THE TERTIARY-QUATERNARY AQUIFER RELATION IN NORTHWESTERN MISSISSIPPI

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INTRODUCTION

Purpose

In the fall of 1993, the staff of the Office of Land and Water Resources (OLWR) began an investigation to determine the influence of underlying Tertiary aquifers (Sparta and Cockfield) on the Mississippi River Valley alluvial aquifer in the Yazoo Basin of northwestern Mississippi, an area commonly known as the Delta. The alluvial aquifer supplies an estimated 2,000 million gallons of water per day, mostly for irrigation and fish culture. According to a report published by the United States Geological Surgey (USGS) in 1984, "continued heavy irrigation pumpage could significantly lower water levels in the alluvial aquifer and indirectly in the Tertiary aquifers" (Sumner and Wasson 1984). Water levels in the alluvial aquifer throughout the Delta have declined since the publication of this report. In some locales, declines have been as much as 25 feet from the early 1950s to 1993 (Bryant 1993).

Ongoing studies by OLWR have shown that direct recharge to the alluvial aquifer from some of the interior streams within the Yazoo Basin, rainfall on the surface of the alluvium, and even from the Mississippi River in certain areas is not as significant as previously thought. As pumping for irrigation and fish culture continues to increase in the Delta, it is imperative that we understand this ground-water flow system and the influences upon it if we are to prudently manage this water resource. One of the least known influences upon the alluvial aquifer is its relationship to underlying Tertiary aquifers. The two main goals of this project were to: 1) determine if the alluvium is connected with an underlying aquifer at several sites; and 2) conduct aquifer tests by which several aquifer properties can be characterized at these sites.

Methods

It was decided that the goals of this project could be attained by a drilling and testing program. This would involve selecting existing large-capacity irrigation or fish-culture wells at several sites and installing observation wells near the existing wells in the alluvial aquifer and in the underlying Tertiary aquifer. Geophysical logs would be run in all boreholes drilled for observation wells.

The next stage of planning involved outlining the parameters to be considered in choosing each of the drilling sites. First, each site should be located in an area where pumping from the alluvial aquifer is relatively intense. To conduct aquifer tests, an existing large-capacity alluvial well was necessary. This well should be able to pump at a rate of at least 1000 gpm so that the alluvial aquifer could be adequately stressed during each aquifer test. Other criteria were: 1) the existing well should have an electric power source; 2) it should have an open-ended discharge pipe or an adequate length of discharge pipe above ground to allow determination of the rate of discharge by either a flowmeter or the orifice pipe method, or by both methods; 3) space between the surface casing and the pump column should allow an electric tape probe or a transducer to be placed in the well to continuously record water levels during the test; 4) access by vehicle should be relatively easy (especially during wet periods); and, 5) the farmer's or landowner's permission to drill. After scouting several areas with these parameters in mind, six sites were chosen in Bolivar, Coahoma, Humphreys, Leflore, and Sunflower Counties (Figure 1).

At each site, the Tertiary observation well was placed as close to the irrigation/fish culture well as possible so that it would be well within the cone of depression created during pumping. The typical distance between the two wells was 15 to 25 feet. The distance between the alluvial observation well and the irrigation/fish culture well was 100 feet. Water levels in all observation wells were monitored by pressure transducers and data loggers. During monitoring, the data loggers were set to record water levels every two minutes.

All observation wells were completed flush with ground level and equipped with a securable manhole cover. In the Tertiary observation wells, a sand pack was placed in the annular space from the bottom of the screened interval up to a few feet below the clay layer separating the two aquifers. A bentonite seal was placed from this point through the clay layer up to several feet above the base of the alluvial aquifer. The bentonite seal ensured that there would be no leakage between the aquifers. Another sand pack was placed from the top of the seal up to within 10 feet of the surface. Neat cement was poured in the remaining annular space up to a concrete pad surrounding the well and manhole at the surface. For the alluvial observation wells, a sand pack was placed in the annular space from the bottom of the screen up to within 10 feet of the surface, and completion was similar to the Tertiary wells. All wells were developed by the air-blown method until the water was relatively clear and free of sediment.

Acknowledgements

A great deal of thanks is due the landowners: Mr. C. W. Jones - Bolivar County; Mr. Dave Labamascus with Nature's Catch - Coahoma County; Mr. Keith Hill with Reed Enterprises - Humphreys County; Mr. Steve Scott - Leflore County; Mr. Turner Arant - Sunflower County at Blaine; and Mr. Roger Boehs - Sunflower County at Sunflower. Without their gracious cooperation, certainly this project would never have been realized. Much credit is due Mr. Roy Geoghegan for, without his participation, the work discussed herein would have been more difficult and certainly not as enjoyable. The author expresses her gratitude to Mr. Jimmy Crellen and Mr. John Marble of the Office of Geology, as well as to Mr. Steve Jennings of the Office of Land and Water Resources for their efforts in making sure each hole was properly logged. The author also wishes to thank Mr. James Hoffmann and Mr. Ernest Boswell for their invaluable insight and assistance during the entire project.

DATA AND RESULTS

The following is a discussion of the results of the drilling, stratigraphic and hydrologic data collection, apparent aquifer interrelationship, and where applicable, aquifer tests for each site.

Bolivar County (Figure 1, Site 1)

Drilling Activity. Site #1 (Figure 1) was the location chosen in Bolivar County. The existing irrigation well, which was powered by a diesel engine, was adjacent to a rice field. The diesel power source was not the preferable choice; however, electric powered wells that could maintain the desired pumping rate were not available in this area.

Throughout the entire Delta, the geology can change significantly over a small distance. This site is no exception. From interpretations of electric logs from a home well 0.5 mile from the drilling site, the base of the alluvium is at about 155 feet below land surface, and there is about 15 feet of clay between the aquifers. However, according to the driller's log and geophysical logs from the Teritiary hole at this site, the alluvium is fairly thick - about 194 feet. The following table shows the complete lithology for site #1:

Depth	Lithology
0 - 20 feet	Clay
20 - 105 feet	Sand
105 - 194 feet	Sand & Gravel
194 - 202 feet	Clay
202 - 250 feet	White Sand

The surficial clay is about 20 feet thick. As the static water level is deeper than 20 feet, the alluvial aquifer is under water table conditions. Typically throughout the Delta, the alluvium grades upward from gravel (which can range in size from large cobbles to pea gravel) to very coarse sand, to medium sand, to fine sand, to silt and clay at the surface. The drillers were very familiar with this site as they had drilled the irrigation well in the summer of 1991. They mentioned encountering large gravel at about 130 feet. While drilling the Tertiary observation well, the large gravel caused several delays.

Immediately underlying the alluvial gravel is a layer of clay about 8 feet thick. Underlying the clay is a very fine, well-sorted, white sand of the Cockfield Formation. As shown on the log, the screen for the Tertiary observation well (well number BO-Q702) was set at a depth of 207 to 217 feet. The screen for the alluvial observation well (well number BO-Q701) was set at a depth of 90 to 100 feet, just above the large gravel.

Aquifer Interrelationship. Due to construction problems with the Tertiary well at this site, there is no conclusion regarding the connection between the alluvial and Tertiary aquifers at this time.

Alluvial Aquifer Test. Water level changes were monitored during the period May 23 - September 7; however, data used for the aquifer test were taken only from 1700 hours on 5/23/94 through about 0700 hours on 5/24/94. Figure 2 shows a hydrograph representing water level changes in the alluvial observation well during the aquifer test period. The sudden rise and decline of the water level between 0700 and 0800 hours on 5/24 was caused by the well being turned off for a few minutes and then turned on once again.

Alluvial aquifer characteristics for which calculations were made include: 1) transmissivity, and 2) hydraulic conductivity.

1) Transmissivity - The definition of transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer. A variation of the Theis method was used to calculate this characteristic, and the equation for this method is:

$$T = 264 \times Q/(h_2 - h_1)$$

where T = transmissivity (ft^2/day), Q = flow (gallons per minute), and (h_2-h_1) = the change in head or amount of drawdown with time. An average pumping rate of 2,068 gpm was measured during this first drawdown period. A semi-log plot was constructed showing drawdown versus time. A straight line was drawn through the plotted points over each log cycle. To make sure each line was the best-fitted line possible, a regression analysis of all log cycles was run, and only those cycles with a best fit of 0.95 or greater were considered. Then, the most conservative transmissivities obtained were deemed usable. The two log cycles of 60 - 600 minutes and 70 - 700 minutes met these criteria. The average transmissivity for this test was 77,000 ft^2/day.

2) Hydraulic Conductivity - This is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The equation is:

$$K = T/b$$

where K = hydraulic conductivity, T = transmissivity, and b = saturated thickness of the aquifer. The saturated thickness during the time transmissivity was calculated above was roughly 39 feet. Therefore, the hydraulic conductivty at this site was 500 ft/day.

<u>Coahoma County (Figure 1, Site 2)</u>

Drilling Activity. On the location map this is Site #2, which is on a fish farm. The fish culture well is an electric powered well. According to interpretations of electric logs run on a home well 1,348 feet deep screened in the Meridian-Upper Wilcox aquifer and about 500 feet from our drilling site, the base of the alluvium is about 173 feet below land surface, and there is only a few feet of clay separating the alluvium and the underlying Tertiary sediments. The geophysical log run on the Tertiary hole revealed the same thickness of clay. Based on the driller's log and geophysical logs from the Tertiary hole, the lithology at this site is as follows:

Depth	Lithology
0 - 20 feet	Clay
20 - 100 feet	Sand
100 - 170 feet	Gravel
170 - 174 feet	Clay
174 - 240 feet	White Sand

This site is similar to the Bolivar County site in two respects: the alluvium is fairly thick (approximately 170 feet) and near the base of the aquifer an interval of large gravel was penetrated. The large gravel caused several delays in drilling just as it did in Bolivar County.

The surficial clay is about 20 feet in thickness. The static water level was about 36 feet below land surface; therefore, the alluvial aquifer at this site was under water-table conditions. Underlying the alluvium is a sandy clay bed that is about 4 or 5 feet thick. Immediately underlying this clay is very fine-grained, well-sorted, white sand of the Sparta Formation. The screen in the Tertiary observation well (well number CO-N702) was set at a depth of 189 to 199 feet, and the screen in the alluvial well (well number CO-N701) at a depth of 95 to 105 feet, just above the interval of large gravel.

Aquifer Interrelationship. Water-level changes in both observation wells at this site were monitored for about 3 weeks; however, the fish culture well adjacent to the two observation wells only pumped for a short time period. The hydrograph in Figure 3 shows the period of pumpage. The significant drawdown in the Tertiary water level proves a very good connection between the aquifers. Apparently the clay underlying the alluvium has a high concentration of sand that allows the excellent hydraulic connection between the two aquifers.

Another interesting aspect of this hydrograph is the slight decline in the Tertiary water level between 0800 and 0900 hours. A nearby alluvial fish-culture well, approximately 0.15 mile from the drilling site, began pumping at this time causing this small decline. This is probably the result of the Tertiary aquifer being a much less transmissive aquifer than the alluvium which allows the affects of pumpage to be observed over a much greater area.

Another observation from the hydrographs is that during times when there was no pumping, the water level in the Tertiary aquifer was lower than that of the alluvial aquifer. Therefore, at this site, under static conditions, the potential for movement of water is from the alluvial aquifer to the Tertiary aquifer.

Humphreys County, (Figure 1, Site 3)

Drilling Activity. This is another site on a fish farm. The fish-culture well adjacent to the observation wells is an electric-powered well. Interpretations of the electric logs from a home well (about 0.25 mile from the drilling site) on the farm show the base of the alluvium to be about 130 feet below land surface and about 20 feet of clay between the two aquifers.

Based on the analysis of the geophysical logs of the Tertiary well, the base of the alluvium is at about 124 feet. The lithology (based on driller's log and geophysical logs) is as follows:

Depth	Lithology
0 - 40 feet	Clay
40 - 80 feet	Clay and Sand
80 - 124 feet	Sand and Gravel
124 - 152 feet	Clay and Sand
152 - 220 feet	White Sand

The surficial clay at this site is about 40 feet thick. The static water level is 28.90 feet below land surface; therefore, at this location, the alluvial aquifer is under confined conditions. The clay underlying the alluvium is about 20 feet thick; however, analysis of the gamma-ray log indicates that this clay may be fairly sandy. The sand of the underlying Cockfield aquifer is white, well-sorted, and very fine-grained.

The screen for the Tertiary observation well (HU-E702) was set at a depth of 158 to 168 feet. The screen for the alluvial observation well (HU-E701) was set at a depth of 82 to 92 feet.

Aquifer Interrelationship. The hydrograph in Figure 4 shows the water level changes in the two aquifers as the fish-culture well is pumped for a short period. The fact that the static water levels in each aquifer are almost identical is a good indicator that these aquifers are in excellent connection. Another indicator is the quickness and amount of decline in the Tertiary water level. Apparently the clay between the aquifers has a very high concentration of sand allowing the excellent hydraulic connection.

Leflore County (Figure 1, Site 4)

Drilling Activity. This site is on a fish farm. The fish-culture well near the observation wells was electric powered. The driller's log from a fish hatchery well about 0.75 mile away shows the base of the alluvium to be about 138 feet below land surface and approximately 8 feet of clay between the alluvial aquifer and the underlying Tertiary aquifer.

According to interpretations of the geophysical logs from the Tertiary well, the base of the alluvium is at a depth of 142 feet. The following table shows the lithology at this site:

Depth	Lithology
0 - 36 feet	Clay
36 - 51 feet	Sand
51 - 65 feet	Coarse Sand
65 - 103 feet	Coarse Sand and Pea Gravel
103 - 108 feet	Clay
108 - 142 feet	Sand and Pea Gravel
142 - 152 feet	Clay
152 - 184 feet	Sand

Thickness of the surficial clay is 36 feet, and the static water level in the alluvial observation well is below 41 feet, which indicates that the alluvial aquifer at this site is under water-table conditions. The clay underlying the alluvium is about 10 feet thick. The Tertiary sand is white, well-sorted, and very fine-grained typical of the Sparta Formation.

The screen for the Tertiary observation well (LE-J702) was set at a depth of 157 to 167 feet. The alluvial well (LE-J701) screen was set at a depth of 90 to 100 feet.

Aquifer Interrelationship. The hydrograph in Figure 5 shows only a slight decline in the Tertiary water level during pumpage of the adjacent fish-culture well and a slight recovery when the fish well is stopped. The very small change in water level at these times may be indicative of a response in the Tertiary aquifer to change in overburden or pressure in the overlying alluvial aquifer. The tiny spikes in the Tertiary hydrograph coincide with times the well was turned on or off. These also may indicate a response to a change in pressure in the overlying aquifer in the form of a pressure or shock wave produced when the fish-culture well is turned on and off.

As shown in the hydrograph in Figure 5, the head in the Tertiary aquifer is higher than that of the alluvial aquifer; however, due to the poor hydraulic connection between the aquifers at this site, there is probably very little recharge from the Tertiary to the alluvium.

Alluvial Aquifer Test. Water-level changes in the alluvial observation well were monitored during the period May 12 - 26. Pumping first began on May 12 at 0850 hours and continued for approximately six hours. The well was then turned off until about 2100 hours, at which time pumping resumed for several days. Data for the aquifer test were taken from the second pumping period. Discharge from the well was measured during the first pumping period and was assumed to be the same for the second period. An average discharge of 1,143 gpm was used to calculate transmissivity and hydraulic conductivity.

1) Transmissivity - The same method as used at the Bolivar County site was used for the Leflore County site. Four log cycles met the pre-determined criteria for these calculations, and they were the 50 - 500 minute through 80 - 800 minute cycles. An average transmissivity value of 59,000 ft^2/day was obtained.

2) Hydraulic Conductivity - An average saturated thickness over the above-mentioned log cycles was roughly 100 feet. The hydraulic conductivity calculated for this site was 590 ft/day.

Sunflower County at Blaine (Figure 1, Site 5)

Drilling Activity. The fish-culture well adjacent to the observation wells at this site is powered by electricity. Interpretations of electric logs from the farm headquarters well, about 0.25 mile from the drilling site, show the base of the alluvium to be about 130 feet below land surface and only 9 feet of clay between the aquifers; analysis of the geophysical logs from the Tertiary well, however, show about 40 feet of clay underlying the alluvium at this site. This clay is divided into two units that are separated by a thin sand. Based on the gamma ray log, the upper clay unit has a small concentration of sand, while the lower clay unit is fairly sandy. The lithology, based on geophysical logs and driller's logs, is listed below:

Depth	Lithology
0 - 40 feet	Clay
40 - 60 feet	Coarse Sand
60 - 115 feet	Sand and Gravel
115 - 120 feet	Gravel
120 - 160 feet	Clay and Sand
160 - 220 feet	Sand

The thickness of the surficial clay is about 40 feet. The alluvial aquifer is under water-table conditions as the static water level is about 44 feet below land surface. The Tertiary sand is very similar to that at the other sites - well-sorted, very fine-grained, white sand of the Cockfield Formation.

The screen in the Tertiary observation well (SU-L702) was set at a depth of 166 - 176 feet, and the alluvial observation well (SU-L701) screen was set at a depth of 90 - 100 feet.

Aquifer Interrelationship. This site is similar to the Leflore County site in that there is probably very little connection between the two aquifers as shown in the hydrograph in Figure 6. The Tertiary hydrograph is similar to that from the Leflore County site (Figure 5) in that there are small spikes at the times the well was turned on and off. The fact that there is less than a foot of decline in the Tertiary water level along with the presence of the small spikes may indicate the influence of change in the overburden or pressure from the alluvial aquifer.

Under static conditions, the head in the Teritary aquifer is higher that of the alluvial aquifer indicating that the potential for movement of water is from the Tertiary to the alluvium.

Sunflower County at Sunflower (Figure 1, Site 6)

Drilling Activity. The fish-culture well adjacent to the observation wells was electric powered. Interpretations of electric logs for an industrial water-supply well about 0.25 mile from the drilling site show the base of the alluvium to be about 120 feet below land surface and about 12 feet of clay between the aquifers.

The lithology of this site, as shown in the following table, is based on interpretations of geophysical logs and driller's logs:

Depth	Lithology
0 - 40 feet	Clay
40 - 80 feet	Pea Gravel
80 - 92 feet	Gravel and Sand
92 - 128 feet	Gravel, Sand, some Clay
128 - 146 feet	Sandy Clay
146 - 156 feet	Sand
156 - 162 feet	Clay
162 - 180 feet	Sand

The thickness of the surficial clay is about 40 feet. The static water level is 45 feet below land surface; therefore, the alluvial aquifer is under water-table conditions at this site. The base of the alluvium is at a depth of 128 feet. Underlying the alluvium are two clay units that are separated by about 10 feet of sand. According to the geophysical logs run on the Tertiary hole, the upper clay is slightly sandy and is about 18 feet thick, while the lower clay unit is about 6 feet thick and has a very small concentration of sand. The Tertiary sand underlying the clay is similar to that at the other sites in that it is well-sorted, very fine-grained, white sand of the Cockfield Formation.

The screen in the Tertiary observation well (SU-O702) was set at a depth of 164 - 174 feet. The screen for the alluvial observation well (SU-O701) was at a depth of 85 - 95 feet.

Aquifer Interrelationship. The hydrograph for this site (Figure 7) covers a time period of 2 days. In addition to the fish-culture well at the drilling site, there is another large-capacity alluvial well adjacent to a rice field approximately 175 feet from the drilling site. Pumping from these wells, both individually and simultaneously, is reflected in the hydrograph. The section of drawdown curve on July 25 from about 0800 hours to about 1830 hours represents pumping from the fish-culture well. The next section of the drawdown curve from July 25 at 1830 hours to July 26 at 0900 hours reflects pumping from the rice well. On July 26 between 0900 hours to 1000 hours, the fish-culture well was turned off and just after 1000 hours the rice well was turned off. The section of the hydrograph after this time reflects recovery in the water level. During the times of drawdown and recovery, there is a small change in the Tertiary water level. There is also some lag time between the times the pumping well was turned on or off and the response in the Tertiary water level. This is thought to indicate a small amount of leakage bewteen the Tertiary and the alluvial aquifers.

As shown in the hydrograph for this site, the head in the Tertiary aquifer is higher than that of the alluvial aquifer; however, due to the poor hydraulic connection between the aquifers, there is probably very little local recharge from the Tertiary to the alluvium.

SUMMARY AND CONCLUSIONS

The geology at each of the six sites is different; therefore, the hydraulic connection between the alluvium and the immediately underlying aquifer at different locations is never the same. The best hydraulic connection between the two aquifers was observed at the Humphreys County and Coahoma County sites where the clay separating the aquifers was very sandy. Poor connection was indicated by leakage at the Sunflower County site where a much better developed clay is present between the two aquifers. Then, at the Leflore County and Sunflower County at Blaine sites, a change in pressure in the alluvial aquifer during periods of pumpage was the main influence on the Tertiary water level.

Aquifer tests have been conducted at only the Bolivar and Leflore County sites. Transmissivities were 77,000 ft^2/day and 59,000 ft^2/day, respectively. Hydraulic conductivities were 500 ft/day and 590 ft/day, respectively. Aquifer tests will be conducted at the other four sites in the near future.

More of this type research is needed for the entire Delta region. Due to the significant differences in the geohydrology in this study area, extreme care should be used when we assume that the characteristics of one site are very similar to those at another site. Only after a number of studies of this type are completed may we begin to see a trend in similarities of characteristics for certain situations.

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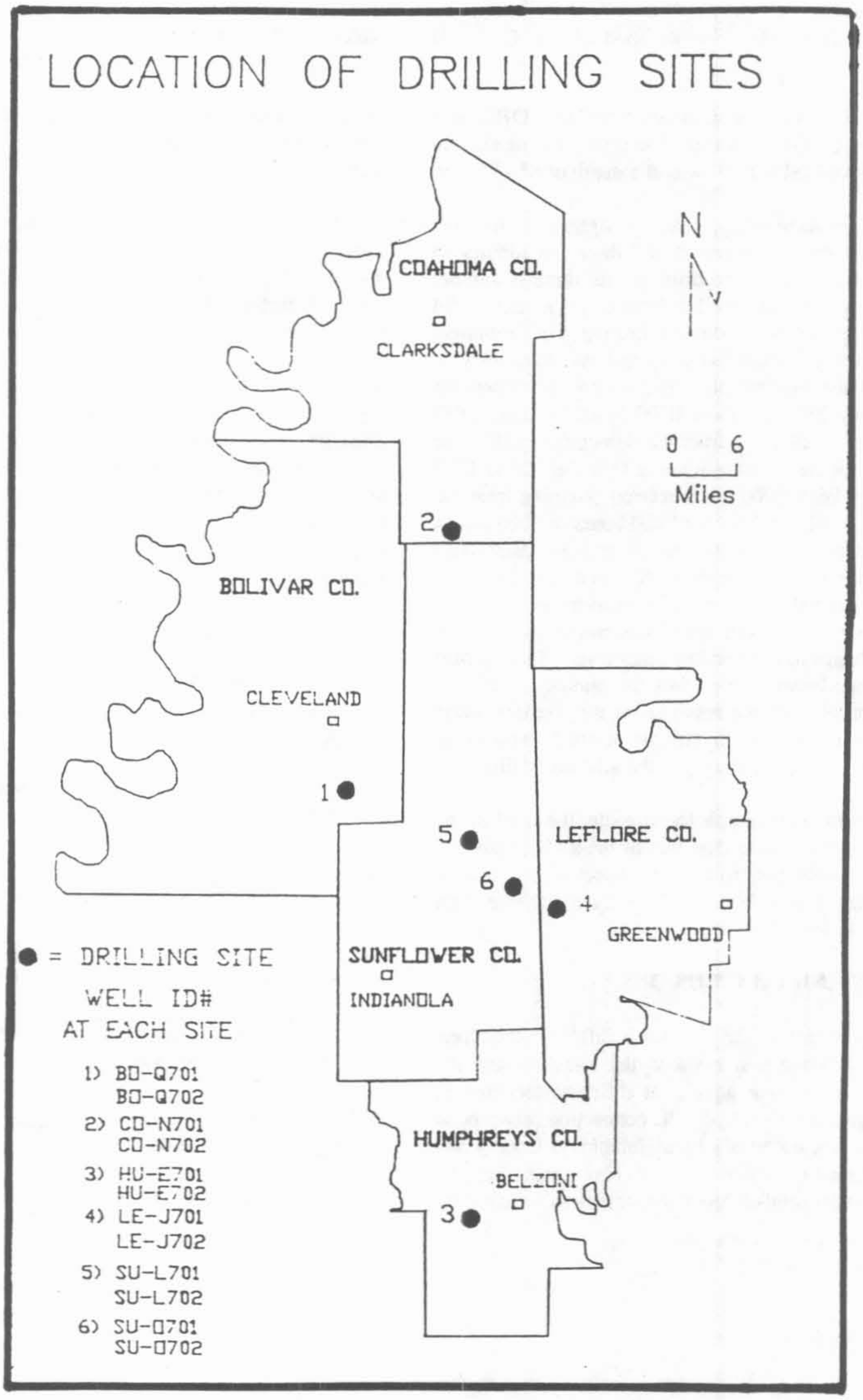
LOCATION OF DRILLING SITES
N
0 6
Miles
COAHOMA CO.
CLARKSDALE
BOLIVAR CO.
CLEVELAND
LEFLORE CO.
GREENWOOD
SUNFLOWER CO.
INDIANOLA
HUMPHREYS CO.
BELZONI
1
2
3
4
5
6
= DRILLING SITE
WELL ID#
AT EACH SITE
1) BO-Q701
BO-Q702
2) CO-N701
CO-N702
3) HU-E701
HU-E702
4) LE-J701
LE-J702
5) SU-L701
SU-L702
6) SU-O701
SU-O702

Figure 1

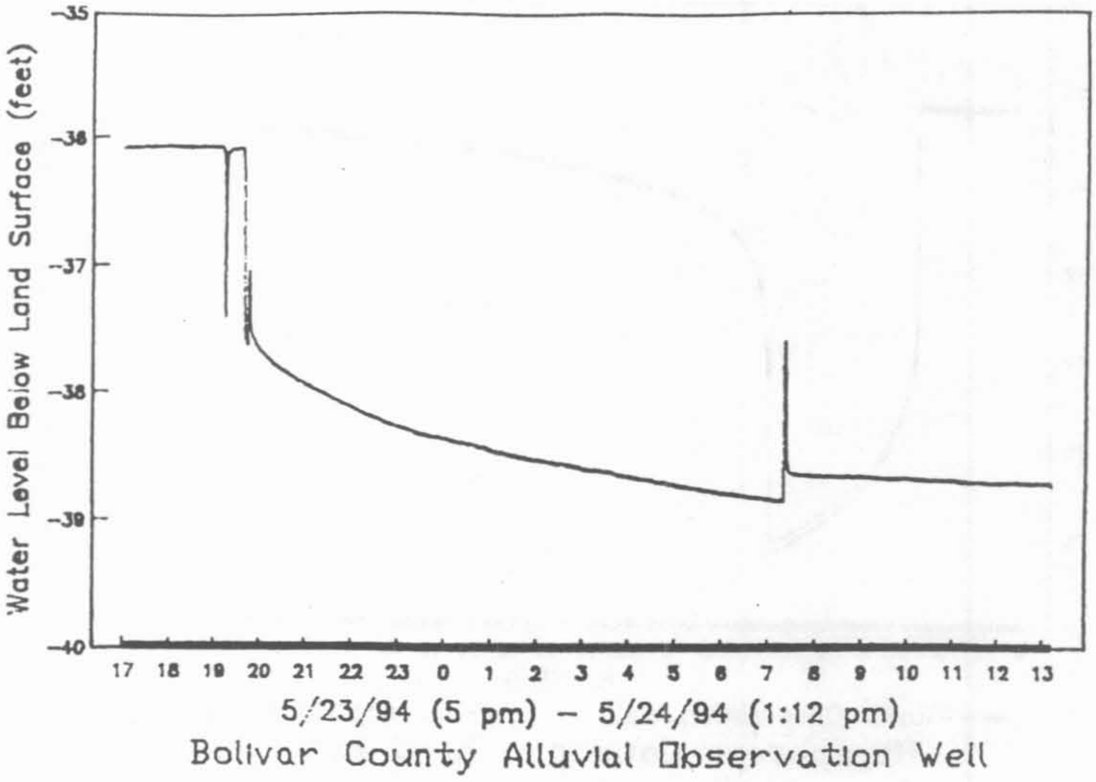

Figure 2

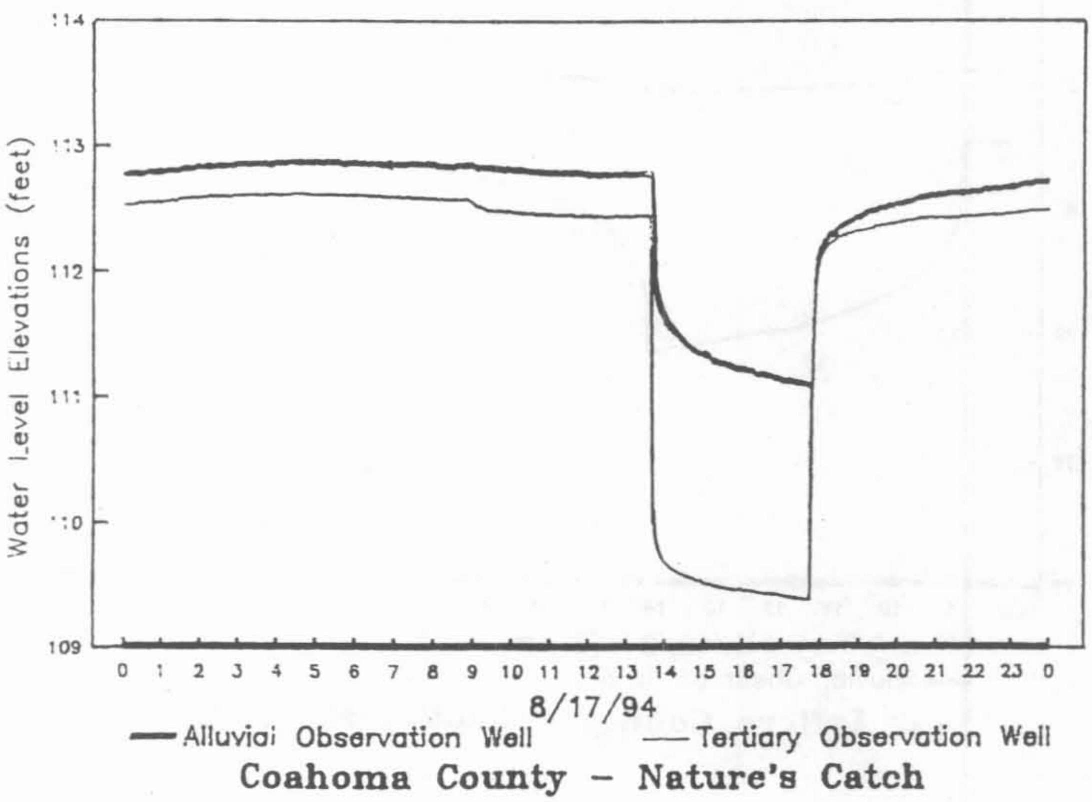

Figure 3

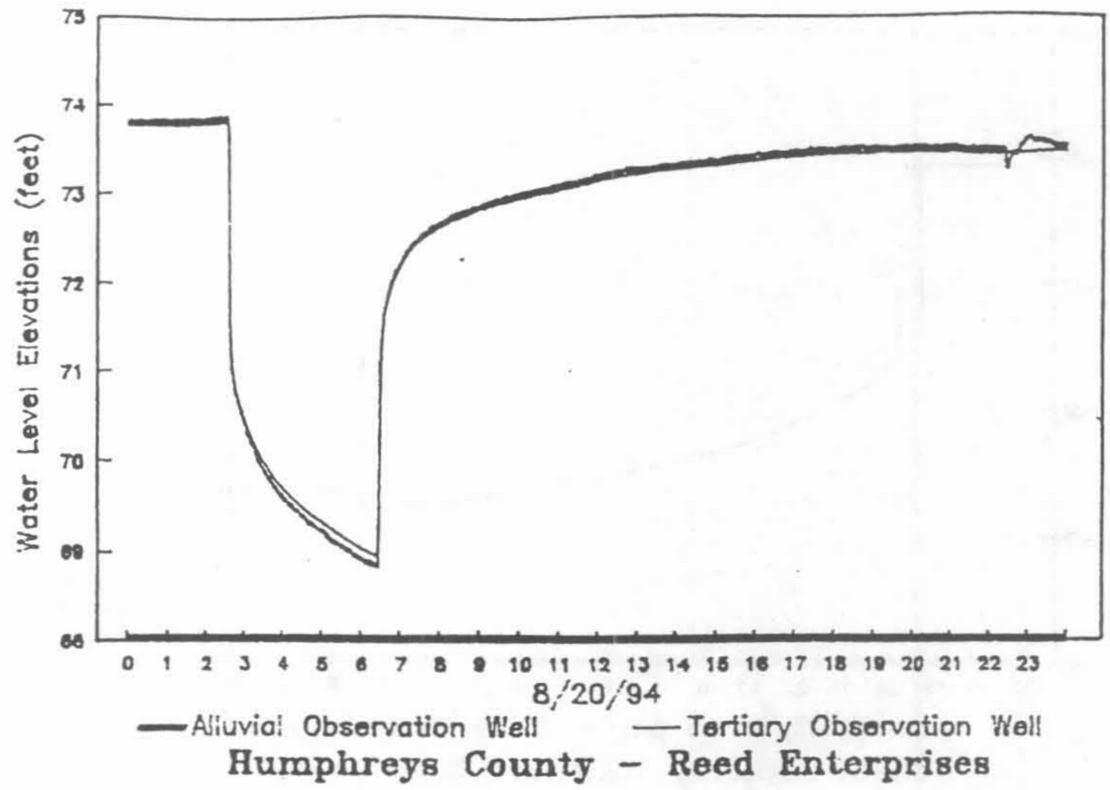

Figure 4

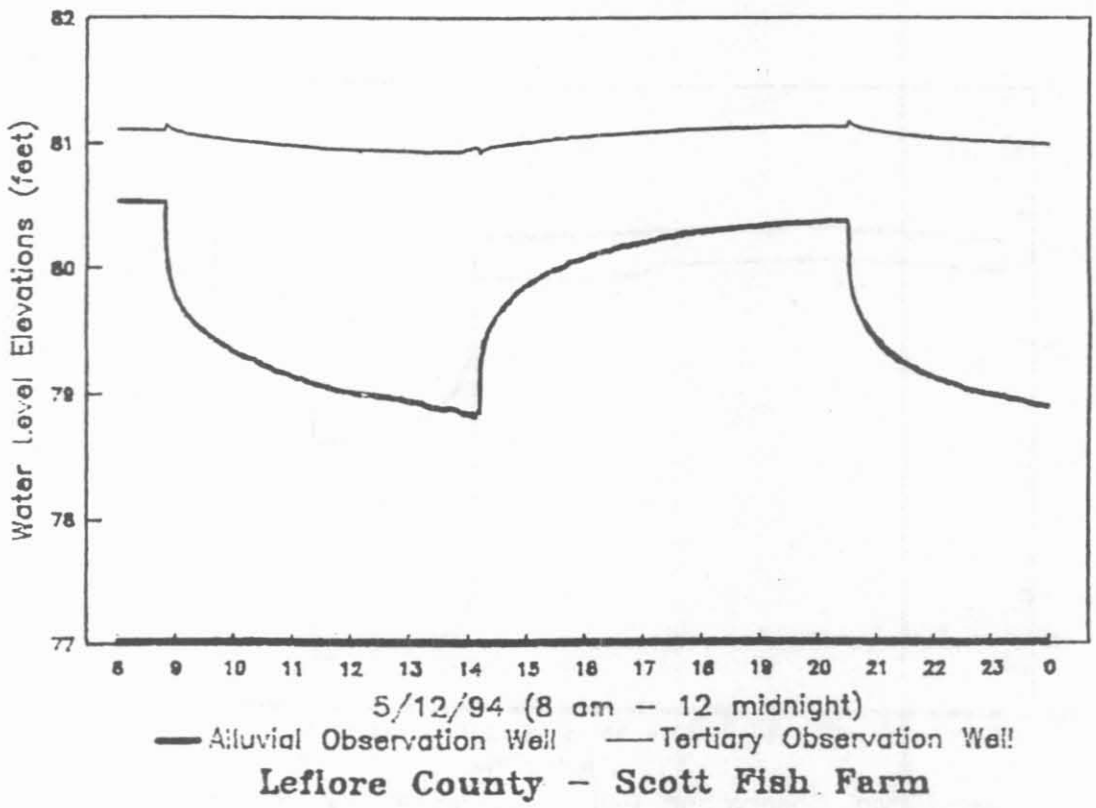

Figure 5

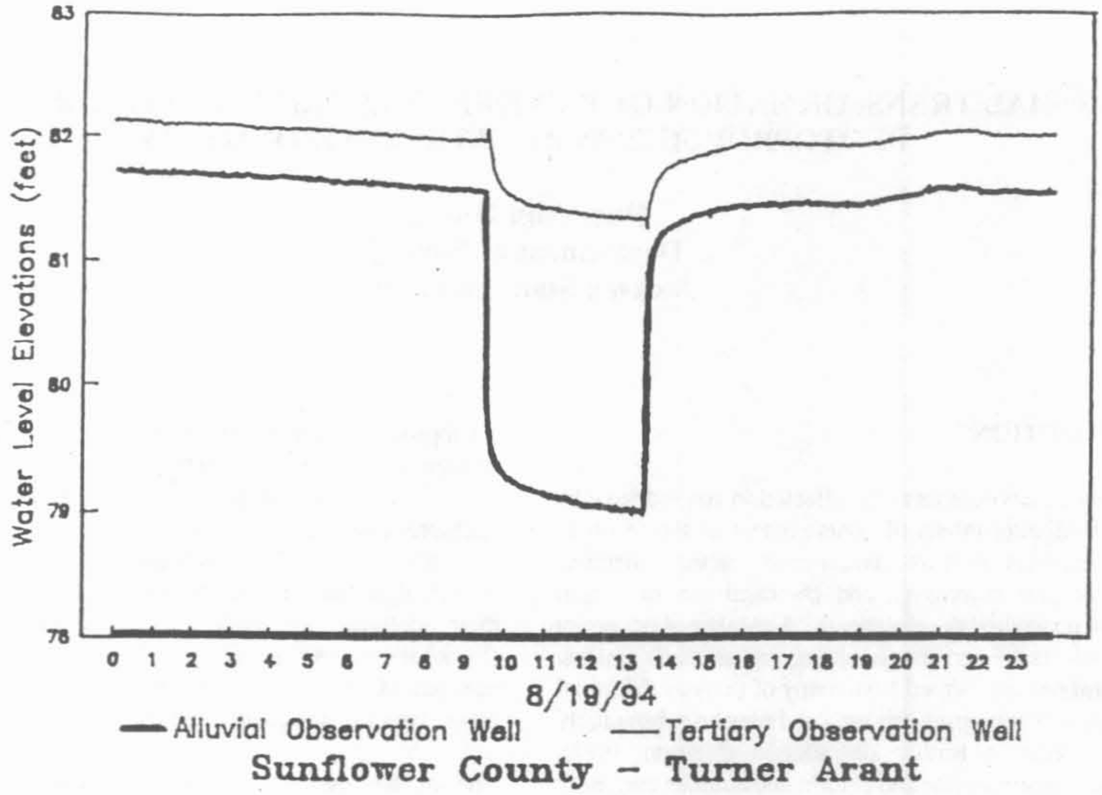

Figure 6

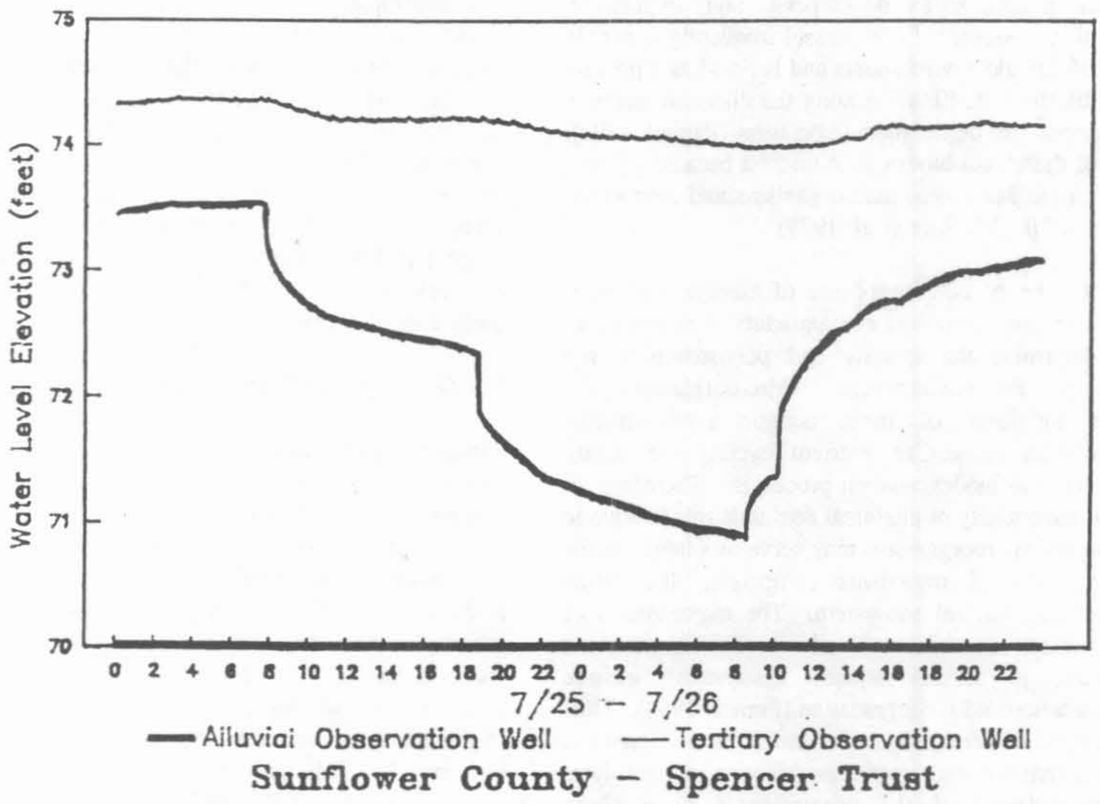

Figure 7