SALINE WATER OCCURRENCE WITHIN THE TERTIARY SPARTA SAND AND COCKFIELD AQUIFERS OF WASHINGTON COUNTY, MISSISSIPPI

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INTRODUCTION

Washington County is located in west central Mississippi in the Delta region. It is bounded to the west by the Mississippi River, to the north by Bolivar County, to the east by Sunflower and Humphreys Counties and to the south by Sharkey and Issaquena Counties.

The Cockfield and Sparta Sand aquifers are formations of the Claiborne Group and are Tertiary in age. Both aquifers are present under all of Washington County and are widely utilized as ground-water sources for domestic and municipal drinking water purposes. General water quality from the two aquifers is considered good throughout most of the county. However, higher than normal chloride and dissolved solids concentration levels have been noted at various areas within the county. In order to locate these areas, water quality analysis data for the Cockfield and Sparta Sand aquifers were obtained from the Mississippi State Department of Health and the United States Geological Survey (USGS). Additional ground-water samples were collected and analyzed by personnel from the Mississippi Department of Natural Resources in order to fill in gaps in the existing data and update older data. Chloride and dissolved solids concentrations as high as 1170 mg/1 (milligrams per liter) and 2700 mg/1 respectively were found in water from the Cockfield aquifer. Chloride and dissolved solids concentrations as high as 860 mg/1 and 1960 mg/1 respectively were found in water from the Sparta Sand aquifer. The U.S. Public Health Service recommended limit for chloride content of drinking water is 250 mg/1 and the USGS designates freshwater as having less than 1000 mg/1 dissolved solids. These higher than normal chloride and dissolved solids concentrations are a result of the physical characteristics of the two aquifers and the subsurface geology of the area. Artificial contamination from outside sources does not appear to be a factor.

It is the intent of this report to provide sufficient information to define chloride and dissolved solids concentration levels in Washington County with respect to geography and depth within the two individual aquifer systems. In addition, a method utilizing geophysical electric logs to estimate ground-water quality will be discussed. It is hoped that this information will prove useful to water managers in Washington County in selecting future well sites and well depths and in obtaining consistent high quality drinking water.

GEOLOGICAL SETTING

Washington County is located in an area having a unique geological setting. The Monroe Uplift, also known as the Monroe-Sharkey Platform, is a regional structurally high feature situated in parts of Arkansas, Louisiana and west-central Mississippi (Fig. 1). It is a relatively flat-topped, complexly truncated dome of approximately eighty miles in diameter (7). The northern flank of the uplift extends from west-central to southeastern Washington County. The uplift is bounded to the north by the Desha Basin and to the east by the structural trough of the Mississippi Embayment which trends on a northwest-southeast line through northeastern Washington County.

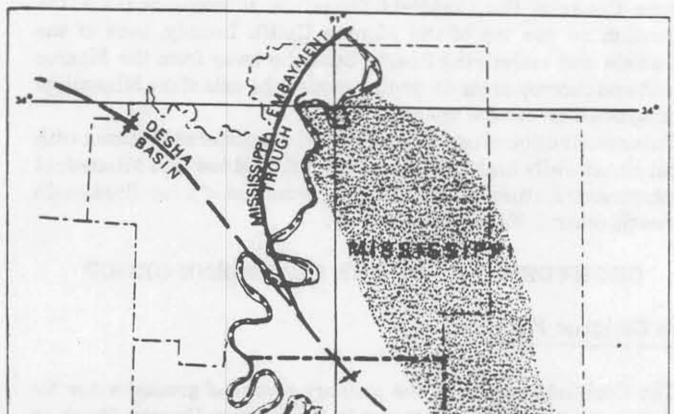


Figure 1. Map showing geologic features. (Modified from Taylor and Thomson, 1971)

Surface expression of these high and low structural features has been masked by Quaternary alluvial deposits.

The Monroe Uplift has undergone four major periods of growth beginning in the Cretaceous and extending through Tertiary, Claiborne time (7). Coincident with these periods of uplift were periods of gradual subsidence in the adjacent Desha Basin and Mississippi Embayment. These periods of uplift and associated subsidence resulted in the thinning and pinching-out of sediments being deposited on the flanks and on top of the Monroe Uplift and the thickening of sediments being deposited along the axis of the Mississippi Embayment and the axis of the Desha Basin. This sequence of thinning and thickening is apparent in both the Cockfield and Sparta Sand Formations which were deposited during the final period of uplift and subsidence in Claiborne time.

General trend of the Cockfield Formation is to the south and southeast. In the area north and east of Washington County the Cockfield Formation subcrops beneath the Mississippi River Valley Alluvium along this regional trend line (Fig. 1). In the southern part of Washington County and in the northern parts of Sharkey and Issaquena Counties the Cockfield formation subcrops beneath the Alluvium on the top of the Monroe Uplift. Locally, beds of the Cockfield and underlying Sparta Sand dip away from the Monroe Uplift and subcrop areas deepening toward the axis of the Mississippi Embayment structural trough.

This combination of regional trend and dip patterns blending with local structurally high (the Monroe Uplift) and low (the Mississippi Embayment) features resulted in the formation of a localized basin beneath central Washington County.

GEOHYDROLOGY OF THE CLAIBORNE GROUP

The Cockfield Formation

The Cockfield aquifer is the primary source of ground-water for municipal and domestic purposes in Washington County. Depth to the top of the aquifer system varies from 100 ft. below land surface in the subcrop areas to 300 ft. below land surface near the axis of the Mississippi Embayment. The formation thickens away from subcrop areas toward the axis of the Mississippi Embayment and ranges from 300 to 500 ft. thick (18). Variations in thickness are a result of increased deposition associated with local subsidence and partial erosion of Cockfield sediments in the subcrop areas.

Beds of the Cockfield Formation consist of interbedded shales and sands which were deposited in a fluvial-deltaic environment. The shales are gray to dark brown and silty. The sands are composed of fine to medium sized, subangular to rounded quartz grains with varying amounts of lignitic and carbonaceous fragments (16). This lignitic and carbonaceous material is responsible for ground-water color problems in most of Washington County. Individual sand beds range in thickness from 10 to 100 ft. These beds appear to be lenticular in shape with limited areal extent and are, at best, difficult to correlate from one well to another. This discontinuity of sand beds in conjunction with additional thinning and pinching-out of beds toward the Monroe Uplift has resulted in restricted ground-water flow patterns within the aquifer. This is characterized by abnormally high concentrations of original connate saline water that has not been completely flushed from the aquifer. The wide range of transmissivity values for the Cockfield aquifer, 80 to 21,000 cubic feet/day/foot (3), also indicates the varying nature of ground-water flow through the aquifer. Transmissivity values are highest in areas with thick channel type sand deposits and decrease in areas where the sand beds are thin and the formation becomes shalier.

The Cook Mountain Formation

The Cook Mountain Formation is situated between the Cockfield and Sparta Sand Formations. It is predominately a marine shale sequence with thin sand stringers and serves as a confining layer between the Cockfield and Sparta Sand aquifer systems throughout most of Washington County. Figure 2b is a north-south cross-section through western Washington County (cross-section line is shown in Figure 2a). The base of the fresh-water (fresh-water having less than

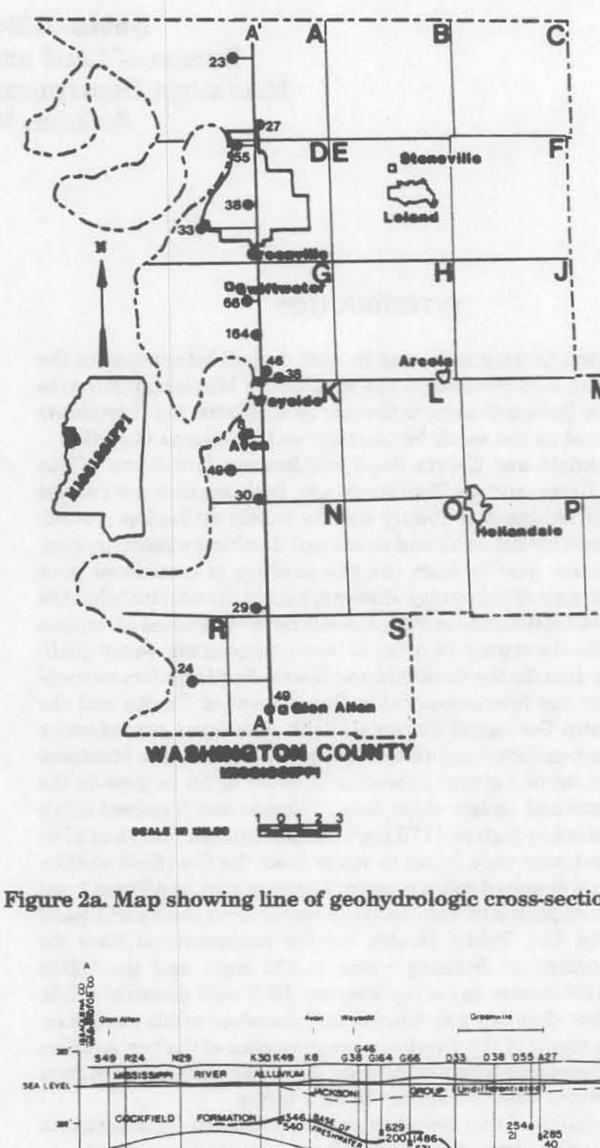


Figure 2a. Map showing line of geohydrologic cross-section A-A'.

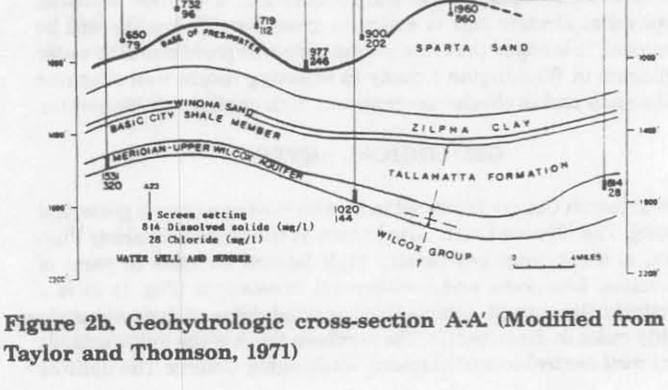


Figure 2b. Geohydrologic cross-section A-A'. (Modified from Taylor and Thomson, 1971)

1000 mg/1 dissolved solids) for the Cockfield and Sparta Sand aquifers is shown on this cross-section. A decrease in dissolved solids and chloride concentration levels north of well G-66 in the Cockfield aquifer and a corresponding increase in concentration levels at well D-33 in the Sparta Sand aquifer suggests that a hydraulic connection exists between the two aquifers resulting in the downward migration of denser more saline water from the Cockfield through the Cook Mountain into the Sparta Sand. This downward migration could occur due to an increase in sand content within the Cook Mountain, however, insufficient data exist to confirm this.

The Sparta Sand Aquifer

The Sparta Sand aquifer is bounded above by the Cook Mountain Formation and below by the Zilpha Clay. It is a source of municipal drinking water for the towns of Avon and Glen Allan and a relatively small number of domestic users. Depth to the top of the aquifer varies from about 550 to more than 700 feet below land surface (18), thickening toward the axis of the Mississippi Embayment and thinning toward the Monroe Uplift. Like the Cockfield, the Sparta Sand was deposited in a fluvial-deltaic environment and consists of interbedded sands and shales. Shales are gray to dark brown or black. Sands consist of rounded to subrounded, fine to medium sized quartz grains with varying amounts of lignitic and carbonaceous fragments (15). Water color, associated with lignitic and carbonaceous material, is as much a problem in the Sparta Sand aquifer as it is in the Cockfield.

Flushing of original connate saline water in the Sparta Sand has been incomplete for the same reasons as in the Cockfield. These being discontinuous, lenticular sand beds which thin and pinch-out toward the Monroe Uplift resulting in restricted ground-water flow patterns. Transmissivity values for the Sparta Sand range from 330 to 13,000 cubic feet/day/foot (3) indicating the varying character of ground-water flow patterns and rates through the aquifer.

GROUND-WATER QUALITY

Data from a total of 230 water samples representing 135 separate wells in Washington County were analyzed in order to determine general water quality and locate areas of higher than normal saline concentrations. Of these wells, 110 were screened in the Cockfield aquifer and 25 were screened in the Sparta Sand aquifer (the locations of these wells are shown in Figure 3). In some instances, primarily for municipal wells, several water samples covering a period of years were available for a single well. Ground-water quality data used in this report are on file and available from the Mississippi Department of Natural Resources, Bureau of Land and Water Resources.

Ground-water from the Cockfield and Sparta Sand aquifers is of a sodium bicarbonate type grading to a sodium chloride type in the more saline areas. Figures 4a and 4b are isocon maps showing dissolved solids and chloride content of the Cockfield aquifer and Figures 5a and 5b show dissolved solids and chloride content of the Sparta Sand aquifer. An examination of these maps shows that increases in chloride concentrations correspond to increases in dissolved solids concentrations with the 250 mg/1 chloride isocon closely approximating the 1000 mg/1 dissolved solids isocon.

As shown in Figures 4a and 4b, general ground-water quality of the Cockfield is good throughout the northern and southern portions of the county. In the central portion of the county saline water concentrations are abnormally high and can increase rapidly over relatively short distances. Those areas with chloride concentration levels greater than 250 mg/1 (the U.S. Public Health Service recommended limit for chloride content of drinking water) are, east of Arcola on a line south to Hollandale and north toward Leland, east of Wayside and Avon and south of Greenville near Swiftwater. The concentration of saline water near Swiftwater is of particular interest because of it's proximity to the major population center of Greenville.

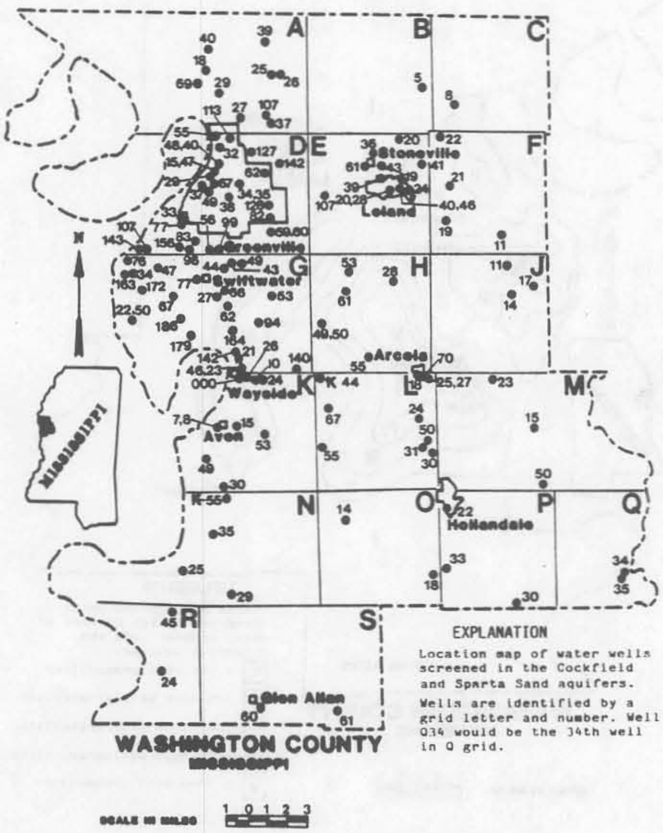


Figure 3. Map showing locations of wells screened in the Cockfield and Sparta Sand aquifers.

Figure 6 is a graph showing an increase in chloride concentration levels with respect to time for four wells screened in the Cockfield aquifer. Wells G-44, G-66 and G-77 are located near Swiftwater and well D-49 is located in southern Greenville. The rather dramatic increase in chloride levels in well G-44 (184 mg/1 in 1967 to 440 mg/1 in 1981) and well G-66 (150 mg/1 in 1968 to 631 mg/1 in 1986) are attributed to the up-coning of deeper more saline water. The rather moderate increase in chloride concentration levels in wells G-77 and G-49 may be the result of lateral movement of saline water through the aquifer in response to the deepening cone of depression in the Cockfield water level beneath Greenville.

Saline water concentrations within the Cockfield and Sparta Sand aquifers not only vary areally but also with depth, generally increasing downward within an individual aquifer. This relationship is shown in Figure 2b by the line defining the base of the fresh-water in each aquifer. Fresh-water (less than 1000 mg/1 dissolved solids) is found above these lines while saline water (greater than 1000 mg/1 dissolved solids) is found below these lines.

Figures 5a and 5b are isocon maps showing dissolved solids and chloride concentration levels, respectively, for the Sparta Sand aquifer. Chloride concentration levels in the Sparta Sand exceed 250 mg/1 in an area east of Avon and Wayside and extending northwest into southern Greenville where levels reach 860 mg/1. Insufficient data exist north of Greenville to determine if this high level of chloride concentration continues in that direction. Ground-water quality throughout the remainder of the county, to the east and south, is generally considered to be good. The similarity in high saline concentration areas within the Cockfield and Sparta Sand aquifers can not be overlooked. These corresponding concentration areas are a result of similar flow patterns and regimes within each aquifer. These flow patterns and regimes are dictated by individual aquifer

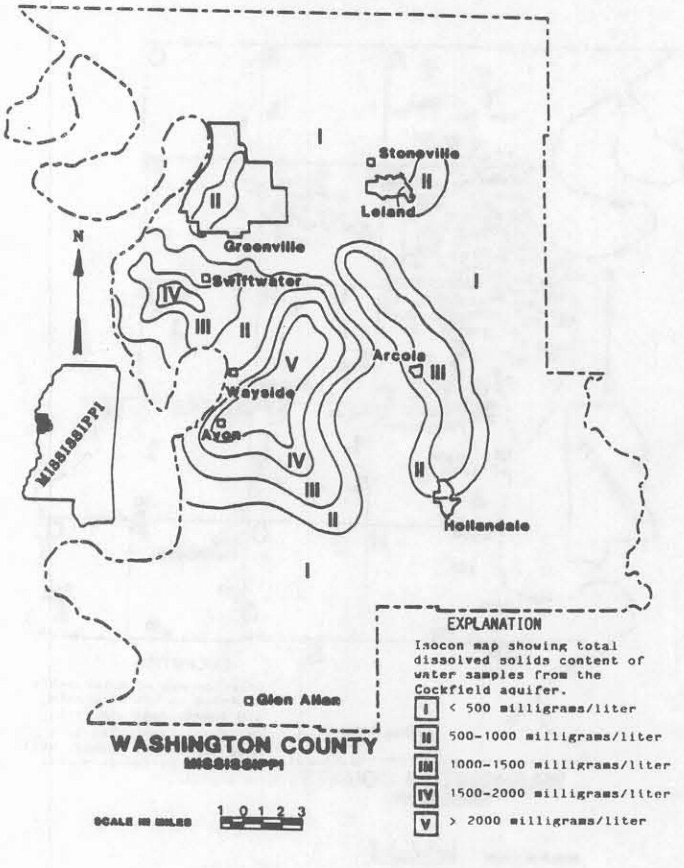


Figure 4a. Isocon map showing dissolved solids content of water samples from the Cockfield aquifer.

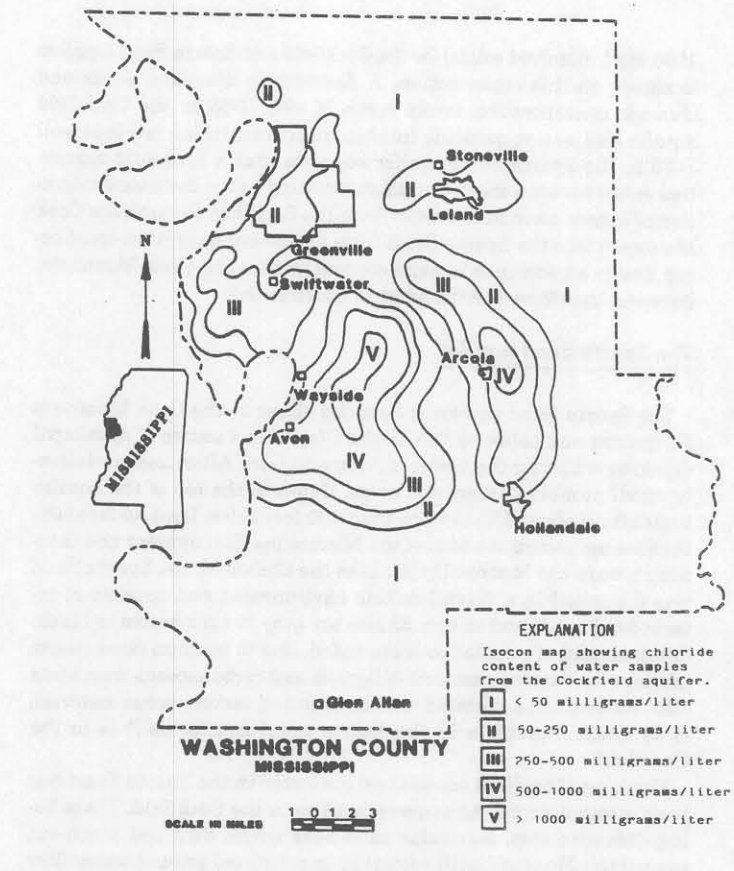


Figure 4b. Isocon map showing chloride content of water samples from the Cockfield aquifer.

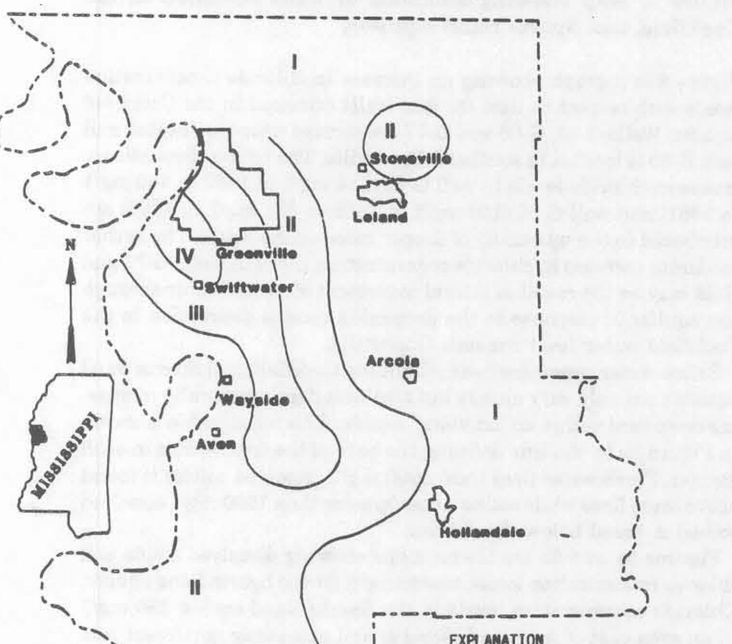


Figure 5a. Isocon map showing dissolved solids content of water samples from the Sparta Sand aquifer.

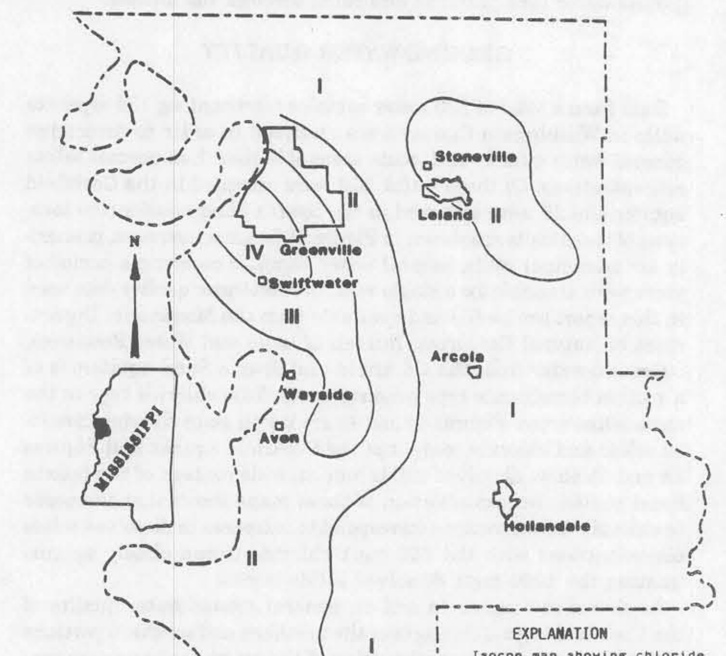


Figure 5b. Isocon map showing chloride content of water samples from the Sparta Sand aquifer.

parameters and, perhaps more importantly, by regional trend and dip patterns and local structural features.

ESTIMATION OF AQUIFER WATER QUALITY FROM ELECTRIC LOGS

The saline water problems in Washington County are not ones that will simply go away. In fact, data presented in Figure 6 demonstrates that in some areas these problems are worsening. The saline concentration maps that were previously discussed will serve in determining whether or not a potential well site is located in a high saline problem area. However, once a well is drilled a method is needed to determine the best zone or zone of least saline concentration in which to screen the well. This is where the use of a multi-resistivity electric log can be most helpful.

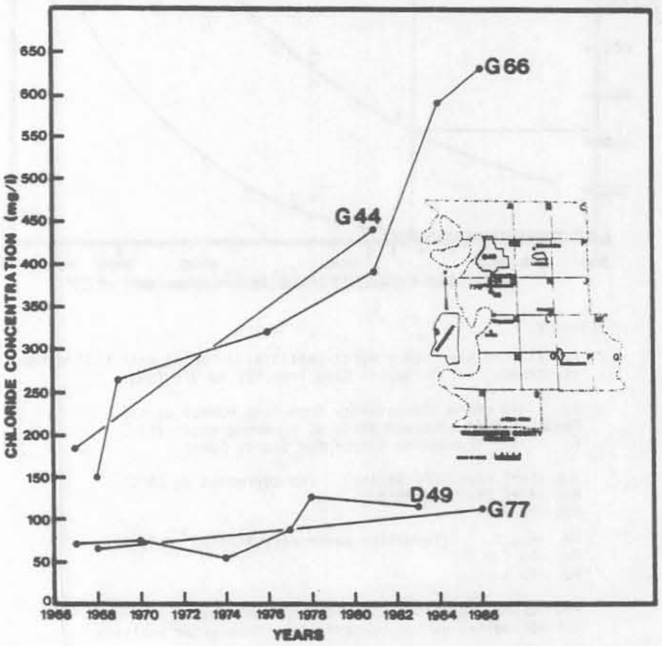


Figure 6. Graph showing an increase in chloride concentration levels with time for four wells screened in the Cockfield aquifer.

In general, formations that contain fresh-water will show a relatively high resistivity reading (measured in ohm*meters) while formations that contain saline water will exhibit a comparatively low resistivity reading. This is because fresh-water has a low dissolved mineral content and thus is not a good conductor of electrical current, the opposite being true for saline water.

There are two types of resistivity curves that are plotted on a multi-resistivity log, the long normal and short normal resistivity curves. The resistivity measurement taken from the long normal curve is the most useful in quantitatively calculating ground-water quality in that it has a longer electrode spacing than the short normal curve and can penetrate beyond the flushed zone of a well borehole to give a "true" resistivity measurement of the saturated formation.

If a sufficient quantity of water quality analysis data is available a reliable, quantitative estimation of water quality can be obtained by applying the measurement taken from a long normal resistivity curve to an empirical relationship between the resistivity of the saturated formation and the resistivity of the formation water. This empirical relationship is referred to as the formation resistivity factor and is expressed by the formula:

$$F = Ro/Rw \qquad (1)$$

where: F = formation resistivity factor (dimensionless),
Ro = resistivity of the saturated formation (ohm*m) from a long normal resistivity curve, and
Rw = resistivity of the formation water (ohm*m).

Formation factors for various aquifers can be determined by a comparison of water analysis data and electric log resistivity data. Newcome, in his paper "Formation Factors and Their Use in Estimating Water Quality in Mississippi Aquifers", used electric logs and laboratory analysis of water samples to estimate over a hundred formation factors for different aquifers throughout Mississippi. The values obtained ranged from 1.7 to 8.9 (12). This range in formation factor values is related to differences in water type, matrix cementation, sand/clay ratio, porosity and pore geometry. It is therefore desirable to establish separate formation factors for aquifers in different areas. A comparison of electric log resistivity data and water analysis data in Washington County has shown that formation factors of 3.9 for the Cockfield aquifer and 3.2 for the Sparta Sand aquifer will yield usable estimates of ground-water quality.

Ground-water is analyzed in the laboratory at a temperature of 25 degrees Celsius (77 degrees Fahrenheit). In order to properly calculate the formation water resistivity (Rw) the resistivity of the saturated formation (Ro), as read from a long normal resistivity curve, must be adjusted to 25 degrees Celsius. This can either be accomplished by the use of temperature gradient and correction factor graphs (12) or with the following equation:

$$Roc=Ro*[.85+(.0002*D)] \qquad (2)$$

where: Roc = resistivity of the saturated formation (ohm*m) corrected to 25 degrees Celsius,
Ro = resistivity of the saturated formation (ohm*m), and
D = depth of the formation (ft).

After a corrected saturated formation resistivity (Roc) is obtained it is possible to calculate the formation water resistivity (Rw) by replacing Ro in Equation 1 with Roc and manipulating it to the form:

$$Rw=Roc/F \qquad (3)$$

Once the formation water resistivity (Rw) is determined for a particular aquifer or zone within a well it can be used in the appropriate graph (Figures 7 and 8) to estimate dissolved solids and chloride concentration levels for either the Cockfield or Sparta Sand aquifers in Washington County. Figures 7 and 8 are semi-log plots of ground-water data from the Cockfield and Sparta Sand aquifers showing dissolved solids and chloride concentration levels versus specific conductance. The formation water resistivity (Rw) scale shown at the top of each graph is established by the following relationship:

$$Rw=10,000/K \qquad (4)$$

where: K = specific conductance (micromhos/cm) of ground-water sample.

Figure 7 is a plot of ground-water quality data for the Cockfield aquifer in Washington County and Figure 8 shows data plotted for the Sparta Sand aquifer in Washington County. Also given in Figure 8 is an example of the series of calculations used in order to estimate the dissolved solids and chloride concentration levels for a particular aquifer or zone in a well. The values used in this example were taken from a multi-resistivity electric log of well L-70 in Washington County which is screened in the Sparta Sand aquifer. It can be seen from the results of this example that a reliable estimate of ground-water quality, with respect to dissolved solids and chlorides, can be obtained utilizing electric logs and the method described.

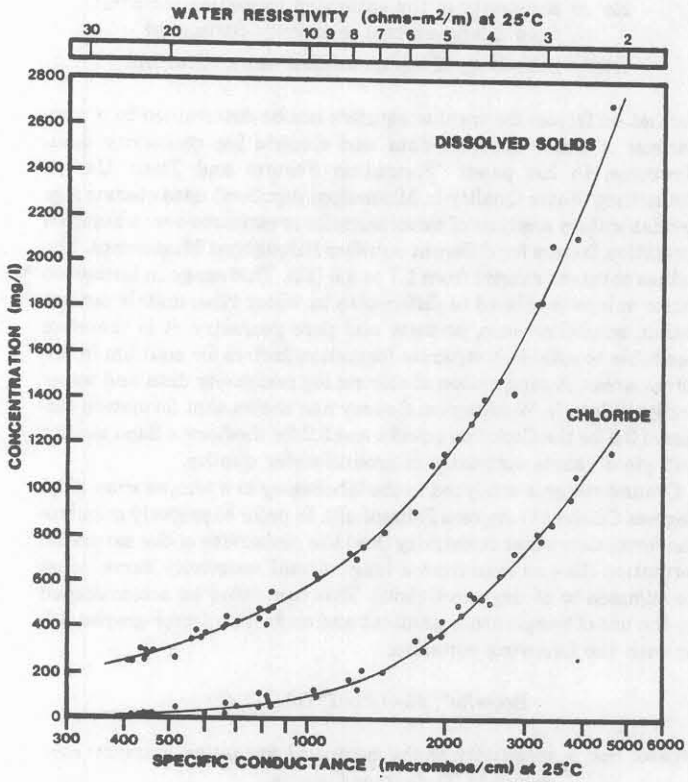


Figure 7. Graph showing the relationship of specific conductance and water resistivity to dissolved solids and chloride concentrations of ground-water from the Cockfield aquifer.

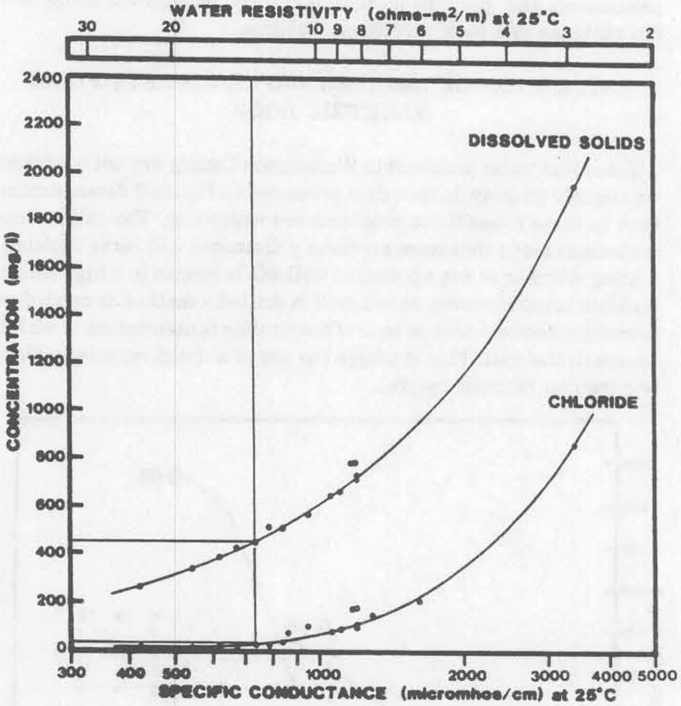
It should be noted at this point that several of the factors, such as the saturated formation resistivity (Ro), used in these calculations are subject to variables which can not always be predicted. These equations represent an empirical relationship and should be considered as an additional tool to be used in conjunction with a general knowledge of the geology, hydrology and aquifer systems of an area.

CONCLUSIONS

Saline water present within the Cockfield and Sparta Sand aquifers in Washington County are original connate saline waters that have never been adequately flushed from the aquifers. Geographic areas with abnormally high saline concentrations are dictated by a combination of discontinuous sand beds, regional trend and dip patterns and local structural features. These higher than normal saline areas can be defined using concentration (isocon) mapping techniques.

At least four wells have shown an increase in chloride concentration levels with time; one of these wells is located in southern Greenville while the other three wells are located just south of Greenville near Swiftwater.

Dissolved solids and chloride concentration levels within individual sand zones of the Cockfield and Sparta Sand aquifer systems in Washington County could be reliably estimated prior to the completion of a well. This can be accomplished by using a representative formation factor, measurements from the long normal curve of a multi-resistivity electric log and the graphs presented in Figures 7 and 8. Utilization of this method should allow for wells to be screened in the zone of least saline concentration and thus minimize the chance for future increases in chloride concentration levels.

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EXAMPLE:

Values used are from a multi-resistivity log of well L-70 which
is screened in the Sparta Sand from 922 to 972 feet.

Ro    =42 ohm*m (Resistivity from long normal curve)
Depth =950 ft (Average depth of screened interval)
F     =3.2 (Formation factor for Sparta Sand)

Roc =Ro*[.85+(.0002*Depth)]   (Ro corrected to 25°C)
Roc =42*[.85+(.0002*950)]
Roc =43.7

Rw  =Roc/F      (Formation water resistivity)
Rw  =43.7/3.2
Rw  =13.6

450 =Dissolved solids concentration estimated.
404 =Dissolved solids concentration from water analysis.

20  =Chloride concentration estimated.
23  =Chloride concentration from water analysis.
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Figure 8. Graph showing the relationship of specific conductance and water resistivity to dissolved solids and chloride concentrations of ground-water from the Sparta Sand aquifer with example of calculations used in estimating dissolved solids and chloride concentrations from electric log data.

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