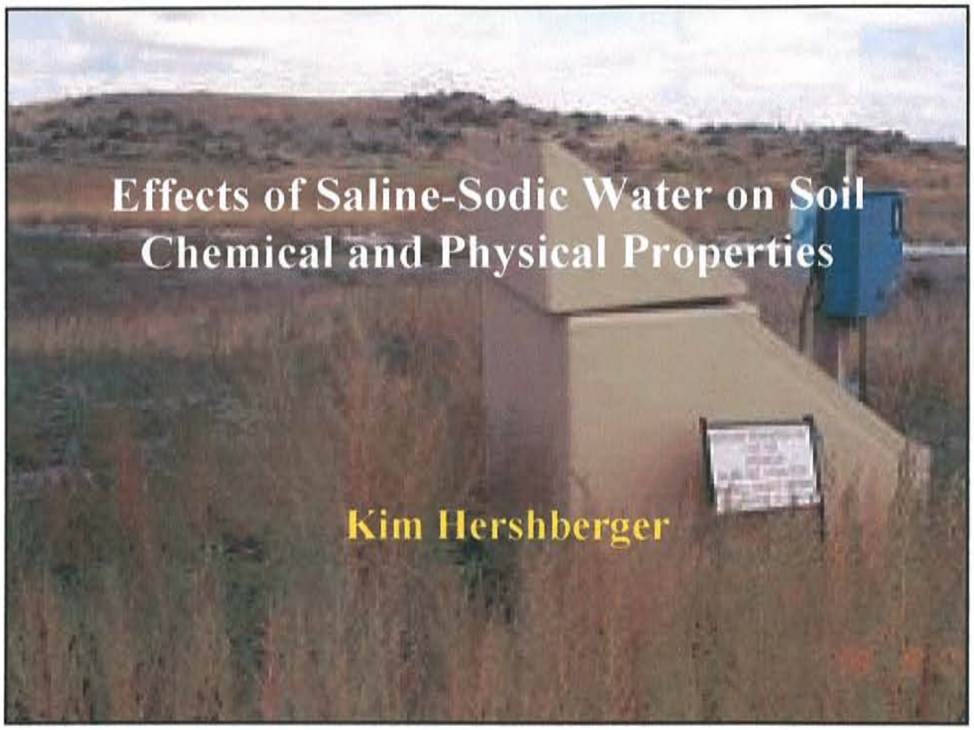
Appendix 5 - Objective 5: evaluate compatibility between coalbed methane product water and irrigable soils and/or landscapes which might be considered for commercially based, large-scale land applied disposal or utilization of coalbed methane product water;

Power Point Presentation - File title: Soil Physical and Chemical Responses

Title: Effects of saline-sodic water on soil chemical and physical properties, with emphasis on potentially irrigable soils of the lower Powder and Tongue River watersheds.

Author: Kimberly Hershberger, Montana State University

Content: 42-frame power point presentation summarizing results of controlled laboratory studies assessing the effects of modestly saline-sodic water on soil chemical and physical properties of selected soil materials; overall goal of these studies was to determine the suitability of irrigating with modestly saline sodic waters (simulated coalbed methane product water), while still maintaining the sustainability of the soil. Presentation summarizes two laboratory experiments which subjected soils of varying clay content and clay type to diverse wetting/drying regimes using two water regimes simulating diverse salinity-sodicity combinations. Complete details provided in appendix document of same title, Appendix 6 - Completed Thesis.



My Study

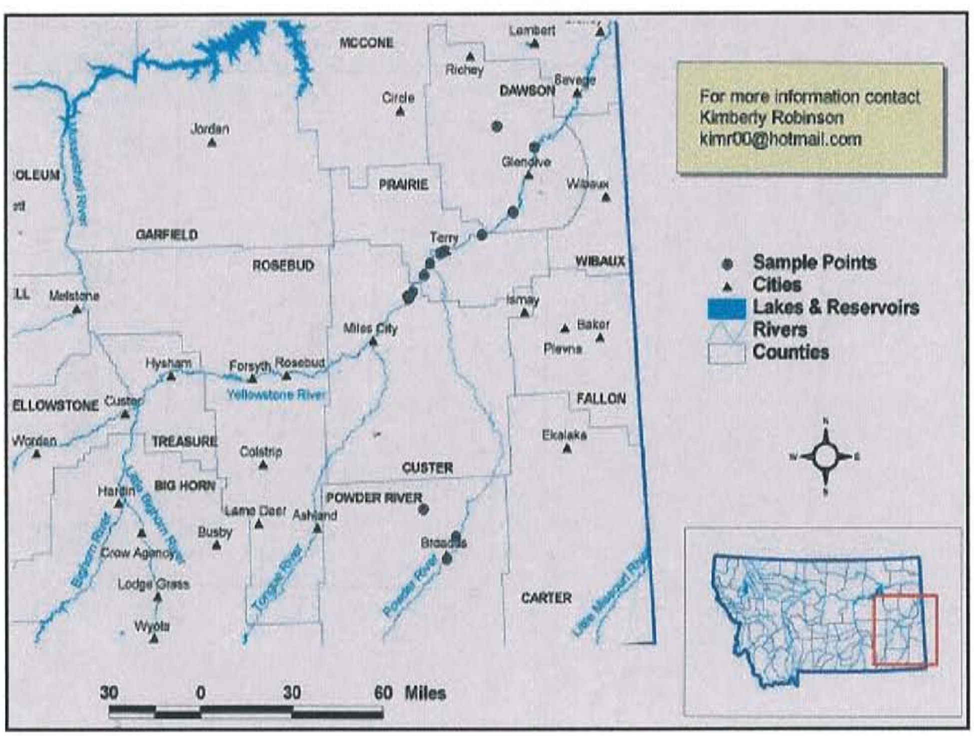
Assess the effects of modestly saline-sodic water on soil chemical and physical properties of selected soil materials.

Overall Goal-Determine the suitability of irrigating with modestly saline-sodic waters, while still maintaining the sustainability of the soil.

Two laboratory experiments which subjected soils of varying clay content to diverse wetting/drying regimes using two water qualities.

Irrigable Acreages within the Buffalo Rapids Irrigation District

Soil Series	*Taxonomy*	*Texture*	*Acres*
Cherry	Fine-silty, mixed, frigid Typic Ustochrepts	sicl	6052.4
Marias	Fine, smectitic, frigid Chronic Haphsturts	sic	3527.1
Spinekop	Fine-loamy, mixed, superactive, frigid Aridic Haplustepts	sicl	3045.3
Trembles	Coarse-loamy, mixed, calcareous, frigid Typic Ustifluvents	fsl/l	2640.8
Havre	Fine-loamy, mixed calcareous frigid Ustic Torifluvents	sil/sicl	2157.8
Busby	Coarse-loamy, mixed Borollic Camborthids	fsl	2002.1



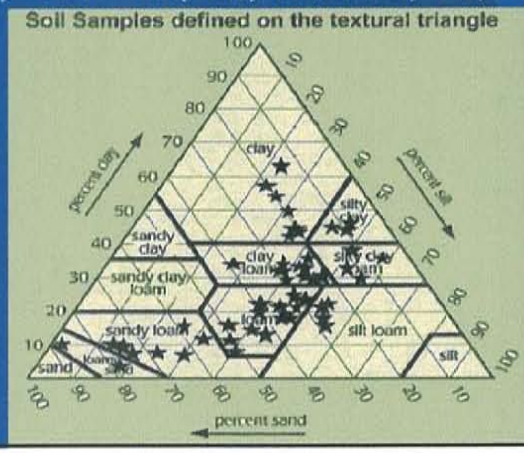
TEXTURAL CLASSES

1- Clay % 0-11% - Loamy Sand, Sandy Loam, Loam

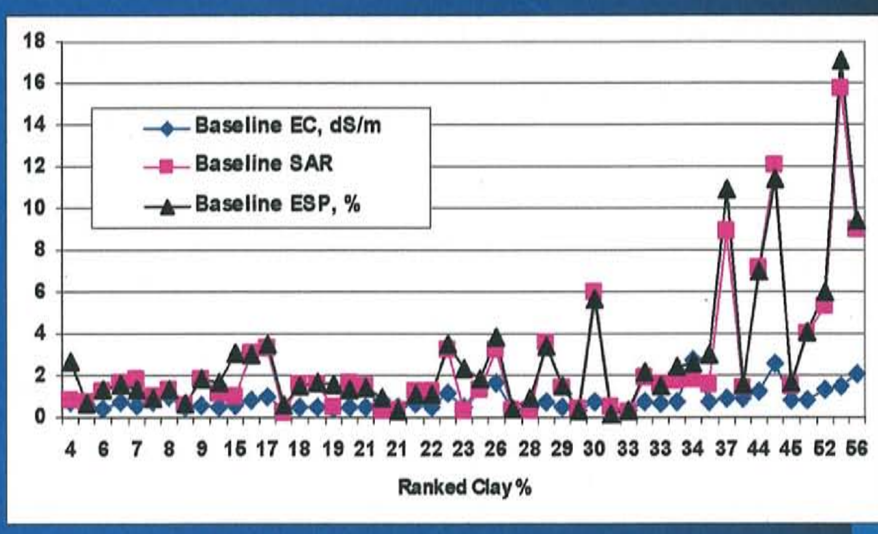
2- Clay % 12-22% - Sandy Loam, Loam, Silt Loam

3- Clay % 23-33% - Loam, Clay Loam, Silty Clay Loam

4- Clay % 34+ - Silty Clay Loam, Silty Clay, Clay



Baseline Chemistry Data



Water Quality Targets

POWDER RIVER

EC = 1.56 dS/m

SAR = 4.54

pH = 8.03

CBM (PRODUCT WATER)

EC = 3.12 dS/m

SAR = 13.09

pH = 8.22

Wetting Regimes

- 1X Wet/Dry with P.R.
- 1X Wet/Dry with CBM
- 5X Wet/Dry with P.R.
- 5X Wet/Dry with CBM
- 5X Wet/Dry with P.R. followed by leaching with 1 pore volume distilled water
- 5X Wet/Dry with CBM followed by leaching with 1 pore volume of distilled water

Study of Soil Chemical Responses

- Treatment effect on soil chemistry was evaluated by monitoring the resultant saturated paste extract EC and SAR and comparing results with baseline conditions.
- Comparisons made by analyzing data based on their textural class.

Methods

- Soil materials were saturated according to the water quality x wetting regime treatment combinations.
- 1X treatments-following wetting soils were oven dried.
- 5X treatments-intermediate drying cycles for 24 hours at 95 deg F; following fifth wetting soils were oven dried.

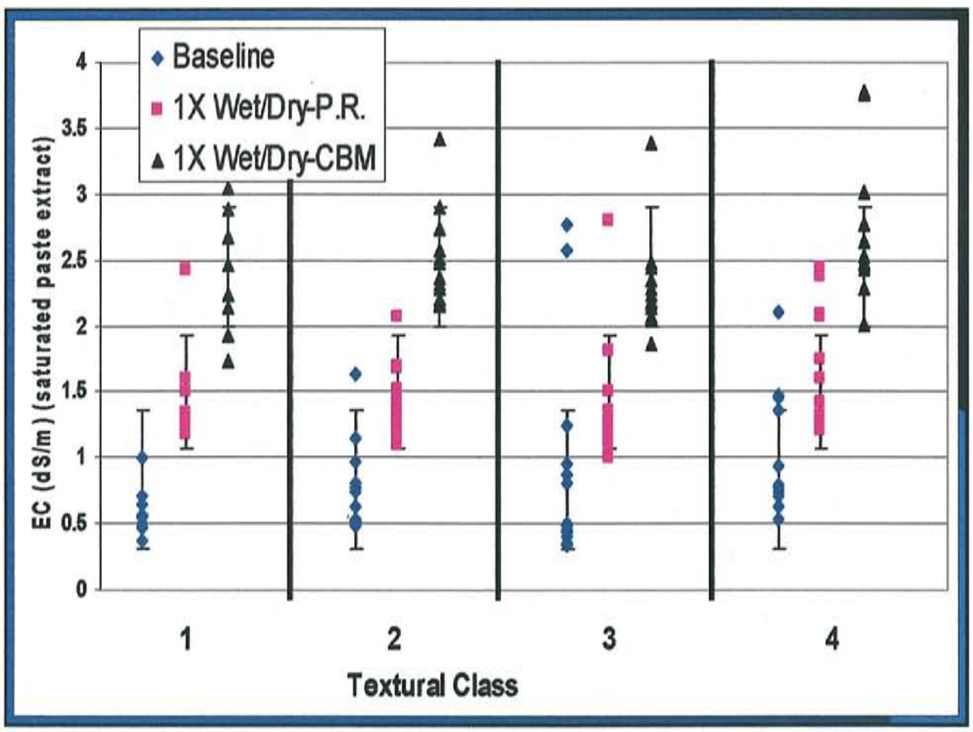
For 5X+d, after fifth drying to 95 deg. F, soils were placed on wire mesh racks where ~1 pore volume of D.I. water was poured on the surface of each sample. Leachate water was allowed to drain for 24 hrs. Following drainage period, soils were oven dried.

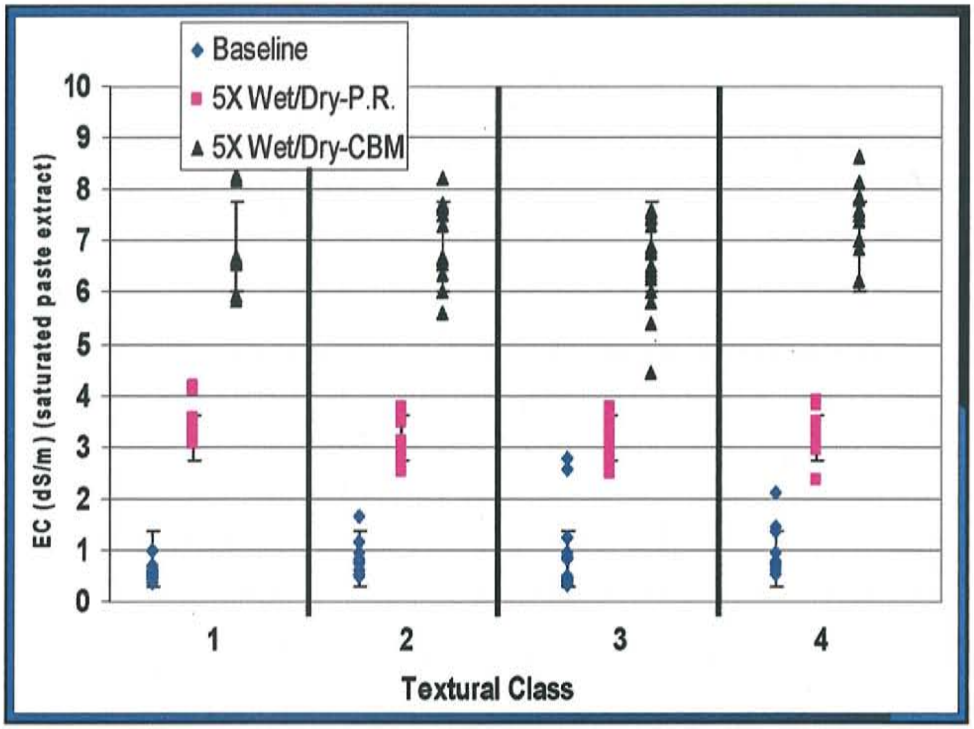
Resultant Mean Saturated Paste Extract EC and SAR for Textural Classes (across all treatments)

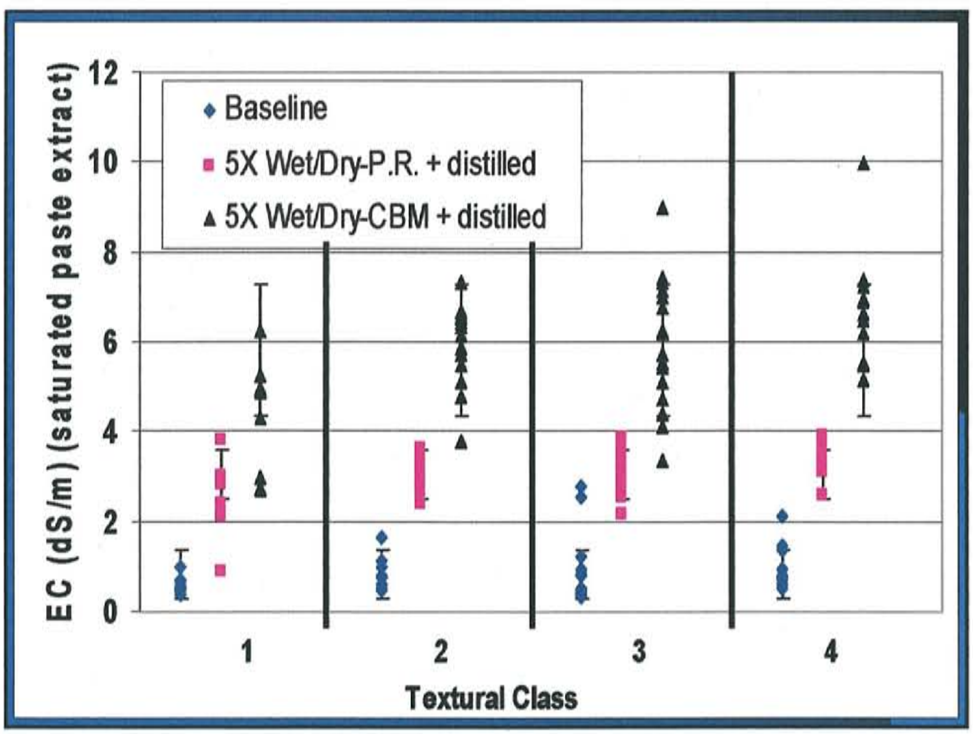
	n	Mean EC (dS/m)$^{+}$	Mean SAR^{+}
Textural Class			
1	9	3.08 a	6.06 a
2	13	3.39 a	6.04 a
3	16	3.28 a	5.34 a
4	11	3.78 b	7.91 b

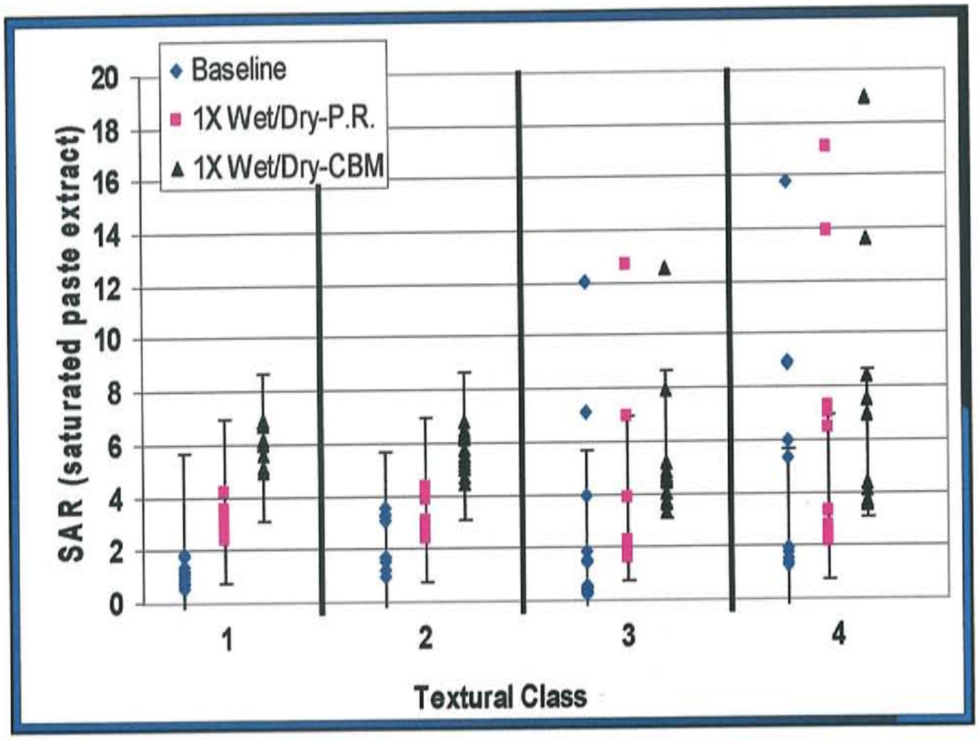
Resultant Mean Saturated Paste EC and SAR for Treatment Combinations (across all textures)

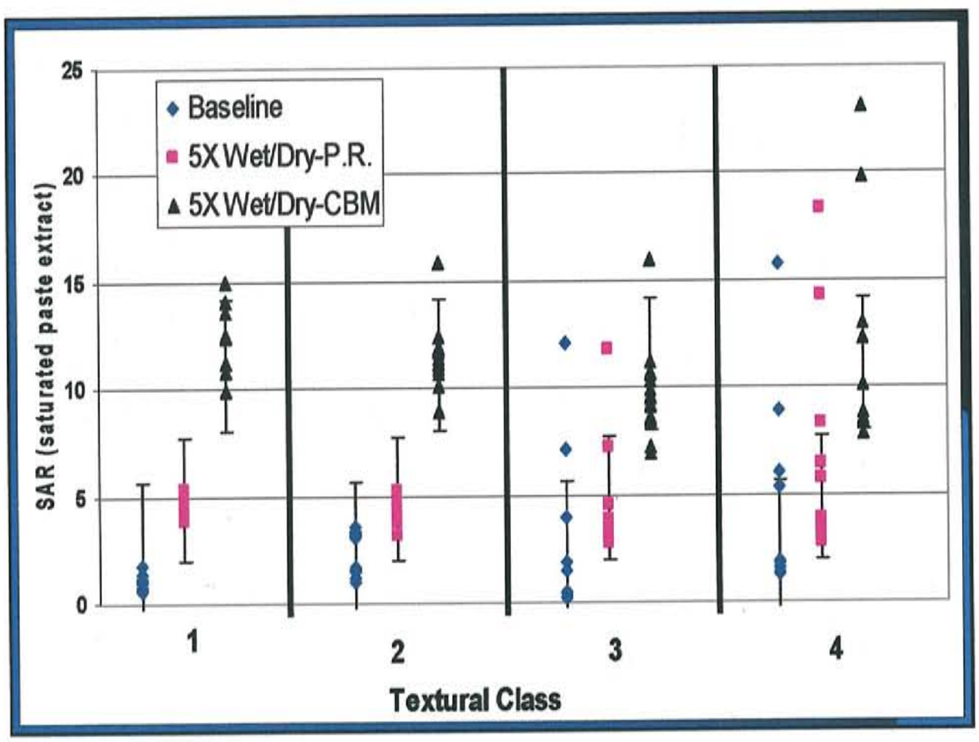
Water Quality Treatment			Mean EC (dS/m)	Mean SAR
	Base	49	0.82 a	2.56 a
	1X P.R.	49	1.51 b	5.94 b
	1X CBM	49	2.46 c	3.92 b
	5X P.R.	49	3.21 d	4.94 b
	5X P+d	49	3.02 e	4.86 b
	5X CBM	49	6.93 f	11.31 c
	5X C+d	49	5.73 g	10.85 c

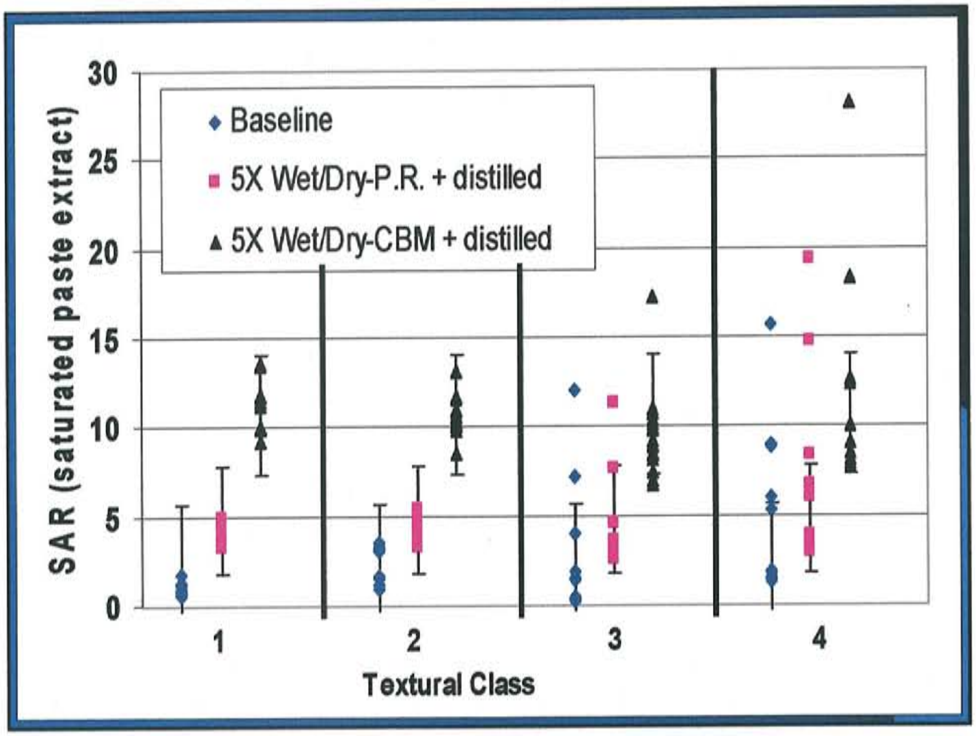



Baseline
5X Wet/Dry-P.R.
5X Wet/Dry-CBM
EC (dS/m) (saturated paste extract)
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
Textural Class

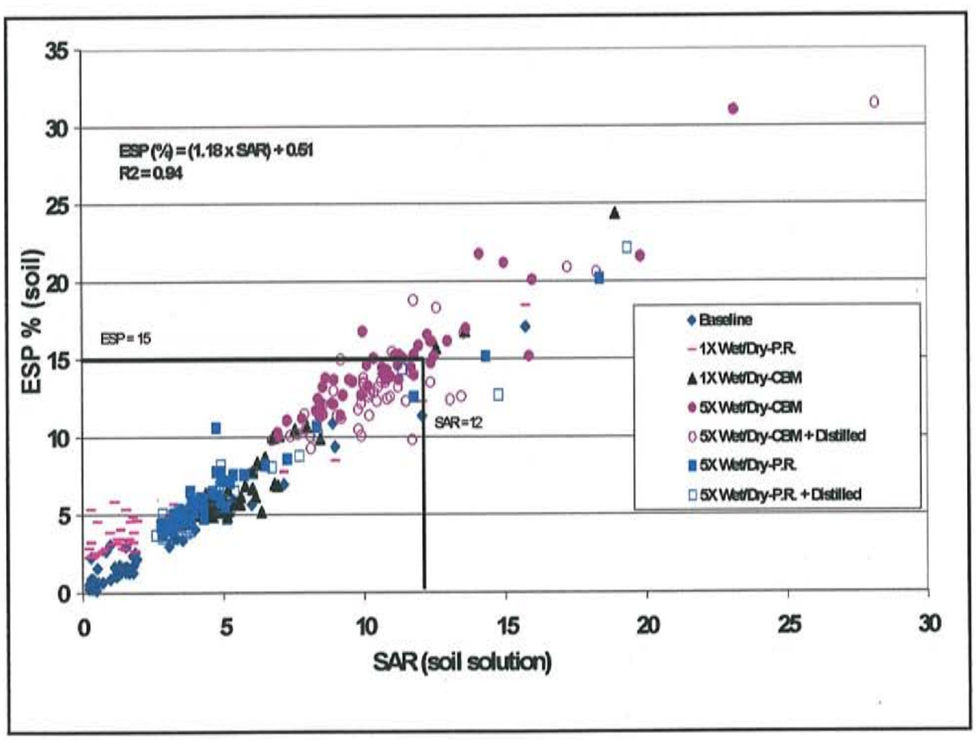

Baseline
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM + distilled
EC (dS/m) (saturated paste extract)
12
10
8
6
4
2
0
1
2
3
4
Textural Class


Baseline
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
SAR (saturated paste extract)
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
Textural Class

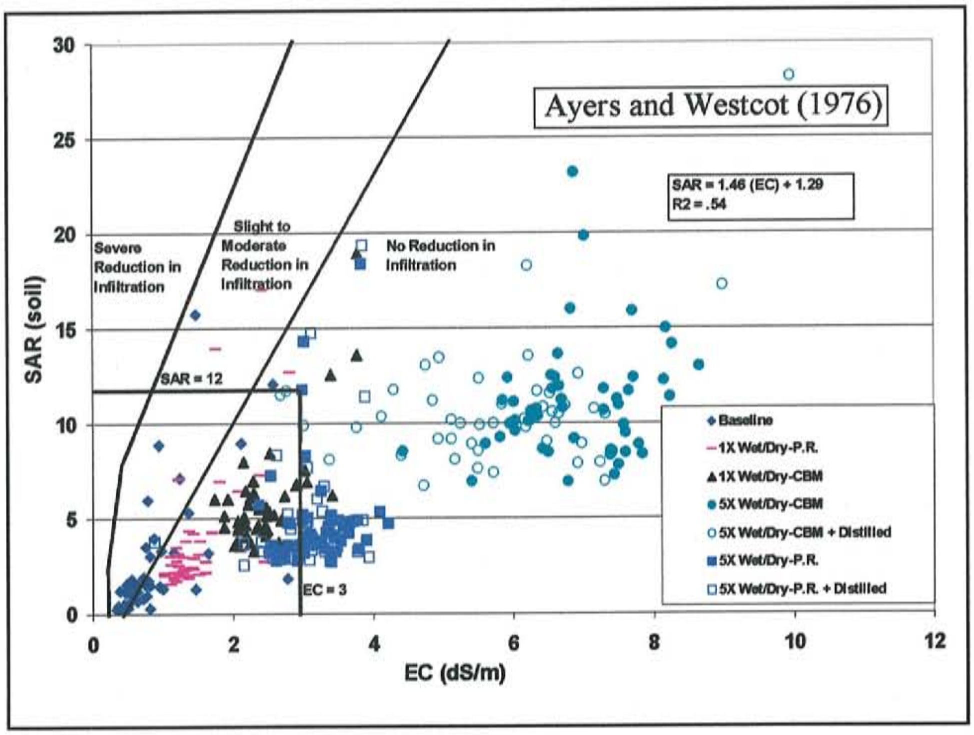

Baseline
5X Wet/Dry-P.R.
5X Wet/Dry-CBM
SAR (saturated paste extract)
25
20
15
10
5
0
1
2
3
4
Textural Class



SAR (saturated paste extract)
Baseline
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM + distilled
Textural Class



ESP (%) = (1.18 x SAR) + 0.51
R2 = 0.94
ESP = 15
SAR = 12
ESP % (soil)
SAR (soil solution)
Baseline
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
5X Wet/Dry-CBM
5X Wet/Dry-CBM + Distilled
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + Distilled



Soil Chemistry Conclusions

1. Repeated irrigation with saline-sodic water will result in a general increase in the soil salinity and sodicity.

2. Repeated irrigation or dispersal of CBM product water to irrigable land is likely to result in elevated soil salinity levels substantially higher than published thresholds for some irrigated crops.

3. Soil solution salinity will equilibrate at an EC value approximately 2-3 times the EC of the applied water; soil solution SAR appears to equilibrate at a level comparable to the SAR of the applied water as long as leaching occurs.

4. Application of salt-free water following elevation of soil solution salinity and SAR through repeated wetting effectively reduced soil solution salinity while having little or no effect on sodicity.

5. The lowering impact of rainfall on EC and SAR is more predominant when salt concentrations are high, and in coarser-textured soils.

6. The greatest increases in EC and SAR upon wetting with either CBM or P.R. water were in coarser-textured soils.

7. In few instances of this study were soil solution salinity x sodicity combinations measured which exceed these thresholds following single wetting events. In essentially all instances where saline-sodic water was repeatably applied, the resulting soil solution salinity and sodicity were significantly elevated to levels in close proximity to the previously published EC x SAR standards.

8. Results of this study appear to be consistent with previously published reports of the relationship between exchangeable sodium percentage (ESP) and solution SAR, i.e., SAR = 0.8 x ESP (approximately). Utilizing an ESP threshold of 15, the majority of treated soil samples exceeding this value resulted from alternate wetting regimes with CBM product water followed by simulated rainfall.

Soil Physical Properties Study

Methods

- Soil water retention was measured at 1/10 - 15 -bars of applied pressure.
- Water content was measured after soils had undergone treatment combinations (same as the soil chemistry study treatments.
- For 1X treatments, soils were saturated for 24 hrs before pressure was applied.
- For 5X treatments, soils were placed on wire racks for wet/dry cycles and transferred to pressure plates for the final wetting period.

Methods cont.

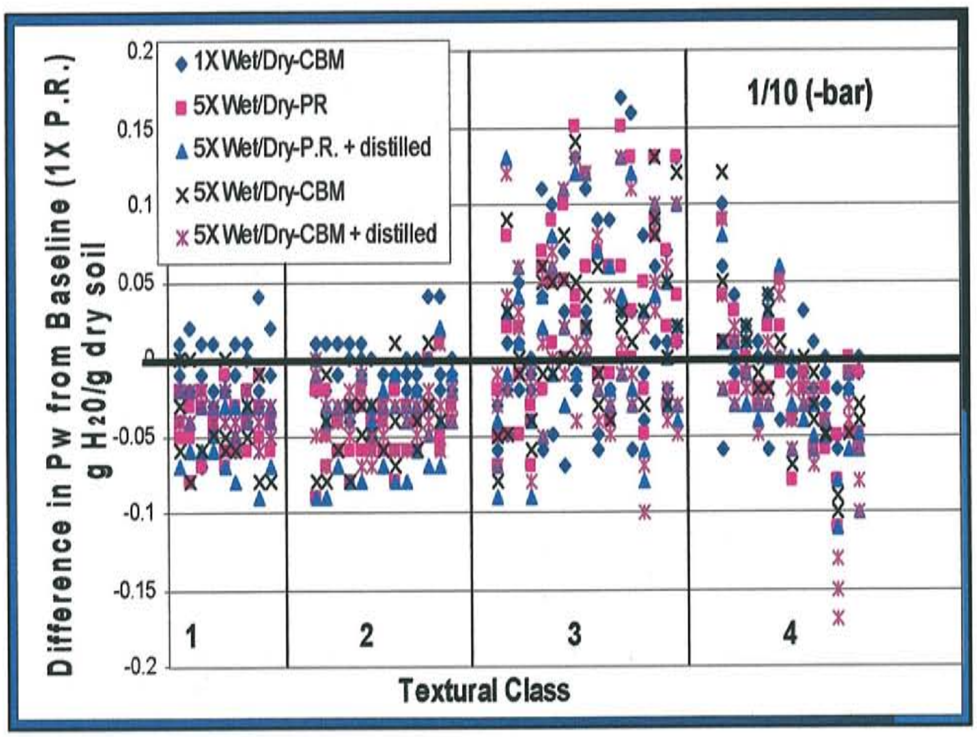
- 5X+d-Same procedure as the 5X
  - Final wetting on the plate consisted of DI application

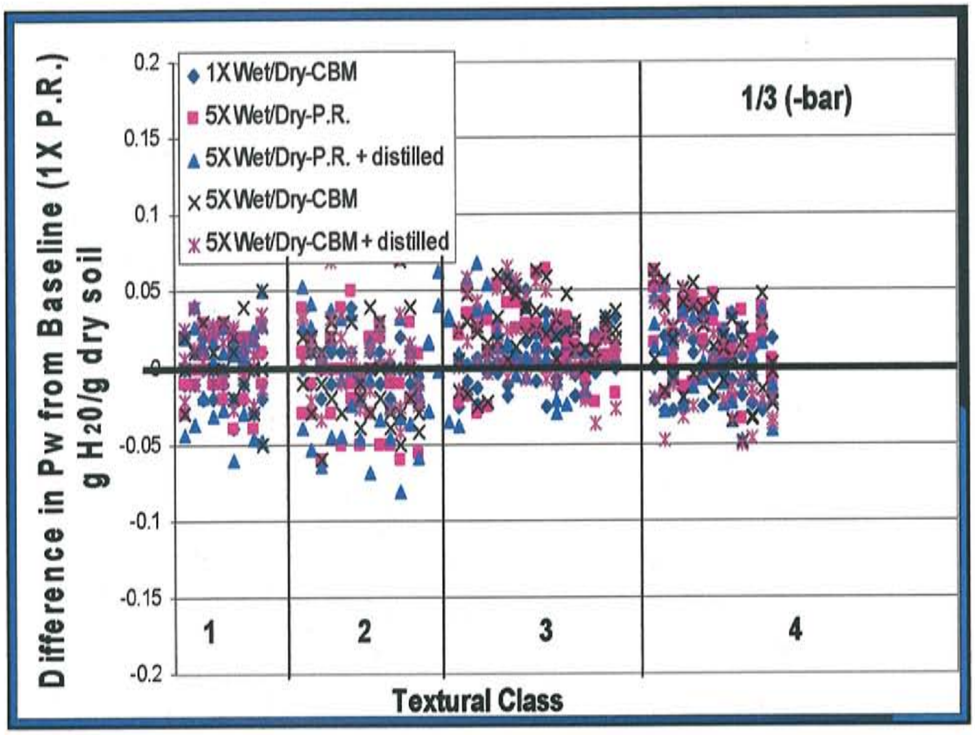
Mean Gravimetric Water Content at Applied Pressure Potentials for each Textural Class (across all treatment combinations)

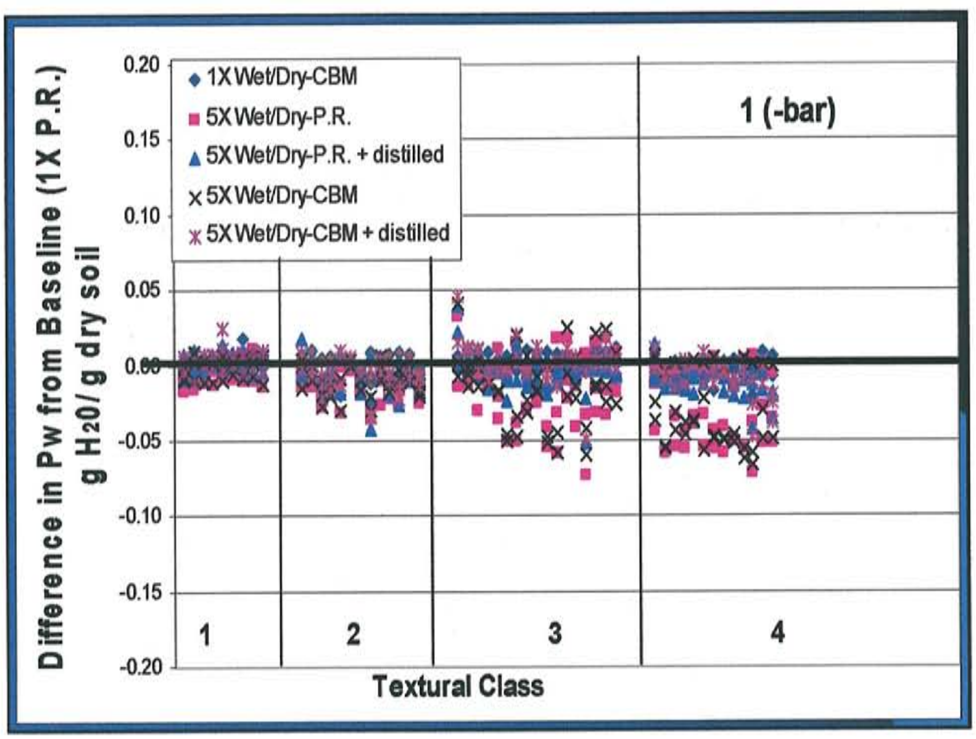
Texture	-1/10 bar	-1/3 bar	-1 bar	-5 bar	-15 bar
1	0.25 a	0.11 a	0.06 a	0.05 a	0.04 a
2	0.33 b	0.21 b	0.13 b	0.10 b	0.08 b
3	0.39 c	0.28 c	0.20 c	0.15 c	0.11 c
4	0.45 d	0.32 d	0.23 d	0.18 d	0.14 d

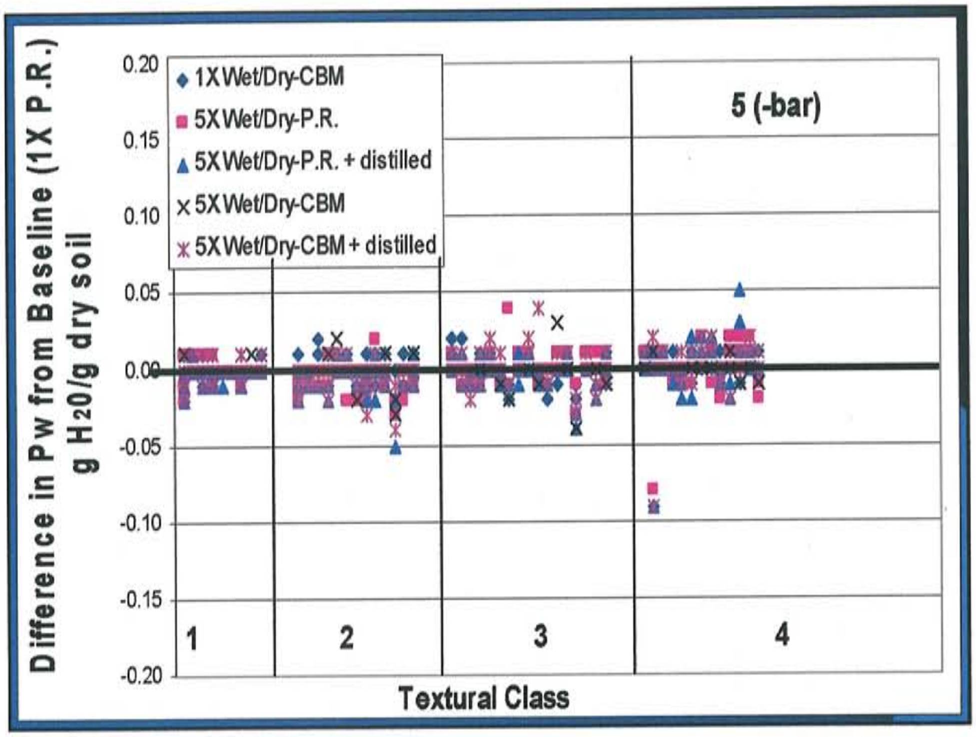
Mean Gravimetric Water Content at Applied Pressure Potentials for each Treatment Combination (across all textures)

WQ Treatment	-1/10 bar	-1/3 bar	-1 bar	-5 bar	-15 bar
1X P.R.	0.37 a	0.23 a	0.16 a	0.12 a	0.09 a
1X CBM	0.37 a	0.22 a	0.16 a	0.12 a	0.09 a
5X P.R.	0.35 b	0.23 a	0.14 b	0.12 a	0.09 a
5X P+d	0.35 b	0.23 a	0.16 a	0.12 a	0.09 a
5X CBM	0.35 b	0.23 a	0.15 c	0.12 a	0.09 a
5X C+d	0.35 b	0.23 a	0.16 a	0.12 a	0.09 a

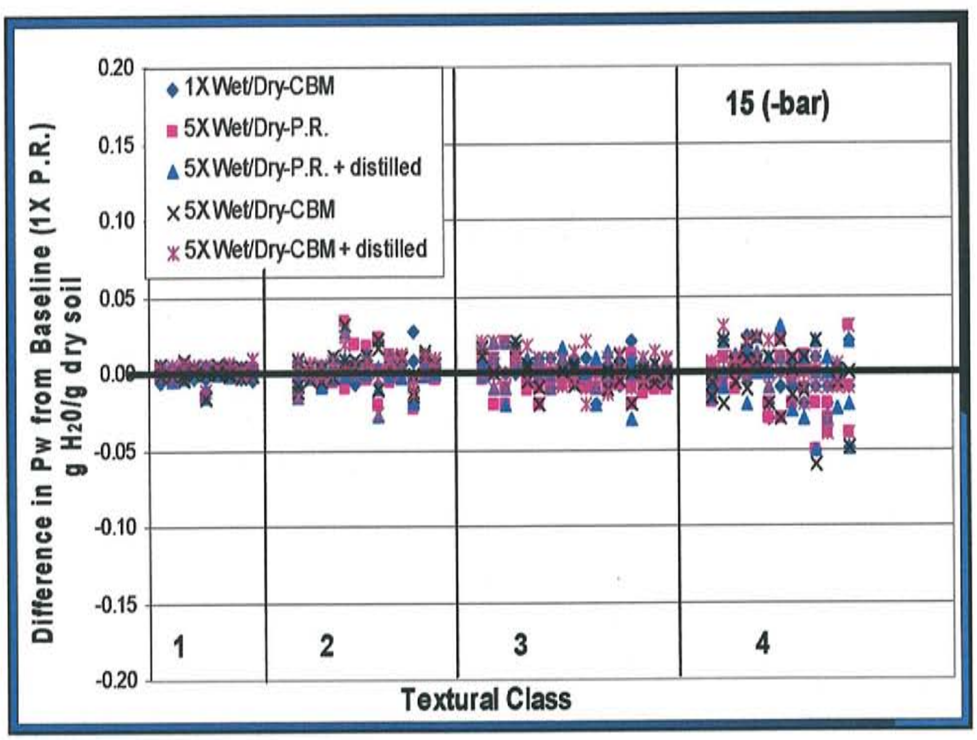



1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
1/3 (-bar)
Difference in Pw from Baseline (1X P.R.) g H20/g dry soil
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
1
2
3
4
Textural Class

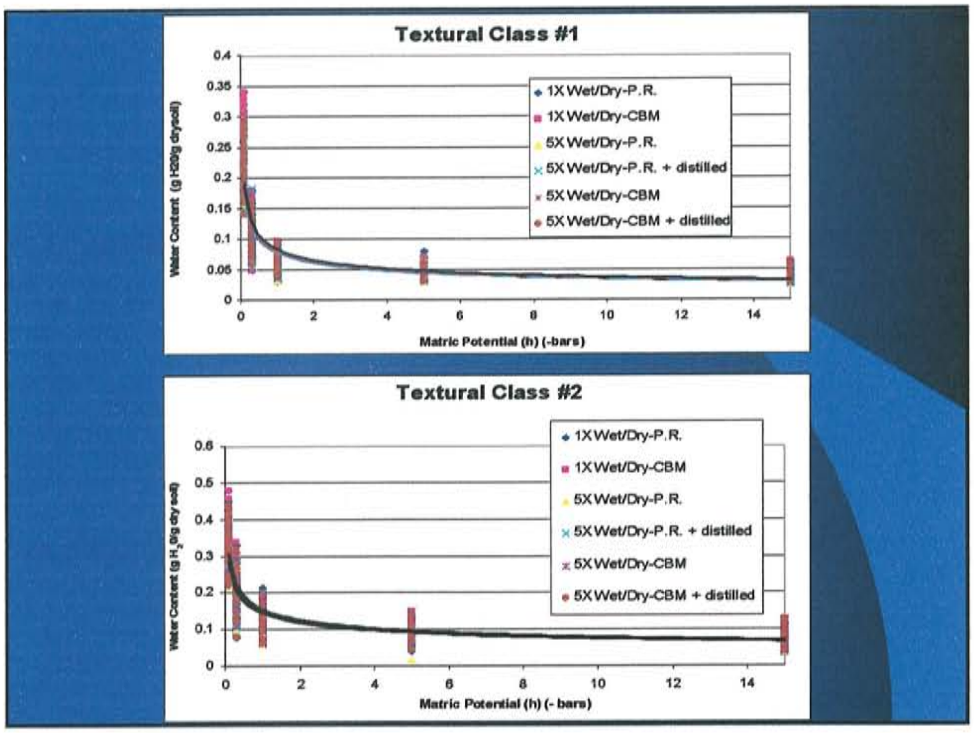

1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
1 (-bar)
Difference in Pw from Baseline (1X P.R.) g H20/g dry soil
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1
2
3
4
Textural Class

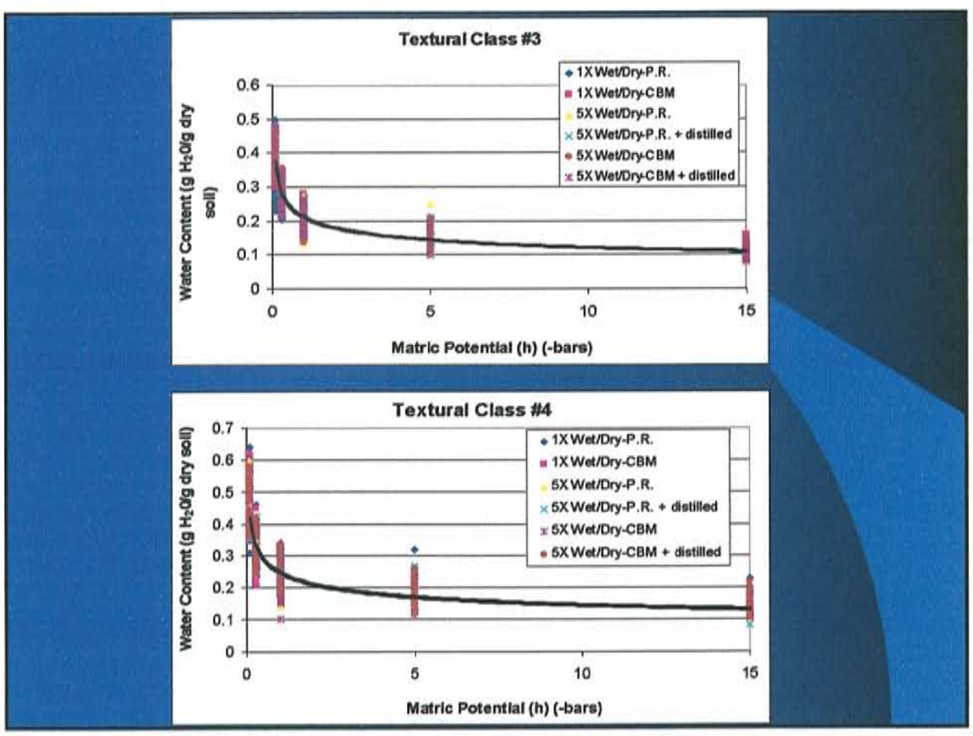


Difference in Pw from Baseline (1X P.R.) g H20/g dry soil
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
5 (-bar)
1
2
3
4
Textural Class



Difference in Pw from Baseline (1X P.R.) g H20/g dry soil
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
15 (-bar)
1
2
3
4
Textural Class


Textural Class #1
Water Content (g H20/g dry soil)
Matric Potential (h) (-bars)
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
Textural Class #2
Water Content (g H2O/g dry soil)
Matric Potential (h) (- bars)


Textural Class #3
Water Content (g H2O/g dry soil)
Matric Potential (h) (-bars)
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + distilled
5X Wet/Dry-CBM
5X Wet/Dry-CBM + distilled
Textural Class #4
Water Content (g H2O/g dry soil)
Matric Potential (h) (-bars)

Soil Physical Properties
Conclusions

1. Water content associated with matric potential differed significantly due to predominant soil texture at all matric potentials investigated in this study.
2. Significant differences in water holding capacity of coarser-textured soils occur due to water quality treatment more often at greater matric potentials. In finer-textured soils differences in water holding capacity due to water quality treatment are more likely to occur at lower potentials.

3. Significant changes in water holding capacity due to water quality treatment are only on the order of 0.02-0.04 g H_20/g dry soil. The change reflected a decrease in water holding capacity in textural classes 1 & 2 and an increase in water holding capacity in textural class 3.
4. Reductions in water retention in coarser-textured soils are attributable to the loss of large pore spaces.

5. The addition of saline-sodic water had the greatest effect on soil physical properties when the soil is near saturation. Changes in water holding capacity are likely to have non-discernible impact on irrigation suitability.
6. Successive wetting/drying cycles can cause aggregate coalescence and the loss of interaggregate porosity; this appeared to occur more often in the coarser-textured soils.

7. Although statistically significant differences were detected among water quality treatments, differences were not large enough to have a significant ecological impact.

8. CBM product water applied at these levels did not have a consistent significant impact on soil physical properties, i.e., water-holding capacity.

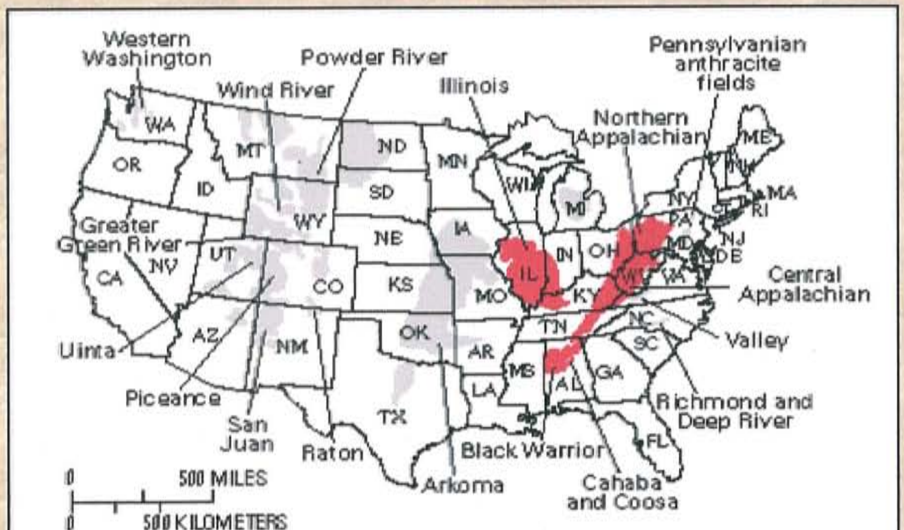
Power Point Presentation - File title: Bauder-Drake1.ppt

Title: Coalbed methane product water: landscape distributions, management and handling strategies, chemistry and reactions with soil materials.

Author: James W. Bauder, Montana State University

Content: 37-frame power point presentation providing an overview of the physical, geologic, and water chemistry conditions associated with coalbed methane extraction industry within the Powder River Basin; introduction to water x landscape issues, principles of dispersion of clay soils when exposed to sodium-rich water, chemical reactions of coalbed methane product water, and summary of selected soil responses to frequent and infrequent wetting with simulated coalbed methane product water.

CBM development potential in U.S. as of 2002



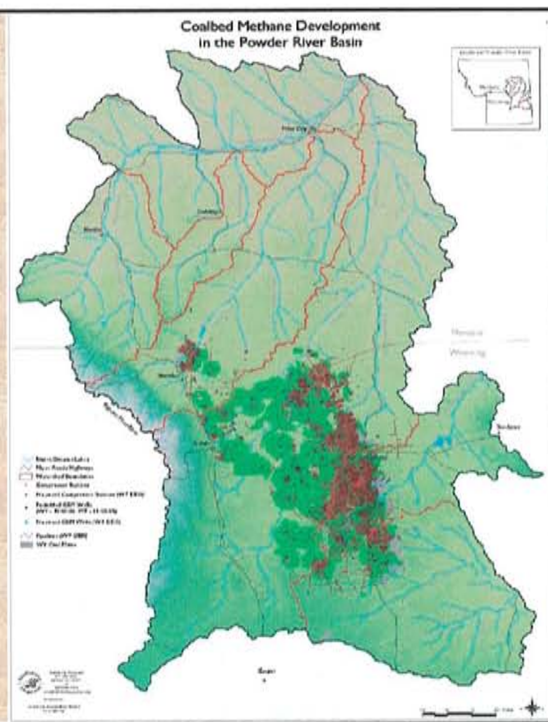
A little background and some essential foundation information – then we'll begin

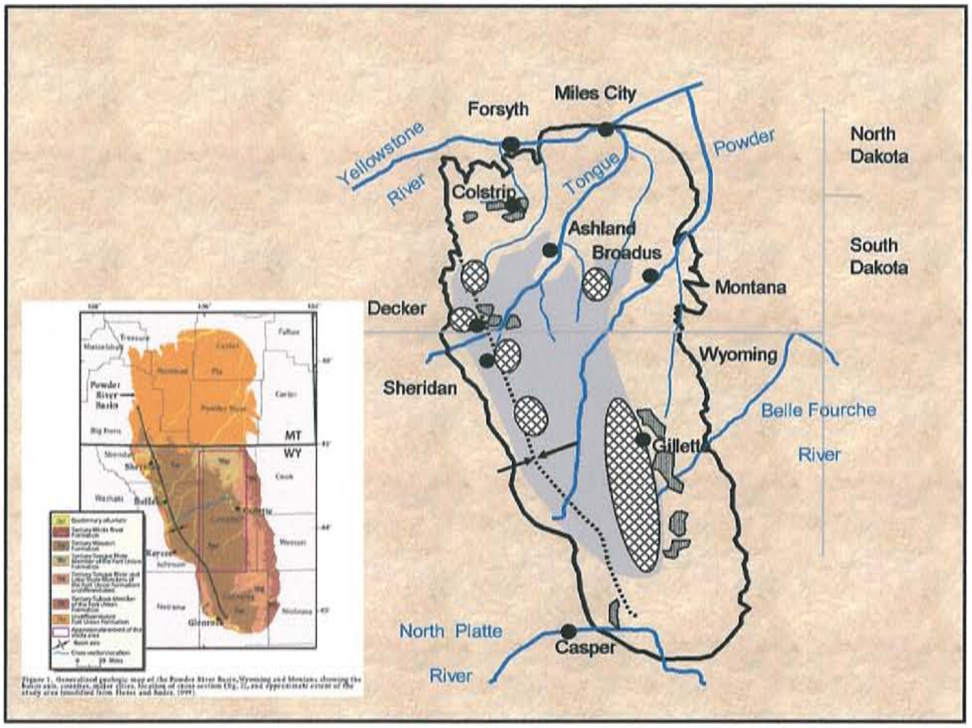
Bbl – barrels = 42 gal

Mcf = thousand cu. ft.

CBM = CBNG

cfs = cu. ft/sec





Powder River Basin

- Approximately 35,000 square kilometers
- Principle watershed for the Powder River,Tongue River, East Rosebud Creek
- Approximately 70% of the U.S. proposed CBM development in next decade scheduled here
- 7.5% of all U.S. natural gas production is CBM

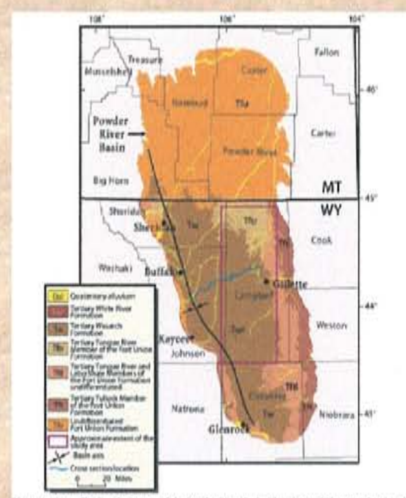
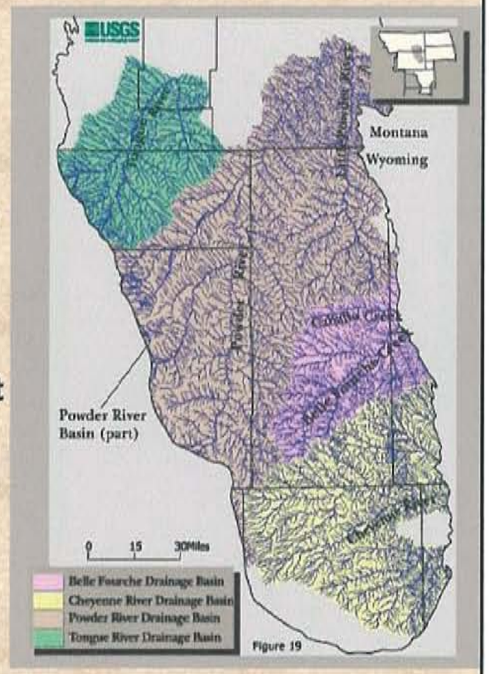


Figure 1. Generalized geologic map of the Powder River Basin, Wyoming and Montana showing the basin axis, counties, major cities, location of cross section (fig. 2), and approximate extent of the study area (modified from Flores and Bader, 1999).

Background Information

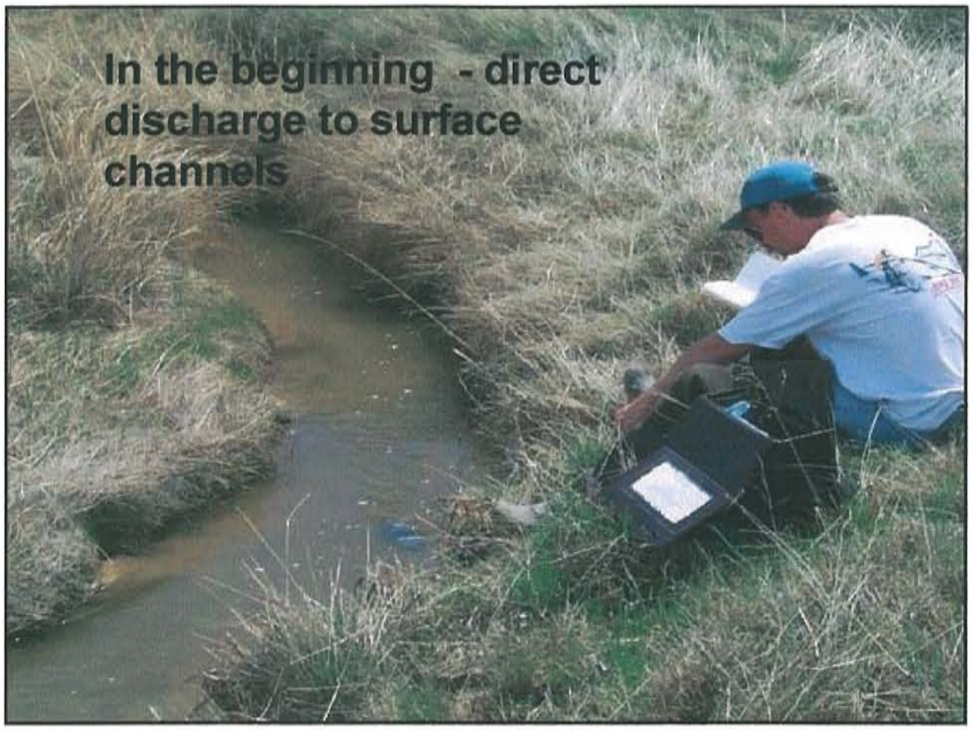
- **Extraction of CBM requires withdrawal of large amounts of saline-sodic water from coal seams containing methane.**
- **Projections call for disposal or management of one quarter million acre-feet of product water annually in the Powder River Basin**
- **(80 x Bozemans).**
- Common signature = salinity x sodicity



CBM Produced Water in the Rocky Mountain Region

- **<u>More than 3.5 billion barrels of produced water in 2002</u>**
- **Wyoming = 1,901,087,161 (63% of total produced water)**
- **New Mexico = 593,053,102**
- **Colorado = 250,986,180**
- **Utah = 145,213,852**
- **Montana = 113,365,939**

***Based on 2002 Production Data, 42 gallons/bbl**


In the beginning - direct discharge to surface channels


Discharge to ephemeral channels – or contain on landowner property
CBM Coordination Coalition photo

Ephemeral channel discharges challenged and downstream water rights holder prevailed

WILDCAT CREEK, CAMPBELL COUNTY WYO. TRIBUTARY TO LITTLE POWER RIVER

Arguments – loss of channel integrity; forfeiture of priority water right; loss of beneficial use opportunity

Current CBM Product Water Management

- Discharged into a stream channel – meeting permitted standards
- Impounded
  - Holding pond, infiltration pond,
  - "0 discharge" pond
- Land applied to crop or range land
- In Montana – two permitted discharges directly to the Tongue River

Water quality and quantity

- Quality

  Elevated salinity

  Elevated sodicity

- Quantity
  - **A typical CBM well produces about 13 gpm of production water**
  - **By 2010 well numbers are expected to increase to 30,000 wells**
  - **Production water volume is expected to increase to 400,000 gpm**

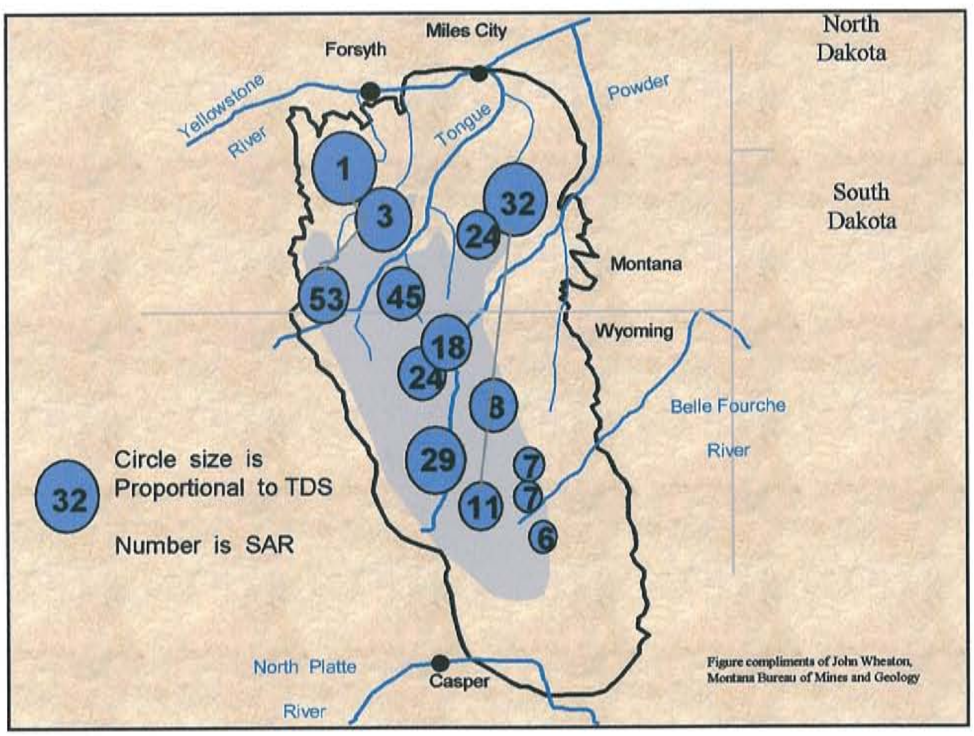
Generalizations about CBM Product Water Quality

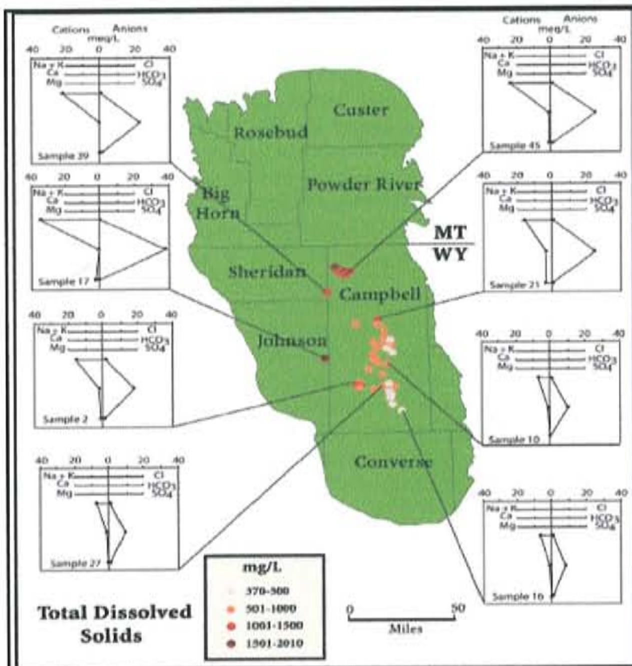
- **Range in TDS of PRB CBM product water is 270-2,730 ppm, average is 740 ppm; median is 838 ppm**
- **Drinking water standard is 500 ppm**
- **Livestock water standard is 5,000-10,000 ppm**
- **SAR range of 5-68.7, median 8.8; threshold = 12**
- **EC (SP) ranges from < 0.5 to > 10 dS/m across basin; threshold = 3.0 dS/m**

CBM product water in the Powder River Basin - knowns

- Trend of increasing sodium adsorption ratio (SAR), electrical conductivity (EC) and total dissolved solids (TDS) progressing north and west through the basin (Rice et al., 2000).

- Most wells in the northern section are above the limits for salinity and sodicity (Rice et al., 2002) w/r to irrigation suitability .





igure 6. Distribution of total dissolved solids in water co-produced with coalbed methane from the Wyodak-Anderson coal zone. Composition of selected samples indicated by Stiff diagrams.

Composition of selected samples indicated by Stiff diagrams (Rice et al., 2000)

- Soils are generally high in clays and can be saline-sodic.
- Predominant clay type is smectitic, 2:1 high shrink-swell clay types
- solonetzic, natragids, Aridisols, Vertisols

MSU CBM Product Water Management Team Goals

Understand the chemistry, quantity, and distribution of CBM product water in the Powder River Basin.

Assess the interaction between surface dispersed CBM product water and soil, water, plants, groundwater and land resources.

Conduct research to help define CBM product water management strategies which will ensure sustainability of Montana's soil, plant, and water resources while allowing for CBM development.

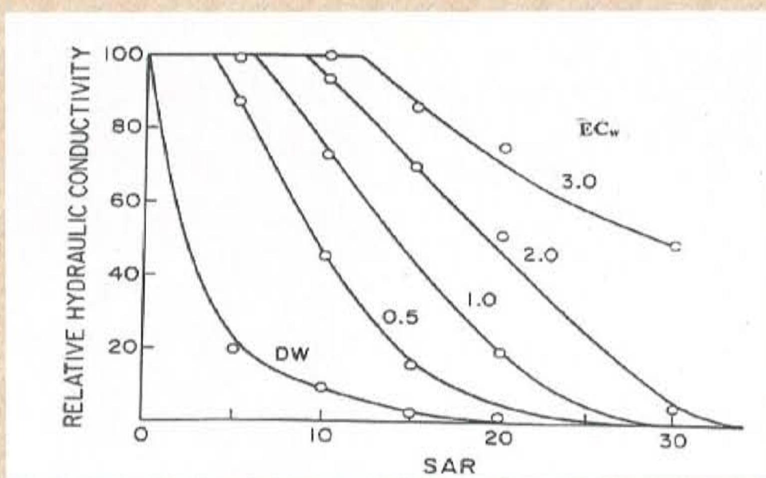
What is sodic water and why is it considered sodic?

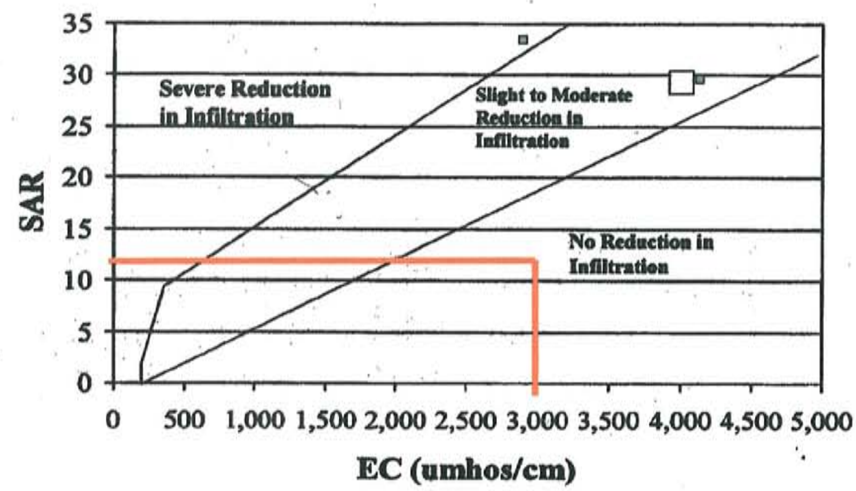
- The sodicity of water is expressed as the Sodium Adsorption Ratio (SAR)
- Sodic water is any water with a SAR greater than 12. Sodic water is not necessarily saline.
- Sodic soil is one with an exchangeable sodium percentage (ES)) greater than 15%.

What are the common difficulties with the use of sodic water for irrigation?

- Use of sodic water for irrigation can be risky business on soils having significant amounts of swelling clay. On such soils:
  - sodium changes soil physical properties, leading to poor drainage and crusting, which can affect crop growth and yield.
  - Irrigation with sodic water on sandy soils does not cause crusting and poor drainage. However, if the water is saline-sodic, it may affect crop growth and yield.

REDUCED HYDRAULIC CONDUCTIVITY -Shainberg and Letey, 1984



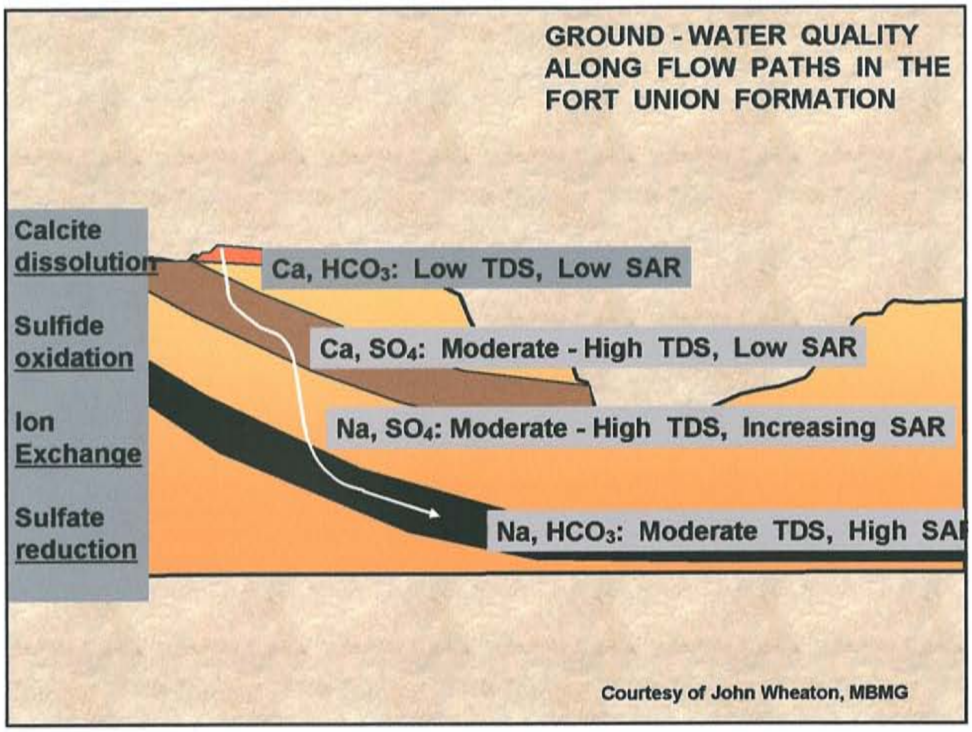


Hanson et al., 1999. Agricultural Salinity and Drainage. University of California, Davis

Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^{+1}}{[(Ca^{+2} + Mg^{+2}) / 2]^{1/2}}$$

where Na^{+1}, Ca^{+2}, and Mg^{+2} refer to soluble ionic concentrations in $mmol_e L^{-1}$



Primary geochemical processes controlling ground-water quality in the Fort Union Formation aquifers of Montana (Slide 1 of 2)

$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$

H^+ from dissociation of H_2CO_3 or from oxidation of FeS_2

TDS increases 70 mg/L per 1 mmole/L H^+

$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+$

TDS increases 51 mg/L per 1 mmole/L O_2

$4Na^+$ (clay) + Ca^{2+} + Mg^{2+} $\rightarrow$ Ca, Mg (clay) + $4Na^+$

TDS increases 60 mg/L (average) per 1 mmole/L Ca or Mg

Primary geochemical processes controlling ground-water quality in the Fort Union Formation aquifers of Montana
(Slide 2 of 2)

Sulfate reduction in anaerobic conditions

Also, Water quality may be an exploration tool:

$SO_4^{2-} + 2CH_2O \xrightarrow{\text{bacteria}} H_2O + CO_2 + HCO_3^- + HS^-$

TDS decreases 66 mg/L per 1 mmole SO_4^{2-}

$SO_4^{-2} + CH_4 \xrightarrow{\text{anaerobic bacteria}} H_2S + HCO_3^- + OH^-$

General Chemistry:

- CBM product water is sodium bicarbonate rich. When discharged to the surface or applied to the soil, sodium bicarbonate undergoes the following reaction:

$$NaHCO_3^- \longrightarrow H^+ + CO3^- + Na^{++}$$

- Free carbonate (CO_3) in solution is now available to bind with calcium in the surface water or soil to form calcium carbonate ($CaCO_3$):

$$Ca^{++} + CO_3^{--} \longrightarrow CaCO_3$$

- Calcium carbonate is relatively insoluble and precipitates from solution, thereby increasing the SAR.

- The dissolution of sodium bicarbonate also causes the pH to increase with the formation of sodium hydroxide:

$$Na^{++} + H^{+} + CO_3^{--} \longrightarrow CO_2 + NaOH^{-}$$

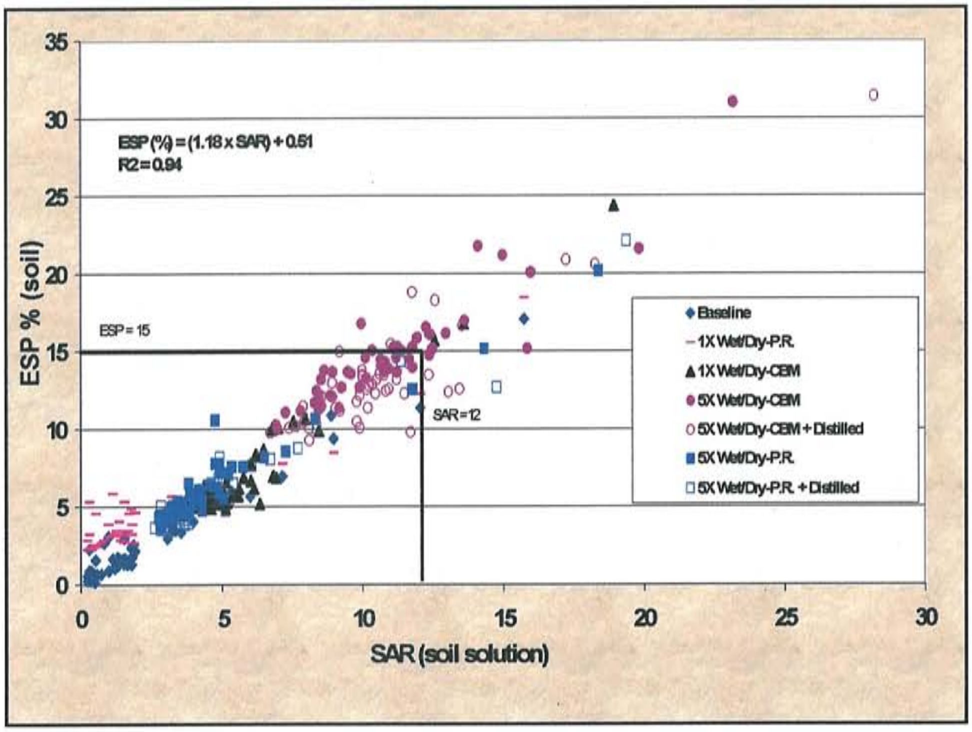
Discharge standards as of April 25th, 2003 :

- **Irrigation Season**
  - **Powder River**
    - **Max EC 2.5 dS/m**
    - **Max SAR 6.0**
  - **Tongue River**
    - **Max EC 1.5 dS/m**
    - **Max SAR 4.5**

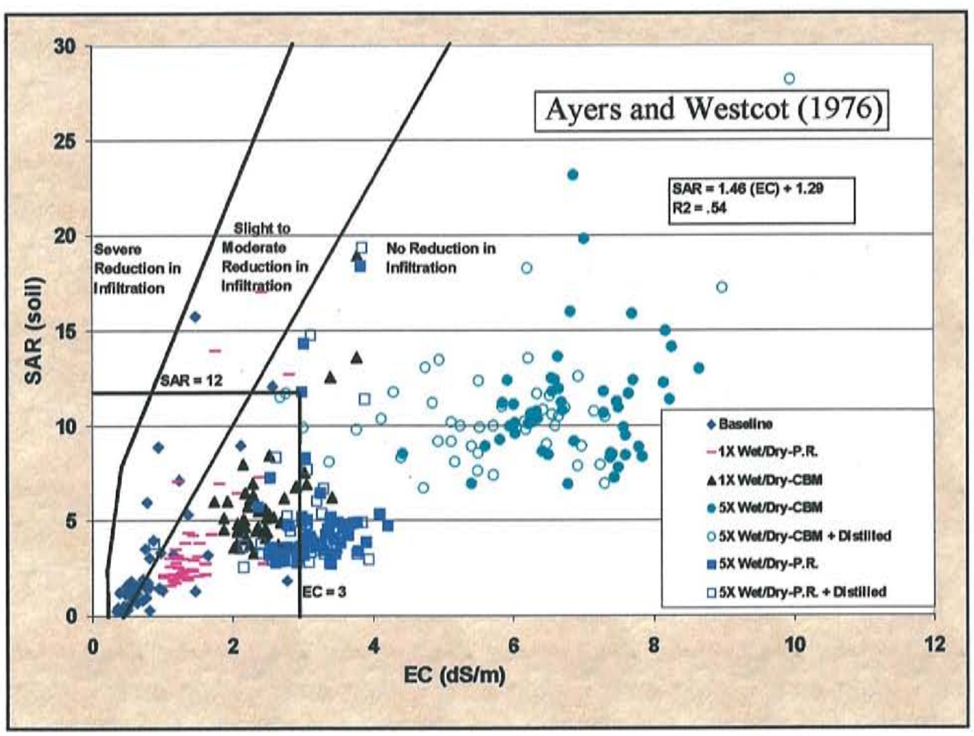
- **Non-Irrigation Season**
  - **Powder River**
    - **Max EC 2.5 dS/m**
    - **Max SAR 9.75**
  - **Tongue River**
    - **Max EC 2.5 dS/m**
    - **Max SAR 7.5**

Resultant Mean Saturated Paste EC and SAR for Treatment Combinations (across all textures)

Water Quality Treatment			Mean EC (dS/m)	Mean SAR
	Base	49	0.82 a	2.56 a
	1X P.R.	49	1.51 b	5.94 b
	1X CBM	49	2.46 c	3.92 b
	5X P.R.	49	3.21 d	4.94 b
	5X P+d	49	3.02 e	4.86 b
	5X CBM	49	6.93 f	11.31 c
	5X C+d	49	5.73 g	10.85 c



ESP (%) = (1.18 x SAR) + 0.51
R2 = 0.94
ESP = 15
SAR = 12
Baseline
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
5X Wet/Dry-CBM
5X Wet/Dry-CBM + Distilled
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + Distilled
ESP % (soil)
SAR (soil solution)



Ayers and Westcot (1976)
SAR = 1.46 (EC) + 1.29
R2 = .54
Severe Reduction in Infiltration
Slight to Moderate Reduction in Infiltration
No Reduction in Infiltration
SAR = 12
EC = 3
Baseline
1X Wet/Dry-P.R.
1X Wet/Dry-CBM
5X Wet/Dry-CBM
5X Wet/Dry-CBM + Distilled
5X Wet/Dry-P.R.
5X Wet/Dry-P.R. + Distilled
SAR (soil)
EC (dS/m)

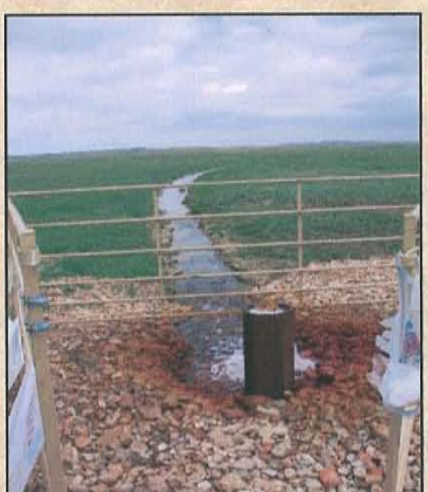

NPRC photo

Impacts on Shallow Groundwater and Streams

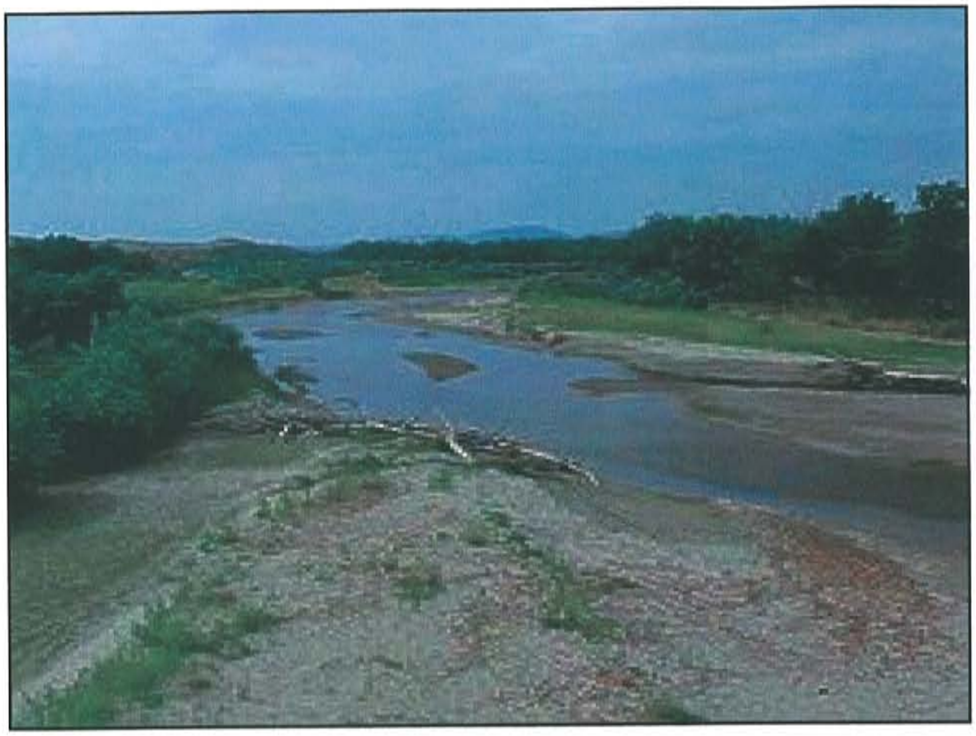
- Direct discharge of CBM product water
- Seepage of CBM water stored in ponds and reservoirs
- Will there be any water quality impacts to alluvial water?

Photo courtesy of Northern Plains Resource Council
CBM Holding Pond

Infiltration of CBM Water from Surface Discharge



- **Creek conveyance losses are >80% of CBM discharge** (BLM, 2000; AHA, 2000)
- **Ephemeral drainages of SE PRB lose 0.43 to 1.44 acre-feet per mile** (USGS, 1987)
- **Powder River conveyance loss is 0.31 cfs per valley mile** (Rankl and Lowry, 1990)
- **Infiltration averages ~82% of conveyance loss**

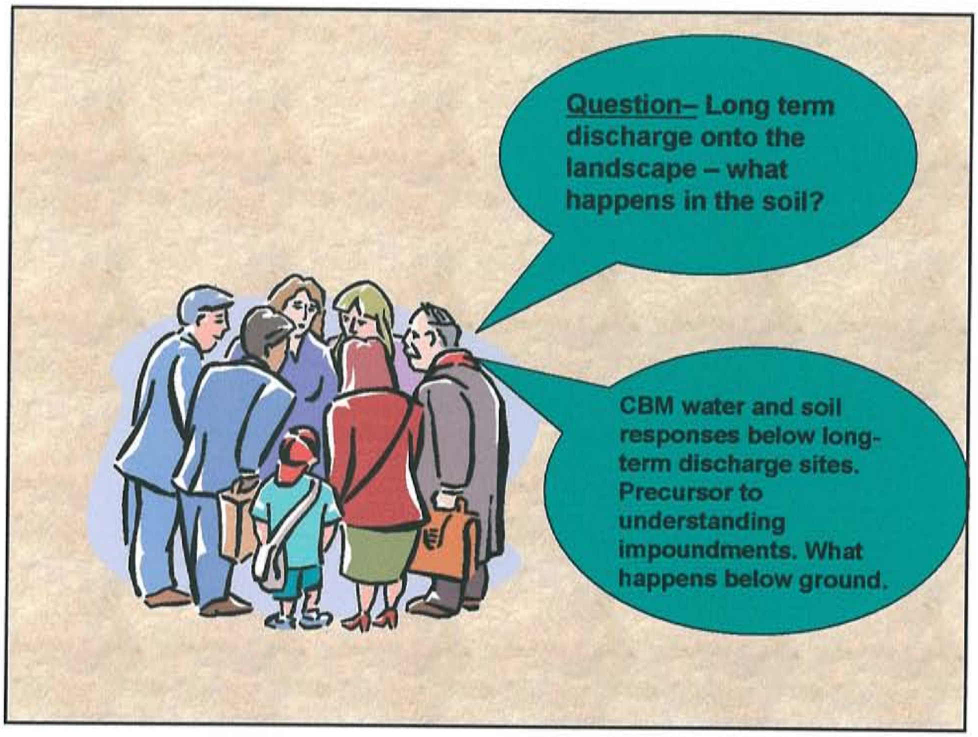


Power Point Presentation - File title: Hayes and Gay sites-Bauder

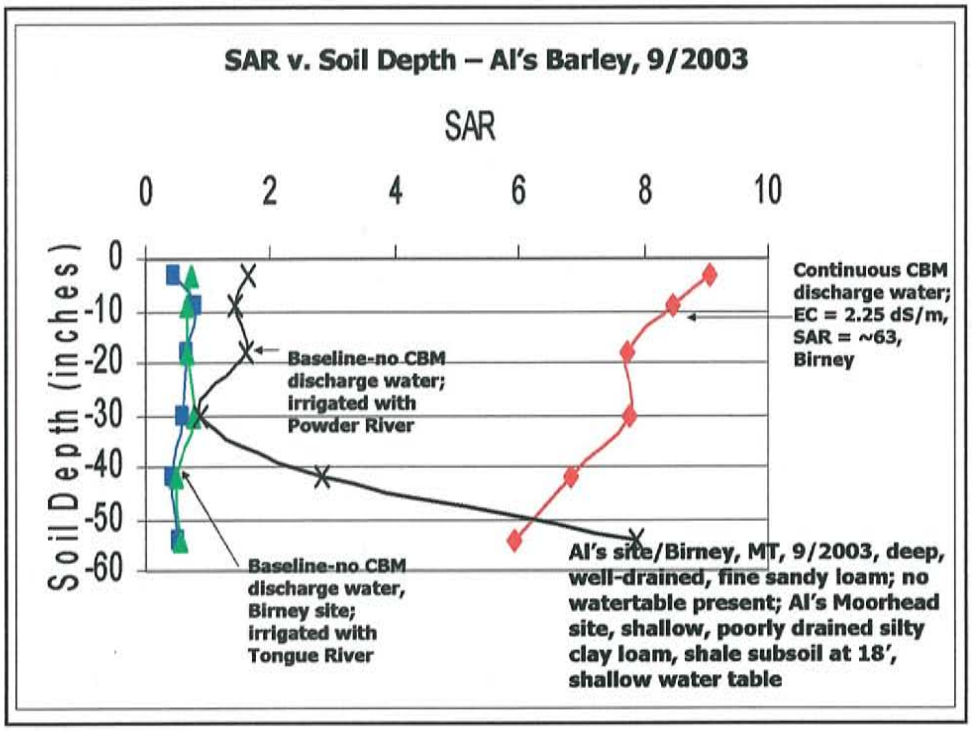
Title: Case studies of soil solution changes (salinity and sodicity) as a consequence of long-term dispersal of coalbed methane product water on selected landscapes of the Tongue River and Powder River alluvial channel.

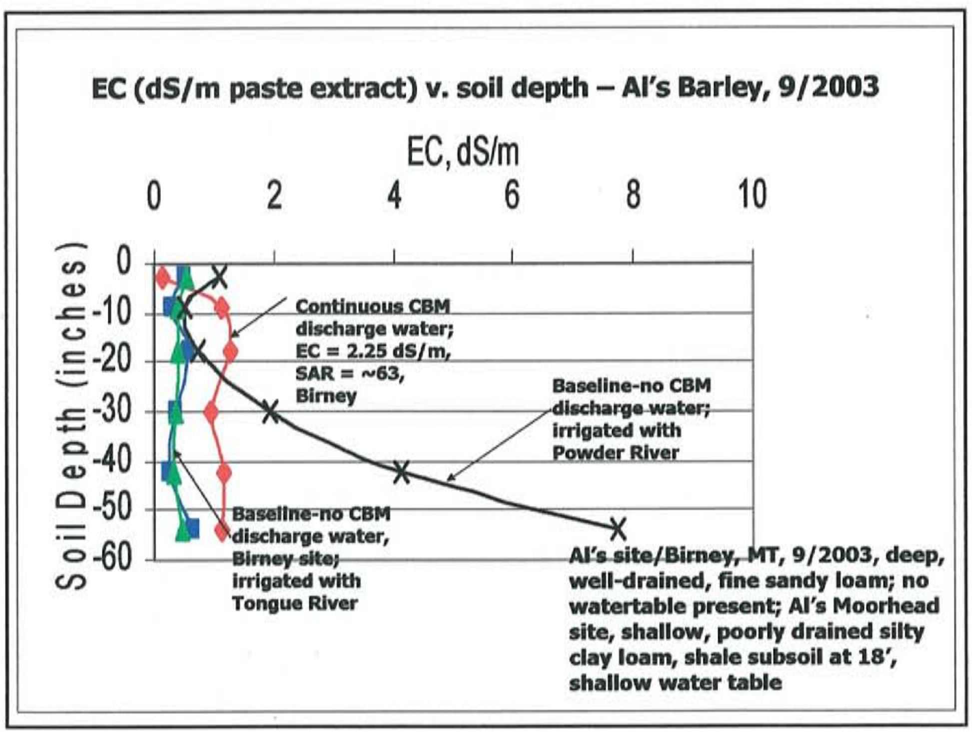
Author: Jason Drake and James W. Bauder, Montana State University

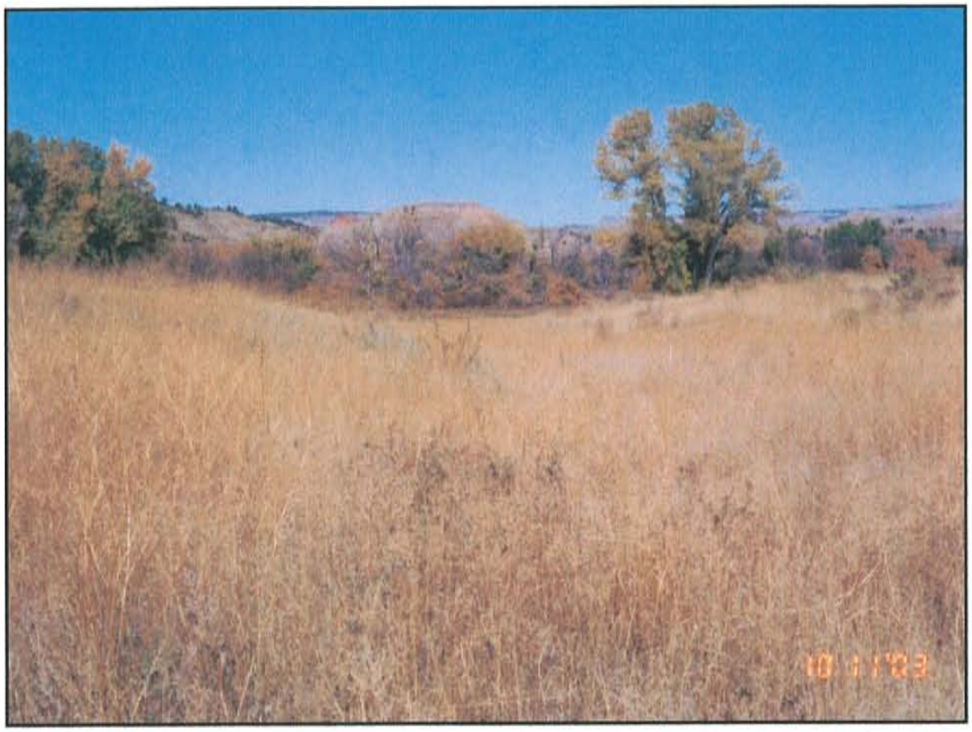
Content: 13-frame power point presentation summarizing salinity and sodicity profiles below multiple sampling sites of the Powder River and Tongue River alluvial corridor with long-term histories of coalbed methane product water dispersals, compared to adjacent sites not receiving coalbed methane product water dispersals.


Question– Long term discharge onto the landscape – what happens in the soil?
CBM water and soil responses below long-term discharge sites. Precursor to understanding impoundments. What happens below ground.

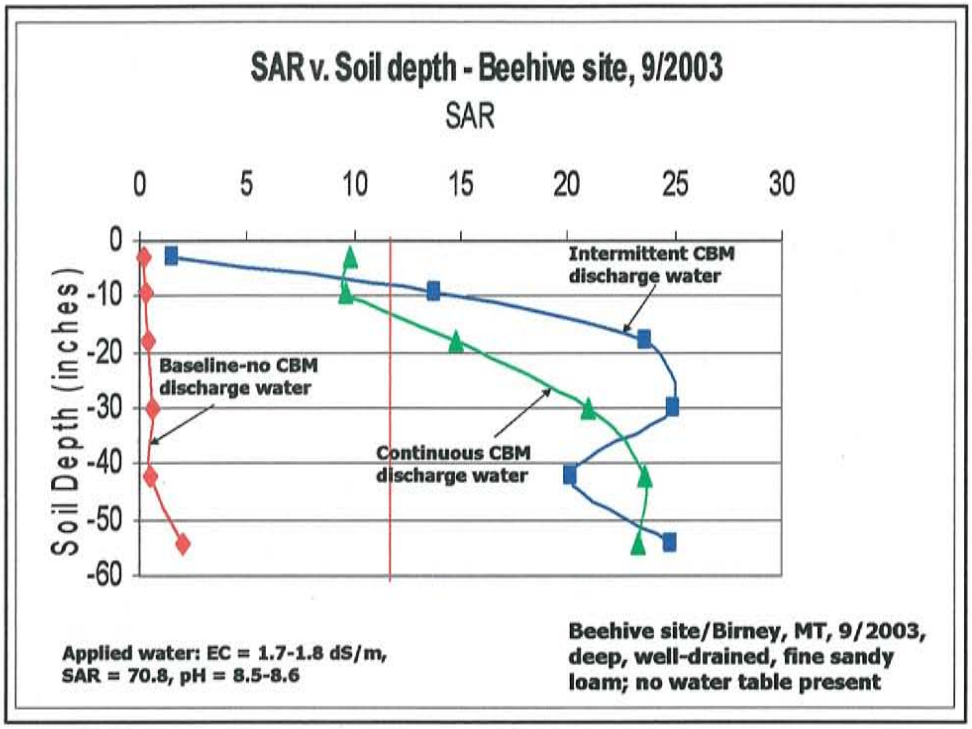

10 21 '03

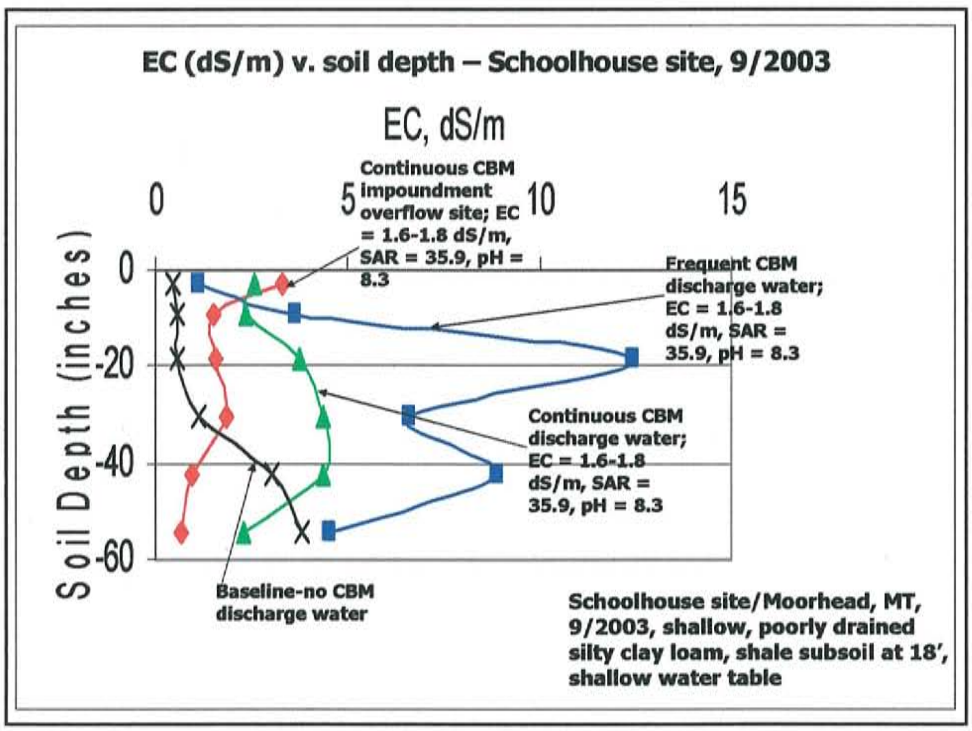

SAR v. Soil Depth – Al's Barley, 9/2003
SAR
0
2
4
6
8
10
Soil Depth (inches)
0
-10
-20
-30
-40
-50
-60
Continuous CBM discharge water; EC = 2.25 dS/m, SAR = ~63, Birney
Baseline-no CBM discharge water; irrigated with Powder River
Baseline-no CBM discharge water, Birney site; irrigated with Tongue River
Al's site/Birney, MT, 9/2003, deep, well-drained, fine sandy loam; no watertable present; Al's Moorhead site, shallow, poorly drained silty clay loam, shale subsoil at 18', shallow water table

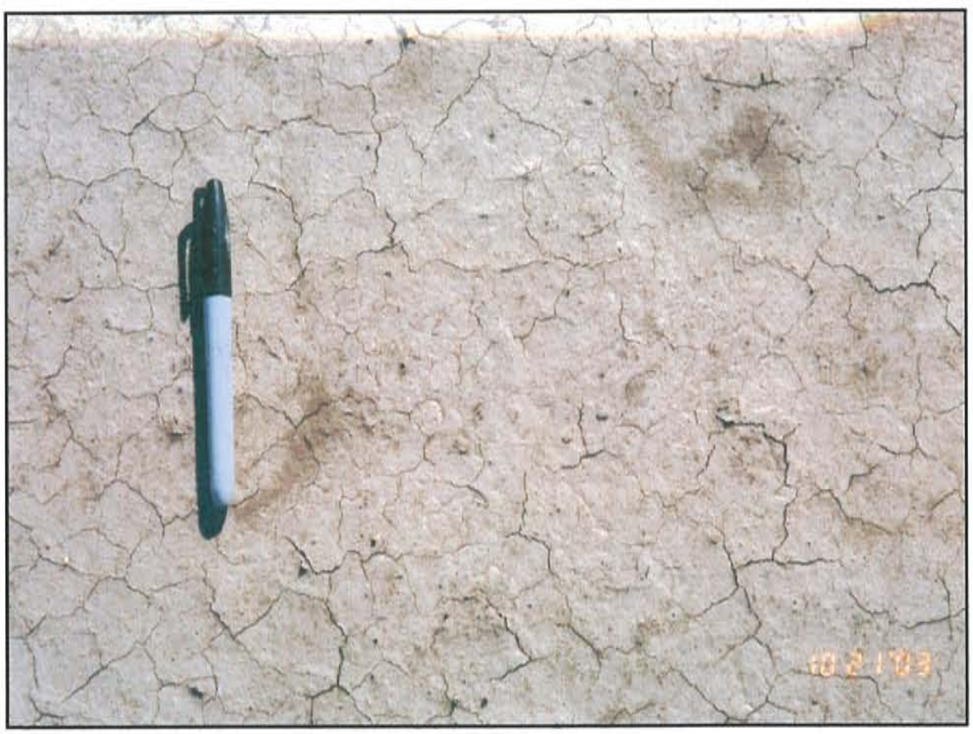

EC (dS/m paste extract) v. soil depth – Al's Barley, 9/2003
EC, dS/m
0
2
4
6
8
10
Soil Depth (inches)
0
-10
-20
-30
-40
-50
-60
Continuous CBM discharge water; EC = 2.25 dS/m, SAR = ~63, Birney
Baseline-no CBM discharge water; irrigated with Powder River
Baseline-no CBM discharge water, Birney site; irrigated with Tongue River
Al's site/Birney, MT, 9/2003, deep, well-drained, fine sandy loam; no watertable present; Al's Moorhead site, shallow, poorly drained silty clay loam, shale subsoil at 18', shallow water table

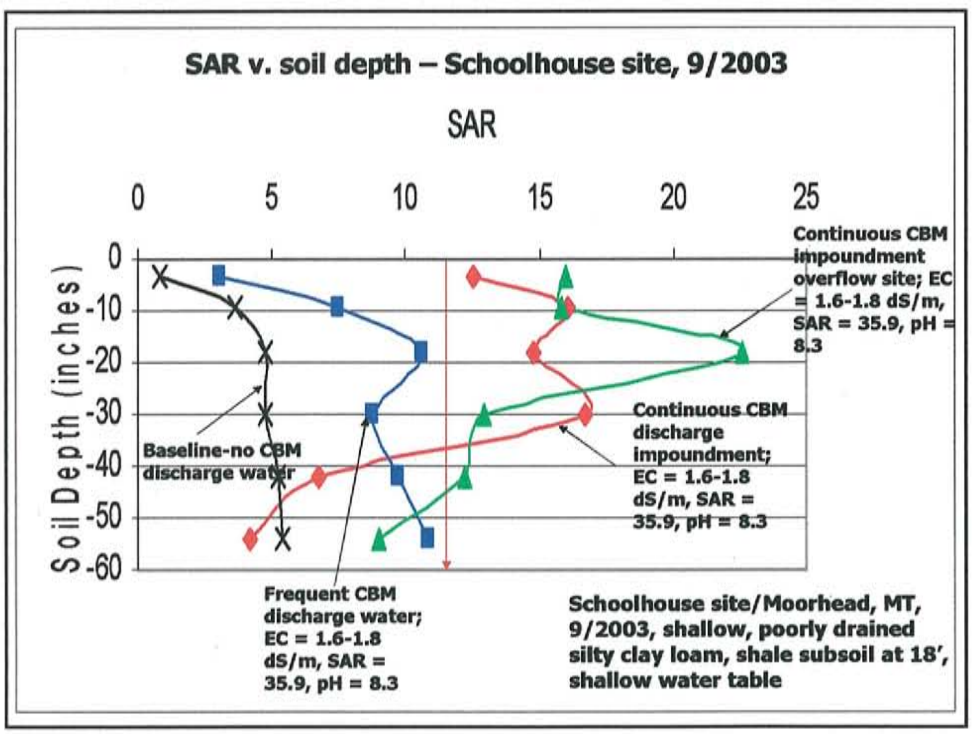

10 11'03

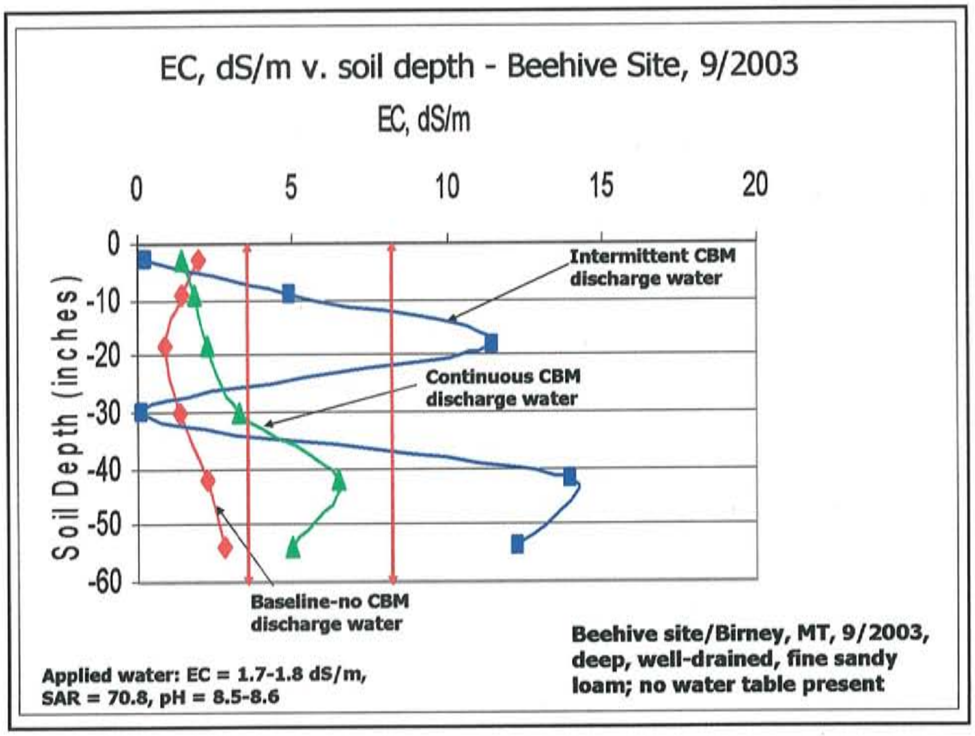

10 11'03


SAR v. Soil depth - Beehive site, 9/2003
SAR
0
5
10
15
20
25
30
0
-10
-20
-30
-40
-50
-60
Soil Depth (inches)
Intermittent CBM discharge water
Baseline-no CBM discharge water
Continuous CBM discharge water
Applied water: EC = 1.7-1.8 dS/m, SAR = 70.8, pH = 8.5-8.6
Beehive site/Birney, MT, 9/2003, deep, well-drained, fine sandy loam; no water table present


EC (dS/m) v. soil depth – Schoolhouse site, 9/2003
EC, dS/m
0
5
10
15
0
-20
-40
-60
Soil Depth (inches)
Continuous CBM impoundment overflow site; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Frequent CBM discharge water; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Continuous CBM discharge water; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Baseline-no CBM discharge water
Schoolhouse site/Moorhead, MT, 9/2003, shallow, poorly drained silty clay loam, shale subsoil at 18', shallow water table




SAR v. soil depth – Schoolhouse site, 9/2003
SAR
0
5
10
15
20
25
Soil Depth (inches)
0
-10
-20
-30
-40
-50
-60
Continuous CBM impoundment overflow site; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Baseline-no CBM discharge water
Continuous CBM discharge impoundment; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Frequent CBM discharge water; EC = 1.6-1.8 dS/m, SAR = 35.9, pH = 8.3
Schoolhouse site/Moorhead, MT, 9/2003, shallow, poorly drained silty clay loam, shale subsoil at 18', shallow water table



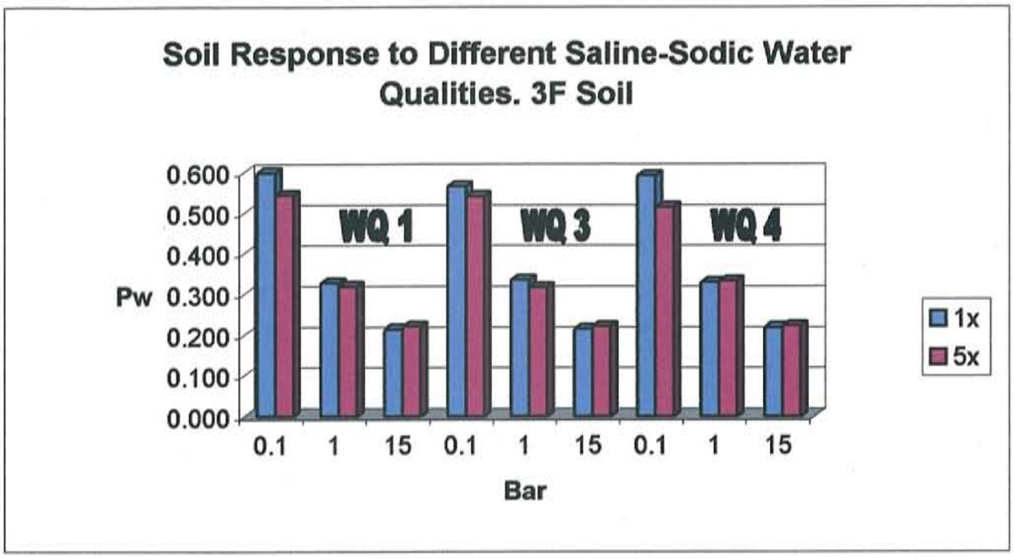
EC, dS/m v. soil depth - Beehive Site, 9/2003
EC, dS/m
0
5
10
15
20
0
-10
-20
-30
-40
-50
-60
Soil Depth (inches)
Intermittent CBM discharge water
Continuous CBM discharge water
Baseline-no CBM discharge water
Applied water: EC = 1.7-1.8 dS/m, SAR = 70.8, pH = 8.5-8.6
Beehive site/Birney, MT, 9/2003, deep, well-drained, fine sandy loam; no water table present

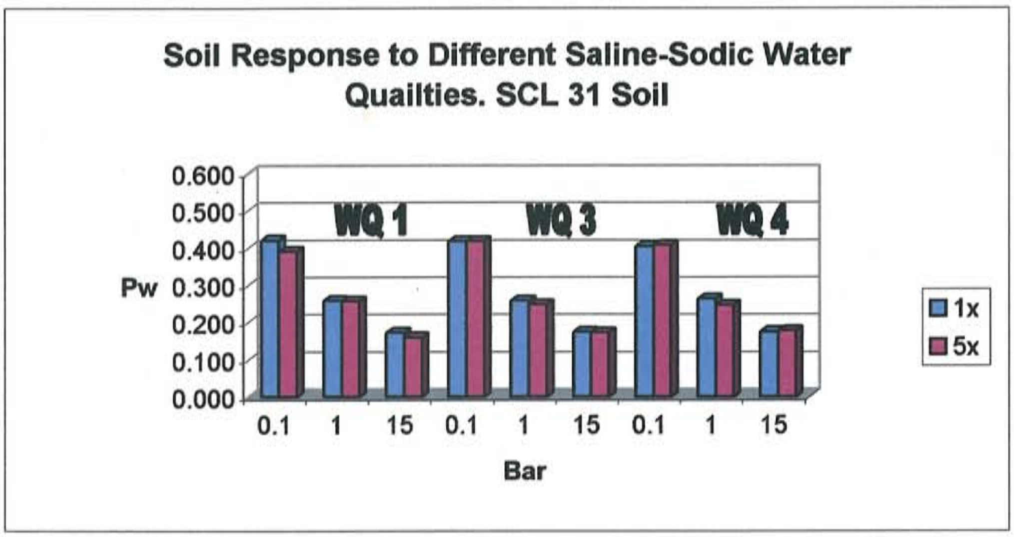
File title: Drake Pressure Plate Studies

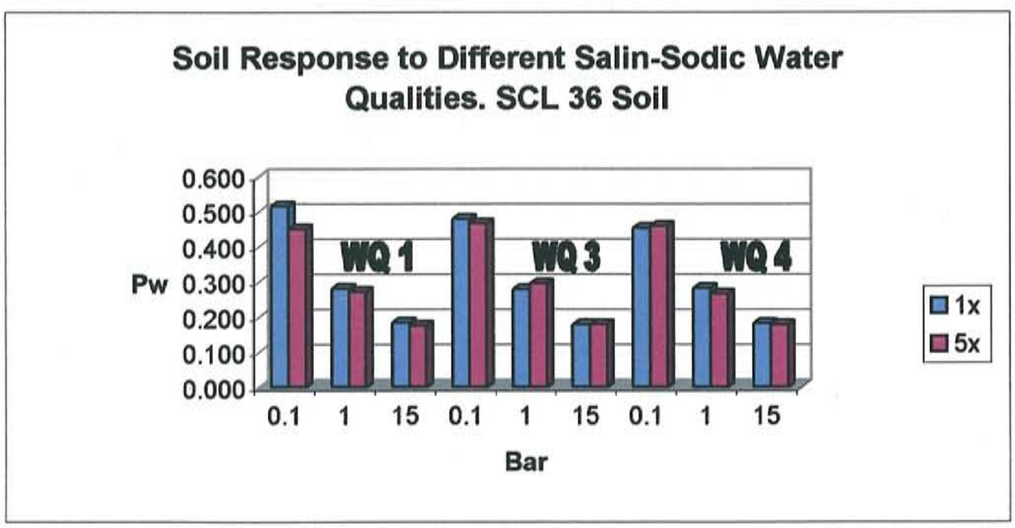
Title: Soil physical property response to wetting and drying cycles with different saline-sodic water qualities; contrast of three different soil materials

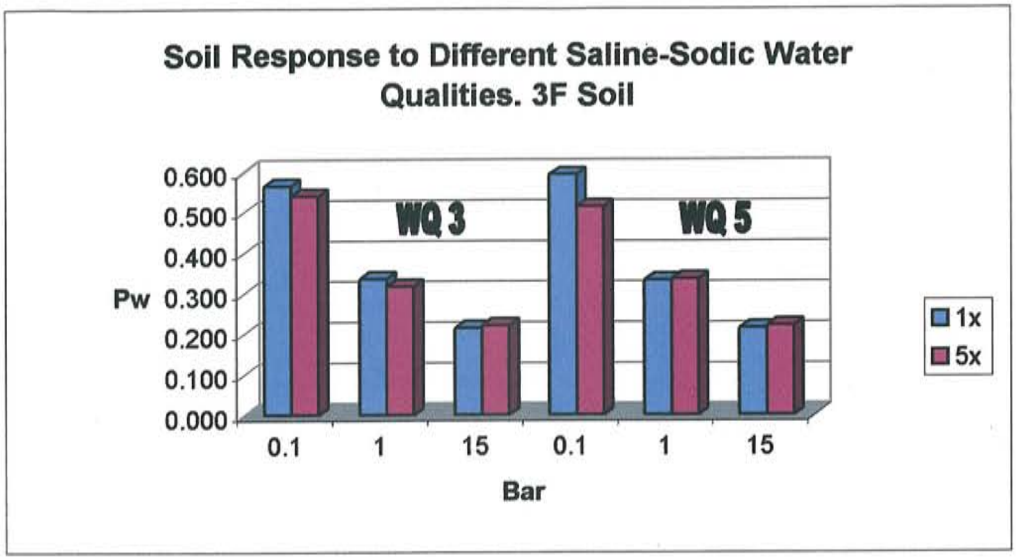
Author: Jason Drake, Montana State University

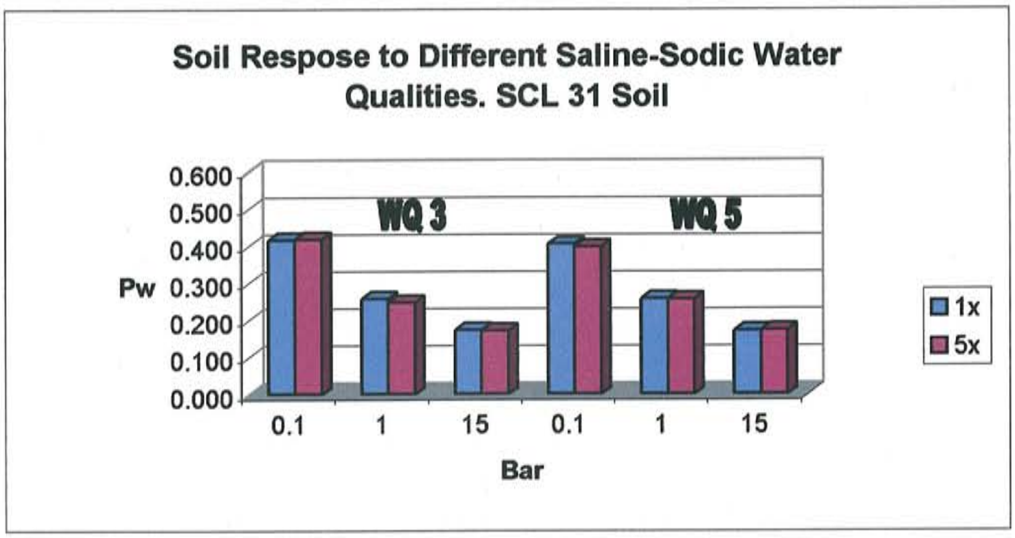
Content: 9-graph Excel presentation (total data set included), illustrating soil water storage (gravimetric water content) between saturation and permanent wilting point of three soils when subjected to 1 and 5 time wetting with three contrasting water qualities representing in-stream, modestly saline-sodic, excessively saline-sodic water sources. Contrasting soil materials consist of silty clay loam initially with elevated salinity x sodicity; silty clay loam initially with low salinity x sodicity; sandy clay loam with initially low salinity x sodicity.

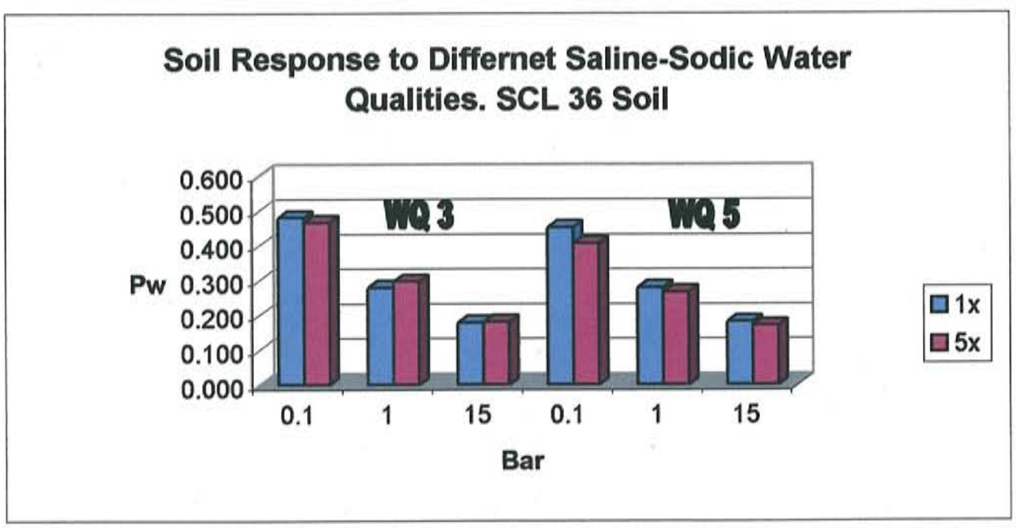

Soil Response to Different Saline-Sodic Water Qualities. 3F Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 1
WQ 3
WQ 4
0.1
1
15
0.1
1
15
0.1
1
15
Bar
1x
5x

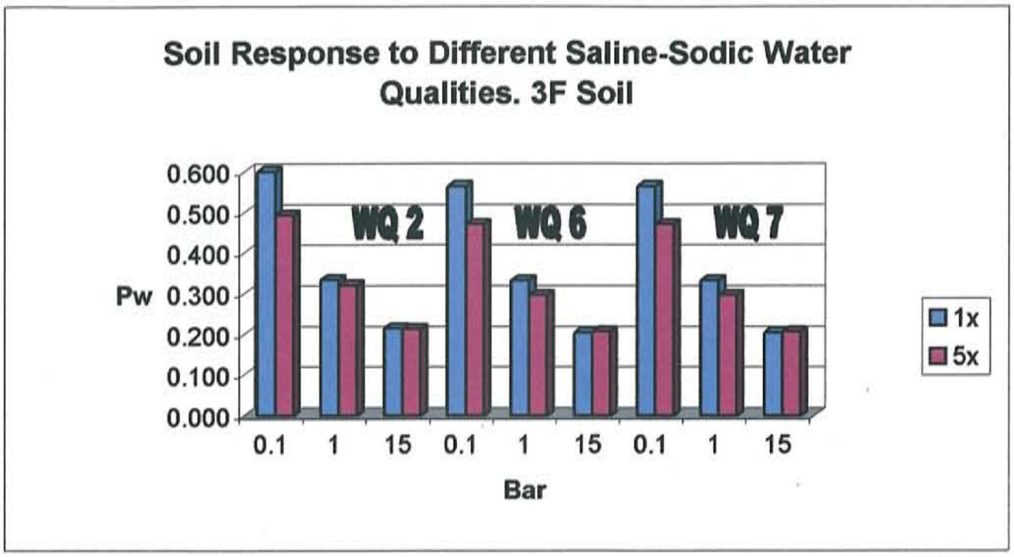

Soil Response to Different Saline-Sodic Water Quailties. SCL 31 Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 1
WQ 3
WQ 4
0.1
1
15
0.1
1
15
0.1
1
15
Bar
1x
5x

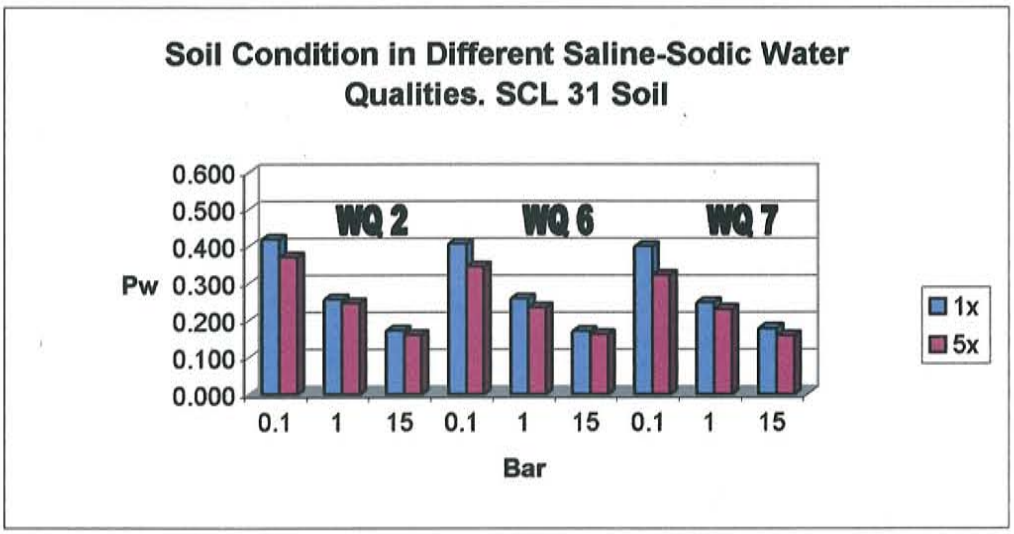

Soil Response to Different Salin-Sodic Water Qualities. SCL 36 Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 1
WQ 3
WQ 4
0.1
1
15
0.1
1
15
0.1
1
15
Bar
1x
5x

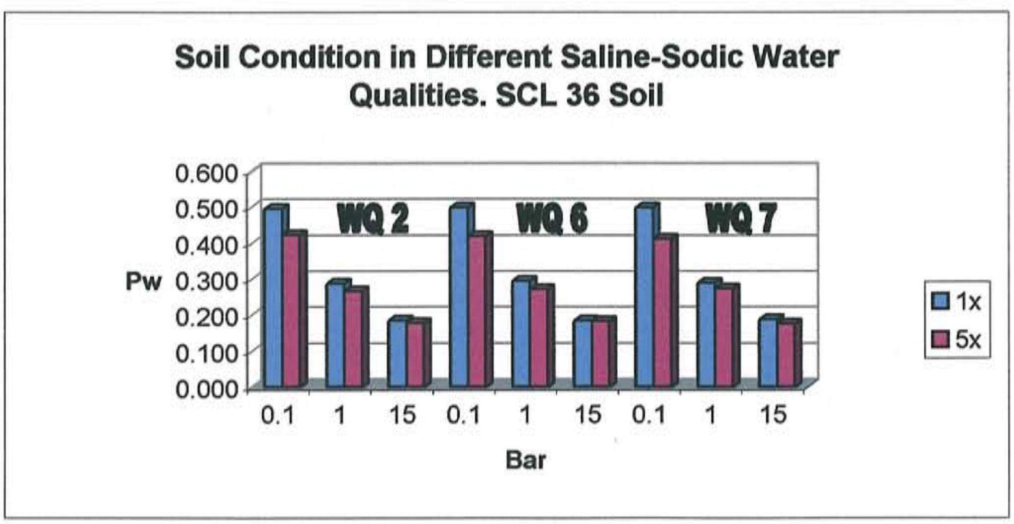

Soil Response to Different Saline-Sodic Water Qualities. 3F Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 3
WQ 5
0.1
1
15
0.1
1
15
Bar
1x
5x


Soil Respose to Different Saline-Sodic Water Qualities. SCL 31 Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 3
WQ 5
0.1
1
15
0.1
1
15
Bar
1x
5x


Soil Response to Differnet Saline-Sodic Water Qualities. SCL 36 Soil
0.600
0.500
0.400
Pw 0.300
0.200
0.100
0.000
WQ 3
WQ 5
0.1
1
15
0.1
1
15
Bar
1x
5x


Soil Response to Different Saline-Sodic Water Qualities. 3F Soil
Pw
0.600
0.500
0.400
0.300
0.200
0.100
0.000
WQ 2
WQ 6
WQ 7
0.1
1
15
Bar
1x
5x


Soil Condition in Different Saline-Sodic Water Qualities. SCL 31 Soil
Pw
0.600
0.500
0.400
0.300
0.200
0.100
0.000
WQ 2
WQ 6
WQ 7
0.1
1
15
Bar
1x
5x


Soil Condition in Different Saline-Sodic Water Qualities. SCL 36 Soil
Pw
0.600
0.500
0.400
0.300
0.200
0.100
0.000
WQ 2
WQ 6
WQ 7
0.1
1
15
Bar
1x
5x

EC	SAR	pH	Soil	%Clay	%Sand	%Silt	EC	SAR
2.95	11.05	7.80	SCL 36	44	14.66	41.34	2.57	12.06
1.48	3.57	7.87	SCL 31	45	13.4	41.6	0.81	1.55
3.07	19.82	8.09	3F	41	38	21	0.68	3.54
3.17	35.34	8.37						
6.15	20.15	7.60						
0.05	0.67	8.24						
0.24	0.28	8.23						

EC	SAR
2.95	11.05
3.07	19.82
3.17	35.34
3.07	19.82
6.15	20.15
1.48	3.57
0.05	0.67
0.24	0.28

Power Point Presentation - File title: Little Powder Trend Analysis

Title: Assessment of Coalbed Methane Product Water Intervention on Water Quality Parameters of Significance in the Little Powder River at Weston, Wyoming

Author: Keri Garver, Montana State University

Content: 46-frame power point presentation detailing the background, methods, approach and outcomes of intervention analyses for waters of the Little Powder River, Weston, Wyoming. The first 17 frames provide extensive background on the geology, lithology of coal bearing seams and water bearing coal seams of the Powder River Basin. Additionally included in the introduction is a collection of visual illustrations of coalbed methane product water management currently in place in the Powder River Basin, Wyoming portion. Complete details provided in appendix document of same title, Appendix 6 - Completed Thesis.

Assessment of Coalbed Methane Product Water Intervention on Water Quality Parameters of Significance in the Little Powder River at Weston, Wyoming

Professional Paper Defense Seminar
by Keri Garver

Little Powder Trend Analyses

Outline

- Coalbed methane co-produced water
- Relevant geology
- Objective
- Trend analysis and results
  - Parametric
  - Nonparametric

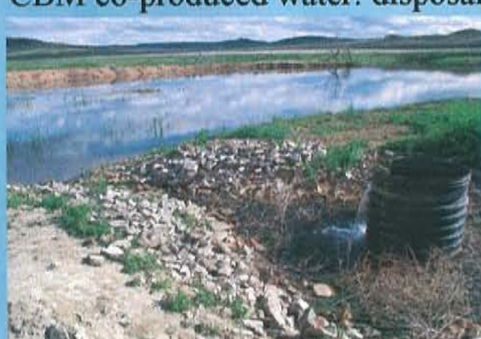
Little Powder Trend Analyses

CBM co-produced water: where?

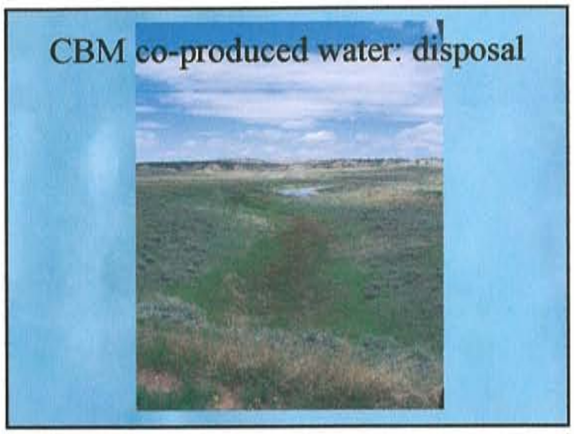
CBM co-produced water: how much?

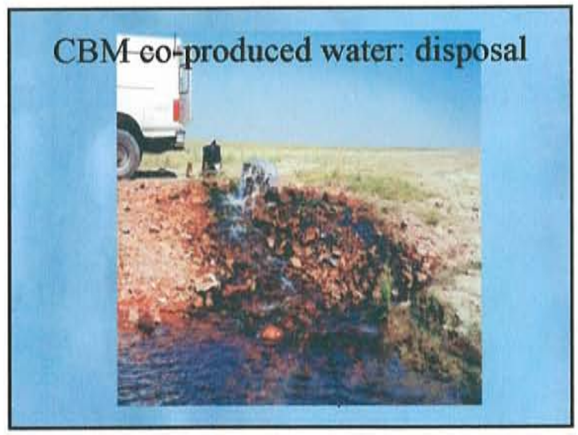
year	annual water production (cubic meters)
1989	47,360
1990	92,858
1991	287,010
1992	345,633
1993	357,448
1994	323,076
1995	446,123
1996	503,771
1997	1,036,859
1998	2,564,298
1999	5,194,937
2000	10,387,594
2001	12,327,776
2002	13,746,563
2003	10,543,059

CBM co-produced water: disposal

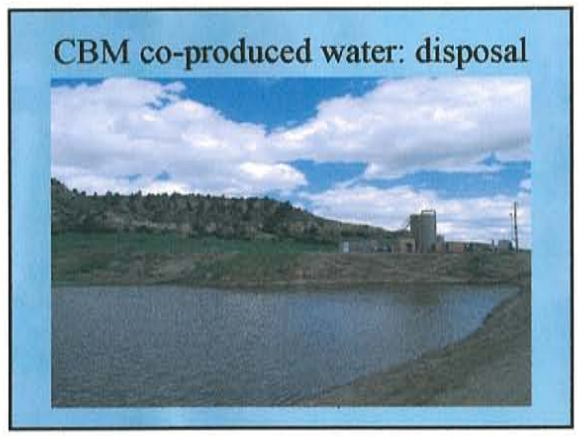


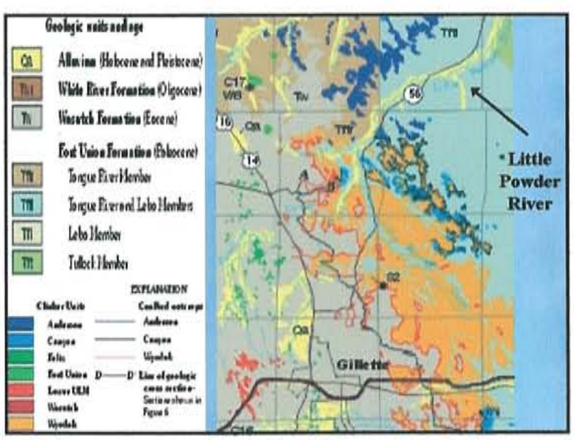
CBM co-produced water: disposal

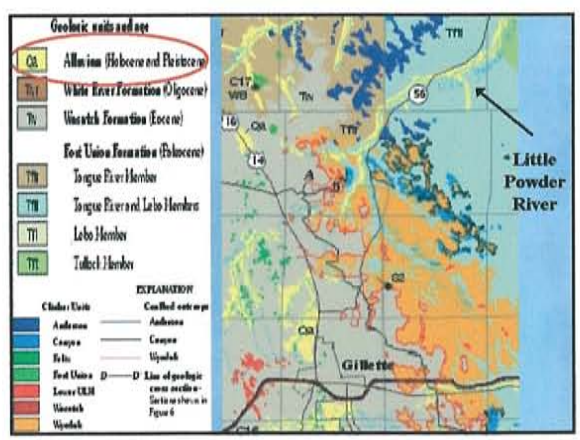

CBM co-produced water: disposal


CBM co-produced water: disposal


CBM co-produced water: disposal


CBM co-produced water: disposal


Geologic units and age
Alluvium (Holocene and Pleistocene)
White River Formation (Oligocene)
Wasatch Formation (Eocene)
Fort Union Formation (Paleocene)
Tongue River Member
Tongue River and Lebo Members
Lebo Member
Tullock Member
EXPLANATION
Little Powder River
Gillette


Geologic units and age
Alluvium (Holocene and Pleistocene)
White River Formation (Oligocene)
Wasatch Formation (Eocene)
Fort Union Formation (Paleocene)
Tongue River Member
Tongue River and Lebo Members
Lebo Member
Tullock Member
EXPLANATION
Little Powder River
Gillette

ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC UNIT			HYDROGEOLOGIC UNIT
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium			Alluvial aquifers[1]
	Tertiary	Pliocene	*Not present in study area*			*Not present in study area*
		Miocene				
		Oligocene				
		Eocene	Wasatch Formation			Wasatch aquifer[1]
		Paleocene	Fort Union Formation	Tongue River Member	Tongue River Member[2]	
						Confining unit
					Wyodak-Anderson coal zone and other coal zones and coal beds	Wyodak-Anderson coal bed aquifer and other coal bed aquifers
						Confining unit
					Tongue River Member	Tongue River aquifer
				Lebo Member[3]		Lebo confining layer
				Tullock Member		Tullock aquifer

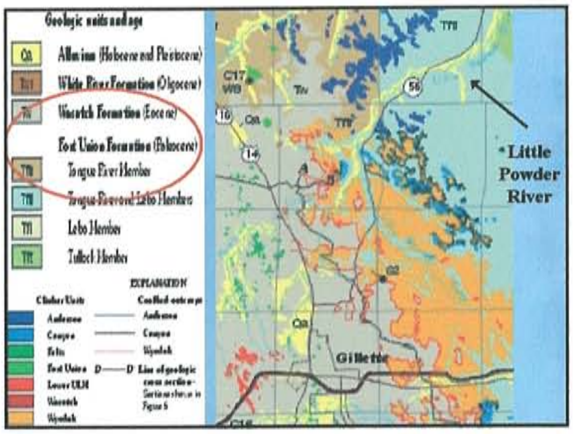
[1]Alluvial aquifers and Wasatch Formation combined into one hydrogeologic unit in Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988).

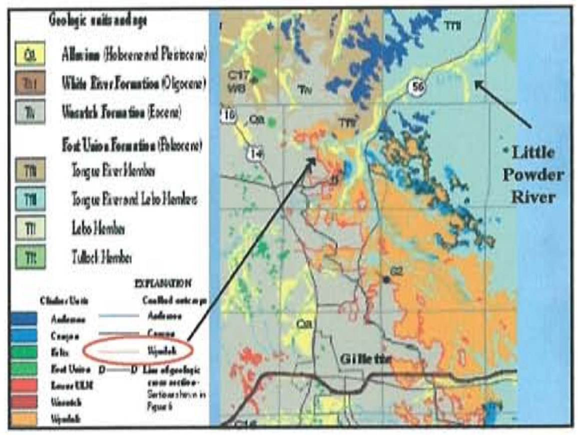
[2]The Tongue River Member of the Fort Union Formation, when present above the Wyodak-Anderson coal zone, was not included as part of the Wasatch aquifer in Bloyd and others (1986) and in Martin and others (1988).

[3]Defined as the Lebo Shale Member of the Fort Union Formation in Montana.

Figure 7. Relation of Cenozoic stratigraphic units to hydrogeologic units, eastern Powder River Basin, Wyoming (modified from Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988)).

- **CBM co-produced water chemistry**
  - **sodium bicarbonate**
- **Little Powder River chemistry**
  - **calcium and magnesium cations**
  - **chloride and sulfate anions**





ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC UNIT		HYDROGEOLOGIC UNIT
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium		Alluvial aquifers[1]
	Tertiary	Pliocene	*Not present in study area*		*Not present in study area*
		Miocene			
		Oligocene			
		Eocene	Wasatch Formation		Wasatch aquifer[1]
		Paleocene	Fort Union Formation	Tongue River Member: Tongue River Member[2]	Confining unit
				Tongue River Member: Wyodak-Anderson coal zone and other coal zones and coal beds	Wyodak-Anderson coalbed aquifer and other coalbed aquifers
					Confining unit
				Tongue River Member	Tongue River aquifer
				Lebo Member[3]	Lebo confining layer
				Tullock Member	Tullock aquifer

[1]Alluvial aquifers and Wasatch Formation combined into one hydrogeologic unit in Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988).

[2]The Tongue River Member of the Fort Union Formation, when present above the Wyodak-Anderson coal zone, was not included as part of the Wasatch aquifer in Bloyd and others (1986) and in Martin and others (1988).

[3]Defined as the Lebo Shale Member of the Fort Union Formation in Montana.

Figure 7. Relation of Cenozoic stratigraphic units to hydrogeologic units, eastern Powder River Basin, Wyoming (modified from Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988)).

ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC UNIT		HYDROGEOLOGIC UNIT
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium		Alluvial aquifers[1]
	Tertiary	Pliocene	*Not present in study area*		*Not present in study area*
		Miocene			
		Oligocene			
		Eocene	Wasatch Formation		Wasatch aquifer[1]
		Paleocene	Fort Union Formation	Tongue River Member: Tongue River Member[2]	Confining unit
				Tongue River Member: Wyodak-Anderson coal zone and other coal zones and coal beds	Wyodak-Anderson coalbed aquifer and other coalbed aquifers
					Confining unit
				Tongue River Member	Tongue River aquifer
				Lebo Member[3]	Lebo confining layer
				Tullock Member	Tullock aquifer

[1]Alluvial aquifers and Wasatch Formation combined into one hydrogeologic unit in Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988).

[2]The Tongue River Member of the Fort Union Formation, when present above the Wyodak-Anderson coal zone, was not included as part of the Wasatch aquifer in Bloyd and others (1986) and in Martin and others (1988).

[3]Defined as the Lebo Shale Member of the Fort Union Formation in Montana.

Figure 7. Relation of Cenozoic stratigraphic units to hydrogeologic units, eastern Powder River Basin, Wyoming (modified from Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988)).

ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC UNIT		HYDROGEOLOGIC UNIT
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium		Alluvial aquifers[1]
	Tertiary	Pliocene	*Not present in study area*		*Not present in study area*
		Miocene			
		Oligocene			
		Eocene	Wasatch Formation		Wasatch aquifer[1]
		Paleocene	Fort Union Formation	Tongue River Member: Tongue River Member[2]	Confining unit
				Tongue River Member: Wyodak-Anderson coal zone and other coal zones and coal beds	Wyodak-Anderson coalbed aquifer and other coalbed aquifers
					Confining unit
				Tongue River Member	Tongue River aquifer
				Lebo Member[3]	Lebo confining layer
				Tullock Member	Tullock aquifer

[1]Alluvial aquifers and Wasatch Formation combined into one hydrogeologic unit in Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988).

[2]The Tongue River Member of the Fort Union Formation, when present above the Wyodak-Anderson coal zone, was not included as part of the Wasatch aquifer in Bloyd and others (1986) and in Martin and others (1988).

[3]Defined as the Lebo Shale Member of the Fort Union Formation in Montana.

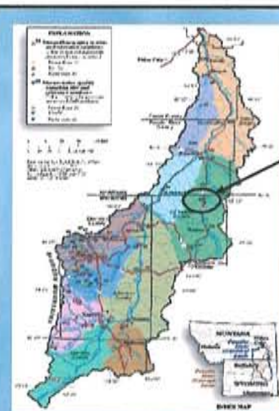
Figure 7. Relation of Cenozoic stratigraphic units to hydrogeologic units, eastern Powder River Basin, Wyoming (modified from Lewis and Hotchkiss (1981), Bloyd and others (1986), and Martin and others (1988)).

- **CBM co-produced water chemistry**
  - **sodium bicarbonate**
- **Little Powder River chemistry**
  - **calcium and magnesium cations**
  - **chloride and sulfate anions**

Little Powder Trend Analyses

Objective

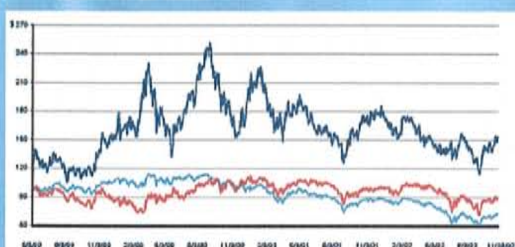
- Can trend analyses identify or quantify significant changes in the Little Powder River sodium concentration and sodium adsorption ratio (SAR) over time?
- Specifically, is the change coincident with coalbed methane co-produced water discharge in the area?



USGS 06324970: Little Powder River above Dry Creek near Weston, Wyoming

Trend analysis: Time Series

- A time series is a set of observations ordered in time



Trend Analysis: Water Resources Data

- **Non-normally distribution**
  - **Skewness**
  - **Lower bound of zero**
  - **Outliers**
- **Autocorrelation**
- **Periodicity**
- **Missing/censored data**
- **Covariance**

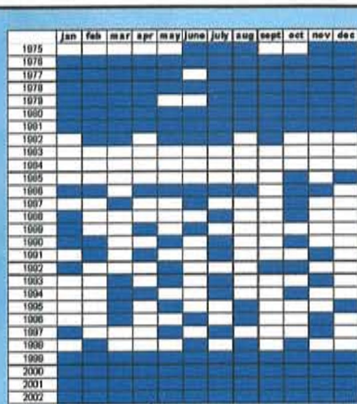
Trend Analysis

- **Parametric methods**
  - **Paired t-test**
  - **ANOVA**
- **Nonparametric methods**
  - **Wilcoxon-Mann-Whitney rank sum test**
  - **Seasonal Kendall test**
  - **Seasonal Kendall Slope estimator**
  - **Flow-Adjusted Concentration Seasonal Kendall test**

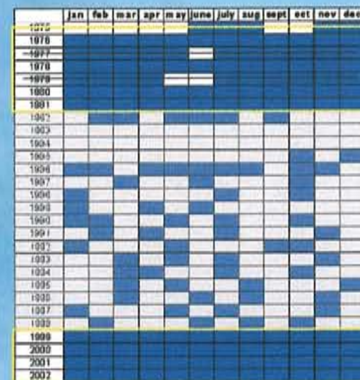
Parametric method: Paired t-test

discharge (cms)	pre-CBM inception sodium conentration (mg/L)	post-CBM inception sodium conentration (mg/L)
0.0003	370	430
0.0003	370	603
0.0006	440	400
0.0006	420	420
0.0006	370	505
0.0025	540	474
0.0031	560	214
0.0142	530	950
0.0283	500	637
0.0311	770	650
0.0311	540	684
0.0340	500	582
0.0425	500	482
0.0453	490	476
0.0510	420	603
0.0651	720	399
0.0906	550	492
0.1104	220	454
0.1246	540	669
0.1699	440	494
0.3398	530	260
0.4248	320	303
0.8778	430	552

Parametric method: ANOVA



Parametric method: ANOVA



Parametric method: ANOVA

- Main effect of months
- Main effect of periods
- Interaction of month x period

	jan	feb	mar	apr	may	june	july	aug	sept	oct	nov	dec
1978												
1981												
1980												
1976												

	jan	feb	mar	apr	may	june	july	aug	sept	oct	nov	dec
2001												
1999												
2000												
2002												

Trend Analysis: Parametric Results

Paired t-test: no significant difference between pre- and post-coalbed inception means at the 90% confidence level

	Sodium		Sodium Adsorption		Specific Conductance	
	pre-	post-	pre-	post-	pre-	post-
Mean	481	510	6.9	7.5	3297	3561
Standard deviation	119	158	1.1	1.8	673	813
Observations	23	23	23	23	19	19
conclusion	fail to reject H_0		fail to reject H_0		fail to reject H_0	

Little Powder Trend Analyses

Trend Analysis: Parametric Results

ANOVA:
- Month
- Period
- Interaction

Parameter	Source of Variation
Sodium Concentration (mg/L)	Month**
	Period**
	Month x Period
Sodium Adsorption Ratio	Month**
	Period**
	Month x Period
Specific Conductance (uS/cm)	Month**
	Period**
	Month x Period
Discharge (cms)	Month**
	Period
	Month x Period

Trend Analysis: Parametric Results

ANOVA:
- Interaction

Parameter	Source of Variation
Sodium Concentration (mg/L)	Month**
	Period**
	Month x Period
Sodium Adsorption Ratio	Month**
	Period**
	Month x Period
Specific Conductance (uS/cm)	Month**
	Period**
	Month x Period
Discharge (cms)	Month**
	Period
	Month x Period

Trend Analysis: Parametric Results

ANOVA:
- Month
- Period
- Interaction

Parameter	Source of Variation
Sodium Concentration (mg/L)	Month**
	Period**
	Month x Period
Sodium Adsorption Ratio	Month**
	Period**
	Month x Period
Specific Conductance (uS/cm)	Month**
	Period**
	Month x Period
Discharge (cms)	Month**
	Period
	Month x Period

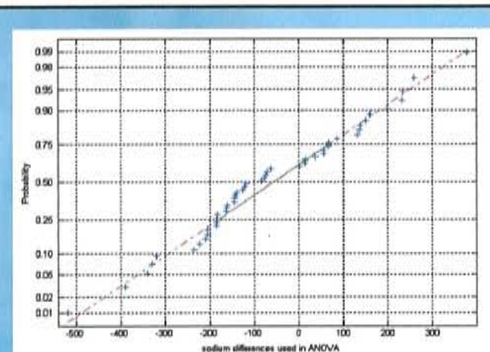
Trend Analysis: Parametric Results

ANOVA:
- Month
- Period
- Interaction

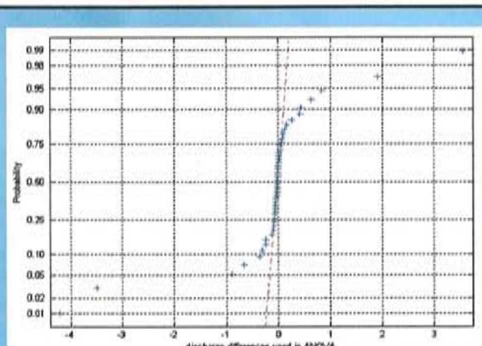
Parameter	Source of Variation
Sodium Concentration (mg/L)	Month**
	Period**
	Month x Period
Sodium Adsorption Ratio	Month**
	Period**
	Month x Period
Specific Conductance (uS/cm)	Month**
	Period**
	Month x Period
Discharge (cms)	Month**
	Period
	Month x Period

Trend Analysis: Parametric…Conclusion?

- Paired t-test
  - Covariance?
  - Small sample size?
  - No change in means?
- ANOVA
  - Period tested?
  - Non-normal distribution?



Normal probability plot for sodium concentration (mg/L) differences



Normal probability plot for discharge (cms) differences

Nonparametric method: Rank sum test

- Analyzed same dataset as that of paired t-test (pairing based on discharges that occurred in both the pre- and post-coalbed methane datasets
- Data are ranked, and the sum of the ranks are compared

Nonparametric method: Seasonal Kendall test

- Truncate dataset to lowest common sampling frequency
- Divide into four hydrologic seasons
- Divide each hydrologic season into three sub-periods
- Calculate test statistic for each sub-period, season, and overall

Nonparametric method: Seasonal Kendall test

summer (6,7,8)
sodium concentration

month	year	mg/L																							
7	1975	240	-1	1	1	1	1	-1	-1	1	1	1	1	1	1	1	-1	1	1	-1	1	1	1	1	1
7	1976	120	1	1	1	1	0	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
7	1977	360	1	1	1	-1	-1	1	1	-1	1	1	-1	1	-1	1	1	-1	1	1	1	1	1		
7	1978	630	1	-1	-1	-1	1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1			
7	1979	600	-1	-1	-1	1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1				
7	1980	370	-1	-1	1	1	-1	1	1	-1	1	-1	1	1	-1	1	1	1	1	1					
7	1981	120	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
7	1982	75	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
7	1986	620	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1								
6	1987	410	-1	1	1	-1	-1	-1	1	1	-1	1	1	1	1	1									
7	1988	280	1	1	1	1	-1	1	1	-1	1	1	1	1	1										
6	1989	600	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1											
7	1990	580	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1												
7	1991	290	1	-1	1	1	-1	1	1	1	1	1													
7	1993	380	-1	1	1	-1	1	1	1	1	1														
7	1994	190	1	1	-1	1	1	1	1	1															
8	1995	440	0	-1	1	1	1	1	1																
6	1996	440	-1	1	1	1	1	1																	
7	1997	178	1	1	1	1	1																		
6	1998	534	-1	0	-1	-1																			
7	1999	510	1	-1	-1																				
7	2000	534	-1	-1																					
7	2001	475	-1																						
7	2002	449																							
sum=	54		-3	1	5	4	0	2	6	3	5	2	1	4	1	4	1	4	3	2	1	2	3	2	1

summer (6,7,8)
sodium concentration

	month	year	mg/L										row sum	sum total
	7	1975	240	-1	1	1	1	1	-1				2	
first quarter	7	1976	120	1	1	1	1	0					4	sum total
	7	1977	360	1	1	1	-1						2	4
	7	1978	630	1	-1	-1							-1	
	7	1979	600	-1	-1								-2	
	7	1980	370	-1									-1	
	7	1981	120										0	
													row sum	
	7	1982	75	1	1	1	1	1	1	1	1	1	9	
	7	1986	620	-1	-1	-1	-1	-1	-1	-1	-1		-8	
transition	6	1987	410	-1	1	1	-1	-1	-1	1			-1	sum total
	7	1988	200	1	1	1	1	-1	1				4	-2
	6	1989	500	0	-1	-1	-1	-1					-4	
	7	1990	580	-1	-1	-1	-1						-4	
	7	1991	290	1	-1	1							1	
	7	1993	380	-1	1								0	
	7	1994	190	1									1	
	8	1995	440										0	
													row sum	
	6	1996	440	-1	1	1	1	1	1				4	
	7	1997	178	1	1	1	1	1					5	sum total
last quarter	6	1998	534	-1	0	-1	-1						-3	2
	7	1999	510	1	-1	-1							-1	
	7	2000	534	-1	-1								-2	
	7	2001	475	-1									-1	
	7	2002	449											

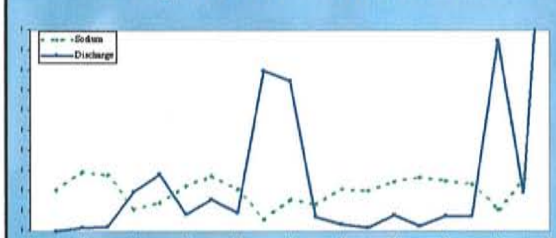
Nonparametric method: Seasonal Kendall Slope estimator

- Enables an estimate of the trend magnitude, expressed as a slope
- Use data from Seasonal Kendall test, with the median of the differences as the slope estimator

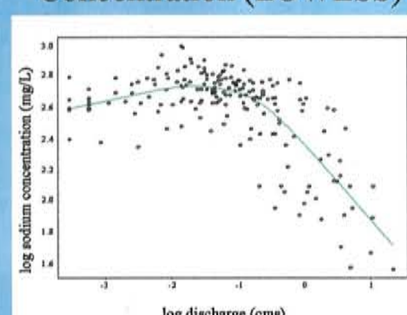
$$d_{ijk} = (x_{ij} - x_{ik}) / (j - k)$$

$$\text{Ex: difference} = \frac{Na_{Jan.,\,1995} - Na_{Jan.,\,2000}}{1995 - 2000}$$

Nonparametric method: Flow-Adjusted Concentration



Nonparametric method: Flow-Adjusted Concentration (LOWESS)



Trend Analysis: Nonparametric Results

Wilcoxon-Mann-Whitney Rank Sum test:

Results the same as the paired t-test (no significant differences between pre- and post-coalbed inception means)

Results: Seasonal Kendall test, Seasonal Kendall Slope Estimator, and Flow-Adjusted Concentration

		Fall	Winter	Spring	Summer
Sodium Concentration (mg/L)	First quarter				
	Transition				
	Last quarter		11.00		
	Overall				
Sodium Adsorption Ratio	First quarter				
	Transition				
	Last quarter		0.598		
	Overall				
Discharge (cms)	First quarter				
	Transition			-0.010	
	Last quarter		-0.049		-0.066
	Overall				
Load (Na * Q)	First quarter				
	Transition				
	Last quarter		-16.21		
	Overall		1.17		
LOWESS FAC	First quarter				
	Transition				
	Last quarter				
	Overall				

Trend Analysis: Nonparametric conclusions

- Winter had the most significant values
- Discharge and chemistry parameters behaved as expected
- Arbitrary sub-periods

Conclusions

- Period of analysis matters
- Too early to distinguish changes?
- Unknown natural or anthropogenic changes?
- With various disposal techniques it is difficult to estimate travel times/distances
- A complete dataset sure would be nice!!