PS Establishing the Base of Underground Sources of Drinking Water (USDW) using Geophysical Logs and Chemical Reports in the Southern San Joaquin Basin, California*

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Abstract

Recent concerns about well stimulation and oilfield disposal practices has resulted in the desire to learn more about the distribution of usable groundwater that might be impacted by these practices. Waters that require protection are classified by the US EPA as USDW (Underground Sources of Drinking Water). These waters have a concentration of 10,000 parts per million total dissolved solids and are not within an exempt aquifer. Direct sampling and chemical analyses of the water from oil and gas producing formations provide the most accurate values for the formation water salinities, but the data is scarce. The method in this analysis uses open-hole geophysical logs and Archie's equation to calculate the salinity. The two methods used in the analysis are the spontaneous potential method that uses the spontaneous potential log and the mud and formation resistivities to calculate salinity, and the resistivity-porosity method that uses the resistivity and porosity logs. Sonic, density, and neutron logs are available in the southern San Joaquin as well as porosity values from cores. Results shows that the resistivity porosity method has a smaller error than the spontaneous potential method, therefore, the resistivity-porosity method is chosen for the analysis of the 10,000 parts per million boundary. Due to the lack of porosity logs in wells with chemical analyses, porosity values recorded in DOGGR reports are used in the Humble equation to link the formation water resistivity to salinity. In this way, we can back calculate the deep resistivity vales that should correspond to the 10,000 salinity boundary to determine the depth at which the base of the USDW is found.

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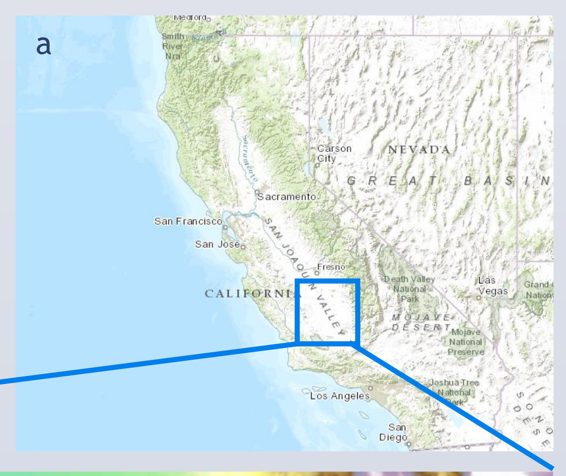
Introduction

The base of underground sources of drinking water (USDW) in the Southern San Joaquin Valley is not clearly defined. A USDW is an aquifer that is not exempt, is fewer than 10,000 parts per million (ppm) total dissolved solids (TDS), and contains sufficient groundwater for public use. The U.S. Environmental Protection Agency's Underground Injection Control (UIC) established regulations to protect aquifers that are USDW. A boundary for the 10,000 ppm TDS horizon needs to be established so the reinjection of produced brine waters will not contaminate useable water resources. Water in aquifers greater than 500 ppm TDS are not frequently used for the drinking water supply, but protecting water under 10,000 ppm TDS will protect water resources that can be made useable through treatment (Lyle, 1988).

Project Tasks

- Record formation water chemical analyses from the CA DOGGR FTP site into Excel spreadsheet.
- Gather available geophysical logs (electrical, sonic, neutron, density logs) in the southern San Joaquin Basin for the wells with chemical analyses.
- Calibrate the resistivity-porosity method by comparing calculated salinity values from the method and tested salinity values from the chemical analyses.
- Use log analysis to establish the depth to 10,000 ppm salinity formation waters.
- Map the depth to the 10,000ppm salinity boundary in the southern San Joaquin using geographical information systems software (GIS).



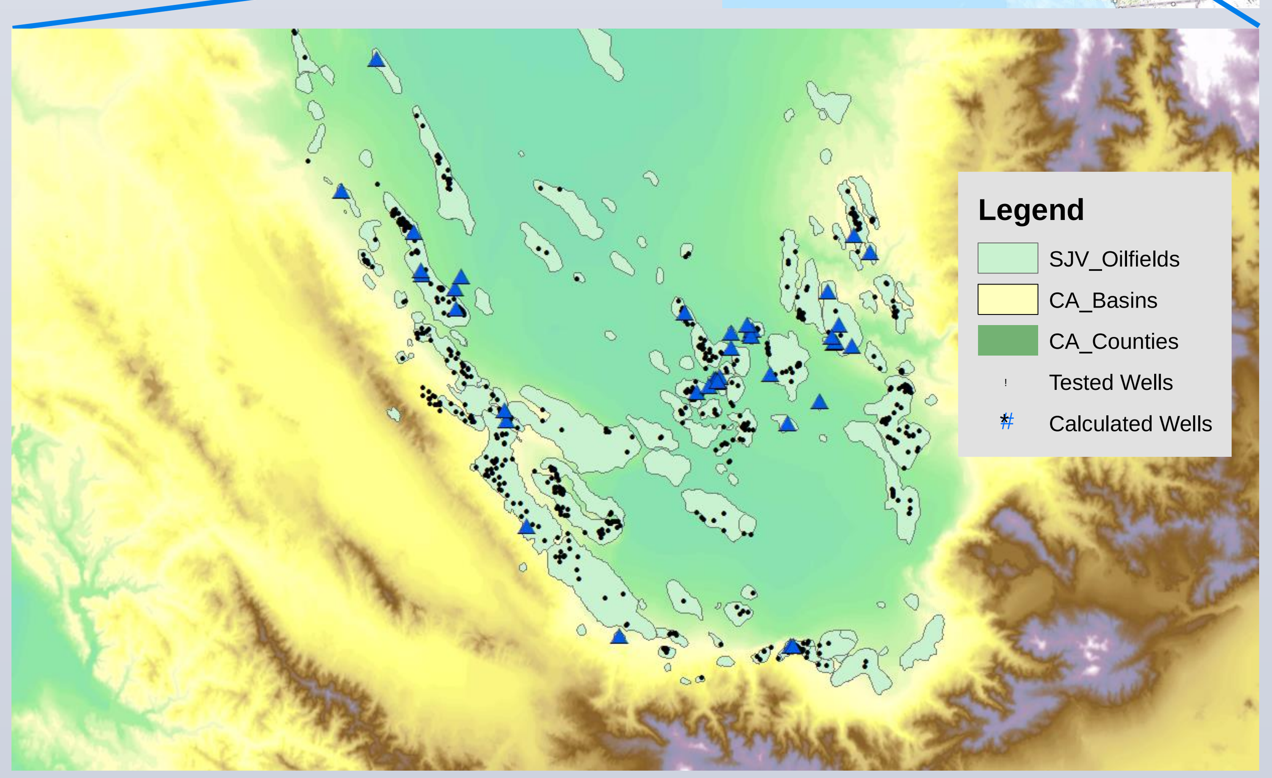


Figure 1: (CA DOGGR) The project is focused in the southern San Joaquin Basin in California (1a). Figure 1b shows the wells with chemical reports (736 total) and wells with both chemical and useful porosity data (46 total) in the represented in the study. The number of wells with both chemical tests and porosity data is much lower than the number of wells in the excel spreadsheet.

Methods

The method used in this study is the resistivity-porosity method (RP) that requires the availability of geophysical logs such as density, neutron, or sonic logs to determine the formation porosity. The resistivity values are read from 100% wet sand and the Rt value will be the Ro value (resistivity of a 100% water wet sand). This method also makes use of Archie's equation (equation 1) to determine the formation water resistivity (Rw) to estimate formation water salinity.

$$S_w = \left(\frac{a}{\varphi^m} \times \frac{R_w}{R_t}\right)^{\frac{1}{n}} \qquad \text{Equation 1}$$

In a 100% water saturated sandy formation, the water saturation (Sw) is assumed to be 1, and this eliminates the saturation exponent (n) from the right side of equation 1. Rearranging the equation by solving for Rw and moving the tortuosity constant (a), porosity (ϕ), cementation constant (m), and deep resistivity (Rt) on the same side of the equation results in equation 2. The value of Rw is corrected to formation temperature and used to relate to the formation salinity.

$$R_w = \left(\frac{\varphi^m}{a}\right) \times R_t \qquad \text{Equation 2}$$

Archie's equation is rearranged to solve for the deep resistivity (Rt) at the 10,000 ppm salinity boundary. The resistivity is corrected to formation temperature using the bottom hole temperature (BHT) recorded in the log header. The resistivity curve is examined using this calculated value to find the depth to the base of USDW. Figure 2 is an example of a well in Bellevue that has the 10,000 ppm salinity boundary at 3.5 ohm-m.

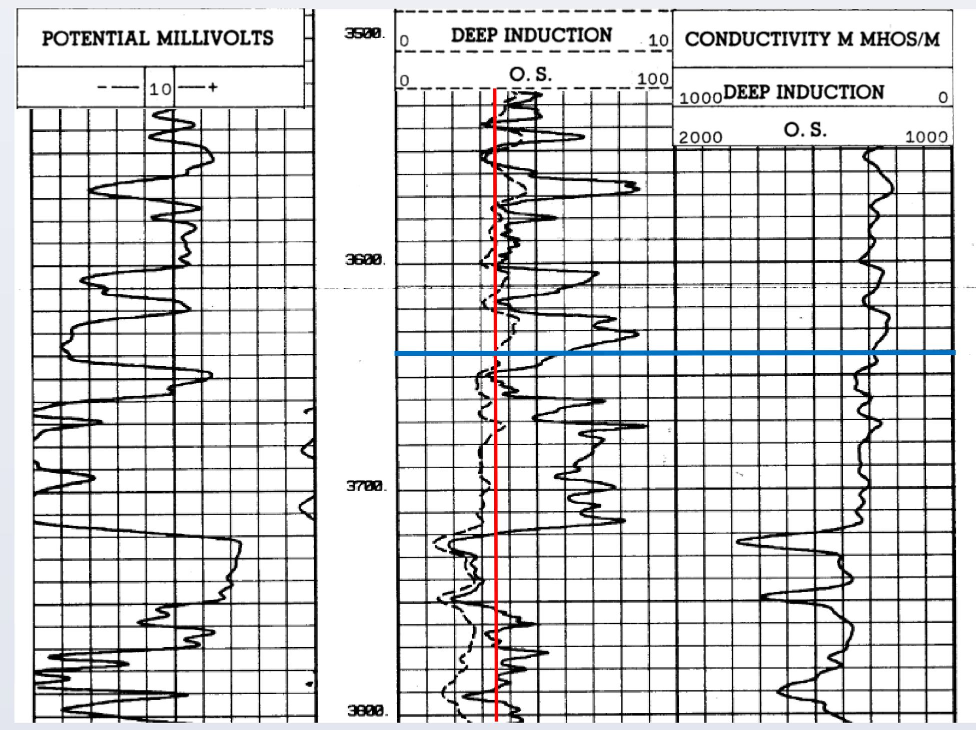


Figure 2: (CA DOGGR) Bellevue Well: 74X-35
The calculated Rt at the 10,000 ppm salinity boundary is 3.5 ohm-m. The resistivity log shows a depth of 3640ft at this value. The resistivity after the marker drops below 3.5 ohm-m, representing formation waters with greater salinity than 10,000 ppm.

Results/Conclusions

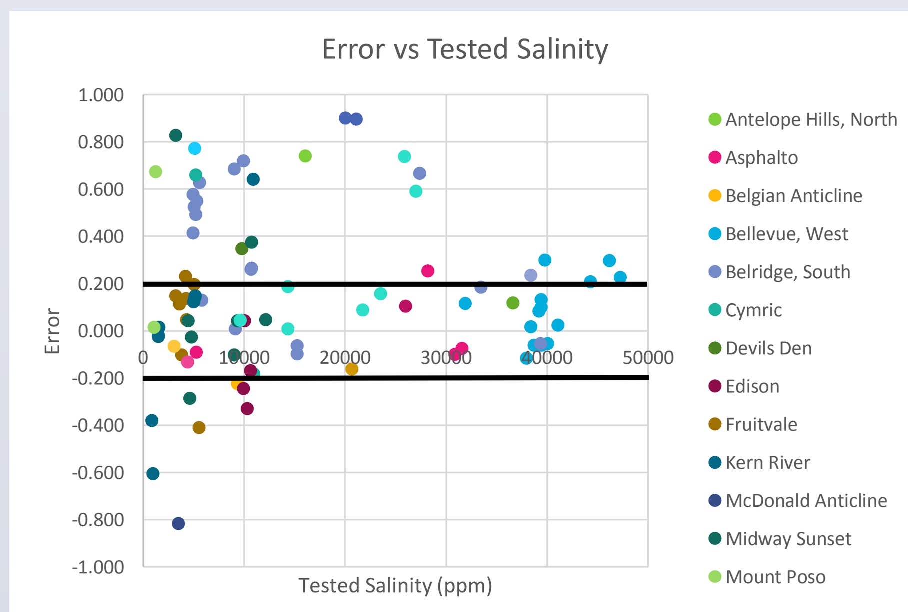


Figure 3: The data is plotted with markers on the 20% error.

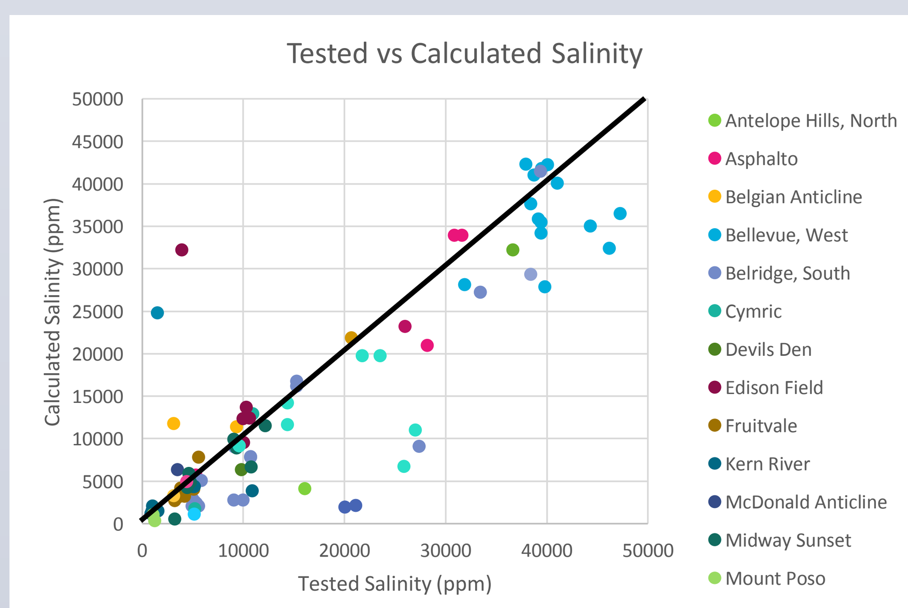


Figure 4: Calculated salinity is plotted against measured salinity with the 1-to-1 line shown.

Figures 4 and 5 show the results from comparing the RP method salinity calculations to the chemical test salinity. Figure 4 shows that most of the data is within the 20% error margin with the larger errors occurring in the regions with lower salinity. With the lower salinities coming from shallower formations, this also highlights the fact that it is harder to separate oil and fresh water formations using the logs. Figure 5 shows the relationship between the measured and calculated salinities, with most of the data located near the 1-to-1 ratio line. As the overall salinity increases, the RP method tends to underestimate the salinity value. Figure 5 shows the base of USDW in the southern San Joaquin Basin. Aquifer recharge in the east from the Sierra Nevada streams has caused the base of USDW in the eastern part of the basin to occur at lower depths than the west. The base to USDW is also deeper in the south where it is possible that more than one USDW aquifer is present and that the USDW zones are separated by a more saline formation especially in the fields of Edison, Mountain View, and Wheeler Ridge.

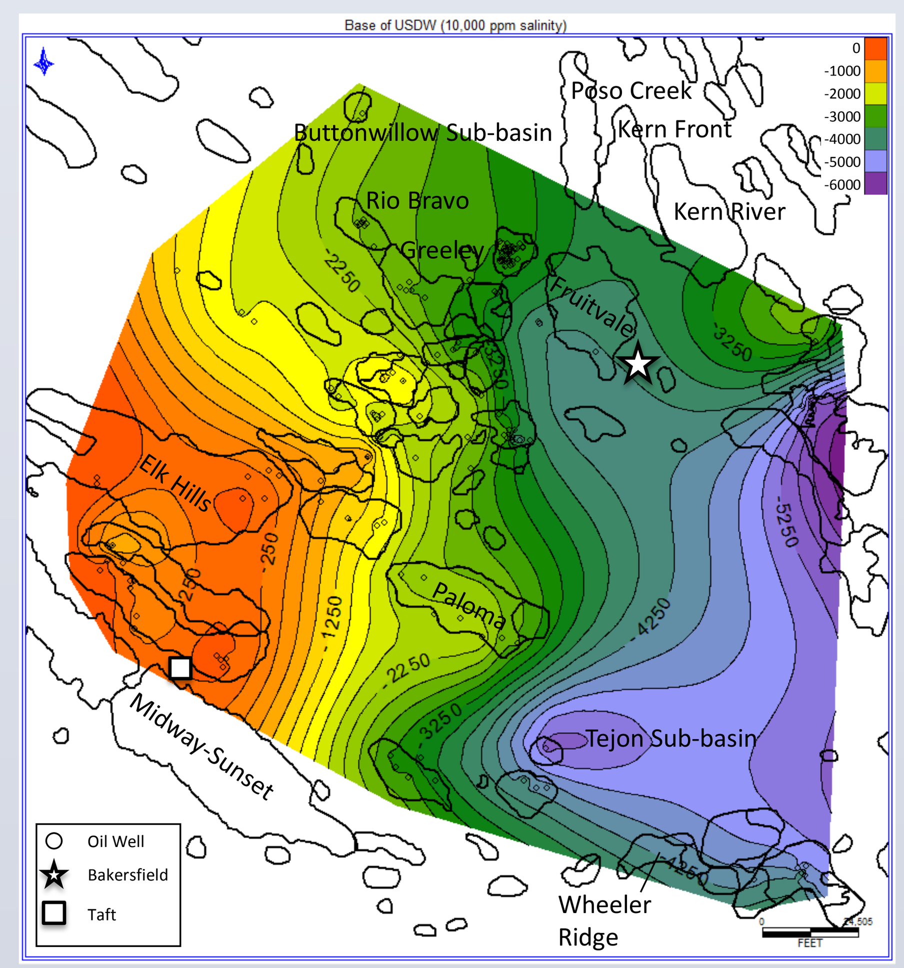


Figure 5: This map shows the subsea depth to the 10,000 ppm salinity boundary in the southern San Joaquin Basin. The boundary is deeper in the east and shallows toward the west. The Bakersfield Arch has shallower USDW than the Buttonwillow Sub-basin to the north and the Tejon Sub-basin to the south.

Acknowledgements

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Discussion

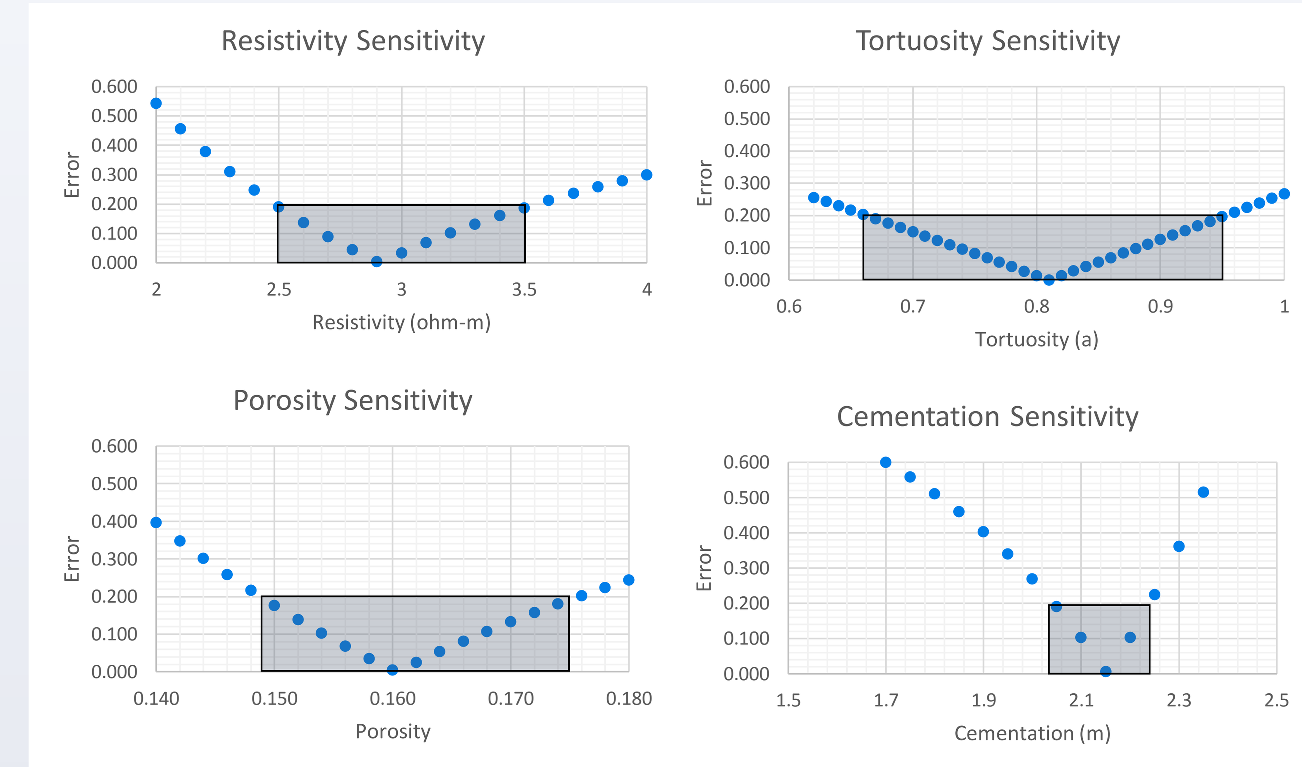

Figure 6: These graphs show the sensitivity of variables in the RP method.

The charts in figure 6 show the different variables used in the RP method and how the uncertainty in their values affects the error of the TDS calculation using the well KM 23XA-33 in the West Bellevue oilfield. Each variable, the deep resistivity (Rt), tortuosity (a), porosity (ϕ), and cementation factor (m) was varied while holding the others constant to determine the effect of each on the overall error in the calculated TDS measurement. The resistivity variable is best constrained because electrical log data is widely available. The tortuosity chart shows that a wide range of values can be used and still be under the 20% error limit. The cementation constant also shows a narrow range of values within the 20% error limit.

The main concern in the method is the poorly constrained porosity data. Few porosity logs are available from public databases such as that maintained by CA DOGGR. A 7-10% error in the porosity may cause a 20% error in the salinity calculation. Figure 1b shows that the available porosity logs for the wells with chemical tests are few, therefore, other methods are used to obtain a porosity value. The CA DOGGR source, California Oil & Gas Fields Volume 1 - Central California, lists the average porosity values for each formation (Fig. 7). This value is used as a last resort for the RP method to estimate the formation water salinity. Since, this is a reservoir-wide estimation, it may affect the errors on the salinity calculations in individual wells.

	RESERVOIR ROCK PROPERTIES		
Porosity (%)	30	29**	28**
Soi (%)	72**	58**	61**
Swi (%)	28**	42**	39**
Sgi (%)			
Permeability to air (md)	800**	750**	600**

Figure 7: This table from CA DOGGR shows the field-wide porosity for producing formations.

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