ENABLING ZERO FRESH WATER WITHDRAWAL IN SHALE GAS OPERATIONS

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GOAL OF ZERO DISCHARGE AND ZERO WITHDRAWALS

REQUIRES

- Salt Tolerance
  - Allows easier re-use of flowback water
  - Allows use of saline waters of convenience

- Addressing Potential Issues with High Salt
  - Scaling: can be repository for radioactive species
  - Divalent ions can retard efficacy of cross-linkers, friction reducers
  - Reservoir effects need better definition
  - More desalination may be needed than with fresh water make up

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SALINE WATERS OF CONVENIENCE

- Sea Water
  - Simplest to process
  - TDS average of 35000 ppm is already acceptable
- Saline Aquifers
  - Target shallow ones preferably for easy access and lower salinity
  - USGS has not mapped since middle of last century
  - Available maps show presence in many shale gas areas
  - Withdrawal could affect hydrology of proximal fresh bodies
- Produced Water
  - Potentially the most challenging
  - But use offsets need to dispose of

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OPERATIONAL CHEMISTRY CONSIDERATIONS

- TDS Tolerance
  - 40000 ppm tolerated today, soon 80000, maybe higher
  - Beneficial for clay component of shale
  - Optimal: balancing with connate water?
- Divalent Ion removal
  - Standard softening methods
  - Cost versus tolerance
- Other Species Needing Removal
  - Bacteria: how prevalent in saline aquifers?
  - Flowback water will need to be treated anyway
  - Radioactive elements if any
  - Other?

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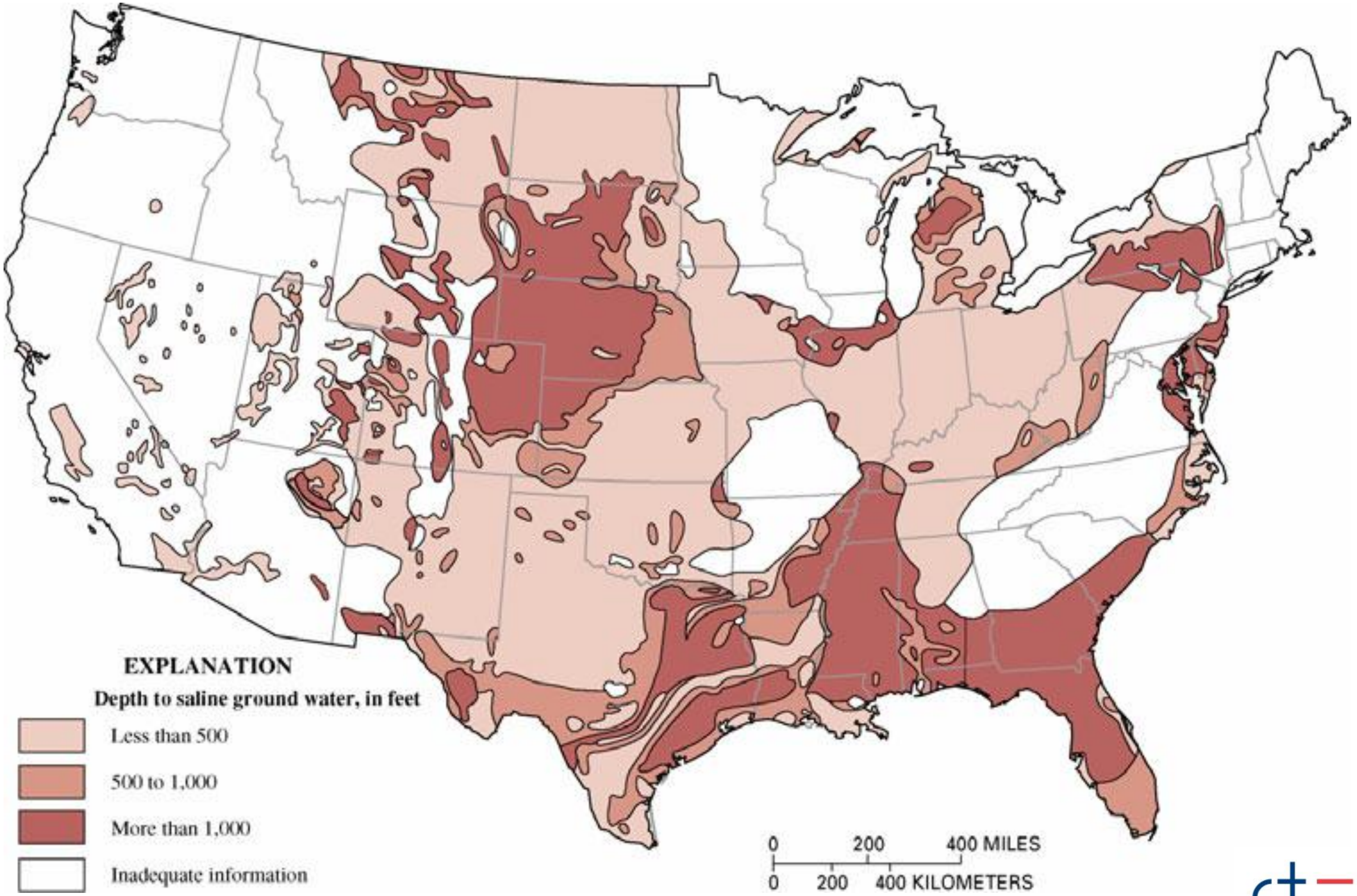

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TYPICAL MARCELLUS SALT LEVELS (ppm)

	Total Dissolved Solid	Mg	Ca
Average	**47,364**	**175**	**1750**
Range	**16,000 – 220,000**	**10-927**	**400-8600**

Source: Blauch et al SPE Paper 125740, 2009

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SALINE AQUIFER CONSIDERATIONS

- Needs Investigation
  - Location by depth and salinity
  - Chemical characterization
- Access
  - For withdrawal
  - For return of desalination waste heavy brine
  - Typical distances for transport
- Bacterial Content
  - One report: terrestrial bacteria present in three locations

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DISCUSSION

- Salt Tolerance: practical upper limits
  - divalent ions: removal versus tolerance
  - if tolerated how do we handle scaling
  - full implications of salt tolerance
- Saline Aquifer Access
  - practicalities: depth, distance, chemistry
  - if feasible: USGS should produce new map
- Produced Water Use Issues

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Enabling Fracturing Operations with Zero Fresh Water Withdrawals

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The statements made during the workshop do not represent the views or opinions of EPA. The claims made by participants have not been verified or endorsed by EPA.

Abstract

Water withdrawals represent an issue in some parts of the country where shale gas operations are active. Attempts to use surface water instead of ground water, and in some cases gray water, are worthwhile and should be pursued. However, the industry should be challenged to do without these. Industry has already responded to the challenge of recycling flowback water by becoming more salt tolerant. The ability to use saline waters of convenience should be seriously investigated. The primary candidates are sea water, saline aquifer water and produced water. Removal of some constituents such as solids, divalent ions and bacteria will likely be necessary.

Principal Issues

Of the water issues facing shale gas operations, the two demanding the greatest attention are fresh water withdrawals and discharges of contaminated water. The latter can largely be addressed through re-use of flowback water, albeit with some treatment. But shale gas formations are such that only about a quarter to a third of the fracturing fluid returns. This causes a need for makeup water. The gel frac operations of the early Barnett are in the past except in some instances such as the Haynesville. These days most operations run slick that is with less than half of one percent of chemicals. This causes the volumes to go up, and up to 5 million gallons are used per well. Consequently, makeup water will run up to 3.5 million gallons.

To date makeup water has been sourced from ground water primarily, but also surface water. Schemes to use other sources with low utility, such as gray water, are also being executed. We suggest here a discourse on the proposition that all makeup water comprise produced water, saline aquifer water or sea water, whichever of these are the saline waters of convenience.

Handling Salinity

Fracturing operations have become increasing salt tolerant. To some degree, this has been driven by the need to re-use flowback water with a minimum of processing, but once the industry approached the problem, it became obvious that in many instances the salinity had advantages. In the ternary diagram of carbonate, silica and clay, the preferred compositions are those with a higher proportion of the first two constituents. Nevertheless, there is enough clay to cause water absorption and swelling. This can be minimized at higher salinities. So a measure of salinity is actually a net benefit. In the limit one may want to match the salinity of the connate water in order to create a chemical potential balance.

Even if salinity is tolerable to about 80,000 ppm TDS, we know that flowback water can exceed that number. Table 2 shows some data for the Marcellus. In this particular study TDS topped out at around 220,000 ppm, but instances of 350,000 ppm are not completely uncommon in the Marcellus.

Table 2. Typical Marcellus Salt Levels (ppm). Source: Blauch et al. SPE Paper 125740, 2009

	Total Dissolved Solids (ppm)	**Mg (ppm)**	**Ca (ppm)**
Average	47,364	175	1750
Range	16,000 – 220,000	10-927	400-8600

It is possible that these are due to evaporite sequences or from accidentally allowing fractures to penetrate the highly saline Onandaga below the reservoirs. Assuming these are unavoidable in the main, one must be prepared to handle high numbers. This means that some level of desalination may be necessary although clearly not the levels dictated by the old paradigm of fresh water as base fluid. All desalination methods leave a residue that needs disposal, and in the case of reverse osmosis, the residue from sea water desalination has TDS of around 75,000 ppm. This may be usable, but in general one needs to be prepared to dispose of these residues. An option would be the saline aquifers, even if they were the source of water. Regulations allowing this would need to be studied. Produced water is currently being reinjected in some locations. This would not be that different.

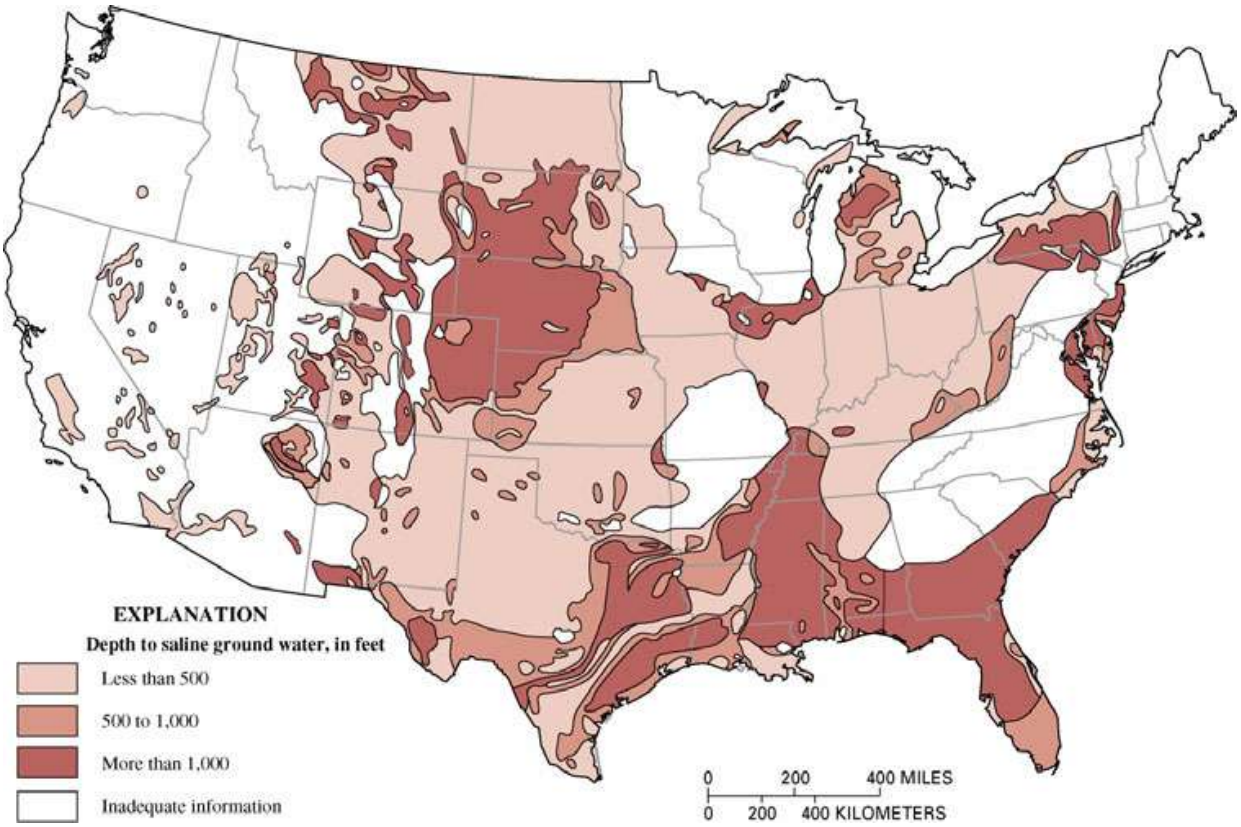
Saline Aquifers

Since ground water tends to get saltier with depth, one can reasonably assume that saline aquifers are ubiquitous. Deep saline aquifers have been studied as repositories for captured carbon dioxide, and the Frio is the largest in the country. The last map was published around 1960 and one assumes the lack of updating is due to not enough importance being attached to these water bodies. (Figure 13 shows the available map of saline aquifers in the US.) Even this map demonstrates the existence of such water over much of the shale production areas. It also shows the depths to be low to moderate. This likely equates to modest salinity, which is good for hydraulic fracturing. The actual figures are almost certainly available in many instances. If the viability of use of this sort of water is confirmed, a mapping of location and composition would be of value.

Divalent Ions

Divalent ions, in particular Mg and Ca, cause issues with some the ingredients of fracturing fluid. The affected chemicals include surfactants, breakers and friction reducers. All of this can be traversed through substitution. The worst actor is likely the formation of scale. In of itself it can be deleterious, but the propensity of scale to concentrate the very low concentration of radioactive elements sometimes present is a concern. Absent scaling, the divalent ions would

Figure 13. Saline Aquifers in the US



likely be returned to the formation through reuse of the flowback water therefore removal of these species is probably for the best. Technology for removal of divalent ions is very straightforward but the practicality of doing so at every site may be daunting. One fairly recent trend that could increase the use of treatment technology is the practice of pad drilling, which involves drilling up to 20 wells from a single location. This allows for aggregation of facilities of all types and has other environmental benefits.

Bacteria

Bacteria are known to be bad actors in reservoirs because they cause the formation of various undesirables such as sulfates that plug pores and cause the formation of H_2S. Therefore, any frac fluid must be free of bacteria. The bacterial content of saline aquifers is not known systematically. A 1975 study (Willis, et al., 1975) determined that three shallow unpolluted saline aquifers in the southeast contained various species, mostly anaerobic. Methanogenic bacteria were also found in each case. One can reasonably expect that biocidal treatment will be necessary.

Discussion

The workshop participants should debate the advisability of using saline waters of convenience as makeup water. Saline aquifers are likely the most viable targets. These would need to be more completely mapped for the benefit of the industry. Economic considerations would include the levels of processing required and the practicality of moving this water over distances.

Reference

Willis, CJ, GH Elkan, E Horvath, and KR Dail. 1975. Bacterial flora of saline aquifers. *Ground Water* 13(5): 406-409.