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Real-Time Monitoring and Regression Analysis for Specific Conductance and Sodium-Adsorption Ratios in an Area of Coalbed Natural Gas Development in the Powder River Basin, Wyoming and Montana

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Introduction

The Powder River structural basin in northeastern Wyoming and southeastern Montana contains important energy resources for the United States. Coal, conventional natural gas, oil, uranium, and most recently, coalbed natural gas (CBNG) are developed in the basin. During the production of CBNG, water is pumped from wells, lowering hydrostatic pressure in the coalbeds and allowing the natural gas that was confined and stored within the internal surfaces and voids of the coal to flow (DeBruin and others, 2000). Currently, most water produced during CBNG production in Wyoming is discharged into constructed reservoirs or into surface drainages, where it may infiltrate into the ground, become part of the streamflow, or evaporate.

The quantity and quality of the produced waters varies depending on the coalbed source. Specific conductance and sodium-adsorption ratios (SAR) may be larger in coalbed waters than in stream waters that may receive the discharge waters and are a concern for irrigation water use. The U.S. Geological Survey, in cooperation with the Wyoming Department of Environmental Quality, monitors streams throughout the Powder River structural basin for potential effects of CBNG development. Continuous water-quality instruments for specific conductance were installed, and discrete water-quality samples were collected to characterize water quality at four sites in the Powder River drainage basin (fig. 1):

- Powder River at Sussex, Wyoming (PR1);
- Crazy Woman Creek near Arvada, Wyoming (CWC);
- Clear Creek near Arvada, Wyoming (CC); and
- Powder River at Moorhead, Montana (PR2).

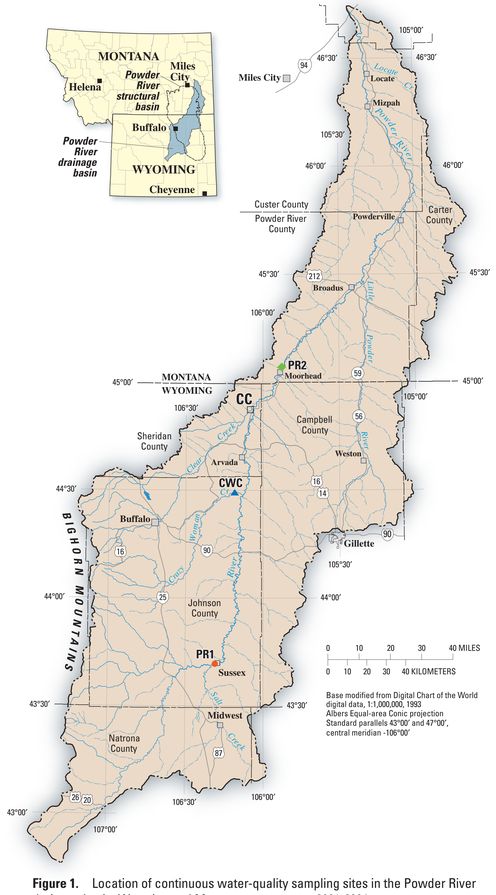


Figure 1. Location of continuous water-quality sampling sites in the Powder River drainage basin, Wyoming and Montana, water years 2001-2004.

Coalbed natural gas discharge point.

Study Area

The study area in the Powder River drainage basin covers 8,088 square miles at Moorhead, Montana. Elevation in the basin ranges from about 3,350 feet above the North American Vertical Datum of 1988 (NAVD 88) at the stream gage at Moorhead, Montana to more than 13,100 feet above NAVD 88 in the Bighorn Mountains. Streamflow characteristics for the study area are a combination of those characteristics typical of streams that originate in the plains and streams that originate in the mountains. Mean annual runoff for the Powder River at Moorhead, Montana is 320,000 acre-feet for the period of record from 1930 to 2004.

Water-Quality Characteristics

The suitability of water for irrigation use is dependent on several factors, including specific conductance and SAR. The salinity hazard of stream waters at the study sites generally is high to very high, and the sodium hazard generally is low to medium (fig. 2). Specific conductance and SAR values for discrete samples collected from the four study sites were plotted on a diagram that describes potential for reduction in the rate of infiltration from irrigation waters for a range of specific conductance and SAR values (fig. 3). Most of the samples from water years 2001-2004 plot in the area of the diagram where no reduction in the rate of infiltration is expected. The concern exists that CBNG discharge waters could change these relations in the future.

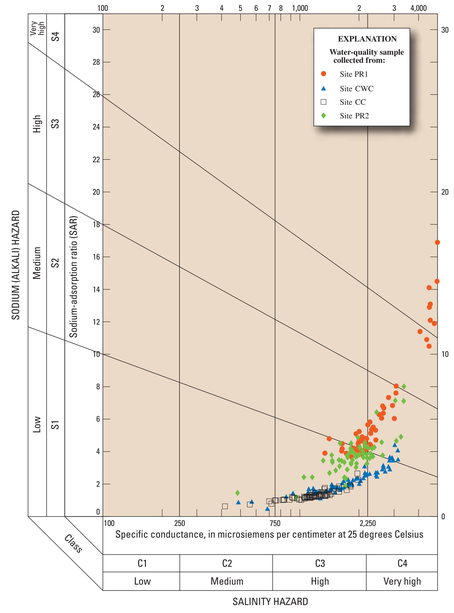


Figure 2. Diagram showing suitability of water for use in irrigation for four sites in the Powder River drainage basin, Wyoming and Montana, water years 2001-2004 (diagram modified from U.S. Salinity Laboratory Staff, 1954).

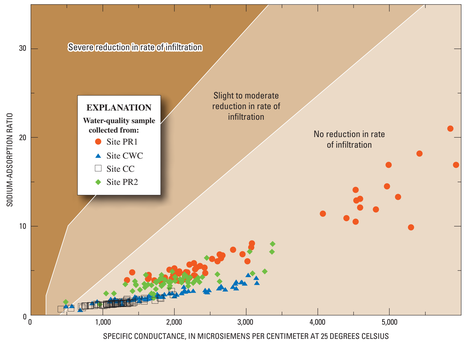


Figure 3. Diagram showing specific conductance and sodium-adsorption ratio and potential for reduction in rate of infiltration for water-quality samples collected from sites in the Powder River drainage basin, Wyoming and Montana, water years 2001-2004 (diagram modified from Hanson and others, 1993).

Real-time Monitoring and Regression Analysis

Continuous water-quality instruments measure specific conductance at sites in the Powder River drainage basin during the irrigation season. Daily mean specific conductance was variable and had a large range of values during the irrigation season at all four sites. The daily mean specific conductance for the Powder River ranged from 953 to 7,100 µS/cm at Sussex, and from 492 to 5,920 µS/cm at Moorhead. Daily mean specific conductance generally was smaller for the tributaries than for the mainstem and ranged from 394 to 3,280 µS/cm for Crazy Woman Creek (fig. 4) and from 387 to 2,070 µS/cm for Clear Creek.

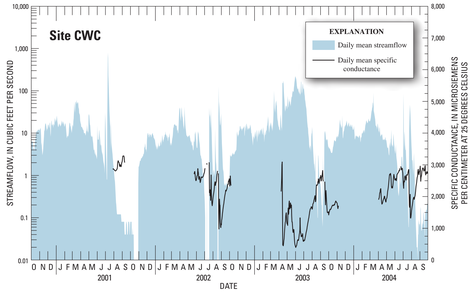


Figure 4. Daily mean streamflow and specific conductance for Crazy Woman Creek, Wyoming, water years 2001-2004.

Water-quality sampling on the Powder River.

Crazy Woman Creek near Arvada, Wyoming.

Data relations were examined to determine if specific conductance values are a good surrogate for laboratory analyses of SAR. Regression equations for discrete values of specific conductance and SAR were statistically significant (p-values <0.001) at all four sites (table 1). The strongest relation (R^2=0.92) was at the Powder River at Sussex, Wyoming. Relations on Crazy Woman Creek (R^2=0.91, fig. 5) and Clear Creek (R^2=0.83) also were strong. The relation between specific conductance and SAR was weakest (R^2=0.65) at the Powder River at Moorhead, Montana; however, the relation was still significant. The substantially larger and geologically diverse drainage area of the Powder River at Moorhead probably is the source of the additional scatter in data from Moorhead.

Table 1. Regression equations for estimates of sodium-adsorption ratios for sites in the Powder River drainage basin, Wyoming and Montana, 2001-2004.

[SAR, sodium-adsorption ratio; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; MSE, mean square error; R^2, coefficient of determination]

Site	Equation	MSE	R^2	p-value
PR1	SAR=0.0033(SC) - 2.2	1.29	0.92	<0.001
CWC	SAR=0.0011(SC) + 0.088	0.242	.91	<.001
CC	SAR=0.0010(SC) + 0.17	.130	.83	<.001
PR2	SAR=0.0018(SC) + 0.38	.711	.65	<.001

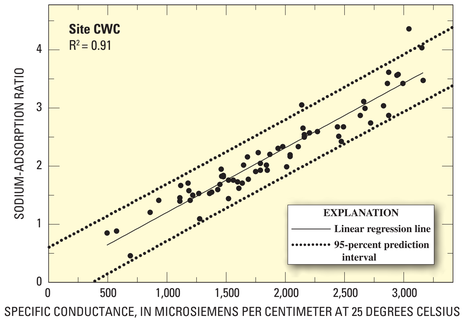


Figure 5. Sodium-adsorption ratios in relation to specific conductance in water-quality samples collected from Crazy Woman Creek, Wyoming, water years 2001-2004.

The estimated SAR values from the regression equation were compared to the SAR values calculated from the discrete samples (fig. 6). Some of the estimated values were outside of the range of the SAR values for discrete samples, indicating samples may not be representative of some hydrologic conditions. The estimated SAR values may more adequately characterize the fluctuations of SAR values that occur in the streams because the continuous specific conductance values show more fluctuations.

Specific conductance and estimated SAR values (fig. 7) are available to the public in real time using NWISWeb (*http://waterdata.usgs.gov/nwis/*). Using continuous specific conductance to estimate SAR values increases the amount of information available in real time to irrigators for decision making.

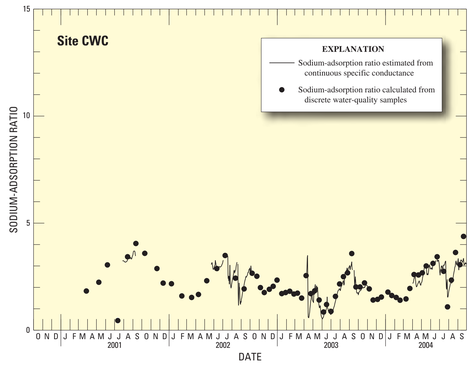
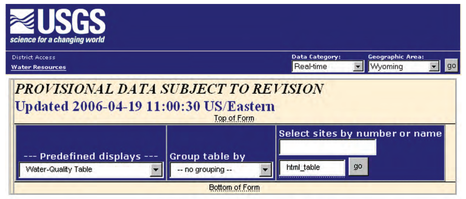


Figure 6. Estimated and calculated sodium-adsorption ratios for Crazy Woman Creek, Wyoming, water years 2001-2004.



Station Number	Station name	Date/Time	Specif. conductance, wat unf uS/cm 25 degC	Sodium adsorption ratio	Streamflow (ft³/s)
06313500	Powder River at Sussex, WY	04/19 08:15	1,650	3.24	314
06316400	Crazy Woman Creek near Arvada, WY	04/19 07:45	1,440	1.67	8.5
06324000	Clear Creek near Arvada, WY	04/19 08:00	581	0.75	182
06324500	Powder River at Moorhead, MT	04/19 08:00	1,470	3.0	282

Figure 7. Real-time data for Wyoming.

Clear Creek near Arvada, Wyoming.

References

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Hanson, B.R, Grattan, S.R., and Fulton, A., 1993, Agricultural salinity and drainage: Davis, California, University of California Irrigation Program, Water Management Handbook Series, Publication 93-01, 141 p.

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