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Environmental Impacts of BRINE (Produced Water)

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Brine is a direct by-product of the oil and gas industry that is brought to the surface during the extraction of oil and gas. A higher quantity of brine will need to be stored, transported and disposed of as the result of increased energy development. These larger quantities can lead to greater risks for spills. Brine spills negatively affect the soil and vegetation, impairing their ability to produce crops and forage (Figure 1).

What is Brine?

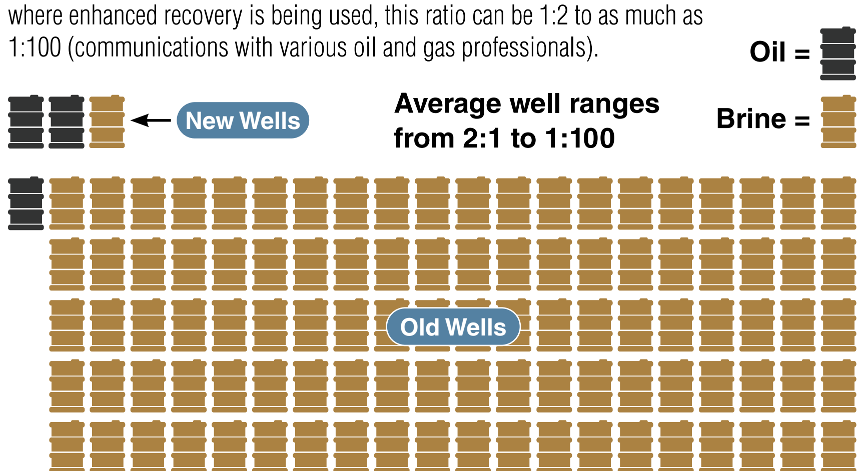
Brine, or produced water, is a byproduct of oil and gas production. It consists of water from the geologic formation, injection water, oil and salts. To learn more about how brine is formed refer to NDSU Extension publication WQ2083 Origination of Produced Water (Brine) in the Williston Basin.

Brine has a high salt concentration that has been recorded up to four times the salinity of ocean water. Brine solutions can have electrical conductivities (EC) in excess of 200 deciSiemens per meter (dS/m; 1 dS/m = 1 millimho per centimeter [mmho/cm]), sodium adsorption ratios (SAR) of more than 300 and total dissolved solids (TDS) concentrations of 100,000 parts per million.

The high salt concentrations in brine come from salt deposits in oil-producing rock formations containing oil, as seen in the Bakken and Three Forks formations in western North Dakota. However, the overall salinity and concentrations of sodium can vary widely by location and depth of extraction.

Figure 1. This is a 50-year-old brine spill in northwestern North Dakota.

Figure 2. The average well in North Dakota, depending on the field, location and the age of the well, the oil:brine ratios in the Williston Basin (Bakken and Three Forks formations) range from 2:1 to 1:4, whereas in older formations where enhanced recovery is being used, this ratio can be 1:2 to as much as 1:100 (communications with various oil and gas professionals).



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Brine Effects on Soil

The salts in brine alter the chemical and physical properties of soils. Due to the high amounts of soluble salts (predominately sodium chloride, NaCl), brine negatively impacts soils in many ways.

Chloride levels in and around the spill area are toxic to many biological species. Sodium is a natural dispersant and can cause soils to swell and disperse, but only if the total salt level in the soil falls below a flocculation threshold limit. A flocculant, such as calcium, binds the soil together and helps create soil structure.

For most soils in the region, when the SAR from a saturated paste extract (assume that at values of less than 50, the SAR ≈ exchangeable sodium percentage (ESP) ≈ % sodium) is 5 or more and the EC of the saturated paste is 2 dS/m or less, soils will swell and/or disperse (Figure 3). Thus, remediation strategies should focus on reducing the concentration of sodium (a known dispersant), increasing the concentration of calcium (a known flocculant), and maintaining EC levels above the threshold at which swelling and dispersion will occur.

Swelling soils will retain their natural structure, but soil structure will be lost once dispersion occurs. This loss of structure impedes the ability of water to infiltrate and move through the soil, increasing the potential for erosion.

Brine Effects on Vegetation

Salts from brine impair plants' ability to take up water and nutrients. High salt concentrations in the soil restrict the plants' ability to take up water despite adequate water being available in the soil. This causes the plant to exhibit symptoms of drought due to an osmotic effect, which causes water to move from areas of low salt concentrations to areas of high salt concentrations (Figure 4).

Due to the impacts of high salt concentrations on soil and vegetation, impacted sites suffer from a decline in plant growth. This is magnified by the inability of many seeds to germinate in highly saline soils. Under these conditions, seeds have difficulty taking up water, causing damage to the embryo or dormancy in response to water stress.

In addition to the inability to take up water, nutrient uptake is also reduced. Excess sodium and chloride ions can interfere with the plants' ability to generate energy and reduce the uptake and/or use of key nutrients. Excess sodium and chloride can be toxic to plants.

Plants exposed to brine often die due to salt stress resulting from the inability to take up water and key nutrients. Most plants will show signs of salt stress if sodium exceeds 70 milligrams per liter in water, 5% in plant tissue or 230 milligrams per liter in soil (saturated paste extract).

Chloride negatively impacts most plants when it exceeds 350 milligrams per liter in water, 1% in plant tissue or 250 milligrams per liter in soil (saturated paste extract). However, some plant species are salt-tolerant; they are called halophytes.

Halophytes are able to grow and reproduce in soils with EC values of 20 dS/m or more. In comparison, EC values above 2 dS/m negatively affect the growth of many row crops and small grains. Halophyte plants are able to survive due to adaptations that allow them to regulate, transport or store salts safely in specialized compartments of the plants' tissues.

Figure 3. Soil EC and sodium impact the structure of soils when swelling and dispersion occur, which impedes the ability of water to infiltrate through the soil.

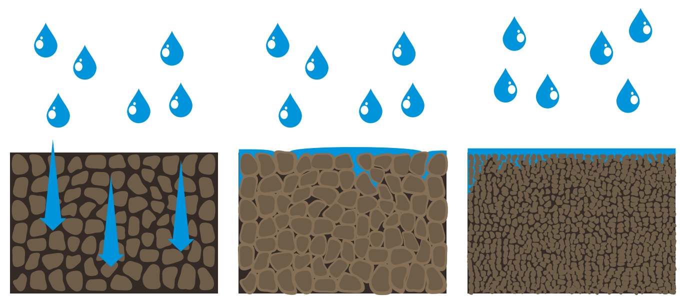

Figure 4. Effects of brine on vegetation.

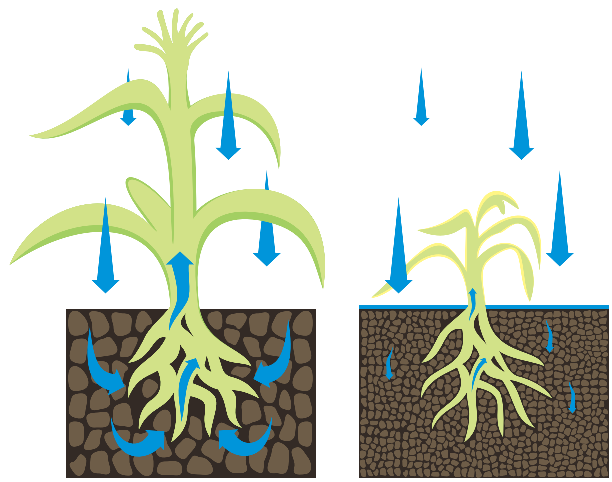

Table 1. Relative Saline Tolerance Levels (EC) of Agronomic Crops[1,2,3].

Crop	EC (dS/m) Production Affected – Seeding Stage	EC (dS/m) Production Affected	Upper Limit	Tolerance Rating
Canola		10	14	High
Barley	24	8	16	High
Wheat (durum)		7	14	Moderate
Wheat (semidwarf)		7	14	Moderate
Sugar beets	8	7	14	Moderate
Sunflowers	8	6	14	Moderate
Safflowers	8	6	10	Moderate
Oats		4	8	Low
Soybeans		4	8	Low
Alfalfa		4	8	Low
Corn		3	6	Low
Flax		2	4	Low
Edible beans		1	2	Low

[1] Source: Ogle and St. John (2009).
[2] Source: Franzen (2013).
[3] Source: Green et al. 2020

Brine Spill Remediation

When brine spills occur, there is a need to remove the excess chloride to prevent contamination of surface and groundwaters and also to reduce sodium to limit its impact on soil structure. The ultimate goal of brine spill remediation is to remove or minimize salts in the soil, allowing for improved vegetation growth and establishment. Remediation can be accomplished through *ex situ* or *in situ* methods.

Ex Situ Remediation

Ex situ methods are most often utilized in North Dakota. During *ex situ* remediation, the topsoil or impacted depth is excavated from the site and moved to a landfill that is approved for the containment of oil-field wastes. New soil is brought in to replace the removed soil.

The new topsoil may have different chemical and physical properties, including a different seedbank, than the original soils. The new soil will not be contaminated with brine and it should be managed to maintain a clean, weed-free seedbed for the reclamation process.

In Situ Remediation

In situ methods remove the salts from the topsoil while keeping the soil in place. The most common methods include the application of chemical amendments, which can be supplemented with tile drainage.

Calcium-based amendments are used to replace sodium on the soil's exchange sites, reducing soil swelling and dispersion and allowing the sodium to be leached lower in the soil profile, where it does not impact plant growth and establishment. There is then a reduced risk of sodium redepositing near the surface again.

Chemical amendments are typically calcium-based, such as gypsum. Gypsum is the most commonly applied amendment used for *in situ* remediation in North Dakota.

However, the use of gypsum has limitations because it is only effective to the depth to which it is incorporated into the soil. In addition, the particle size of the gypsum being applied can influence reclamation. Smaller gypsum particles have greater surface area, causing it to react more quickly than larger particles.

Alternatively, calcium acetate, which is more soluble than gypsum, has been shown to be an effective Ca-amendment in replacement or used in conjunction with gypsum.

The use of tile drainage aids in permanently removing the leached waters containing sodium and chloride to offsite disposal areas. However, one of the main limitations to successful remediation is applying enough water to 1) solubilize the calcium amendment that can counteract the negative effects of the sodium, and to maintain soil EC; 2) move calcium through the soil profile; and 3) leach the sodium and chloride into the tile and collection tanks, or below the rooting zone.

The success of *in situ* remediation can be enhanced through the establishment of halophytic vegetation. Halophytes take up salts and store them in plant parts. Harvesting the above-ground biomass and removing it from the site can reduce salts in the soil.

Figure 5. A crew is doing *ex situ* remediation of a brine spill.

Figure 6. The topsoil was removed from this spill site as part of *ex situ* remediation.

Remediation Results

Remediation is a long and costly process, often with varied success. However, new research and technologies have improved the success of remediation projects greatly. Important factors to consider when tackling a remediation project include:

- who is responsible for cleaning up the spill
- the extent of the impacted area
- the soil EC and SAR levels
- estimated cost of cleanup
- the desired land use

Answering these questions will help you determine the method(s) best suited for a brine impacted site.

Following any remediation project, continuous monitoring of the site to document the success of the project is important. Pay close attention to soil structure, EC and SAR levels, and vegetation cover and production.

Table 2. Relative Saline Tolerance Levels (EC) of Selected Range and Pasture Species[1, 2].

	EC (dS/m) Production Affected – Seedling Stage	EC (dS/m) Production Affected – Vegetative Stage	Upper Limit	Tolerance Rating	Palatability
Grass					
Nuttall's alkaligrass	8	14	32	Very high	Medium
Inland saltgrass	12	16	32	Very high	Medium
Alkali sacaton	10	32	32	Very high	Medium
Beardless wildrye	8	13	26	Very high	Medium
Tall wheatgrass		13	26	Very high	Low
Green wheatgrass (Newhy)	32	13	26	Very high	High
Russian wildrye		13	24	Very high	Medium
Alkali cordgrass		12	24	Very high	–
Prairie cordgrass		10	15	Moderate	Low
Alkali bluegrass		12	24	Very high	–
Slender wheatgrass	16	10	22	Very high	Medium
Altai wildrye		10	20	Very high	Medium
Plains bluegrass		10	20	Very high	Medium
Tall fescue		8	18	High	Medium
Western wheatgrass	24	8	16	High	High
Crested wheatgrass		6	14	Moderate	High
Intermediate wheatgrass		6	12	Moderate	High
Little bluestem	6	6	10	Moderate	Medium
Smooth brome		5	10	Moderate	Highest
Meadow brome		4	10	Moderate	Highest
Switchgrass	16	–	6	Low	Medium
Blue grama	4	4	6	Low	Highest
Forbs and Shrubs					
Forage kochia		10	18+	High	Medium
Fourwing saltbush		10	18+	High	Medium
Winterfat		10	18+	High	High
Strawberry clover		6	16	High	Highest
Yellow sweetclover		5	10	Moderate	High
Cicer milkvetch		4	10	Moderate	Highest
Birdsfoot trefoil		5	8	Low	High
Alfalfa		4	8	Low	Highest
Clovers (red, alsike, ladino)		3	4	Low	Highest

[1] Source: Ogle and St. John (2009).
[2] Source: Thomlinson, H. (2016).
[3] Source: Green et al. 2020
[4] Source: Wallace 2019

Citations

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For more information on this and other topics, see www.ag.ndsu.edu

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