# Soil Behavior Upon Wetting with Saline-Sodic Water
# Part 1 - Background Information

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**The following article constitutes Part 1 of a project report submitted to the Prairie County Conservation District and the Buffalo Rapids Irrigation District.**

## ABSTRACT

The purpose of this project was to determine the compatibility between coal bed methane (CBM) product water and potentially irrigable soils and the effects product water may have on soil physical properties when applied to the irrigable soils of southeastern Montana. Soil samples representing four soil textures (fine sandy loam, silt loam, silty clay loam, silty clay) were collected from sites within the Powder River Basin in Montana. Soil sampling **locations** were selected on the basis of their representativeness of potential or actual irrigated acreage in the proposed development area of Montana. CBM and Powder River water was synthesized and applied to the soil samples. Changes in soil chemical and physical properties have been monitored throughout a variety of water application scenarios.

## Overview - Project Justification and Rationale

One question which has been repeatedly raised regarding dispersal, disposal, and utilization of CBM product water and existing surface waters mixed with CBM product water is what effects CBM-signature water has on soil physical and chemical properties. Generally, the identified signature of CBM product water is elevated salinity and sodicity, relative to existing surface water resources routinely used for irrigation. However, this is not universally the case. In some instances, particularly during periods of low stream flow coinciding with the irrigation season, CBM product water may have a lesser salinity and/or sodicity than surface water resources.

Research has repeatedly documented the deleterious effects of salinity on crop performance and quality and the deleterious effect of sodicity on soil structure, particularly in soils dominated by fine textures and smectitic clays (Miller and Donahu, 1995; Ayers and Westcot, 1976). Published USDA-NRCS soil survey data and independent analyses of clay types conducted as part of this research have verified extensive alluvial soils in eastern Montana with a predominance/preponderance of smectitic clay. Additional research has revealed that elevated soil solution salinity levels can enhance flocculation of fine particles, thereby offsetting the dispersive effect of elevated sodium. A third complicating factor which has been reported in the scientific literature is the disruption of the salinity-sodicity equilibrium as a result of either salt-free rainfall/precipitation or subsequent irrigation with relatively salt-free or low salinity water.

In anticipation of significant landowner questions regarding the potential impact of discharges of saline-sodic water from CBM development sites into the Powder River, the Prairie County Conservation District, along with several other soil and water conservation districts and the Buffalo Rapids Irrigation District contracted the Department of Land Resources and Environmental Sciences at Montana State University-Bozeman to conduct an extensive assessment of the responsiveness of irrigable soils to wetting and irrigation with saline-sodic water. Saline-sodic water is a characteristic signature of coal bed methane product water. In addition, during specific times of the irrigation season, and particularly during drought years, surface waters of the Powder River may become saline-sodic.

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## Stage I: Background Information

The specific objective of this study was to assess soil physical and chemical responses upon wetting with saline–sodic water. This was accomplished by exposing approximately 54 soil materials, collected from 16 different sites within the Powder River watershed and Buffalo Rapids Irrigation District, to various combinations of two water qualities and three wetting/irrigation regimes. The water qualities consisted of simulated Powder River surface water characteristic of June each year and an aggregate CBM product water derived from the Powder River basin. Wetting and irrigation regimes consisted of: 1) a single wetting event simulating flood irrigation, 2) a cycle of wetting and drying, completed 5 times in succession, simulating sprinkler or repeated flood irrigation, and 3) a cycle of wetting and drying, completed 5 times in succession, followed by a single flood (flushing) event with distilled water, simulating repeated irrigation followed by rainfall.

To understand what effects CBM product water may have on the environment, an understanding of current irrigation water quality is needed. Initially, 30 years of USGS data from the Powder River was assembled and analyzed to determine any existing correlations among the parameters in the database. The existing **Powder River water quality data** was assembled into graphic format to illustrate some of the relationships investigated. The next step was examination of discharge data from 56 CBM wells in the Wildcat Creek Watershed and Powder River Basin in Wyoming. Water chemistry and flow data from these wells was assumed to be typical of discharge from CBM wells in Montana. This **CBM discharge water quality data** was also assembled into graphic format for analysis of similarities and differences between water sources.

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## Stage II: Sampling

Initial soil sampling was conducted in the Buffalo Rapids Irrigation district and along the Powder River, located in southeastern Montana on July 10-11 and 24-26, 2001. The sample area included sites in Custer, Dawson, Prairie, and Powder River counties. NRCS provided a list of all the soils and their total acreage within the Buffalo Rapids Irrigation District. This information was used to define by texture the soils with the most acreage within the district. These data were then correlated with the irrigable acreage along the Powder River. Sampling focused on collecting soils from series with extensive acreage within this district and along the Powder River.

Soil samples representing a variety of textures (fine sandy loam - fsl, silt loam - sil, silty clay loam - sicl, and silty clay/clay loam - sic) of irrigated and non-irrigated soils occurring along the Powder River corridor from the Montana-Wyoming line (Moorhead) to the Yellowstone River and irrigated soils within the Buffalo Rapids Irrigation District were collected. In each of the four counties, a soil profile was sampled representing each texture group, sample holes were excavated to -40 inches (-100 cm), and approximately 60 pounds (25 kg) of soil from each horizon was collected.

These soil samples (54 in total) were then subjected to various wetting and drying cycles with synthesized waters representative of CBM product water, Powder River water during the peak of the irrigation season, and rainfall. Subsamples from before treatment (baseline) and following each treatment were analyzed for pH, EC (salinity), extractable base cations, and exchangeable cations. Moisture release retention characteristics of each soil material were also determined after each water quality x wetting regime.

## Stage III: Baseline Characterizations

Samples were returned to Montana State University and air dried. Particle size analyses were run on each sample using the hydrometer method. Results were summarized as sand, silt, and clay fractions in g/100 g soil. From these results, we defined the texture of each sample on the **textural triangle**.

Sub-samples of each sample were also ground, sieved, and sent to MDS Harris labs in Lincoln, Nebraska for analysis of baseline chemical properties (base cations, EC, pH, CEC, bicarbonate). The results of this **baseline data** were used to determine changes in soil chemical properties when CBM product water is applied.

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## Stage IV: Determining CBM Effects on Soil Chemical, Physical, and Hydraulic Characteristics

A four pressure plate apparatus was used to measure soil water retention at 1/10, 1/3, 1, 5, and 15 bars of pressure. In the lab, soils were treated with either synthesized CBM product water or Powder River water and subjected to the following treatments:

**Treatments:** Treatments consist of six different water quality x wetting regime combinations, in addition to characterization of the baseline of pre-existing condition.

| **Table 1. Treatment Combinations**<br>**Water Quality** | **Irrigation Strategy** |
|---|---|
| **PR = Powder River** | **Baseline (Pre-existing)** |
| EC = 1.56 dS/m | 1 x wet - dry w/PR |
| SAR = 4.54 | 5 x wet - dry w/PR |
| pH - 8.03 | 1 x wet - dry w/CBM<br>5 x wet - dry w/CBM |
| **CBM = Product Water** | **Discharge Water Quality** |
| EC = 3.12 dS/m | 5 x wet - dry w/CBM followed by 1 pore volume DW leaching |
| SAR = 13.09 | 5 X wet - dry w/PR followed by 1 pore volume DW leaching |

With the exception of the baseline (pre-existing characterization), soil from each of the 54 horizons was treated with six water quality x wetting regime combinations. Water quality treatments consisted of either synthesized Powder River water or synthesized

CBM product water (Table 1). For example 1 X wet-dry w/PR consisted of a single wetting with synthesized Powder River water, followed by air drying. Following drying, the samples were then subjected to chemical analyses or used to assess changes in physical properties. The basis for selection of the target signatures for Powder River and CBM water was an extensive analyses of the chemistry of Powder River surface water and permitted CBM outfalls (discharges) within the Powder River watershed, as of October 2001 (Figure 12).

Synthesized water created for this project had the following characteristics. Powder River water: EC ~1.5 dS/m, SAR ~ 3; CBM water: EC ~3 dS/m, SAR~12. Data collected from the pressure plates was used to construct moisture release curves and examine water holding capacities of soils of varying textures as a function of water quality (CBM vs. Powder River). This information will be used to develop a dispersion risk index. This index will predict the likelihood of soil dispersion as a function of soil texture, EC, and SAR.

**Results**: Following a single wet-dry regime with synthesized CBM product water (EC = 3.12, SAR = 13.09), the salinity of the soil extract of the soils with the least baseline EC increased approximately 1.5 dS/m, to a value of slightly greater than 2 dS/m. The increase in EC upon wetting with CBM product water was least for soils with the greatest initial EC. A wetting-drying regime of 5 cycles with CBM product water resulted in a significant increase in EC of the saturated paste extract. EC increased 4-6 dS/m above the baseline, resulting in an average EC of approximately 7.5 dS/m. This represents more than a two-fold increase over the EC of the synthesized CBM product water. Subsequent wetting a single time with simulated rainfall resulted in a decrease in the EC of 41 of 49 samples. This decrease, averaging approximately 2 dS/m, represents a significant change when considering the flocculating effect of salinity in overcoming sodium-induced dispersion.

Upon single wetting events with either Powder River water or synthesized CBM product water, essentially all soils experienced both elevated SAR and ESP. SAR values increased in association with the SAR of the treatment water. A single wetting with Powder River water increased SAR approximately 2 units in soils with lowest initial solution SAR. For soils with baseline SAR values greater than about 3, a single wetting with either Powder River water or CBM product water had little effect on solution SAR. A single wetting with CBM product water increased soil solution SAR approximately 2 to 5 SAR units in soils, with the lowest baseline SAR showing the greatest increase in SAR upon wetting. Two different criteria are currently recognized in the scientific literature as indices of dispersion risk or potential for dispersion. These are the sodium adsorption ratio (SAR) with a reported threshold of 12, and the exchangeable sodium percentage (ESP) with a reported threshold of 15%. The baseline data clearly suggest that under present conditions, only two of the sampled soils are at any substantial risk of dispersion. In general, however, neither does the resultant SAR exceed approximately 7 nor does the resultant ESP exceed approximately 8%.

Treatment involving a regime of five wetting-drying cycles with CBM product water resulted in solution SAR values nearly equal to the SAR of the treatment water, i.e., SAR approaching a value of 10-12. Hence, it is reasonable to conclude that soil solution SAR will equilibrate with the SAR of the applied water over time. In the present study, upon repeated addition of CBM product water, approximately 40% of the ESP values exceeded 15% and corresponding SAR values exceeded 12. Subsequent leaching with simulated rainfall reduced the ESP approximately 3%.

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## Stage IV: Final Product

Information generated from this project will be used to develop a diagnostic and decision support tool (a user-friendly, Internet accessible and printed worksheet) for irrigators to use in determining the suitability of CBM-impacted irrigation water for specific irrigated soil x crop combinations. This worksheet will be also be included in a tool kit which will be made available for irrigators to use in the field. These "tool kits" will contain diagnostic and analytical tools with instructions to collect the sufficient data necessary to make decisions while in the field about irrigation water quality x soil type suitability.

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If you are interested or have any questions contact Kim Robinson at **kimr00@hotmail.com**.