Saline Water Aquifer Mapping Project in the Southeastern United States

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Background: The principal source of municipal, industrial, and agricultural water supply in the southeastern United States is the Floridan Aquifer System. Over 3.6 billion gallons of water are withdrawn daily (Maupin and Barber, 2005) and, this entire amount is drawn from freshwater portions of the aquifer system. A variety of problems have developed over the years principally as a result of declining water levels, saltwater intrusion in coastal areas, and insufficient supplies in local areas. To meet the growing demand in this region, alternative sources of water must be assessed. Previous studies have identified saline aquifers within carbonate rocks that comprise the Floridan aquifer system (Miller, 1986) and in the underlying deeply buried clastic sedimentary rocks of the Southeastern Coastal Plain aquifer system (Renken, 1996) (fig. 1).

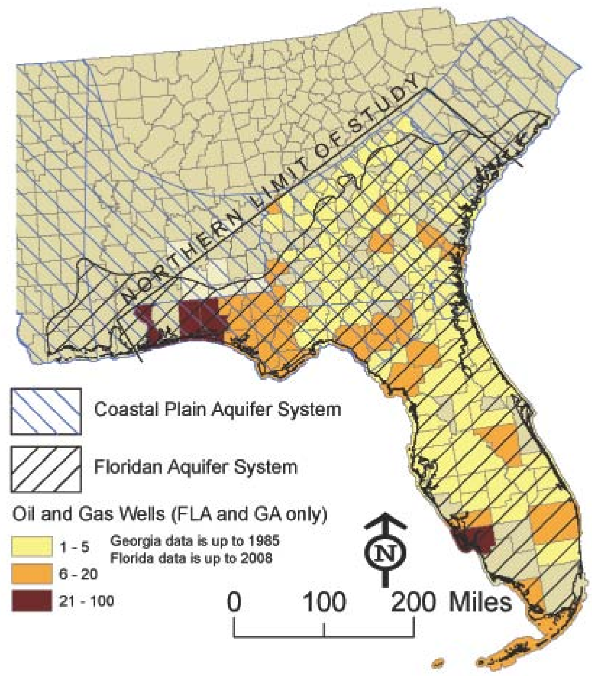

Figure 1. Saline Water Aquifer Mapping Study Area

Objectives: The objective of the proposed study is to improve the overall understanding of the available saline water resources for potential future development. Specific tasks are to:

1. Develop a digital georeferenced database of borehole geophysical data to enable analysis for characterization of saline aquifers
2. Identify and map the regional extent of saline aquifer systems and to describe the thickness and character of hydrologic units that comprise these systems.
3. Delineate salinity variations at key well sites and along section lines to provide a regional depiction of the fresh and saltwater interfaces.

Collaboration: There are several ongoing projects that would benefit from results of the proposed study. The Groundwater Resource Program's evaluation of the groundwater availability of the Floridan aquifer system could use information compiled as part of the proposed study to refine the hydrogeologic framework and develop freshwater/saline water interface maps for detailed groundwater modeling studies. The Department of Energy geologic carbon sequestration program could use information compiled by the proposed study to help assess potential for injection into saline aquifers.

Approach: The Saline Water Aquifer Mapping Project for the southeastern United States will be a 3-year effort beginning in 2010. The study area, as outlined in fig. 1, includes all of Florida, and parts of Alabama, Georgia, and South Carolina. This area was selected to compliment the USGS's study of ground-water availability of the Floridan Aquifer System. A tentative schedule of project tasks is presented on table 1.

The largest part of this effort will be to compile and analyze existing borehole geophysical logs (collected primarily from oil and gas exploration test wells) into a regional framework of saline water resources. In

Georgia and Florida alone there are an estimated 1,200 oil and gas test wells that penetrate potential saline water aquifers (fig. 1). Only a selected number of these would be used for analysis as described below. Paper copies of geophysical logs can be readily obtained from the files of the state surveys and/or from the files of various USGS offices. None of these logs, to our knowledge, have been digitized nor has any systematic assessment of borehole geophysical log data been made for the purpose of mapping saline water resources.

Table 1. Schedule of project tasks by Year.

	2010		2011	2012	
Data acquisition and database development	Assembly of borehole geophysical logs and data	Water quality data compilation	Add logs to USGS systems and build GIS projects		
Scanning/Digitizing and Well Log Analysis	Scanning --> georeferencing --> cataloging --> digitizing --> and log data and cleanup		Log analysis --> correlation --> geohydrologic cross sections	Data verification review	
Data Analysis and Interpretation		Log analysis method development	Regional correlation --> integrate previous studies/data into framework	Final report preparation	Peer reviews and interpretation adjustment
Report Preparation		Conference papers	Methods documentation, journal articles, open-file reports		Final report

Geophysical logs will be compiled using a process similar to that used in the Mississippi Embayment Regional Aquifer Study. In that study approximately 2,700 geophysical logs were processed to construct a framework of the subsurface. In this proposed study, although fewer logs are available, a broader suite logging parameters will need to be compiled for the analysis. The process includes scanning, georeferencing, cataloging, interpreting, and digitizing logs. Since the success of the study will be contingent on the quality and types of the logs available it will be important to assess the quality of the logs and make a determination which logs can be used in the evaluations, both quantitatively and qualitatively. Only the best logs suited for the study will be selected for analysis.

Formation water salinity will be calculated by using either spontaneous potential logs (SP), as previously used to map the freshwater-saltwater interface in the southeastern Coastal Plain Aquifer System by Strickland and Mahon (1986), or by using a variety of methods and techniques that utilize resistivity logs. The SP method is appropriate for the deep saline aquifers in the Coastal Plain Aquifer System but will not work for the carbonate rocks that comprise the Floridan aquifer system because of the lack of SP log response. Also, many of the conditions required to use the SP method are not satisfied in most freshwater wells (Keys, 1990), so this will need to be taken into account when evaluating aquifers with salinities between 1,000 and 10,000 mg/L of total dissolved solids .

Resistivity logs (long- and short normal, medium and deep induction) are widely used in the oil and gas industry for determination of formation water quality and will be extensively used in this study. All of these devices measure apparent resistivity which must be converted into true resistivity taking into account a number of factors including the resistivity of the invaded zone, diameter of the invaded zone, mud resistivity, borehole diameter, bed thickness and the AM spacing. The resistivity measured with resistivity logs is a function of both the resistivity of the rock and resistivity of the water in the pore spaces, which can be expressed as $F = \frac{R_0}{R_w}$ where F = formation factor, Ro = resistivity of the rock at 100 percent water saturation and Rw = resistivity of the formation fluid. A well known empirical relation between the formation factor (F) and porosity is known as the Archie equation (Archie, 1942):

$$F = \frac{a}{\emptyset^m}$$

Where
F = the formation factor
a = a constant determined empirically to compensate for variations in compaction and pore structure; usually falls between 0.6 and 1.0
ø = porosity
m = the cementation factor

All calculations of water quality using resistivity logs use some form of the Archie equation. Since the cementation factor is an exponent in the above equation, it is critical that this value be determined as accurately as possible. Fortunately, the cementation factor can be determined by using resistivity-porosity cross plots. The logs needed to make these plots include a resistivity log (either a long- or short-normal resistivity or induction) and a porosity log (density, neutron, or sonic velocity).

At the time of writing this proposal it is uncertain as to how effective the cross-plotting methods will be in the various rock types across the study area. Numerous variables must be considered. It is likely that as the study progresses new algorithms and field relations will be developed for various parts of the study area and for different formations. Turcan (1966) used water quality data (mostly from drill-stem tests) to empirically derive field formation factors for local formations. A similar field approach could be used in this study. Regardless of what methods are ultimately used or developed, all of these techniques will be carefully documented so they can be utilized in other areas with similar geologic conditions.

Although this study will focus on compiling data from oil and gas wells, data collected through the USGS Southeastern Logging Program will probably provide a better suite of logs to evaluate salinity in the shallower freshwater aquifers. A typical suite of logs from that program included caliper, SP, long- and short-normal resistivity, and three different types of porosity logs (density, neutron, and acoustic velocity). This suite of logs is particularly effective in delineating lithology and permeability variations in carbonate sections of the Floridan aquifer system. Numerous other logging techniques, such as acoustic and optical televiewer and flowmeter logging have also been applied in more recent studies throughout the region. All of this data will be useful for this study.

Water samples collected from deep wells and test holes will be critical for salinity determinations where the quality of the well logs is poor or not available. A small subset of the water quality data will come from deep oil test wells (drill-stem tests) and from samples collected during construction of deep well waste-injection systems. For example, data collected during injection tests in Pinellas County, Florida (Hickey, 1982), gives valuable information on the aquifer properties and formation water quality at that location. Numerous such studies have been conducted by all of the water-management districts in Florida. Deep water samples have also been collected to investigate areas of problematic salt-water intrusion. In Brunswick Georgia, for example, a 2,727 foot deep test well was drilled on Colonels Island by the USGS to investigate the hydrogeology and geochemistry of the Floridan aquifer system in that area (Jones and others, 2002). A full suite of borehole geophysical logs and water quality data is available for detailed analysis at this location. Similar studies have been conducted throughout the region and much of this data is readily available from NWIS.

A key part of the approach will be to use computer-based log analysis to obtain rock and formation water properties wherever possible. For example, the resistivity-porosity cross plotting techniques described above could easily be applied to the deep test hole at Colonels Island Georgia (Jones and others, 2002). Conducting this type of analysis manually is time consuming. Development of algorithms and scripts to automate this process will be necessary. All of the data and resulting log analysis will be managed through the USGS Log Archive System, also known as Log Archiver (Williams and Palamakula, 2007). A generalized workflow that could be used is shown in fig. 2. During log analysis all of the steps and calculations will be documented and stored along with the original well-log data files.

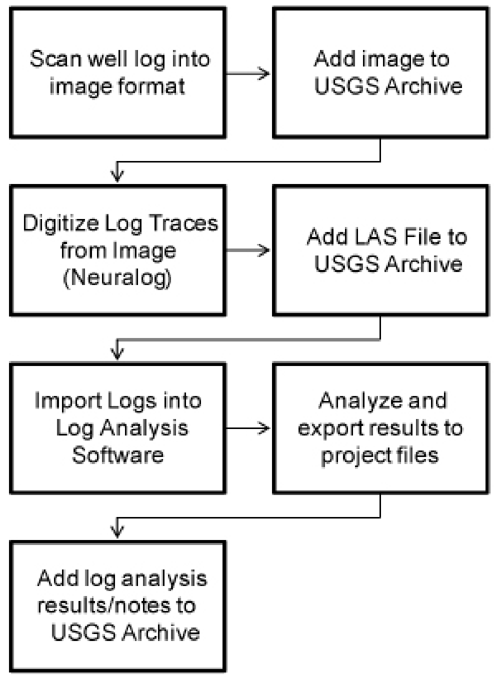

Figure 2. Well Log Data Management Workflow

Products: The primary products for this study will include maps, geohydrologic cross-sections, and reports. A methods paper is anticipated to be written during the second year of this study in order to document log analysis techniques (fig. 2). A final report will be produced containing geophysical log data and quantitative/qualitative analysis of borehole geophysical logs for estimation of ground-water salinity. In addition, digitized and attributed geophysical log data would be added to the USGS log archives for easy retrieval by other investigators.

Budget: We are requesting the maximum funding possible for the 3-year study. If this amount is not available, then the number of logs being evaluated or the area being studied can be decreased. The proposed budget of $100,000 per year is based on our best estimates of the labor necessary to scan/digitize and analyze 250 to 300 logs into a regional framework. As shown on table 1, during the first year most of the funding would be used for scanning and digitizing well logs and data acquisition activities (i.e. visiting state surveys). During the second year, the bulk of the funding would be used for log analysis and interpretive work. During the last year of the study the funding would be used for data verification, peer reviews, and final report preparation. The budget details are shown below in table 2.

Table 2. Project Budget By Task and Year

	YEAR		
Task	**2010**	**2011**	**2012**
Data acquisition and database development	$34,823	$7,842	$10,000
Scanning/Digitizing and Well Log Analysis	$47,766	$31,369	$0
Data Analysis, Interpretation, Reports	$17,411	$60,789	$90,000
Total:	$100,000	$100,000	$100,000

Personnel: USGS personnel from 4 separate offices have been tentatively selected to work on the project team. A list of the primary project duties of these individuals is listed in table 3.

References:

Table 3. Tentatively Identified Project Personnel and Primary Duties.

Personnel	Duties
Williams, Lester J.	Team leader: Establish procedures for log analysis; regional interpretation; oversee log analysis calculations; prepare reports (GWSC)
GS 03/01	Scanning and digitizing logs (GWSC)
GS 05/01	Perform log analysis, assist in report preparation (GWSC)
Dausman, Alyssa	Assist in project design; oversee water quality compilation (FISC)
Falls, William F.	Assist with hydrogeology in South Carolina (SWSC)
Dixon, Joann F.	Compile water quality data; help with database and GIS mapping (FISC)
Spechler, Rick M.	Assist with hydrogeology in Florida, and data compilation (FIWS)
Beck, Amy L.	Scanning and digitizing logs (AWSC)
Clark, Brian R.	Oversee employee(s) performing log scanning and digitizing (AWSC)

ASWC = Arkansas Water Science Center, GWSC = Georgia WSC

FISC = Florida Integrated Science Center, SWSC = South Carolina WSC

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Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p.

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