Final Report

FATE OF COALBED METHANE PRODUCED WATER IN DISPOSAL PONDS IN THE POWDER RIVER BASIN

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1. Abstract

The Powder River basin (PRB) in Wyoming has seen a rapid increase in coalbed methane (CBM) production over the past decade. Product water from the ~20,000 active CBM wells is mostly released in surface ponds. The product water may be high in total dissolved solids, be sodium dominated, and may contain trace elements that are toxic to humans, livestock, and wildlife. The fate of the pond water is generally unknown. Infiltration of pond water could lead to the contamination of shallow groundwater and surface water. Concentration of pond water due to evaporation could lead to unacceptable high trace element concentrations. Previous studies suggest that pond water infiltration reduces with time because of soil dispersion related to the high sodium content of the CBM water. We examined the relationship between soil type, CBM water quality, and infiltration rate for a variety of unlined ponds across the PRB. We were particularly interested in determining the time frame over which the infiltration rate reduces as compared to the total lifetime of the ponds. We completed the analysis for four sites. For two sites we found that infiltration rates were unaffected by the CBM water. For two other sites we did observe a reduction in infiltration rates due to CBM water disposal. This type of information is currently lacking for the PRB and would greatly benefit pond operators, landowners, and agencies in assessing the environmental impact of the ponds (i.e. groundwater contamination versus concentration of pond water constituents). Infiltration experiments conducted in the laboratory will be supplemented with numerical modeling of subsurface water flow and solute transport to assess the practical implications of the measured infiltration rates.

2. Progress

2.1 Objectives

The study examined the relationship between soil type, CBM produced water quality, and infiltration rate for unlined disposal ponds in the PRB. The specific objectives were:

(1) Identify combinations of soil type and CBM water quality that are representative for conditions in the PRB;
(2) Measure saturated soil hydraulic conductivity as a function of time during CBM water infiltration in the laboratory;

(3) Model water flow and solute transport for typical PRB CBM ponds over an assumed 10-year lifetime.

2.2 Methodology

[Completed]
Objective (1): Five representative sites were identified in the PRB for which soil and water samples were collected: Site 1 North of Gillette, WY; Site 2 near Sheridan, WY; Site 3 West of Gillette, WY; Site 4 near Buffalo, WY; and Site 5 near Wright, WY. The original plan to use data from an existing network of water quality measurement sites across the PRB established by the research group of KJ Reddy had to be abandoned because many of the original wells had stopped pumping (the amount of water pumping decreases as the well ages). So instead, five new sites were selected.

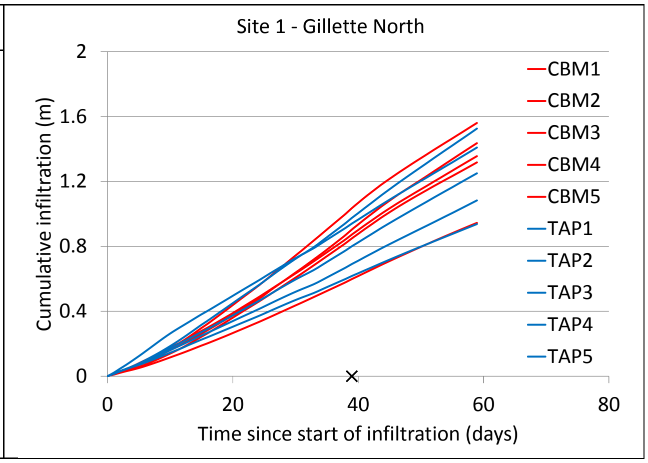
[Mostly completed]
Objective (2): Soil samples were collected from selected sites and taken to the laboratory for the infiltration experiments. The sampled soil was used to represent pre-CBM discharge soil conditions for the pond area. The infiltration experiments were conducted using CBM well water which was collected at the time of soil sampling. The infiltration experiments were conducted in the laboratory by packing the soil in PVC columns with metal screens at the bottom. At the start of the experiment, the columns were wetted from the bottom up with tap water to drive all the air out. Subsequently, well water was applied to the top of the columns at a constant head using a mariotte bottle and outflow quantity and quality was monitored at the bottom of the columns. Outflow quality was measured as Electrical conductivity (EC) and Sodium Adsorption Ratio (SAR) of the water. After about 10 pore volumes were flushed from the columns, the CBM well water was replaced by pristine stream water. The pristine stream water was selected to represent water from rainfall & snow and was used to investigate the impact of non-saline, non-sodic precipitation water on the pond sediments upon cessation of CBM water discharge. Soil water quality inside the columns was analyzed upon completion of the infiltration experiment. The CBM water infiltration results were compared to "baseline" tap water infiltration results for the same soils to more clearly assess the impact of the saline-sodic well water. The "baseline" columns received only tap water (no stream water). For each site 5 columns were infiltrated with CBM / stream water and 5 columns were infiltrated with tap water.

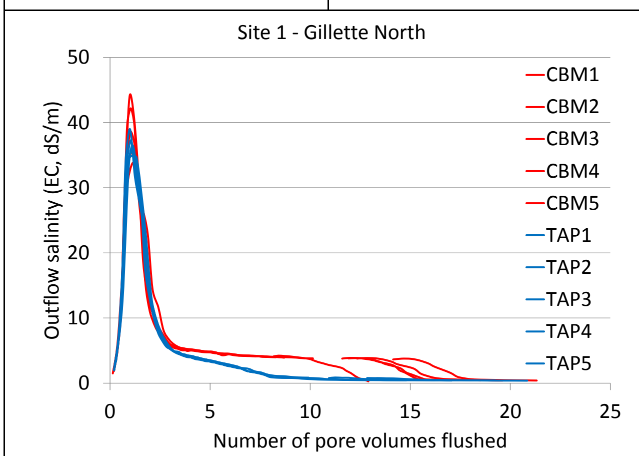
[Yet to be done]
Objective (3): Saturated soil hydraulic conductivity will be calculated from the infiltration data using the Darcy Equation. The practical implications of temporal variations in the saturated hydraulic conductivity of the pond sediments will be studied using the Hydrus-2D model for water flow and solute transport in variably-saturated porous media. The model will be applied in axisymmetric mode to describe a vertical cross section of the pond sediments. A sensitivity analysis will be conducted for a number of idealized pond settings to quantify the effect of reduced hydraulic conductivity on water flow and solute transport over the assumed 10-yr lifetime of the ponds.

2.3 Principal Findings

At the time of writing this report, the laboratory measurements for sites 1-3 were completed, while the measurements for site 4 were being wrapped up. Measurements for Site 5 are anticipated to start once site 4 is completed. The reason for the ongoing laboratory measurements is the long duration of this type of column experiments of up to 100 days. Results for the 3 completed sites are shown below. The results for Site 1, North of Gillette, WY are summarized in Figure 1. The soil type is clay, while the CBM water can be classified as saline, non-sodic. Cumulative infiltration versus time, outflow salinity versus number of pore volumes flushed, and outflow sodicity versus number of pore volumes flushed are shown. The "X" on the "time since start of infiltration" axis (top-right panel) marks the moment when the CBM water was replaced by stream water to see whether the low salinity water would induce soil dispersion. The results for Site 1 show that: (1) On average, infiltration is highest for the CBM water columns; (2) infiltration rates for the CBM and tap water columns remains relatively constant with time; (3) large quantities of salts are flushed from the soil at the onset of infiltration, reflecting the saline nature of the soil; (4) the tap water columns reduce to a lower outflow salinity and sodicity than the CBM water columns; and (5) infiltrating the CBM water columns with good quality stream water does not trigger soil dispersion, judging from the unchanged trend in cumulative infiltration.

Site 1 – Gillette North	
Sand	0 %
Silt	30 %
Clay	70 %
Soil type	Clay
Soil $EC_{1:1}$	10.2 dS m^{-1}
Dry bulk density	1.27 g cm^{-3}
EC CBM water	3.3 dS m^{-1}
SAR CBM water	6.2 $(mmol_c\ l^{-1})^{0.5}$





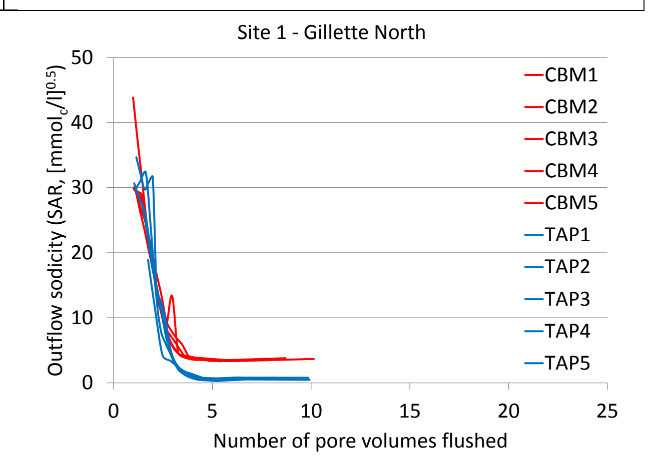
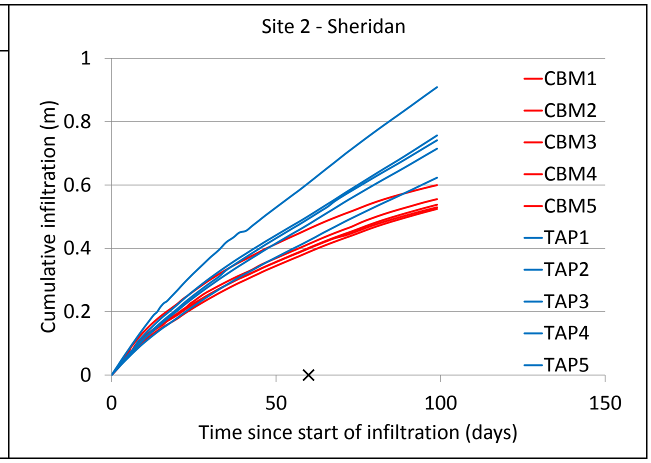


Figure 1Soil & water description, cumulative infiltration, outflow water salinity, and outflow sodicity description for the laboratory soil column experiments for Site 1, North of Gillette, WY.

The results for Site 2 near Sheridan, WY are summarized in Figure 2. The same information is shown as for Site 1. The soil is a clay loam and the CBM water can be classified as moderately saline and highly sodic. The results for Site 2 show that: (1) Infiltration rates decrease with time for both the CBM and tap water treatments; (2) The CBM water columns exhibit a continuous decrease in infiltration rates after CBM water has been replaced by stream water; (3) The tap water columns reduce to a lower outflow salinity and sodicity than the CBM columns; (4) The outflow SAR values remain well below the CBM water SAR values over the course of the entire experiment, possibly indicating that sodium is becoming the dominant cation in the soil solution.

Site 2 – Sheridan	
Sand	22 %
Silt	39 %
Clay	39 %
Soil type	Clay loam
Soil $EC_{1:1}$	0.3 dS m^{-1}
Dry bulk density	1.49 g cm^{-3}
EC CBM water	1.6 dS m^{-1}
SAR CBM water	87.9 $(mmol_c\ l^{-1})^{0.5}$



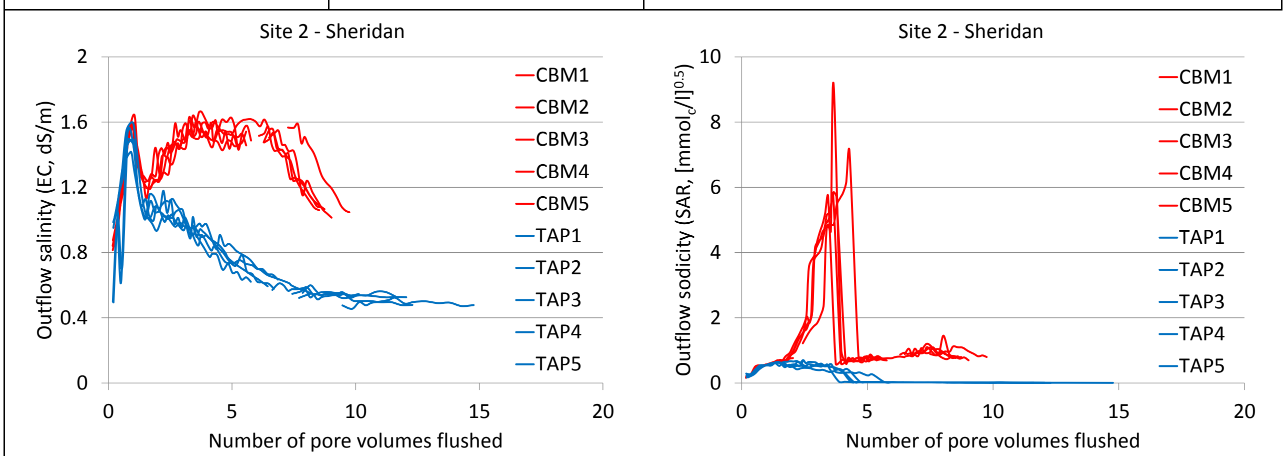
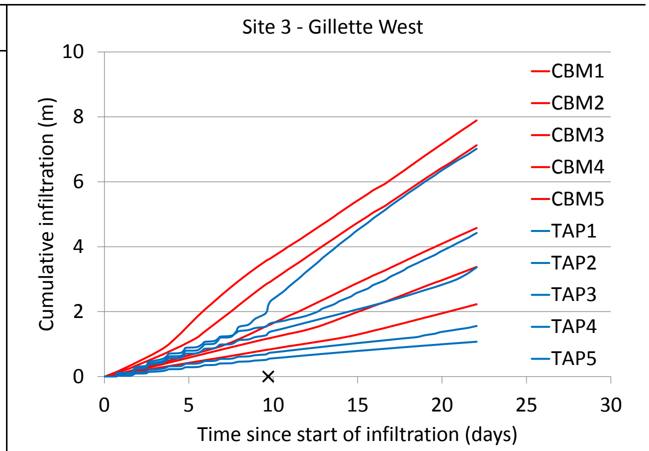
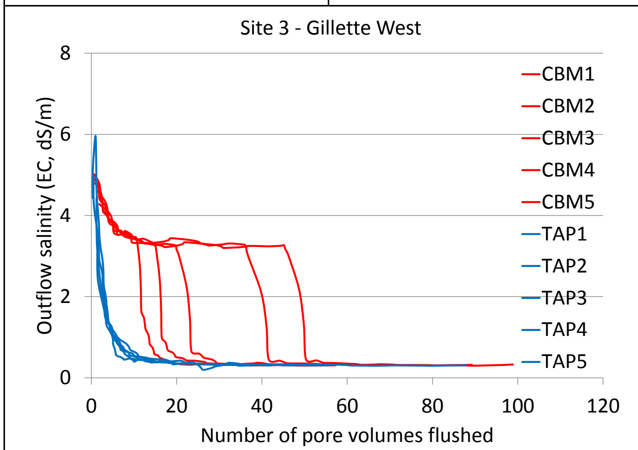


Figure 2Soil & water description, cumulative infiltration, outflow water salinity, and outflow sodicity description for the laboratory soil column experiments for Site 2, Sheridan, WY.

The results for Site 3, West of Gillette, WY are summarized in Figure 3. The soil is a clay loam and the CBM water quality can be classified as saline, non-sodic. The results for Site 3 show that: (1) infiltration rates are higher for CBM water than for tap water and show no decrease with time; (2) leaching of salts by the CBM water is relatively insignificant, compared to Site 1, reflecting the low soil EC; and (3) The introduction of stream water after CBM water results in additional leaching of salts without affecting infiltration rates, indicating no soil dispersion.

Site 3 – Gillette West	
Sand	21 %
Silt	39 %
Clay	40 %
Soil type	Clay loam
Soil $EC_{1:1}$	2.5 dS m^{-1}
Dry bulk density	1.24 g cm^{-3}
EC CBM water	3.4 dS m^{-1}
SAR CBM water	6.3 $(mmol_c\ l^{-1})^{0.5}$





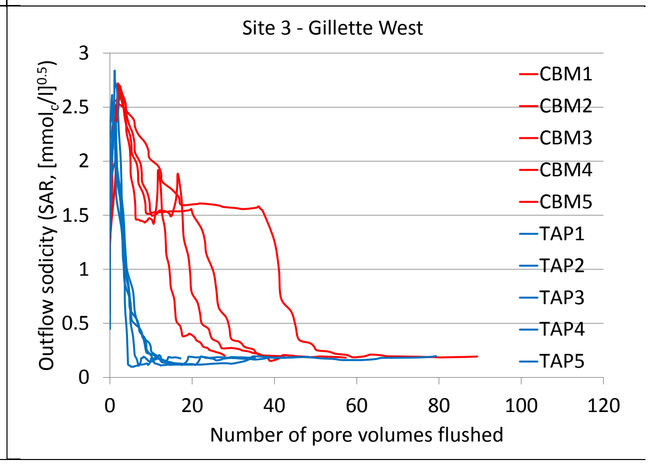


Figure 3Soil & water description, cumulative infiltration, outflow water salinity, and outflow sodicity description for the laboratory soil column experiments for Site 3, West of Gillette, WY.

The preliminary results for Site 4, near Buffalo, WY (not shown) are similar to those for Site 2 (Sheridan), with sodic CBM water having a significant impact on infiltration rates with time.

2.4 Significance

The fate of CBM water in the unlined ponds is not well understood. Both infiltration and evaporation are likely. Infiltration of pond water may lead to contamination of the shallow groundwater and to degradation of streams that are fed by the groundwater. The contamination is caused by the solutes in the pond water and by the mobilization of solutes already present in the soil. Evaporation of pond water may lead to the concentration of trace elements to levels that are toxic for livestock and wildlife that use the pond for drinking water. The infiltration characteristics of the soil determine whether infiltration will be dominant, or, in case of low infiltration rates, evaporation. Previous studies suggest that pond water infiltration reduces with time because of soil dispersion related to the high sodium content of the CBM water. The results from the column infiltration studies for the two Gillette sites seem to contradict this as no drop in infiltration rate with time is observed. In contrast, results for the Sheridan site, and possibly the Buffalo site, do indicate that CBM water sodicity is impacting infiltration rates. Additional column infiltration experiments (Site 5near Wright, WY), will be conducted to provide a more comprehensive picture.

3. Publications

As part of the study, three presentations were given:

Drapeau, R., T.J. Kelleners, and K.J. Reddy. Fate of coalbed natural gas co-produced water in disposal ponds in the Powder River Basin. Oral and poster presentation at the Soil Sci. Soc. Am. Annual Meeting, Oct 21-24, 2012, Cincinnati, OH.

Kelleners, T.J. Water Research Program: Fate of coalbed methane produced water in disposal ponds in the Powder River Basin. Oral presentation for the Wyoming Water Development Commission, Nov 29, 2011, Cheyenne, WY.

Kelleners, T.J. The effects of coal-bed natural gas produced water on infiltration. Oral presentation at the UCOWR/NIWR annual conference, July 11-14, 2011, Boulder, CO.

A journal paper will be drafted and submitted upon completion of the laboratory measurements and the computer modeling. Submission of the paper is anticipated for Fall 2013.

4. Student Support Information

MS student Robert Drapeau was hired for the duration of the 2-year project. The course and research work should result in a MS soil/water resources degree by Fall 2013. Robert attended the Soil Science Society of America Annual meeting in Cincinnati, OH in October 2012 and presented results from the study to a large audience.

5. Awards and achievements

MS student Robert Drapeau has been awarded an energy assistantship by the Office of Academic Affairs of the University of Wyoming.