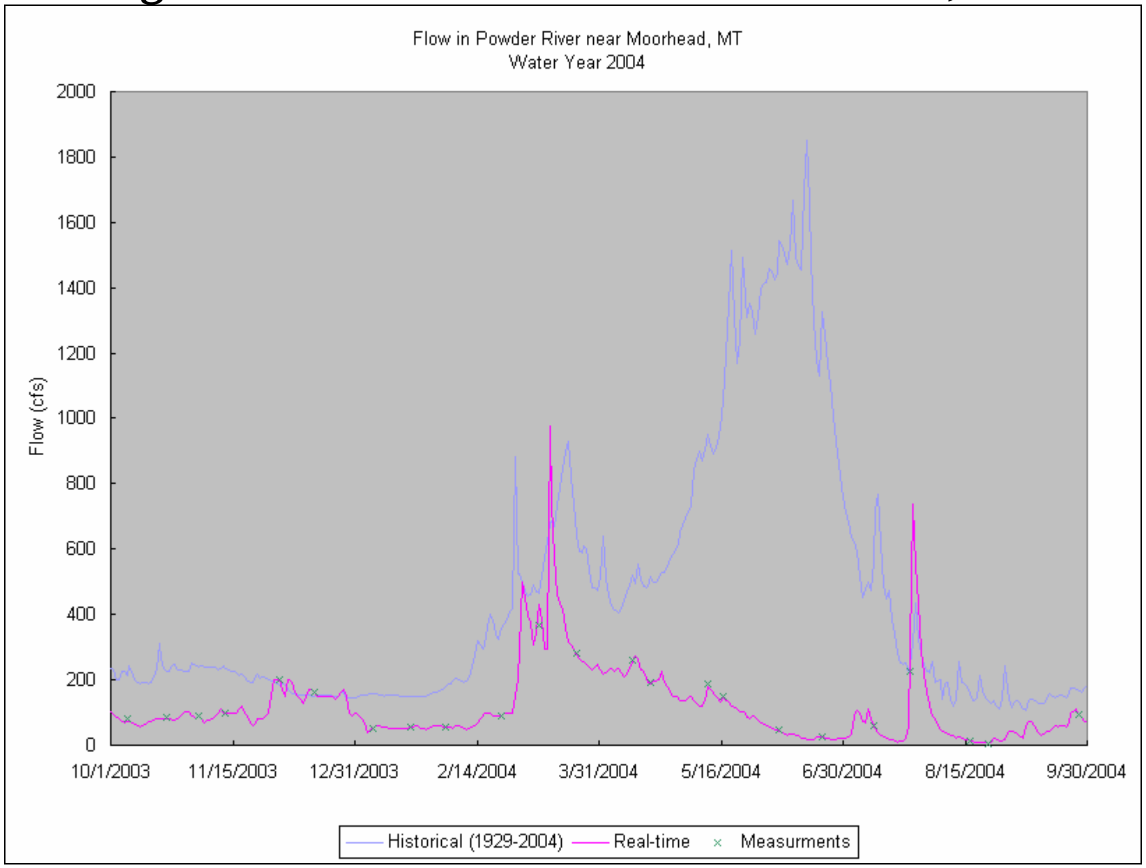
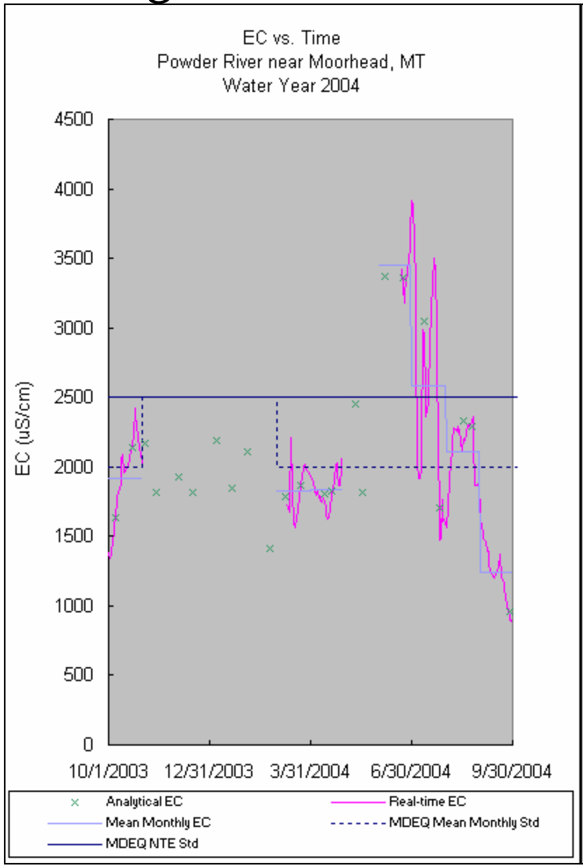
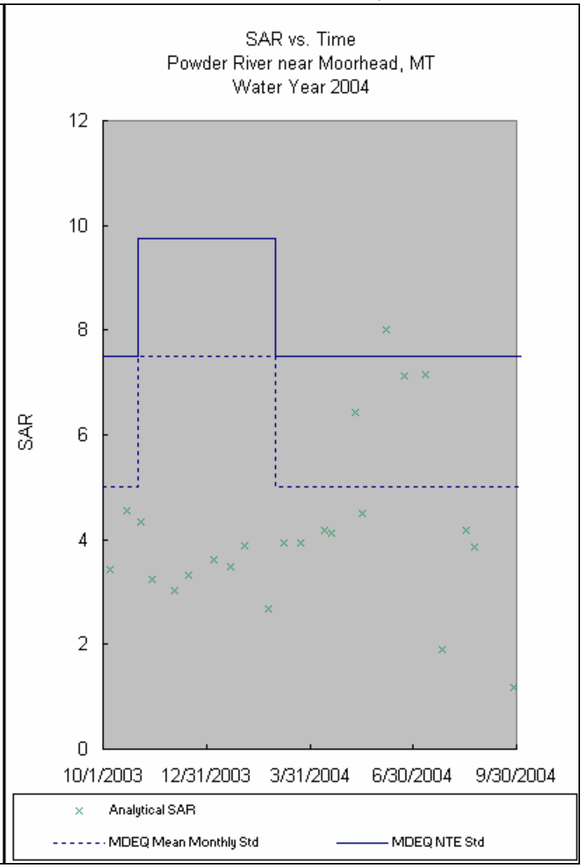


Figure 17 shows real time flow values in a time series plot for 2004 for the Powder River near Moorhead, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 5.0 to 975 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

Figure 18: Powder River near Moorhead, MT



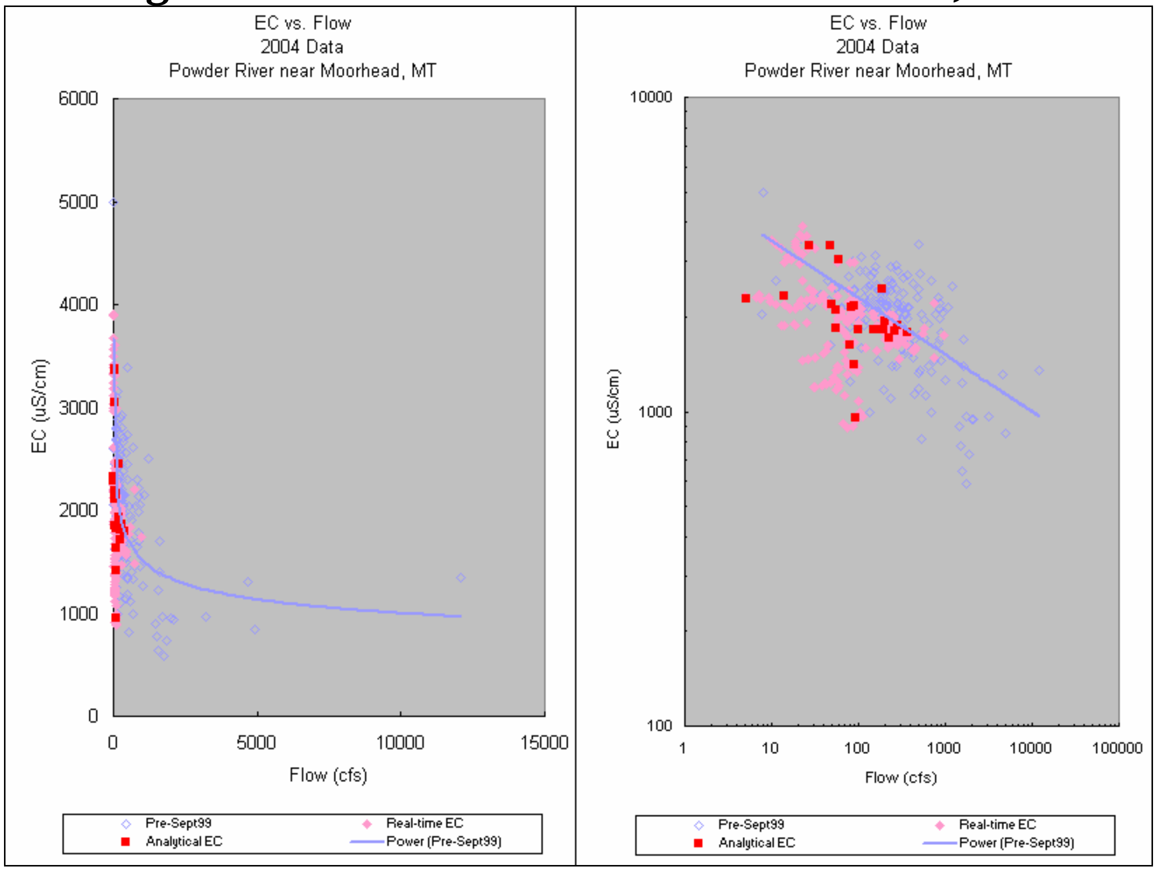
A



B

Figure 18 shows analytical and realtime EC (A) and analytical SAR (B) values in time series plots for 2004 for the Powder River near Moorhead. Mean Monthly EC values are also shown. Realtime EC values during 2004 ranged from 902 to 3960 uS/cm. Mean Monthly EC values ranged from 1239 to 3451 uS/cm. Analytical SAR values ranged from 1.2 to 8.0. These values are compared to the instantaneous maximum and mean monthly standards developed by the MDEQ. Recorded values were above the MDEQ standards at times.

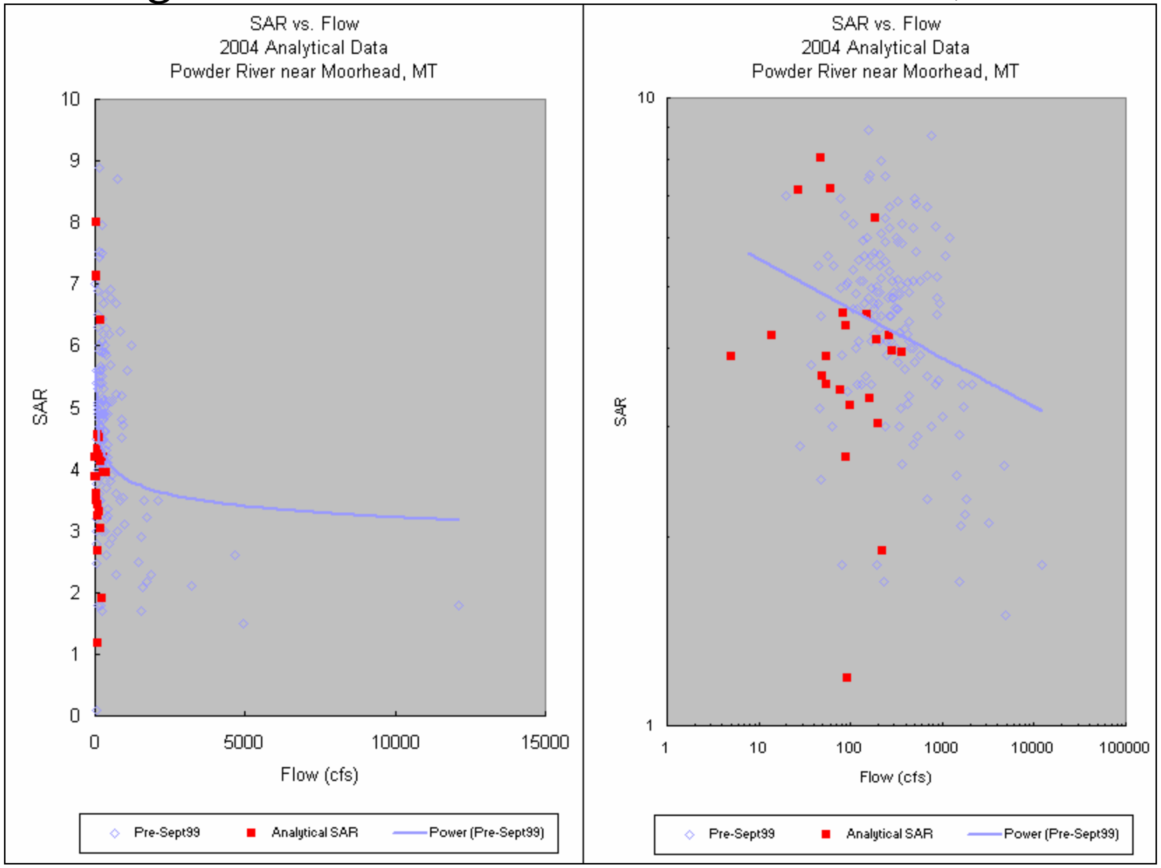
Figure 19: Powder River near Moorhead, MT



A **B**

Figure 19 shows realtime and analytical EC values charted vs. Flow for 2004 for the Powder River near Moorhead. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 20: Powder River near Moorhead, MT



A **B**

Figure 20 shows analytical SAR values charted vs. Flow for 2004 for the Powder River near Moorhead. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows; however the scatter in both data sets is quite large.

Figure 21: Powder River near Locate, MT

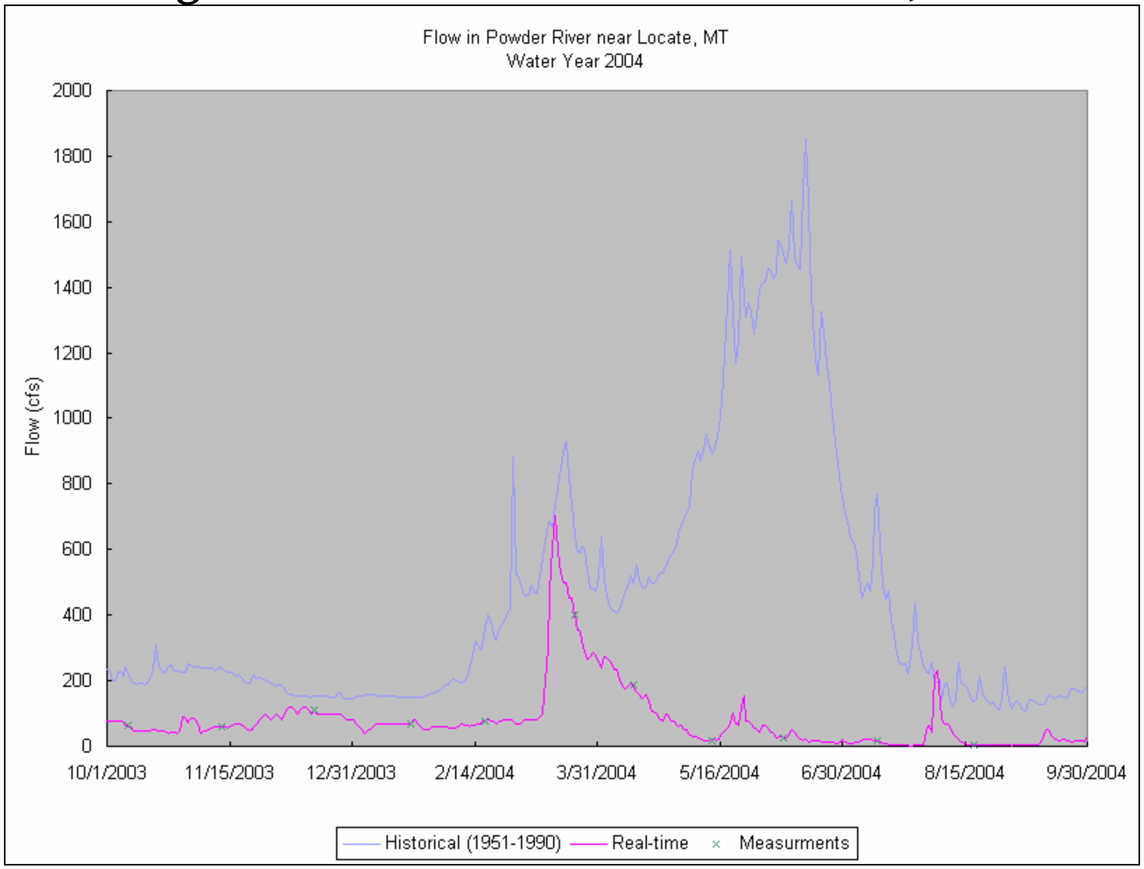
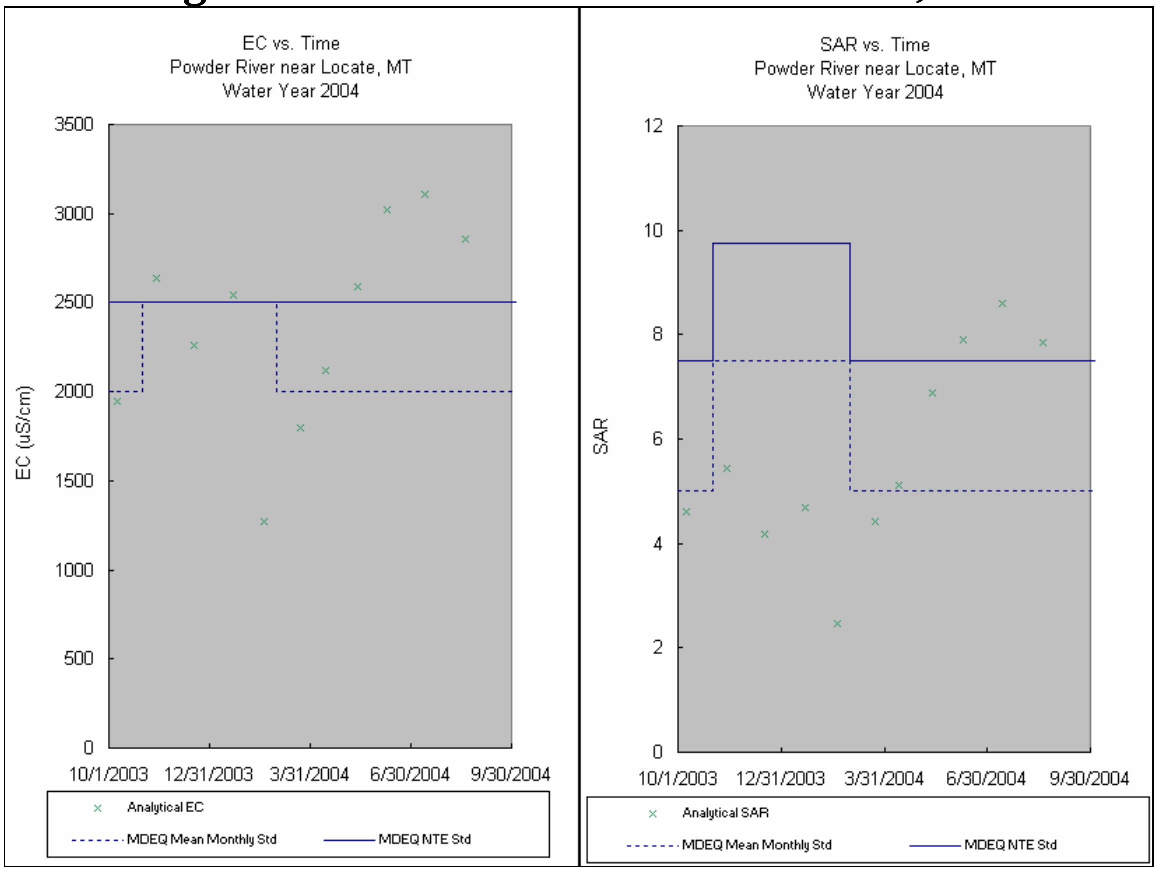


Figure 21 shows real time flow values in a time series plot for 2004 for the Powder River near Locate, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 2.0 to 704 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

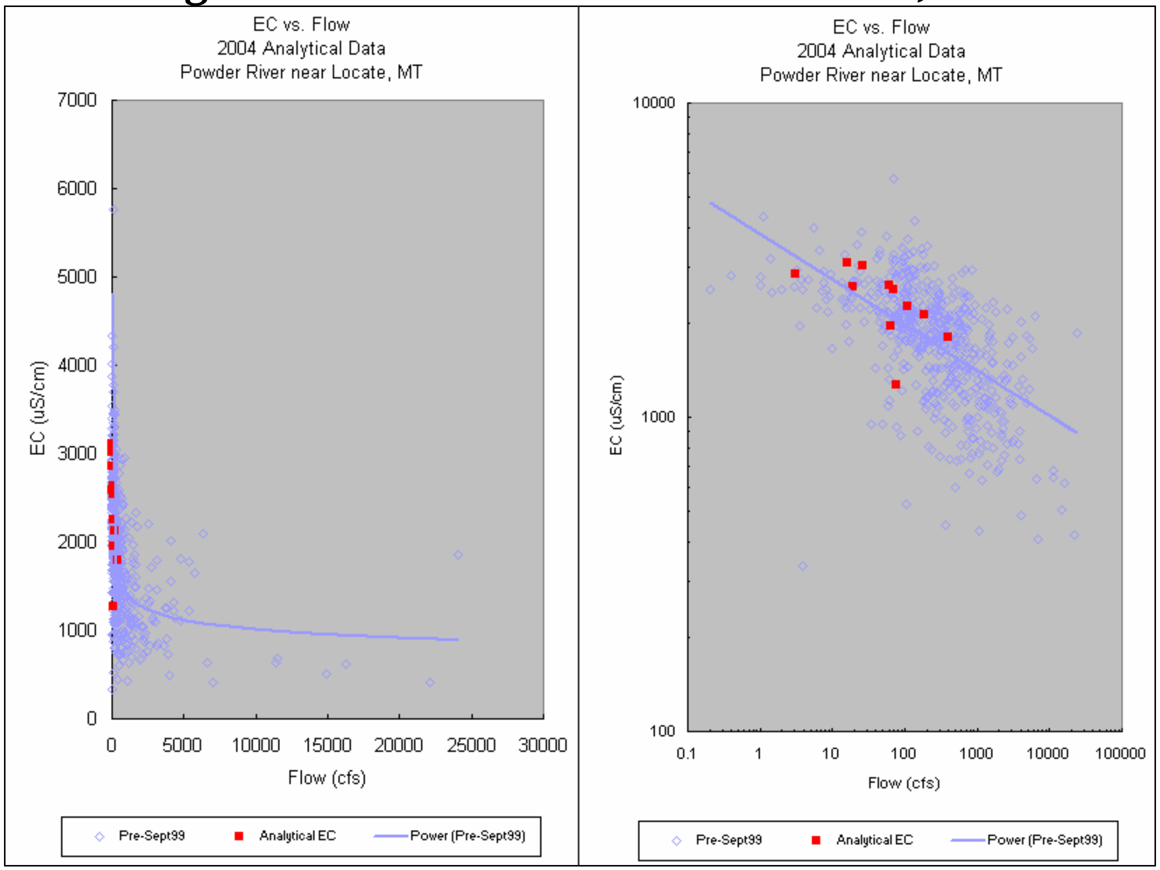
Figure 22: Powder River near Locate, MT



A **B**

Figure 22 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Powder River near Locate. Analytical EC values during 2004 ranged from 1270 to 3110 uS/cm. Analytical SAR values ranged from 2.5 to 8.6. These values are compared to the instantaneous maximum developed by the MDEQ. Recorded EC values were often above the MDEQ standard while recorded SAR values were occasionally above the MDEQ standard.

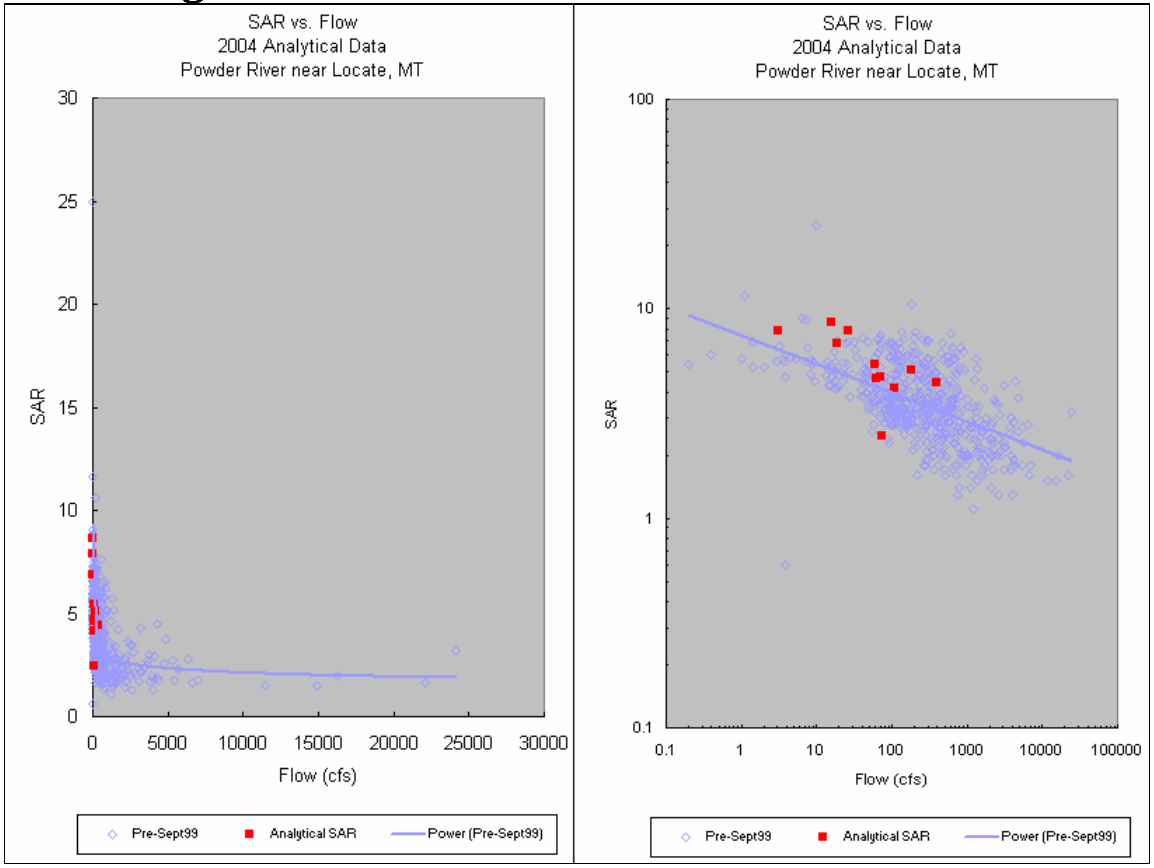
Figure 23: Powder River near Locate, MT



A **B**

Figure 23 shows analytical EC values charted vs. Flow for 2004 for the Powder River near Locate. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 24: Powder River near Locate, MT



A **B**

Figure 24 shows analytical SAR values charted vs. Flow for 2004 for the Powder River near Locate. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Figure 25: Crazy Woman Creek at Upper Station, near Arvada, WY

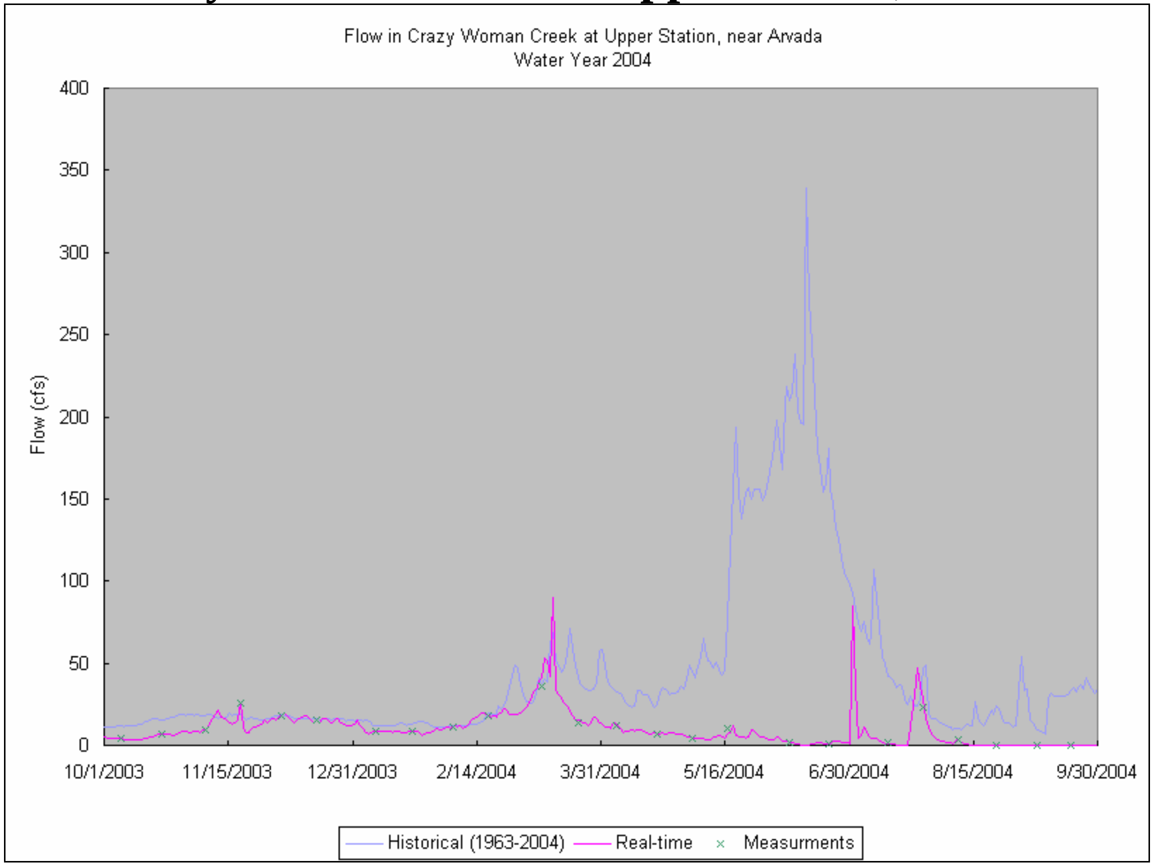


Figure 25 shows real time flow values in a time series plot for 2004 for Crazy Woman Creek near Arvada, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 0.01 to 90 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

Figure 26: Crazy Woman Creek at Upper Station, near Arvada, WY

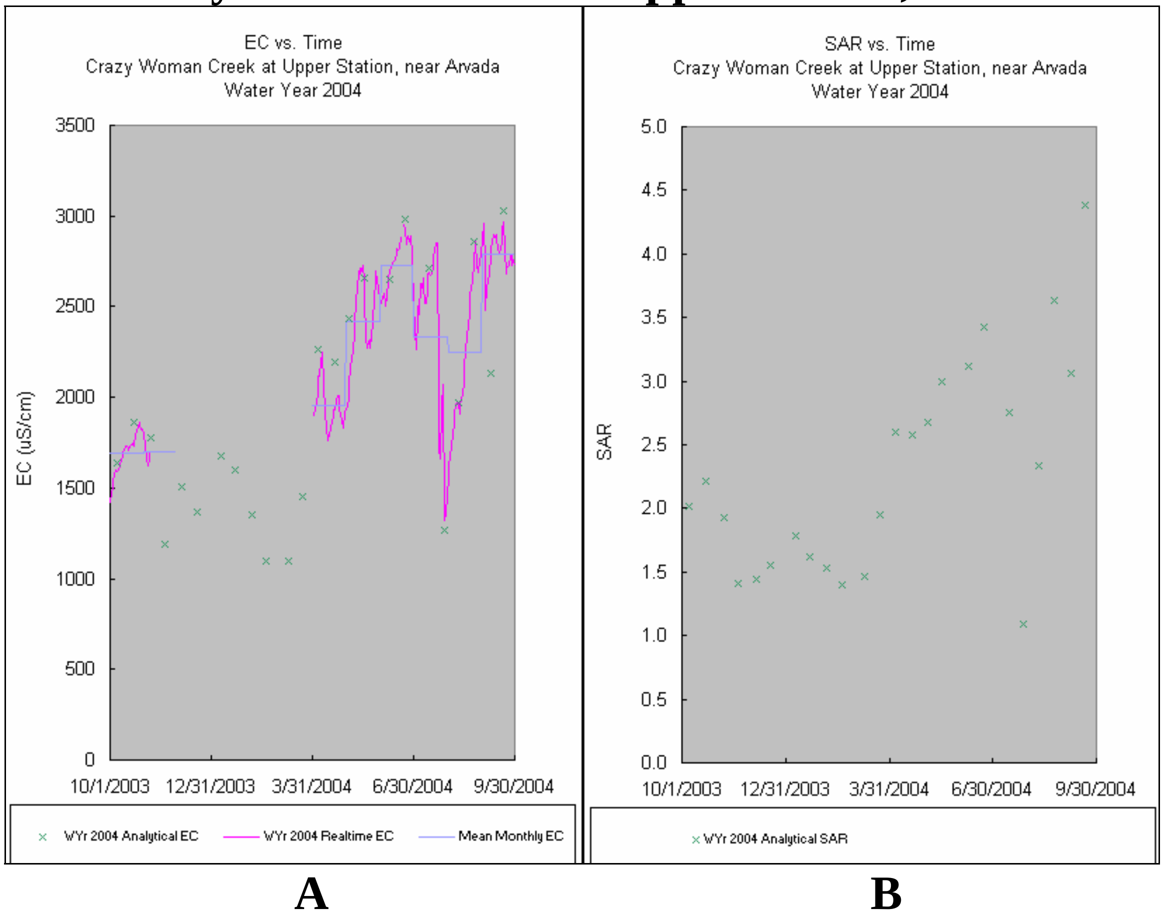


Figure 26 shows analytical and realtime EC (A) and analytical SAR (B) values in time series plots for 2004 for Crazy Woman Creek near Arvada. Mean Monthly EC values are also shown. Realtime EC values during 2004 ranged from 1320 to 2970 uS/cm. Mean Monthly EC values ranged from 1691 to 2787 uS/cm. Analytical SAR values ranged from 1.1 to 4.4.

Figure 27: Crazy Woman Creek at Upper Station, near Arvada, WY

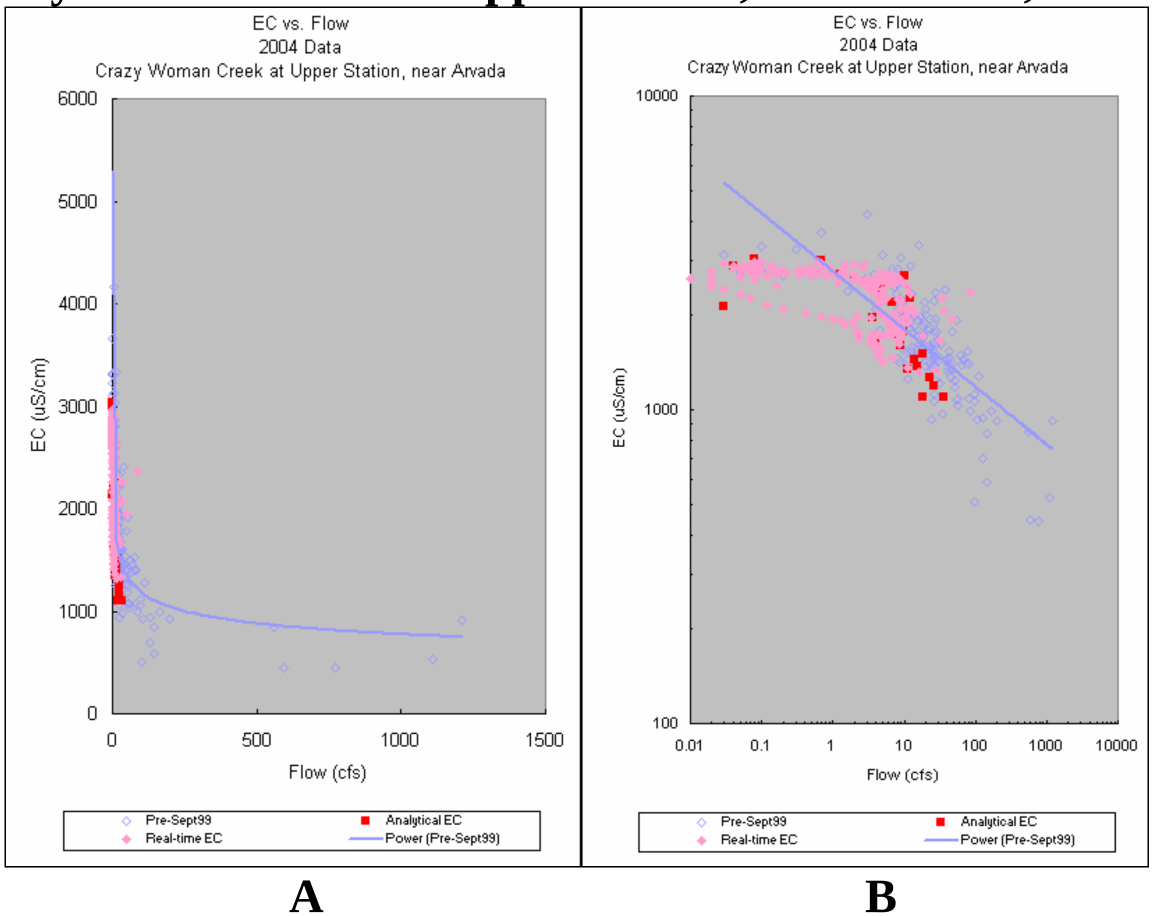
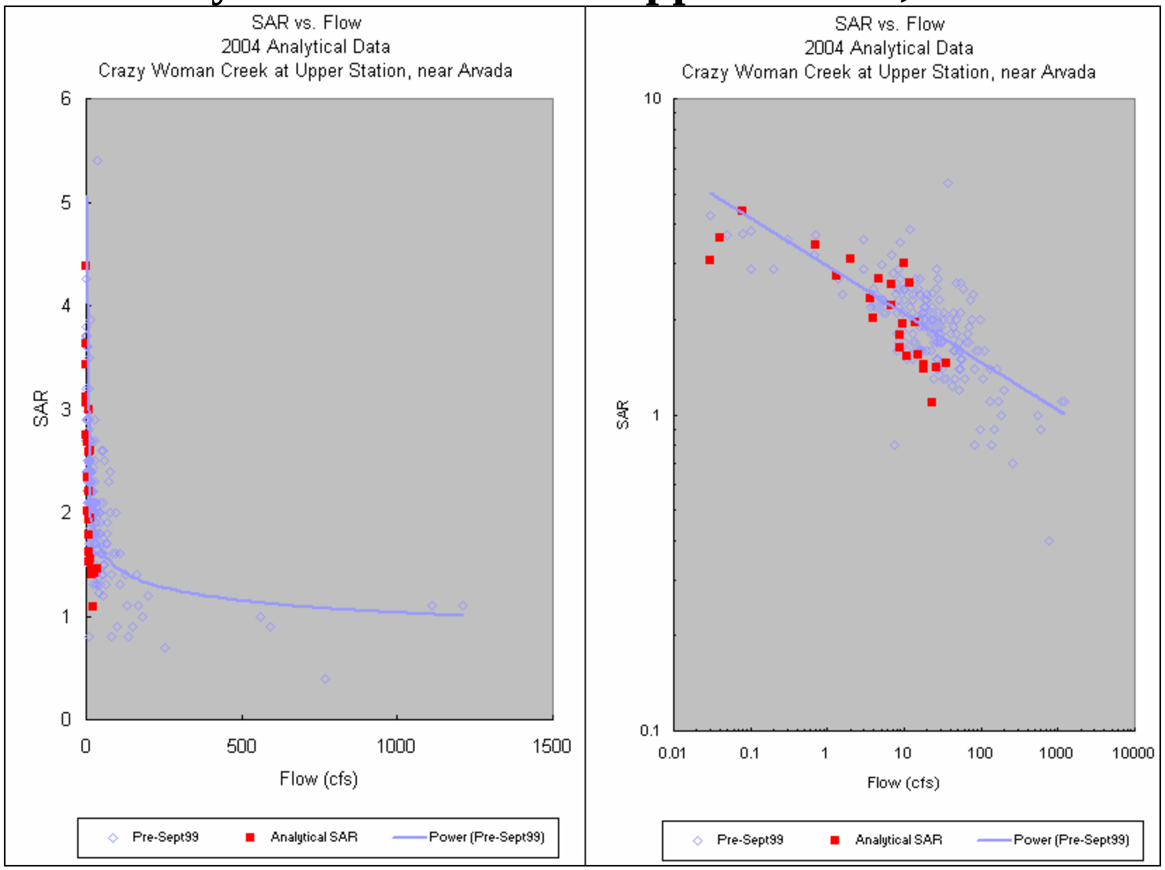


Figure 27 shows realtime and analytical EC values charted vs. Flow for 2004 for Crazy Woman Creek near Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 28: Crazy Woman Creek at Upper Station, near Arvada, WY



A **B**

Figure 28 shows analytical SAR values charted vs. Flow for 2004 for Crazy Woman Creek near Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Figure 29: Clear Creek near Arvada, WY

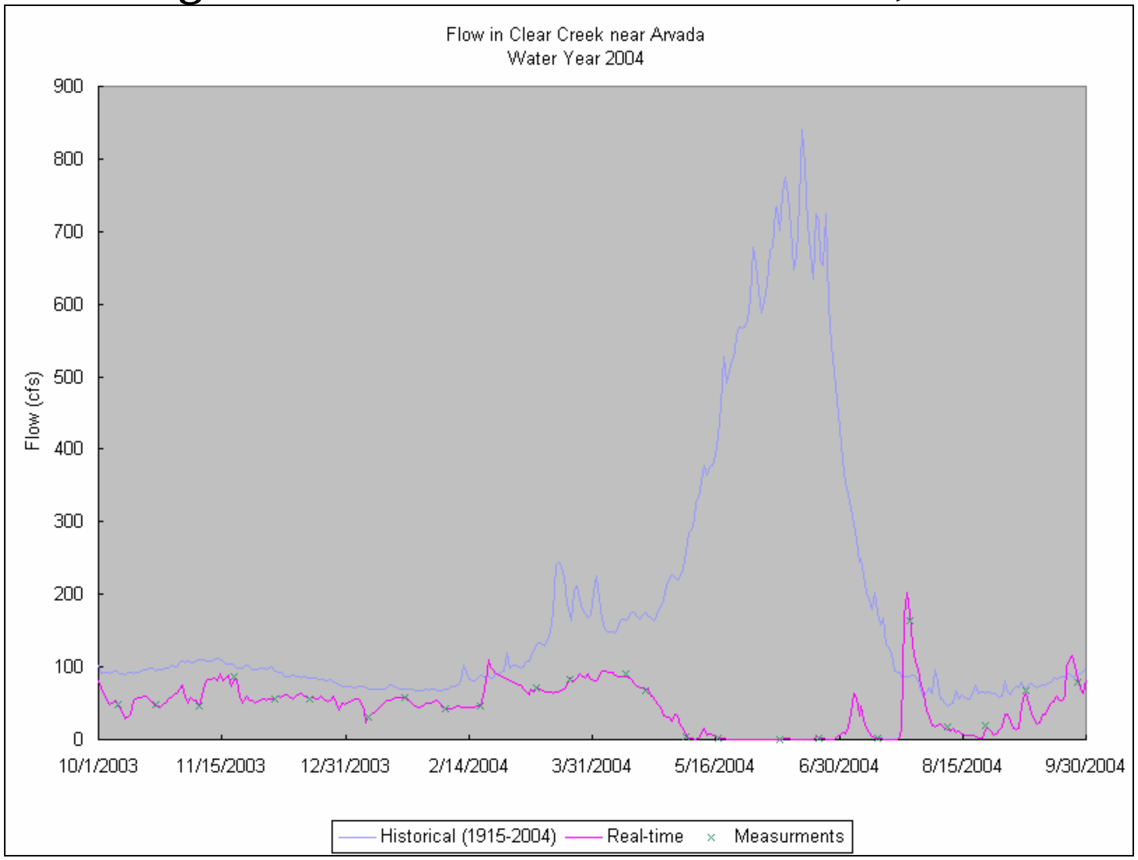


Figure 29 shows real time flow values in a time series plot for 2004 for Clear Creek near Arvada, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 0.35 to 202 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

Figure 30: Clear Creek near Arvada, WY

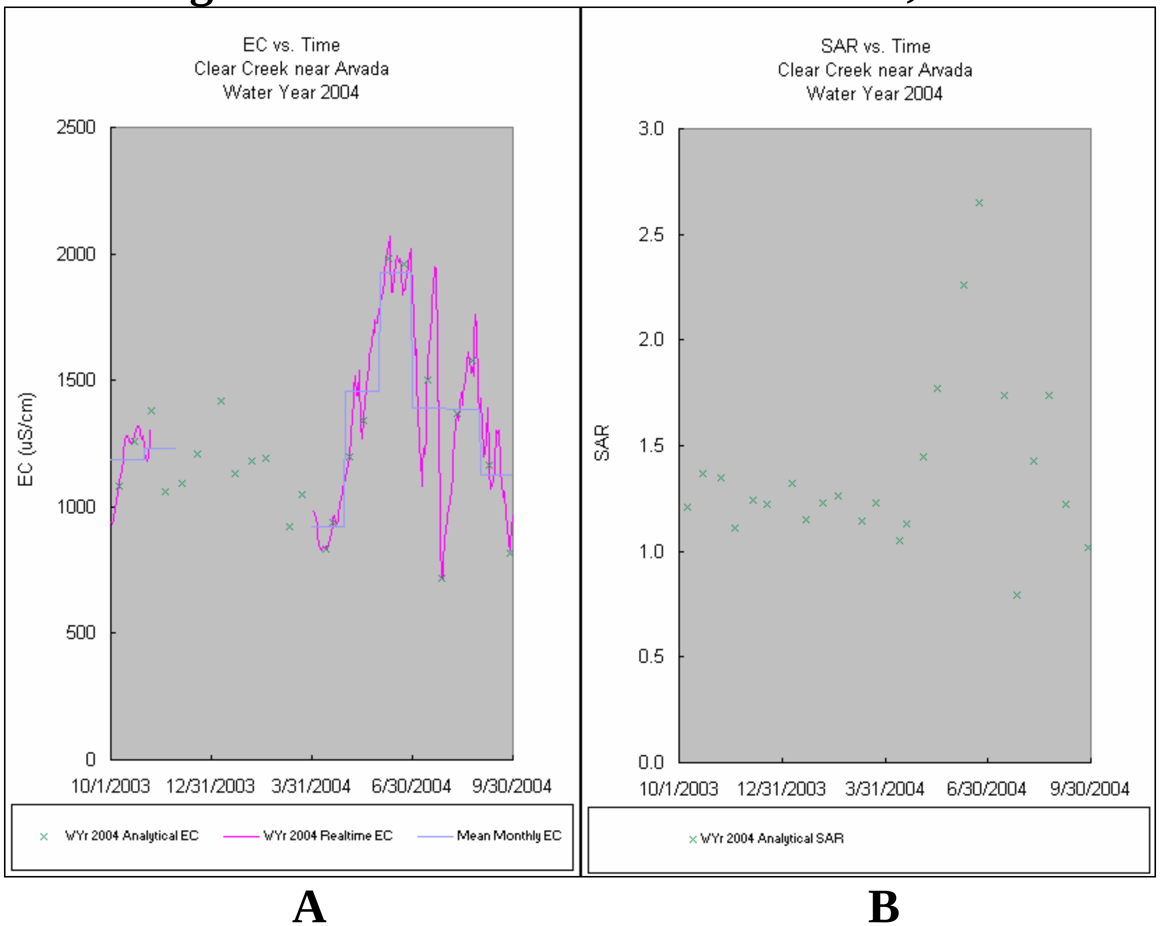
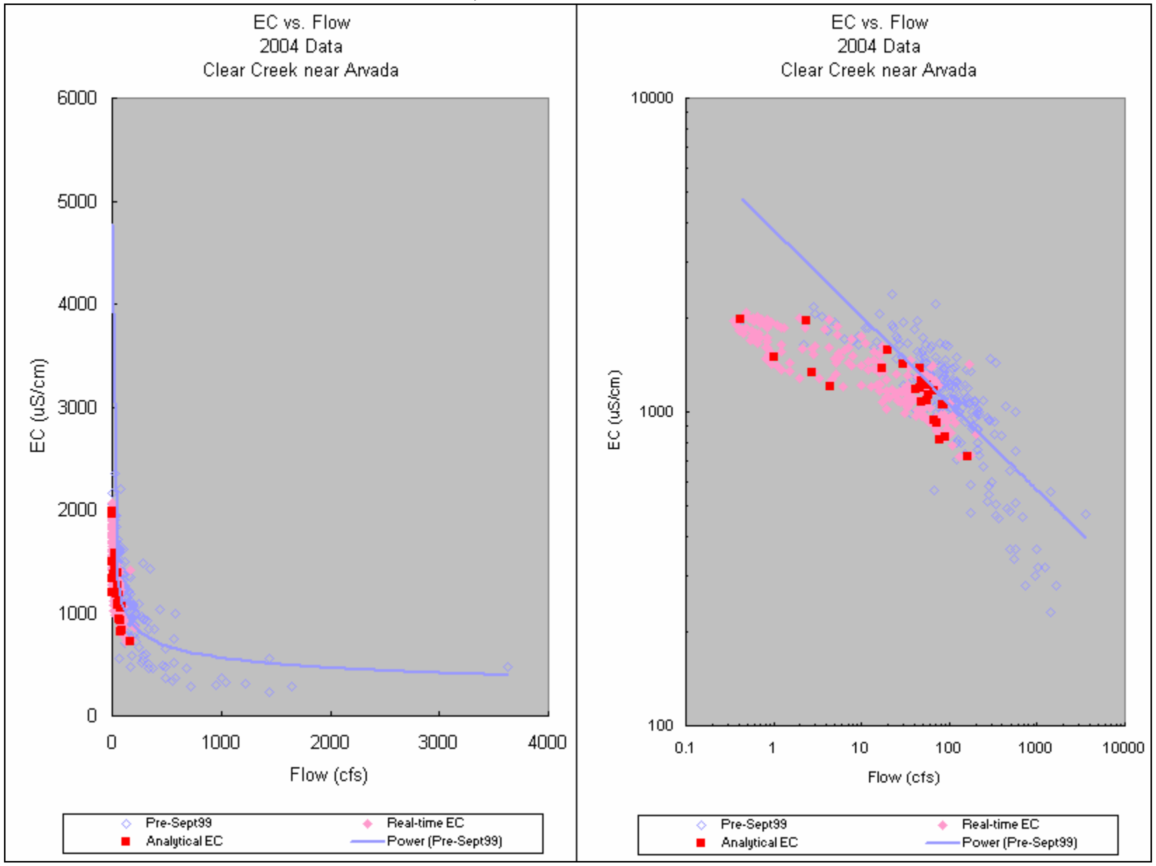


Figure 30 shows analytical and realtime EC (A) and analytical SAR (B) values in time series plots for 2004 for Clear Creek near Arvada. Mean Monthly EC values are also shown. Realtime EC values during 2004 ranged from 716 to 2070 uS/cm. Mean Monthly EC values ranged from 924 to 1925 uS/cm. Analytical SAR values ranged from 0.8 to 2.7.

Figure 31: Clear Creek near Arvada, WY



A **B**

Figure 31 shows realtime and analytical EC values charted vs. Flow for 2004 for Clear Creek near Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows.

Figure 32: Clear Creek near Arvada, WY

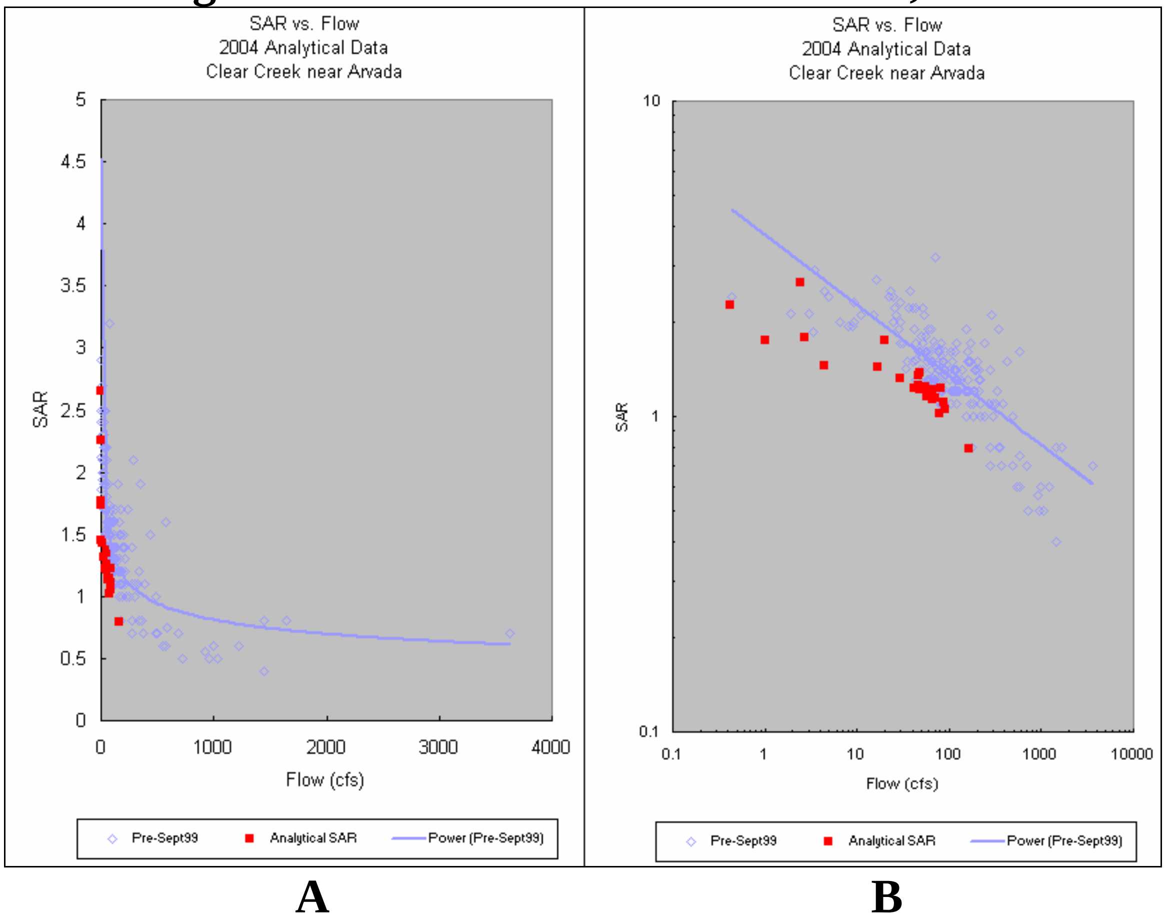


Figure 32 shows analytical SAR values charted vs. Flow for 2004 for Clear Creek near Arvada. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Figure 33: Little Powder River above Dry Creek, near Weston, WY

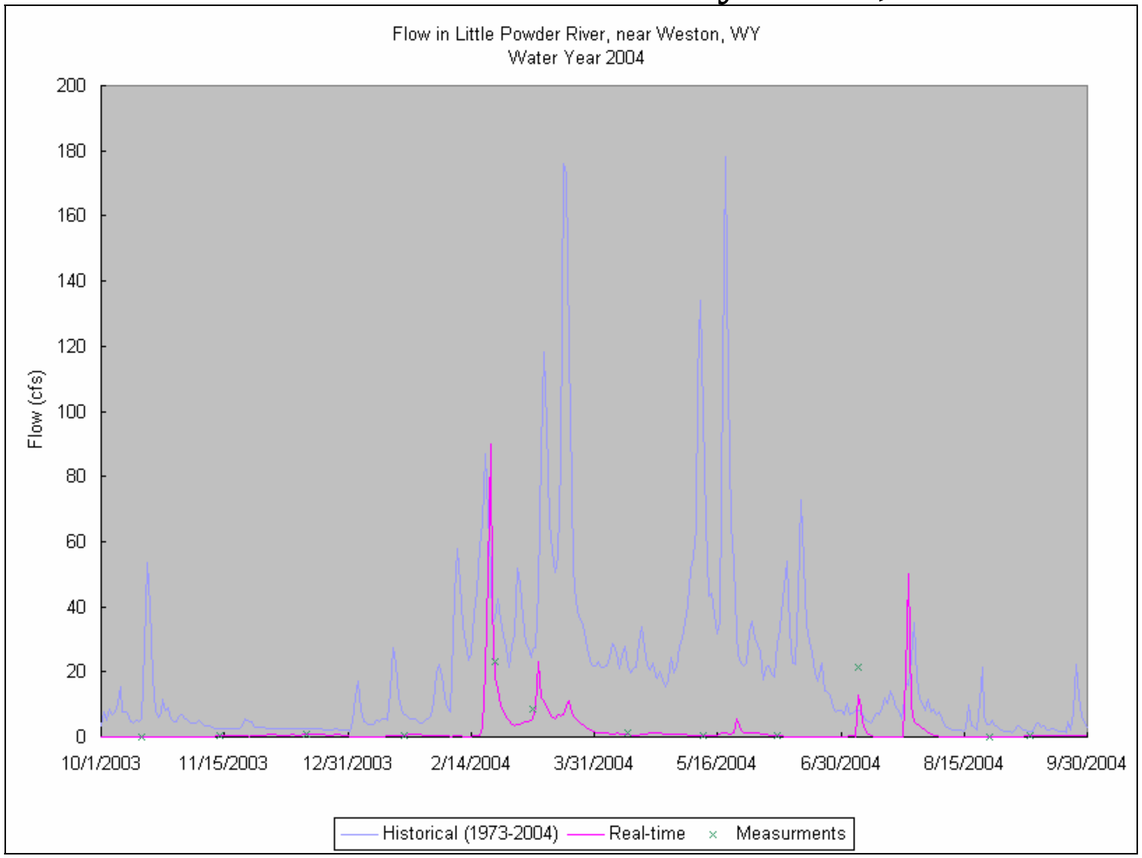
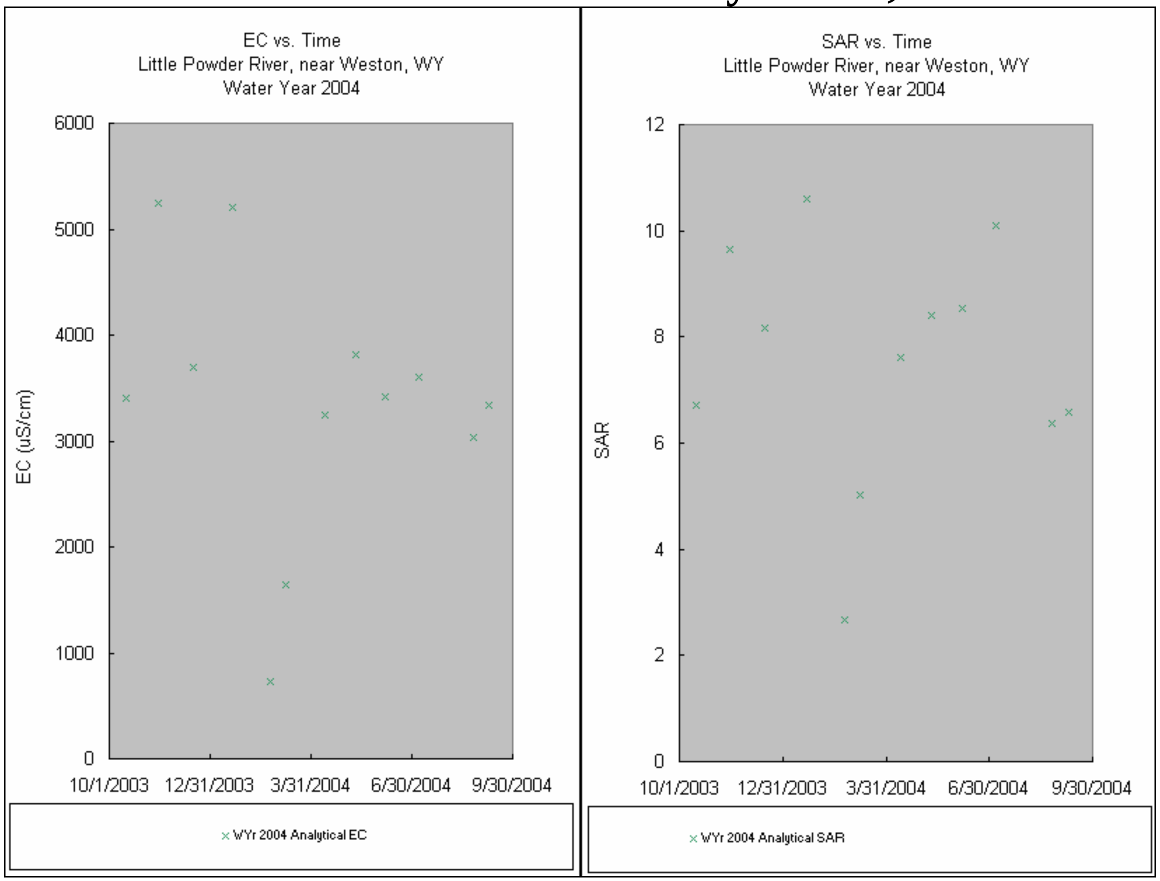


Figure 33 shows real time flow values in a time series plot for 2004 for the Little Powder River near Weston, and field measurements of flow. The historical daily mean flow values are also shown. Recorded flow values during 2004 ranged from 0 to 90 cfs. The spring flow was substantially less then historical values, and flows were less than historical daily mean values for most of the year.

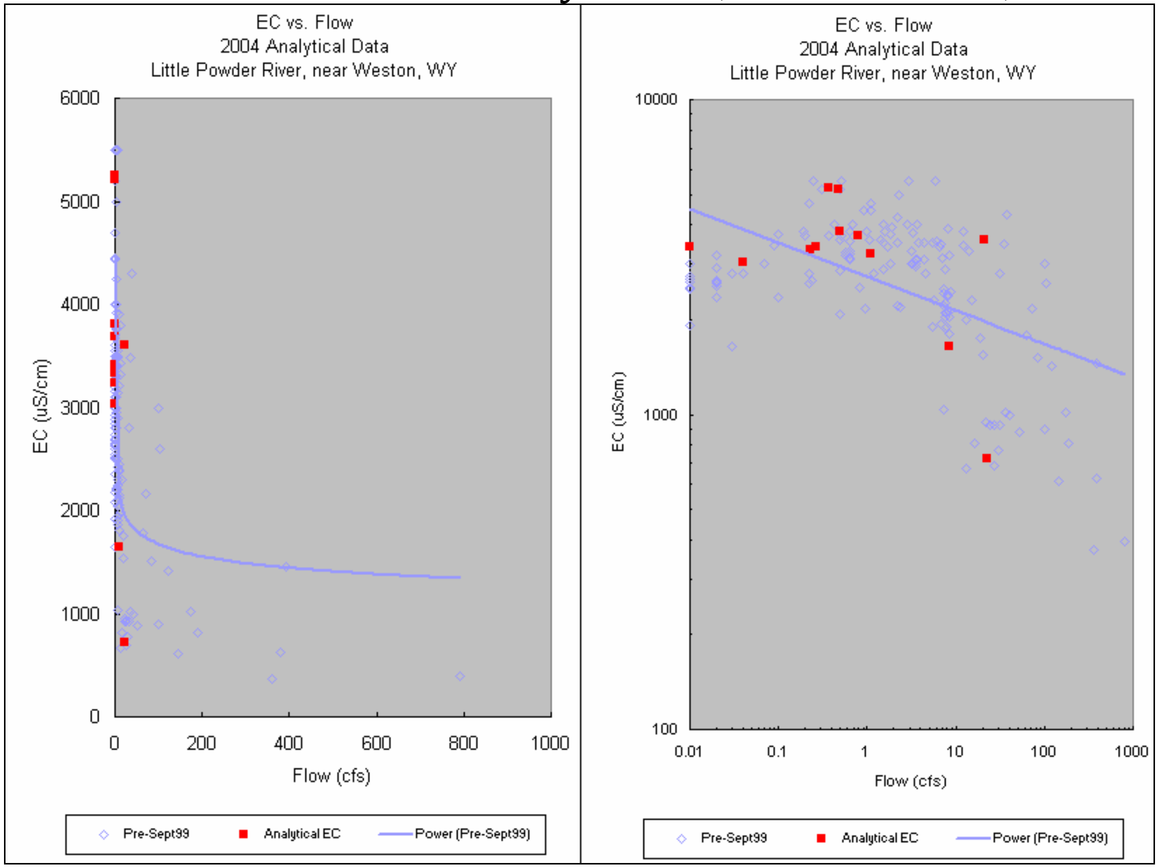
Figure 34: Little Powder River above Dry Creek, near Weston, WY



A **B**

Figure 34 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Little Powder River near Weston. Analytical EC values during 2004 ranged from 725 to 5250 uS/cm. Analytical SAR values ranged from 2.7 to 10.6.

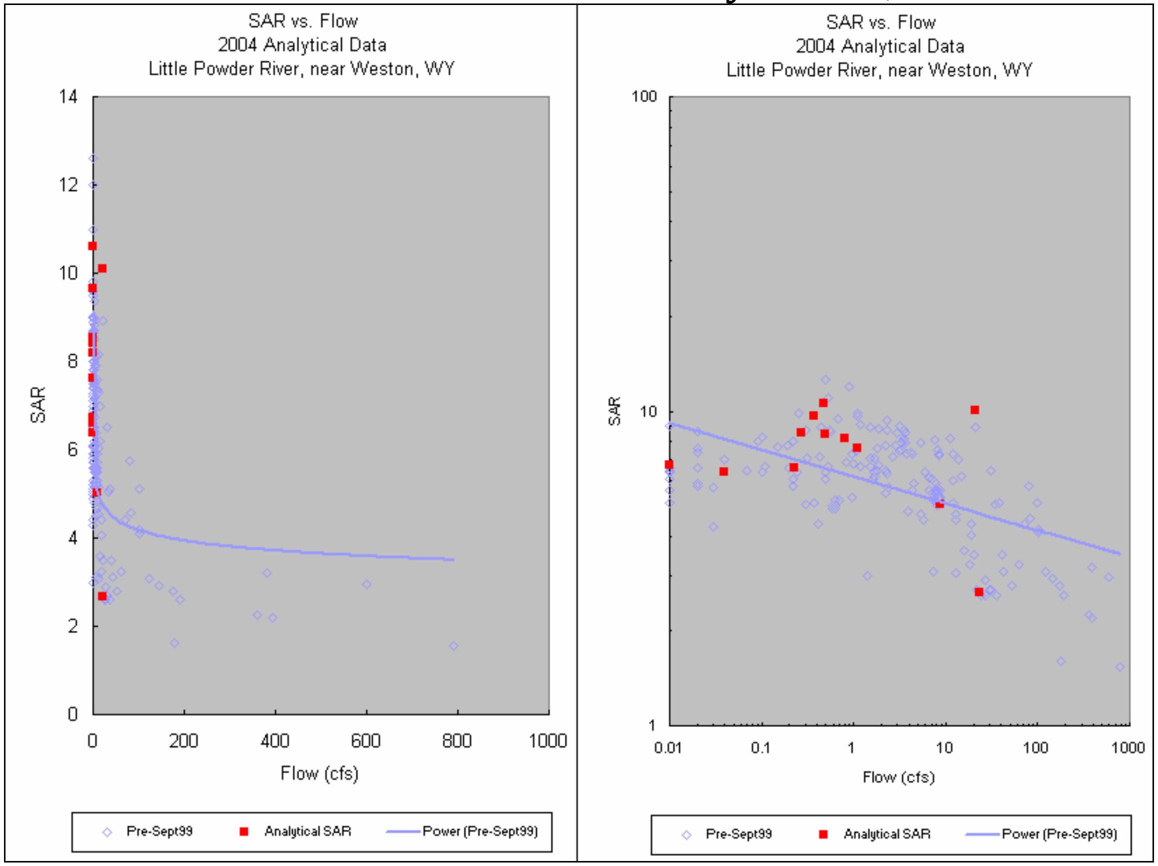
Figure 35: Little Powder River above Dry Creek, near Weston, WY



A **B**

Figure 35 shows analytical EC values charted vs. Flow for 2004 for the Little Powder River near Weston. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows, however the scatter in both data sets is quite large.

Figure 36: Little Powder River above Dry Creek, near Weston, WY



A **B**

Figure 36 shows analytical SAR values charted vs. Flow for 2004 for the Little Powder River near Weston. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Figure 37: Little Powder River near Broadus, MT

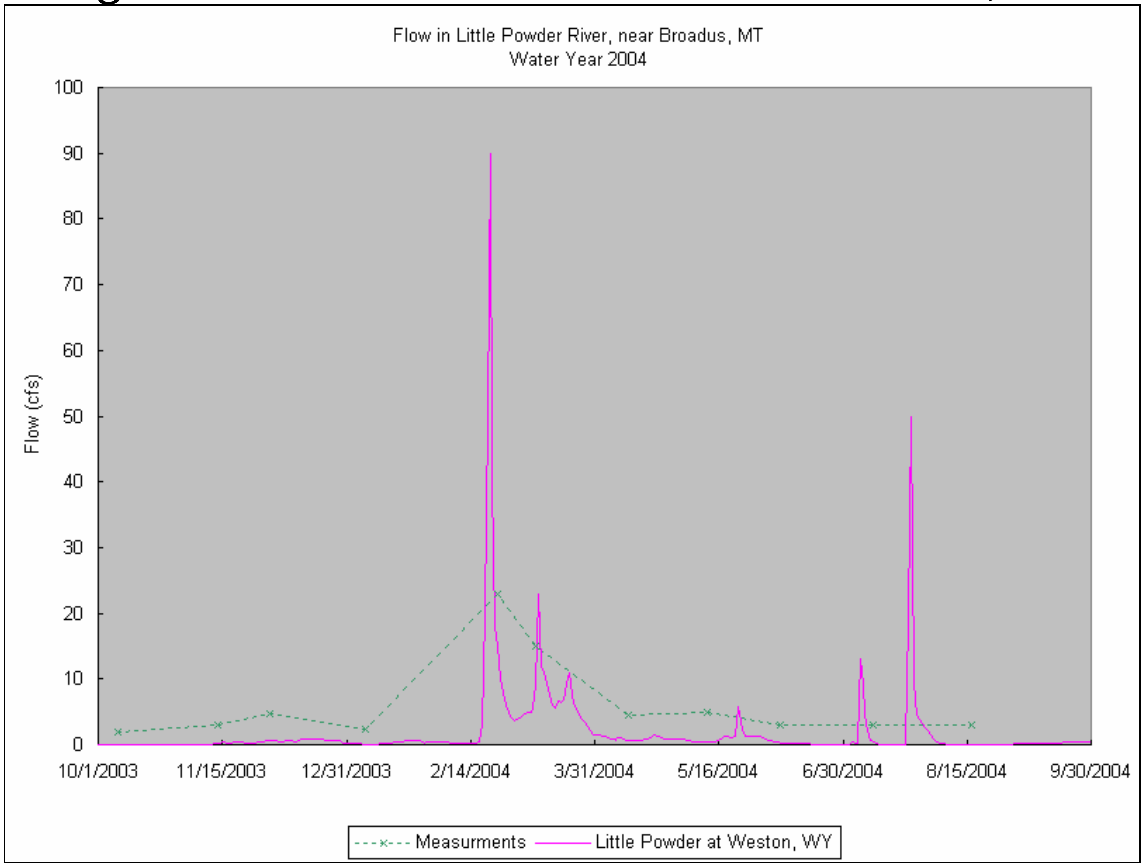


Figure 37 shows field measurements of flow for water year 2004 for the Little Powder River near Broadus. Historical daily mean flow values are not available for this station. Recorded flow values during 2004 ranged from 1.9 to 23 cfs. Comparison between this site, and the site near Weston, WY, indicates a noticeable increase in flow between the two stations.

Figure 38: Little Powder River near Broadus, MT

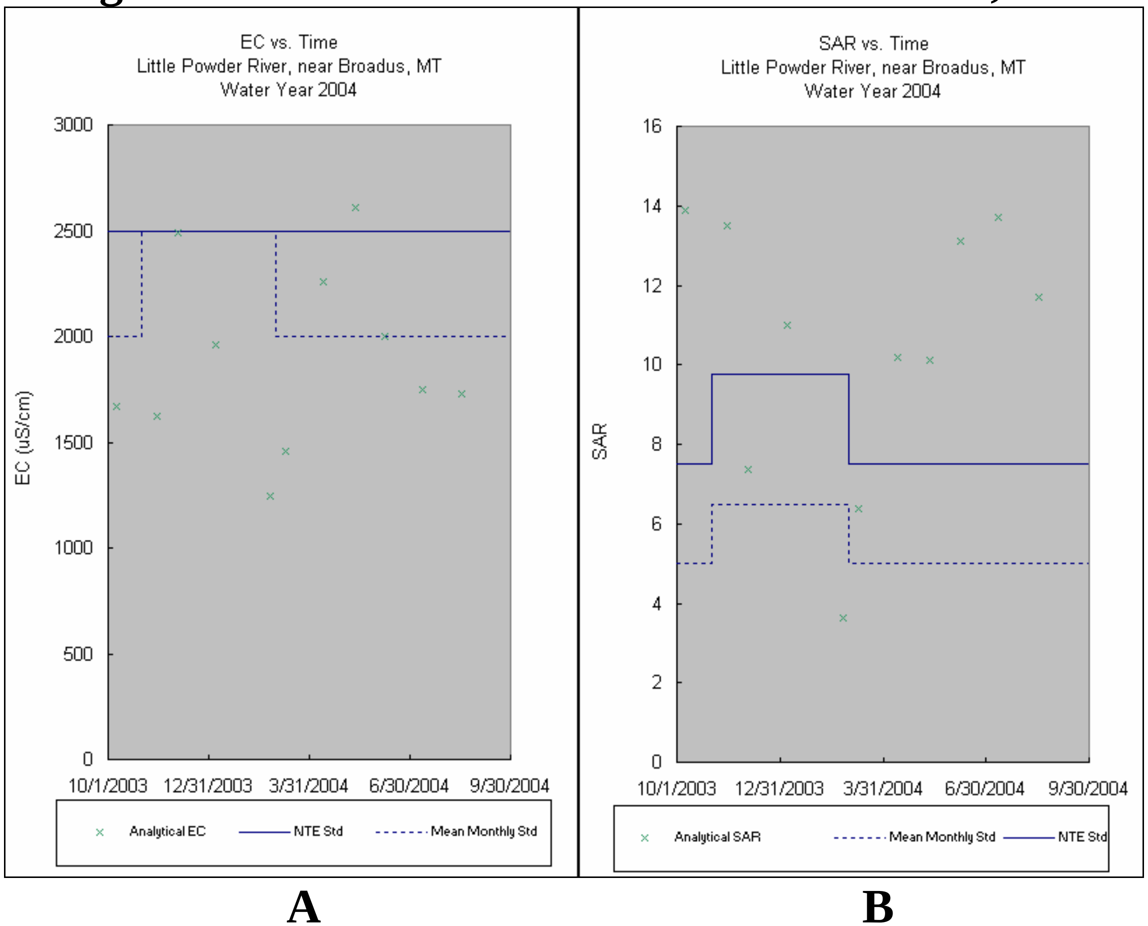


Figure 38 shows analytical EC (A) and SAR (B) values in time series plots for 2004 for the Little Powder River near Broadus. Analytical EC values during 2004 ranged from 1250 to 2610 uS/cm. Analytical SAR values ranged from 3.6 to 13.9. These values are compared to the instantaneous maximum developed by the MDEQ. Recorded EC values were once above the MDEQ standard while recorded SAR values were often above the MDEQ standard.

Figure 39: Little Powder River near Broadus, MT

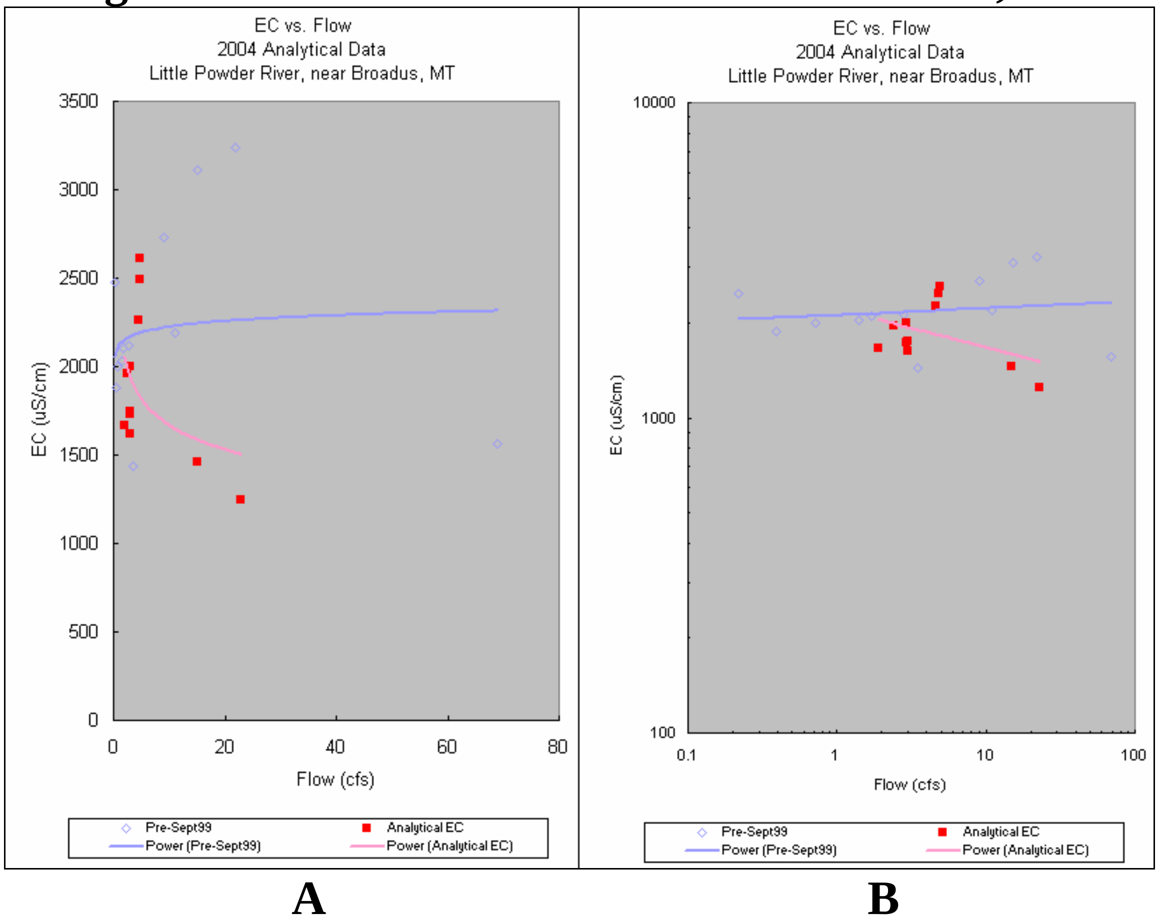


Figure 39 shows analytical EC values charted vs. Flow for 2004 for the Little Powder River near Broadus. These values are charted on both linier (A) and logarithmic (B) scales. Historical EC vs. Flow values are also shown. 2004 EC values appear to be within the range of historical values during comparable flows. Note that the historical data when fitted with a power curve shows an increase in EC with flow (a positive slope on the log-log graph). It is believed that this is a result of having too little data, with a few high values. The overall trend is probably more like the trends seen at other sites, with EC decreasing with flow (a negative slope on the log-log graph), as is seen in the 2004 data.

Figure 40: Little Powder River near Broadus, MT

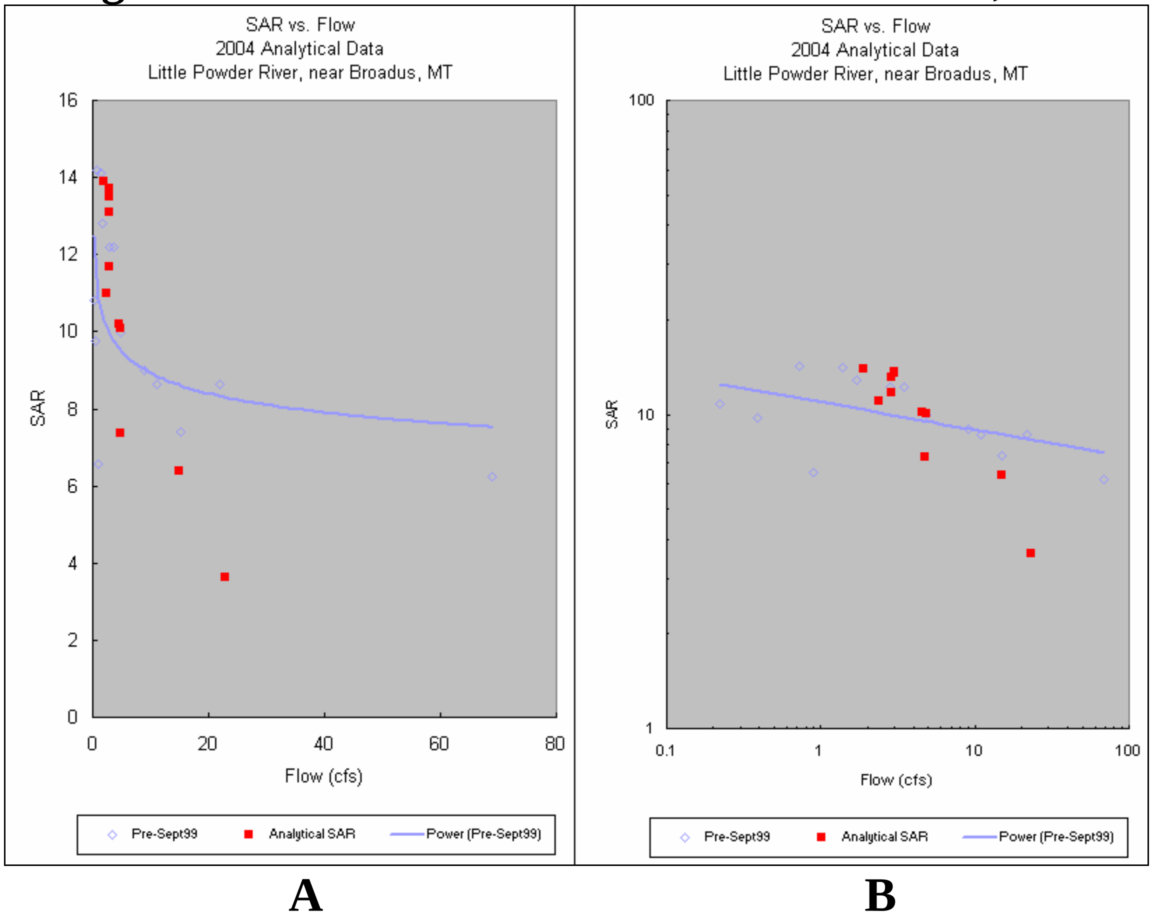


Figure 40 shows analytical SAR values charted vs. Flow for 2004 for the Little Powder River near Broadus. These values are charted on both linier (A) and logarithmic (B) scales. Historical SAR vs. Flow values are also shown. 2004 SAR values appear to be within the range of historical values during comparable flows.

Appendix A: Summary Statistics by Station

Table A1: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06313500 POWDER RIVER AT SUSSEX, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	245	24	183	24	229	24
Min	6.3	8.6	655	1340	2.0	4.0
Max	10700	621	7000	6060	40.0	21.0
Mean	479	105	2672	3039	8.3	8.2
Median	154	83	2400	2250	7.0	5.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	1.5	6.8	930	1050	None	None
Max	14100	1040	5400	6200	None	None
Mean	205	86	2970	3316	None	None
Median	125	82	2900	3180	None	None
Min Monthly Mean	3.54	11.5	1300	1898	None	None
Max Monthly Mean	2553	194	4960	4502	None	None

Flow = cfs EC = uS/cm

Table A2: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06313590 POWDER RIVER ABOVE BURGER DRAW, NEAR BUFFALO, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	None	12	None	12	None	12
Min	None	7.9	None	1960	None	4.0
Max	None	170	None	4480	None	12.0
Mean	None	70.5	None	2960	None	7.1
Median	None	38.5	None	2635	None	5.5
	Mean Streamflow		Specific Conductance		SAR	
Realtime Statistics	pre-99	2004	pre-99	2004	pre-99	2004
Min	None	1.9	None	None	None	None
Max	None	724	None	None	None	None
Mean	None	92.3	None	None	None	None
Median	None	80	None	None	None	None
Min Monthly Mean	None	9.82	None	None	None	None
Max Monthly Mean	None	233	None	None	None	None

Flow = cfs EC=uS/cm

Table A3: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06313605 POWDER RIVER BELOW BURGER DRAW, NEAR BUFFALO, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	None	12	None	12	None	12
Min	None	8.8	None	2020	None	5.0
Max	None	171	None	4400	None	13
Mean	None	71.8	None	2974	None	7.7
Median	None	40.5	None	2665	None	6.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	None	None	None	None	None	None
Max	None	None	None	None	None	None
Mean	None	None	None	None	None	None
Median	None	None	None	None	None	None
Min Monthly Mean	None	None	None	None	None	None
Max Monthly Mean	None	None	None	None	None	None

Flow = cfs EC = uS/cm

Table A4: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06317000 POWDER RIVER AT ARVADA, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	248	24	375	20	340	21
Min	0.0	0.0	70	1940	1.0	4.0
Max	17800	244	6500	4430	28.0	11.0
Mean	607	90.5	2588	2740	6.4	6.3
Median	170	94.5	2500	2395	6.0	6.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	0.0	None	None	None	None
Max	22600	649	None	None	None	None
Mean	278	87.3	None	None	None	None
Median	130	77	None	None	None	None
Min Monthly Mean	0.00	0.51	None	None	None	None
Max Monthly Mean	4025	244	None	None	None	None

Flow = cfs EC = uS/cm

Table A5: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06324500 POWDER RIVER NEAR MOORHEAD, MT

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	142	23	170	23	156	23
Min	20	5.1	591	957	0.1	1.0
Max	12100	368	5000	3370	9.0	8.0
Mean	532	125	2027	2074	4.6	4.1
Median	272	90	2125	1870	5.0	4.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	5.0	None	902	None	None
Max	27500	975	None	3960	None	None
Mean	455	117	None	2000	None	None
Median	220	81	None	1920	None	None
Min Monthly Mean	0.60	31.1	None	1239	None	None
Max Monthly Mean	5553	368	None	3451	None	None

Flow = cfs EC = uS/cm

Table A6: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06326500 POWDER RIVER NEAR LOCATE, MT

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	160	11	623	11	603	11
Min	1.1	3.1	338	1270	0.6	2.0
Max	24100	400	5760	3110	25.0	9.0
Mean	804	93.5	1879	2377	3.9	5.6
Median	300	63.0	1890	2540	4.0	5.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	2.0	523	None	None	None
Max	26000	704	4000	None	None	None
Mean	590	79.1	2066	None	None	None
Median	240	60	2150	None	None	None
Min Monthly Mean	0.19	9.34	None	None	None	None
Max Monthly Mean	8045	290	None	None	None	None

Flow = cfs EC = uS/cm

Table A7: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06316400 CRAZY WOMAN CREEK AT UPPER STATION, NEAR ARVADA, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	188	24	179	24	185	24
Min	0.03	0.03	348	1100	0.4	1.0
Max	1640	36.0	4170	3030	5.0	4.0
Mean	80.7	10.0	1737	1949	2	2.3
Median	26.0	8.75	1620	1820	2.0	2.0
	Mean Streamflow		Specific Conductance		SAR	
Realtime Statistics	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	0.01	None	1320	None	None
Max	2030	90	None	2970	None	None
Mean	50.2	9.52	None	2288	None	None
Median	18	7.4	None	2370	None	None
Min Monthly Mean	0.00	0.11	None	1691	None	None
Max Monthly Mean	629	27.5	None	2787	None	None

Flow = cfs EC = uS/cm

Table A8: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)
06324000 CLEAR CREEK NEAR ARVADA, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	317	24	236	24	204	24
Min	1.9	0.4	230	717	0.4	0.8
Max	3540	164	2360	1980	3.0	3.0
Mean	239	49.6	1170	1223	1.4	1.2
Median	96.0	49.0	1150	1185	1.0	1.0
	Mean Streamflow		Specific Conductance		SAR	
Realtime Statistics	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	0.35	None	716	None	None
Max	4880	202	None	2070	None	None
Mean	182	45.6	None	1341	None	None
Median	86.0	50.0	None	1280	None	None
Min Monthly Mean	0.98	1.00	None	924	None	None
Max Monthly Mean	2229	74.3	None	1925	None	None

Flow = cfs EC = uS/cm

Table A9: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)

06324970 LITTLE POWDER RIVER ABOVE DRY CREEK, NEAR WESTON, WY

Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	256	12	165	12	185	12
Min	0.0	0.01	373	725	2.0	3.0
Max	4210	23	5500	5250	13.0	11.0
Mean	60.3	4.7	2809	3363	6.1	7.7
Median	3.4	0.49	2880	3410	6.0	8.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	0.0	0.0	None	None	None	None
Max	5000	90.0	None	None	None	None
Mean	22.8	1.96	None	None	None	None
Median	2.9	0.37	None	None	None	None
Min Monthly Mean	0.00	0.02	None	None	None	None
Max Monthly Mean	703	9.32	None	None	None	None

Flow = cfs EC = uS/cm

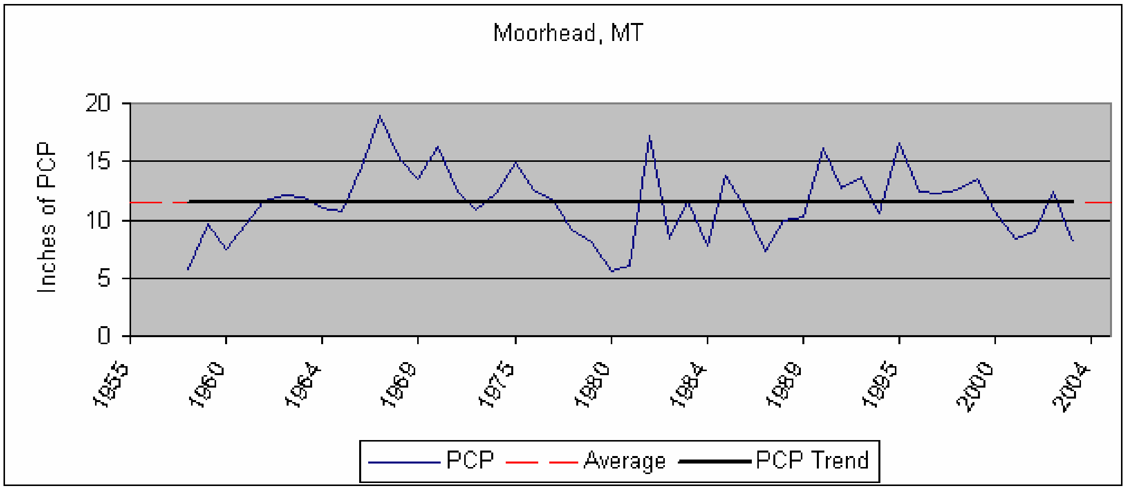
Table A10: Summary Statistics - Water Year 2004 vs. Historical (Pre-1999)

06325500 LITTLE POWDER RIVER NEAR BROADUS, MT
06325550 LITTLE POWDER RIVER AT MOUTH, NEAR BROADUS, MT
(Pre-1999 at 06325550; site relocated upstream in 2002)

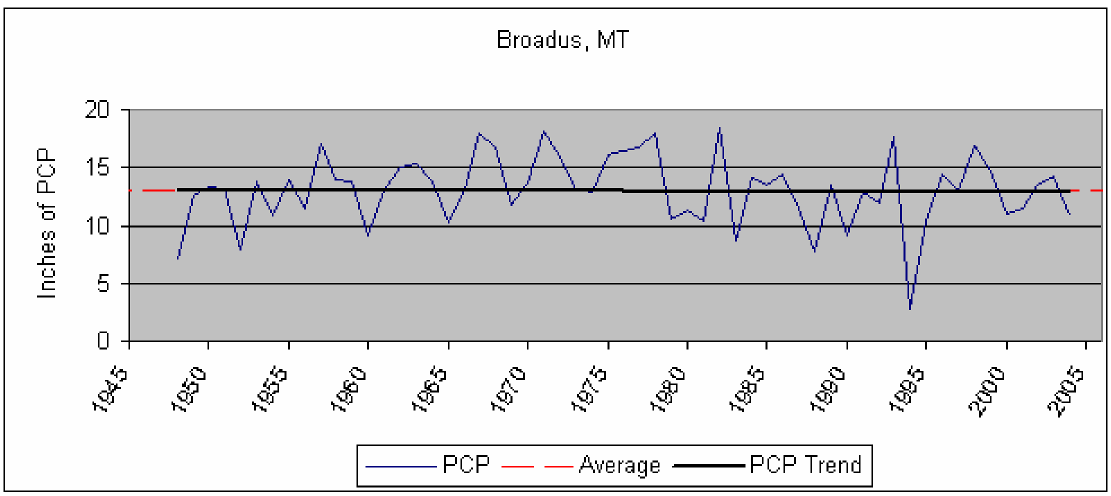
Analytical Statistics	Instant. Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
n	14	11	12	11	14	11
Min	0.22	1.9	1440	1250	6.0	4.0
Max	69	23	3240	2610	14.0	14.0
Mean	10.2	6.2	2240	1890	10.2	10.4
Median	3.2	3.0	2110	1750	10.0	11.0
Realtime Statistics	Mean Streamflow		Specific Conductance		SAR	
	pre-99	2004	pre-99	2004	pre-99	2004
Min	None	None	None	None	None	None
Max	None	None	None	None	None	None
Mean	None	None	None	None	None	None
Median	None	None	None	None	None	None
Min Monthly Mean	None	None	None	None	None	None
Max Monthly Mean	None	None	None	None	None	None

Flow = cfs EC = uS/cm

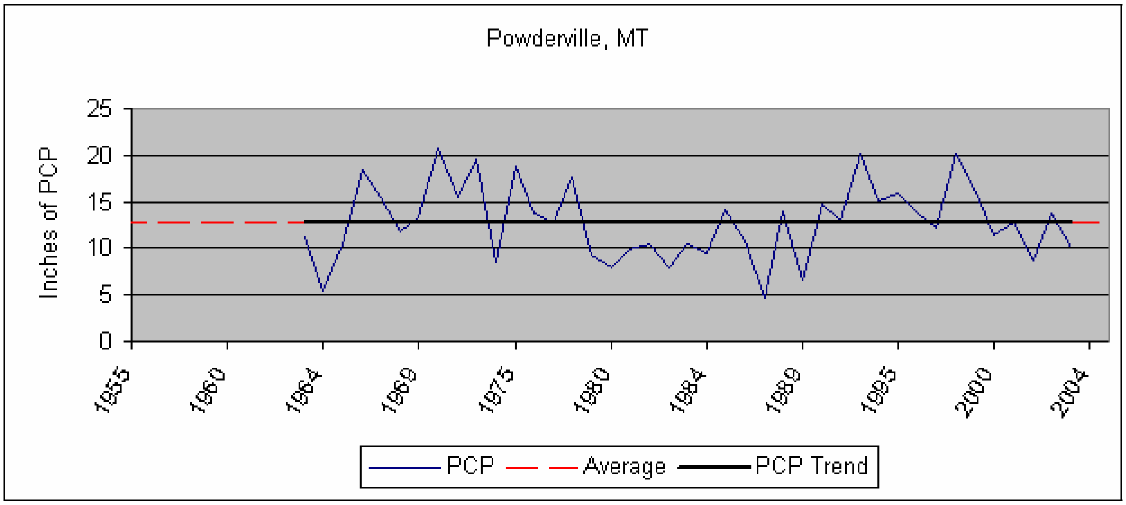
Appendix B: Precipitation Data



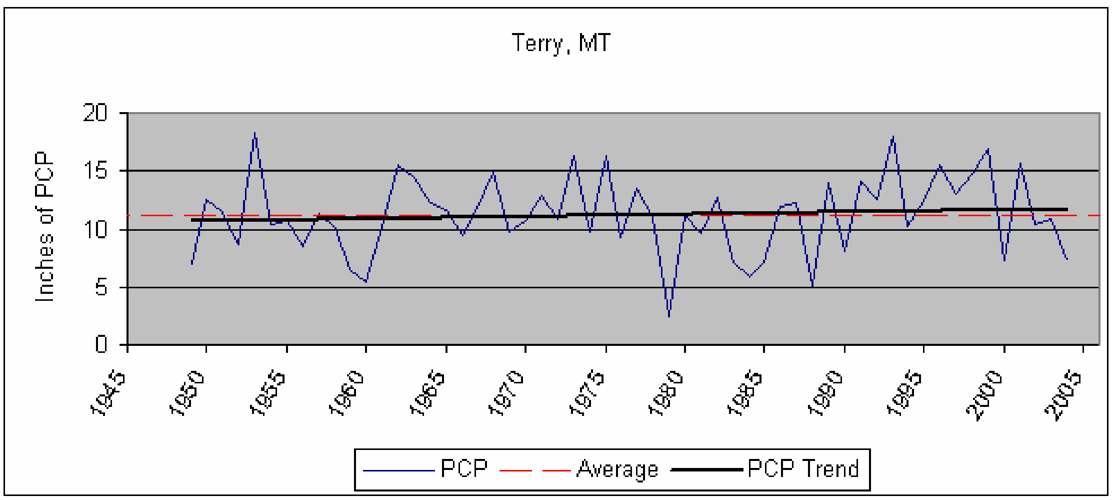
Precipitation data from Moorhead show little change in overall precipitation since 1958; however annual precipitation totals have been mostly lower than average since 1999.



Precipitation data from Broadus show little change in overall precipitation since 1948; however annual precipitation totals have been mostly lower than average since 1999.



Precipitation data from Powderville show little change in overall precipitation since 1964; however annual precipitation totals have been mostly lower than average since 1999.



Precipitation data from Terry show a slight increase in overall precipitation since 1948; however annual precipitation totals have been mostly lower than average since 1999.