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Delineating and Assessing Saline Groundwater Resources in the Southern Midcontinent

By

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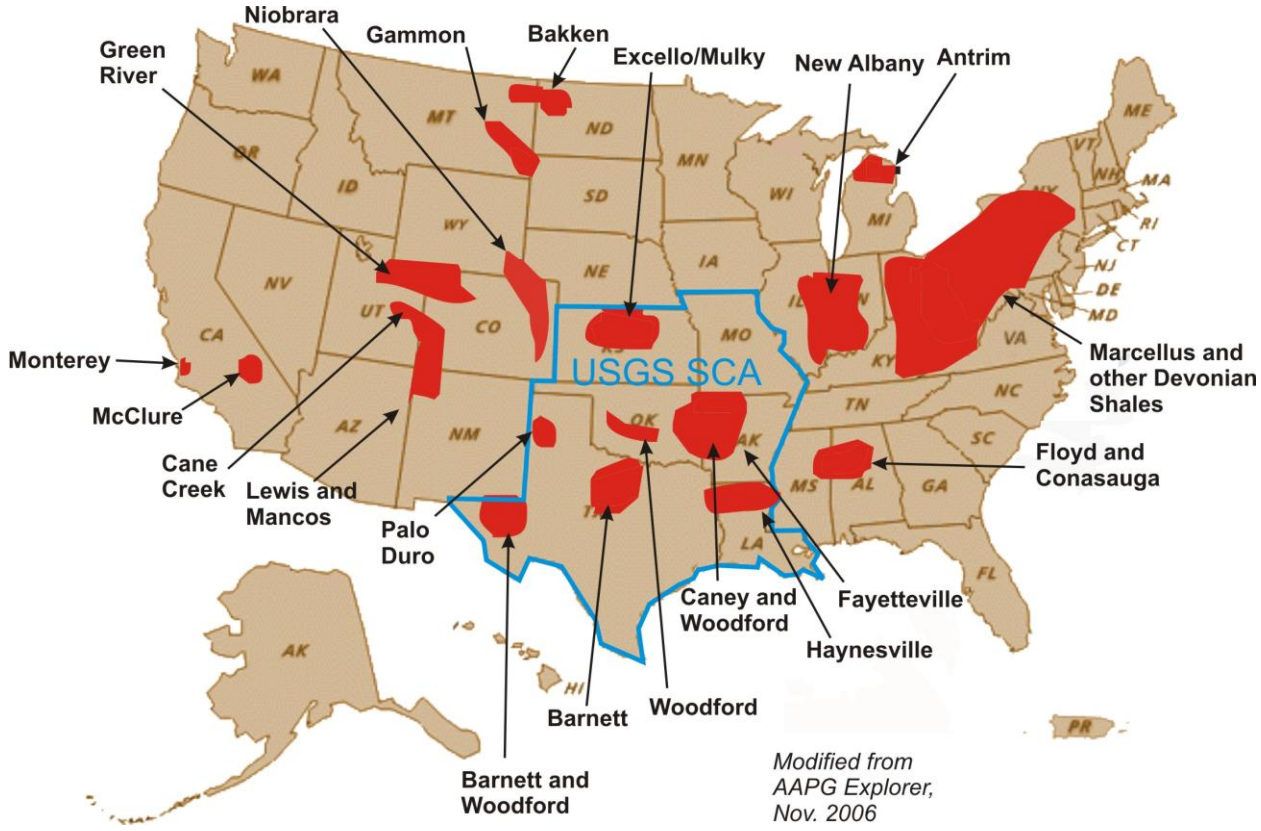

Shale-Gas Basins of the United States
that may require a source of saline water for completion and development purposes

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Summary

Saline groundwater occurs at depth in most sedimentary basins of the world. Saline groundwater is located between the base of fresh water (at 1000 TDS) and above brine (at 35,000 TDS). To date, the spatial distribution of this resource has not been fully delineated. The USGS proposes to conduct a pilot study in the southern midcontinent of the U.S. for the purpose of delineating and assessing saline groundwater resources. The major product will be a 1:250,000 scale map that can be used to delineate, assess, and characterize saline aquifers. The map will be of value to managers and scientists concerned with planning for future water-resource needs, including groundwater for commercial use (including energy development) and desalinization of water for consumptive and recreational uses. The tools and methods that emerge from this work will be exportable to other parts of the United States where delineation and assessment of saline water is important to economic development and sustainability.

Background and Problem

Saline groundwater is an undeveloped resource that is present in the subsurface of most sedimentary basins of the world. According to Alley (2003), speaking in reference to the United States in particular, *"little is known about the hydrogeology of the parts of most aquifers that contain saline water compared to the parts that contain freshwater, because the need to utilize saline groundwater has been limited."* In response to the growing interest in use of saline-water resources by both public and private sectors, the USGS Oklahoma Water Science Center (OK-WSC) proposes a pilot study to identify and assess saline groundwater resources in the southern midcontinent of the U.S. The use of saline groundwater in lieu of freshwater would minimize the impact on water sources commonly used for drinking, commerce, and recreation. The proposed study is aligned with the SECURE Water Act and the USGS Science Strategy (Ayers and others, 2007): 1) water census, 2) climate change, and 3) energy development

Objective and Scope

The objective of the proposed study is to develop a map for the purpose of delineating and assessing the spatial distribution of saline groundwater resources in the southern midcontinent of the U.S. The study location in the southern midcontinent includes Arkansas, Louisiana, Texas, Oklahoma, Kansas, and Missouri. The targeted water is located in the subsurface between the base of fresh water and above the occurrence of brine. This groundwater is classified as "slightly-to-very saline" water according to the classification of Robinove (1958) (Table 1). The study will be conducted in four stages, each of which has specific objectives, tasks, and interim products.

Class	Total Dissolved Solids (Milligrams per liter)
Fresh	0 - 1,000
Slightly Saline	1,000 - 3,000
Moderately Saline	3,000 - 10,000
Very Saline	10,000 - 35,000
Briny	>35,000

Table 1. *Salinity classification based on TDS ranges (Robinove and others, 1958).*

Data for the initial work effort, in the form of currently existing maps that define salinity gradients or boundaries, will be identified from the literature. In many cases, these maps were constructed from borehole geophysical measurements with emphasis on spontaneous potential and electrical resistivity (figure 1). Construction of a map (1:250,000 scale), with supporting data sets and cross sections, will be undertaken by the OK-WSC in consultation with the respective WSCs in the USGS South-Central Area. The OK-WSC has already established a USGS South-Central Area gas-shale technical team to promote communication between SCA-WSCs. Pending additional funding, the scope of this proposed work could be further expanded through collaboration with the USGS Northeast and

Midwest Area WSCs (where water for gas-shale development is a major concern). The OK-WSC also has on-going collaborations with the USGS Energy Resources Programs (Eastern and Central Regions). As appropriate, cooperative agreements with other agencies will be established and industry collaborators will be aggressively pursued. We anticipate that the tools and methods that emerge from this work will be exportable to other parts of the United States for the purpose of saline-groundwater delineation and assessment.

Approach and Data Sources

Stage 1: Compile existing salinity maps (figure 2) and datasets into a geodatabase for each of the states and/or major hydrologic basins and generate a base of fresh-water map (1,000 TDS) for the southern midcontinent. Published maps currently available for this effort include Hart, 1966; Cushing, 1966; Winslow and others, 1968; Ryals, 1980; Winslow and Kister, 1956; LBG-Guyon Associates, 2003; Feth, 1965; Imes and Emmett, 1994; McFarlane and Hathaway, 1987; and USGS PP 1414. An additional data source is the USGS Produced Waters Database (Breit, 2002). Data gaps will be identified to determine the extent of new data acquisition required for subsequent stages.

Stage 2: Update map with the addition of new well-log data to areas of mapped salinity as needed and for areas that are unmapped (Kansas, Missouri, and portions of Arkansas and Texas, see figure 2). New salinity data from well logs will be collected from publically available logs. Minimum data density in unmapped areas will be 4 wells per township. Determination of data quality will be assessed during this stage through comparison of the Stage 1 map to the new data. Cross sections will be constructed to provide insight to locations of elevated salinity relative to stratigraphy.

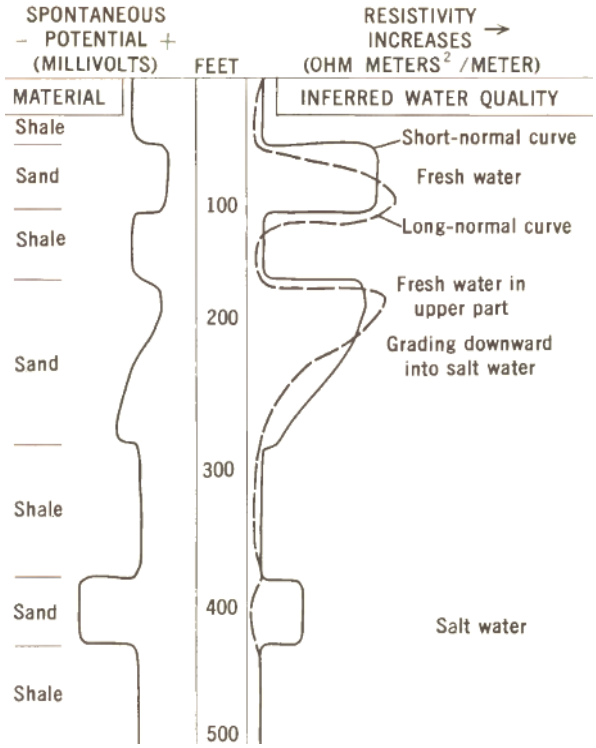

Figure 1. *Example well-log interpretation technique used to identify the base of fresh water and the transition to briny formation water (from Hart, 1966).*

Another task initiated during Stage 2 will be to classify the origin of the salinity based on literature sources (e.g., proximity to bedded salt, rock-fluid interaction during meteoric recharge, connate water, etc.). Classifying the origin of salinity is important to the overall description of saline water resources on a regional basis because the origin of salinity will temper expectations about the steepness of salinity gradients observed on geophysical well logs and in the map (Richter and Kreitler, 1991). For instance, if the source of salinity is because of interbedded salt layers, the transition from fresh to saline water on the map is expected to be abrupt. If instead, the salinity gradient is gradual or muted with depth, the origin of the salinity may be related to progressive interaction of meteoric water with the aquifer in the area of recharge. In some cases, sources of salinity may be human-induced. Comparison of salinity gradients on the map with proposed sources of salinity cited in the literature will assist in early-stage quality control of the map.

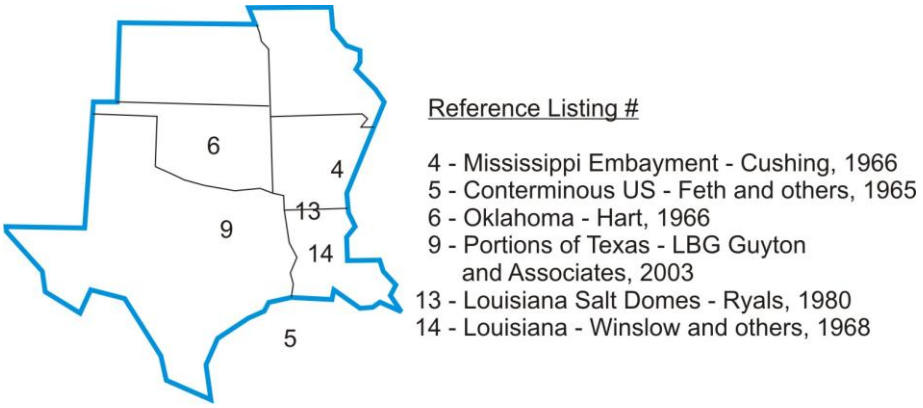

Figure 2. Inventory of *existing salinity maps for the USGS South-Central Area keyed to reference list. To our knowledge, salinity maps are unavailable for Kansas, Missouri, northwestern Arkansas, and portions of Texas.*

Stage 3: Estimate volume of saline water: define the mapped depth to the base of freshwater (at 1,000 TDS) and depth to top of brine (at 35,000 TDS) through projection and interpolation of the current map and supporting map data. Borehole geophysical logs, along with existing groundwater-quality data will be used to define the depth to the base of freshwater and depth to the top of brine. The cross sections developed during Stage 2 will be updated during Stage 3. The stratigraphic origin of salinity classification initiated in Stage 2 should be updated to honor the salinity gradients that emerge from the geophysical well logs and observations about the mapped-based salinity gradients.

Stage 4: Through vertical data integration (GIS), mapped patterns of salinity in the subsurface should be resolvable (and quantifiable) through evaluation of the interactions among various factors, including precipitation, topography, regional geology, properties of the rocks (mineral composition and intrinsic permeability), and distribution of shallow oil and gas fields. The cross sections will be further updated based on refinements provided by addition of topography and bedrock geology to the mapping exercise. During Stage 4, the classification of the origin of the salinity will be reviewed and revised as appropriate. Resolving the appearance of the mapped patterns of salinity relative to the above factors is important to evaluating the accuracy and quality of the map and cross sections (figure 2). The amount of field checking and data QA/QC required will depend on the degree of correspondence between the distribution of saline water and these factors.

The thickness of aquifer containing saline water will be the difference between the top of brine and the base of freshwater at any given location. Spatially, once adjusted for aquifer properties, these map data can be converted to saline water volumes in the subsurface.

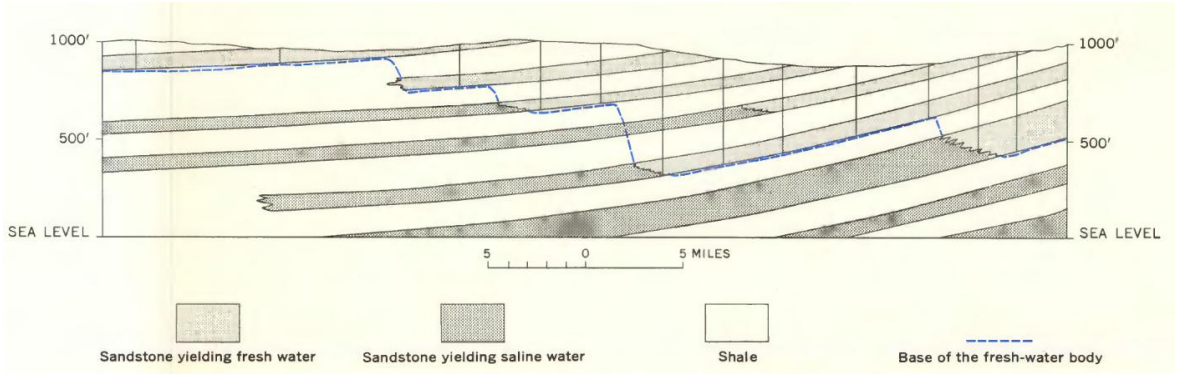

Figure 3. *Hypothetical cross section showing the depth to base of fresh water in Oklahoma (blue line). The depth to base of fresh water varies with stratigraphy, dip of the beds, and permeability of the formations. The saline-water zone occurs at and immediately below the blue line (from Hart, 1966).*

Products

The products for Stages 1-4 will include a map (1:250,000 scale), cross sections, geodatabase with supporting datasets, and reports that focus on subsurface salinity distribution and the factors that control the distribution. Stage 1 interim products will include an edge-joined (GIS merged) map to the base of fresh water constructed from currently existing salinity maps which will result in one map for the southern midcontinent (Louisiana, parts of Texas, Oklahoma, and parts of Arkansas combined). Activities during Stage 2 will include infilling of data gaps with published salinity data sets and the addition of new salinity data interpreted from subsurface well logs. Because of a lack of mapped salinity coverage (partial or total) for some of the states, special attention during Stage 2 will be given to Kansas, Missouri, and parts of Texas and Arkansas. Stage 2 activities will result in improvements to the Stage 1 base of fresh-water map. Stage 3 products will include the mapped definition of the top and base of saline water (base of fresh water and top of brine). The Stage 4 final product will place the salinity map in the context of topography, precipitation, and bedrock geology (a vertically integrated GIS product). Saline-water volumes will be summarized in tabular format subdivided by stratigraphy.

Depending on the significance of the scientific findings, interim reports will be prepared during Stages 2-4 to document the quantitative comparisons of the salinity map to 1) precipitation, 2) topography, 3) rock types, and 4) regional geology. A Scientific Investigations Report will document the findings.

Personnel Requirements, Synergies, and Collaborations

This project requires a broad range of skills; groundwater hydrology, sedimentary geology and stratigraphy, aqueous geochemistry and mineralogy, borehole geophysics (analysis and interpretation), and GIS (spatial analysis) techniques. OK-WSC personnel have that range of skills required to conduct this research. GS levels will range from GS-5 to GS-13 depending on the skills and competencies required.

A strong potential exists for supplementing the USGS study budget with funding from entities that are interested in use of saline groundwater for development of shale-gas resources. Currently, the southern midcontinent (USGS South-Central Area) and north-central Appalachian (USGS Northeast and Midwest Areas) basins are the most active locations in the United States for this emerging energy play. In addition, the OK-WSC is currently working closely with the USGS Energy Resources Program (Geology Discipline) to develop a salinity map for the Anadarko basin of Oklahoma based on the USGS Produced Waters Database (Breit, 2002).

Quality Assurance

During Stages 2-4, the map compilation and data sets will be quality assured and some well log salinities verified in order to increase accuracy and precision. In addition, qualitative accuracy of the map will be assessed through comparison of the mapped patterns of salinity to factors such as precipitation, topography, regional geology, rock properties, and sources of salinity. The mapped patterns of salinity should correspond to these external factors.

Workplan Timeline and Budget

Tasks	Federal Fiscal Year											
	2010				2011				2012			
	1	2	3	4	1	2	3	4	1	2	3	4
Literature search												
Compile extant maps, datasets												
Compile geospatial data												
Merge geospatial data												
- Interpolate contours												
- Generate edge-joined map												
- Identify data gaps												
Integrate USGS Produced Waters Database												
Infill data as needed												
Evaluate data integrity (QA/QC)												
Identify sources of salinity												
Prepare vertically integrated map												
- Salinity												
- Topography												
- Precipitation												
- Bed rock / fractures / faults												
Write metadata for GIS layers												
Write reports to accompany map												
Review map / reports												
Publish map / reports												
Stages	1		2		3		4		Complete Documentation			

Fiscal Year	USGS	Collaborators	Total
2010	$100,000	-	-
2011	$100,000	-	-
2012	$100,000	-	-
TOTAL	$300,000	-	-

References

1. Alley, W.M., 2003, Desalination of groundwater: Earth science perspectives, U.S. Geological Survey Fact Sheet 075-03, 4 p.
2. Ayers, M.A., Baron, J.S., Beauchemin, P.R., Gallagher, K.T., Goldhaber, M.B., Hutchinson, J.W., LaBaugh, J.W., Sayer, R., Schwarzbach, S.E., Schweig, E.S., Thormodsgard, J., van Riper, C. III, and Wilde, W., 2007, Facing tomorrow's challenges, U.S. Geological Survey Science in the Decade 2007-2017, U.S. Geological Survey Circular 1309, 67 p.
3. Breit, G.M., 2002, USGS Produced Waters Database: http://energy.cr.usgs.gov/prov/prodwat/index.htm
4. Cushing, E.M., 1966, Map showing altitude of the base of fresh water in coastal plain aquifers of the Mississippi Embayment, U.S. Geological Survey Hydrologic Investigation Atlas HA-221.
5. Feth, J.H., and others, 1965, Preliminary map of the conterminous United States showing depth to and quality of shallowest groundwater containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Investigations Atlas HA-199.
6. Hart, D.L., 1966, Base of fresh water in southern Oklahoma, U.S. Geological Survey Hydrologic Investigation Atlas HA-223.
7. Imes, J.L.; Emmett, L.F., 1994, Geohydrology of the Ozark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas, U.S. Geological Survey Professional Paper 1414-D, 127 p.
8. Krieger, R.A., Hatchett, J.L., and Poole, J.L., 1957, Preliminary survey of the saline-resources of the United States: U.S. Geological Survey Water-Supply Paper 1374, 172 p.
9. LBG-Guyton Associates (in association with NRS Consulting Engineering), 2003, Brackish groundwater manual for Texas regional water planning groups (prepared for: Texas Water Development Board), 199 p.
10. Macfarlane, P.A., and Hathaway, L.R., 1987, The hydrogeology and chemical quality of groundwaters from the lower Paleozoic aquifers in the Tri-State region of Kansas, Missouri, and Oklahoma: Kansas Geological Survey Ground Water Series 9, 37 p.
11. Richter, B.C. and Kreitler, C.W., 1991, Identification of sources of groundwater salinization using geochemical techniques, Cooperative Agreement No. CR-815748, U.S. Environmental Protection Agency, Ada, Oklahoma, 259 p.
12. Robinove, C.J., Langford, R.H., and Brookhart, J.W., 1958, Saline-water resources of North Dakota, U.S. Geological Survey Water-Supply Paper 1428, 72 p.
13. Ryals, G.N. 1980, Base of fresh groundwater, northern Louisiana salt dome basin and vicinity, northern Louisiana and southern Arkansas, U.S. Geological Survey Open-File Report 80-2038
14. Winslow, A.G., Hillier, D.E., and Turcan, Jr., A.N., 1968, Saline groundwater in Louisiana, U.S. Geological Survey Hydrologic Investigation Atlas HA-310.
15. Winslow, A.G., and Kister, L.R., 1956, Saline-water resources of Texas: U.S. Geological Survey Water-Supply Paper 1365, 105 p.