USING ELECTRIC LOGS TO PREDICT GROUND-WATER QUALITY IN THE SAND AQUIFERS OF THE SOUTH CAROLINA COASTAL PLAIN

by

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ABSTRACT

Information on the mineralization of ground water may be obtained by means of electric logs of wells without the expense of collecting water samples for analysis. Formation factors, which can be determined empirically by comparing electric-log resistivity readings with water-sample specific conductance, may than be applied elsewhere in an aquifer or area to predict the total mineralization where only an electric log is available. The reliability of predictions is a function of the number of control wells for which the formation factor has been calculated. As of early 1990, a formation factor of 2.4 seems to be the best value to use for the Coastal Plain aquifers.

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Electric logs are widely used for differentiating sand, clay, and limestone beds in wells drilled for water in the Coastal Plain of South Carolina. The resistivity (R) and spontaneous-potential (SP) traces on logs not only indicate precisely where contacts occur between these different rock types but, for the sand beds (aquifers), they reflect the mineralization of the water. The value of this lies in the opportunity it provides the hydrologist to determine, without the expense of collecting and analyzing a water sample, whether an aquifer contains fresh or saline water.

Saline water is generally considered to contain more than 1,000 mg/L (milligrams per liter) of dissolved solids. The dissolved solids are made up, almost entirely, of silica, calcium, magnesium, sodium, potassium, iron, bicarbonate, carbonate, sulfate, chloride, fluoride, and nitrate.

Freshwater would, by definition, contain less than 1,000 mg/L of dissolved solids. Very small amounts of many other elements and compounds can be present in ground water. Their concentrations are so low that they are expressed in micrograms per liter (one-thousandth of a milligram).

The cations (calcium, magnesium, sodium, and potassium) will always be in the form of compounds with the anions (bicarbonate, carbonate, sulfate, chloride, fluoride, and nitrate). The predominant water types in the Coastal Plain sand aquifers are sodium bicarbonate and sodium chloride, the latter type being common in the near-coastal areas and near the base of the freshwater section farther inland. Whatever the makeup of the water, if the dissolved-solids concentration (mineralization) exceeds 1,000 mg/L it is saline.

High mineralization is indicated on electric logs by little or no resistivity (because a high mineral content makes water more conductive, hence less resistive to the passage of an electric current). Conversely, if there is a low mineral content the electric log shows high resistivity, indicating freshwater.

Resistivity recorded on an electric log is a measure of the electrical properties of the water and the aquifer material together. The water alone can have its electrical properties measured when it is pumped from a well. One property is specific conductance, which is a measure of the water's capacity to conduct an electric current. Specific conductance is a reflection of the degree and mineralization of the water. Typically, the dissolved-solids content of water (in milligrams per liter) is related to specific conductance (in micromhos per centimeter) by a factor between 0.55 and 0.75; an average value of 0.65 may be used if a more accurate value is unknown. This is merely a number relation, not an equation.

Sand and water together have greater electrical resistivity than water alone. The relation of the two can be calculated and is termed the "formation resistivity factor", or more briefly the "formation factor" (F). This factor varies with the composition and permeability of the aquifer. A "clean" sand, one containing little or no clay or other minerals such as mica or glauconite, will show a greater resistivity (on the electric log) than a sand admixed with clay or other impurities. Water withdrawn from both aquifers could have the same chemical quality (as indicated by specific conductance) but appear substantially different on an electric- log trace.

The factor that is required for converting electric-log resistivity readings to specific-conductance values can only be obtained empirically and in situations where a suitable electric log and a discrete water sample are available. By "suitable" electric log is meant a log containing the long-normal resistivity (64-inch electrode spacing) trace. This trace is required because the short-normal resistivity log, made at closer electrode spacing, is often distorted by drilling-mud invasion. By "discrete" water sample is meant a sample from one aquifer.

In the South Carolina Coastal Plain region it is very much the custom to screen several aquifers in the large wells. This, of course, is an effort to obtain all the water possible. Unfortunately, this means that there are few wells that satisfy the requirements for calculating the formation factor. The ideal situation is a single-screen well for which there is a multi-resistivity electric log and a chemical analysis. The writer has identified only about 50 wells that, more or less, qualify for calculation of the factor. The table presents the findings as of the date of this report. The range of F values is of immediate interest. Note that the values range as widely within a county as they do among the counties. Probably the most useful data in the table are the average and/or median values for the individual counties. For the 50 available values, both the average and median are 2.4. It is to be expected that as new data become available the average and median values will change, especially for the counties having few values. The reliability of the averages will improve greatly as the number of values increases. At this point it might be well to demonstrate the use of the formation factor.

<u>Example</u>

An electric log shows a sand bed in the depth interval of 500-520 feet. The long-normal resistivity is 20 ohm-meters (R_o). Because depth affects temperature, and warm water is more conductive (less resistive) than cold water, the observed resistivity (R_o) must be corrected for temperature in order to be comparable to specific conductance, which is calculated for a standard temperature of 77°F (25°C). In the South Carolina Coastal Plain the temperature at 500 feet is about 75°F (See Figure 1). A temperature correction chart (Fig. 2) shows that the resistivity at 77°F is 97.5 percent of what it would be at 75°; therefore the corrected observed resistivity is 0.975 x 20, or 19.5 ohm-meters. This is not a great difference, but for deep aquifers, in which the temperature might be near 100°F, the effect is substantial (correction factor 1.25).

The formula for calculating the resistivity of the water alone is $R_w = Ro/F$, in which F is the formation factor. Using the F of 2.4 (median of 50 values determined in the Coastal Plain), $R_w = 19.5/2.4 = 8.1$. Resistivity is the reciprocal of conductivity; therefore the specific conductance (in micromhos per centimeter) corresponding to a

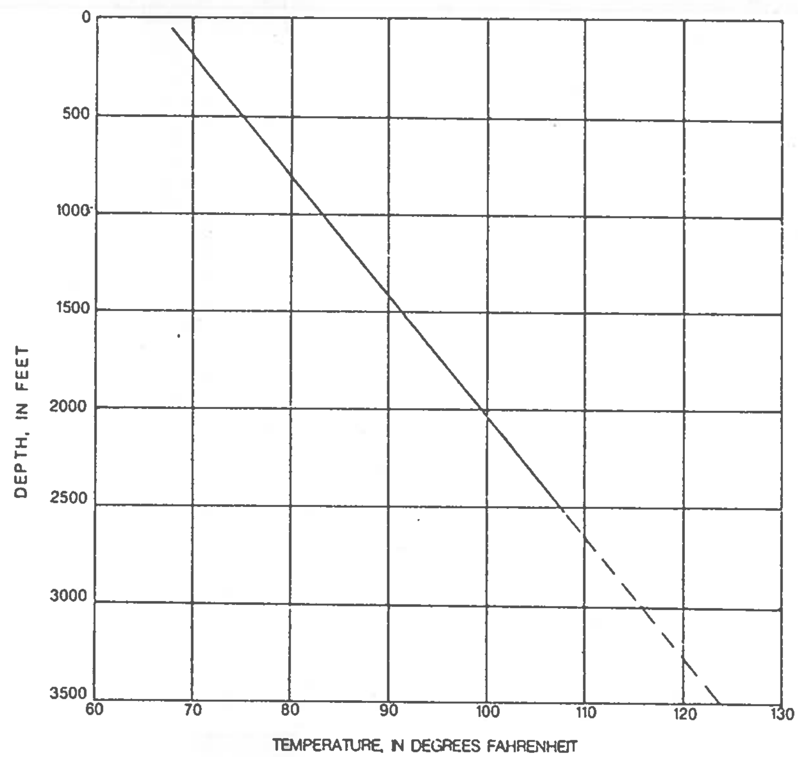

Figure 1. Generalized thermal gradient in the South Carolina Coastal Plain.

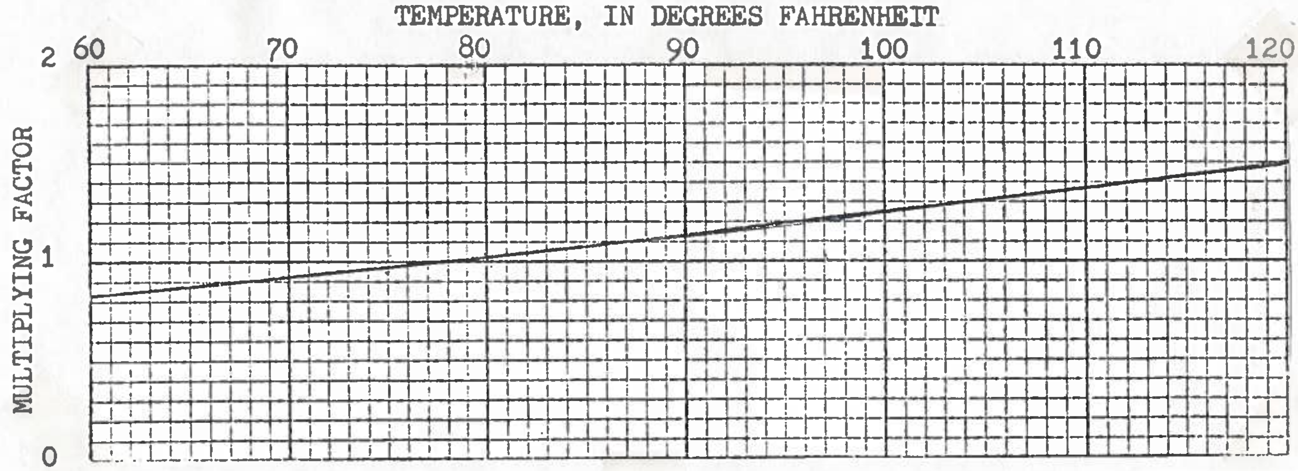

Figure 2. Graph for correction of resistivity when water in aquifer is not at 77° F.

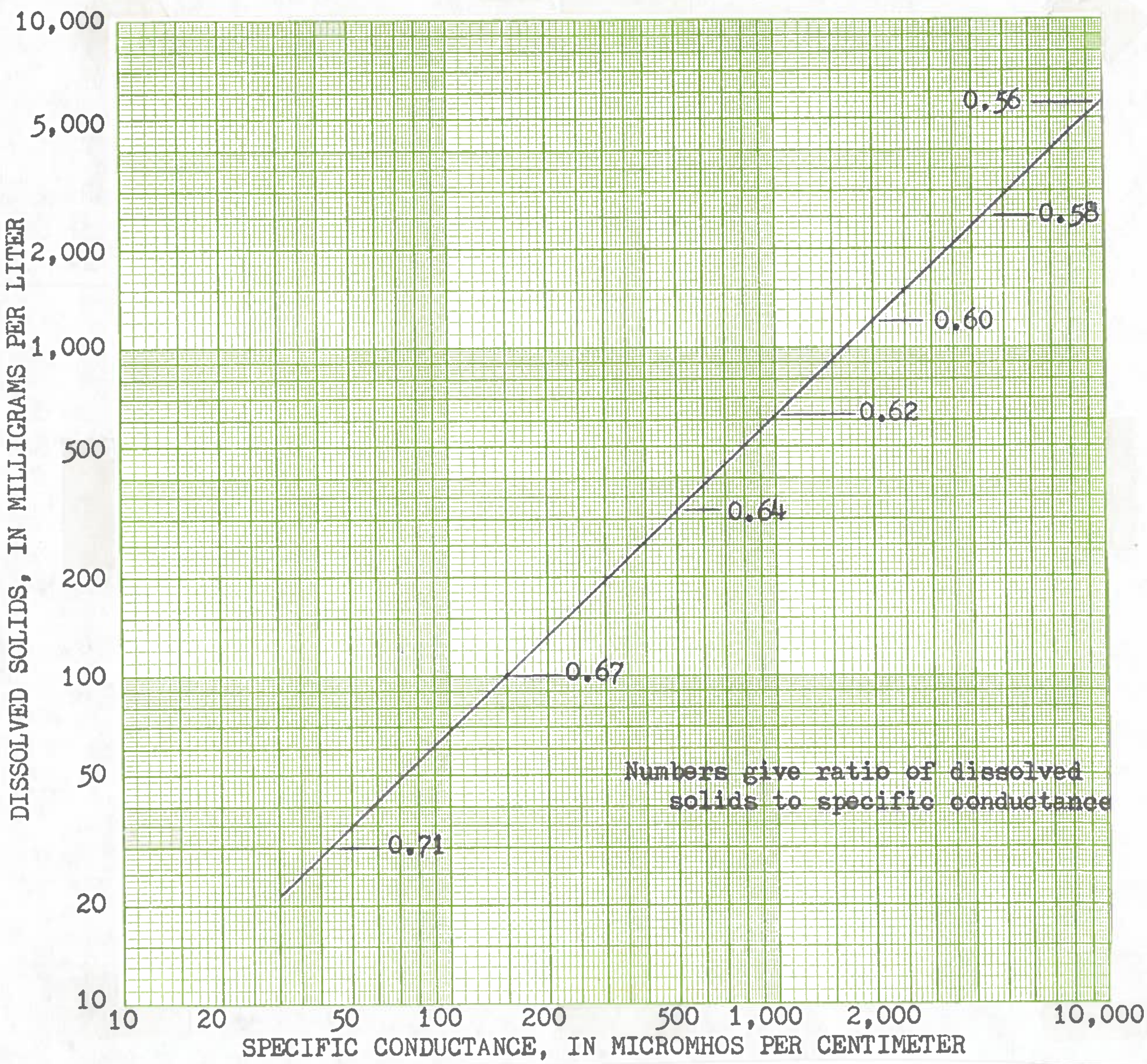

Figure 3. Dissolved solids-specific conductance relation in Cretaceous aquifers in South Carolina.

resistivity (in ohm-meters) of 8.1 is 10,000/8.1 or 1,235.[1/] A graph of the relation between specific conductance and dissolved solids for the Cretaceous aquifers of the Coastal Plain (Fig.3) shows that a dissolved-solids concentration of 760 mg/L is indicated by the specific conductance of 1,235 micromhos per centimeter. Note that the ratio of dissolved solids to specific conductance in this example is about 0.61.

It would be helpful if characteristic differences in median values for formation factor could be found, for either formations or areas. There is a possibility that such differences will emerge as more values are obtained; however, the lack of hydrologic distinctiveness among the Cretaceous sand aquifers of the Coastal Plain discourages optimism. As for areal differences, there are not, at present, enough values to make even a tentative conclusion as to where the highest and lowest formation factors will prevail.

1/ The reporting of resistivity in ohm-meters and specific conductance in micromhos per centimeter necessitates a coversion factor of 10,000 to relate the two in an equation.

FORMATION FACTORS DETERMINED FOR SAND AQUIFERS IN SOUTH CAROLINA

County	Number of values	Range in values	Average F	Median F
Aiken	1	–	1.4	–
Barnwell	1	–	1.7	–
Berkeley	5	1.8–3.2	2.4	2.2
Charleston	5	1.8–4.3	3.0	3.2
Dorchester	7	1.5–3.5	2.1	2.2
Georgetown	4	2.4–3.8	3.1	3.1
Horry	12	1.3–4.2	2.7	2.8
Marion	6	1.4–2.6	2.1	2.2
Marlboro	1	–	1.4	–
Orangeburg	3	1.6–2.7	2.2	2.4
Richland	3	2.3–3.4	2.8	2.6
Williamsburg	2	1.2–1.3	1.2	–
	50	1.2–4.3	2.4 (for 50 values)	2.4 (for 50 values)

Additional discussions of the use of formation factor in predicting ground-water mineralization are available in the following publications, among others.

Alger, R. P., 1966, Interpretation of electric logs in fresh water wells in unconsolidated formations: Trans. Society of Professional Well Logging Analysts Symposium, Houston, Tex., 25 p.

Jones, P. H., and Buford, T. B., 1951, Electric logging applied to ground-water exploration: Jour. Geophysics, v. 16, no. 1, p. 115-139.

Newcome, Roy, Jr., 1975, Formation factors and their use in estimating water quality in Mississippi aquifers: U.S Geological Survey Water-Resources Investigations 2-75, 1 sheet.

Pryor, W. A., 1956, Quality of groundwater estimated from electric resistivity logs: Illinois State Geological Survey Circular 215, 15 p.

Turcan, A. N., Jr., 1966, Calculation of water quality from electrical logs, theory and practice: Louisiana Dept. Conservation, Geol. Survey, and Louisiana Dept. Public Works Water Resources Pamph. no. 19, 23 p.