Effects of Oil Field Brine Wastewater Spills on Soil Hydraulic Conductivity

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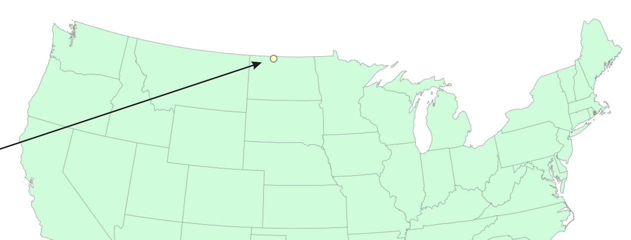
Abstract

Oil field brine is wastewater produced during the oil well drilling process. Brine spills have occurred in North Dakota, resulting in complete crop production loss on the affected soil. Remediation requires removal of the salt from the soil, which might be accomplished by leaching to subsurface drains. A laboratory study was conducted to determine the effects of brine on the saturated hydraulic conductivity (K_{sat}) of four soils from western ND. Tempe cells were packed with dried, ground soil. Steady state flow of water was established, followed by either 1 or 3 pore volumes of brine to simulate a spill. Finally, water was reintroduced in an attempt to leach the brine from the soil. While K_{sat} was relatively unaffected during the brine application, subsequent leaching with deionized water caused a dramatic reduction in K_{sat}, an average of 60 times slower than pre-brine K_{sat} in one soil. After brine application, total dissolved solids (TDS) concentration in the effluent rose to near original brine levels (0.3 Mg L^{-1}), but then declined back towards initial pre-brine concentrations (0.002 Mg L^{-1}) with continued leaching with water. However, the K_{sat} did not increase with continued leaching. Removal of soluble salts during leaching increased the relative sodium concentrations on the exchange complex (ESP>60), causing dispersion/swelling of clay particles and reduced K_{sat}. Post-brine application of gypsum ($CaSO_4$) at a rate equivalent to 5 tons/acre in an attempt to add calcium to the exchange complex did not improve the K_{sat}. This evidence suggests that subsurface drainage may not be effective in removing salts from the crop root zone due to very low permeability caused by sodium induced clay dispersion/swelling.

Methods

The soils used for this study were from two sites designated AG and WD in northwestern ND in areas near where brine spills had occurred. Samples were taken from upper (U) and lower (L) landscape positions.

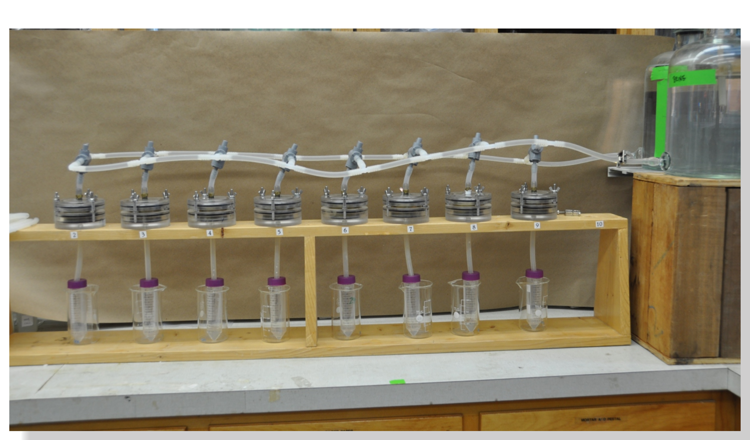


According to a North Dakota Health Department database, the size and frequency of brine spills has been increasing. If these spills occur on the soil, that land could be barren for decades.

Initial soil properties.

Site	Series	Depth cm	Texture	EC mS cm^{-1}	pH
AG_U	Barnes-Svea-Tonka	0-33	loam	0.53	7.46
AG_L	Barnes-Svea	0-61	loam	0.69	6.78
WD_U	Barnes	0-20	loam	0.50	7.50
WD_L	Barnes	0-41	sandy-loam	0.84	7.38

- Air dried, ground, and sieved (2mm) soil was packed into modified Tempe cells for K_{sat} determination. Packing was done by tapping on the sides to settle consecutive 0.5-cm layers of the material to a uniform bulk density.
- Stainless steel screens and filter papers were used to contain the soil within the brass ring of the Tempe cell and allow even wetting and prevent swelling (Sommerfeldt, et al., 1984).



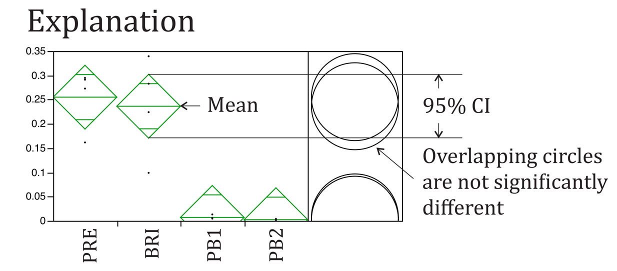
- Cores were saturated from the bottom with de-gassed water. Once saturated, the water supply was switched to the top of the Tempe cells to establish steady-state saturated flow and to determine K_{sat}.
- After steady state flow was achieved with water, 1 or 3 pore volumes of a brine solution (TDS = 0.3 Mg L^{-1}) was applied.
- Following brine addition, water was again supplied to the cores until steady state flow was observed.
- Effluent samples were collected after initial steady-state flow was observed, after brine application, and several times during post-brine water application.
- Total dissolved solids (TDS) concentration was determined by drying and weighing effluent samples.
- Soil was removed from the Tempe cells for determination of exchangeable sodium percentage (ESP).

Results

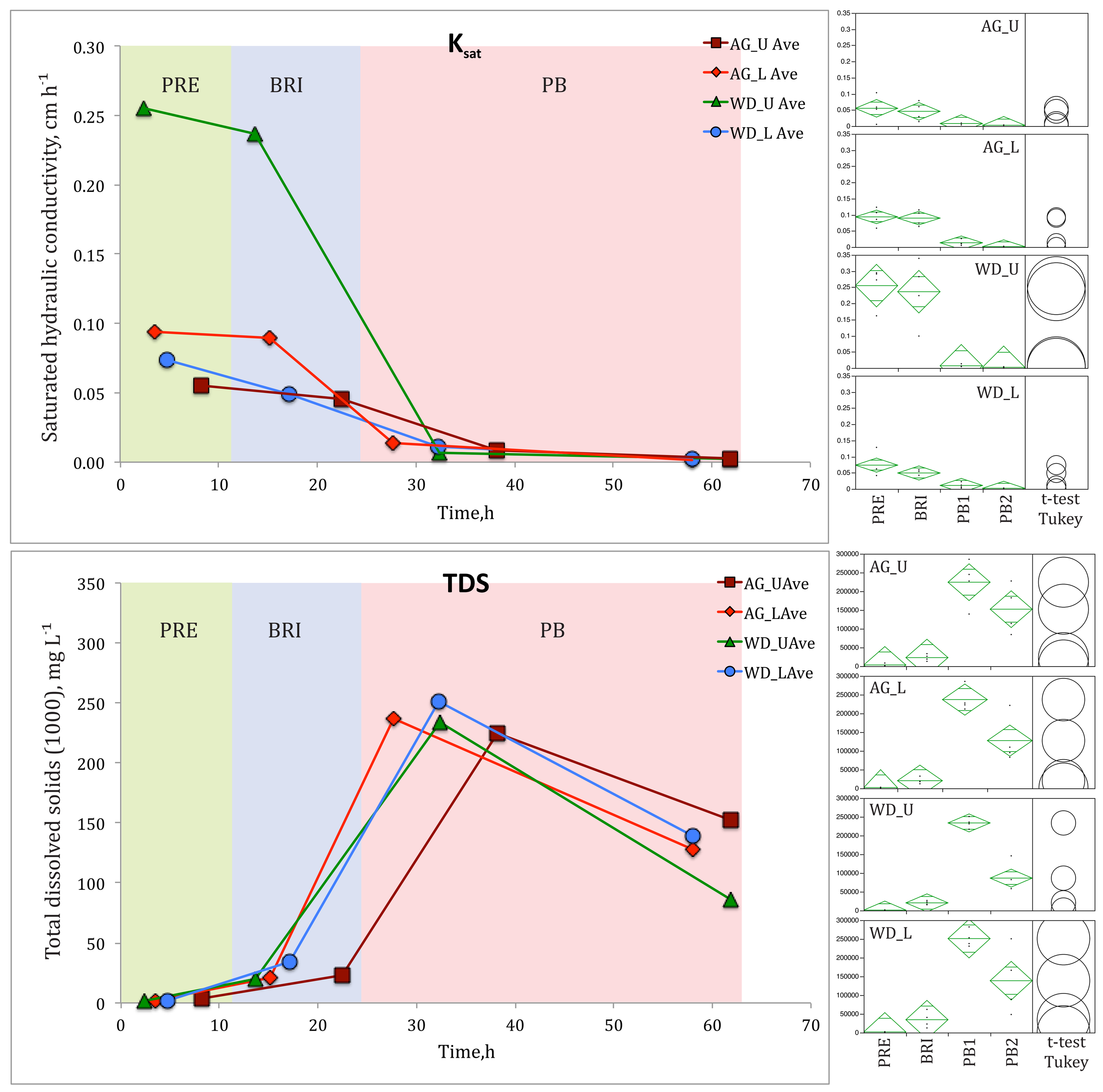
The following are time-series charts of mean K_{sat} and effluent TDS for the four soils during the leaching experiments; before, during, and after application of oil field brine.

Smaller charts to the right of each time series are means diamonds and t-test circles (JMP). X-axis labels for leaching time periods are:
PRE, pre-brine application
BRI, brine application
PBx, post-brine application
PGx, post gypsum application

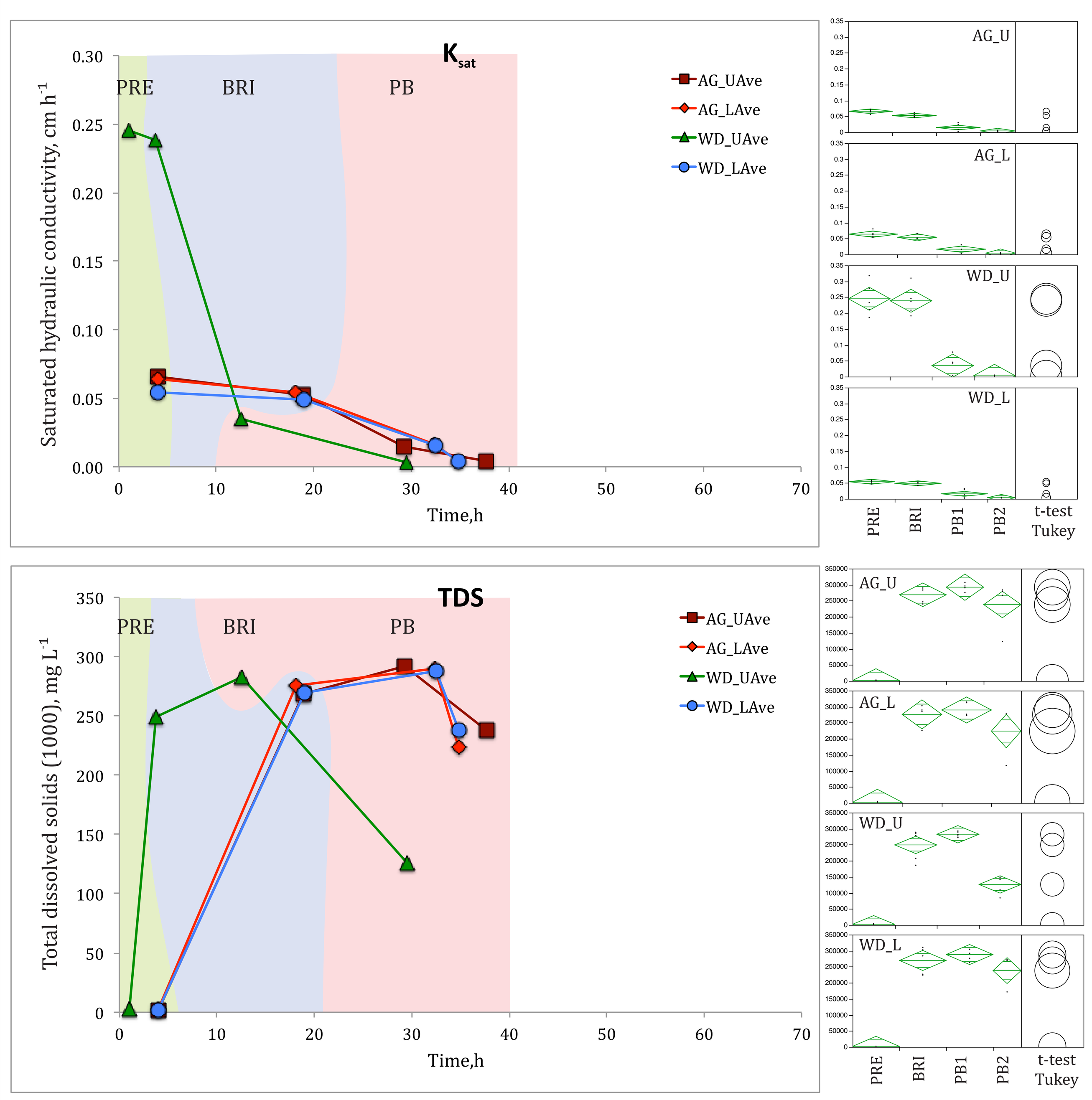
Explanation



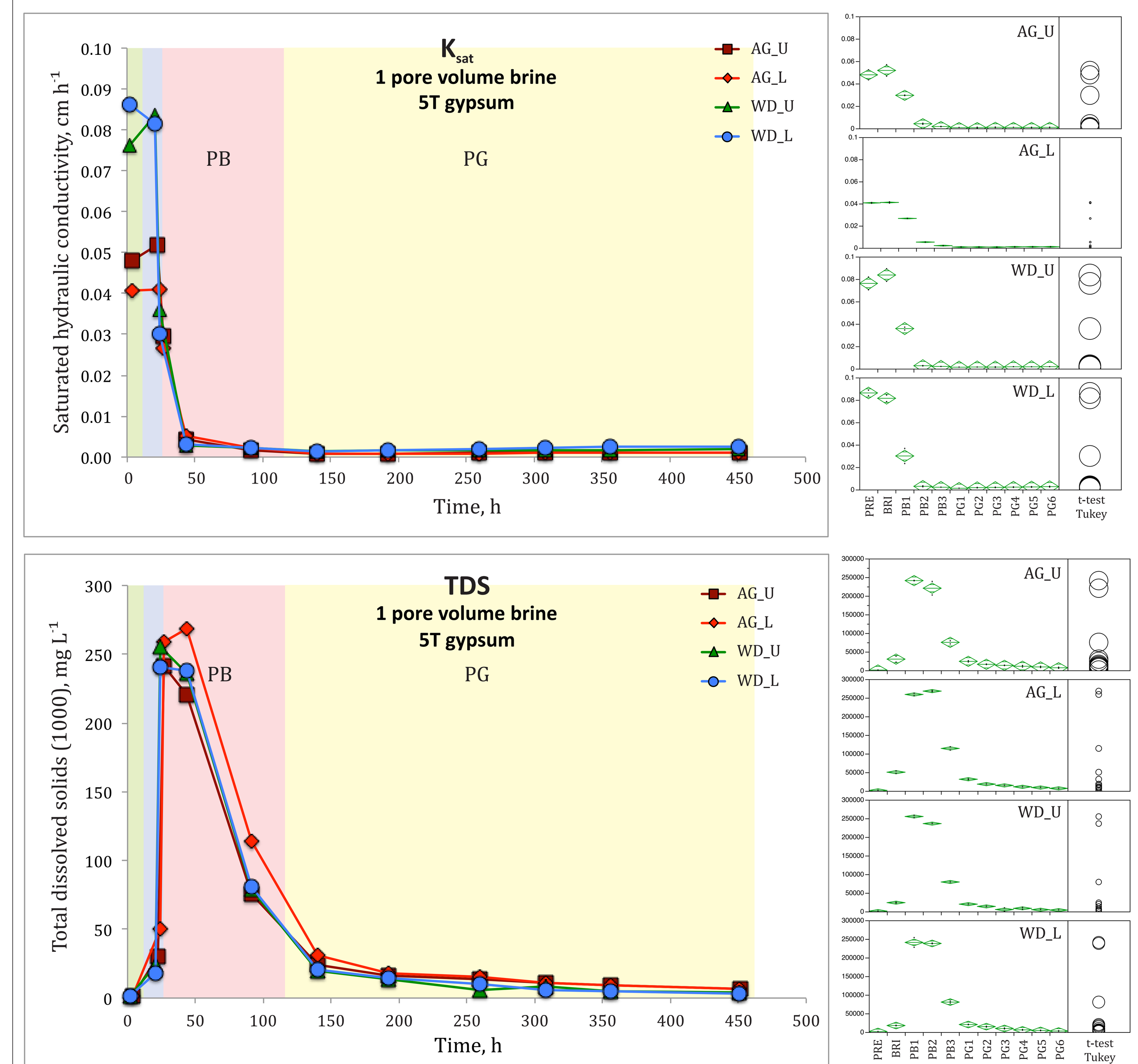
Time series plots of mean K_{sat} and effluent TDS for leaching experiment including addition of **1 pore volume of brine**.



Time series plots of mean K_{sat} and effluent TDS for leaching experiment including addition of **3 pore volumes of brine**.



A separate set of cores was subjected to **1 pore volume brine** and then opened and gypsum was incorporated into the top 2-3 mm of the soil. **Gypsum** rates was equivalent to **5 T/acre**.



- After leaching, the soil was analyzed for major cations and exchangeable sodium percentage (ESP) was determined. Very high ESP indicated that sodium was the dominant cation remaining in the soil, leading to dispersion of clays and swelling of the soil.

Exchangeable sodium percentage (ESP) of soils after leaching.

Sample	CEC cmol[+] kg^{-1}	Brine pore volumes	ESP†	Std. Err.
AG_U	11.2	0	0.9 a	2.24
		1	62.8 b	1.94
		3	58.1 b	2.24
AG_L	12.6	0	1.0 a	2.32
		1	59.8 c	1.64
		3	53.2 b	1.89
WD_U	9.4	0	1.0 a	8.68
		1	56.6 b	6.14
		3	62.4 b	7.09
WD_L	10.3	0	1.0 a	2.23
		1	55.5 c	1.58
		3	47.7 b	1.58

† ESP means separated by different letters are significantly different at 0.05.

Conclusions

- Leaching soil columns with oil field brine to simulate a brine spill indicated that hydraulic conductivity was significantly reduced when fresh water was subsequently applied.
- TDS concentrations of the effluent indicated removal of salts from the soil; however, ESP values of the post-leaching soil indicated very high residual sodium.
- High sodium levels in the absence of other salts lead to dispersion and/or swelling of clays. Hence, K_{sat} did not increase after the brine was leached out of the soil.
- K_{sat} for 3 pore volumes of applied brine was not significantly different than K_{sat} for 1 pore volume for any soil/stage combination
- Addition of gypsum in an attempt to replace sodium on the exchange complex with calcium was not successful in restoring pre-brine K_{sat}.
- Based on this work, it is unlikely that subsurface drainage would be effective in remediation of brine affected soils.
- Future work may include using alternate, more soluble, calcium sources to attempt to remove the sodium from the soil exchange complex.

References

Sommerfeldt, T.G., G.B. Schaalje, and W. Hulstein. 1984. Use of Tempe cell, modified to restrain swelling, for determination of hydraulic conductivity and soil water content. Can. J. Soil Sci. 64: 265-272.

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