Determining Potential for Direct Recharge in the Mississippi River Valley Alluvial Aquifer Using Soil Core Analyses, Washington County, Northwestern Mississippi

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ABSTRACT

In 2005, the U.S. Geological Survey National Water-Quality Assessment program selected a site in the Bogue Phalia Basin for a study involving the sources, transport, and fate of agricultural chemicals. Because of its unique natural features, which include rich soils and an ample water supply, the basin is an ideal setting for agricultural activities, making it an area heavy in application of agricultural chemicals. In 2006, the U.S. Geological Survey began study at a site in Washington County, Mississippi. The objective of the study was to assess the potential for water and agricultural chemical transport to the Mississippi River alluvial aquifer by interaction with surface water and recharge from precipitation.

Previous water-quality and flow system studies of the Mississippi River alluvial aquifer in northwestern Mississippi, locally referred to as the "Delta", have given rise to the questions about the effect and magnitude of the vertical recharge component of the flow system. Some models have indicated that rainfall is the single largest contributor to recharge of the alluvial aquifer, which is a surprising result given the dense clay soils overlaying the aquifer. In the topostratum of an agricultural field adjacent to the Bogue Phalia near Leland, soil cores were collected during installation of four shallow wells (all less than 24 feet deep). The soil cores were analyzed for bulk density, grain size distribution, and permeability. Hydraulic conductivity was estimated using three methods: (1) a falling head permeameter to determine vertical hydraulic conductivity; (2) the Rosetta Stone program, which uses bulk density and grain size values to model hydraulic conductivity values; and (3) the Hazen method, which uses effective grain size and sorting of the soil to determine empirically the hydraulic conductivity. The resulting data indicate that the upper 8 feet of topostratum consists of a clay loam with vertical hydraulic conductivity values ranging from 10^{-5} to as low as 10^{-7} centimeters per second. The interval from 10 to about 16 feet was a sandy loam with hydraulic conductivity values ranging from 10^{-3} to 10^{-4} centimeters per second. The data and the relatively homogenous and continuous blanket of lower permeability clay loam suggest that the potential for vertical recharge is low. However, appreciable lateral recharge from the Bogue Phalia is likely as the river incises the clay loam to the higher conductivity fine, sandy loam interval.

Keywords: Agriculture, Ground Water, Hydrology, Sediments, Surface Water

Introduction

The Delta, a 7,000-square-mile area of the Mississippi River alluvial plain in northwestern Mississippi, is underlain by the Mississippi River alluvial aquifer. This aquifer is the most heavily pumped in the state and is the sole source aquifer for agricultural and industrial water. The hydrology of the alluvial aquifer has been defined extensively by Arthur (2001), Boswell and others (1968) and Snider and Sanford (1981).

Arthur (2001) used MODFLOW, a modular 3D finite-difference ground-water flow model, to study the flow system of the alluvial aquifer. Arthur reported that the most important source of vertical recharge to the alluvial aquifer is precipitation, which is surprising because it is seemingly incongruent

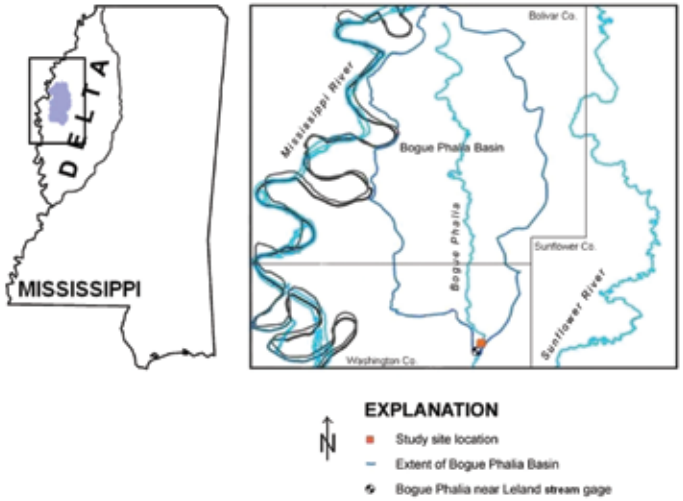

Figure 1. Location of Bogue Phalia Basin in the Delta of northwestern Mississippi.

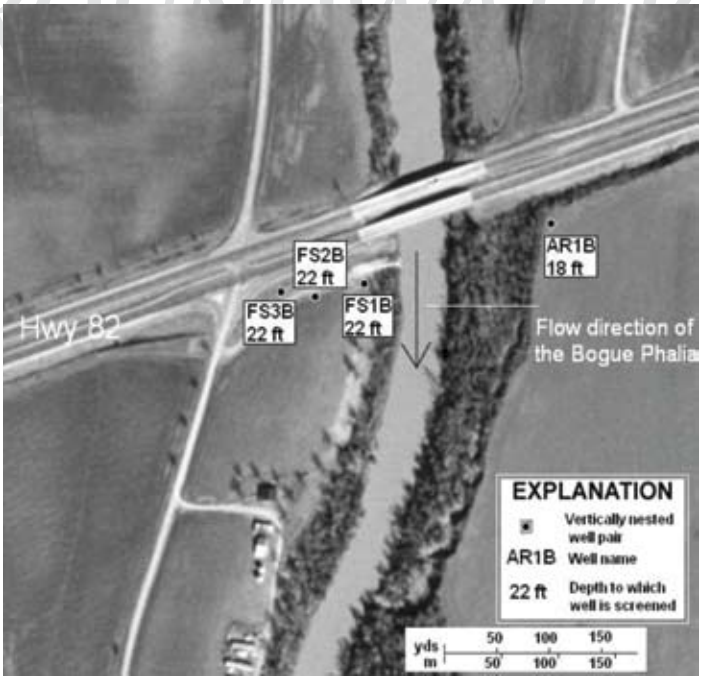

Figure 2. Aerial view of Bogue Phalia study site and location of the vertically nested well pairs.

with the lithology of the Delta. Additional study is needed in the Delta to better understand the magnitude and distribution of recharge from rainfall (Arthur, 2001).

In 2001, the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began studies in five agricultural basins within the United States to better understand how the transport and fate of water and agricultural chemicals is affected by natural factors and agricultural management practices. Assessments of two more basins began in 2005, including the Bogue Phalia Basin in northwestern Mississippi (fig. 1), which was selected because of its unique natural features.

The need to further define the source of vertical recharge to the alluvial aquifer prompted a study to identify the types of soil and assess soil permeability in the basin. In 2006 a site was selected in an agricultural field along the Bogue Phalia, east of Leland, Washington County, Mississippi, to investigate the potential for water and agricultural chemical transport to the alluvial aquifer.

This paper presents the results of an investigation into the mechanisms and pathways of water transportation through the unconsolidated soils overlying the Mississippi River alluvial aquifer in the Bogue Phalia Basin by determining the saturated vertical and empirical hydraulic conductivity values of the different soil types overlying the aquifer. In the study area, four shallow wells were installed in two agricultural fields on the banks of the Bogue Phalia.

Study Area

The study area, identified as "Bogue Phalia at Highway 82, Fratesi Boat Ramp," is located in a soybean field in the Bogue Phalia Basin, east of Leland, Mississippi. The field is adjacent to U.S. Highway 82, and the Bogue Phalia divides the field into two separate parcels of land (fig. 2). A public boat ramp is located on the west side of the Bogue Phalia.

The study site contains rich floodplain soils and an ample water supply. The average rainfall for Washington County is 52 inches annually, which makes for an ideal agricultural setting (Taylor and others, 1971), and an area in which agricultural chemicals are heavily used. Agricultural chemicals have been detected recurrently in surface water and rainfall in this area since the 1990s (Coupe and Capel, 2005). An earlier study on the Bogue Phalia indicated the presence of many herbicides. (Coupe, 2000).

Data Collection and Analysis

In March 2006, vertically nested shallow wells were installed, oriented in an east-west axis, which is assumed to be the direction of regional ground-water flow. Four shallow wells were installed with a Geoprobe, a direct-push hydrau-

lic-sampling device. The wells were cased and instrumented to collect temperature and water-level data. Water levels ranged from a depth of 17.5 to 18.5 feet below land surface. Eighteen soil cores, 4-foot by approximately 2-inches, were collected using the Geoprobe. The Geoprobe allowed for the soil to be extracted in cylinders, making it possible to analyze the soil by depth because each core was representative of a small section of the soil stratum. As cores were extracted, they were collected in plastic tubes, which were then enclosed with rubber caps and sealed with electrical tape to retain the in-situ water for soil moisture data analysis. At the site, the soil type and interval change were recorded on the core tube with permanent marker. Subsequently, data sheets were completed in the field to document the depth to which the wells were drilled, what material was encountered and at what depths, and to what interval the wells were screened. Any use of trade, product, or firm names is for identification purposes only and does not constitute endorsement by the U.S. Government.

The collected soil cores were analyzed for permeability, bulk density, and grain size distribution during summer 2006. The first step in analyzing the cores was to differentiate each soil type by depth. A first assessment was done as the cores were extracted from the ground; but, to improve accuracy, the cores were visually and texturally analyzed further to note any subtle grain size changes or distribution that might have been overlooked while in the field. This assessment was performed in the laboratory using the methods described by the USDA in their Soil Texturing Field Flow Chart (Midwest Geosciences Group, 2001). The USDA Texturing Field Flow chart identifies soils based on the feel of the soil material, its grittiness when wet, and its cohesiveness, or propensity to roll into a ball and produce a ribbon when squeezed. Values for hydraulic conductivity (K) were obtained directly using a falling head permeameter (FHP) test (Raynolds and others, 2001) and modeled by the Rosetta Model (Rosetta Model, 1999) using bulk density values and grain size percentages, which were obtained using the Pipette method of grain size distribution (Hall, undated). The grain size distribution data were used to determine the empirical K from the Hazen method (Fetter, 2001).

Analytical Methods

Methods used to analyze the data include the falling head permeameter to determine K, the Rosetta Model to determine K, and the Hazen method to determine K. The Pipette method was used to determine grain size distribution, and X-Ray diffraction was used to identify the clay minerals.

Bulk Density

For bulk density, the samples were extracted so that the exact volume of the soil was known. In some cases, when possible, remaining sections of core that were tested in the permeameter were used, because the volume of soil could be calculated from the equation for the volume of a cylinder. The samples were then dried in a laboratory oven for 48 hours, and weighed. The bulk density is equal to the dry weight of the sample divided by the volume of the sample (Hall, undated).

Pipette Method of Grain Size Distribution

After the sections of core were taken for the permeameter, samples from each soil type were then taken to determine grain size distribution. The samples for the grain size distribution were analyzed using the Pipette method of grain size distribution by weight percentage (Hall accessed July 2006). Each test used a 20-gram sample from each soil type that was sieved through 0.90-, 1.17-, 2.29-, 7.62-, and 10.16-millimeter openings.

The dry weight retained for each grain size was determined using the Pipette method, (Hall, accessed July 2006) and those values were used to calculate the grain size percentage of each sample. Grain size distribution curves were then plotted from the percentage data and were used to determine the d_{10} (the grain size that is 10 percent finer by weight) and d_{60} (the grain size that is 60 percent finer by weight) values, which were used for the Hazen method.

Falling Head Permeameter

The falling head permeameter (FHP) method was determined to be the better testing method rather than the constant head permeameter method, because the sample material was primarily unconsolidated, non-granular soils.

The procedure for the falling head permeameter was adapted from Raynolds and others (2001). The equation used to calculate the K values from the falling head permeameter test is as follows:

$$K = aL/At(\ln h_0/h_1), \quad (1)$$

where:

K equals hydraulic conductivity in centimeters per second;
a equals the area of the manometer (the tube through which the water is transported to the core);
A equals the sample area;
h_0 equals initial head;
h_1 equals the final head;
L equals the sample length; and
t equals time.

Cores were first selected for the FHP test based on the cohesiveness and homogeneity of the sediment in each section. Sections of core, 6 centimeters long, were removed from each soil type to test in the permeameters. Each section of core had to contain enough clay or silt to hold it together during the testing. The permeameter test was modified from Raynolds and others (2001) to adjust for the soil type that was collected from the study area. Because the soil sections were smaller in diameter than most permeameters have the capacity to test, a specialized falling head permeameter was built. Using Raynolds and others (2001) as a model and using common hardware store supplies, a modified falling head permeameter was successfully built.

After extracting the soil section, the exact dimensions of the cylinder of soil were measured, and the section was encased in paraffin wax before any evaporation occurred and to ensure that no shrinkage of the core occurred. Before encasing, the core was inspected for any surface features that might cause preferential flow during testing. Nearly half of all sections that were to be tested had vertical, shallow gouges down the length of the section caused by the plastic "rabbit" used by the Geoprobe during extraction of the cores from the subsurface. To prevent water from running through the grooves, a razor knife was used to slice horizontal grooves into the outside of the cylinder of soil. These cuts were made slightly deeper than the vertical gouges. The carved grooves captured the wax and prevented water from running down between the wall of the core and the wax.

After the permeameter test was completed, the encased section of soil was saturated with a blue dye solution to test for flow on the outside of the core. The dye would, theoretically, travel the same paths that the water traveled through the core. Then the core was cut from its encasement and inspected for blue areas around the surface of the core and on the inside of the wax casing. The test was complete unless evidence of preferential flow was found. If blue dye was visible on the outside of the soil core, another section of the same soil type was tested again. The head values and recorded times, along with the dimensions of the core and manometer, were used in a formula that gave the K value in centimeters per second.

Hazen Method

The Hazen method of grain size analysis is empirically based. The method uses the effective grain size and the sorting of the soil to determine the K.

The equation used to determine the K for the Hazen method is as follows:

$$K = C(d_{10})^2, \quad (2)$$

where:

K is hydraulic conductivity in centimeters per second;
d_{10} is the effective grain size in centimeters; and
C is a coefficient based on grain size and correlated values.

Very fine, poorly sorted sand has a C coefficient ranging in value from 40 to 80. The C coefficient for fine sand with appreciable fines ranges from 40 to 80. Medium, well-sorted sand has a coefficient that ranges from 80 to 120. Coarse, poorly sorted sand has a C coefficient that ranges

from 80 to 120, and clean, coarse, well-sorted sand has a C coefficient that ranges from 120 to 150 (Fetter, 2001). The d10 value is derived from the grain size distribution curve plotted for each sample.

Rosetta Model

The Rosetta Model is an empirically-based method for determining the hydraulic conductivity. The Roestta Model is a computer program that uses bulk density values and sand, silt, and clay percentages as input to derive a value for hydraulic conductivity (Rosetta Model, 1999).

X-Ray Diffraction

To determine the clay mineralogy of the soil, representative samples were scanned on a Scintag XDS 2000 diffractometer. Approximately 1 gram of powdered soil was placed in a centrifuge tube filled with water. Following agitation, the sample was placed for 10 seconds in a centrifuge to remove higher specific gravity minerals. The supernatant fluid was drawn off into a separate tube and centrifuged again for 20 minutes. The sediment at the bottom of the centrifuge tube was re-suspended in a small amount of water and deposited on a glass slide with a pipette and permitted to dry. All slurry-mounted samples were scanned. Expandable layer clays were detected by an increase in the d-spacing after exposing the slides to ethylene glycol vapors overnight. The final scans were done after heating the slides to 400° C and again after heating to 550° C to destroy heat sensitive clays (Starkey and others, 1984).

Results

The sand percentage found above the 10-foot depth for all wells ranges from 4.1 to 18.2 percent, with an average of 11.6 percent. A significant increase in the sand percentage occurs below the 10-foot depth. The sand percentage from below the 10-foot depth for all wells ranges from 20.8 percent to 99.6 percent (table 1). The average sand percentage below the 10-foot depth for all wells is 75.8 percent. The bulk density data indicate a similar shift at the same depth interval (fig. 3).

There is an apparent change in the bulk density values of the soil above and below the 10-foot depth (fig. 3). There is a transitional area in the 10-foot depth zone in which the sediments transition from a silty loam to a fine sandy loam (table 1). In looking at the different lithologies, there is a notable close range of bulk density values for each soil type, and there is also a notable shift in bulk density below 10 feet. The bulk density values decrease with depth due to increase in percentage of sand. These values indicate that the soil porosity increases with depth. One might expect K to increase as the bulk density values decrease. The range of bulk density values above the 10-foot depth is about 1.7 to 2.2 grams per cubic centimeter, with an average bulk density value of about 2.0 grams per cubic centimeter. The range of bulk density values below the 10-foot depth, but above the 17-foot depth is lower, from about 1.2 to 1.7 grams per cubic centimeter with an average bulk density value of 1.36 grams per cubic centimeter. As the depth reaches 17 and 19 feet, and as the soil begins to include larger-grained sand, the bulk density values are on the higher end of the range for the fine sandy loams above (between 1.36 and 1.70 grams per cubic centimeter) with an average bulk density value of 1.51 grams per cubic centimeter (fig. 3).

Figure 4 shows how the three different methods used to obtain hydraulic conductivity relate. Because the FHP (falling head permeameter) could test only the shallower sections of the wells, and the Hazen method could be used only on the

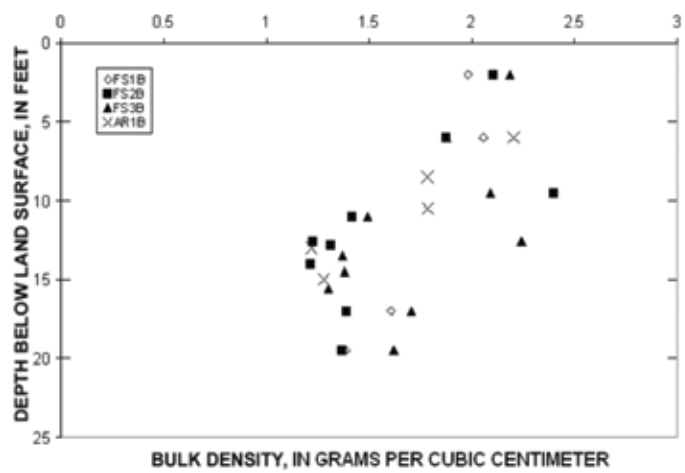

Figure 3. Bulk density by depth at four well locations at the study site.

Table 1. Hydraulic conductivity values as estimated by falling head permeameters (Raynolds and others, 2001), Rosetta (Rosetta Model, 1999), and Hazen methods (Fetter, 2001), and the silt, sand, and clay percentages determined using the Pipette method of grain size distribution for four shallow wells at the study site.
[ft, feet; cm/s, centimeters per second; N/A, not applicable]

Well	Depth (ft)	Kz Permeameter (cm/s)	Rosetta k cm/s	Hazen k cm/s	Percent Sand	Percent Silt	Percent Clay
FS1B	2.0	7.11E-06	2.39E-04	N/A	11.8	88.2	0.00
FS1B	8.00 - 10.00	Soil cores not recoverable					
FS1B	6.00	no flow after 24 hours	2.00E-04	N/A	10.6	89.4	0.00
FS1B	17.0	N/A	8.62E-04	5.76E-03	99.6	0.30	0.15
FS1B	19.5	N/A	8.88E-04	4.00E-03	99.6	0.35	0.05
FS2B	2.00	7.80E-05	7.17E-05	N/A	4.1	87.2	8.70
FS2B	6.00	no flow after 24 hours	1.94E-04	N/A	11.0	79.3	9.64
FS2B	9.50	6.45E-06	8.41E-06	N/A	12.1	81.6	6.36
FS2B	11.0	N/A	6.34E-04	1.00E-03	80.0	20.1	0.00
FS2B	12.6	N/A	5.50E-04	N/A	26.9	67.0	6.17
FS2B	12.8	N/A	5.16E-04	1.96E-03	81.1	18.2	0.72
FS2B	14.0	N/A	8.41E-04	4.00E-03	96.4	3.34	0.27
FS2B	17.0	N/A	8.86E-04	4.84E-03	99.4	0.60	0.00
FS2B	19.5	N/A	6.36E-04	2.25E-03	79.9	17.5	2.64
FS3B	2.00	1.73E-05	7.25E-05	N/A	14.0	78.7	7.32
FS3B	6.00	no flow after 24 hours	2.97E-04	N/A	14.4	82.6	0.00
FS3B	9.50	1.71E-05	1.09E-04	N/A	8.8	84.3	6.90
FS3B	12.6	N/A	5.83E-05	N/A	20.8	72.3	6.91
FS3B	12.8	N/A	5.16E-04	1.96E-03	81.1	18.2	0.72
FS3B	13.5	N/A	8.79E-04	6.76E-03	99.0	0.76	0.29
FS3B	14.5	N/A	8.47E-04	4.00E-03	96.7	2.21	1.11
FS3B	17.0	N/A	6.15E-04	2.89E-03	88.3	7.79	3.90
AR1B	6.00	5.86E-07	4.73E-05	N/A	11.6	79.6	8.80
AR1B	8.50	5.82E-07	2.65E-04	N/A	18.2	74.2	7.68
AR1B	10.5	N/A	2.65E-04	N/A	26.1	66.3	7.64
AR1B	13.0	N/A	7.61E-04	2.25E-03	88.6	11.4	0.00
AR1B	15.0	N/A	5.62E-04	6.40E-04	51.0	49.0	0.00

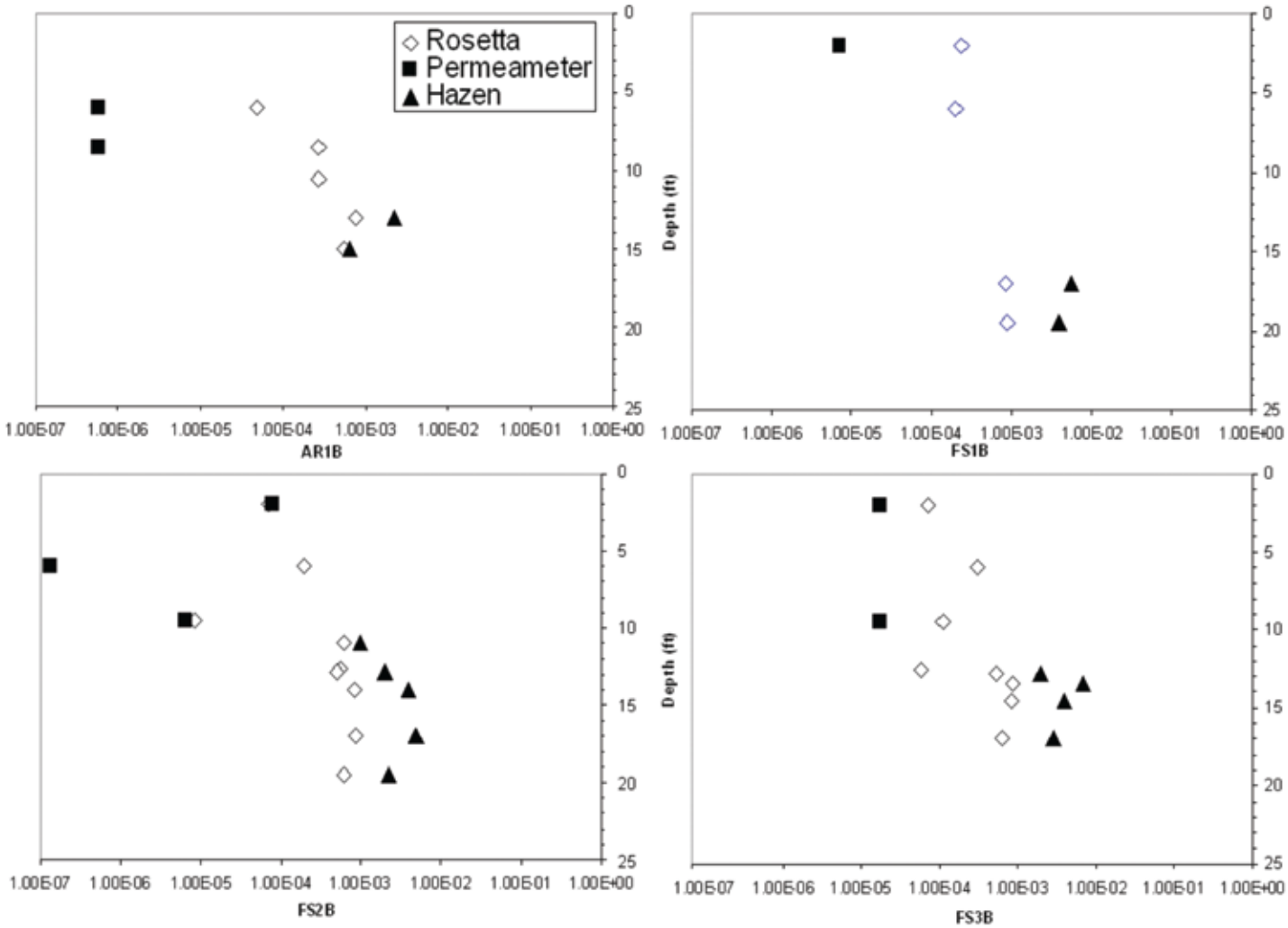

Figure 4. Relation of hydraulic conductivity values in centimeters per second, as estimated by three methods (falling head permeameter, Rosetta, Hazen) to depth in feet.

deeper sections of the wells to determine K values, these two methods could not be compared to each other. In the graph showing hydraulic conductivity values for the samples from AR1B, the FHP values do not match with the Rosetta values. The permeameter values are more than one order of magnitude lower from the Rosetta values. However, in this same graph, Rosetta and Hazen values are less than an order of magnitude different. In the graph of the hydraulic conductivity values for samples tested from FS1B, the FHP value is more than one order of magnitude less than the Rosetta value. For all other graphs, the FHP and the Rosetta values of K are not more than an order of magnitude different. Similarly, the Rosetta and the Hazen values of K are not more than one order of magnitude different in all graphs from each well.

Figure 5 shows a cross section through the study area that illustrates the placement of each well. The cross section of the study site, created from data gathered from analysis of soil cores, shows the layers of soil and the correlations of the layers between the wells. The cross section illustrates what all of the permeability, bulk density, and grain size data indicate, which is that there is a change in lithology below the 10-foot depth (fig. 5). Below the 10-foot depth, on the cross section, the lithology shifts from a silty clay loam and a silty loam to a fine, sandy loam (fig. 5).

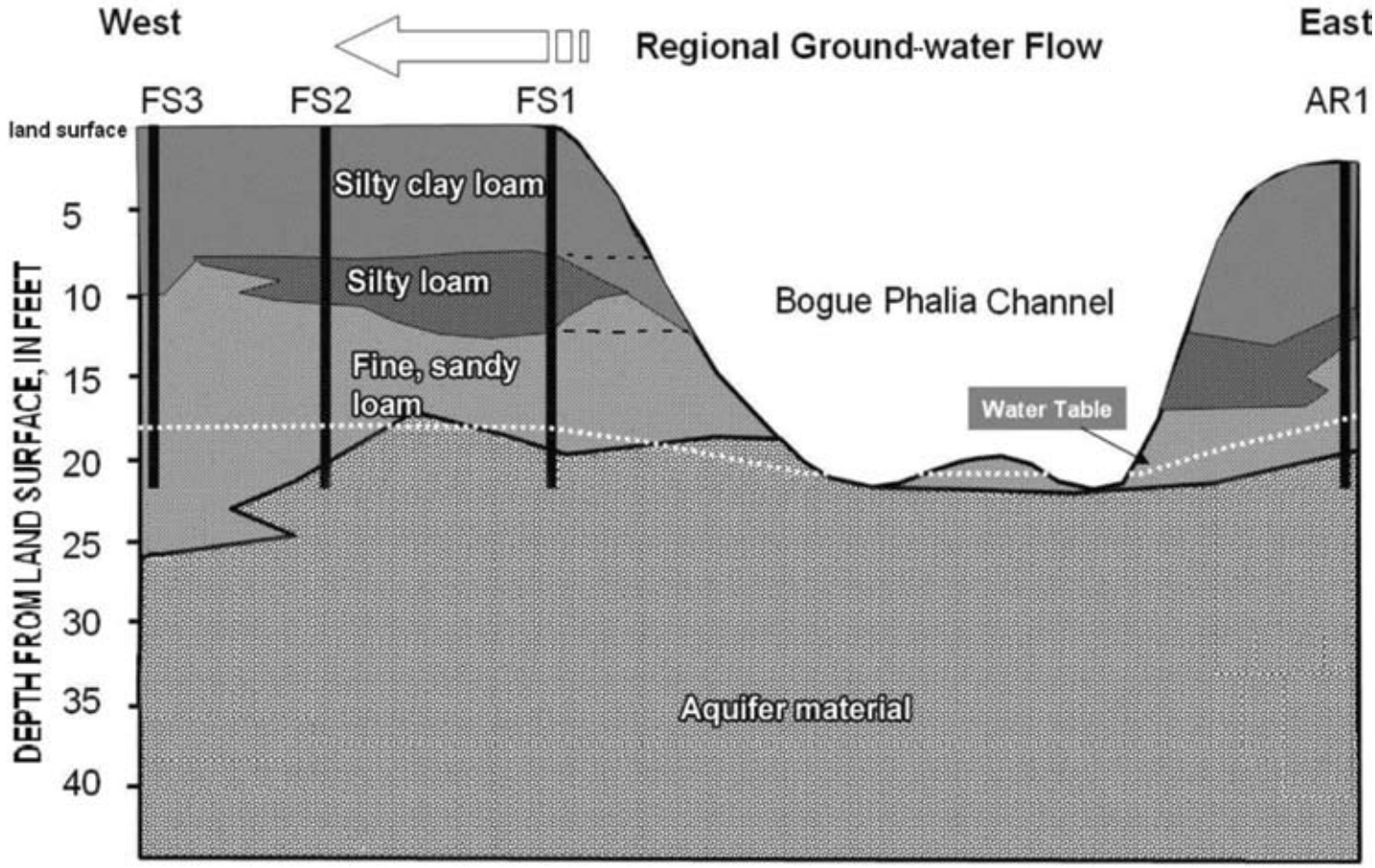

Figure 5. Generalized cross section of study site showing lithology.

Based on X-Ray diffraction (XRD), the mineralogy of the soil from 2 through 15 feet includes smectite clay, kaolinite, muscovite or illite, and quartz. In each sample, there were primarily four main d-spacing peaks. There was an ~14 Å (angstrom) peak, a 10.009 Å peak, a 7.180 Å peak, and a 3.342 Å peak. After glycolation, the 14 Å peak shifted magnitude to a 16-17 Å peak. This indicated a swelling clay was present. There was no other change after glycolation. However, after the 400°C heating, the 16-17 Å peak collapsed to 10 Å. This indicated that smectite was the swelling clay. Because the smectite peak collapsed to 10 Å, it was impossible to determine whether the original 10 Å Angstrom peak had collapsed or remained; therefore, it cannot be stated with certainty whether the 10 Å peak represents illite or muscovite. The 7 Å peak remained until 550°C heating, after which it collapsed; this represents kaolinite. However, for the sample AR1B 13.5 feet, the 7 Å peak remained even after it was heated to 550°C. The 3.342 Å peak remained throughout all tests, and thus, it represents quartz.

Discussion and Conclusions

Previous models of the Mississippi River alluvial aquifer indicated that precipitation is the most important recharge component, as well as the greatest source of recharge in the alluvial aquifer flow system in the Delta. However, it is also the least studied component of the alluvial aquifer (Arthur, 2001).

The three methods used to determine K were the FHP, the Rosetta Model, and the Hazen method. These methods cannot all be compared directly, however, because the lack of cohesion of soil made it impossible to test the sandier sections in the permeameter, and the small grain sizes of the silty sections of soil made it impossible to test the sections using the Hazen method. It is good practice to obtain the hydraulic

conductivity by several different methods. Generally, the data show that the FHP yielded lower hydraulic conductivity values, whereas the Hazen method yielded higher values than both the FHP and the Rosetta Model (table 1). However, the results from each method generally fell within the same order of magnitude (fig. 4).

Below the 10-foot depth, there is a change in material, validated by apparent changes in bulk density values, sand percentage, and permeability. The bulk density values above the 10-foot depth range from 1.78 to 2.20 grams per cubic centimeter, whereas below the 10-foot depth the bulk density values are lower, ranging from 1.21 to 1.78 grams per cubic centimeter (table 2). The sand percentage increases as depth increases. Above the 10-foot depth, the sand percentage ranges from 4.0 to 18.1 percent, whereas below the 10-foot depth, the sand percentage ranges from 20.7 to 99.6. The hydraulic conductivity data indicate that the upper 8 to 10 feet of soil consists of a silty clay loam with saturated vertical hydraulic conductivity values ranging from 10-5 to as low as 10-7 centimeters per second. The interval from 10 to about 16 feet was a sandy loam with hydraulic conductivity values ranging from 10-3 to 10-4 centimeters per second. The hydraulic conductivity values increase as the percentage of sand increases, and the K data from all four wells show that the hydraulic conductivity increases with depth.

K values obtained by the FHP test, for the upper 8 feet of soil, range from a magnitude of 10-6 to 10-5 centimeters per second. These values are typical for sandy silts and clayey sands (table 3). At a depth of 6 feet, there was no flow through the soil cores after 24 hours from three of the four wells. This is due probably to the swelling smectite clay identified in the samples by X-Ray diffraction. The Rosetta Model predicted hydraulic conductivity values as high as 10-4 centimeters per second for the soil at a 2-foot depth. These values are also typical ranges of K values for sandy silts and clayey sands (table 3). The Hazen method predicted hydraulic conductivity values as high as 10-3 centimeters per second for the soils at a depth of 12-feet and more, which is in accord with the fine sands found at this depth, based on the values of intrinsic permeability (table 3). The FHP provided lower hydraulic conductivity values than the Rosetta Model or the Hazen method provided, because the permeameter gives saturated vertical hydraulic conductivity values whereas the Rosetta Model and the Hazen method both give saturated horizontal hydraulic conductivity values. Because of the stratified nature of the unconsolidated soils, the saturated vertical hydraulic conductivity (Kv) values will be lower (one or two orders of magnitude) than those of the horizontal hydraulic conductivity (Kh).

The results of this study indicate that it is unlikely that appreciable amounts of water penetrate vertically through the upper silty clay loam to the fine sandy unit that makes up the upper part of the alluvial aquifer at the study site, and at other similar locations in the Bogue Phalia Basin. This is not to say that other, non-vertical forms of recharge, such as horizontal recharge, do not occur. The Bogue Phalia incises

Table 2. Average bulk density value in grams per cubic centimeter per type of soil and the range of bulk density values per type of soil.

Soil Type	Average ρ_d value, in g/cm^3	Range of ρ_d value in g/cm^3
silty clay loam with organics to silty loam	2.03	1.78-2.20
fine, sandy loam	1.36	1.21-1.78
fine, sandy loam and medium sand	1.51	1.36-170

Table 3. Ranges of intrinsic hydraulic conductivities for unconsolidated sediments (from Fetter, 2001).

Material	Hydraulic Conductivity (centimeters per second)
Clay	10^{-9} - 10^{-6}
Silt, sandy silts, clayey sands, till	10^{-6} - 10^{-4}
Silty sands, fine sands	10^{-5} - 10^{-3}
Well-sorted sands, glacial outwash	10^{-3} - 1
Well-sorted gravel	10^{-2} - 1

through the silty clay loam to the more permeable fine, sandy loam and, therefore, creates a potential pathway for lateral recharge to occur when the head in the river is greater than the head in the alluvial aquifer. In most cases, the Bogue Phalia is a gaining stream, meaning the head in the alluvial aquifer is usually higher than the head in the Bogue Phalia, causing the aquifer to recharge the river.

There are some discrepancies between the grain size analysis data and the field identification of the soil. The field identification matches the laboratory textural analysis of the soil type for the most part; whereas, both of these soil identification procedures yielded different results when compared to the grain size analysis data. The grain size data showed little or no clay was in the top 6 feet of soil. In the field identification, however, the top 6 feet are recorded as clay with silt and organics. The laboratory textural analysis classified the top 6 feet of soil as a silty clay loam. Natural Resources Conservation Service provides soil horizon data, and these data match closely with those gathered in the field. The upper 3 feet of soil in the study area was mapped as the Sharkey clay (Natural Resources Conservation Service, 2006). The Sharkey clay is listed as having 25-90 percent clay-sized particles. This discrepancy needs further review. In this study, all 26 samples indicated a small percentage of clay-sized particles.

This study did not address the possibility or probability of the occurrence of macroporosity. The possibility of root holes, worm holes, and mudcracks or soft sediment deformation in the soil can cause infiltration to occur if the cracks go deep enough to reach the sandier soil. Macroporosity can be common in low permeability soils, which can be due, in part, to the swelling nature of certain types of clays.

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