

(200)
W.R.

FORMATION FACTORS AND THEIR USE IN ESTIMATING
WATER QUALITY IN MISSISSIPPI AQUIFERS

INTRODUCTION

Electric logs constitute one of the most useful data sources in ground-water hydrology. Particularly in regions of unconsolidated formations, electric logs of water and oil wells provide the best information available on depth, thickness, and continuity of aquifers. Many of the logs contain sufficient information helpful in estimating water quality that money-saving decisions can be made through their use as an alternative to test drilling and well installation.

In Mississippi, thousands of electric logs have been made in holes drilled in search of oil, gas, or water. Most of these logs are available for study. Although oil-test electric logs commonly record (1) a part--or none--of the fresh-water section, many others show all or most of it. Few water-well logs record the entire fresh-water section, but many show a substantial part of it. Most useful are multiresistivity logs; induction-electric logs, commonly made in oil tests in recent years, are less useful because of poor scale readability.

PREVIOUS WORK

Determination of the chemical quality of ground water from electric logs of holes in bedded sequences of sand and clay had its first applications in petroleum exploration. The concern was chiefly with highly saline fluid far beneath the fresh-water-bearing rocks. In the 1940's, attention was directed to the use of electric logs in fresh-water aquifer identification and correlation and in determination of the degree of water mineralization. Some of the widely disseminated papers having application to the fresh-water section are by Jones and Buford (1951), Guyod (1954), Alger (1966), and Turcan (1966). These references, except the one by Guyod, deal with prediction of water quality from electric logs by use of a calculated formation factor. The electrical resistivity formation factor is the subject of the following discussion.

METHODOLOGY

The electrical resistivity of a sand-bed aquifer and its contained water (R_w) bears a relation to the resistivity of the water alone (R_w). This relation was expressed as a ratio (Archie, 1942) called the formation factor (F) which can be determined if the resistivity log and the specific conductance of a water sample from the aquifer are available. The electric-log resistivity should be read on a trace that reflects the quality of the water in the aquifer with a minimum of influence of drilling mud or hole diameter. Ordinarily the long-normal curve on multiresistivity electric logs is the most reliable for the determination. If the specific conductance of a sample of the water produced by a well is measured (usually in micromhos per centimetre at 25°C), it is a simple matter to convert it to resistivity by the relation $10,000 \div \text{conductance} = R_w$ in ohm-metres. The relation that is sought is $F = R_o/R_w$.

R_o , as read on the electric log, and R_w must be compared at the same temperature to be compatible in calculations for F . Therefore, it is important to know the temperature at the depth of the aquifer. For this purpose a graph depicting the geothermal gradient of the region is necessary. It is emphasized here that the temperature of a well's discharge may be an unreliable indicator of aquifer temperature, because water cools as it rises through an environment of lower temperature. The error is especially marked where a deep well of low yield is involved. For the present study, the graph relating water temperature to depth was constructed from a great number of temperature measurements on file. The more reliable measurements were those made at the bottom of wells by temperature-logging instruments and those made at the discharge points of high-yielding wells.

Since warm water is less resistive--that is, more conductive--than cold water, the electric-log resistivity (R_o) indicated for two sand beds and their contained water would be different for different depths of occurrence although the water type and degree of mineralization were the same. Consequently, either R_o or R_w must be adjusted to the temperature of the other. Theoretically, R_o should not be corrected to the temperature of R_w because the sand and the water do not change resistivity to the same degree with addition or reduction of heat--rather, R_o should be corrected. For practical purposes, however, at the temperatures and in the ranges considered, the error introduced by correcting R_o to 25°C is negligible, and the awkwardness of converting a temperature-measured R_o (from the water sample) is avoided along with the need for a second correction graph for use in determining R_w when R_o and F are known. The known or estimated temperature indicates, on the conversion graph, a correction factor by which the observed resistivity on the electric log can be multiplied to convert it to resistivity at 25°C.

Once a corrected observed resistivity (R_o) is obtained, it is divided by the resistivity of the water sample (R_w) to obtain the formation factor that is representative of the aquifer "in situ."

The SP (spontaneous potential) recorded on electric logs is used in the oil industry to calculate water quality in the saline-water section. It is less useful in the fresh-water section where sodium chloride is not the dominant ion. Contrary to common belief, the SP curve on electric logs is not always deflected to the right (positive) opposite a fresh-water sand. Note the interval between 1,860 and 2,010 feet on the log at right.

FINDINGS

More than 100 calculations of the electrical resistivity formation factor have been made for sand bed aquifers of Mississippi (see Table). The locations of wells at which electric logs and water samples were used to determine the factors are shown on the map. Because the factors do not all have the same degree of reliability, they are differentiated in three columns of the table, as explained in the headnote. Formation factors are presented by water-bearing unit in the table to permit averaging of values for a unit and comparison with those of other units. For the units having three or more values recorded, the averages are as follows:

Pliocene and Miocene beds	3.5
Cockfield Formation	2.4
Sparta Sand	2.8
Meridian-upper Wilcox aquifer	2.8
Eutaw Formation	3.7
Gordo Formation	7.3
Coker Formation	4.6

The average of all formation factors determined is 3.6 and the median value is 3.2. There is, however, as much range in the values for a given water-bearing unit as there is among the units. This indicates that in calculation of water quality the overall average value (3.6) may be as valid in many situations as the average determined for the specific water-bearing unit. Differences in formation factor appear to be related to water type and to porosity, cementation, and hydraulic conductivity of the sand.

✓ Fresh water is generally considered to contain less than 1,000 milligrams of dissolved solids per litre of water.

APPLICATION

The purpose of the formation factor is to provide the water-supply planner an estimate of the dissolved-solids content of water in an aquifer for which the only information available--for the site in question--is an electric log. If the general type of water is known--whether sodium bicarbonate, sodium chloride, calcium-magnesium bicarbonate, or other--it is possible, using the methods described by Jones and Buford (1951) and Alger (1966), to estimate the concentrations of the various ions. The chief applications of the formation factor in Mississippi are likely to be in connection with estimating the total mineralization of potential water supplies and protecting fresh-water aquifers from contamination by the agencies of man.

The following example illustrates calculation of the dissolved solids for the aquifer interval 410-450 feet (125-140 metres) on the electric log shown at the right which represents a 2,700-foot (823 m) section of Pliocene and Miocene sand and clay near Pass Christian on Mississippi's gulf coast.

$R_o = 65$ ohm-metres from long-normal curve
(Same as ohms metres/metre).

Temperature = 22°C (72°F) from geothermal gradient graph, depth 450 feet (137 m).

R_o (corrected for temperature) = $65 \times 0.94 = 61$ ohm-metres (See correction factor graph).

$F = 3.5$ (average for Pliocene and Miocene aquifers).

$R_w = R_o/F = 61/3.5 = 17.4$ ohm-metres (from the Equation $F = R_o/R_w$).

Specific conductance = $10,000/17.4 = 575$ micromhos per centimetre at 25°C.

Dissolved solids = $575 \times 0.65 = 374$ milligrams per litre (Dissolved solids and specific conductance are related by a factor of 0.65, on the average).

LIMITATIONS

One of the limitations to use of the formation factor in predicting water quality is apparent in the table listing formation factors. It is the relatively wide range in values obtained for each aquifer. Probably the most reliable values are the averages for the aquifers. A second limitation is the occasional mislabeling of resistivity scales on electric logs. If the scale is erroneous by a factor of 2, 5, or 10, a reliable prediction of the dissolved-solids concentration cannot be made. Fortunately, if the scale is off by a large factor it is usually obvious and can be disregarded. Another limitation is the proliferation of induction-electric logs and single-point resistivity logs at the expense of multiresistivity logs. The latter should be made in water test wells where the economics of the situation permit. The single-point resistivity curve gives only relative values and cannot be used to quantitatively determine the water quality. If more multiresistivity logs were made there would be more opportunities for computing formation factors, thus enhancing their reliability for predictive purposes.

Perhaps the most important limitation of all is the danger of predicting good water and finding at substantial cost that the water is saline, although the possibility of erroneously deleting from consideration a good aquifer is potentially even more costly. To avoid these pitfalls the water searcher should appreciate the inexact nature of the formation factor as a tool. It is merely an indicator and is subject to question on several of the elements that go into its makeup. The variables include porosity, surface-area effect, tortuosity of ion travel path, and conductivity of solids. Electrical effects of these and other factors are incompletely understood. Good results have been obtained through use of the formation factor, and valuable water resources have been brought to light. It should never take the place of judgment but should be considered another tool to supplement knowledge of the geology and the experience gained in previous exploration for water supplies in the area of interest.

The formation factor determined by this method should not be used with Schlumberger's curves to determine porosity. The factor was determined using "in situ" conditions, whereas that used to develop the F and porosity relation was based on "clean" samples.

DATA NEEDS

In general, the reliability of the formation factors calculated for the various aquifers or aquifer systems depends upon the number of values available from which averages can be obtained. It is evident from the table that much more valid average and median values can be obtained for the Pliocene and Miocene beds than for the other units. Therefore, a pressing need exists for multiresistivity electric logs of wells penetrating the formations in the northern half of Mississippi, especially those of Cretaceous age in the northeastern quarter of the State. The few values available for the Cretaceous units are of wide-ranging magnitude and consequently of poor applicability.

It would be helpful, in building up a library of formation factors, to obtain the specific conductance of water from wells in the vicinity of oil tests for which electric logs are available. The formation factors derived would have reliability secondary to those obtained where electric log and water sample represent the same well, but they would have substantial statistical applicability.

REFERENCES

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.

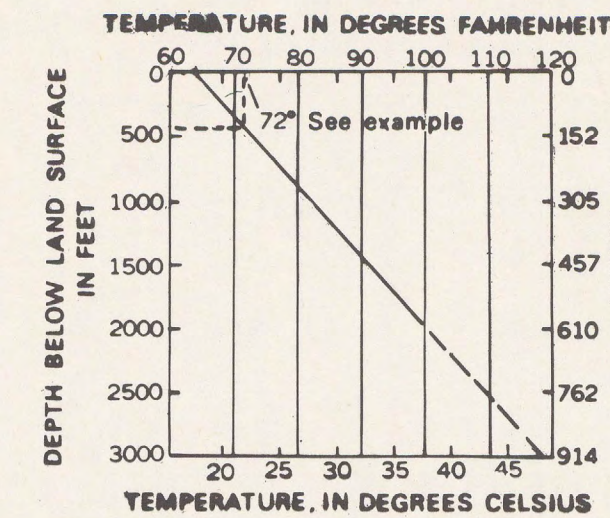
Archie, G. C., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: Am. Inst. Mining Metall. Pub. 1422 Petroleum Technology, 8 p.

Guyod, Hubert, 1954, Electrical well logging: Hubert Guyod, Houston, Tex.

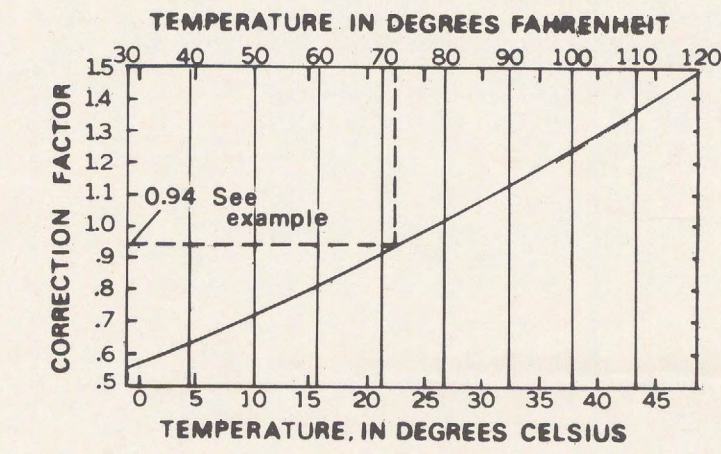
Jones, P. H., and Buford, T. B., 1951, Electric logging applied to ground-water exploration: Jour. Geophysics, v. 16, no. 1, p. 115-139.

Schlumberger Well Surveying Corporation, 1962, Log interpretation charts.

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.

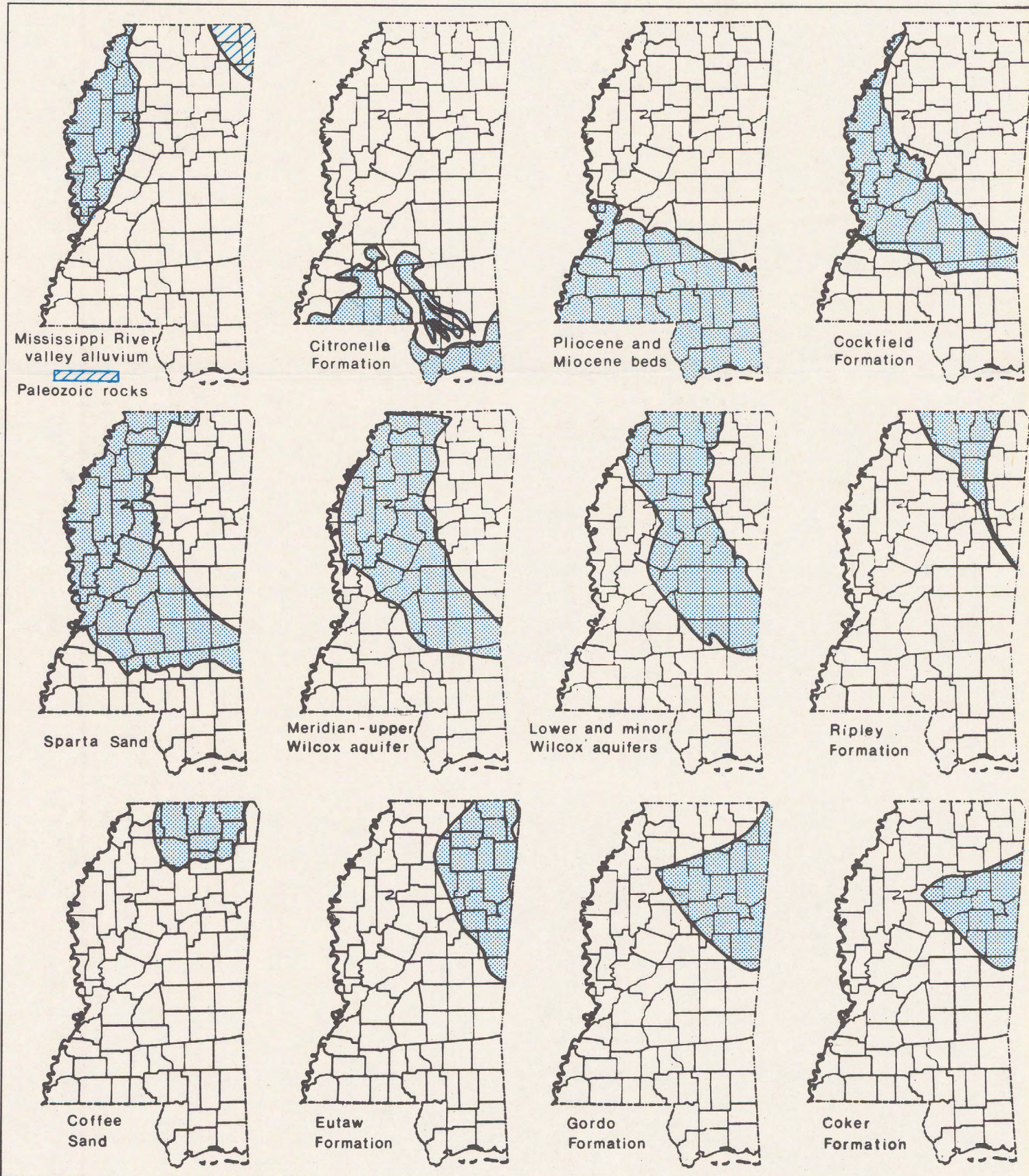


GENERAL GEOTHERMAL GRADIENT FOR MISSISSIPPI

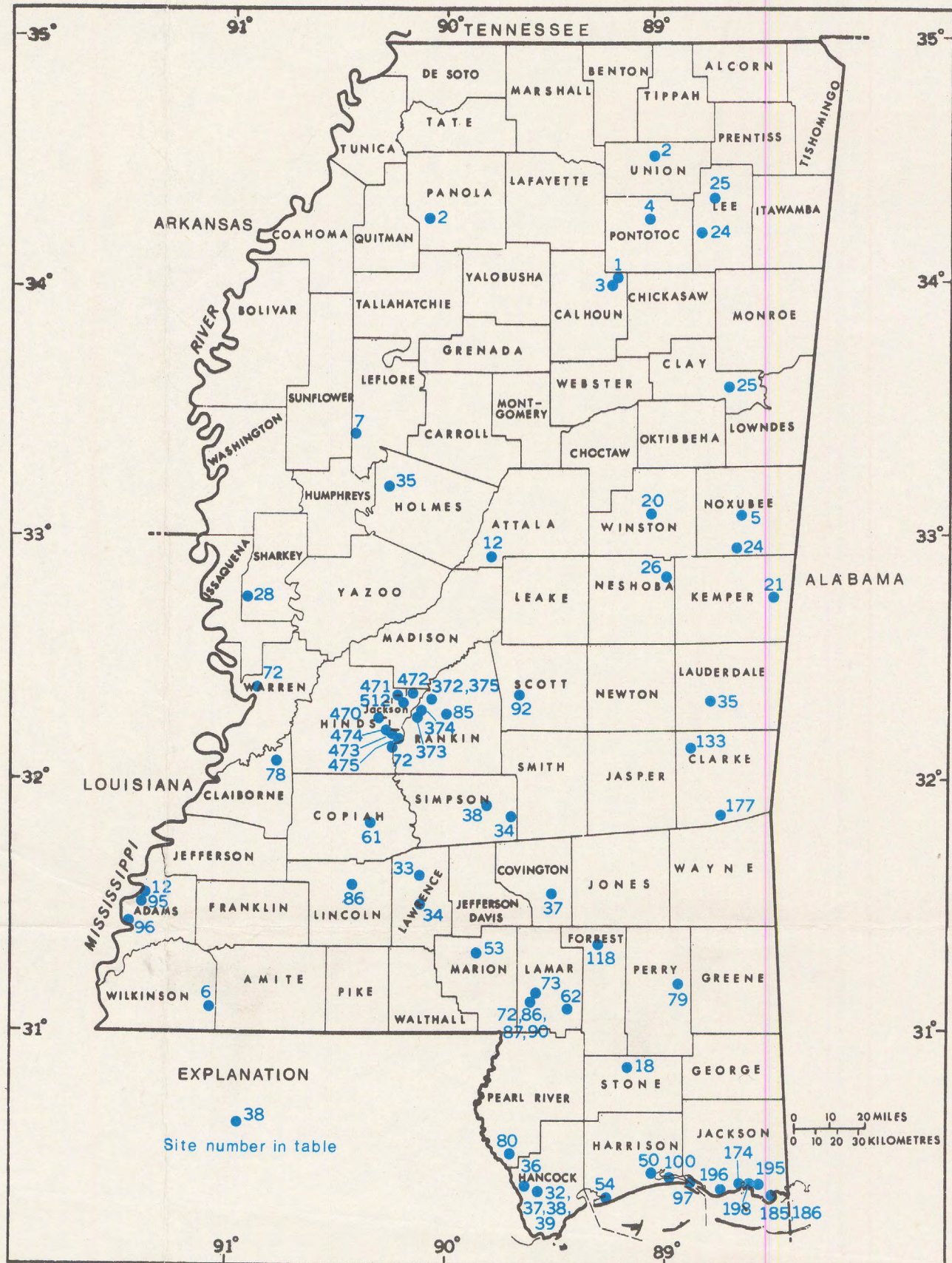


CONVERSION OF RESISTIVITY AT OTHER TEMPERATURES TO RESISTIVITY AT 25°C

PRINCIPAL WATER-BEARING UNITS OF MISSISSIPPI		
System	Series	Water-bearing unit
Quaternary	Pleistocene	Mississippi River valley alluvium
	Pliocene	Citronelle Formation
	Pliocene and Miocene	Undifferentiated
Tertiary	Eocene	Cockfield Formation
		Sparta Sand
		Meridian-upper Wilcox aquifer
		Minor Wilcox aquifers
		Lower Wilcox aquifer
Cretaceous	Upper Cretaceous	Ripley Formation
		Coffee Sand
		Eutaw Formation
		Gordo Formation
		Coker Formation
Consolidated rocks of Paleozoic age (limestone and chert)		



AREAS OF PRESENT AND POTENTIAL USE OF MISSISSIPPI AQUIFERS



SITES AT WHICH FORMATION FACTORS HAVE BEEN DETERMINED

FORMATION FACTORS CALCULATED FOR THE AQUIFERS OF MISSISSIPPI

A - Multiresistivity log and specific conductance available for well.
B - Specific conductance available for well near site of multiresistivity electric log.
C - Induction-electric log and specific conductance available for well.

Water-bearing unit	County	Site No.	Depth (ft)	Formation factor				Water-bearing unit	County	Site No.	Depth (ft)	Formation factor				
				A	B	C	A					B	C			
Citronelle Formation	Hancock	39	140			3.8		Cockfield Formation	Hinds	475	765	2.5				
Pliocene and Miocene beds (undifferentiated)	Adams	12	500			3.6		Rankin	72	85	980		2.4			
	do	12	700			3.9		Warren	72	71	1,208	2.3				
	do	95	240			3.6		Copiah	61	2,585	3.7					
	do	96	310			3.4		Hinds	470	1,035	2.7					
	do	78	515			2.7		do	471	750	3.5					
	Claiborne	37	250			3.6		do	472	750			2.9			
	Covington	37	975			3.6		do	473	1,150	2.9					
	Forrest	118	340			3.8		do	474	1,135	2.9					
	Hancock	32	2,000			3.1		Rankin	85	1,280			1.9			
	do	36	1,480			2.7		do	372	1,150	2.7					
Sparta Sand	do	37	1,435			3.5		do	373	1,005	2.5					
	do	38	1,700			4.3		do	374	870	2.2					
	do	39	140			3.8		do	375	935	2.6					
	do	39	150			3.6		Scott	382	880	3.2					
	do	39	485			2.9		Sharkey	28	1,060	3.0					
	do	39	595			3.6		Warren	72	1,715	2.8					
	do	39	675			2.7		do	72	1,628	3.0					
	Harrison	50	755			2.9		Meridian-upper Wilcox aquifer	Attala	12	780	5.2				
	do	50	2,270			3.1		Clarke	177	975			3.2			
	do	50	2,500			3.7		Hinds	512	1,485	2.6					
Meridian-upper Wilcox aquifer	do	54	1,800			5.0		Holmes	35	1,305	3.2					
	do	54	2,010			4.4		Lauderdale	35	840			2.4			
	do	54	2,255			3.5		LeFlore	7	1,385	3.8					
	do	54	2,490			3.5		Newton	22	640	3.1					
	do	54	880			2.8		Panola	2	620			2.9			
	do	54	1,111			3.0		Scott	92	1,610	2.2					
	do	97	670			2.6		Minor aquifers in Wilcox Group	Neshoba	26	310	3.8				
	do	100	865			2.8		Lower Wilcox aquifer	Clarke	133	1,360	4.4				
	Jackson	174	800			3.0		Ripley Formation	Calhoun	3	600	5.0			4.5	
	do	174	800			3.5		Coffee Sand	Union	2	890	1.7				
Lower and minor Wilcox aquifers	do	186	375			4.0		Eutaw Formation (including McShan fm)	Kemper	21	1,375		3.0			
	do	186	340			3.8		do	24	550		6.0				
	do	195	820			2.8		do	25	490	2.2					
	do	198	800			3.6		Pontotoc	4							
	Lamar	62	975			5.1		Gordo Formation	Calhoun	1	1,600		12			
	do	72	1,410			5.2		Clay	25	820	8.9					
	do	73	1,310			4.0		Kemper	21	1,720	3.9					
	do	86	400			3.6		Lee	25	620	8.9					
	do	86	1,000			4.0		Noxubee	5	1,320			4.8			
	do	87	480			5.0		Winston	20	2,680	5.0					
Coker Formation	do	90	680			3.0		Clay	25	1,020	3.6					
	Lawrence	26	920			1.5		Kemper	21	2,350	8.0					
	do	33	890			3.6		Noxubee	24	2,170	2.3					
	Lincoln	86	440			3.6										
	Marion	53	145			2.3										
	do	53	300			2.3										
	do	53	330			4.8										
	do	53	630			1.7										
	do	53	820			2.4										
	Pearl River	80	255			3.9										
Citronelle Formation	do	80	540			2.8										
	do	80	630			2.4										
	do	80	1,310			4.8										
	do	79	636			4.4										
	Herry	79	636			2.6										
	Simpson	38	410			2.5										
	Smith	34	1,865			2.5										
	Stone	18	950			2.1										
	Wilkinson	6	225			2.5										
	do	6	420			1.8										
do	6	1,700			4.2											

U.S. GEOLOGICAL SURVEY
JUL 21 1976
LIBRARY

3 1818 00168369 5

Multiresistivity electric log, showing fresh-water and saline-water aquifers. Dissolved-solids content (DS) of the water, in milligrams per litre, and formation factor (F) for the aquifer are shown where available.

FORMATION FACTORS AND THEIR USE IN ESTIMATING WATER QUALITY IN MISSISSIPPI AQUIFERS

Roy Newcome, Jr.
1975

M(236)49
1975n
C.1
JACKSON, MISSISSIPPI