Water Year 2007
Overview of Surface Water Monitoring Data for SC, SAR and Flow in the Powder River Watershed

This cover photo shows the Powder River above Salt Creek, Wyoming
(photo obtained from http://wy.water.usgs.gov/projects/atg/index.htm)

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Introduction

When Coal Bed Natural Gas (CBNG) is developed, the methane must be allowed to desorb from the coal so that it can flow to production wells. This desorption is typically achieved by pumping groundwater (referred to as CBNG water) from the coal bed aquifer to reduce the hydrostatic pressure within the coal seam (allowing the methane to desorb) and create a pressure gradient within the aquifer. This pressure gradient causes methane to flow towards the pumping wells.

The management of CBNG water may result in it being introduced into surface waters. CBNG water in the Montana portion of the Powder River Structural Basin (PRB) is moderately saline, having a Specific Conductance (SC) on the order of 2,000 microSiemens per centimeter at 25 degrees Celsius (μS/cm). SC is the ability for water to conduct an electrical current at 25 degrees Celsius, and it is proportional to salinity (concentration of major ions, or salts). High salinity irrigation water may result in decreased crop yields depending on the crop being grown (See Figs. 1 and 3). The technical definition of Electrical Conductivity EC is "the ability of water to conduct a current" (Stednick, 1991); however the Montana Department of Environmental Quality (MDEQ) regulations define EC as "the ability of water to conduct an electrical current at 25ºC". Since the EC definition is the same as the technical definition of SC, the SC values discussed in this report are directly comparable to the EC standards.

CBNG water in the Powder River Basin is a sodium-bicarbonate (Na-HCO_3) type water. The dominance of sodium cations in CBNG water results in a high Sodium Adsorption Ratio (SAR; which is a complex ratio of Na to Ca+Mg) that typically ranges between 30 and 60 (ALL, 2001). Irrigation water with high SAR values may cause impacts to soil structure, and impair the ability for clay rich soils to infiltrate water (see Figs. 2 and 3).

One method of managing CBNG produced water in the PRB is through treated or untreated discharge to surface waters under National Pollutant Discharge Elimination System (NPDES) permits, implemented under the Clean Water Act. In Montana, NPDES permitting is conducted by the Montana Department of Environmental Quality (MDEQ) under the Montana Pollutant Discharge Elimination System (MPDES) permit program. There were no active MPDES permits for CBNG in water year 2007 in the Powder River Watershed. In Wyoming, NPDES discharge permitting is conducted by the Wyoming Department of Environmental Quality (WDEQ) under the Wyoming Pollutant Discharge Elimination System (WYPDES). Surface discharge, either with or without treatment, and to on and off channel impoundments are the major methods of water management in the Wyoming portion of the Powder River Watershed (McKinley, pers com. 2006).

Large scale CBNG development began in the Powder River structural basin in approximately 1999. The first CNBG development within the Powder River watershed began in 2001 (Shreve, pers com., 2007). In response to the potential for CBNG development in the Powder River Basin, the MDEQ has developed surface water-quality standards for EC and SAR in the Powder River watershed. These standards provide criteria against which to compare the monitoring data. These standards are summarized in Table 1 below. The MDEQ standards have been reviewed and approved by the United States Environmental Protection Agency (EPA), and therefore have Clean Water Act standing. Also, note that irrigation season standards are different from the non-irrigation season. MDEQ standards are applicable at the Wyoming-Montana state line; however they are not applicable in Wyoming. It should be noted that these values are used solely as a point of comparison; the comparisons in this report do not constitute regulatory determinations.

During Water Year 2007 the Montana Board of Environmental Review (BER) modified the standards which apply to CBNG in Montana. The most substantial change adopted by the BER was to designate EC and SAR "harmful" parameters. This change has been approved by the EPA, and is in force at this time. This designation requires an "authorization to degrade" if a new or increased discharge would cause an increase in the concentration of a harmful parameter which was already above 40% of the standard. Within the Powder River watershed historical water quality values are rarely less than these 40% criteria.

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

	Irrigation Season (March-October)				Non-Irrigation Season (November-February)			
Stream	**Monthly Mean EC (uS/cm)**	**NTE EC (uS/cm)**	**Monthly Mean SAR**	**NTE SAR**	**Monthly Mean EC (uS/cm)**	**NTE EC (uS/cm)**	**Monthly Mean 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 in the Powder River Basin (IWG) has identified regional surface water monitoring objectives (see Table 2). The status of the stations in the Powder River Watershed for water year 2007 (10/1/06-9/30/07) are listed on Table 3 below. The locations of the active stations are shown on Map 1. Data collected at these stations included continuous flow, continuous SC, continuous estimated SAR, and periodic analytical sampling. Analytical sampling includes the measurement of flow, field parameters (SC, pH, temperature, and dissolved oxygen) and includes the collection of water-quality samples. Although these samples were analyzed by the USGS for many parameters, this report will focus on SC, SAR, and flow. SC and SAR are considered to be the parameters most likely to be affected by CBNG development (MDEQ, 2003), and SC and SAR in the natural system fluctuate significantly with flow (Clark and Mason, 2007). The monitoring at these stations was funded by the USGS, WDEQ, WSEO, MDEQ, and MDNRC. An expanded set of analytical data are available from the USGS at http://waterdata.usgs.gov/nwis.

Table 2: IWG Recommended Surface Water Monitoring Plan

Stream Type	Constituent Class	Sampling Frequency
Mainstem	Streamflow	Continuous
	Field Measurements	12 times per year
	Major Ions	12 times per year
	Suspended sediment	12 times per year
	Primary Metals	12 times per year
	Secondary Metals	2 times per year
	Nutrients	2 times per year
Tributary	Streamflow	Continuous
	Field Measurements	6 times per year
	Major Ions	6 times per year
	Suspended sediment	6 times per year
	Primary Metals	6 times per year
	Secondary Metals	2 times per year
	Nutrients	2 times per year

Data Review

For all sites, please see the figures section for graphical display of the data. Tabulated summary statistics for the sites are provided on Tables 4 and 5 below.

For each station a summary of the Daily Mean flow and daily mean SC recorded by continuous monitors along with daily mean estimated SAR data collected during water year 2007 are presented. Note that the minimum and maximum values shown represent the minimum and maximum Daily Mean values recorded; not the instantaneous minimum or maximum values recorded. Analytical results for SC and SAR measured from periodically collected water-quality samples are also presented. Analytical results are compared to the MDEQ "not to exceed" (NTE) surface water standards for EC and SAR where they are applicable. For comparison to the Monthly Mean EC and SAR standards the Monthly Mean values are calculated as the simple average of all the Daily Mean values and analytical results for each calendar month, so long as at least nine values were available. Note that within the figures section the daily mean and analytical data are combined when discussing the range of measured values recorded. SC vs. Flow, SAR vs. Flow, and SC vs. SAR with historical data are presented in graphical form to allow evaluation of 2007 data in context.

Table 3: Status of Surface Water Monitoring relative to the IWG Surface Water Monitoring Plan in the Powder River Watershed, Water Year 2007

Site	Continuous Stream-flow	Field measure-ments	Major Ions	Nutrients	Trace elements, primary	Trace elements, secondary	Sus-pended sediment
Powder River, at Sussex	●	●	●	○	⊙	○	○
Powder River below Burger Draw, near Buffalo	○*	●	●	○	⊙	○	○
Powder River, at Arvada	●	●	●	○	⊙	○	○
Powder River, at Moorhead	●	●	●	●	●	●	●
Powder River, near Powderville	○	○	○	○	○	○	○
Powder River, near Locate	●	●	●	●	●	●	●
Crazy Woman at Upper Station, near Arvada	●	●	●	●	⊙	○	●
Clear Creek, near Arvada	●	●	●	○	⊙	○	○
Little Powder River above Dry Creek, near Weston	●	●	●	●	⊙	⊙	●
Little Powder River, near Broadus	○	●	●	●	●	●	●
Mizpah Creek, near Mizpah	○	○	○	○	○	○	○

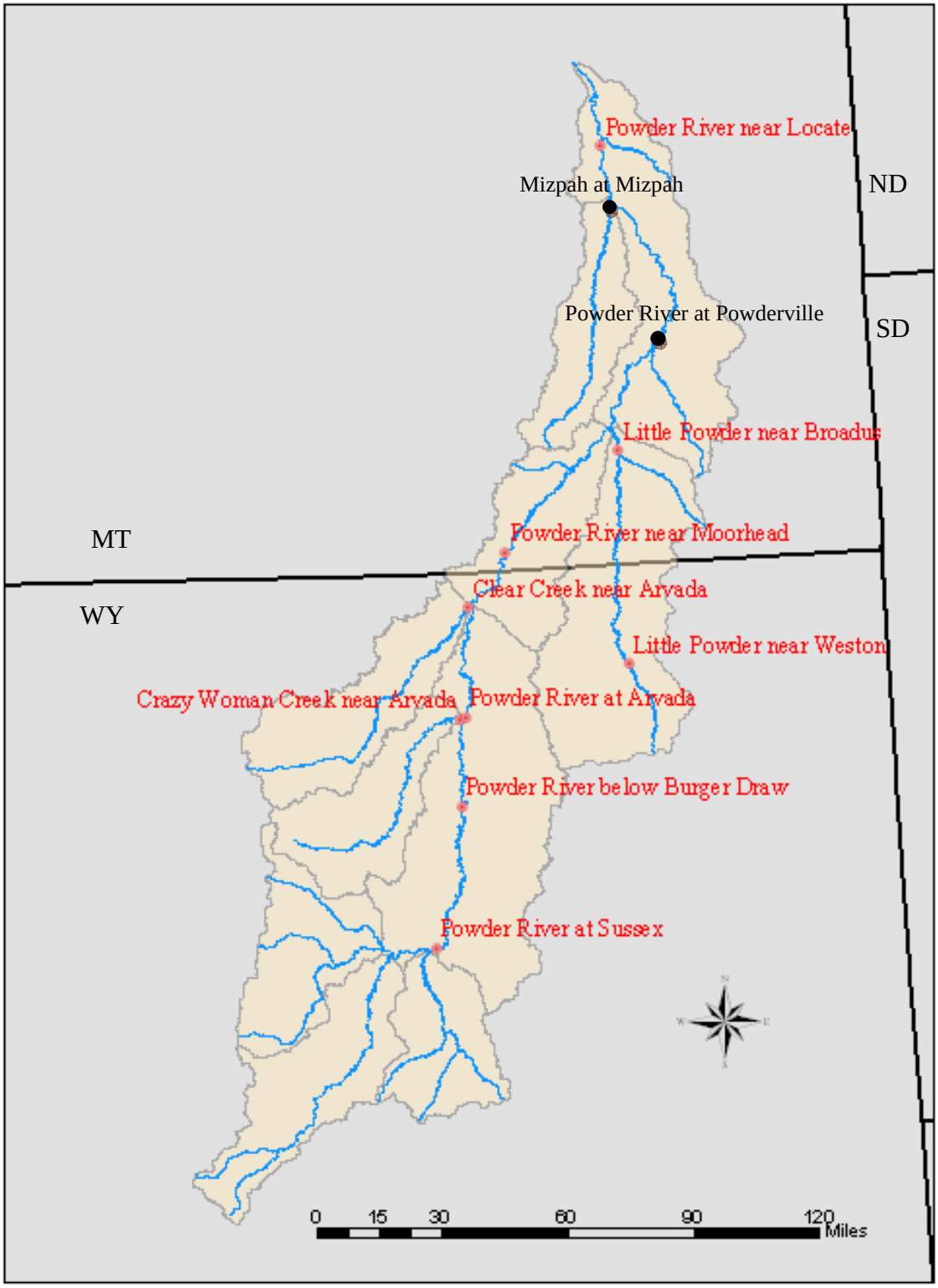
* Continuous Streamflow is collected at Powder River above Burger Draw.

● = Constituent is collected at least as frequently as recommended.

⊙ = Constituent is collected, but not as frequently as recommended.

○ = Constituent is not collected.

Map 1



Map 1 shows the Powder River Watershed as it extends from Wyoming into Montana. The locations of the 9 surface water monitoring sites (6 in Wyoming, 3 in Montana), which are the subject of this report (red), and the other stations purposed for monitoring by the IWG are also shown.

Main Stem Sites

Table 4: Water Year 2007 Summary Statistics for Mainstem Sites in the Powder River Watershed

		Daily Mean			Analytical			Monthly Mean	
		Flow (cfs)	SC (uS/cm)	SAR	Flow (cfs)	SC (uS/cm)	SAR	SC (uS/cm)	SAR
Powder River at Sussex, WY*	n	365	141	138	24	24	24	7	7
	min	15.0	1010	1.1	17.0	1280	3.4	1494	2.9
	max	3190	5650	16.5	853	5730	15.6	4269	11.7
	mean	170	3070	8.0	165	2548	6.2	2781	7.0
	median	100	3090	8.0	109	2010	4.6	2437	5.7
Powder River below Burger Draw, near Buffalo, WY*+	n	365	---	---	12	12	12	---	---
	min	18.0	---	---	19.0	1630	4.6	---	---
	max	3230	---	---	572	3690	10.2	---	---
	mean	188	---	---	187	2423	6.2	---	---
	median	107	---	---	103	2225	5.4	---	---
Powder River at Arvada, WY*	n	365	---	---	24	24	24	---	---
	min	15	---	---	17	1390	3.7	---	---
	max	2910	---	---	656	3730	10.8	---	---
	mean	206	---	---	181	2265	5.9	---	---
	median	96	---	---	100	2220	5.7	---	---
Powder River near Moorhead, MT	n	365	202	---	25	25	24	7	---
	min	47	663	---	60	684	2.3	941	---
	max	3560	3160	---	3430	2600	6.9	2106	---
	mean	349	1669	---	384	1779	4.3	1690	---
	median	147	1665	---	163	1840	4.3	1926	---
Powder River near Locate, MT	n	365	---	---	13	13	12	---	---
	min	35	---	---	48.0	634	3.0	---	---
	max	4840	---	---	3470	3580	7.7	---	---
	mean	478	---	---	526	2107	5.4	---	---
	median	110	---	---	100	2290	5.3	---	---

SC = Specific Conductance
SAR = Sodium Adsorption Ratio
cfs = cubic feet per second
Indicates exceedance of an applicable standard.
uS/cm = microSiemens per centimeter
n = number of data points
---- = no data
* = MDEQ Standards do not apply.
+ = Mean Daily Flow is determined from Powder River above Burger Draw
Daily Mean values are calcualted from the avalible seasonal data, which in many cases is only collected from March to October.
Monthly Mean values are calcualted only when there are at least 9 values collected in the calender month.

Powder River at Sussex

Flow and SC were measured, and SAR was estimated in realtime at this site. Continuous SC and estimated SAR were not collected in the winter (10/12/06 through 3/21/07). Water-quality samples were also collected. Daily Mean flow values ranged from 15 to 3190 cfs, with the mean being 170 cfs (see Fig. 4).

Daily Mean SC data collected at this station ranged from 1010 to 5650 µS/cm, with a mean value of 3070 µS/cm. Analytical SC values at this site ranged from 1280 to 5730 µS/cm, with the mean being 2548 µS/cm. Monthly Mean SC values for this site ranged from 1494 to 4269 µS/cm, with the mean being 2781 µS/cm. Daily Mean SAR data collected at this station ranged from 1.1 to 16.5, with a mean value of 8.0. Analytical SAR values at this site ranged from 3.4 to 15.6 with

the mean being 6.2. Monthly Mean SAR values for this site ranged from 2.9 to 11.7, with the mean being 7.0 (see Fig. 5).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 6-8).

Powder River below Burger Draw

Flow was measured realtime at the station "Powder River above Burger Draw". This flow data is generally representative of flow at this site (see measured vs. daily mean values on Fig. 9). Water-quality samples were also collected. Daily Mean flow values at the station above Burger Draw ranged from 18 to 3230 cfs, with the mean being 188 cfs (see Fig. 9).

Analytical SC values at this site ranged from 1630 to 3690 µS/cm, with the mean being 2423 µS/cm. Analytical SAR values at this site ranged from 4.6 to 10.2 with the mean being 6.2 (see Fig. 10). There is insufficient data to calculate Monthly Mean SC or SAR values.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 11-13).

Powder River at Arvada

Flow was measured in realtime at this site. Water-quality samples were also collected. Daily Mean flow values ranged from 15 to 2910 cfs, with the mean being 206 cfs (see Fig. 14).

Analytical SC values at this site ranged from 1390 to 3730 µS/cm, with the mean being 2265 µS/cm. Analytical SAR values at this site ranged from 3.7 to 10.8 with the mean being 5.9 (see Fig. 15). There is insufficient data to calculate Monthly Mean SC or SAR values.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 16-18).

Powder River near Moorhead

Realtime flow and SC were measured continuously at this site; however SC was not collected in the winter (10/31/06 through 03/13/07). Water-quality samples were also collected. Daily Mean flow values ranged from 47 to 3560 cfs, with the mean being 349 cfs (see Fig. 19).

Daily Mean SC data collected at this station ranged from 663 to 3160 µS/cm, with a mean value of 1669 µS/cm. Analytical SC values at this site ranged from 684 to 2600 µS/cm, with the mean being 1779 µS/cm. Monthly Mean SC values for this site ranged from 941 to 2106 µS/cm, with the mean being 1690 µS/cm. Analytical SAR values at this site ranged from 2.3 to 6.9 with the mean being 4.3 (see Fig. 20). There is insufficient data to calculate Monthly Mean SAR values.

Daily mean SC values were above the MDEQ NTE standard for a total of 16 days between 7/19/07 and 9/3/07. Analytical SC values were at or above the EC instantaneous maximum standard standards for 2 of the 25 samples. Monthly Mean SC values were in excess of the Monthly Mean EC standard during August. Analytical SAR values did not exceed the instantaneous maximum standard. There was insufficient data to evaluate the Monthly Mean SAR standard (see Fig. 20).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 21-23).

Powder River near Locate

Realtime flow was measured continuously at this site. Periodic water-quality samples were also collected. Daily Mean flow values ranged from 35 to 4840 cfs, with the mean being 478 cfs (see Fig. 24).

Analytical SC values at this site ranged from 634 to 3580 μS/cm, with the mean being 2107 μS/cm. Analytical SAR values at this site ranged from 3.0 to 7.7 with the mean being 5.4 (see Fig. 25). There is insufficient data to calculate Monthly Mean SC or SAR values.

Analytical SC values were above the EC instantaneous maximum standard for 3 of the 12 samples collected. Analytical SAR values did not exceed the instantaneous maximum SAR standard (see Fig. 25). There was insufficient data to evaluate the Monthly Mean EC or SAR standards.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 26-28).

Tributary Sites

Table 5: Water Year 2007 Summary Statistics for Tributary Sites in the Powder River Watershed

		Daily Mean			Analytical			Monthly Mean	
		Flow (cfs)	SC (uS/cm)	SAR	Flow (cfs)	SC (uS/cm)	SAR	SC (uS/cm)	SAR
Crazy Woman, near Arvada, WY*	n	365	184	181	24	23	23	8	8
	min	0.0	604	0.8	0.00	1030	1.3	1245	1.5
	max	396	3260	3.7	64	3600	4.1	2909	3.4
	mean	10.7	1825	2.1	9	2184	2.5	1963	2.3
	median	1.2	1740	1.9	2	2340	2.6	1652	1.9
Clear Creek near Arvada, WY*	n	365	200	200	25	25	24	8	8
	min	1.9	235	0.4	9.0	305	0.5	386	0.6
	max	1530	1680	1.8	1080	1490	1.6	1263	1.4
	mean	156	880	1.0	167	1004	1.1	910	1.1
	median	63	928	1.1	61	1070	1.2	923	1.1
Little Powder River above Dry Creek near Weston, WY*	n	365	---	---	13	13	12	---	---
	min	0.3	---	---	1.20	627	1.9	---	---
	max	3050	---	---	95	5170	10.2	---	---
	mean	50.0	---	---	23.1	3282	7.0	---	---
	median	4.2	---	---	5.6	3230	7.8	---	---
Little Powder River near Broadus, MT	n	---	---	---	12	12	12	---	---
	min	---	---	---	3.7	808	3.3	---	---
	max	---	---	---	119	3920	9.5	---	---
	mean	---	---	---	18.7	2643	6.9	---	---
	median	---	---	---	11.5	2640	7.1	---	---

SC = Specific Conductance
SAR = Sodium Adsorption Ratio
cfs = cubic feet per second
Indicates exceedance of an applicable standard.
uS/cm = microSiemens per centimeter
n = number of data points
---- = no data
* = MDEQ Standards do not apply.
Daily Mean values are calcualted from the avalible seasonal data, which in many cases is only collected from March to October.
Monthly Mean values are calcualted only when there are at least 9 values collected in the calender month.

Crazy Woman Creek near Arvada

Flow and SC were measured, and SAR was estimated in realtime at this site. SC and SAR were not collected in the winter (10/11/06 through 3/21/07). Water-quality samples were also collected. Daily Mean flow values ranged from 0 to 396 cfs, with the mean being 10.7 cfs (see Fig. 29).

Daily Mean SC data collected at this station ranged from 604 to 3260 µS/cm, with a mean value of 1870 µS/cm. Analytical SC values at this site ranged from 1030 to 3600 µS/cm, with the mean being 2184 µS/cm. Monthly Mean SC values for this site ranged from 1245 to 2909 µS/cm, with the mean being 1963 µS/cm. Daily Mean SAR data collected at this station ranged from 0.8 to 3.7, with a mean value of 2.1. Analytical SAR values at this site ranged from 1.3 to 4.1 with the mean being 2.5. Monthly Mean SAR values for this site ranged from 1.5 to 3.4, with the mean being 2.3 (see Fig. 30).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 31-33).

Clear Creek near Arvada

Flow and SC were measured, and SAR was estimated in realtime at this site. Water-quality samples were also collected. Daily Mean flow values ranged from 1.9 to 1530 cfs, with the mean being 156 cfs (see Fig. 34).

Daily Mean SC data collected at this station ranged from 235 to 1680 µS/cm, with a mean value of 880 µS/cm. Analytical SC values at this site ranged from 305 to 1490 µS/cm, with the mean being 1004 µS/cm. Monthly Mean SC values for this site ranged from 386 to 1263 µS/cm, with the mean being 910 µS/cm. Daily Mean SAR data collected at this station ranged from 0.4 to 1.8, with a mean value of 1.0. Analytical SAR values at this site ranged from 0.5 to 1.6 with the mean being 1.1. Monthly Mean SAR values for this site ranged from 0.6 to 1.4, with the mean being 1.1 (see Fig. 35).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 36-38).

Little Powder near Weston

Flow was measured continuously at this site. Water-quality samples were also collected. Daily Mean flow values ranged from 0.3 to 3050 cfs, with the mean being 50 cfs (see Fig. 39).

Analytical SC values at this site ranged from 627 to 5170 µS/cm, with the mean being 3282 µS/cm. Analytical SAR values at this site ranged from 1.9 to 10.2 with the mean being 7.0 (see Fig. 40). There is insufficient data to calculate Monthly Mean SC or SAR values.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 41-43).

Little Powder near Broadus

Flow was measured during water-quality sampling at this site. Water-quality samples were also collected. Measured flow values ranged from 3.7 to 119 cfs, with the mean being 18.7 cfs (see Fig. 44).

Analytical SC values at this site ranged from 808 to 3920 µS/cm, with the mean being 2643 µS/cm. Analytical SAR values at this site ranged from 3.3 to 9.5 with the mean being 6.9 (see Fig. 45). There is insufficient data to calculate Monthly Mean SC or SAR values.

Recorded SC values were above the EC instantaneous maximum standard for 6 of the 12 samples collected. SAR values were in excess of the instantaneous maximum standard for 3 of the 12 samples collected (see Fig. 45). There was insufficient data to evaluate the Monthly Mean EC or SAR standards.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 46-48).

Conclusions

During Water Year 2007 (October 2006-September 2007) overall flows within the Powder River watershed were slightly less than historical averages. At the most downstream station (Locate) cumulative flow was 87% of average. Very high flows were seen on some tributaries; particularly on the Little Powder River. EC and SAR are correlated with flow so an evaluation of EC and SAR must also take flow into account.

A comparison to the MDEQ surface water standards for EC and SAR showed that these standards are exceeded part of the time for every parameter at every station to which they apply.

A statistical trend analysis was not conducted for this report; however visual inspection of the SC vs. Flow, SAR vs. Flow, and SC vs. SAR graphs does not indicate obvious deviation from historical trends.

The USGS (Clark and Mason, 2007) recently published a water quality characterization report, which included a Long-Term Trend analysis for several stations in the Powder River watershed. This analysis concludes that significant trends are not seen in flow-adjusted SC values for any of the stations. Flow adjusted SAR values showed an increasing trend for the Salt Creek near Sussex (06313400), the Powder River at Sussex (06313500), and the Powder River at Arvada (06317000). Flow-adjusted SAR values for the Little Powder River above Dry Creek near Weston (06324970) show a decreasing trend. The cause of these trends was not determined. It should be kept in mind that since SAR is a ratio, increases in SAR may be the result of increases in sodium or decreases in calcium and magnesium (Bobst, 2007).

References

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Reviewers

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Figures

Figure 1: Comparison of Crop Yield to SC (Salinity) and Recorded 2007 SC Values in the Powder River Watershed

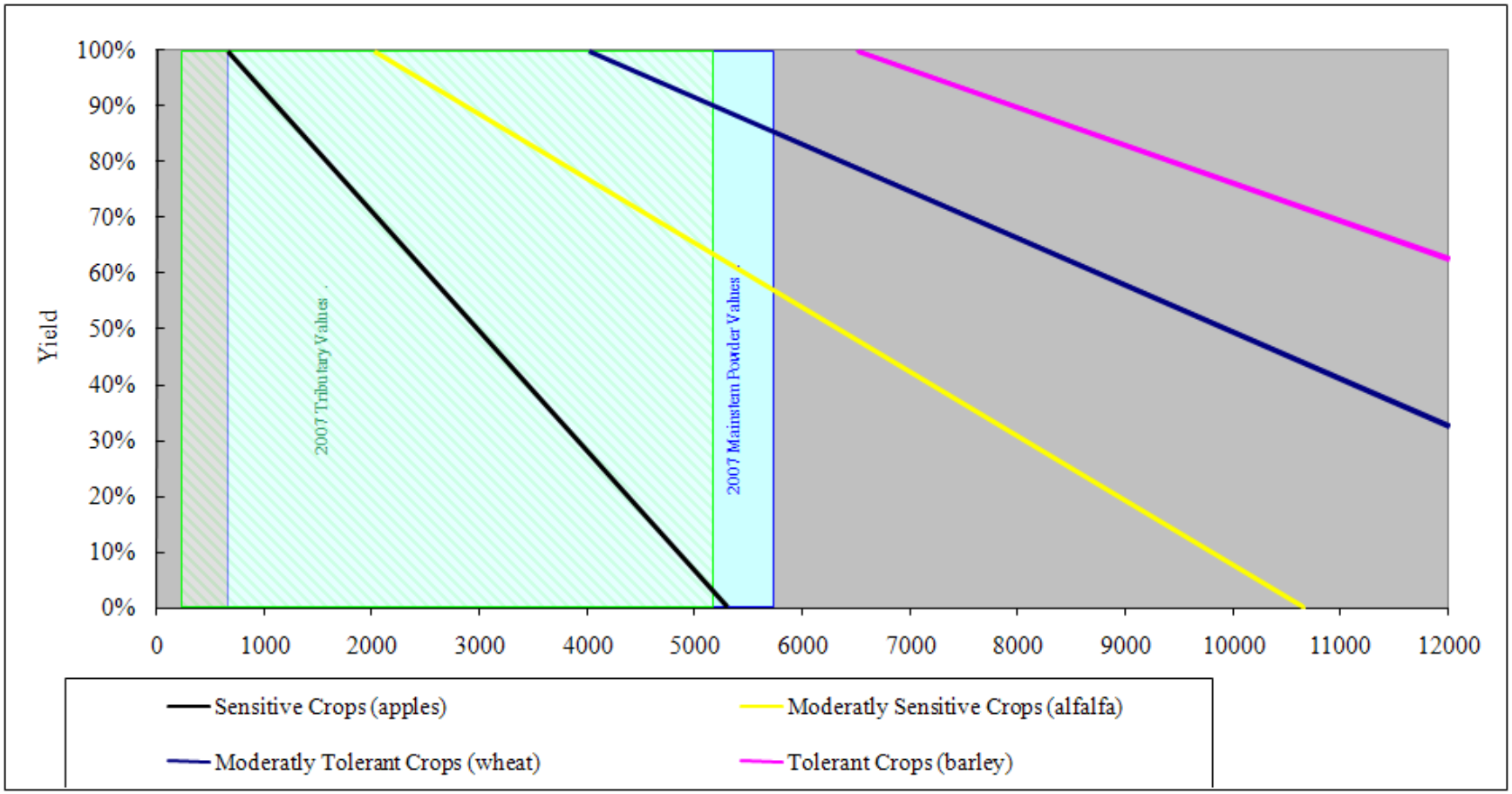

Figure 1 shows the range of SC values recorded during water year 2007 compared to yield vs. salinity curves for representative crops (Ayers and Westcott, 1985). Note that yield comparisons are made to that which would be attained using low salinity irrigation water, and assumes that all other factors (including water availability) are equal. Mainstem values ranged from 634 to 5730 uS/cm. Tributary values ranged from 235 to 5170 uS/cm.

Figure 2: Comparison of Infiltration Criteria and Recorded 2007 SC and SAR Values in the Powder River Watershed

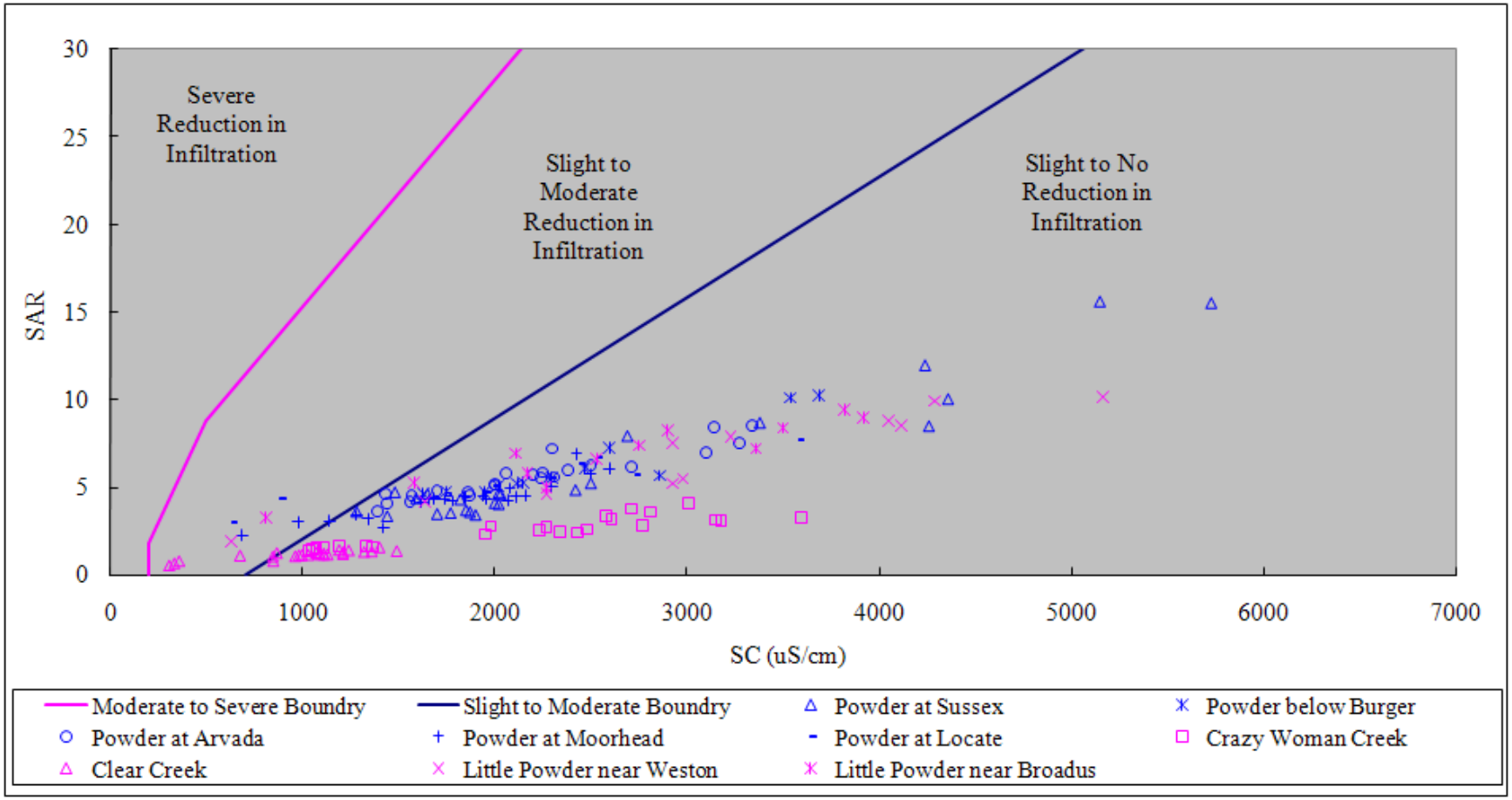

Figure 2 shows water quality data from water year 2007 in the Powder River Watershed compared to the infiltration criteria developed by Hanson et al. (1999). Most values fall within the Slight to No reduction in infiltration field; however individual samples from the Powder River at Moorhead, Powder River at Locate, Clear Creek, Little Powder near Weston, and the Little Powder near Broadus fall within the Slight to Moderate reduction field.

Figure 3: Comparison of Irrigation Water Classification and Recorded 2007 SC and SAR Values in the Powder River Watershed

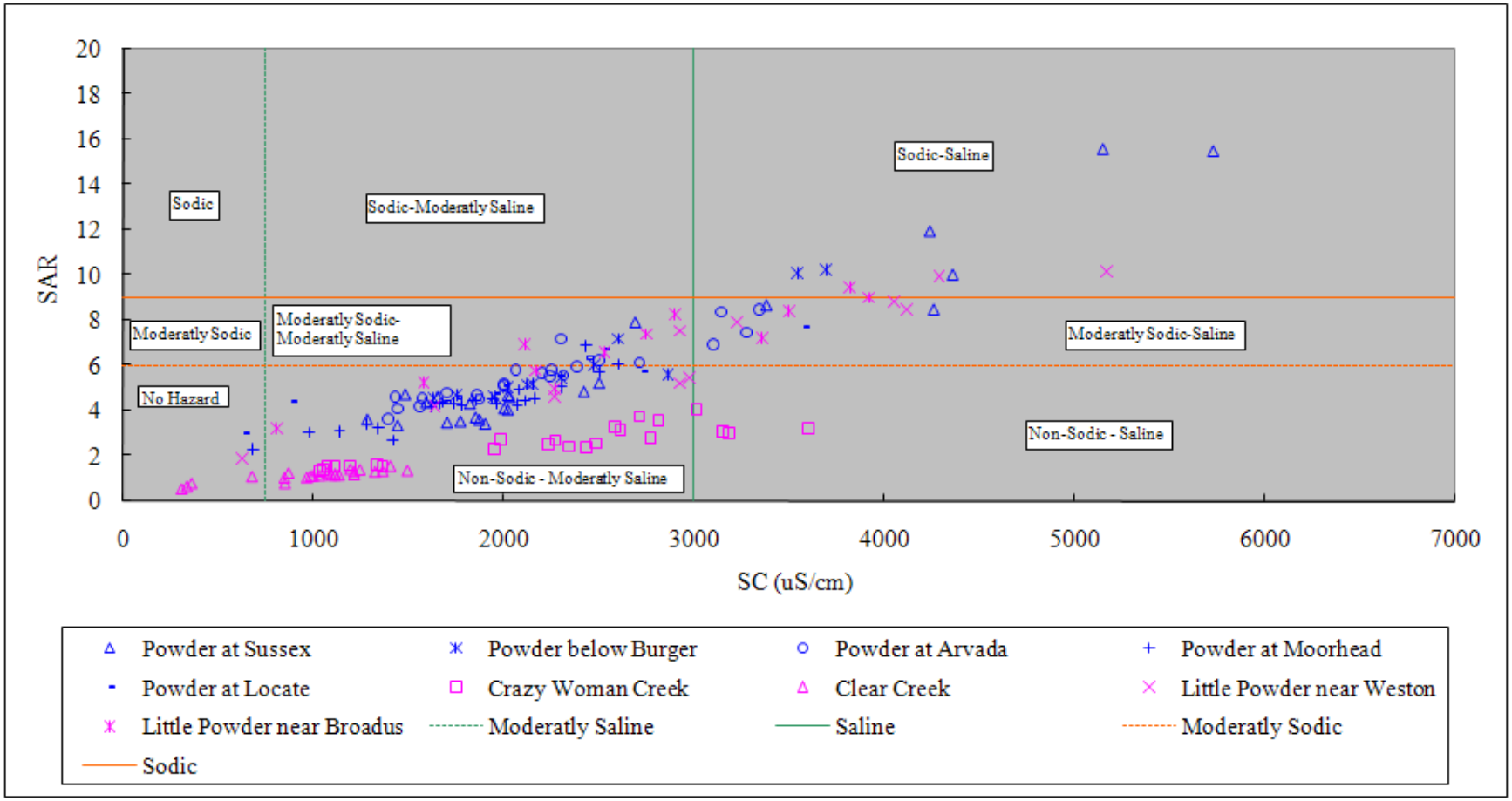

Figure 3 shows water quality data from water year 2007 in the Powder River Watershed compared to irrigation water classifications (Western Fertilizer Handbook, 1995). Most values fall within the Non-Sodic-Moderately Saline field; however samples also fall within the No Hazard, Non-Sodic-Saline, Moderately Sodic – Moderately Saline, Moderately Sodic- Saline, and Sodic – Saline fields.

Figure 4: Powder River at Sussex, WY

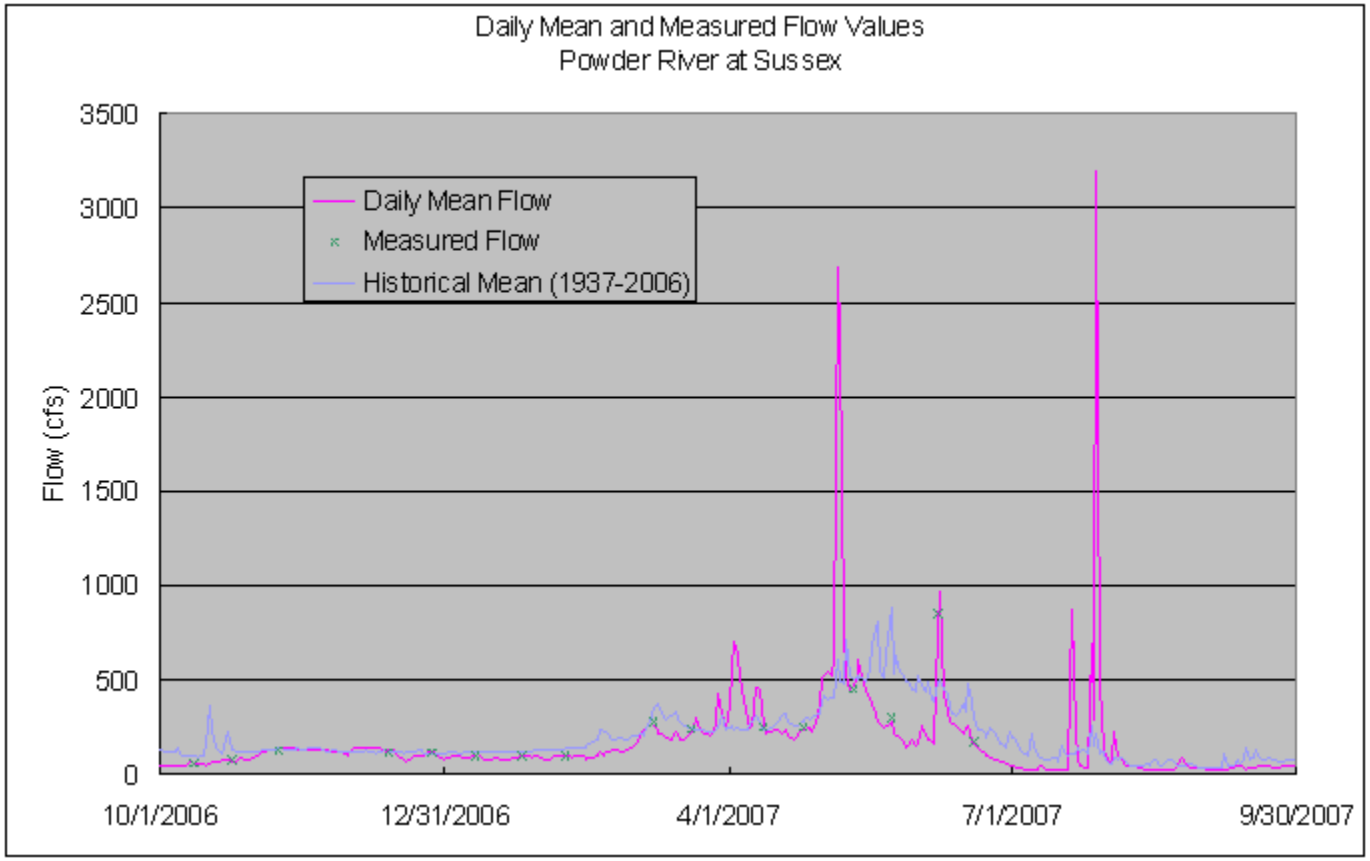

Figure 4 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for the Powder River at Sussex. Flow values ranged from 15 to 3190 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 5: Powder River at Sussex, WY

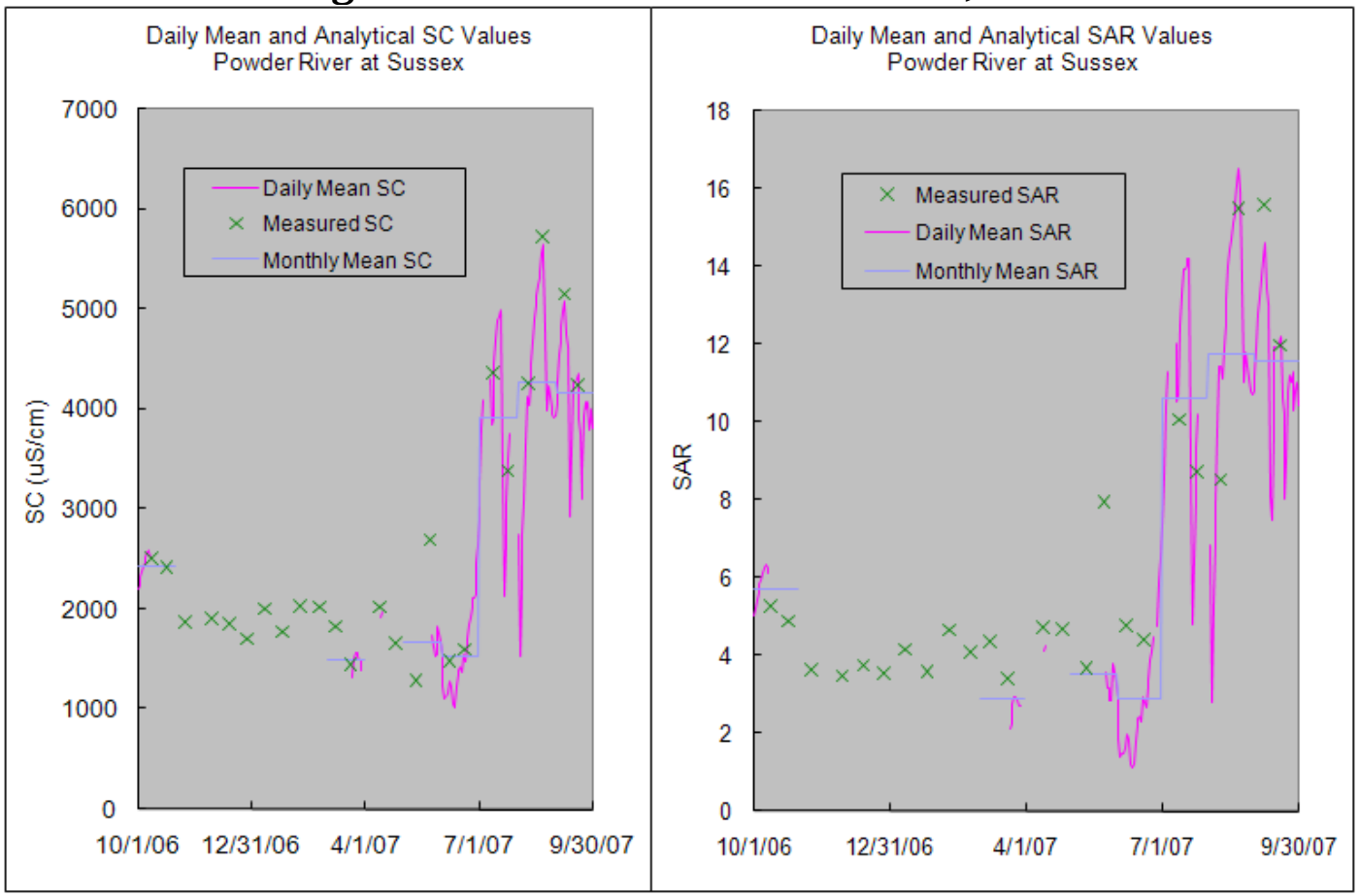

Figure 5 shows analytical and daily mean SC values (A) and analytical and daily mean SAR values (B) in time series plots for water year 2007 for the Powder River at Sussex. Monthly Mean SC and SAR values are also shown. SC values ranged from 1010 to 5730 uS/cm. SAR values ranged from 1.1 to 16.5.

Figure 6: Powder River at Sussex, WY

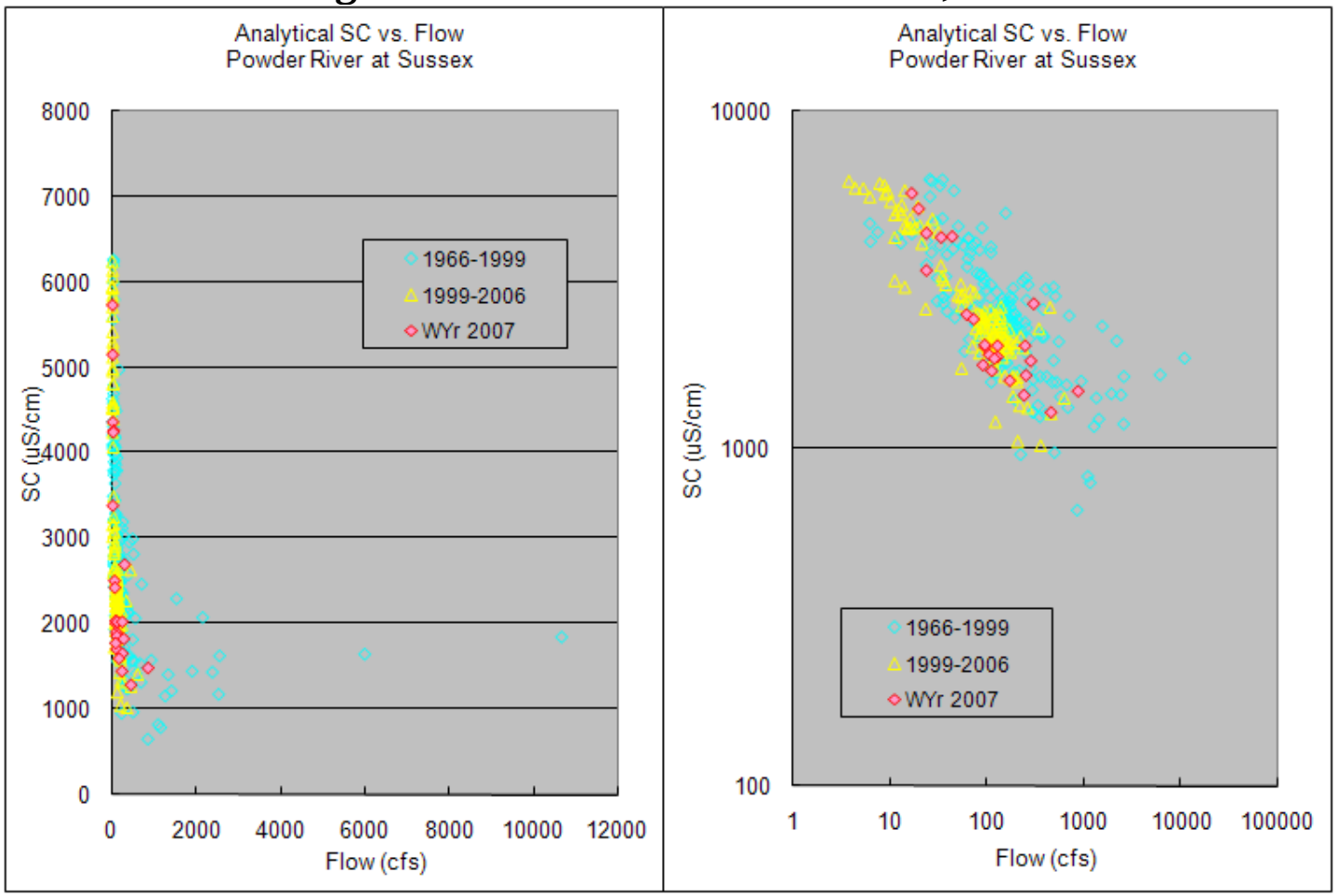

Figure 6 shows analytical SC vs. Flow data for water year 2007 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 7: Powder River at Sussex, WY

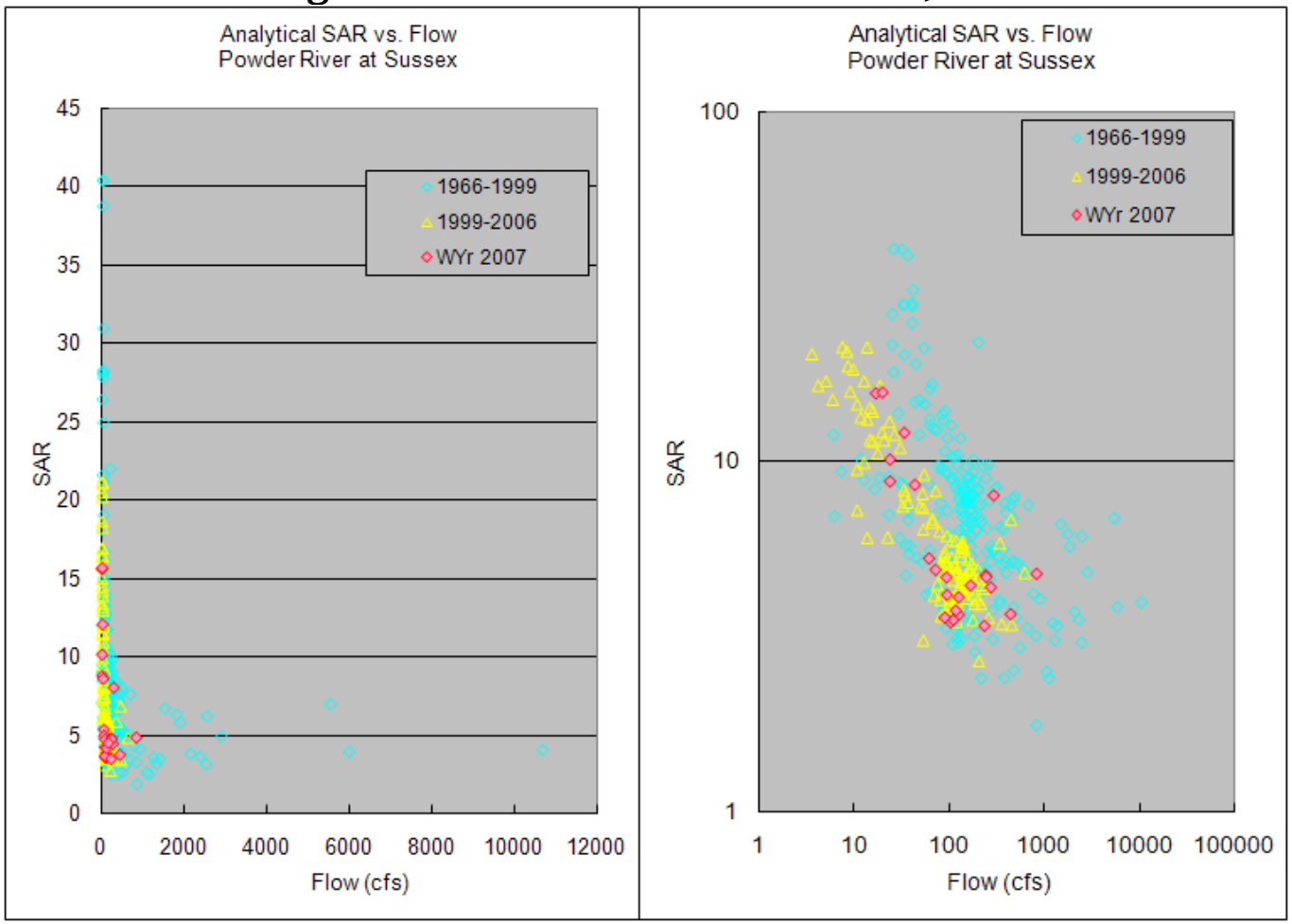

Figure 7 shows analytical SAR vs. Flow data for water year 2007 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 8: Powder River at Sussex, WY

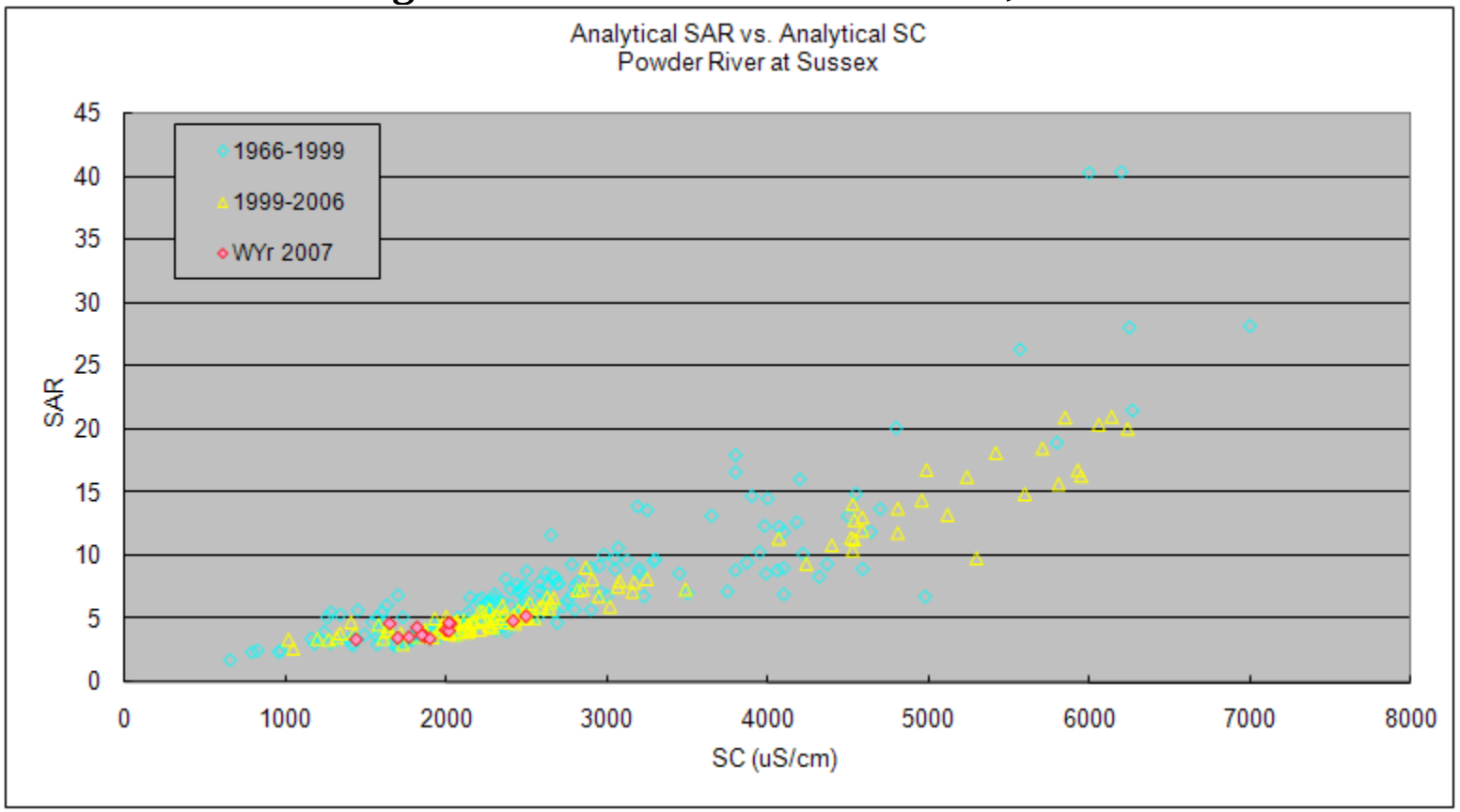

Figure 8 shows analytical SAR vs. analytical SC data for water year 2007 for the Powder River at Sussex. Historical SAR vs. SC data are also shown to place the data in context.

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

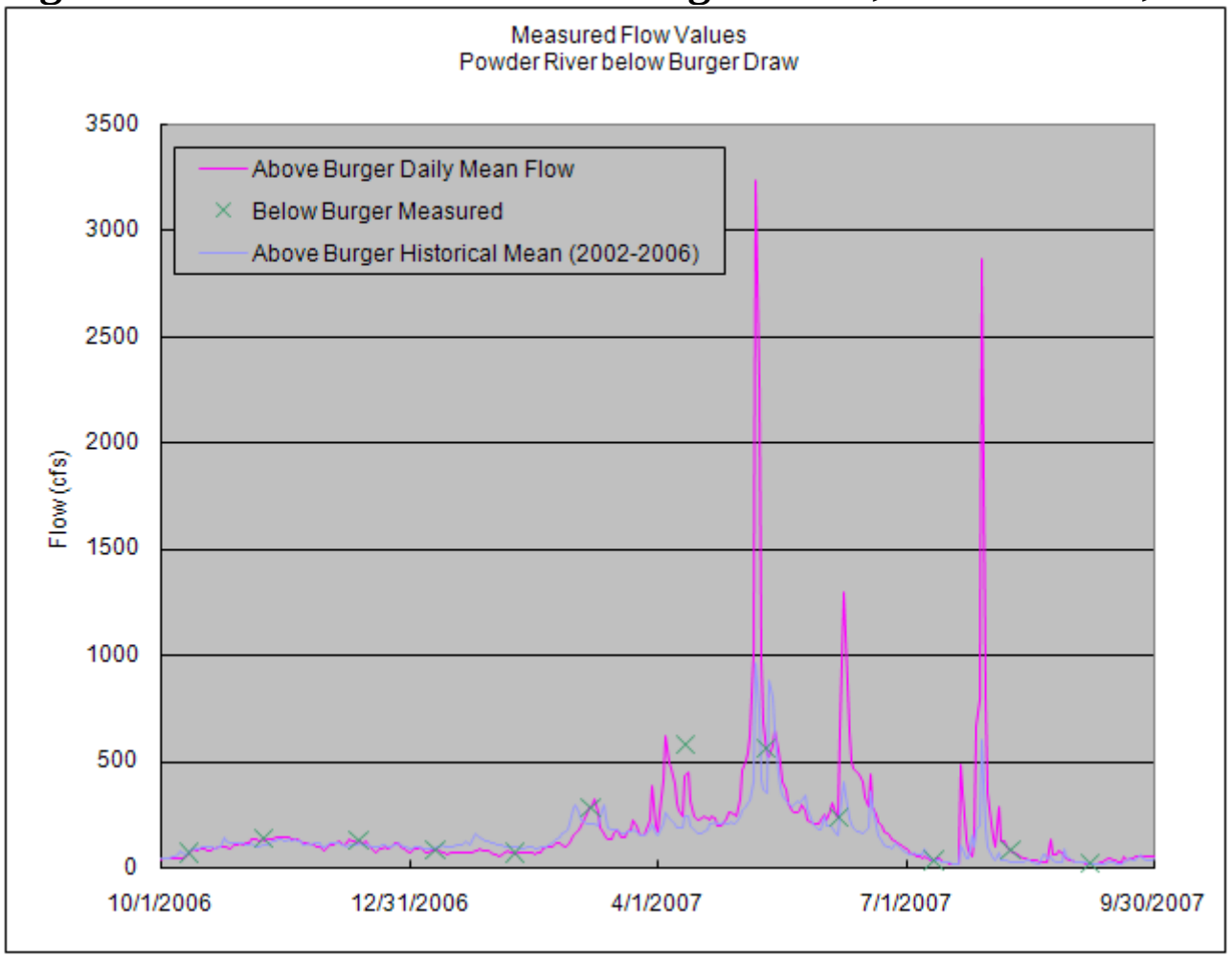

Figure 9 shows field measurements of flow in a time series plot for water year 2007 for the Powder River above and below Burger Draw. Recorded flow values from above Burger Draw ranged from 18 to 3230 cfs. The historical average Daily Mean flow values are also shown to place the data in context. Flow is not measured continuously below Burger Draw, however it is recorded continuously above Burger Draw.

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

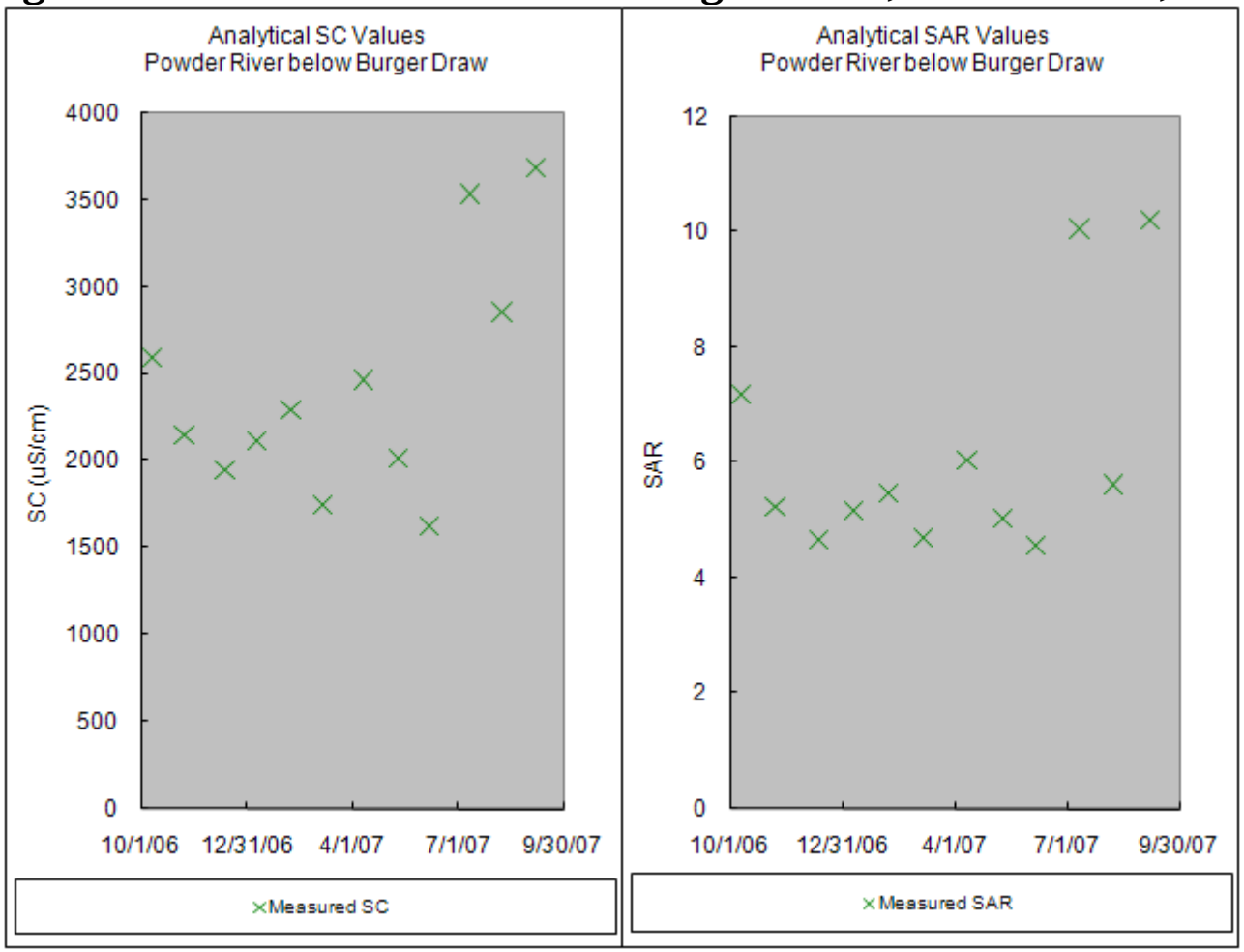

Figure 10 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2007 for the Powder River below Burger Draw. SC values ranged from 1630 to 3690 uS/cm. SAR values ranged from 4.6 to 10.2.

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

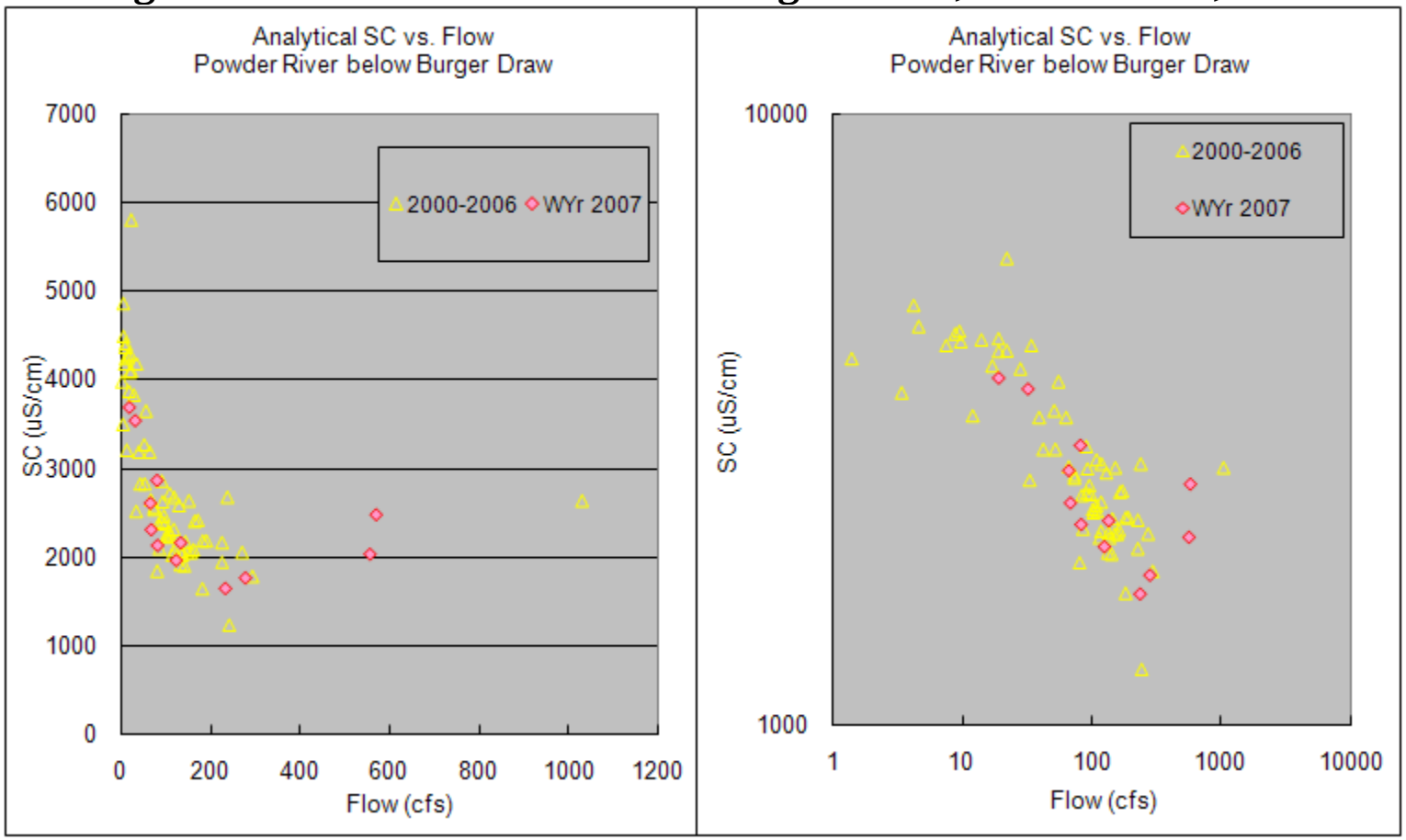

Figure 11 shows analytical SC vs. Flow data for water year 2007 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

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

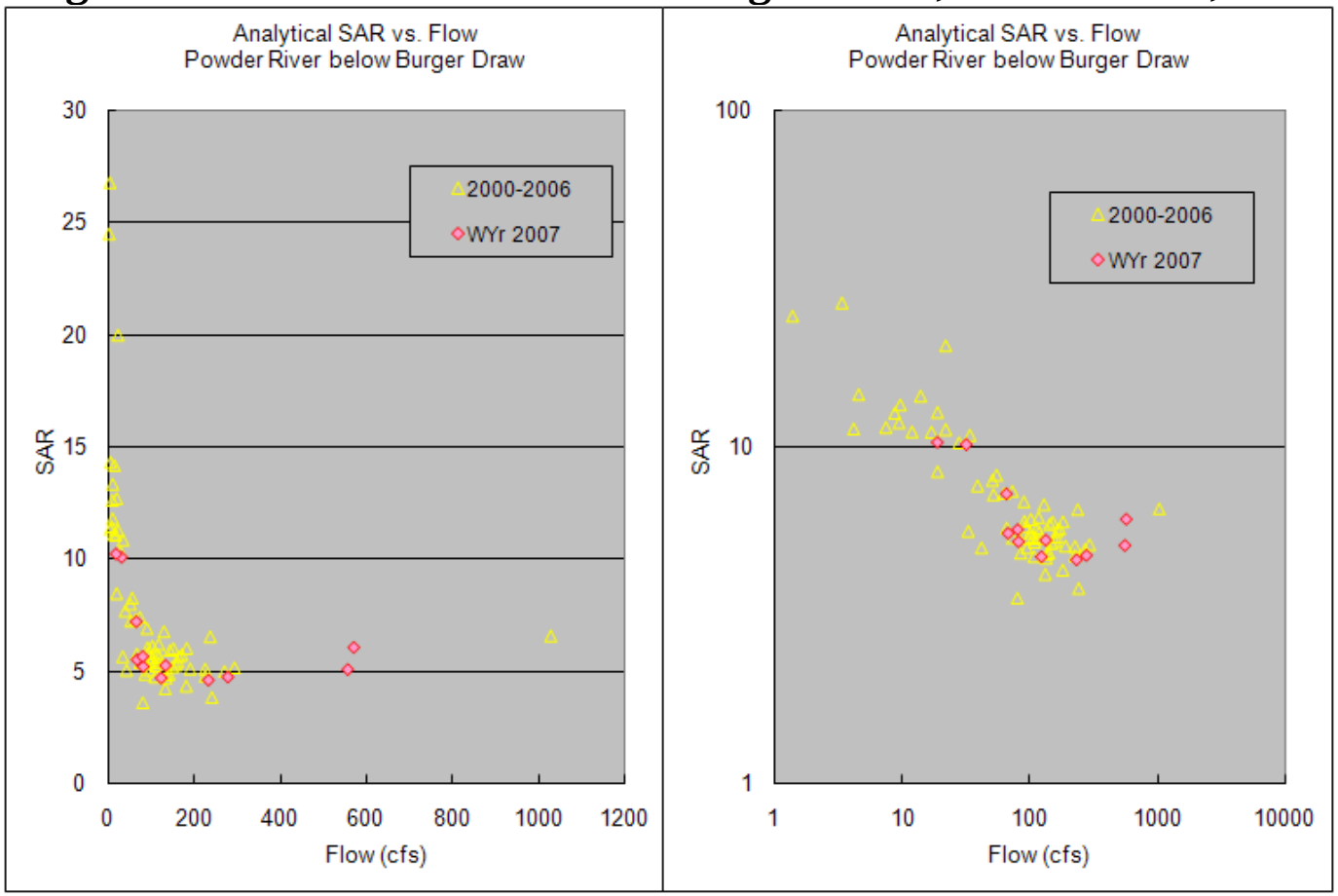

Figure 12 shows analytical SAR vs. Flow data for water year 2007 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 13: Powder River below Burger Draw, near Buffalo, WY

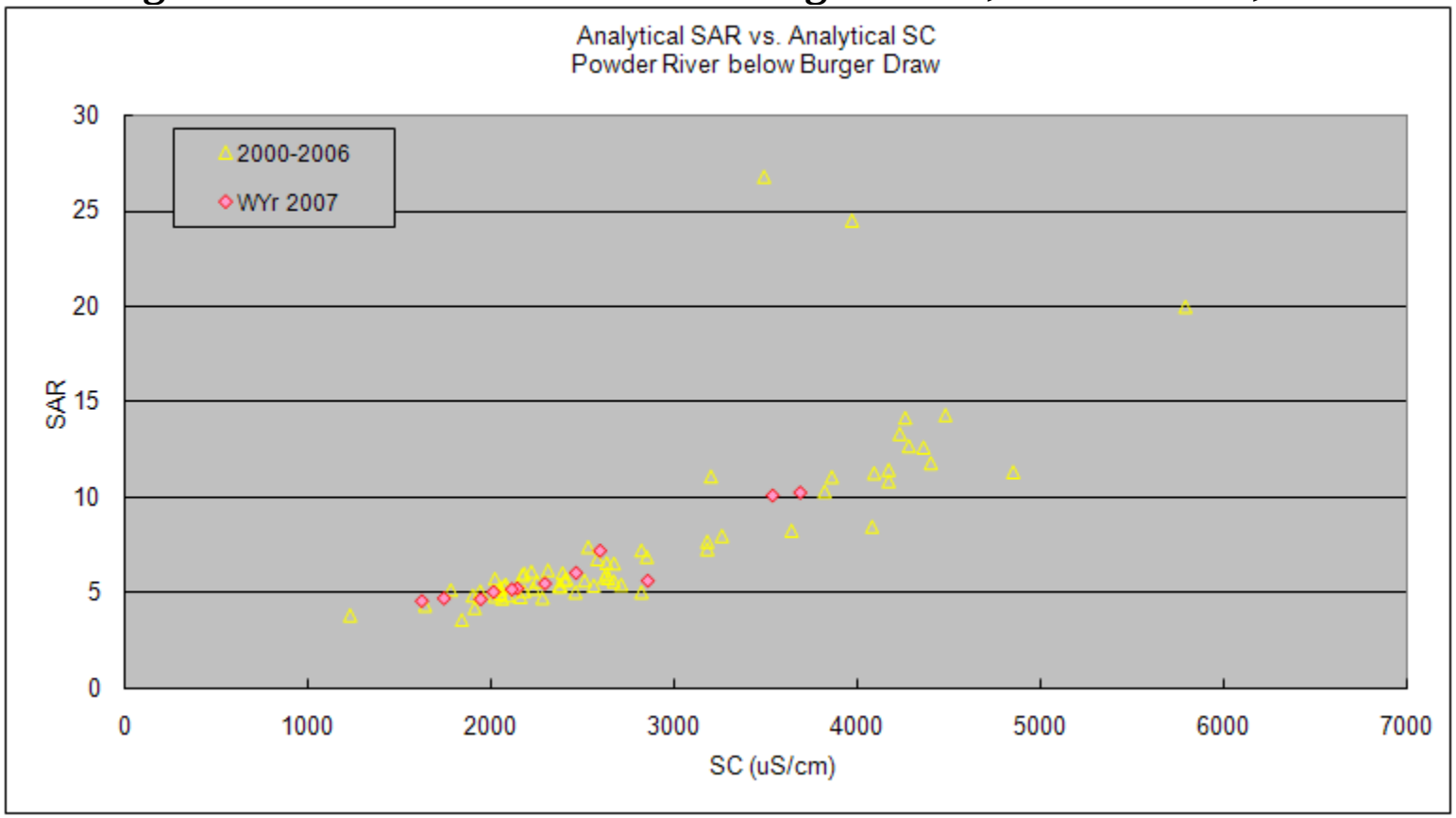

Figure 13 shows analytical SAR vs. analytical SC data for water year 2007 for the Powder River below Burger Draw. Historical SAR vs. SC data are also shown to place the data in context.

Figure 14: Powder River at Arvada, WY

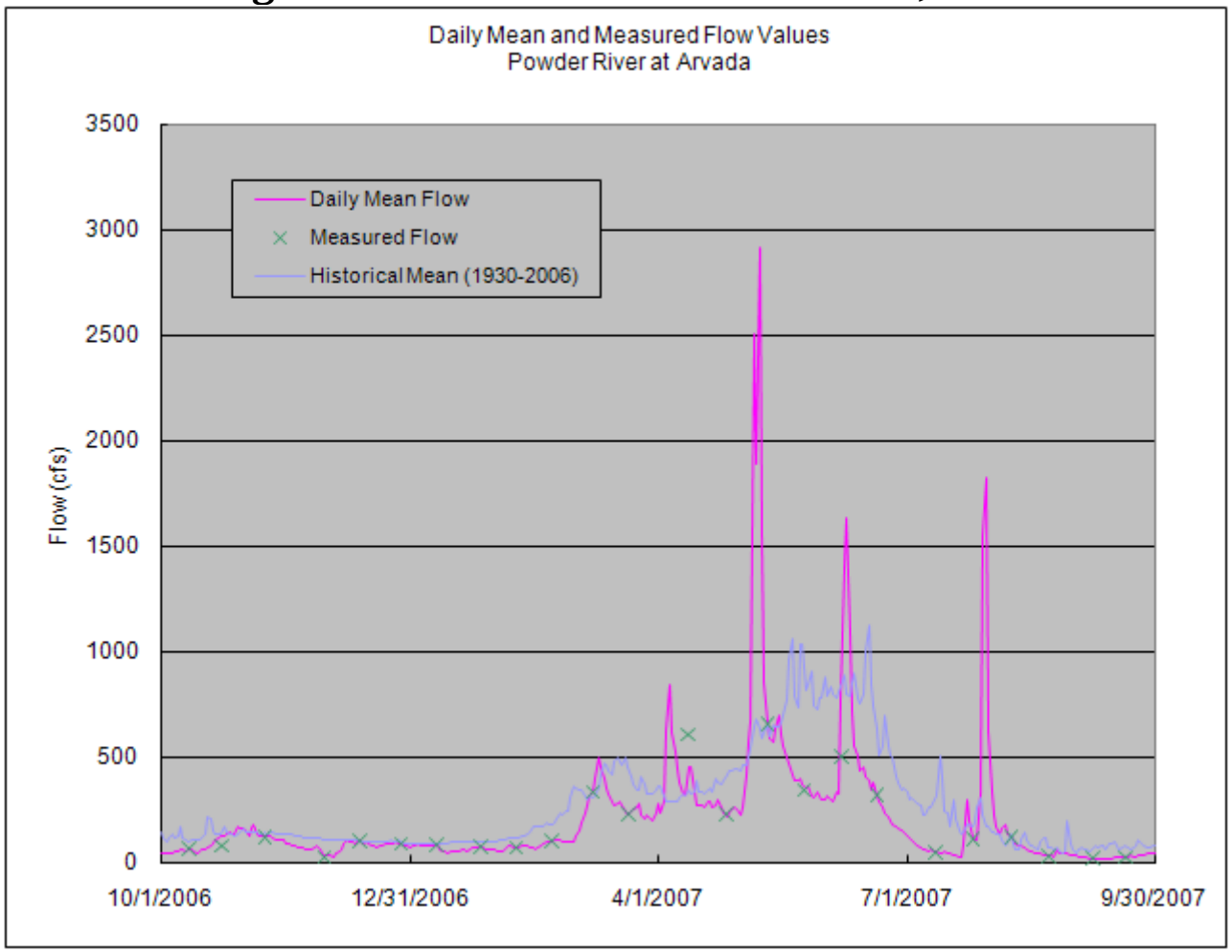

Figure 14 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for the Powder River at Arvada. Daily Mean flow values ranged from 15 to 2910 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 15: Powder River at Arvada, WY

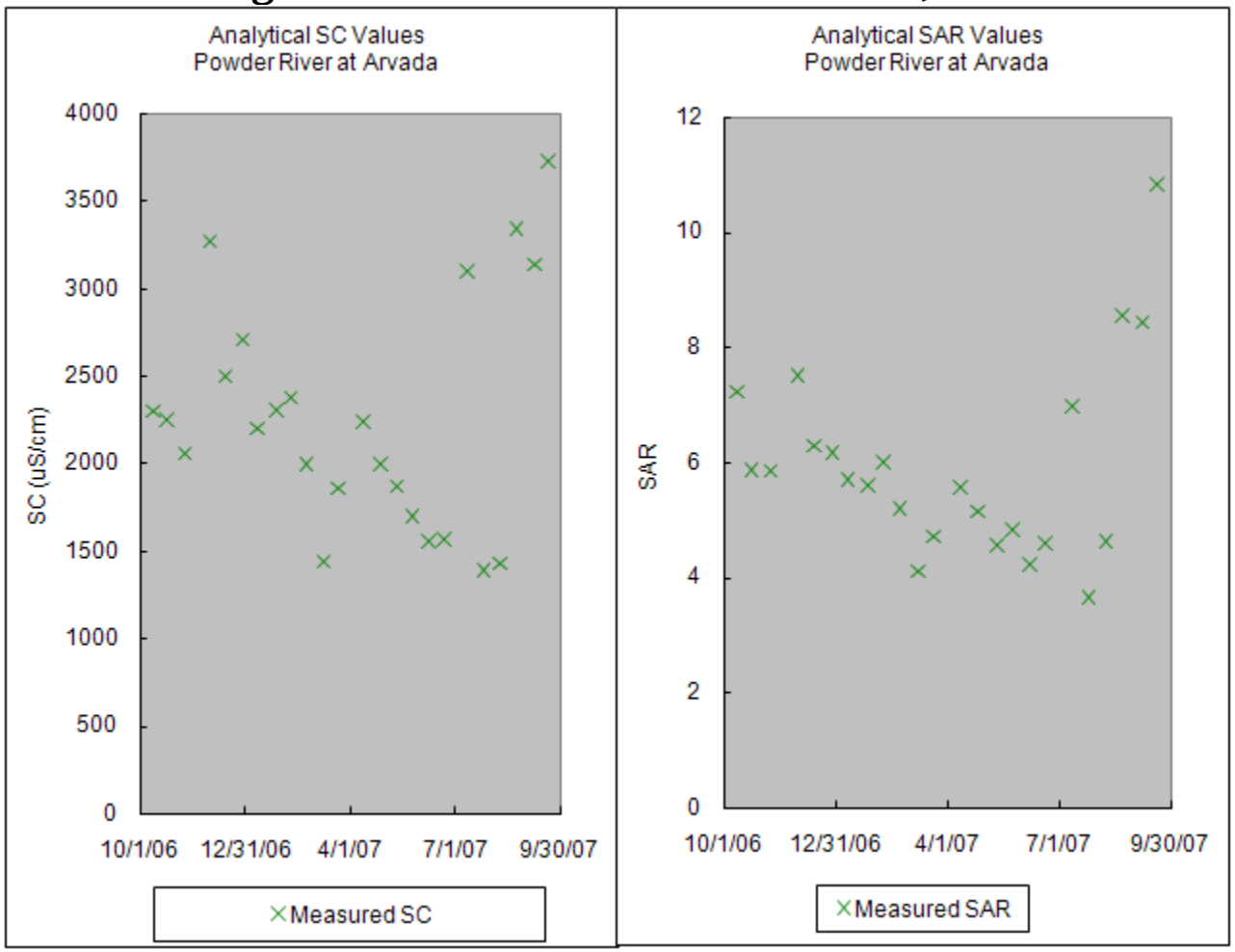

Figure 15 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2007 for the Powder River at Arvada. SC values ranged from 1390 to 3730 uS/cm. SAR values ranged from 3.7 to 10.8.

Figure 16: Powder River at Arvada, WY

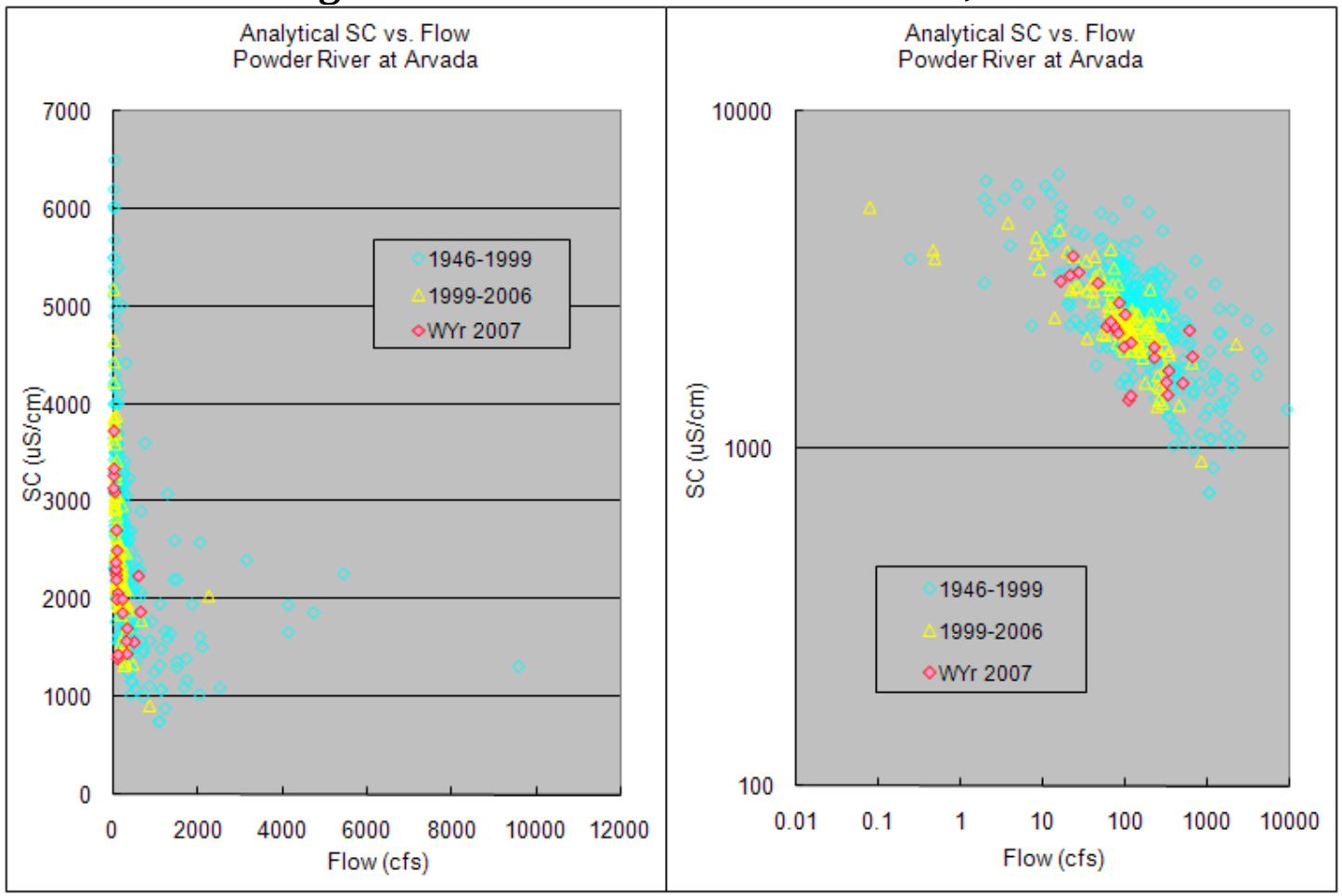

Figure 16 shows analytical SC vs. Flow data for water year 2007 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 17: Powder River at Arvada, WY

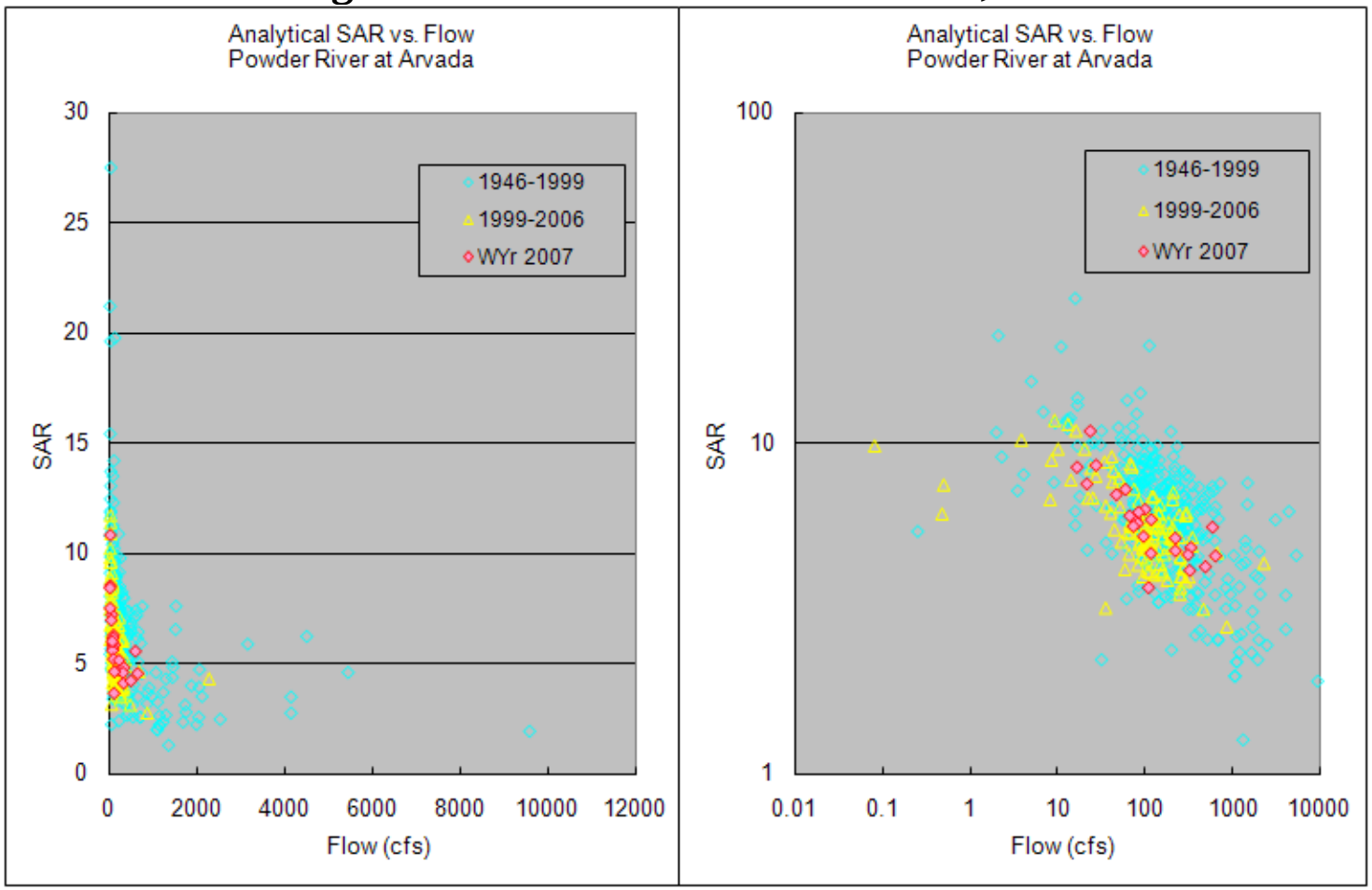

Figure 17 shows analytical SAR vs. Flow data for water year 2007 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 18: Powder River at Arvada, WY

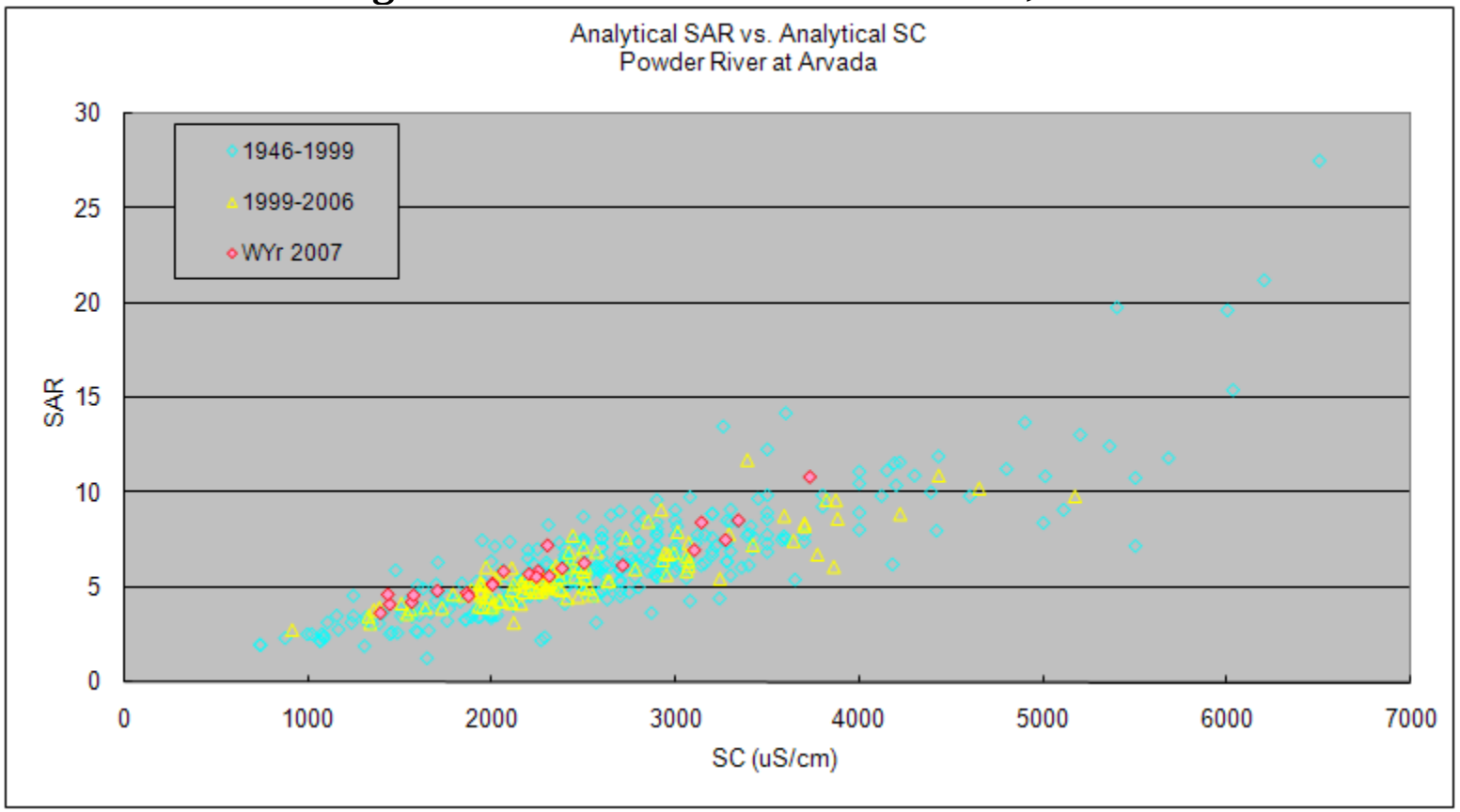

Figure 18 shows analytical SAR vs. analytical SC data for water year 2007 for the Powder River at Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 19: Powder River at Moorhead, MT

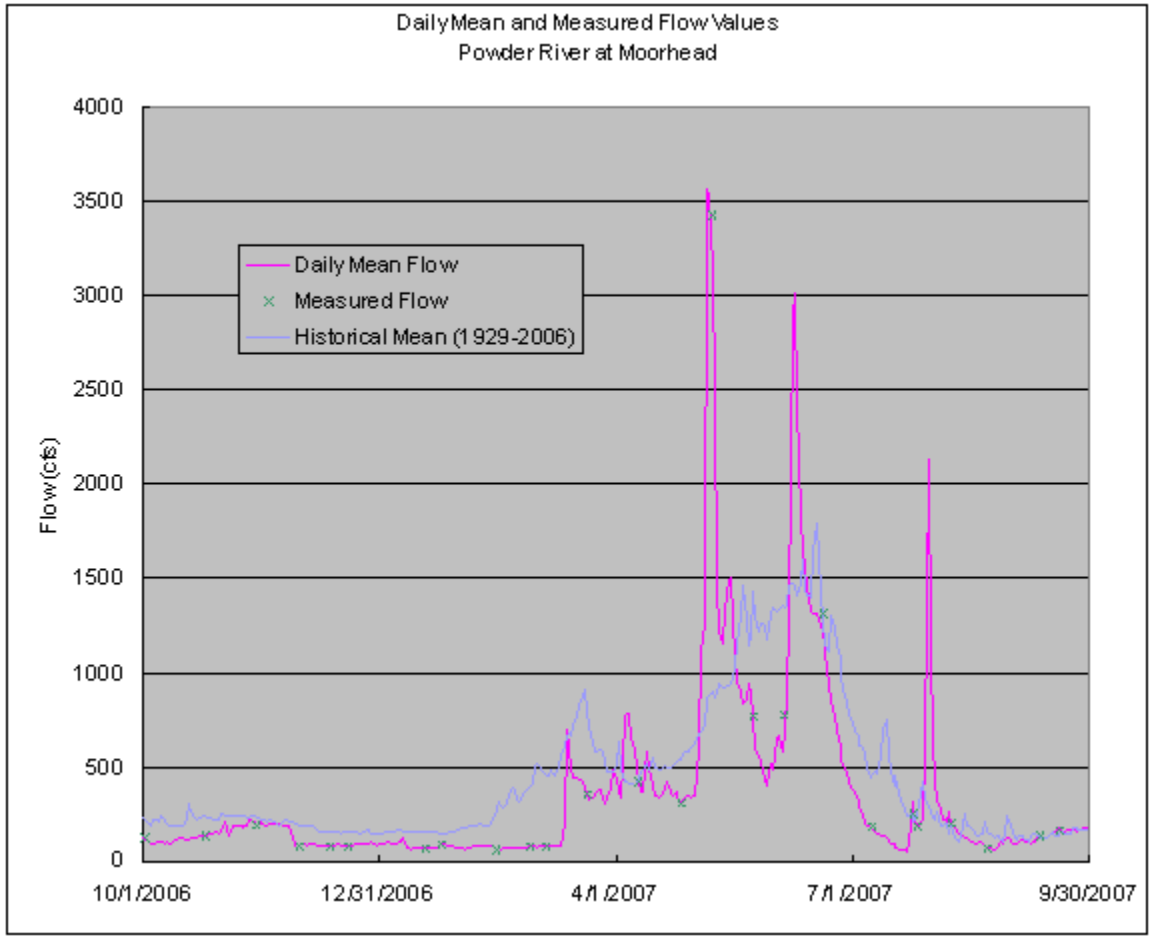

Figure 19 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for the Powder River at Moorhead. Daily Mean flow values ranged from 47 to 3560 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 20: Powder River at Moorhead, MT

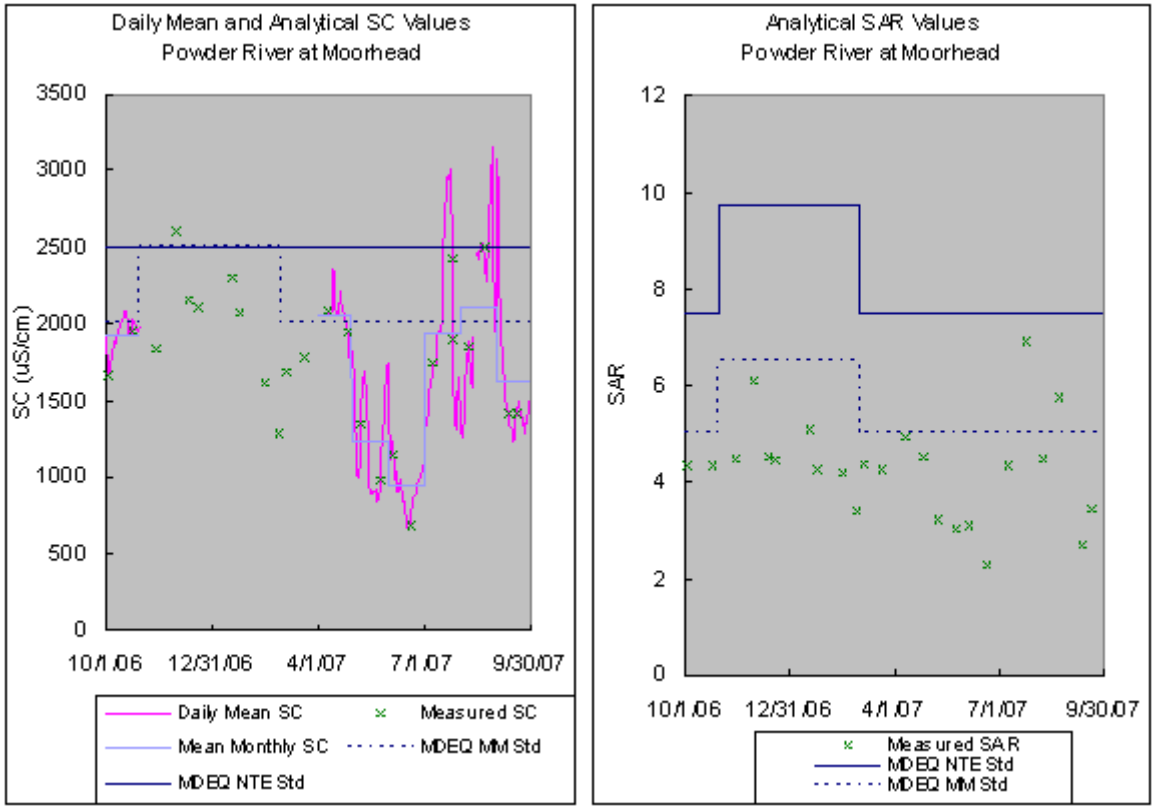

Figure 20 shows analytical and Daily Mean SC values (A) and analytical SAR values (B) values in time series plots for water year 2007 for the Powder River at Moorhead. Monthly Mean SC values are also shown. SC values ranged from 663 to 3160 uS/cm. SAR values ranged from 2.3 to 6.9. MDEQ standards are also displayed for comparison. SC NTE standards are exceeded for a total of 16 days in July, August, and early September. The Monthly Mean SC standard is exceeded in August. The SAR NTE standards are not exceeded. There is insufficient data to evaluate the Monthly Mean SAR standard.

B

Figure 21: Powder River at Moorhead, MT

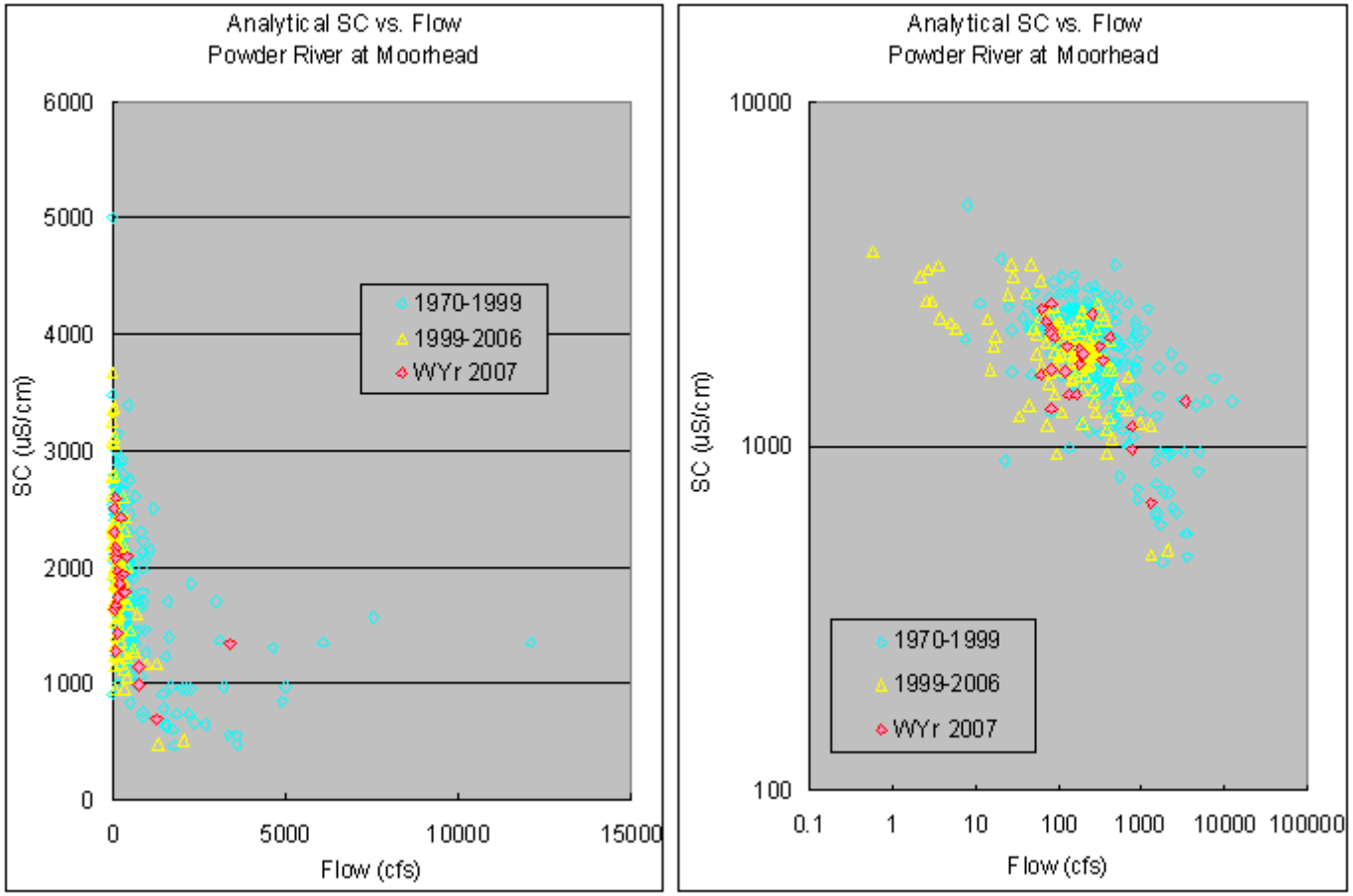

Figure 21 shows analytical SC vs. Flow data for water year 2007 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 22: Powder River at Moorhead, MT

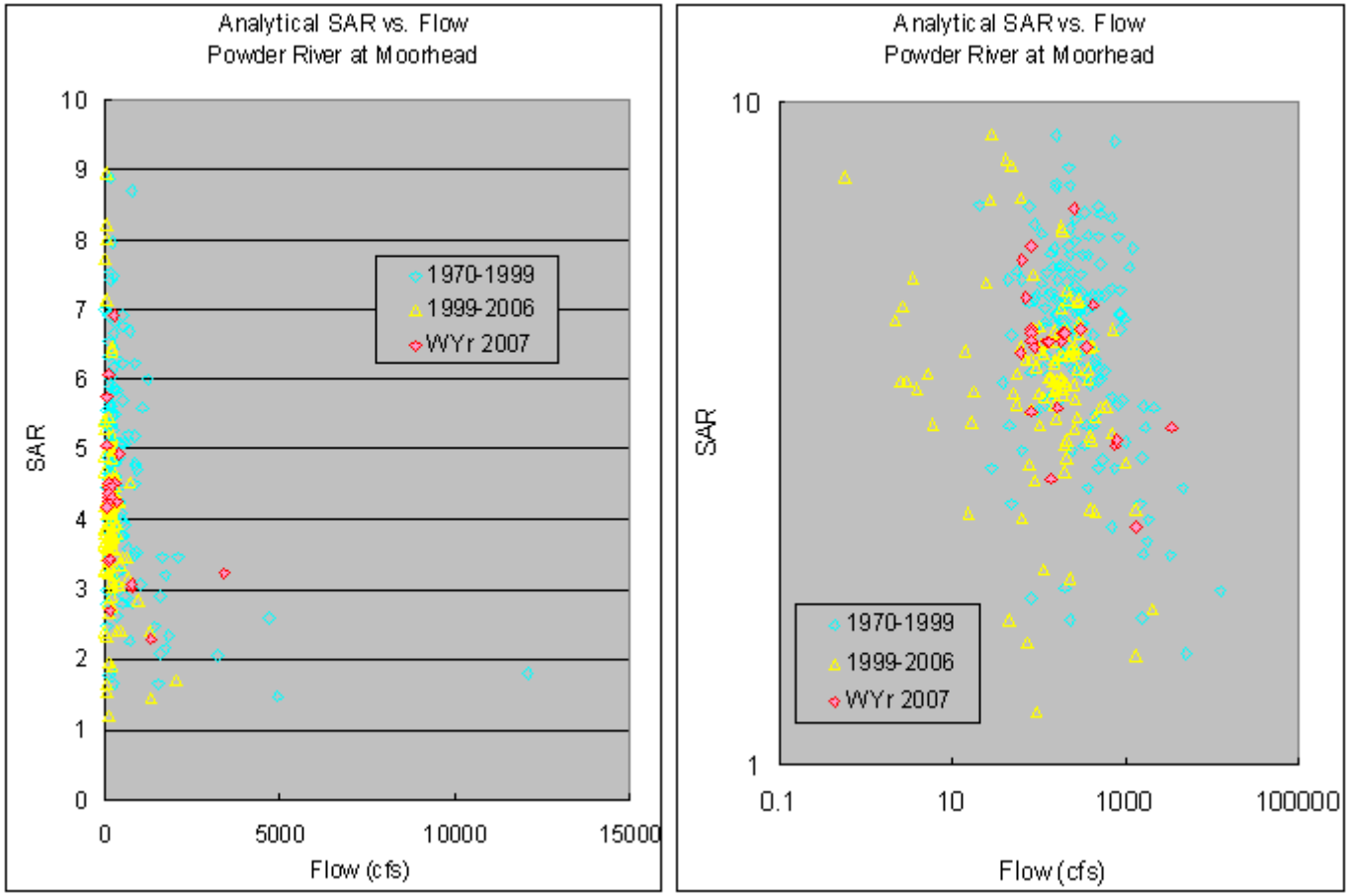

Figure 22 shows analytical SAR vs. Flow data for water year 2007 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 23: Powder River at Moorhead, MT

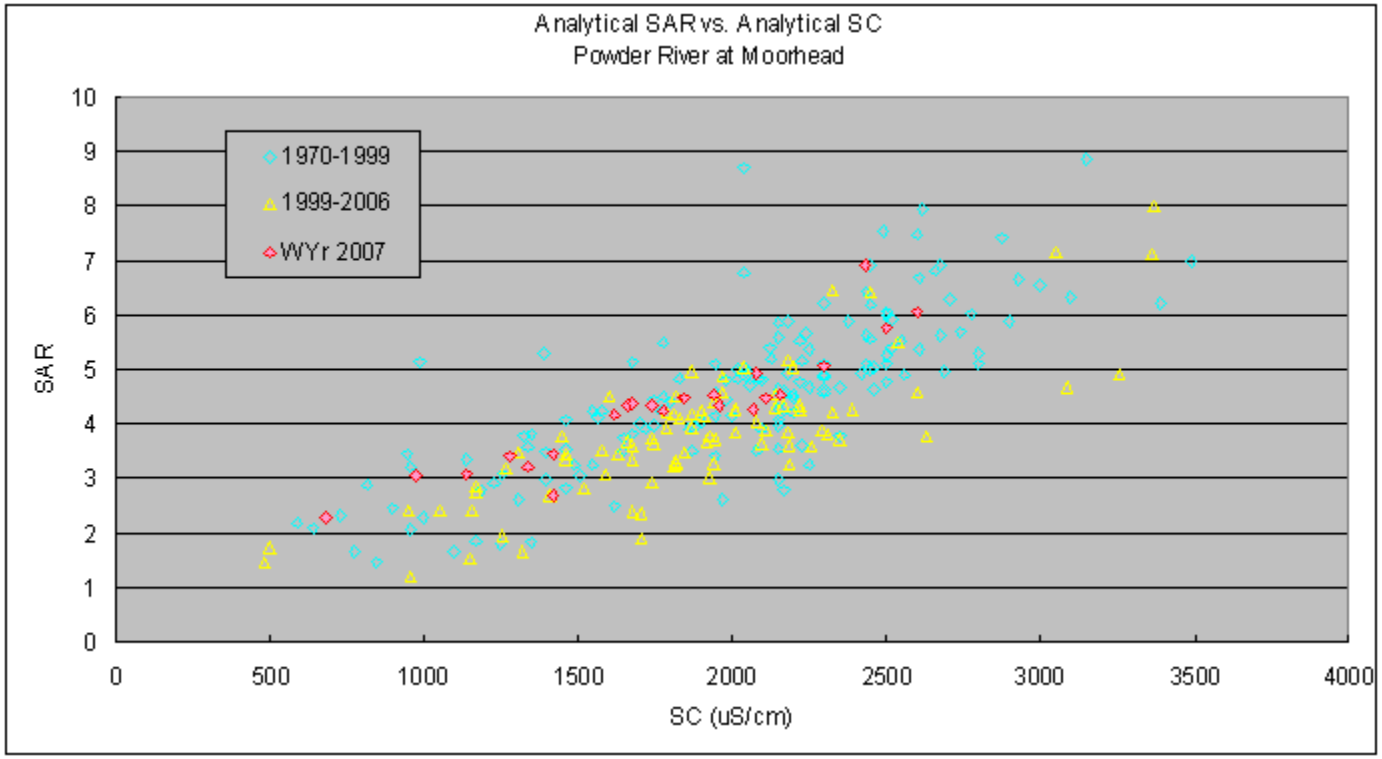

Figure 23 shows analytical SAR vs. analytical SC data for water year 2007 for the Powder River at Moorhead. Historical SAR vs. SC data are also shown to place the data in context.

Figure 24: Powder River near Locate, MT

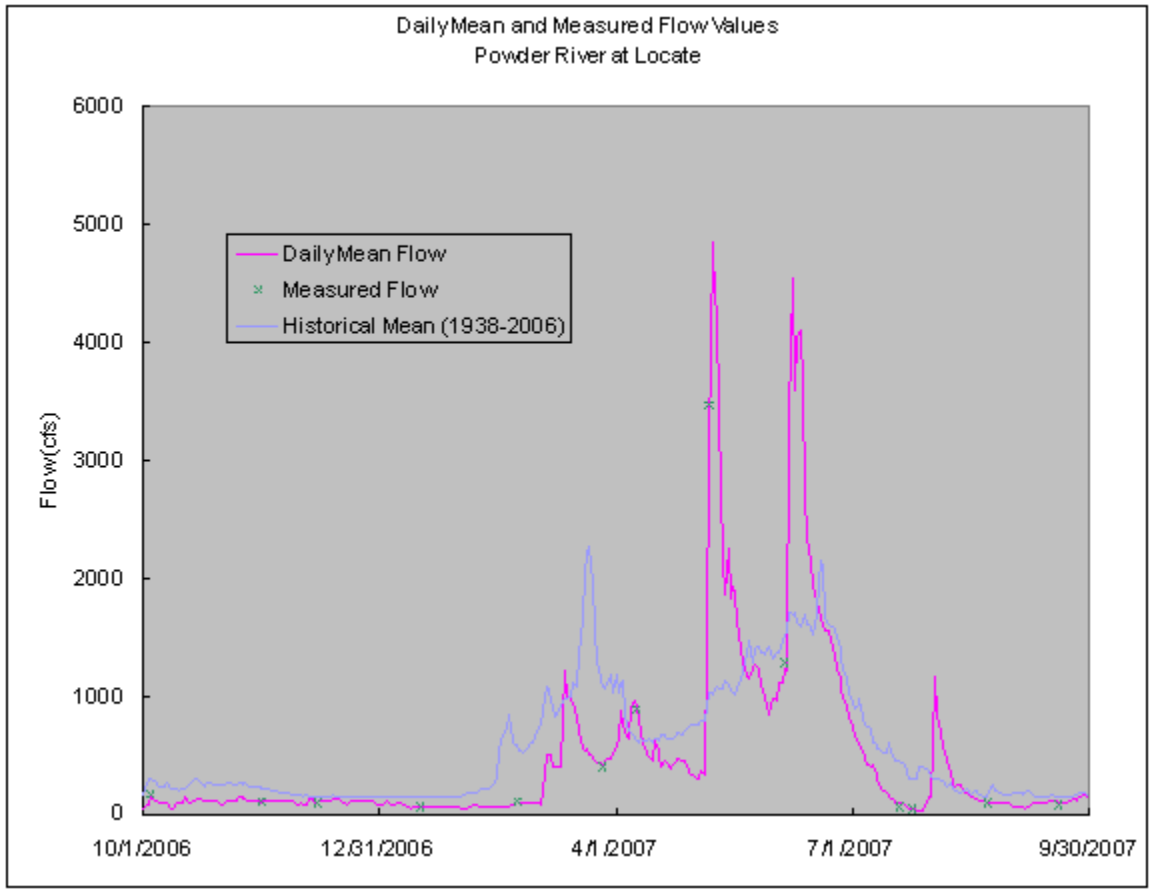

Figure 24 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for the Powder River near Locate. Daily Mean flow values ranged from 35 to 4840 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 25: Powder River near Locate, MT

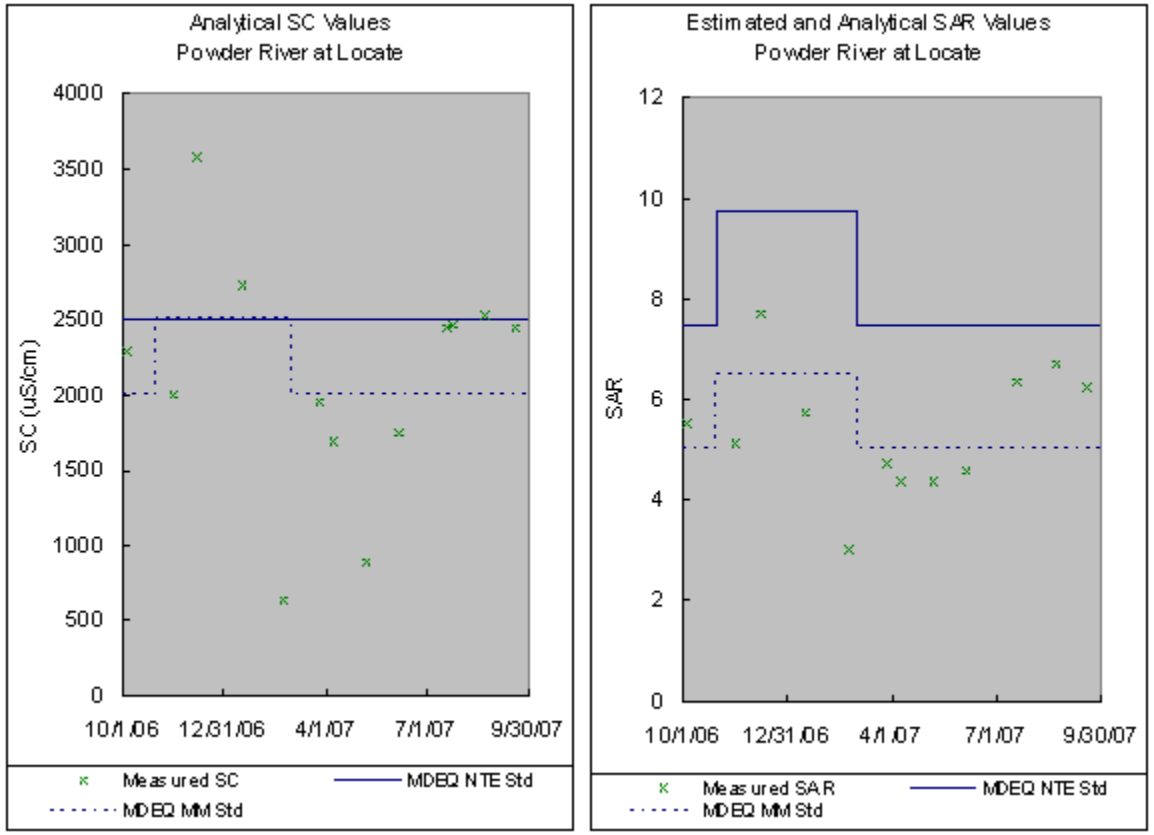

Figure 25 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2007 for the Powder River near Locate. SC values ranged from 634 to 3580uS/cm. SAR values ranged from 3.0 to 7.7. MDEQ standards are also displayed for comparison. SC NTE standards are exceeded for 3 samples. There is insufficient data to evaluate the Monthly Mean EC standard. The SAR NTE standards are not exceeded. There is insufficient data to evaluate the Monthly Mean SAR standard.

Figure 26: Powder River near Locate, MT

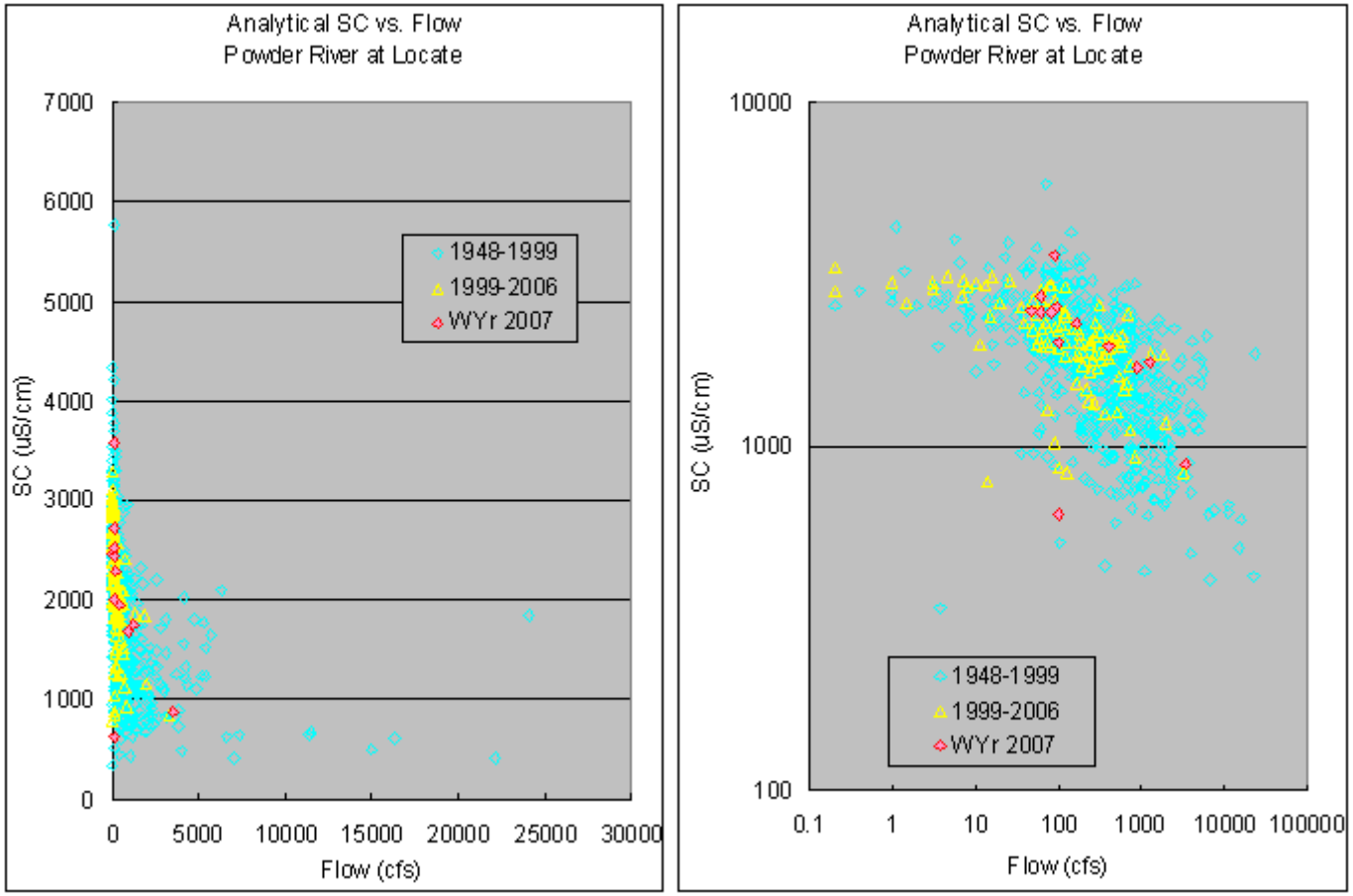

Figure 26 shows analytical SC vs. Flow data for water year 2007 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 27: Powder River near Locate, MT

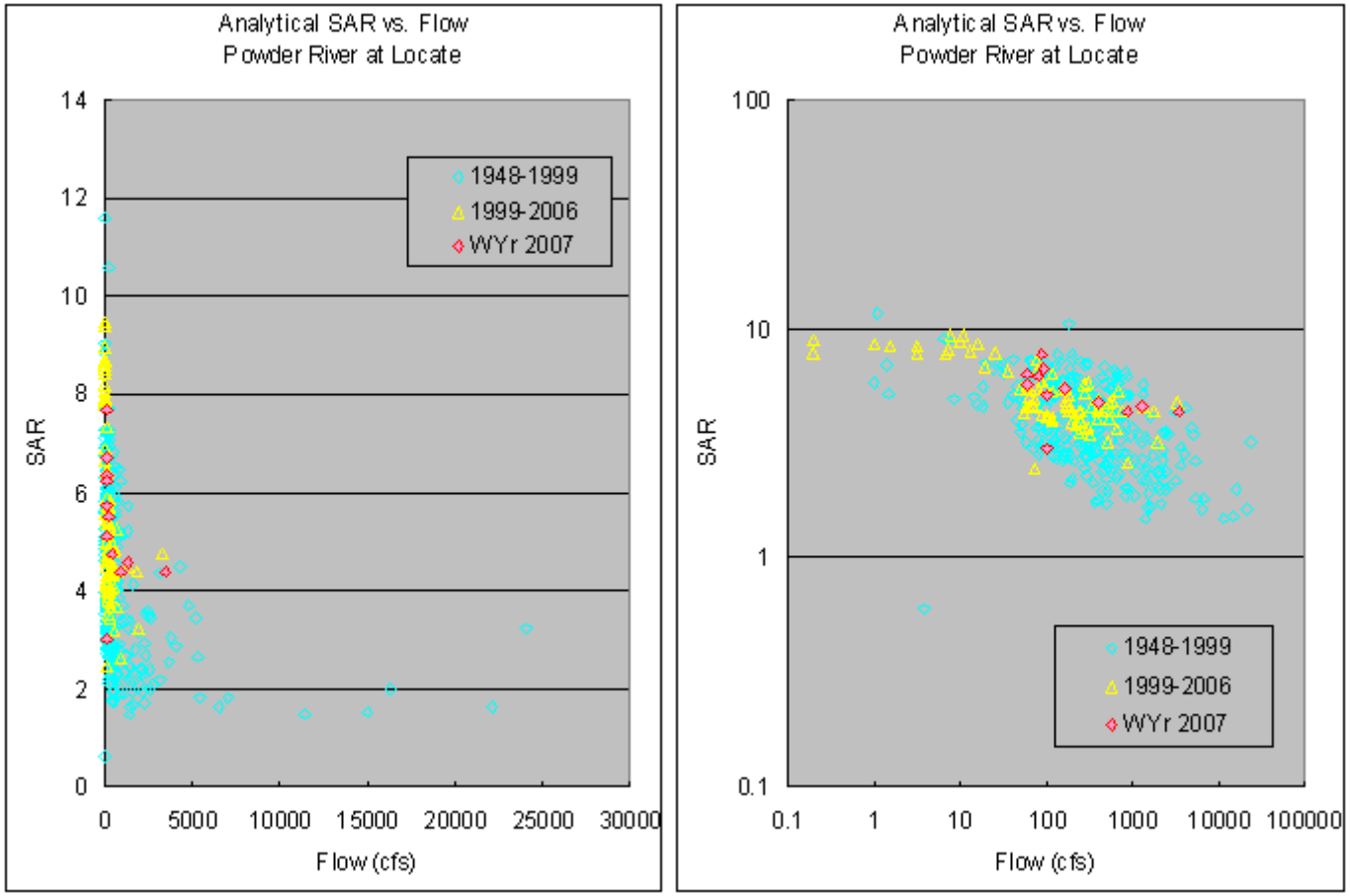

Figure 27 shows analytical SAR vs. Flow data for water year 2007 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 28: Powder River near Locate, MT

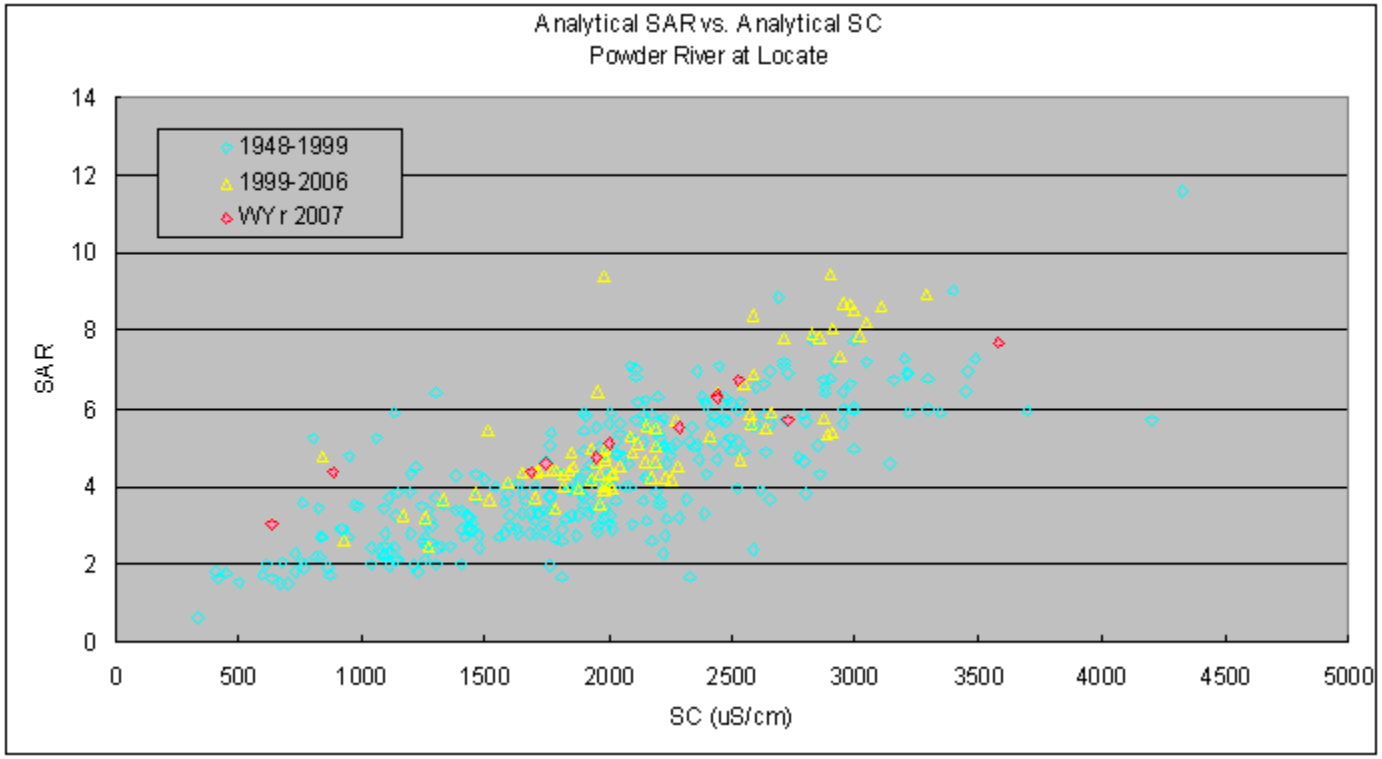

Figure 28 shows analytical SAR vs. analytical SC data for water year 2007 for the Powder River near Locate. Historical SAR vs. SC data are also shown to place the data in context.

Figure 29: Crazy Woman Creek at Upper Station, near Arvada, WY

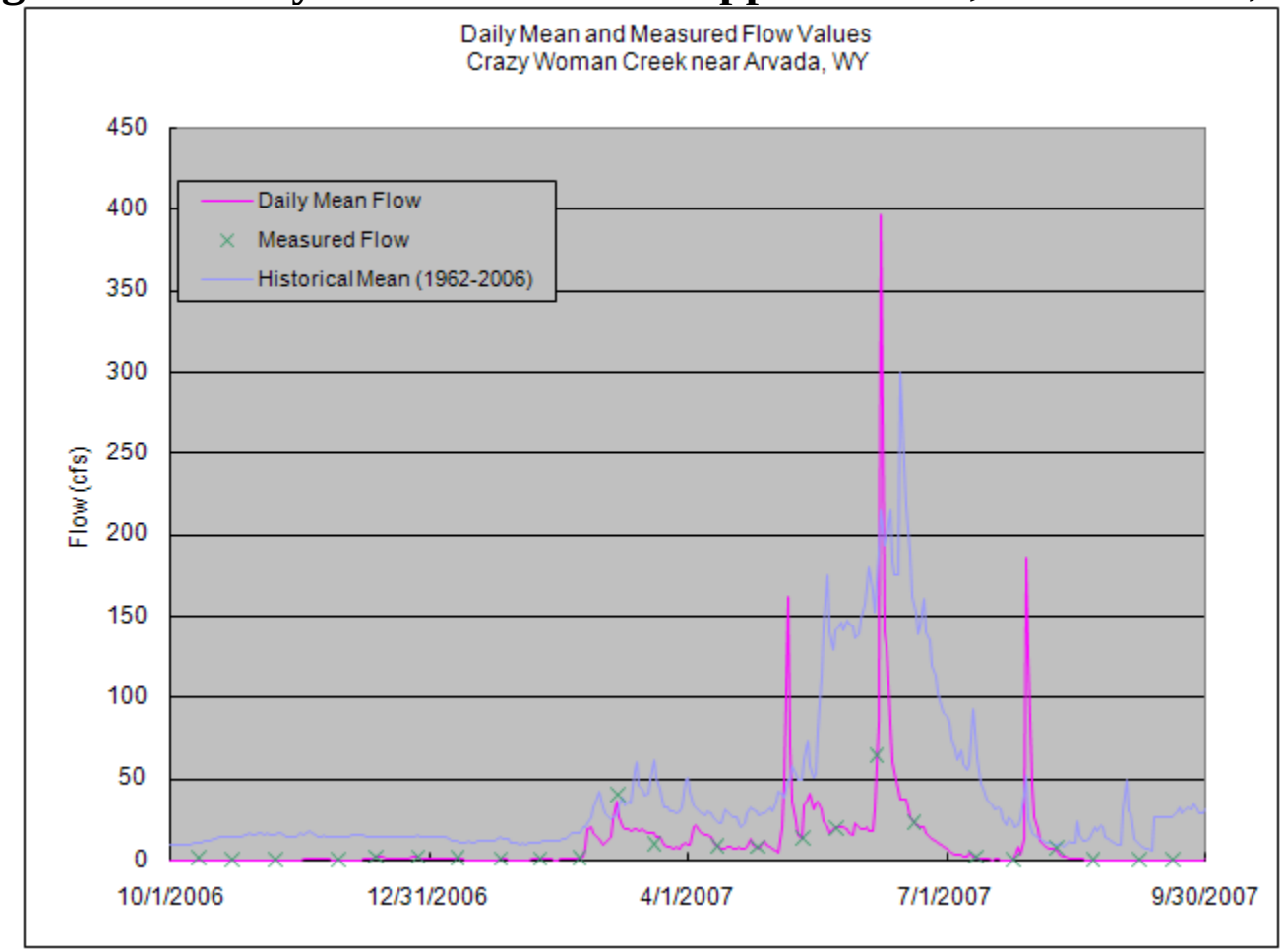

Figure 29 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for Crazy Woman near Arvada. Daily Mean flow values ranged from 0 to 396 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 30: Crazy Woman Creek at Upper Station, near Arvada, WY

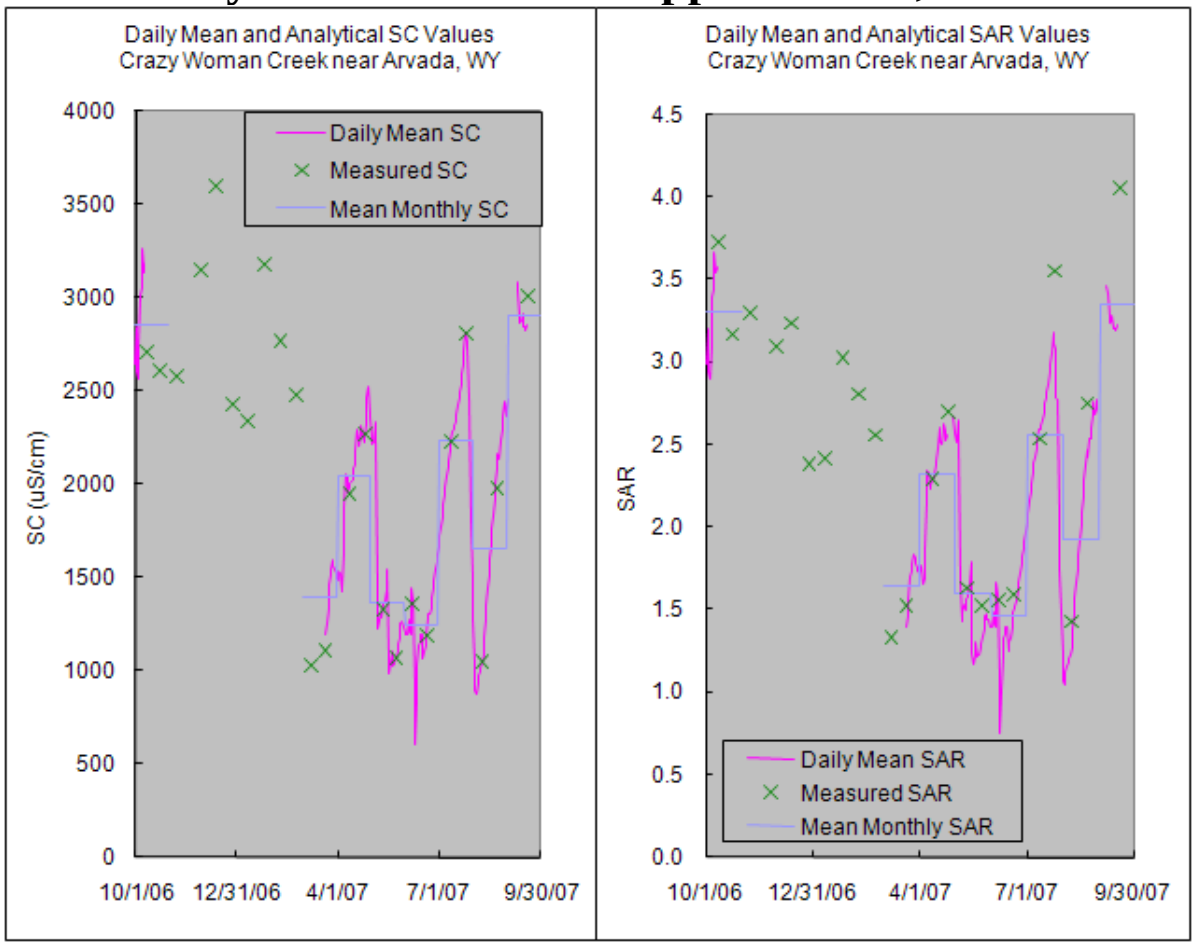

Figure 30 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for Crazy Woman Creek near Arvada. Monthly Mean SC and SAR values are also shown. SC values ranged from 604 to 3600 uS/cm. SAR values ranged from 0.8 to 4.1.

Figure 31: Crazy Woman Creek at Upper Station, near Arvada, WY

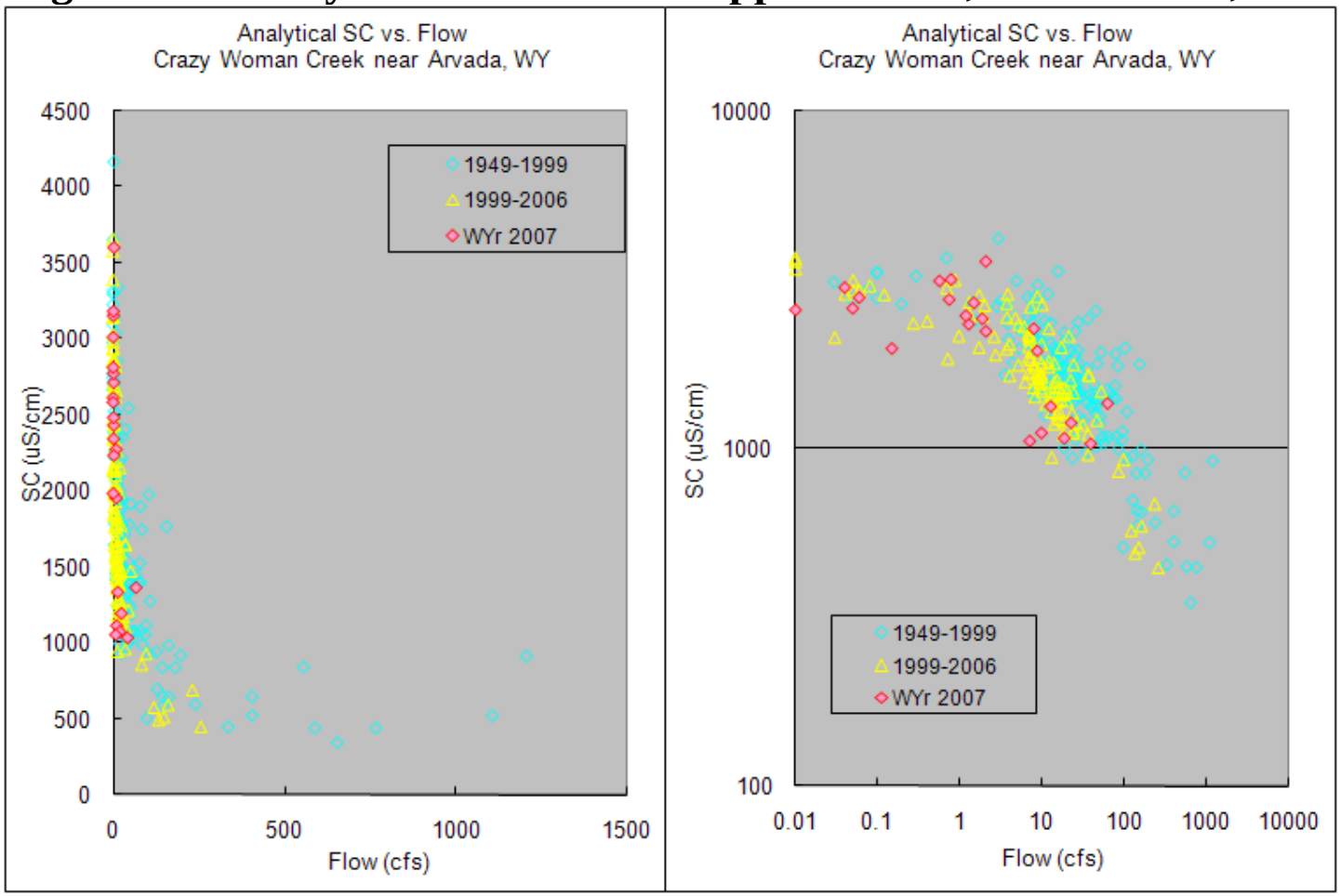

Figure 31 shows analytical SC vs. Flow data for water year 2007 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 32: Crazy Woman Creek at Upper Station, near Arvada, WY

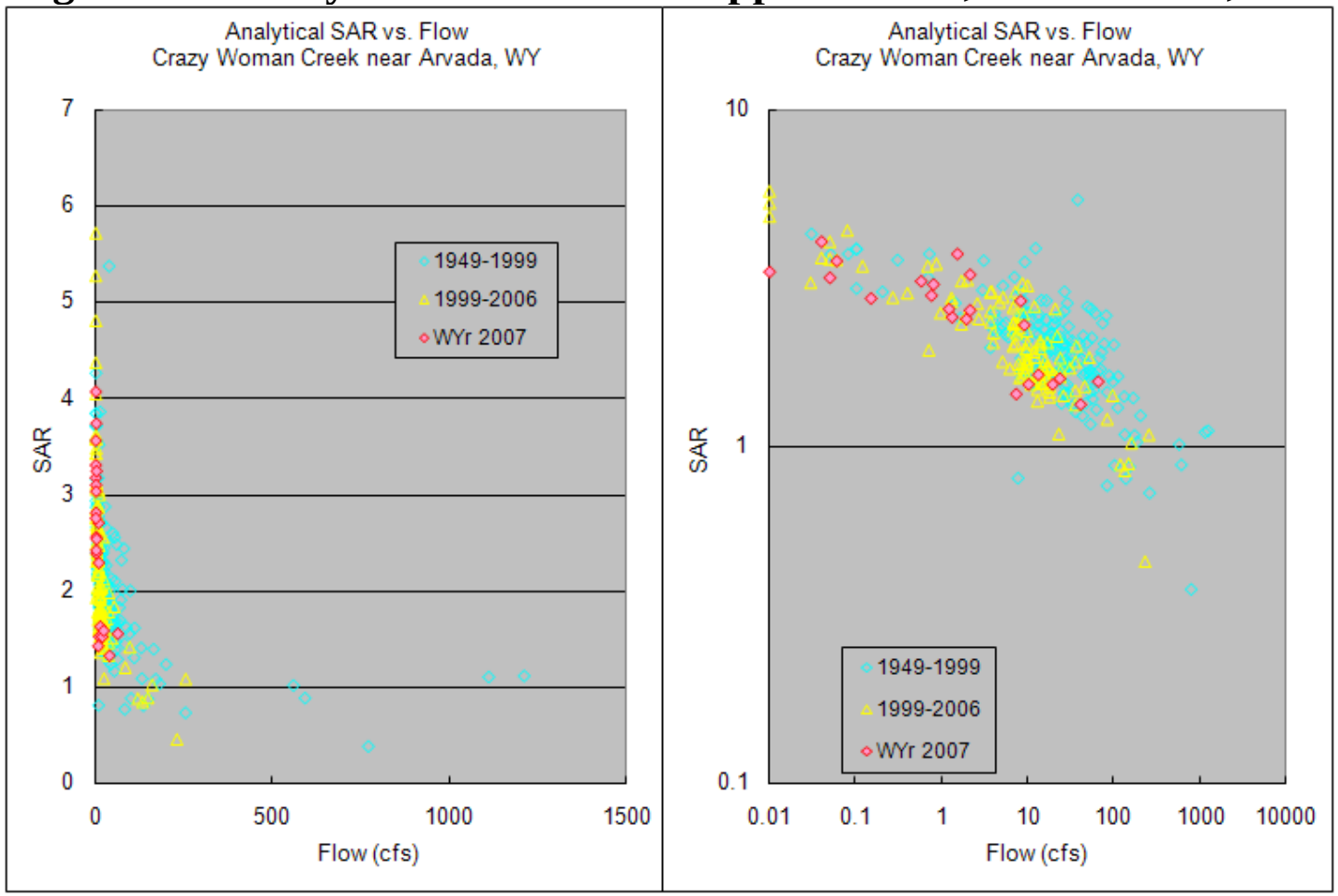

Figure 32 shows analytical SAR vs. Flow data for water year 2007 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 33: Crazy Woman Creek at Upper Station, near Arvada, WY

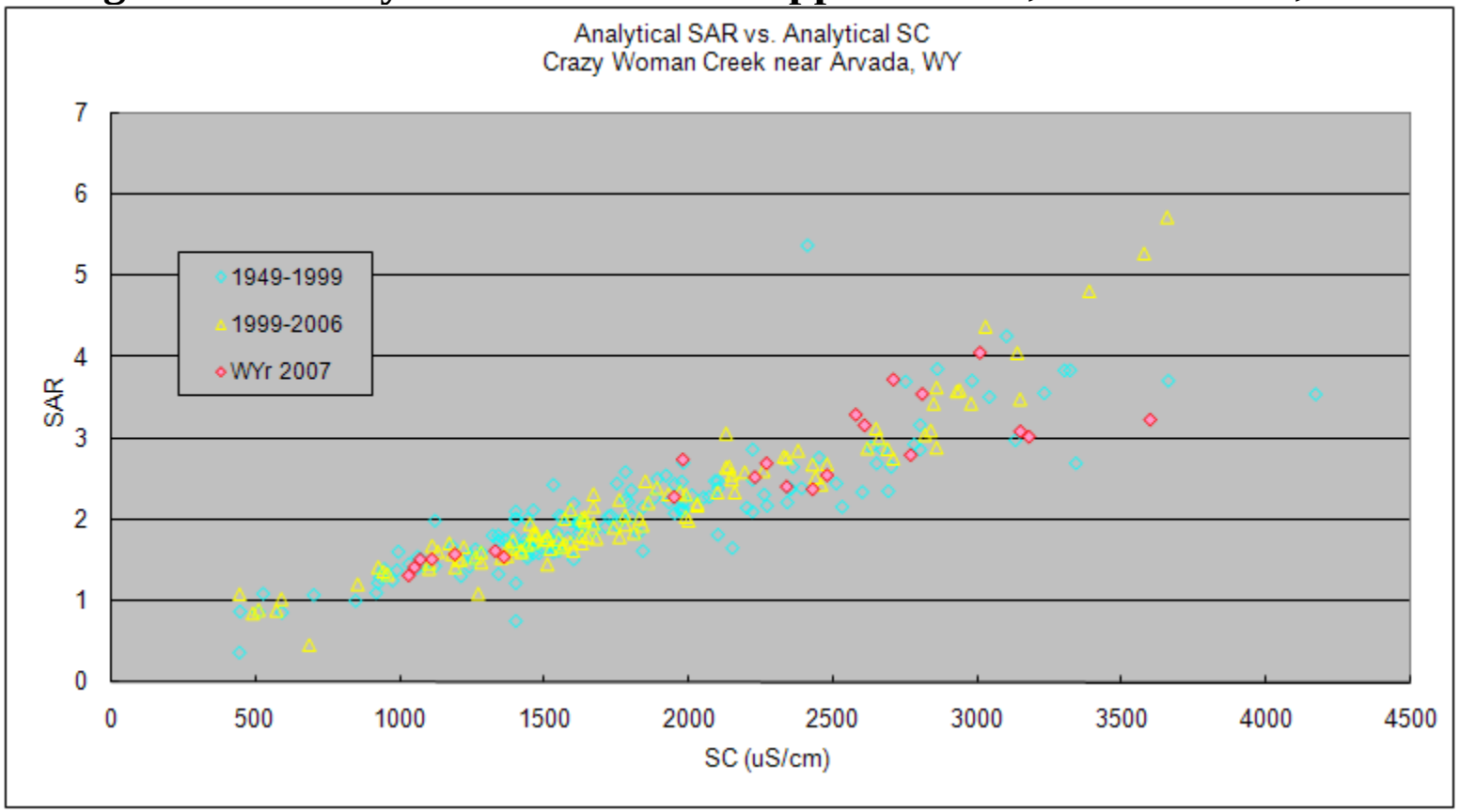

Figure 33 shows analytical SAR vs. analytical SC data for water year 2007 for Crazy Woman near Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 34: Clear Creek near Arvada, WY

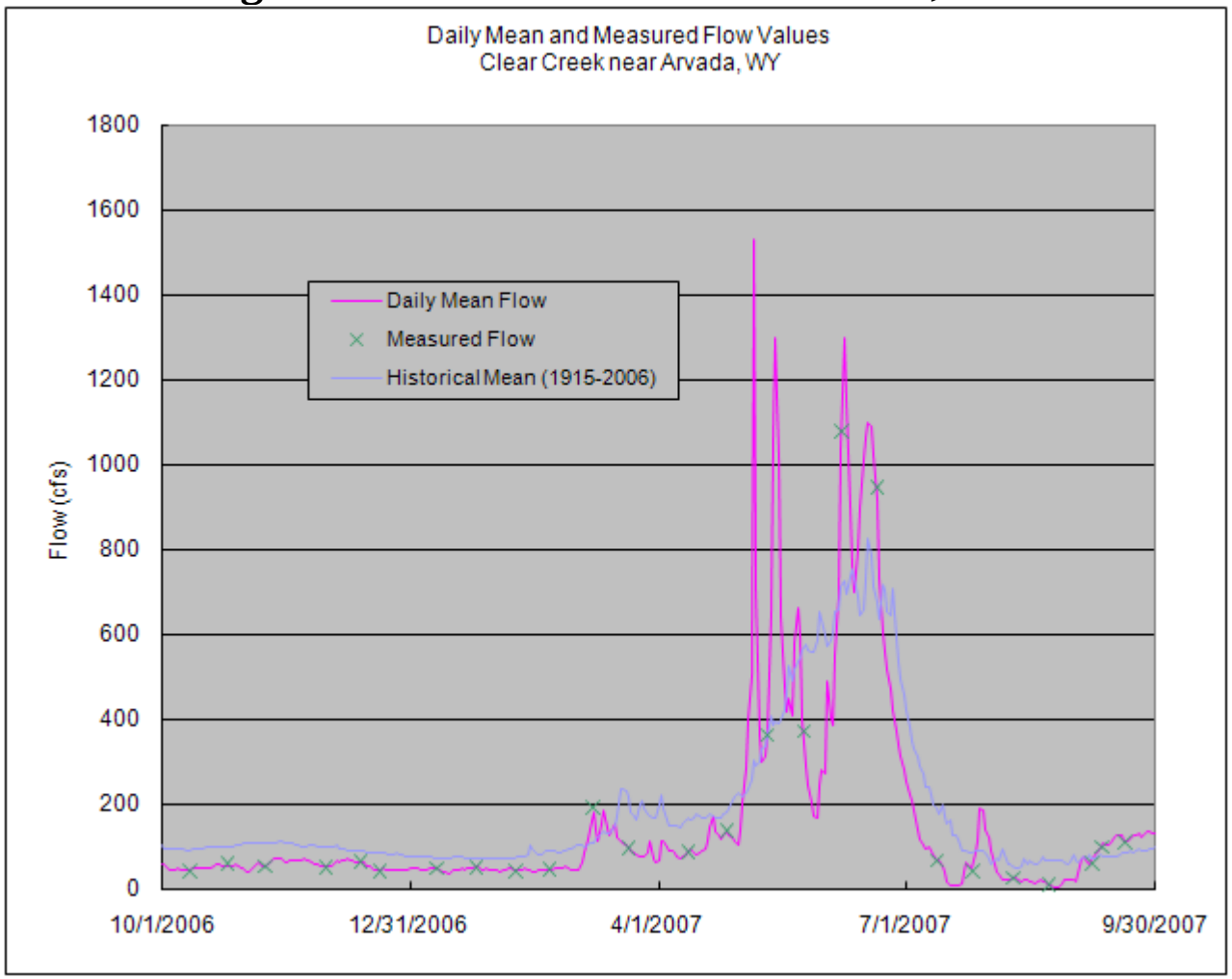

Figure 34 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for Clear Creek near Arvada. Daily Mean flow values ranged from 1.9 to 1530 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 35: Clear Creek near Arvada, WY

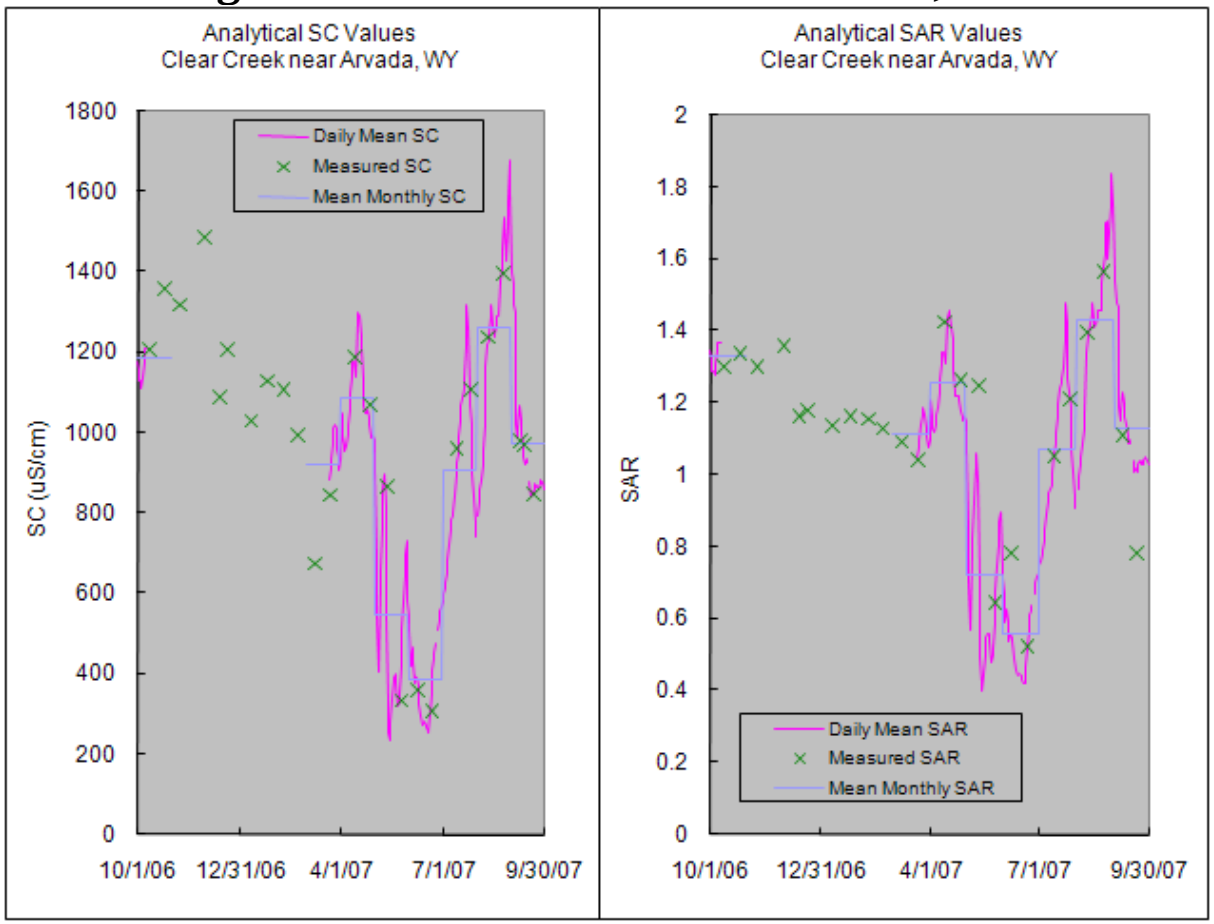

Figure 35 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for Clear Creek near Arvada. Monthly Mean SC and SAR values are also shown. SC values ranged from 235 to 1680 uS/cm. SAR values ranged from 0.4 to 1.8.

Figure 36: Clear Creek near Arvada, WY

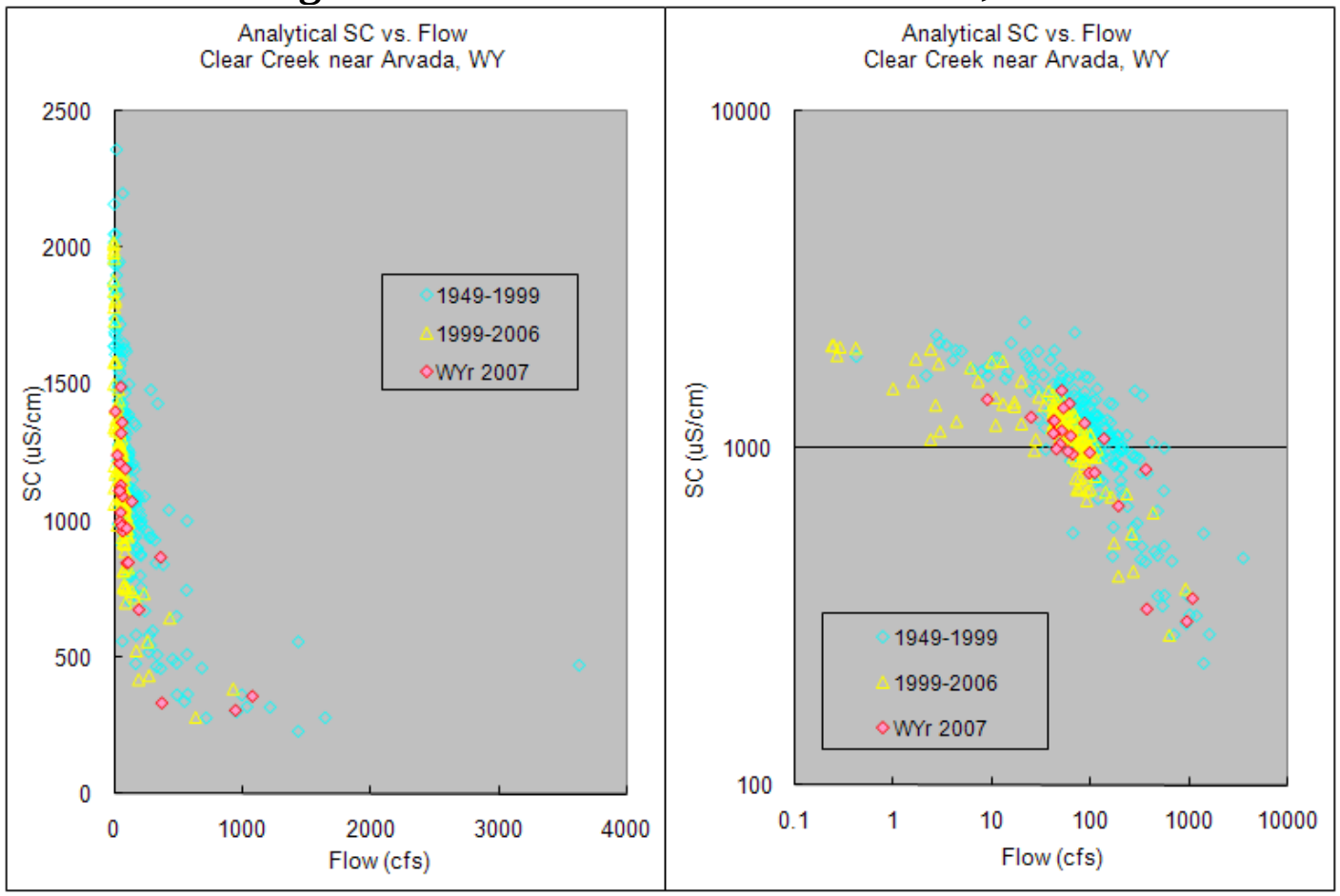

Figure 36 shows analytical SC vs. Flow data for water year 2007 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 37: Clear Creek near Arvada, WY

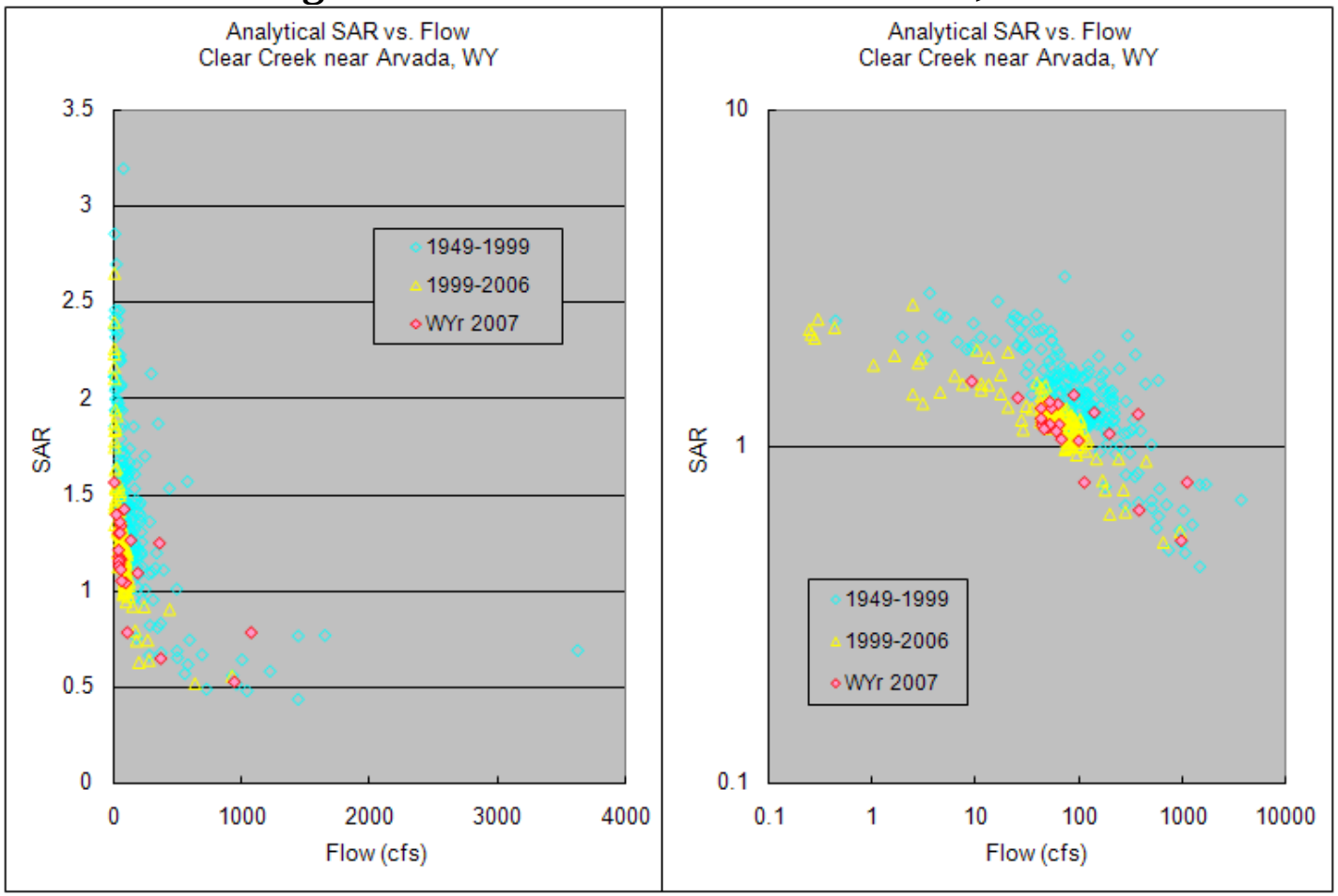

Figure 37 shows analytical SAR vs. Flow data for water year 2007 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 38: Clear Creek near Arvada, WY

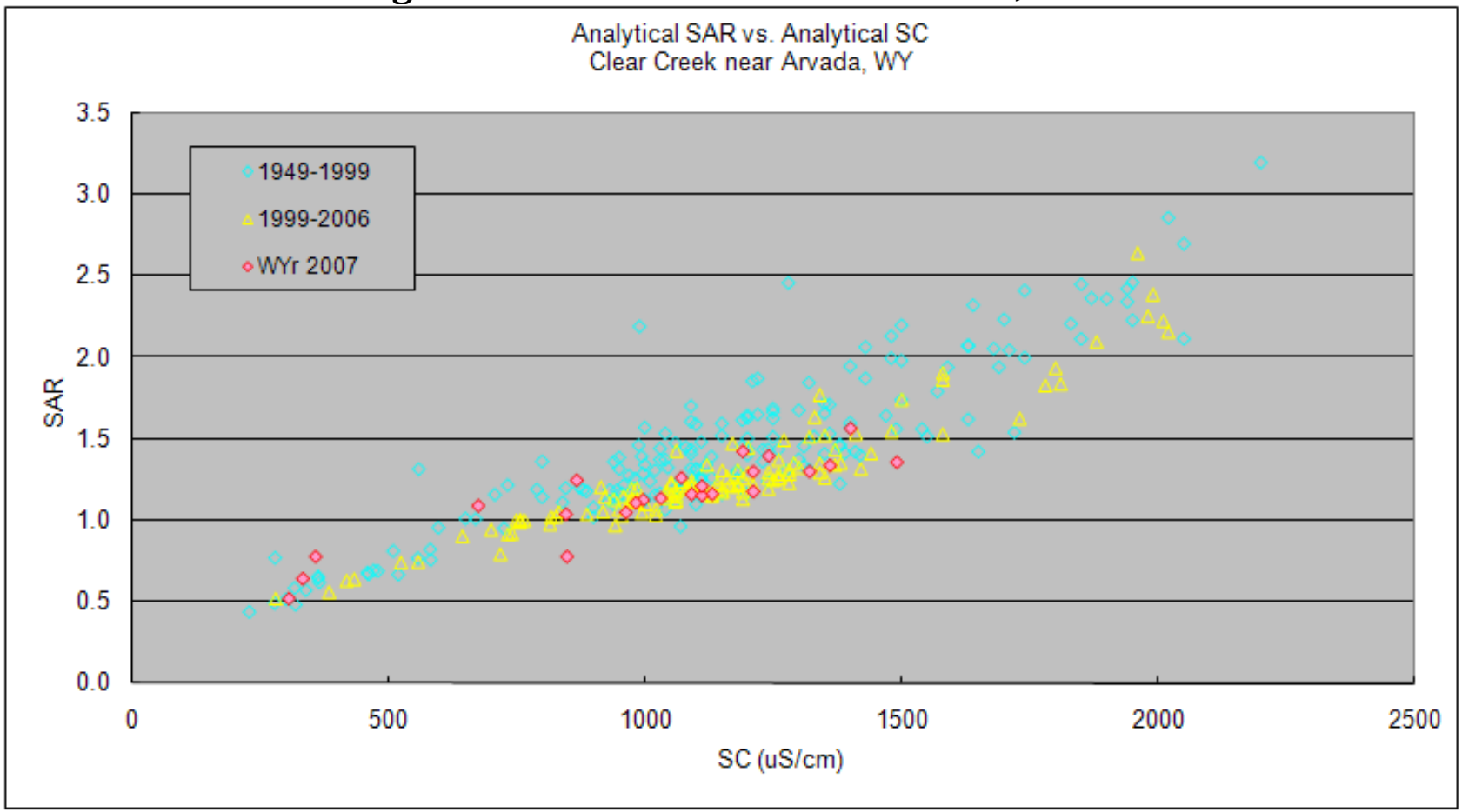

Figure 38 shows analytical SAR vs. analytical SC data for water year 2007 for Clear Creek near Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 39: Little Powder River above Dry Creek, near Weston, WY

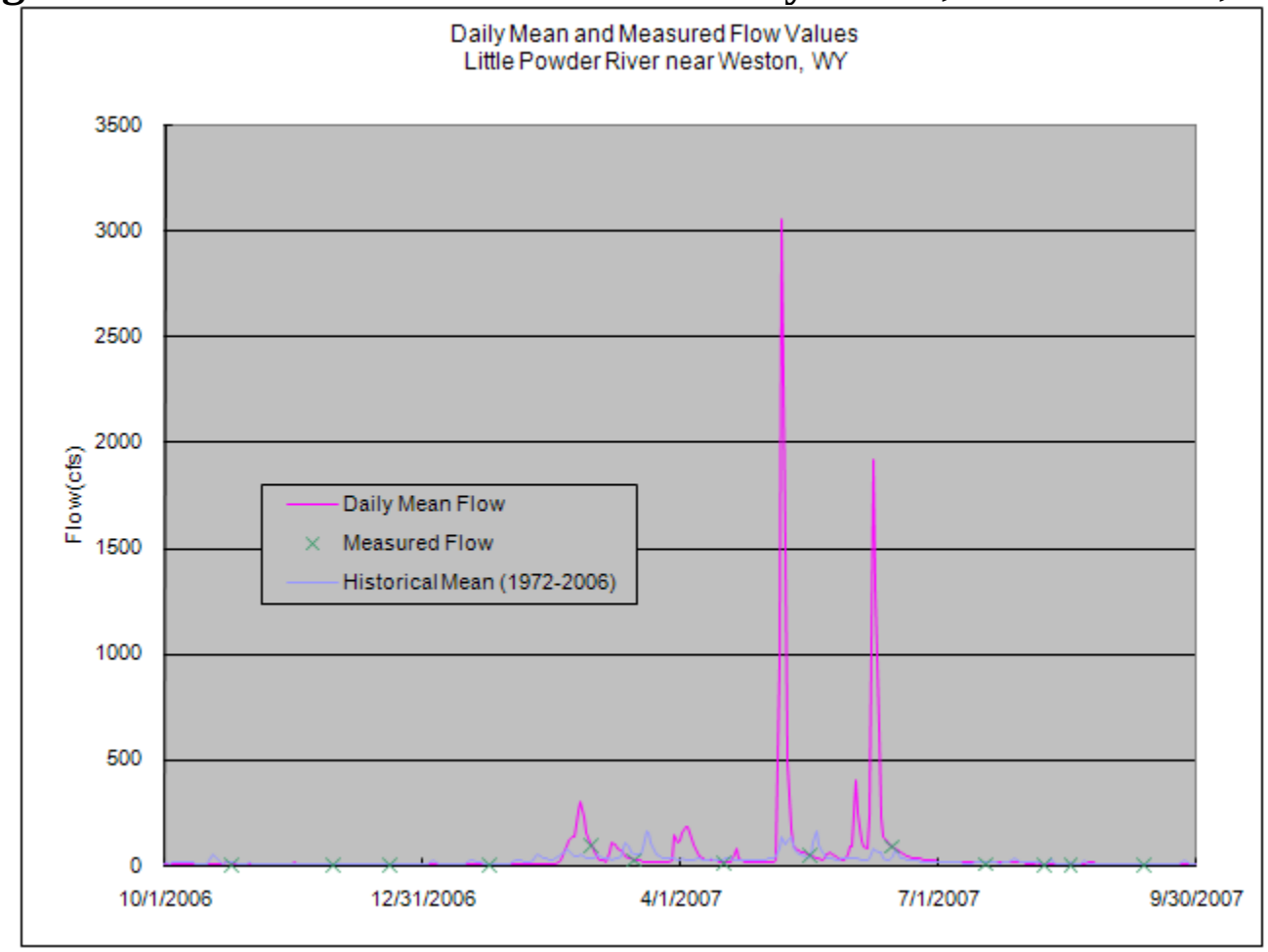

Figure 39 shows Daily Mean and field measurements of flow in a time series plot for water year 2007 for the Little Powder River near Weston. Daily Mean flow values ranged from 0.3 to 3050 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 40: Little Powder River above Dry Creek, near Weston, WY

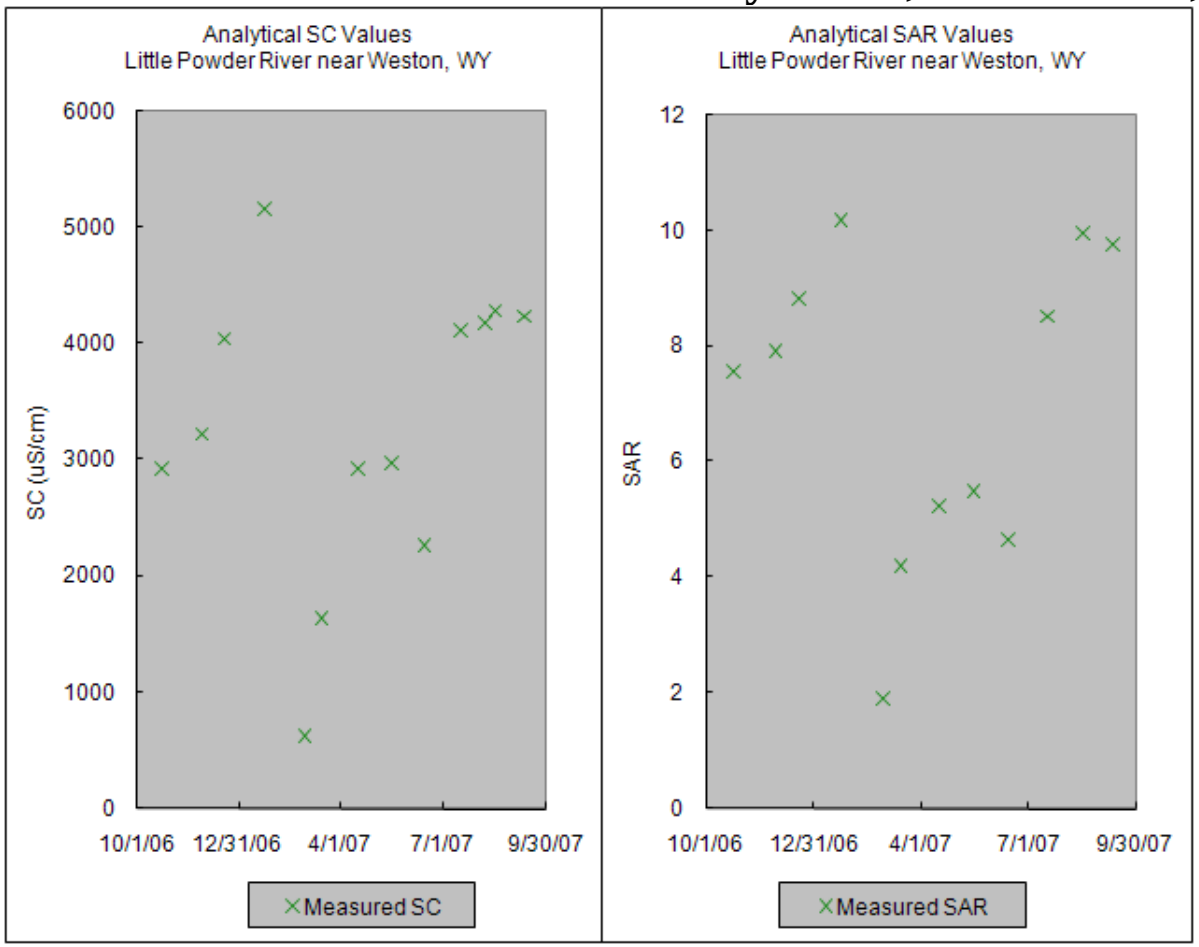

Figure 40 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2007 for the Little Powder River near Weston. SC values ranged from 627 to 5170 uS/cm. SAR values ranged from 1.9 to 10.2.

Figure 41: Little Powder River above Dry Creek, near Weston, WY

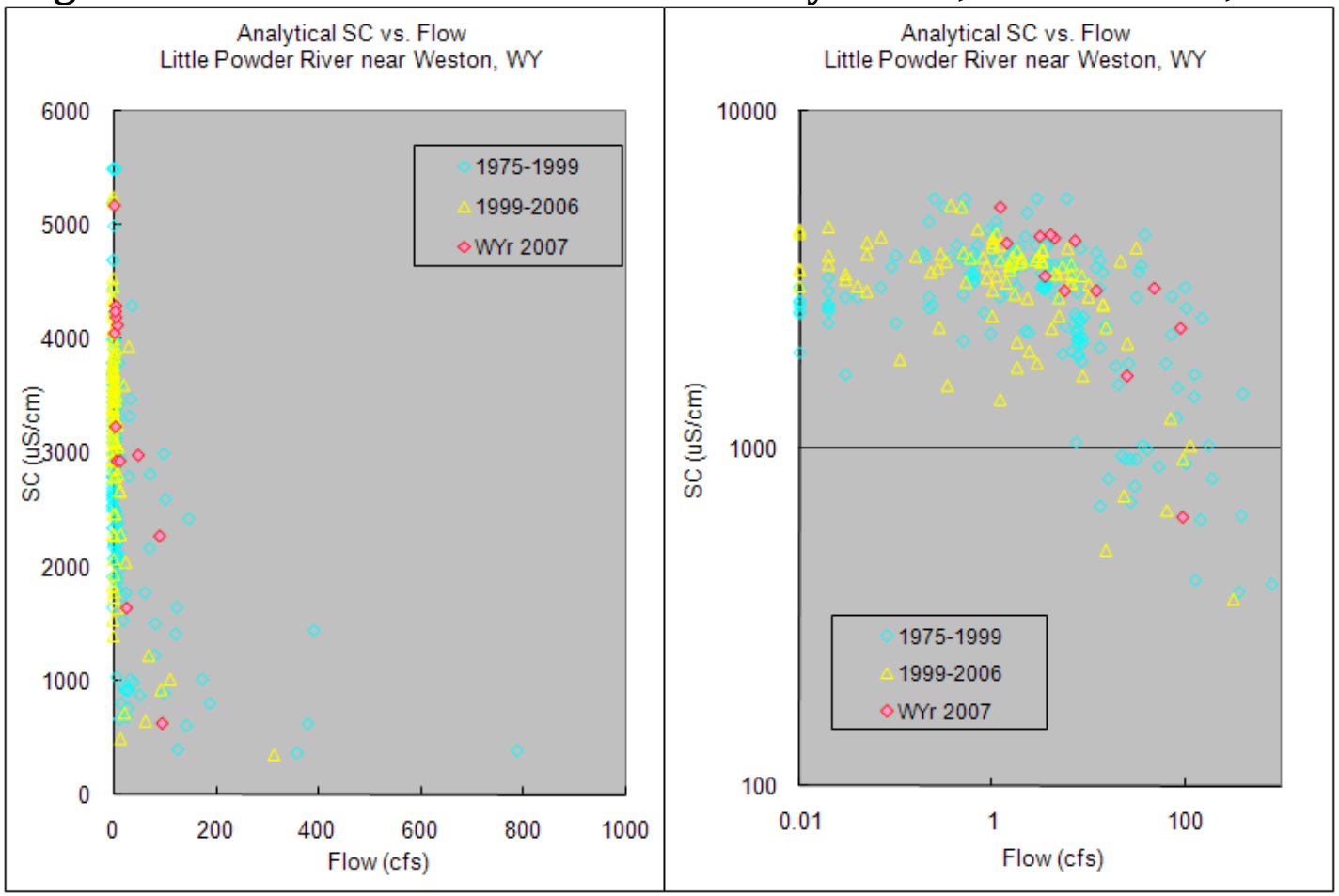

Figure 41 shows analytical SC vs. Flow data for water year 2007 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 42: Little Powder River above Dry Creek, near Weston, WY

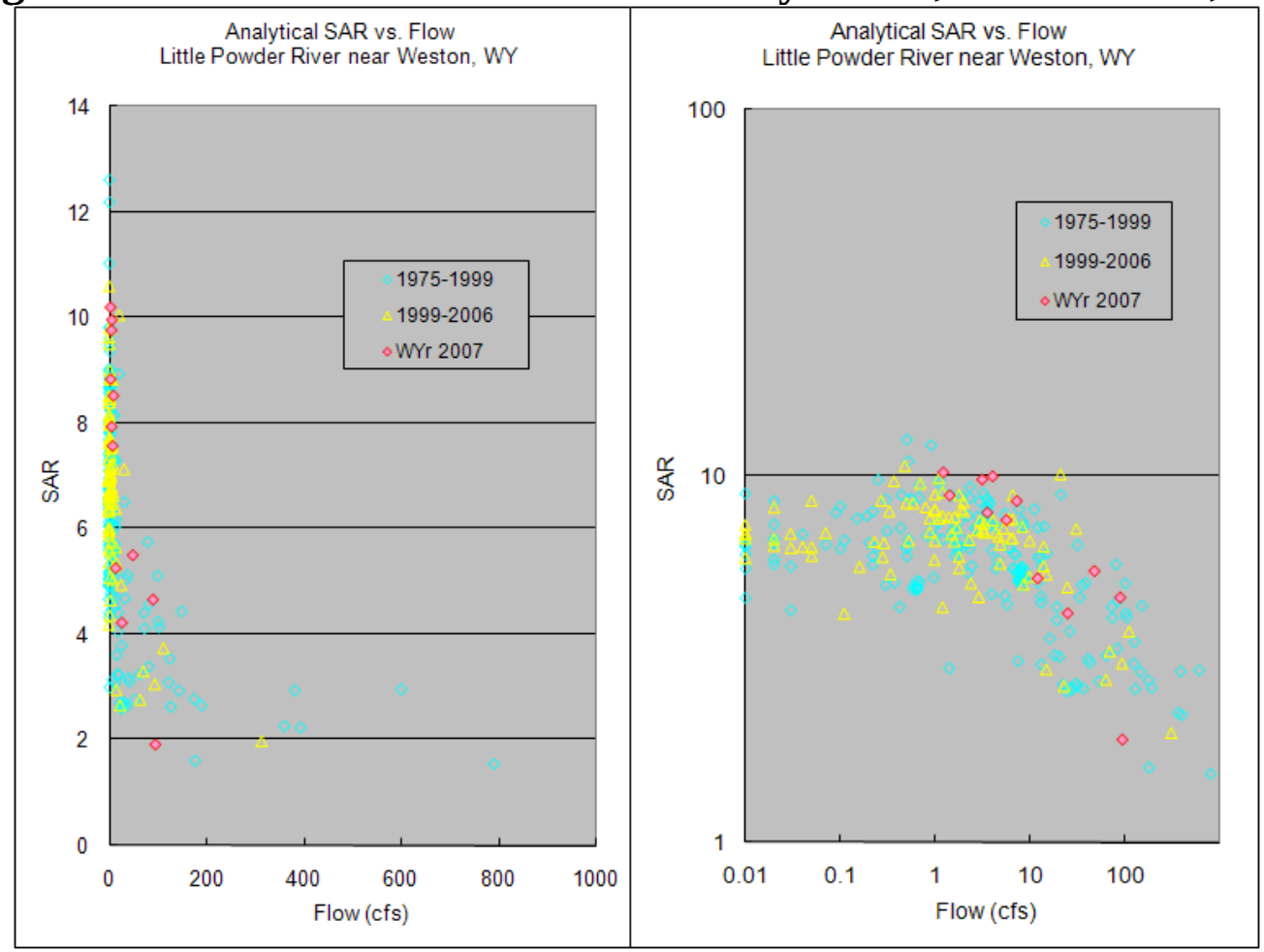

Figure 42 shows analytical SAR vs. Flow data for water year 2007 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 43: Little Powder River above Dry Creek, near Weston, WY

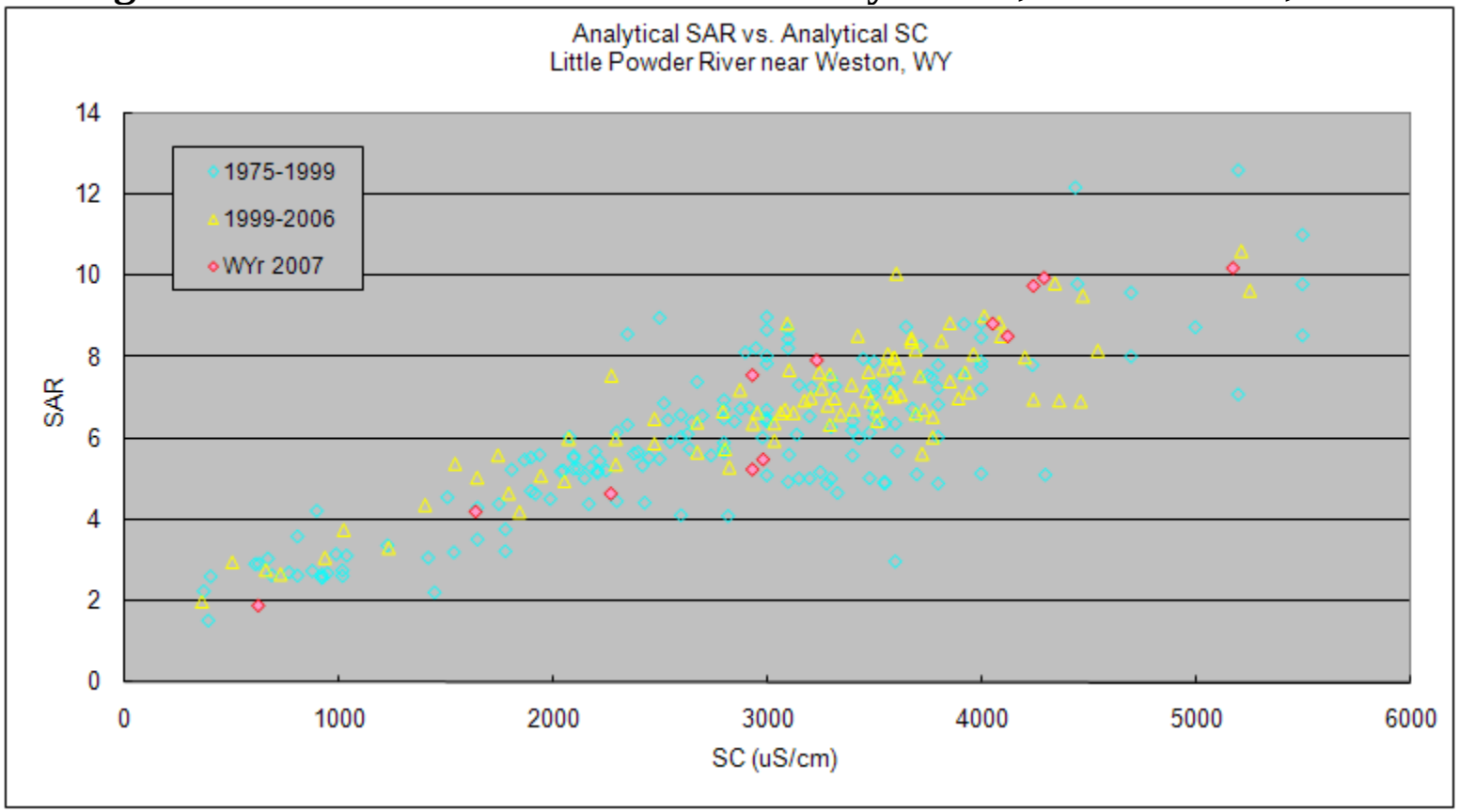

Figure 43 shows analytical SAR vs. analytical SC data for water year 2007 for the Little Powder River near Weston. Historical SAR vs. SC data are also shown to place the data in context.

Figure 44: Little Powder River near Broadus, MT

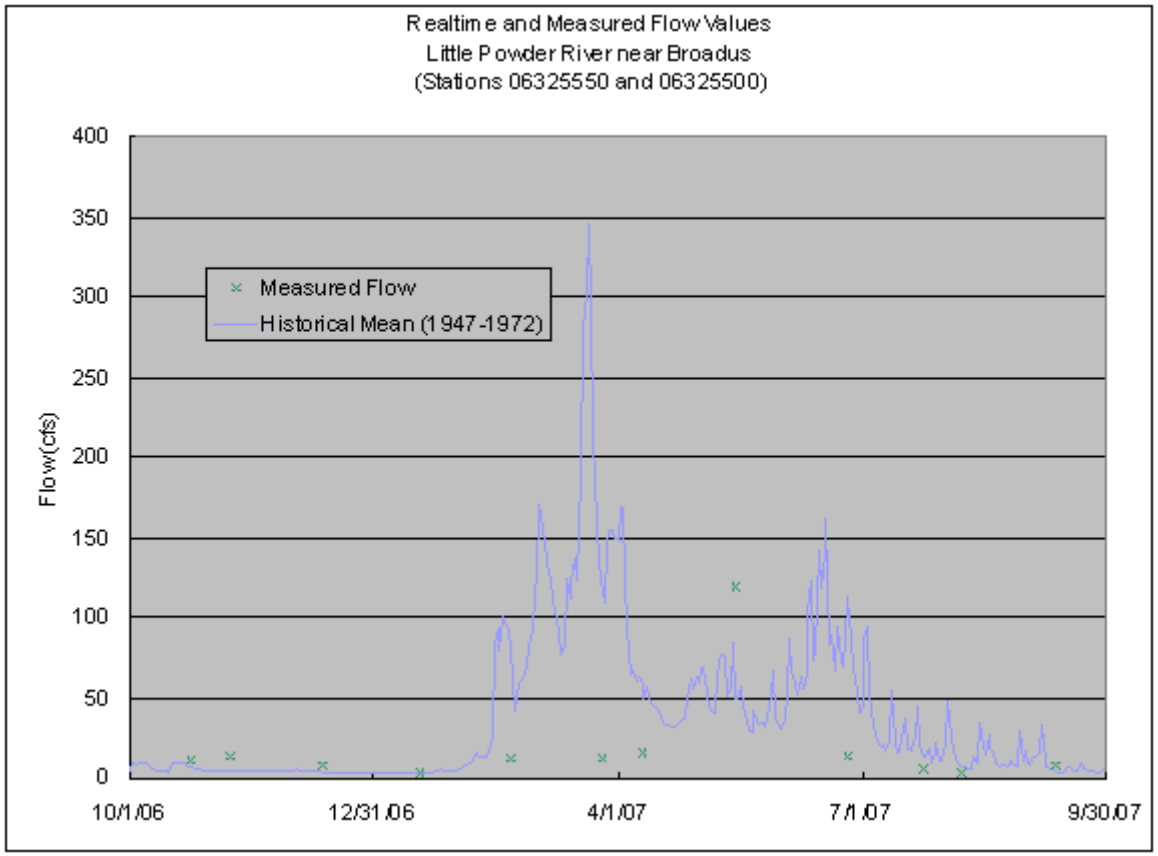

Figure 44 shows field measurements of flow in a time series plot for water year 2007 for the Little Powder River near Broadus. Recorded flow values ranged from 3.7 to 119 cfs. The historical average Daily Mean flow values are also shown to place the data in context.

Figure 45: Little Powder River near Broadus, MT

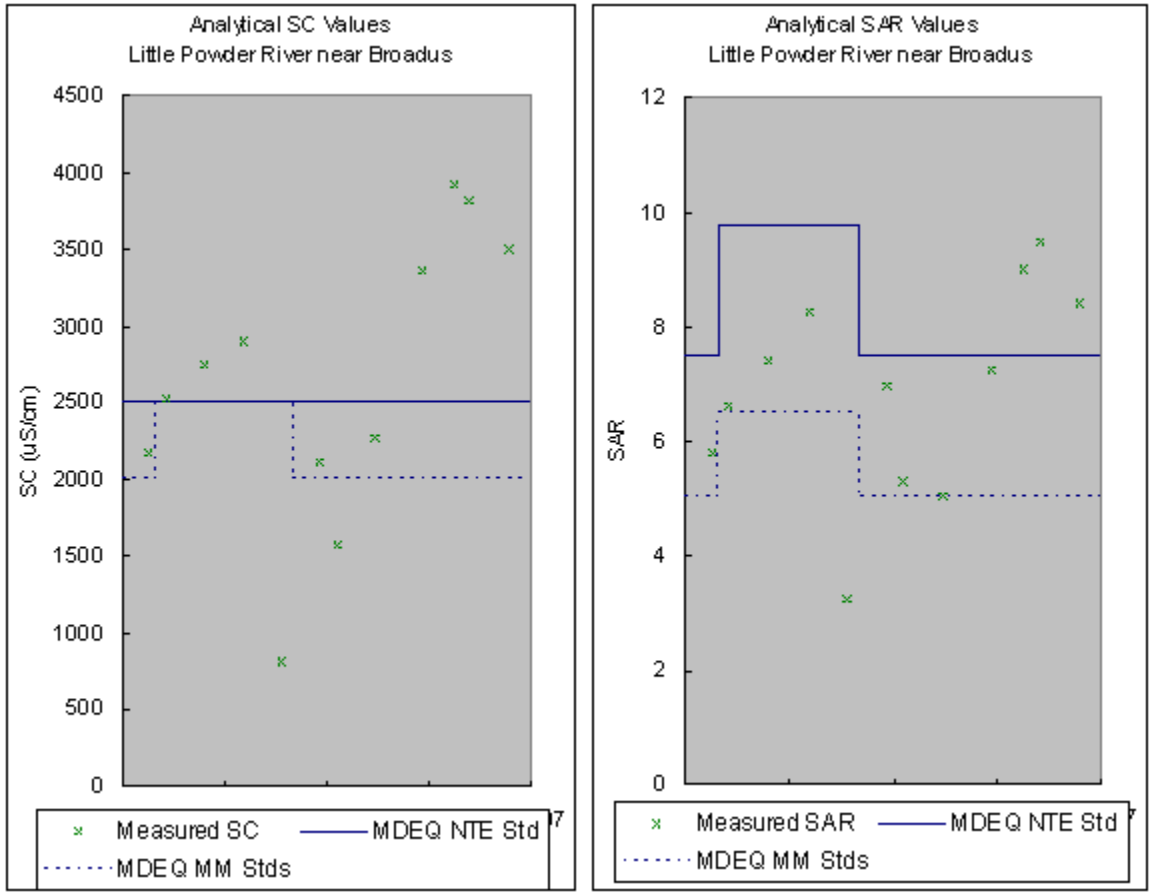

Figure 45 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2007 for the Little Powder River near Broadus. SC values ranged from 808 to 3920 uS/cm. SAR values ranged from 3.3 to 9.5. MDEQ standards are also displayed for comparison. SC NTE standards are exceeded for 7 samples. There is insufficient data to evaluate the Monthly Mean EC standard. The SAR NTE standards are exceeded for 3 samples. There is insufficient data to evaluate the Monthly Mean SAR standard.

Figure 46: Little Powder River near Broadus, MT

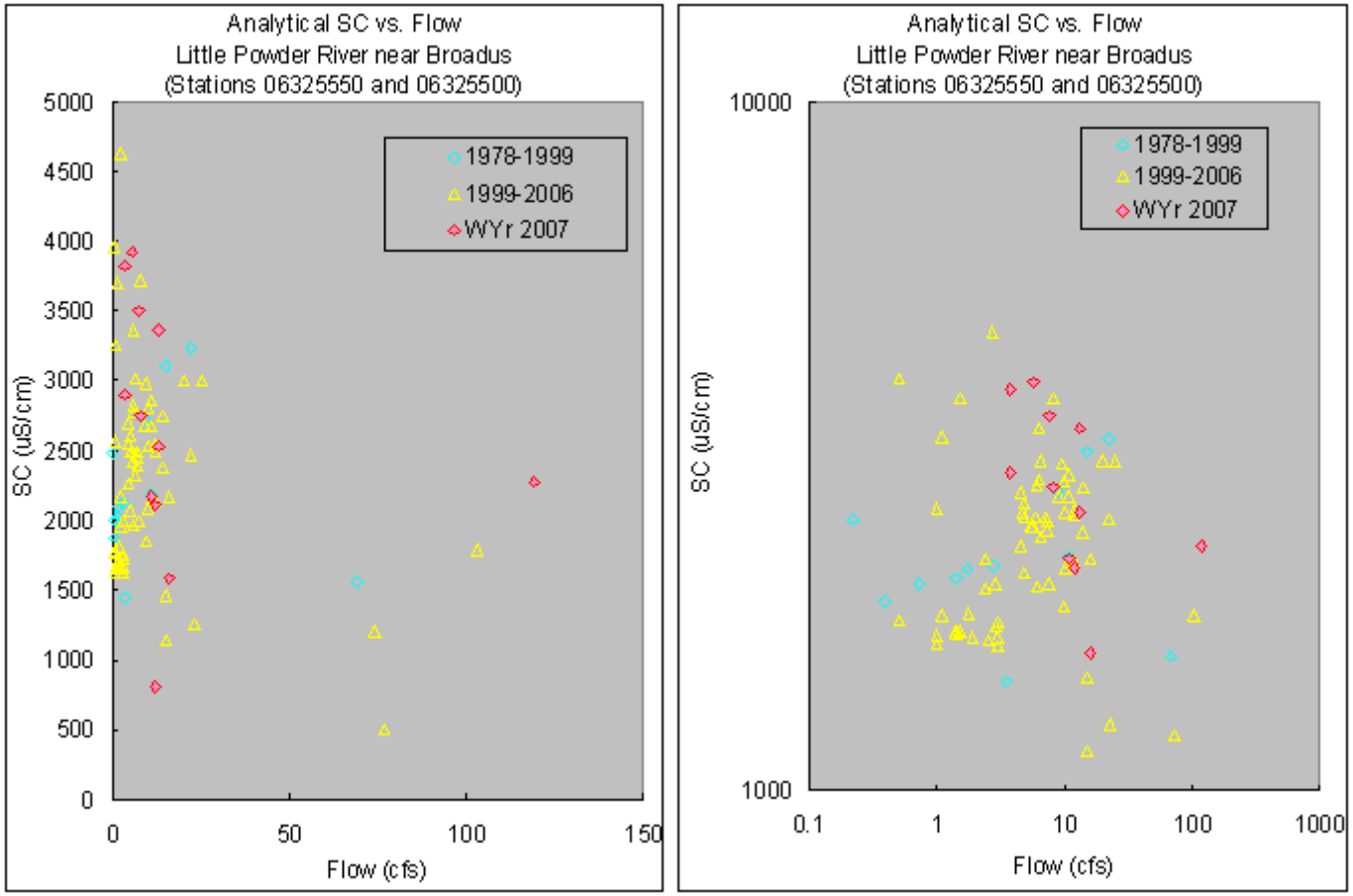

Figure 46 shows analytical SC vs. Flow data for water year 2007 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 47: Little Powder River near Broadus, MT

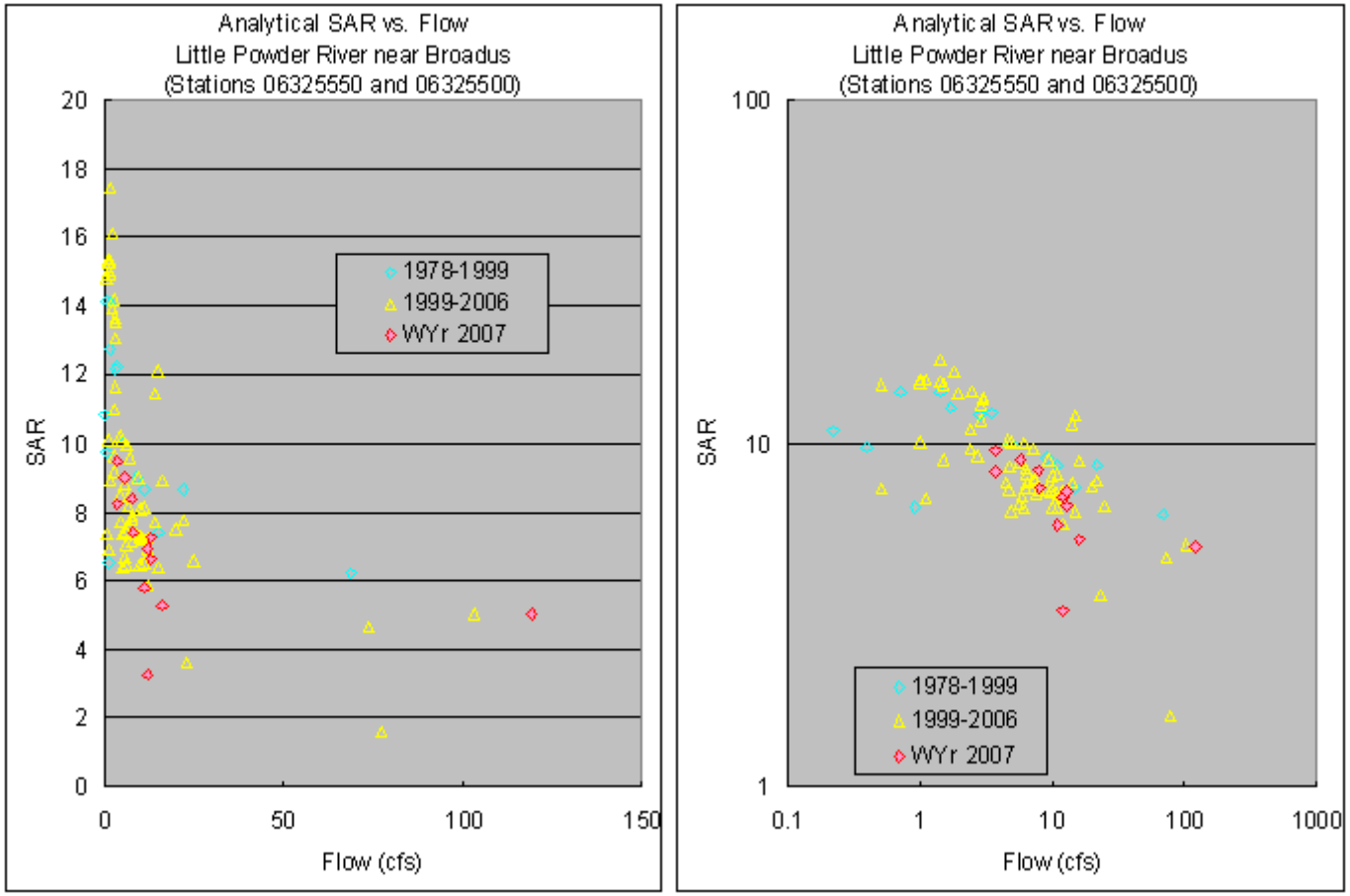

Figure 47 shows analytical SAR vs. Flow data for water year 2007 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 48: Little Powder River near Broadus, MT

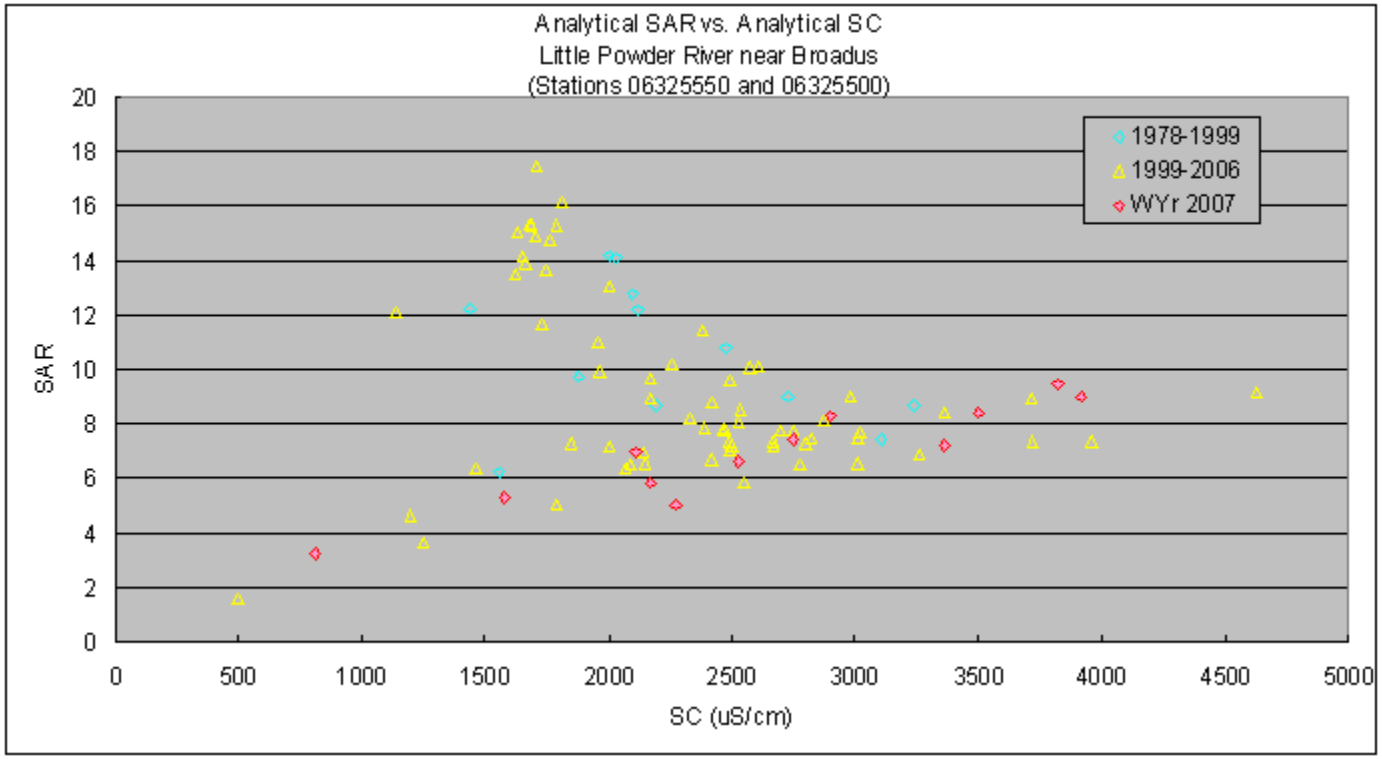

Figure 48 shows analytical SAR vs. analytical SC data for water year 2007 for the Little Powder River near Broadus. Historical SAR vs. SC data are also shown to place the data in context.