POTENTIAL DEVELOPMENT OF FRESH WATER RESOURCES FROM THE LOWER WILCOX AQUIFER IN THE HEIDELBERG OIL FIELD, HEIDELBERG, MISSISSIPPI

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INTRODUCTION

Oil was first discovered at Heidelberg in 1944. Initial production was from the Eutaw Formation, but later wells resulted in the discovery of producing zones in deeper formations in the area. Eventually, more than 200 producing wells were drilled in the Heidelberg Oil Field (Figure 1).

Figure 1. Map showing location of Heidelberg Oil Field.

In the production of oil, salt water is commonly brought to the surface as well. This occurs because most hydrocarbon reservoirs occur within saline water-bearing formations. As the oil is produced, salt water migrates into the pore spaces formerly occupied by the oil, typically resulting in the production of a decreasing quantity of oil and an ever-increasing amount of salt water. At the surface, the salt water is separated from the oil and is normally disposed of in an injection well through which it is pumped back into a subsurface saline water-bearing zone that may be shallower than the producing interval.

Salt water produced in conjunction with oil production at Heidelberg (Figure 2) reportedly ranges from 47,000 to 168,000 milligrams per liter dissolved solids. Since 1950, approximately 410,000,000 barrels of oil field brine have been injected into the sands in the lower part of the Wilcox Group in the vicinity of Heidelberg.

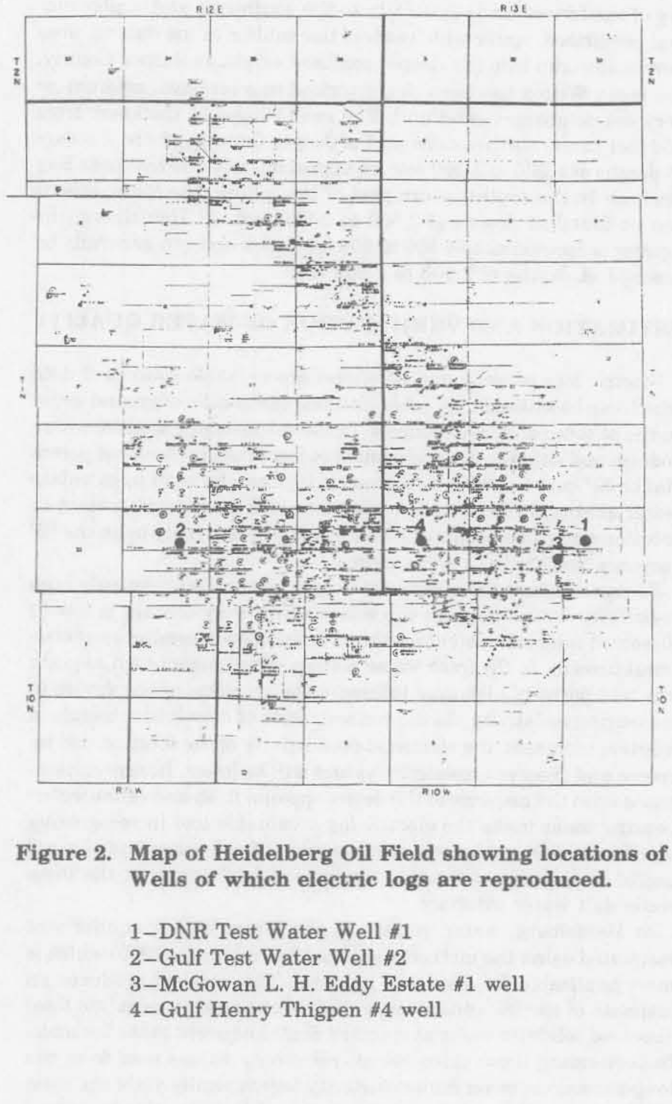

Figure 2. Map of Heidelberg Oil Field showing locations of Wells of which electric logs are reproduced.

1–DNR Test Water Well #1
2–Gulf Test Water Well #2
3–McGowan L. H. Eddy Estate #1 well
4–Gulf Henry Thigpen #4 well

WATER USE AND GEOHYDROLOGY OF THE LOWER WILCOX AQUIFER

A number of water supply wells are screened in the lower Wilcox aquifer in the area of Jasper, Clarke and Wayne counties. In Jasper County, the Rose Hill Water Association has a well about 17 miles north of Heidelberg which is 1,890 feet deep. There are at least 12 wells in the lower Wilcox in Clarke County. The city of Quitman's wells are as much as 1,934 feet deep. Approximately 16 miles to the east of Heidelberg, the town of Shubuta has a well which is 2,286 feet deep and the Hiwanee Water Association has another which is

2,368 feet deep. Two wells in Wayne County are known to be screened in the lower Wilcox. One well, belonging to the Hiwanee Water Association, is 2,777 feet deep and the other, owned by the town of Waynesboro, is 2,402 feet deep.

The lower Wilcox aquifer in the past was referred to as the basal Ackerman sand. It constitutes the deepest and most extensive aquifer system in the area of Jasper, Clarke and Wayne counties, where the base of fresh water is typically within the lower Wilcox. In this region, wells screened in the lower Wilcox may yield more than 1,000 gallons per minute.

The recharge area for the portion of this aquifer in Jasper County is believed to be located in northeastern Lauderdale and central Kemper counties and adjoining parts of Alabama. The direction of dip of the formation is generally to the southwest and, under normal conditions, water which enters the aquifer in the outcrop area moves downdip into the deeper confined sands. In Jasper County, the lower Wilcox has been characterized as a massive, medium- to very coarse-grained sand unit. The sand ranges in thickness from 250 feet in the northeastern part of Jasper County, where it occurs at depths of 1,200 to 1,300 feet, to approximately 400 feet near Bay Springs. In the southwestern part of the county, the lower Wilcox can be found at depths of 2,800 to 2,900 feet. At Heidelberg, the aquifer is approximately 300 to 350 feet thick and can generally be reached at depths of 2,300 to 2,600 feet.

ESTIMATION AND VERIFICATION OF WATER QUALITY

Electric logs of wells and boreholes are valuable sources of data which can be utilized to reliably estimate the quality of ground water in the absence of actual samples. In the saline-water section, where sodium and chloride are the dominant ions, the spontaneous potential or SP curve recorded on electric logs can be used to calculate water quality. In fresh water, other ions become more important in solution and calculations of water quality based solely upon the SP response are likely to be in error.

Formations that bear fresh water typically exhibit relatively high resistivity values because the water which they contain is low in dissolved mineral content and thus is not a good conductor of electrical current. In the fresh water section, other factors such as grain size and porosity also may influence the response of the device in measuring resistivity. As the concentration of dissolved minerals in solution increases, the electrical conductivity of the solution will increase and observed resistivity values will be lower. Interpretations based upon the response of the device opposite fresh and saline water-bearing zones make the electric log a valuable tool in recognizing aquifers which may be potential sources of fresh water and also are useful as a means of locating the base of fresh water or the fresh water-salt water interface.

At Heidelberg, water quality in the lower Wilcox aquifer was estimated using the method suggested by Newcome (1975) which is most applicable for sand bed aquifers. This method produces an estimate of specific conductance that can be used to calculate total dissolved solids for water at specified depths adjacent to the borehole. In performing these calculations, resistivity values read from the long-normal curve on multiresistivity logs typically yield the most valid results. Other information required includes the formation temperature at the chosen depth, which may be directly measured or estimated, and a formation factor which may be determined for an aquifer in a local area if a resistivity log and a water sample from the aquifer are available.

In January 1985, a well drilled in the town of Heidelberg by the Mississippi Department of Natural Resources (Figure 3) obtained the first valid water samples from the lower Wilcox aquifer in the area. The interval from 2,640 to 2,680 feet below land surface was selected for screening the well to collect water samples. Analysis of a water sample collected from this zone yielded a specific conductance of 900 micromhos and a value of 596 milligrams per liter total dissolved

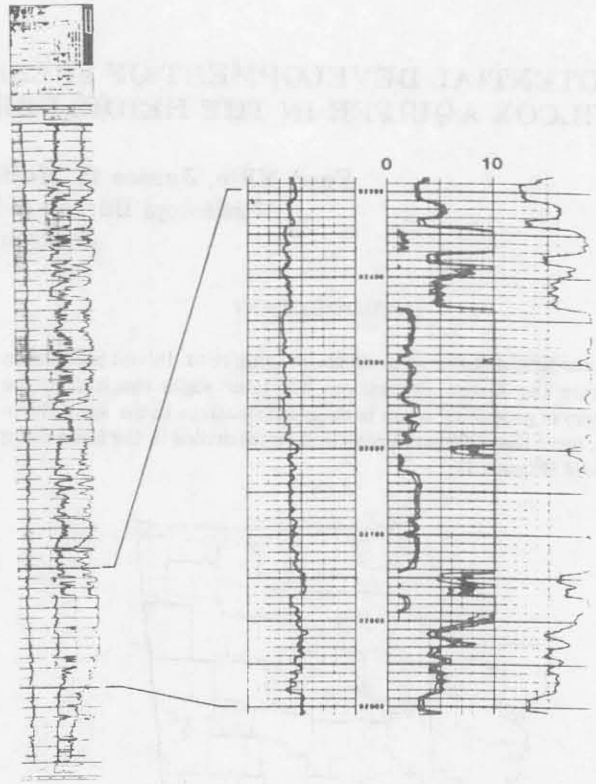

Figure 3. Electric log of DNR Test Water Well #1 (Enlargement shows lower Wilcox aquifer section.)

solids. A suite of geophysical logs was run on this welll prior to collecting water samples. The average value of resistivity measured in the screened interval was approximately 27 ohm-meters and the temperature was 101 degrees Fahrenheit. Since warm water is more conductive than cooler water and specific conductance of a water sample is normally measured for a temperature of 25 degrees Centigrade, a temperature correction factor must be applied to convert the observed resistivity value (Ro) of a sand bed aquifer and its contained water to an equivalent corrected resistivity (Roc). A temperature correction factor of 1.3 for 101 degrees F multiplied by the value Ro of 27 ohm-meters results in a value of 35.1 ohm-meters for the Roc. A formation factor (F) of 3.6 was applied using Newcom's method of calculating dissolved solids in the lower Wilcox in this area. This formation factor was obtained from the relation F = Ro/Rw, where the value of Ro is read directly from the electric log and Rw is the resistivity of the water from the aquifer alone. Both of these values of resistivity must be compared at the same temperature in order to calculate a value of F which can then be applied to other estimates of water quality for the aquifer for which it was determined in a particular locality.

The remaining steps in the calculation are:
Rw = Roc/F = 35.1 ohm-m/ 3.6 = 9.75 ohm-m
Specific Conductance = 10,000/Rw = 10,000/ 9.75 =
1,026 micromhos/cm at 25 degrees C
Dissolved Solids = (Specific Conductance) * (0.65) =
(1,026) * (0.65) = 667 mg/l

In May of 1985, a second test well (Figure 4) was drilled and logged, and a water sample was obtained from the lower Wilcox. This well was located in the western part of the Heidelberg oil field in

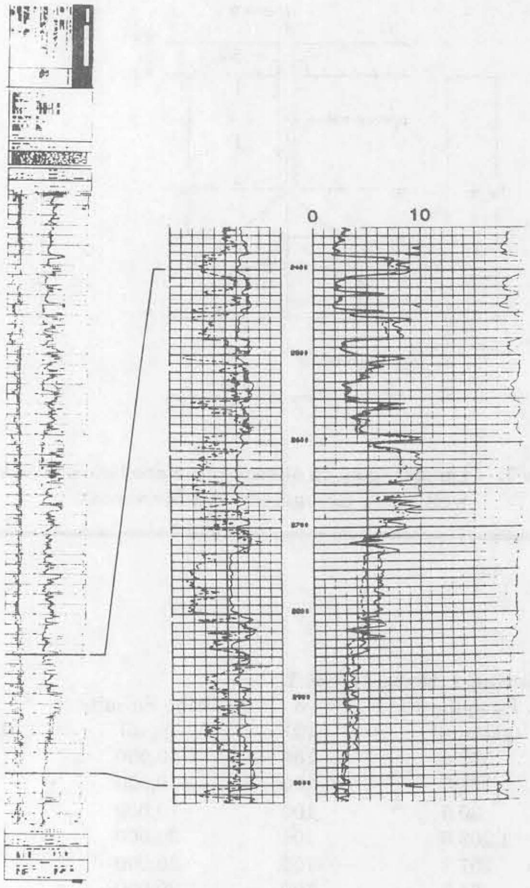

Figure 4. Electric Log of Gulf Test Water Well #2 (Enlarge ment shows lower Wilcox aquifer Section).

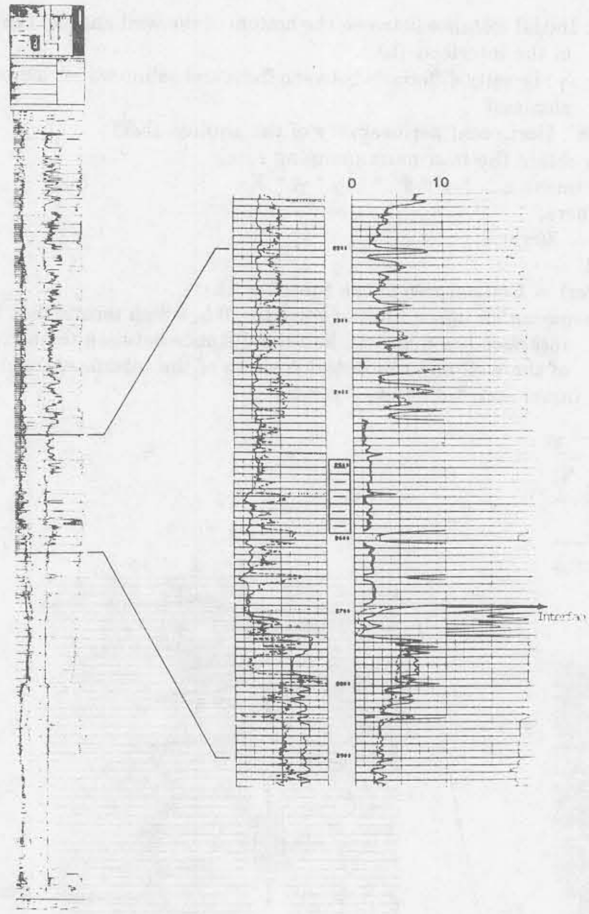

Figure 5. Electric log of McGowan L. H. Eddy Estate #1 well (Enlargement shows lower Wilcox aquifer section with apparent interface and hypothetical screened interval).

an area where the water in the lower Wilcox aquifer should be expected to be more mineralized than at Heidelberg. Analysis of electric log data for the screened interval from 2,617 to 2, 637 feet below land surface yielded estimates of specific conductance and dissolved solids of 3,268 micromhos and 2,124 milligrams per liter, respectively. The results of the lab analysis conducted on a water sample collected from this zone revealed a specific conductance of 3,450 micromhos and dissolved solids of 2,382 milligrams per liter.

These results effectively demonstrate that this method can be applied in the absence of water samples to estimate water quality in the lower Wilcox in the vicinity of Heidelberg. Electric logs of two recently drilled oil test wells in the Heidelberg oil field appear to show the interface between fresh water and salt water in the lower Wilcox aquifer. In the McGowan L.H. Eddy Estate No. 1 well (Figure 5), logged in 1981, the apparent interface is at a depth of approximately 2,690 feet below land surface. Average water quality in the zone from 2,490 to 2,590 feet below land surface was estimated to be about 1,000 milligrams per liter total dissolved solids. The Gulf Henry Thigpen No. 4 well (Figure 6) was logged in 1985. In the log of this well there seems to be an interface in the lower Wilcox aquifer at a depth of about 2,815 feet below land surface. The best quality water in the aquifer above this depth seems to be in the zone from 2,720 to 2,780 feet below land surface. The average value of total dissolved solids in this interval is estimated to be approximately 1,000 milligrams per liter.

POTENTIAL FOR AQUIFER DEVELOPMENT ABOVE A FRESH WATER-SALT WATER INTERFACE

In a dynamic equilibrium, fresh and salt water can exist as separate fluids in an aquifer. Being miscible fluids, there will be a transition zone rather than a sharp interface separating them, primarily the result of hydrodynamic dispersion. In this case, the transition zone is apparently narrow enough in comparison to the total thickness of the fresh and saline water sections to allow one to assume that the boundary between the two fluids is a sharp interface and the effects of hydrodynamic dispersion are negligible.

When pumping a well which is screened in the fresh water section of an aquifer directly above a salt water interface, the interface tends to be drawn upward in the direction of the well intake. This phenomenon is called upconing and is influenced by several factors such as the pumping rate of the well, distance of separation between the interface and the bottom of the well screen, permeability of the aquifer, hydrodynamic dispersion, and the relative densities of the fresh and saline water. If other factors are known, it is possible to estimate the maximum rate of pumpage which can be maintained without drawing salt water into the well screen.

Upconing of an abrupt interface below a pumping well which is screened in an aquifer in which fresh water overlays salt water is illustrated in Figure 7. The two fluids are separated by an abrupt interface, and there is negligible hydrodynamic dispersion.

An approximate analytical solution for upconing of a salt water interface directly beneath a pumping well, based upon the Dupuit assumptions and the Ghyben-Herzberg relation is given by Schmorak and Mercado (1969) as follows:

for $r = 0$ (just below the pumping well), and t approaches infinity

$Z - Q / 2 * \pi * d * (\Delta\gamma / \gamma) * Kx$

where;

Z : The ultimate rise of the interface at the new equilibrium, directly proportional to the pumping rate Q. (L)

Q : Discharge Rate. (L^3/T)

t : Time elapsed since start of pumping. (T) d : Initial distance between the bottom of the well and the center of the interface. (L)

$\Delta\gamma / \gamma$: Density difference between fresh and saline water. (Dimensionless)

Kx : Horizontal permeability of the aquifer. (L/T)

to obtain the maximum pumping rate,

$Q\ (max) \leq 2. * \pi * \theta^2 * (\Delta\gamma / \gamma) * Kx$

where;

$\theta = Z(cr) / d$

and

Z(cr) = Critical rise of the interface. (L)

assuming an upper limit of Z(cr)/d = 0.5, which means that the interface has migrated half the distance between the bottom of the well and the initial position of the interface, then;

$Q\ (max) \leq \pi * d^2 * (\Delta\gamma / \gamma) * Kx.$

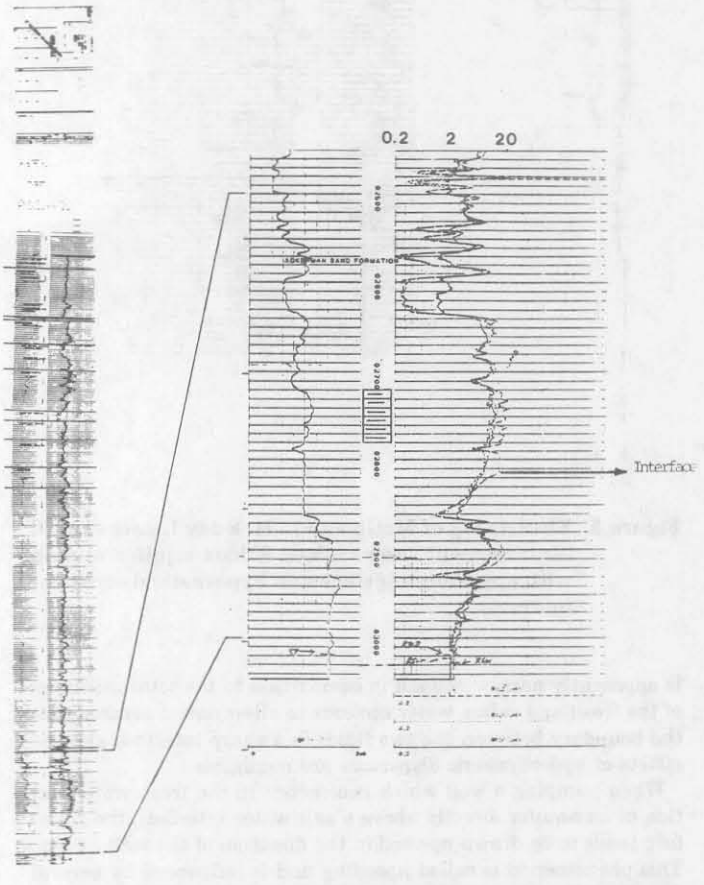

Figure 6. Electric log of Gulf Henry Thigpen #4 well (Enlargement shows lower Wilcox aquifer section with apparent interface and hypothetical screened interval).

For this solution, Wang (1965) assumed that saline water (30,000 ppm NaC1) has a density of 1.025 and distilled water has a density of 1.000. He further assumed that the density of the fluids is directly proportional to the concentration of total dissolved solids. Using this analytical solution and the logs of the McGowan L.H. Eddy Estate No. 1 and the Gulf Henry Thigpen No. 4 wells, a series of calculations was performed for the purpose of estimating the maximum pumping rates for hypothetical wells screened in the lower Wilcox above the apparent interfaces at these locations without inducing the salt water to rise sufficiently to enter the well screen. The results of these calculations, assuming fresh water salinity of 1,000 ppm and a range of values of brine salinity and aquifer hydraulic conductivities, are given below.

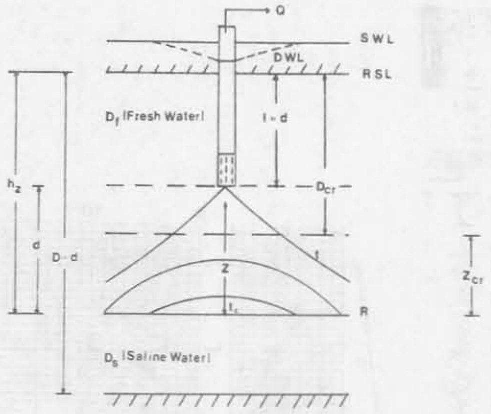

Figure 7. Upconing of an abrupt interface below a pumping well (after Schmorak and Mercado).

McGowan L.H. Eddy No. 1

Max. Pumping Rate (gal/min)	d (ft)	Brine Salinity (ppm)	Kx (ft/day)
572.5	100	10,000	470
121.8	100	10,000	100
30.5	100	10,000	25
1,208.6	100	20,000	470
257.2	100	20,000	100
64.3	100	20,000	25
1,844.7	100	30,000	470
392.5	100	30,000	100
98.1	100	30,000	25

Gulf Henry Thigpen No. 4

Max. Pumping Rate (gal/min)	d (ft)	Brine Salinity (ppm)	Kx (ft/day)
70.1	35	10,000	470
14.9	35	10,000	100
3.7	35	10,000	25
148.1	35	20,000	470
31.5	35	20,000	100
7.9	35	20,000	25
226.0	35	30,000	470
48.1	35	30,000	100
12.0	35	30,000	25

CONCLUSIONS

The results of these calculations suggest that there are substantial supplies of fresh water in the lower Wilcox aquifer in Heidelberg oil field which might be developed, particularly in those areas of suitable water quality located some distance from injection wells which disposed of salt water into the aquifer. In selecting sites for the location of water wells, it would be advisable to utilize electric logs from wells and test holes in the immediate area to determine the available water quality and the thickness of the aquifer section suitable for screening a well above a salt water interface. It is obvious from the calculations that at a location where there is not enough vertical separation between the interface and a supply of water of desirable quality, it might not be possible to produce enough water to justify drilling a well. On the other hand, these results also indicate that at a location where the aquifer contains a supply of good quality water which is sufficiently separated from an interface, it may be possible to produce more than 1,000 gal/min from the lower Wilcox.

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