No. 143, Original

IN THE
Supreme Court of the United States

STATE OF MISSISSIPPI,
Plaintiff,
v.

STATE OF TENNESSEE, CITY OF MEMPHIS, TENNESSEE,
AND MEMPHIS LIGHT, GAS & WATER DIVISION,
Defendants.

On Bill of Complaint
Before the Special Master, Hon. Eugene E. Siler, Jr.

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TABLE OF EXHIBITS

Exhibit	Description
19	Excerpts from Expert Report of Brian Waldron, Ph.D. (June 30, 2017)
20	Excerpts from Deposition of Richard Spruill (Sept. 28, 2017)
21	Excerpts from Hydrogeologic Evaluation and Opinions for State of Mississippi versus State of Tennessee, City of Memphis, and Memphis Light, Gas & Water Division (Expert Report of Richard K. Spruill, Ph.D., P.G.) (June 30, 2017)
22	Excerpts from Expert Report Addendum #1 of Richard K. Spruill, Ph.D., P.G. (July 31, 2017)
23	Excerpts from Sur-Rebuttal Report of Brian Waldron, Ph.D. (Aug. 30, 2017)
24	Tables from Report on Diversion Of Groundwater From Northern Mississippi Due To Memphis Area Well Fields (Expert Report of David Wiley) (May 2007)
25	Tables from Update Report On Diversion And Withdrawal Of Groundwater From Northern Mississippi Into The State Of Tennessee (Expert Report of David Wiley) (June 30, 2017)

Exhibit 19

Excerpts from Expert Report of Brian Waldron, Ph.D.

(June 30, 2017)

Expert Report of Brian Waldron, Ph.D.

Prepared on Behalf of the State of Tennessee

In the Matter of *Mississippi v. Tennessee et al.*, No. 143, Original (U.S.)

June 30, 2017

Signed: B

Brian Waldron, Ph.D.

through the midpoint distances between the points. Interpolated values within the plane that passes through the three points defining that plane are constrained to be within the range of the values of the three defining points. The solution is quick, linear in nature, and unique.

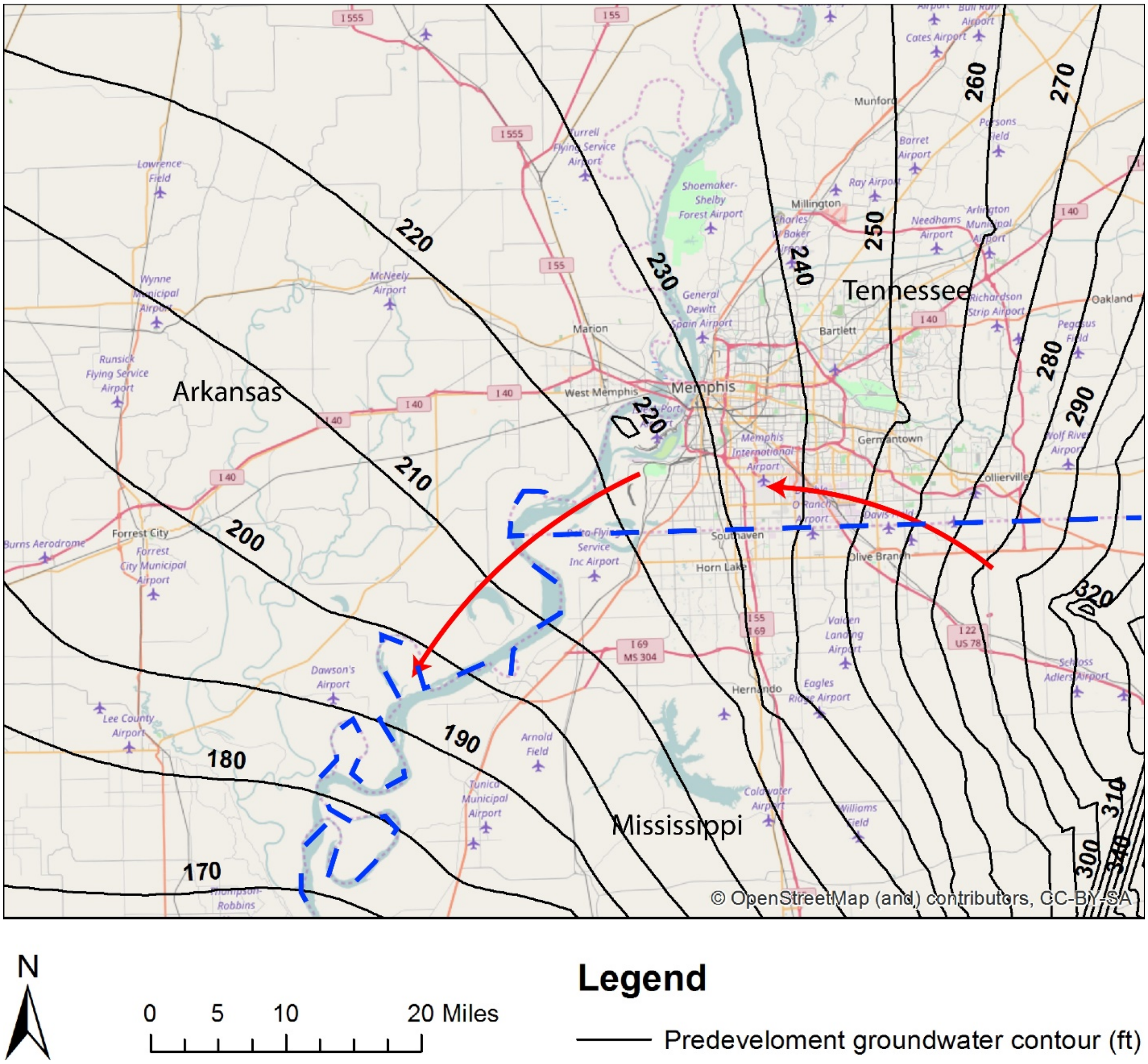

Figure 12. Resulting groundwater predevelopment conditions derived from output from MERAS model (Clark and Hart, 2009). Red arrows have been overlaid to numerically indicate groundwater flow direction and blue hatched line approximates state line boundaries.

47. As shown in Figure 12, the predevelopment conditions (1870) from the Clark and Hart (2009) MERAS numerical groundwater model indicate that groundwater in the Middle Claiborne aquifer was flowing from Mississippi into Tennessee and from Tennessee and Mississippi into Arkansas.

48. Waldron and Larsen (2015) developed a predevelopment surface (1886) of the Middle Claiborne aquifer using 27 groundwater levels from 1886-1906 focused on the Mississippi-Arkansas-Tennessee tri-state region (Figure 13). Compared to past investigations, our data were closest to the

period of predevelopment. The latest measurements we used were from wells that were recorded in one 1903 and two 1906 publications – thus, all wells dated to within 20 years of the first development of the Middle Claiborne aquifer. In comparison, for example, the control wells used by Criner and Parks (1976) and therefore by Brahana and Broshears (2001) date to at least 40 and as many as 70 years after the first development in 1886.

49. Waldron and Larsen (2015) also used substantially more data points than prior analyses of predevelopment conditions. The final analysis used 27 control wells, distributed across multiple counties in Tennessee, Mississippi, and Arkansas. In contrast, Criner and Parks (1976) used four control wells, three in Shelby County and one in Fayette County, and none close to the Mississippi-Tennessee border. Both of these aspects of Waldron and Larsen (2015) – using controls closer in time to the relevant period, and using more controls distributed more broadly over the relevant geographic area – make it likely that this analysis better approximates the predevelopment groundwater conditions of the Middle Claiborne aquifer in the Mid-South region.

50. The resulting predevelopment conditions (1886) are shown in Figure 13. The potentiometric surface shows that, under natural conditions, water did move from Mississippi into Tennessee. Along the Mississippi-Tennessee border, the gradient (which moves perpendicularly to the lines of equal head shown on the map) is mostly north-moving in the area of Marshall County and Fayette County, and gradually turns in a northwest direction in western Shelby County and DeSoto County. This gradient is more northerly, showing more groundwater flowing from Mississippi into Tennessee, than prior analyses.

51. Additionally, using the groundwater gradients derived for 1886 and those developed by Schrader (2008), Waldron and Larsen (2015) estimated that the quantity of groundwater exchanged between Shelby County and DeSoto County was approximately 221,000 m^3/d (cubic meters per day) in 2008 and 186,000 m^3/d in 1886. (pp. 18-19)

52. The investigations by Arthur and Taylor (1990), Reed (1972), Criner and Parks (1976), Brahana and Broshears (2001), Clark and Hart (2009), and Waldron and Larsen (2015) consistently substantiate the fact that, during the predevelopment period (pre-1886), groundwater in the Middle Claiborne aquifer and its equivalents moved from beneath Mississippi across state lines into adjoining states (Tennessee, Arkansas, Louisiana) and as such was not confined within the state boundaries of Mississippi. As discussed above, different studies show different groundwater flow paths transporting water across the Mississippi-Tennessee line to different degrees. Waldron and Larsen (2015) show the most substantial natural movement of groundwater from Mississippi into Tennessee, and quantify that transfer. For the reasons discussed above, the analysis in that paper is most likely to accurately approximate predevelopment conditions in the aquifer. Based on all of these studies, and most especially Waldron and Larsen (2015), there was substantial groundwater flow in the Middle Claiborne aquifer under predevelopment conditions from Mississippi to Tennessee. These studies also emphasize that the Middle Claiborne cannot be considered to "confine" groundwater within Mississippi vis-à-vis Tennessee or other states, and must be considered an interstate aquifer.

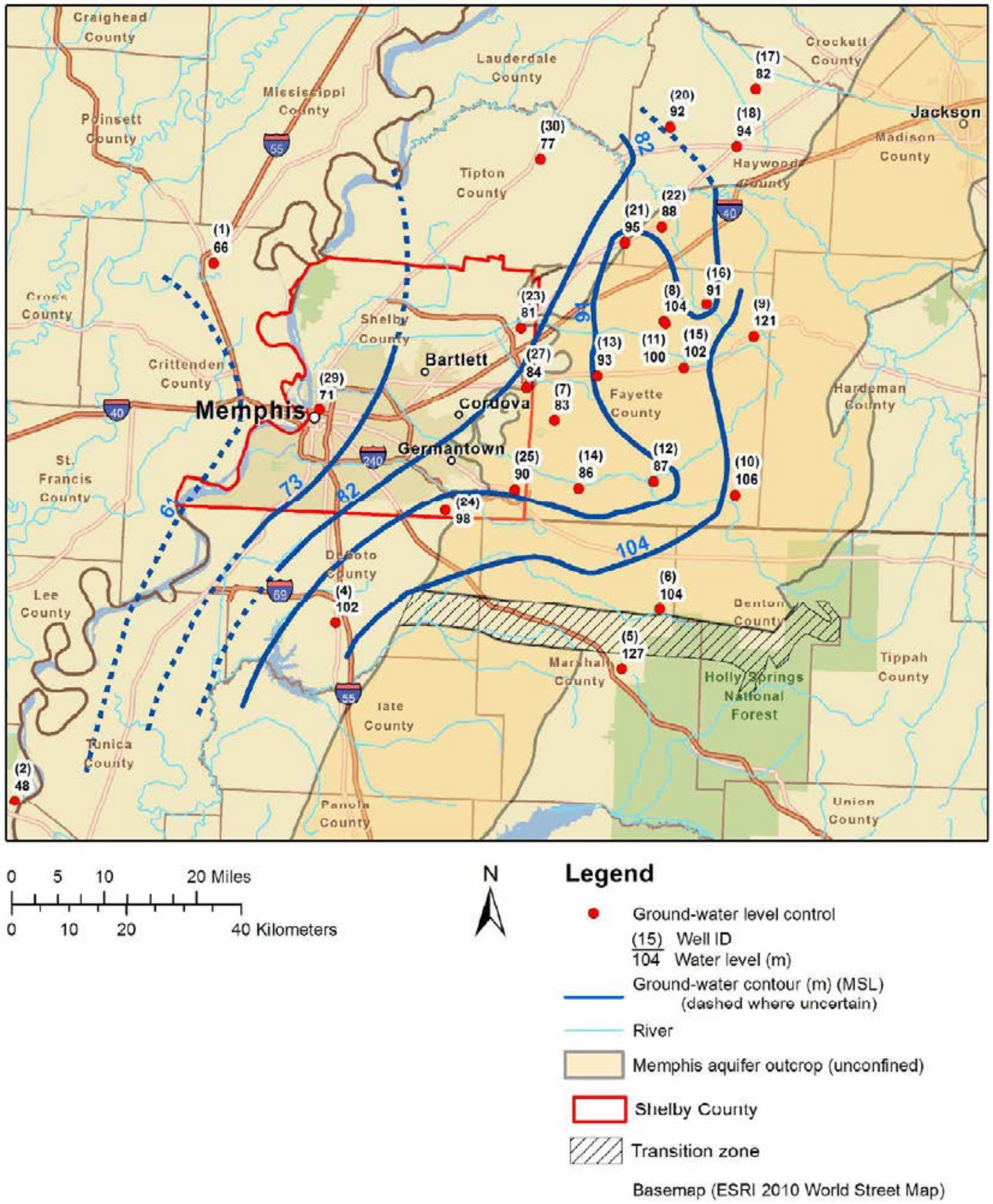

Figure 13. Predevelopment groundwater conditions for the Middle Claiborne aquifer (Waldron and Larsen, 2015).

Exhibit 20

Excerpts from Deposition of
Richard Spruill

(September 28, 2017)

In the Matter Of:

STATE OF MISSISSIPPI vs

STATE OF TENNESSEE

OF TENNESSEE,

RICHARD SPRUILL

September 28, 2017

BEFORE THE SUPREME COURT
OF THE UNITED STATES

STATE OF MISSISSIPPI,
Plaintiff,
Vs. NO.
STATE OF TENNESSEE,
CITY OF MEMPHIS and
MEMPHIS LIGHT, GAS & WATER,
Defendants.

DEPOSITION
OF
RICHARD K. SPRUILL
September 28th, 2017

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just ask that you answer whatever question is pending, and then we can take a break. Is that fair?

A. Fair enough.

Q. We're going to talk a lot today about an aquifer that you have called the Sparta Memphis Sand in your reports. Do you recall that?

A. Yes.

Q. Do you agree that the term "Middle Claiborne" -- you understand that if I use that term, that I'm referring to the same aquifer?

A. Yes.

Q. Do you understand the names "Memphis Sand" and "Sparta Sand" as used at various times in this case are both referring to the same aquifer?

A. I think the "Memphis Sand" and "Sparta Sand" are often used interchangeably, but there are regional differences in the two. In terms of what I would call hydrostratographic interpretations, they are more or less equivalent.

Q. When you say "more or less equivalent," just to make sure we're on the same page, you understand that they are part of a single geological formation, correct?

A. They are part of a single geological formation. The Sparta Sand is not the same unit as the Memphis Sand in terms of its thickness and its areal distribution. There are some differences. They are part of the same hydrostratographic unit.

Q. If I talk about the "Middle Claiborne," you'll understand that name is referring to the entire geologic formation that encompasses what you are referring to, both the Sparta Sand and the Memphis Sand, correct?

A. I think it is really important to say which geographic area we're talking about and make that distinction. Generally I would agree with what you said.

Q. Is there a geographic distinction you would need clarification on if I use the term "Middle Claiborne"?

A. If you use the term "Middle Claiborne," my interpretation is that it would involve both the Memphis Sand, the Sparta Sand and various submembers of the Memphis Sand further south, say into Mississippi, where there are local confining layers that may not exist in the Memphis Sand.

Q. When you say the sub -- what was the term you used?

A. Submemembers.

Q. What do you mean by that?

A. My opinion is as you move south from Tennessee into Mississippi, the thick unit that people in Tennessee call the Memphis Sand becomes more complex in its nature, and it has some interlayers that are actually of lower permeability than you might find in the same Middle Claiborne Aquifer system further north.

Q. We will get to more details about that a little bit later. Just to be sure that we're on the same page terminology-wise, when I use the term "Middle Claiborne," I'm referring to the entire formation that includes both the Sparta Sand and Memphis, the sub units you referred to. Do you understand that?

A. I do.

MR. ELLINGBURG: And the entire

Middle Claiborne Aquifer every molecule of groundwater in that aquifer under natural conditions was moving to some extent, correct?

A. Yes.

Q. Dr. Spruill, how do you define an interstate aquifer?

A. I've never defined an interstate aquifer. I didn't come to this project with the "interstate aquifer" definition in mind. I was originally retained to evaluate the groundwater systems in this area and help educate people about how groundwater flows. I only came to the issue of interstate and intrastate late in the game here. Again, that was not my initial charge.

I have the opinion that there really aren't any interstate aquifers, that groundwater flow in our aquifer systems throughout this country are intrastate-type flows.

Q. So in your view there are no interstate aquifers anywhere in the United States?

A. What is the definition of an interstate aquifer?

Q. That's why I'm asking you.

groundwater to be moving incredibly slow, it is enough for it to be moving slowly at a rate of a foot or two per day. Is that right?

A. My definition would involve typical groundwater flow velocities.

Q. I think I understand you. There is no groundwater that you know of that would be flowing quickly enough for it not to meet this second factor of your test for an interstate aquifer?

A. I would agree.

Q. I believe that the next factor you articulated was that the water has to have a long residency time in the state. Is that right?

A. Right.

Q. How do you understand -- withdrawn. How long does a residency time need to be in terms of years for you to consider it long enough to satisfy this factor?

MR. ELLINGBURG: Objection to form.

A. Groundwater in the Middle Claiborne Aquifer in this area is moving in my opinion at a velocity of about .05, .06 feet per day. So especially compared to a molecule of water in the Mississippi River.

Q. (BY MR. BRANSON) Is there any point at which you would consider -- withdrawn. You are comparing it to the Mississippi River. Is the basic point that residence time of groundwater is significantly longer than flowing surface waters? Is that what I'm understanding you to say?

A. It is significantly longer.

Q. Is there any point in terms of years at which you would consider the residency time of groundwater to be low enough that it would change your assessment of whether or not it is intrastate or not?

A. Given the size of states and the tremendous distances that water can move, once water enters an aquifer within a state with respect to its groundwater velocity, it is going to reside in that state for the use of people in that state for really long period of time.

Q. This might be slightly a more real-world example. What if we're talking about a molecule of water that is near the state border

A. Well, again, I developed that definition with respect to this particular case. It is absolutely clear to me that a small amount of cross-boundary flow occurs, but it doesn't change my definition of an intrastate resource as applicable to this case.

Q. Just to make sure I'm understanding your test, I understand that you think in the Middle Claiborne there are not enough of those molecules to alter your assessment?

A. Right.

Q. You think that the existence of these molecules that would flow across the border in a short period of time would only materially affect the outcome of your test if they made up a majority of the water in the aquifer?

MR. ELLINGBURG: Objection to form.

A. As I said, in this case it is absolutely clear that only a small percentage of water crosses the state border. In this case it is clear to me the majority of water falling within the State of Mississippi resides in the state for long periods of time.

Q. (BY MR. BRANSON) Understanding that you actually crossing the state border relative to the total volume of water that is in the aquifer in that state. I've not done that calculation, but I have seen models that have been prepared that show some cross-boundary flow. My opinion is that it is a very small percentage of total flow within the system.

Q. For purposes of your test, what percentage would you consider to be very small so that the aquifer is intrastate under your definition?

A. A percentage like that which is flowing from Tennessee to Mississippi today, which is small.

Q. Can you put a number on it?

A. No.

Q. If you can't quantify, how do you know it is small?

A. I know the volume of water in Mississippi in the aquifer system is very, very large. It is almost inconceivably large in the Claiborne Aquifer. When I look at the flow patterns just there in that little small area in Northern Mississippi, I can conclude it is a

Q. (BY MR. BRANSON) Dr. Spruill, I've handed you an exhibit that has been marked Exhibit 3. This is a figure from Dr. Waldron's expert report in this case that is drawn from his 2015 paper. I assume you have reviewed this figure before?

A. Yes.

Q. I understand you have some differences with this figure. We'll get to those. I'm asking for purposes of this question let's assume that Dr. Waldron is correct. I understand you don't. Let's assume that he is correct over your objections.

If Dr. Waldron were correct in that this Exhibit 3 accurately depicts the predevelopment potentiometric surface in the Middle Claiborne, would you consider the Middle Claiborne to be an intrastate aquifer?

MR. ELLINGBURG: Objection to form, foundation.

A. As a scientist that is not a question I can even deal with. I can't deal with that question.

Q. (BY MR. BRANSON) Why can't you deal

with it?
A. I can't deal with the question because you are asking me to assume that something is correct that I know is totally incorrect.
Q. You were not capable for a moment assuming this is correct and telling me what that would mean for your test about whether the Middle Claiborne is an intrastate aquifer?
MR. ELLINGBURG: Objection to form. Incomplete based on his definition.
A. As a scientist I just have real trouble dealing with that question of asking me to assume that something is correct that I feel vehemently is incorrect.
Q. (BY MR. BRANSON) You are not willing to offer an opinion on whether the Middle Claiborne would be an intrastate aquifer or not if Dr. Waldron's potentiometric surface map were correct?
MR. ELLINGBURG: Objection to form and incompleteness of hypothetical.
A. Dr. Waldron's equipotential surface map in my opinion is fundamentally flawed.
Q. (BY MR. BRANSON) That's not what I'm

asking you. Because you believe it is flawed, you are not capable of telling me whether the Middle Claiborne is an intrastate resource under your definition if you take Dr. Waldron's analysis as correct in Exhibit 3?

MR. ELLINGBURG: Objection, form, incompleteness of the hypothetical as stated.

A. No. I can't deal with that question.

Q. (BY MR. BRANSON)You are not going to offer an opinion at the hearing -- if you get asked if Dr. Waldron's potentiometric surface map is a correct depiction of predevelopment flow in the Middle Claiborne, you are not going to offer an opinion one way or the other about whether the Middle Claiborne would be an intrastate aquifer in that case?

A. I'm going to offer an opinion that is very clear that I don't think this is correct.

Q. You are not going to do what I said, you are not going to offer an opinion about -- whether the judge disagrees with you and if the judge accepts Dr. Waldron's map, you are not going to say one way or the other whether the Middle Claiborne is an intrastate aquifer or not?

MR. ELLINGBURG: Objection to form based on your hypothetical and the incompleteness of it.

MR. BRANSON: Just say "object to form."

MR. ELLINGBURG: I said that it is incomplete. It is a misrepresentation of facts.

Q. (BY MR. BRANSON) I'm not trying to trick you into agreeing with this map. You've made it very clear you have criticism of this. I'm not trying to trick you. I'm trying to prepare for the hearing. We're trying to understand your opinion. I'm trying to prepare.

If Dr. Waldron's map is accepted by the court and it is taken as an accurate depiction the potentiometric surface in the Middle Claiborne under predevelopment conditions, at that point you are not going to have an opinion under that assumption about whether the Middle Claiborne is intrastate or not?

MR. ELLINGBURG: I'm going to suggest that you accept his assumptions as to the map and you apply your map and give him whatever your opinion is.

A. If I assume this map is correct, and I do not, as this particular figure covers a small portion of the state of Mississippi, and that it is not an accurate representation of the majority of water entering the aquifer system and flowing within the aquifer system, even if I assume this was correct, which I don't, I would still say the Claiborne Aquifer in the state is an interstate resource.

Q. The reason you would say that is because notwithstanding Dr. Waldron's map, the majority of the groundwater in Mississippi in the Middle Claiborne is still not flowing across the state boundary under natural conditions?

MR. ELLINGBURG: Objection to the from as improperly stating his testimony as previously given.

A. These flow lines extend only a short distance down into Mississippi. I disagree with their orientation and, hence, their flow patterns. If you would look at the rest of the picture rather than focus on this area of roughly twenty miles of the northern part of

Mississippi, you would have a completely different story that would be consistent with mine.

Q. (BY MR. BRANSON) The completely-different story would be consistent with your test of an intrastate aquifer because?

A. Because the majority of water entering the system does not flow across the boundary into another state.

Q. Okay. I've not given you your rebuttal report yet, have I?

A. No.

(The above-mentioned document was marked as Exhibit 4.)

Q. (BY MR. BRANSON) I've handed you an exhibit that has been marked Exhibit 4. Take a moment to verify that that this is an accurate copy of your rebuttal report you submitted in July in this case.

A. It seems to be complete.

Q. You are responsible for the contents of this exhibit?

A. Yes.

Q. Did you rely on anybody else in

interstate aquifer. Is that right?
A. In Case 1?
Q. Yes.
A. This is an areally-extensive aquifer. I drew two hypothetical states, A and B. I drew flow lines across both of these states. I concluded that if all of the groundwater was moving really, really slowly and resided in any state for a period of time, someone might consider this an interstate aquifer with interstate flow.
In my earlier statement today, in terms of refinement, I don't remember if I put a statement in here or not, but I don't find any real-world examples where this actually exists in North America.
Q. You mentioned refinements. Have you refined your opinion about whether this hypothetical aquifer in Case 1 is an interstate aquifer?
A. If such an aquifer exists, it is as close to an interstate aquifer in terms of its flow, but I don't think it exists.
Q. You said it is close to an interstate

aquifer. Is it actually an interstate aquifer?
A. It is an interstate aquifer. It exists beneath both states. If an aquifer exists beneath individual states, I described it as an aquifer that exists beneath both of these states as an interstate aquifer, but I separate it from the physical aquifer the flow pattern in the aquifer, but I think I mention in this the really long patterns or residence times.
Q. I didn't see that mentioned. That was going to be my next question. Let's assume you had mentioned it. I do want to know. If you assume that residence times are really long and groundwater velocity is really slow but the flow patterns otherwise look like you've drawn them in Case 1, would you consider that interstate aquifer or an intrastate aquifer?
MR. ELLINGBURG: Objection to form.
A. I clearly have established that this aquifer lies beneath both states and the flow flows from one state to the other. That's the way I use those words. The flow is from one state to the other. In terms of my definition that the flow enters a state and reside within

I tried to draw this analogy of a river system like the St. Johns River in Florida in which the entire river system exists within that state versus the Swaneee River, which flows from one state cross the state border into another state. By use of this term "interstate aquifer," it deals with the aquifer extent. It exists beneath both states. It exists beneath eight states in the embayment.

Q. Let's do Case 2 now, the next case.

A. Okay.

Q. This is on Page 34 is the picture as you see it.

A. Yes.

Q. This has been labeled "Interstate Aquifer/Intrastate Flow."

A. Yes.

Q. I take it you are applying the same definition of "interstate aquifer" to Case 2 that you just applied to Case 1. Is that right?

A. It is a rock or sediment layer capable of producing usable quantities of water and it underlies both of my State A and B and beyond.

Q. Because it underlies both State A and

State B, that's where you labeled it "interstate aquifer"?
A. Drawing the analogy to river systems that I described earlier --
Q. Yes.
A. -- it underlies both states.
Q. That is why you have used the term "interstate aquifer" in Case 2?
A. That's correct.
Q. You use the term "intrastate flow" at the top of this picture. Do you see that?
A. Yes.
Q. What did you mean by that?
A. That water enters in this example of two hypothetical states the groundwater system in State A and moves from east to west and west to east on opposite sides of this hypothetical river system, and the same would be true in State B. So that the water enters the groundwater system by in this case, say, recharge on the eastern side, and all long that flow path new water would enter the groundwater system by recharge, and water flowing in the groundwater system at rates from an inch to two

A river is a channel that has water in it. If it doesn't have water in it, it is a river channel. When you put water in it, it becomes a river.

Q. I've got you.

A. That's the distinction for me.

Q. Under that distinction, and I'm following you, the river in the case I've described where it dries up before it reaches border, that would be an intrastate river, but the river channel would be interstate?

A. I would agree with that.

Q. Let's talk about Lake Michigan, another surface body water that is not a river.

A. Hold one second.

Q. Sure. We're going to talk specifically about Michigan, Lake Michigan. I'm using that as an example of a lake the geographical extent crosses multiple states.

Would you consider a lake like that to be an interstate or intrastate lake given there is no meaningful flow?

MR. ELLINGBURG: Objection to form.

A. I think Lake Michigan occurs at the

state boundary of multiple states. I don't know for a fact if -- let's see. Illinois is on this side. I don't know for a fact if the state border for Illinois goes to the middle of the southern part of Lake Michigan or not. I don't know what the state boundary is.

Q. (BY MR. BRANSON) I take that caveat to mean -- maybe we can look at the break and figure it out. Assume the state boundary -- the lake physically is in multiple states. That's an assumption for right now. Under your surface-water methodology that you have articulated, would you consider that lake to be an interstate lake?

MR. ELLINGBURG: Objection to form, foundation.

A. I wouldn't have an opinion on that. I've not studied these lakes at all. I wouldn't have an opinion on it. Even this issue of interstate streams and so forth, I simply use that as an example to try to get some understanding that I'm talking about the difference between flow and the physical feature, the river and the flow in the river, the aquifer and the flow in the aquifer. Going off in this direction of whether rivers are interstate or not is not what I've done in this study.

Q. I guess you are not going to have an opinion on this, either. What about a glacier that crosses state lines but the flow is very slow? How would you answer that?

A. Really?

Q. Yeah.

MR. ELLINGBURG: Object to form and foundation. What glacier, where?

Q. (BY MR. BRANSON) I'm doing them in the style of your Case 1 and Case 2.

A. There are no glaciers, I'm totally convinced of this, in the United States that cross state lines.

Q. This is not going to apply to a real glacier. Let's take the case -- you have given these hypotheticals in your report. I'm trying to understand them. If a glacier did cross state lines but the flow was extremely slow --

MR. ELLINGBURG: Objection to form and foundation.

Q. (BY MR. BRANSON) -- would you consider that intrastate glacier or not?

MR. ELLINGBURG: Objection to form and foundation if it is a completed question.

A. That's so far-fetched for me, I have real trouble even dealing with it. There simply aren't any. I don't understand the relevance of the question.

Q. (BY MR. BRANSON) You don't have to understand the relevance of the question.

A. I think I do. The relevance of the question is really important. If you want to explain that to me legally, that's okay. There are no glaciers, I'm really confident of this, in the United States that cross state lines. There are no glaciers in Canada that cross state lines because they don't have states, they have provinces.

Q. Would you agree there are no aquifers in the United States that are in your Case 2, that it is not depicting a real-world aquifer?

MR. ELLINGBURG: Objection to form, foundation.

A. My Case 2?

Q. (BY MR. BRANSON) Yeah.
A. There are lots of states in the United States that have flow as described, say, in State B. The flow in State B is really common. The flow in State A, adjacent states, is really common in aquifers in the United States.
Q. Just so I'm following, when you say that, you are saying the flow in State A and B are extremely common for aquifers to be bisected by a river where the flow is parallel to the state boundary and goes into the river?
A. This is a hypothetical case to try to describe flow within a state in which the flow remains in a state and discharges and goes somewhere else. Every aquifer in the coastal plain of Virginia, South Carolina, Georgia, gets recharged by water falling on land surface in those states. Water movers slowly through the aquifer over thousands of years.
We have twenty thousand years in the coastal plain of North Carolina. Instead of discharging to a river, it discharges to a river and ocean and leaves the system without going to another state. That is what intrastate flow is.

It is the rule rather than exception in my opinion regarding most aquifer systems in the U.S.

Q. What I'm trying to follow is why are you willing to answer questions about a hypothetical you provided in Case 2 but you are not willing to answer questions about a glacier hypothetical?

A. I guess for the reason I just described. There is no such thing as a glacier in the United States that crosses state lines.

Q. Is there such thing as the exact flow patterns you depicted on Case 2 in an aquifer in the United States?

A. Yeah.

Q. The exact flow pattern?

A. No, not the exact flow pattern where the flow lines are perfectly straight. The purpose of this illustration is to show intrastate flow is flow that enters the groundwater system in a state, flows slowly to some discharge location where it ultimately leaves the state thousands of years later.

Q. You think that this Case 2 hypothetical is relevant in your view even though test-flow patterns do not exactly match any existing aquifer in the United States?

A. Yes. It is a hypothetical example.

Q. You sometimes think hypothetical examples are relevant to your opinion and sometimes not?

MR. ELLINGBURG: Objection, argumentative.

A. In terms of getting my point across, yeah. My point was to get people to understand what intrastate flow is. There are no states that have flow exactly like that which I've shown to you. It is a hypothetical that addresses the issue of how water moves slowly over millennium from discharge areas to discharge areas, either a river or ocean. I could have drawn the same thing for an aquifer that has intrastate flow and discharges to the ocean.

Q. Can you go back to your rebuttal report.

A. Is it Number 4?

Q. It is. I'm going to focus on the

Q. When you say "documentation," are you talking about documentation outside of the Criner and Parks report itself?

A. I would think that we searched for that but mainly relied on the Criner and Parks report that was provided to me.

Q. Sitting here today, you don't remember anything outside of the Criner and Parks report itself that would have been the source of your conclusion that the control wells were well-documented?

A. No.

Q. We were talking about -- I want to make sure I've got your entire opinion on the extent to which the Criner and Parks study is imperfect. I believe you said it doesn't attempt to extend into the unconfined area. It may not accurately depict leakance values. Anything else?

A. I can't think of anything offhand.

Q. Do I know the time period from which Criner and Parks derived their water-level measurements that they used from their control wells for Figure 3?

A. I don't remember the exact date, but that's why I have the statement that in the area where they are measuring water levels, that annual pumping of those wells probably does not amount to more than an additional two or three percent of the total pumpage values given in the report. It says to me it was an early interpretation of the equipotential surface before significant pumping occurred. The contour lines shown in Figure 3 are consistent with no significant cones of depression developed in Shelby County or Northern Mississippi.

Q. You did not go back and check on the exact year that Criner and Parks got their water level measurements from for the control wells in Figure 3?

A. I did not. I don't recall if I did or not. Right now I don't recall that I did that.

Q. Is that something you would feel was necessary to do in order to have confidence in Criner and Parks' predevelopment surface generated in Figure 3?

A. I don't have a lot of problems with

Criner and Parks' attempt to define the equipotential surface in the confined portions of the groundwater system. Their equipotential lines actually make sense to me, make geological sense to me.

Q. Let me ask you about the contour lines you were just pointing at in Figure 3. Do you see how the contour lines -- let's focus on the 220 through 250 lines as they are going south of Memphis. They are at a northeast-southwest angle orientation roughly. Do you see that?

A. South of Memphis, yes.

Q. Do you see how the contour lines generally bend toward a more north-south orientation right around the Tennessee-Mississippi border?

A. Uh-huh. Yes.

Q. Do you agree with that bend as depicted in the Criner and Parks map?

MR. ELLINGBURG: Objection to the form. Which lines are you referring to?

MR. BRANSON: 220 through 250.

A. It is a contouring interpretation by well-meaning scientists, and so I would have no produced a predevelopment 1986 equipotential map for the Sparta Memphis Sand, Figure 4, that appears remarkably similar in the vicinity of Southwestern Tennessee to the interpretation produced by Criner and Parks." Do you see that?

A. Yes.

Q. Do you have any understanding of what control data Reed used to generate his potentiometric surface map that appears in Figure 4 of your -- the potentiometric surface map that appears in Figure 4 of your rebuttal report?

A. It took me to a minute to catch up with what this map actually shows. Would you ask the question again?

Q. Do you have any understanding of what control data Reed used in order to generate the potentiometric surface lines on Figure 4?

A. I do not at this time remember what data he used.

Q. In preparing your rebuttal report in this matter did you take any steps to go look at the underlying control data that Reed relied on in generating Figure 4?

A. I don't recall doing that, no.

Q. If you hadn't looked at Reed's underlying control data that he used to generate Figure 4 in the rebuttal report, do you have confidence that the equipotential surface map he generated was accurate?

A. These maps produced by a person like Reed back in 1972 were not drawn to try to prove that groundwater was flowing across the state boundary. They were a scientist's best interpretation of groundwater flow patterns on a regional scale. They could be off. They could be wrong. But they are 1972 interpretations of somebody's understanding of how the groundwater system worked.

Q. So in light of that it sounds like you don't have a lot of coincidence in whether Reed got the potentiometric surface correct in Figure 4?

A. The surface makes sense to me as a hydrologist. If somebody handed my this map without those lines on it and said, with no data at all, tell us what the equipotential surface looks like, most hydrologists draw recharge flow points along a river. I'm sure he had some control points. I see some dots there. I don't know how many. They may be cities. These are reasonable 1972 interpretations. I also point out it is for the confined part of the groundwater system.

Q. You don't know whether Reed had any -- was relying on any control wells that were, for instance, properly grouted?

A. No. I'll tell you what I was looking for is the consistency. As I look through the various maps, the only equipotential surface maps I found until the 2013 MERAS report were an attempt by Waldron and the MERAS report to show groundwater flow patterns in the unconfined portions of the system on the eastern side of the area.

Q. On that point on Figure 4, if look right along the Arkansas -- I'm sorry, the Mississippi-Tennessee boundary on the 35 degree latitude and look at the unconfined portion of the aquifer on the eastern side of the confined portion -- do you see that?

A. Yes.

Q. Did you go back and review the primary source references on which Dr. Waldron relied in the 2015 article?

A. I studied it extensively.

Q. Why did you go study the primary source references on which Dr. Waldron relied but not do the same for the Reed 1972 map, for instance?

A. I suppose it is because Reed was not an expert in this case. Reed didn't read my expert report and comment on it. I'm specifically responding to a rebuttal report of my opinions.

In my primary expert report I simply said I have real issues with how you study groundwater flow patterns in the unconfined portion of the groundwater system, and because of that I didn't rely on Dr. Waldron's study. Then I get this report from him with all of this verbiage in it, so I responded to it with some detail.

Q. I assume the same answer applies to why you didn't go back and check the primary source references for Criner and Parks?

A. Yeah.

Q. Let's focus on Point 4 on Page 17. You

Exhibit 21

Excerpts from Hydrogeologic Evaluation and Opinions for State of Mississippi versus State of Tennessee, City of Memphis, and Memphis Light, Gas & Water Division
(Expert Report of Richard K. Spruill, Ph.D., P.G.)

(June 30, 2017)

EXPERT REPORT

Hydrogeologic Evaluation and Opinions for
State of Mississippi versus
State of Tennessee, City of Memphis,
and Memphis Light, Gas & Water Division

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GMA

June 30, 2017

Richard K Spruill

Richard K. Spruill, Ph.D., P.G.
Principal Hydrogeologist

I. Introduction

Groundwater Management Associates (GMA) was retained by the firm of Daniel Coker Horton & Bell, P.A. (DCH&B) to provide expert geologic and hydrogeologic consulting regarding the origin and distribution of groundwater, interactions between surface water and groundwater, natural and man-induced migration patterns of groundwater, and specific topics regarding the geology and hydrogeology of predominantly sandy sediments comprising the Eocene-age Middle Claiborne Group that host the Sparta-Memphis Sand aquifer system in northwestern Mississippi and southwestern Tennessee. GMA's services included producing this expert report, which is focused on known or likely impacts on groundwater distribution and migration patterns within the Sparta-Memphis Sand (aka, the Sparta Sand, Memphis Sand, Memphis Aquifer, and other variations) in response to historic and ongoing pumping in Shelby County, Tennessee.

This expert report was produced for DCH&B using information available from publicly-available maps and reports from a variety of sources, including federal agencies such as the United States Geological Survey (USGS). This information was used in combination with the professional training and experience of the report's author, Dr. Richard K. Spruill, to develop opinions about the geologic and hydrogeologic setting of the study area. A partial list of resources and documents that were reviewed or employed to prepare the expert report is provided as Appendix A.

II. Qualifications

Richard K. Spruill, Ph.D, is GMA's Principal Hydrogeologist, president, and co-owner of the firm. Dr. Spruill's professional practice is focused on the hydrogeological exploration, evaluation, development, sustainable management, and protection of groundwater resources. He has been a geologist for over 40 years, and he is licensed in North Carolina as a professional geologist. Since 1979, Dr. Spruill has been a faculty member in the Department of Geological Sciences at East Carolina University (ECU), Greenville, North Carolina. He teaches hydrogeology, mineralogy, petrology, field geology, and physical geology at ECU. Dr. Spruill has provided litigation support and testified previously regarding geology, hydrogeology, water resources, and environmental contamination. His *curriculum vitae* is provided as Appendix B.

I, Dr. Richard K. Spruill, am the author of this expert report. My descriptions, interpretations, conclusions, and professional opinions described within this expert report are subject to revision, expansion, and/or retraction as additional information becomes available.

III Summary of General Opinions

The following is a summary of my opinions provided within this expert report. The opinions itemized below are based on (1) my education, training, experience, (2) detailed study of the geology and hydrogeology of the Mississippi Embayment, (3) evaluation of the specific geological and hydrological characteristics of the pertinent geological formations in north Mississippi and west Tennessee, and, (4) specific resources and materials referred to and identified with this report.

- The Sparta-Memphis Sand, also known as the Middle Claiborne Aquifer or the Memphis Aquifer, is an important source of potable groundwater within northwestern Mississippi and southwestern Tennessee. Most of the Sparta-Memphis Sand is a hydraulically-confined aquifer that consists of geologic deposits that accumulated within the Mississippi Embayment approximately 40 million years ago. The Sparta-Memphis Sand is inclined (dips) toward the west from areas where the unit crop out in both Mississippi and Tennessee. These sandy deposits thicken toward the center of the Embayment, which generally coincides with the present trace of the Mississippi River.
- The Middle Claiborne formation contains several lithologic constituents, including the Sparta Sand, that comprise an aquifer that has accumulated groundwater over many thousands of years. Historically, most of that groundwater originated as surface precipitation that infiltrated the formation where exposed at or near

the surface, and that groundwater migrated generally westward in both states to create a source of high-quality groundwater that did not naturally flow to any significant extent in a northerly direction out of Mississippi and into Tennessee.

- The Sparta-Aquifer Sand is the most productive source of high-quality groundwater available in the states of Mississippi and Tennessee.
- Massive withdrawal of groundwater by pumping wells operated by Memphis Light, Gas and Water (MLGW) in southwestern Tennessee has reduced substantially the natural hydraulic pressures existing in the Sparta-Memphis Sand in both Tennessee and Mississippi, thus artificially changing the natural flow path of Mississippi's groundwater in this aquifer from westward to northward toward MLGW's pumping wells. This groundwater withdrawal has dramatically reduced the natural discharge of Mississippi's groundwater in the Sparta-Memphis Sand to the Mississippi River's alluvial aquifer system within the state of Mississippi.
- The taking of Mississippi's groundwater by MLGW's pumping has decreased the total amount of available groundwater in the Sparta-Memphis Sand available for development in Mississippi, thus increasing the cost of recovering the remaining available groundwater from the aquifer within the broad area of depressurization (aka, cone of depression) created by MLGW's pumping.
- The intensity of pumping that has been, and continues to be, conducted by MLGW is not consistent with good groundwater management practices, and denies Mississippi the ability to fully manage and utilize its own groundwater natural resource.
- The best management strategy for sustainability of groundwater resources involves withdrawing groundwater at a rate that is equal to or less than the recharge rate of the aquifer being developed.

Richard K. Spruill

Richard K. Spruill, Ph.D., P.G.
Principal Hydrogeologist

IV. Principles of Groundwater Hydrogeology

This section of the expert report provides an overview of key aspects of groundwater hydrogeology, especially as it pertains to the Sparta-Memphis Sand (aka, Memphis Aquifer or Middle Claiborne Aquifer) in northwestern Mississippi and southwestern Tennessee. Geologic and hydrogeologic details of the Sparta-Memphis Sand (SMS) are described elsewhere in the report.

Because groundwater availability depends on specific aspects of the local and regional geologic setting, it is not found in 'usable' quantities everywhere in the subsurface. The location, age, quality, movement, and availability of groundwater for human exploitation are determined by the actual geologic materials (i.e., aquifer) that host the water (e.g., sand) and the geologic and hydraulic characteristics of the aquifer system. This introduction to the basic principles of groundwater hydrology is generally tailored to be applicable to the groundwater system of the Middle Claiborne Group in northwest Mississippi and southwest Tennessee, and an analysis of the natural characteristics of the groundwater that is in legal dispute.

Groundwater originates as precipitation at the land surface, and some of that precipitation infiltrates the surface and enters the subsurface. In some places, groundwater originates as seepage through the bottoms and sides of surface water channels or basins, as well as by migration from other groundwater-bearing materials (e.g., 'confining units' that enclose some aquifers). Groundwater is located in the subsurface within small pore spaces located between rock and mineral particles and/or within fractures or other types of secondary porosity (e.g., voids in limestone from dissolved shell fragments).

Because groundwater typically moves through the subsurface at a rate of only a few feet or tens of feet per year, the water at a particular location and depth may have been in the subsurface for many years, decades, or millennia. By way of comparison, groundwater flowing at 1 foot per day is generally considered to be fast, while the velocity of water flowing in a stream is typically more than 1 foot per second (more than

16 miles/day). Another way to look at this generic comparison is that the 'fast' groundwater flow would require roughly 230 years to travel the same 16 miles that the hypothetical stream could transport water during one day.

Groundwater hydrogeology employs unique terms and concepts. To simplify the discussion provided below, the following are some (modified) definitions of terminology from a well-known USGS primer (Heath, 1983).

AQUIFER: A water-bearing layer of rock (or sediment) that will yield water in a usable quantity to a well or spring.

CONE OF DEPRESSION: The depression of (hydraulic) heads around a pumping well caused by the withdrawal of water.

CONFINING BED: A layer of rock (or sediment) having very low hydraulic conductivity that hampers the movement of water into and out of an aquifer.

DRAWDOWN: The reduction in head at a point caused by the withdrawal of water from an aquifer.

EQUIPOTENTIAL LINE: A line on a map or cross section along which total heads are the same.

FLOW LINE: The idealized path followed by particles of water.

GROUND WATER: Water in the saturated zone that is under a pressure equal to or greater than atmospheric pressure.

(HYDRAULIC) HEAD See TOTAL HEAD

HYDRAULIC CONDUCTIVITY: The capacity of a rock (or sediment) to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT: Change in head per unit of distance measured in the direction of the steepest change.

POROSITY: The voids or openings in a rock (or sediment). Porosity may be expressed quantitatively as the ratio of the volume or openings in a rock (or sediment) to the total volume of the rock (or sediment).

POTENTIOMETRIC SURFACE: A surface that represents the total head in an aquifer; that is, it represents the height above a datum plane (such as sea level) at which the water level stands in tightly cased wells that penetrate the aquifer.

SATURATED ZONE: The subsurface zone in which all openings are full of water.

SPECIFIC CAPACITY: The yield of a well per unit drawdown (commonly expressed as gallons per minute per foot of drawdown).

STORAGE COEFFICIENT: The volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance.

STRATIFICATION: The layered structure of sedimentary rocks.

TOTAL (HYDRAULIC) HEAD: The height above a datum plane of a column of water. In a ground-water system, it is composed of elevation head and pressure head.

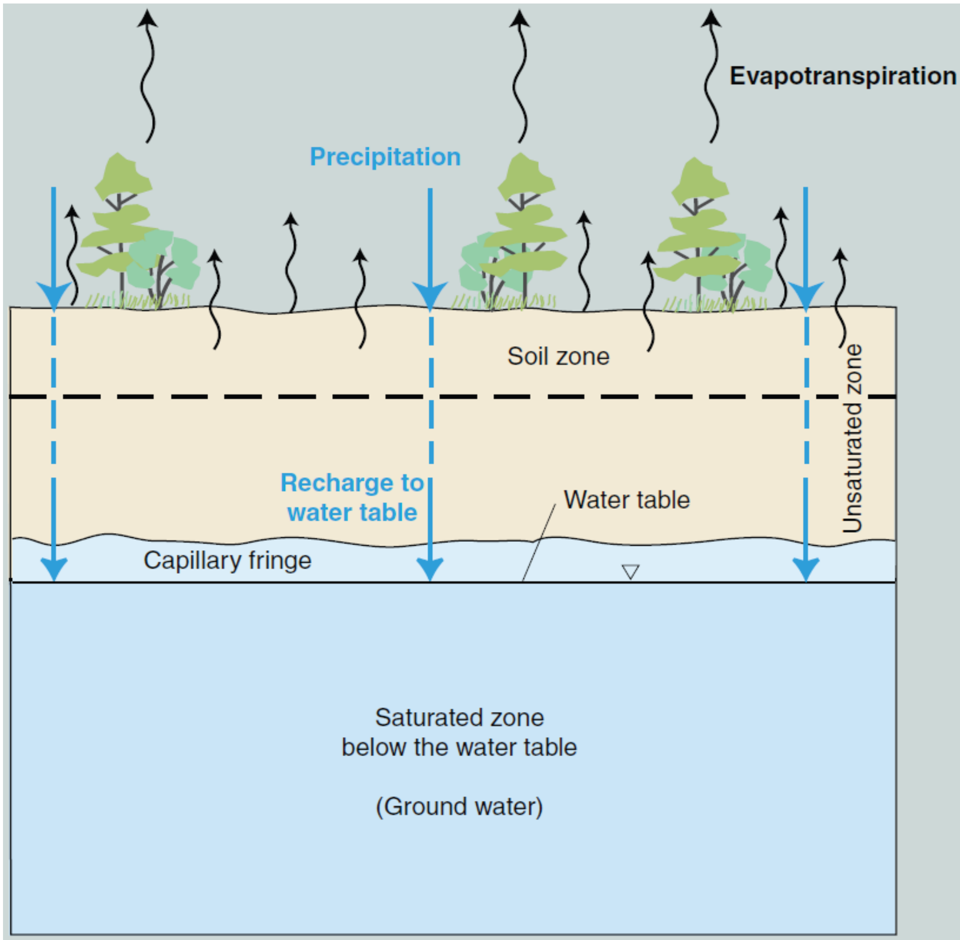
TRANSMISSIVITY: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.

UNSATURATED ZONE: The subsurface zone, usually starting at the land surface, that contains both water and air.

WATER TABLE: The level in the saturated zone at which the pressure is equal to the atmospheric pressure.

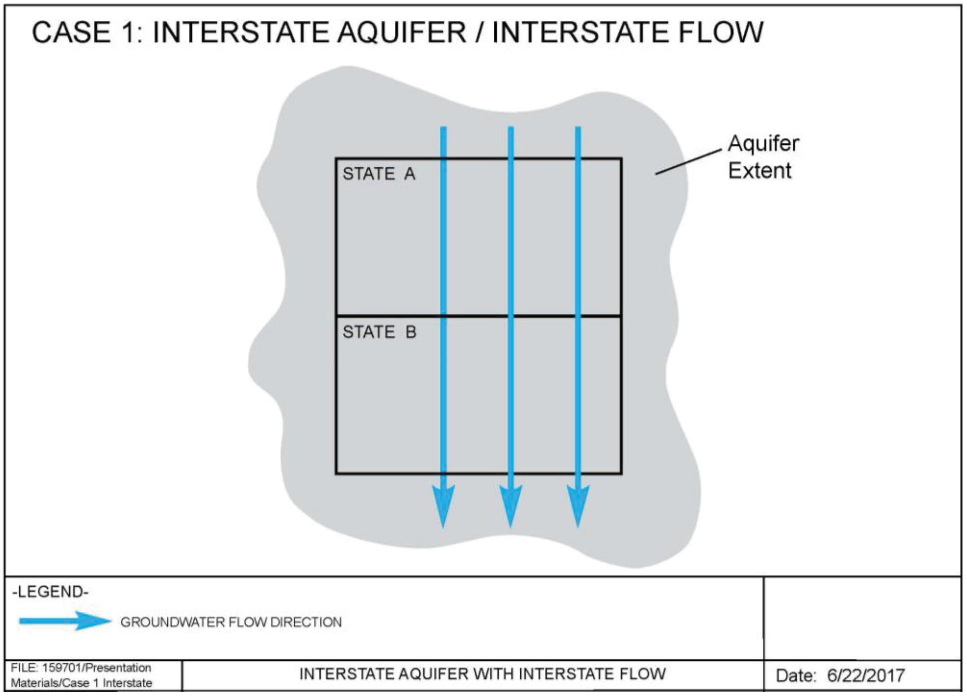
Groundwater occurs in two basic zones that are defined by the degree of water saturation (Figure 1). The unsaturated zone occurs below the land surface where the primary and secondary porosity of the earth materials present will contain both air and water. Groundwater in the unsaturated zone is not available for extraction or exploitation by people. All porosity is filled with water in the saturated zone (Figure 1), and the boundary between the saturated zone and the overlying unsaturated zone is called the water table (discounting the capillary fringe where groundwater is at less than atmospheric pressure). Groundwater in the saturated zone is potentially recoverable, although there may be practical or financial limitations that preclude extraction.

Figure 1: Groundwater Distribution in the Shallow Subsurface (modified from Alley et al., 1999)

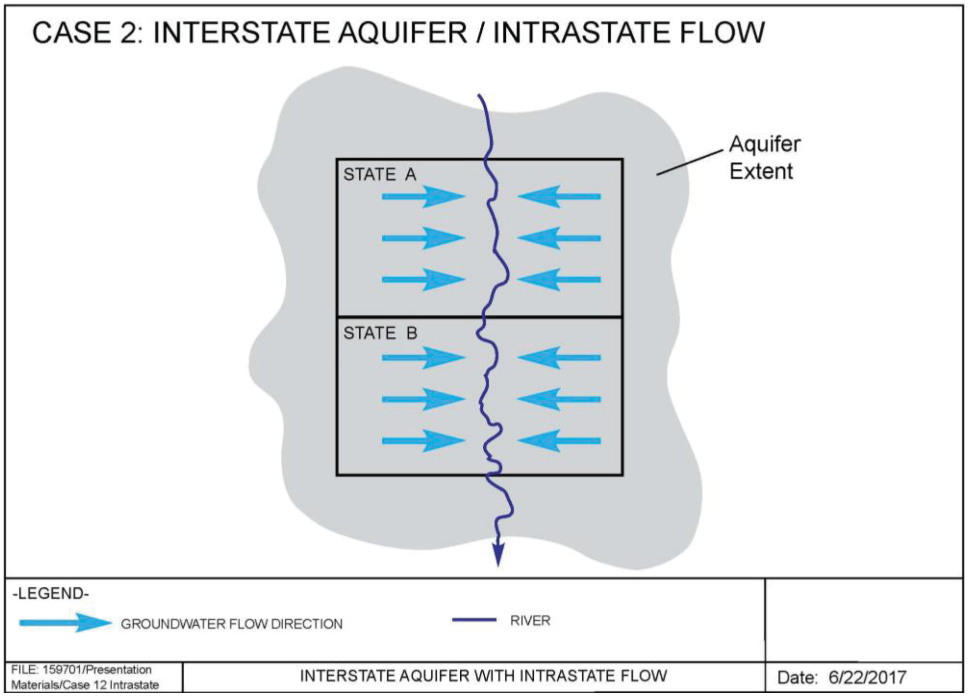


Aquifers consist of groundwater hosted by unconsolidated sedimentary deposits (e.g., sand) or consolidated rocks. To be considered an aquifer, there must be adequate interconnection of the primary and/or secondary porosity such that the geologic materials can hold, transmit, and release groundwater in sufficient volumes for some purpose (e.g., a water-supply well). There is no minimum area, thickness, or quantity of groundwater potentially 'useable' or 'extractable' by people that must exist before a mass of groundwater-bearing geologic material can be termed an aquifer. Water-bearing sediments or rocks may be exploited by people as a significant source of water in one place, thus constituting an aquifer, but the same combination of water and solid materials might not constitute a viable aquifer at a different place or time.

accumulates within, and flows through, both states under natural conditions, thus the groundwater is a shared natural resource under natural conditions analogous to an interstate river.



- **Case 2**. Figure 15 is a map of a regionally extensive aquifer, and two states sharing an east-west border lie entirely within the extent of the aquifer. In this case, a river running southward bisects both states. Because of the geologic conditions, the natural groundwater flow within this aquifer is directed toward the river from both the east and the west. In this case, the groundwater accumulation and flow is confined to each state, as shown by flow lines parallel to the boundary separating the two states. In this example, the groundwater accumulates and flows (for millennia) through one state under natural conditions to its discharge area located within that state. Therefore, the groundwater is that state's natural resource under natural conditions, and the groundwater is analogous to the water in an intrastate river.



Although these hypothetical examples are simple, they are applicable to this litigation. The fundamental question in the specific case of groundwater flow in the northern part of the Mississippian Embayment, and specifically in the Wilcox and Claiborne Aquifer Systems, is: What is the nature of groundwater flow within an aquifer system that is laterally extensive, and what did a groundwater flow net (flow lines and equipotential contours) look like during the pre-development time frame? The only viable way to answer this question is to carefully examine the flow patterns in the confined portions of these aquifer systems prior to any significant development of the groundwater system (i.e., the construction and operation of groundwater production well fields).

Several researchers have produced analyses of the pre-development flow patterns for the Wilcox and/or Claiborne Aquifer Systems for the border region of northwestern Mississippi and southwestern Tennessee, including (1) numerous studies by the United States Geological Survey and (2) investigations by private and academic scientists and engineers. Examples for each group of researchers are described below.

Studies by the United States Geological Survey include the work by Cushing et al. (1964), which provides a good summary of stratigraphy of the Mississippi Embayment.

Exhibit 22

Excerpts from Expert Report Addendum #1 of Richard K. Spruill, Ph.D., P.G.

(July 31, 2017)

EXPERT REPORT
Addendum #1

Hydrogeologic Evaluation and Opinions
for State of Mississippi versus
State of Tennessee, City of Memphis,
and Memphis Light, Gas & Water Division

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GMA

July 31, 2017

Richard K. Spruill

Richard K. Spruill, Ph.D
Principal Hydrogeologist

addendum report represent the scientific reality that groundwater within Mississippi in the SMS aquifer originated and resided within Mississippi's state territory for thousands of years under natural conditions on a slow-motion journey that has lasted many times longer than the United States has been in existence. Larson's <u>only</u> acknowledgement of the time component of groundwater flow is misleading at best: "*Because groundwater moves continuously (albeit slowly) under natural conditions, it eventually would have left Mississippi's territory – with or without any pumping – and would have been replaced by new groundwater recharge*…" (page 4, paragraph 12). The fact that this groundwater would *eventually* naturally leave Mississippi many thousands of years after it initially entered the subsurface by recharge has <u>no</u> practical application to the issue of whether the groundwater is a natural resource within the territory of the state of Mississippi.

Larson's justifying paragraph 13 contains several fundamental misstatements about hydrogeology that appear designed to confuse or misrepresent the concept of an aquifer's groundwater budget. I surmise that Larson is attempting to justify his unsupported notion that massive groundwater pumping in Tennessee has not had, and will not have, any meaningful impact on Mississippi's natural groundwater resources. From a hydrologic standpoint, the reduction of pressure in a confined aquifer system induced by pumping will not only change the pattern and velocity of flow, it reduces the volume of recoverable groundwater and well yield, thus limiting the quantity that can be withdrawn by a well and increasing the total cost of recovery.

Larson, page 4: "*Opinion 4. The United States Geological Survey has repeatedly recognized that the Middle Claiborne aquifer is an interstate resource*." This is not an expert opinion of a geologist or hydrologist. Nor have I located a single written instance where the USGS has referred to the Middle Claiborne aquifer as an "interstate resource". As stated above, the USGS did use the word 'interstate' on one occasion, describing their computer framework as a "…*tool that is useful for interstate sustainability issues while focusing on a particular State*…" (Clark et al., 2013, page 2). This single statement by the USGS is not a comment about, or opinion on, any aspect of any state's claim to, or management of, the naturally present groundwater within its borders.

- An aquifer system is *not* an interstate resource because the aquifer's geologic framework (i.e., solid parts of the system such as grains of sand, sedimentary rock, etc.) extends over large areas.
- An aquifer system is *not* an interstate resource because hydrogeologists and hydrologists study aquifer systems over large areas.
- An aquifer system is *not* an interstate resource because some well-meaning scientists have produced groundwater computer models that extend over multi-state regions.
- An aquifer system is *not* an interstate resource because a small percentage of groundwater flowing in the aquifer crosses the boundary from one state to another state.
- An aquifer system in *not* an interstate resource because a scientist says it is an interstate resource based on an interpretation of what the USGS may or may not have said.

It is my opinion that the definition of an intrastate groundwater resource must be based on the fate of water in the groundwater system under natural conditions. If the majority of groundwater in an aquifer enters the groundwater system by recharge within a specific state, and that water flows *VERY* slowly through the aquifer within that same state, such that the water remains in the state for *VERY* long periods of time before ultimately being discharged from the groundwater system, then that groundwater is an intrastate resource.

Aquifers are *not* rivers of water flowing underground. The residence time for groundwater in the hydraulically-confined portions of the Middle Claiborne aquifer within Mississippi is measured in thousands of years, not days. Groundwater in this important and valuable aquifer is a life-sustaining resource for the residents of Mississippi, and it is an intrastate resource as based on my definition.

It is also my opinion that decisions regarding the classification of groundwater resources as intrastate versus interstate should not be conducted without a detailed consideration of the advantages and disadvantages of such a classification on the ability of a state to

Exhibit 23

Excerpts from Sur-Rebuttal Report of
Brian Waldron, Ph.D.

(August 30, 2017)

Sur-Rebuttal Expert Report of Brian Waldron, Ph.D.

Prepared on Behalf of the State of Tennessee

In the Matter of *Mississippi v. Tennessee et al.*, No. 143, Original (U.S.)

August 30, 2017

Signed: ____________________

Brian Waldron, Ph.D.

SECTION 2. Opinions

5. Spruill's criticisms of Waldron and Larsen (2015) ("W&L") in his rebuttal report fall into three general categories. First, he criticizes the reliability of the data underlying W&L's analysis and compares it unfavorably with the data underlying other attempts to estimate the predevelopment potentiometric surface of the Middle Claiborne. Second, he criticizes W&L's analysis of those data, including the contouring technique used. Third, he suggests (at 23) that W&L failed to "consider the time component."

6. I respond below in some detail to the critiques that fall into the first and second categories. In most cases, Spruill's characterizations of W&L are simply erroneous and fall apart upon closer inspection. Spruill also notes some of the limitations of using data that are more than a century old, but fails to show that there are better data for this purpose or that the data are too unreliable to use. He also fails to account for the fact that W&L performed an error analysis that specifically showed that uncertainty relating to old data did not have a significant effect on the resulting predevelopment surface set forth in the paper.

7. As for Spruill's suggestion that W&L failed to "consider the time component," he apparently means that W&L did not discuss the velocity of groundwater flow, at least in detail. However, there is no reason to have done so. Although Spruill opines (at 23) that a "layman" might "assume incorrectly that the groundwater is migrating" faster than it is, laymen were not the article's intended audience. In any event, the distinction is irrelevant to the question raised by the Special Master. Indeed, the precise speed of the groundwater flow does not determine whether the Middle Claiborne is an interstate resource. As explained in my prior reports and in more detail below, the Middle Claiborne is plainly an interstate resource, even though the groundwater within it is migrating at a slower rate of speed than surface waters.

<u>Spruill's Criticism of the Data's Reliability Is Misplaced</u>

8. To begin with, Spruill states (at 17) that many of the wells cited by W&L "*are <u>not</u> actually wells"* (emphasis by Spruill), but are "generic observations or claims about zones that were being targeted in particular areas for the potential drilling of water-supply wells in the late 1800s or very early 1900s." In fact, however, the points used by W&L are wells identified in three early U.S. Geological Survey (USGS) publications – Fuller (1903), Crider and Johnson (1906), and Glenn (1906) – which also describe their uses as water for steam locomotives, mercantile stores, post offices, stage coach stops, lumber mills, and private usage.

<u>Spatial Accuracy</u>

9. Spruill suggests (at 17) that "[e]xact locations" of the wells are unknown. However, W&L used a number of methods to determine the location of each well as precisely as possible, and in each case the location was determined with enough precision for the article's purposes. In the USGS publications (Fuller, 1903; Crider and Johnson, 1906; Glenn, 1906), well locations were identified by town; however, additional information allowed for improved mapping of well locations such as: (1) well ownership; (2) water usage; (3) witness accounts; and (4) building blueprints.

a. Well ownership: Ownership provided a means for better locating a well's actual location. Well ownership was cross-referenced with 1900 and 1910 census records, which served two purposes: (1) the well owner's name may have an associated street address that would place the well along the correct road and (2) the well owner's job may be listed in the census, further substantiating use of the groundwater at a mercantile or lumber mill. Any address information was correlated with historic town maps available at the county seat library, from parcel maps usually existing within Plat Book 1 (the first record of parcel ownership in the county) available at the county courthouse or planning office, or approximated using existing road networks.

b. Water usage: When addresses where not available, the purpose of each well was used to improve the accuracy of its location. For example, railroads used groundwater for steam locomotives. Historic town maps were used to identify railyard locations that often were near the town center. Sometimes rail company maps were used to verify the existence of rail in the town. As rail lines extend through a town, well placement was placed near the town center at the intersection of main roads (identified by name such as Main or because the road existed as a county road as it entered and left the town).

c. Witness accounts: In some cases, personal investigation allowed W&L to more accurately locate historical wells. For the well in Ged, Tennessee, the well was used at a home that also served as a store. During a visit to the Haywood courthouse, an older resident whose mother was friends with the owner of the relevant well, Mrs. E.A. Davie, who was able to provide the approximate location of Ged (as the town is no longer there) and the store. In another instance, I visited the Kirby family, after whom Kirby Road in Memphis, Tennessee, is named. I visited them at their home, and they personally walked me into the field where the old well used to exist.

d. Building blueprints: When attempting to locate the well in Forest City, AR, I was visiting the current water utility facility. Hanging on their wall was a framed blueprint of the original water facility, which showed the room where the well existed. The original building still existed, though in disrepair. Using the blueprint, I found the room. I then surveyed to the well location using a benchmark on the local post office steps. Similarly, though not an actual blueprint, Sanborn maps detail structures and their wall construction for fire resistance purposes. The R.C. Graves ice house well, which reportedly was the first well to tap the Middle Claiborne in Shelby County, was thought to have existed near present day St. Jude Children's Research Hospital. However, upon a detailed investigation, the R.C. Graves ice house was located further south using an 1890 Sanborn map that depicted the ice house. A historic road network was used to locate the well site, as the road network has since been altered and road names had changed.

10. Recognizing that each method of identifying well location has some uncertainty, we estimated spatial error for each well; in essence, creating a radial "buffer" of possible locations around the well site. The more information used to locate the well, the smaller diameter a buffer was applied, because of the greater confidence in its location. Conversely, larger diameter buffers were applied where well locations were more uncertain, such as when the well was placed at the town center. In these latter cases, we used historic road maps obtained in each county courthouse or library to investigate the extent of the town's road network, and the radial buffer diameter was set to the furthest extent of the town's road network. W&L discusses this and lists examples on page 16 under the section entitled "Finding Historic Well Locations." Though not mentioned by Spruill, I accounted for the spatial error derived from the error buffers when developing the contours; however, even at the maximum measured spatial error of 450 m (Waldron and Larsen (2015) p. 16), the scale of the water level map (covering eight counties) vastly dwarfed any spatial error in contour placement. Thus, the well locations were sufficiently precise for the purpose of creating the water level map.

<u>Vertical Accuracy</u>

11. Spruill suggests (at 17-18) that the well elevations W&L used are speculative and unsubstantiated. Spruill also mentions that the published elevations in the USGS reports differ from elevations used by W&L. W&L recorded the published ground surface elevations in *Table 1* of the article (pp. 7-15) as well as the elevations used in their calculations, and a detailed discussion of how ground surface elevations were derived is provided on page 16. Four methods were employed to derive ground surface elevations, each with varying degrees of accuracy but sufficiently reliable for the article's purposes.

a. The most accurate elevations were from field surveys. We performed field surveys for the wells in Forest City and Helena, AR, where the actual well location was known.

b. The second most accurate elevation was taken from a U.S. Army Corps of Engineers land survey map of downtown Memphis in 1932. This was used to obtain the elevation of the R.C. Graves well.

c. The third accurate method was using LiDAR data of Shelby County, which has a 1-meter spatial resolution. Many of the well sites in Shelby County are rural, so the ground surface is not likely to have changed much between when the historical water levels were measured and now; or the well sites were in town centers that still exist (e.g., Collierville, Tennessee).

d. The least accurate method was using the USGS National Elevation Dataset (NED), which has a 30-meter resolution.

12. Again, though not mentioned by Spruill, W&L recognized the uncertainty inherent in the well elevations and performed an analysis of the possible impact of vertical error on the article's results. Vertical errors were set to a maximum based on either measurement or inherent data error (e.g., the USGS NED, which have a large error, would be chosen if it was greater than the local mean vertical error around a location plus a standard deviation). W&L adjusted chosen ground

surface elevations to both ends of the vertical error range to measure whether contour placement or flow direction changed, i.e., whether vertical error might affect the water level map. Accounting for the vertical error at each well, the range of flow quantities moving from Mississippi into Tennessee expands, but the contour placement and flow direction do not change significantly. In particular, flow direction does not materially change to a direct east-west direction.

<u>Combining Confined and Unconfined Water Levels</u>

13. Spruill expresses the view that using groundwater levels or drawing contours from both the confined and unconfined portions of the Middle Claiborne invalidates the representation of actual conditions and flow. He states (at 22) that mixing water level contours between confined and unconfined is improper: "Data for the unconfined aquifer system should <u>never</u> be used to define groundwater flow patterns in the confined portions of the aquifer system which reflect regional flow patterns." (emphasis by Spruill) Spruill further states that Reed (1972) and Criner and Parks (1976) do not include water levels in the unconfined section of the Middle Claiborne, and he relies extensively on these two publications for his arguments. In fact, however, it is standard practice to measure levels and draw contours from both confined and unconfined portions of the aquifer, as demonstrated by USGS hydrologists, including the very authors on which Spruill relies.

14. To see clearly that USGS hydrologists analyze both the confined and unconfined areas together, it is important to determine where those regions are. Parks (1990) identifies thickness of the Upper Claiborne confining clay for the Shelby County area (Figure 1), and shows the limit of the Upper Claiborne pinching out before reaching Fayette County, Tennessee, to the east. Therefore, west of the dotted line the Middle Claiborne is considered confined and to the east unconfined.

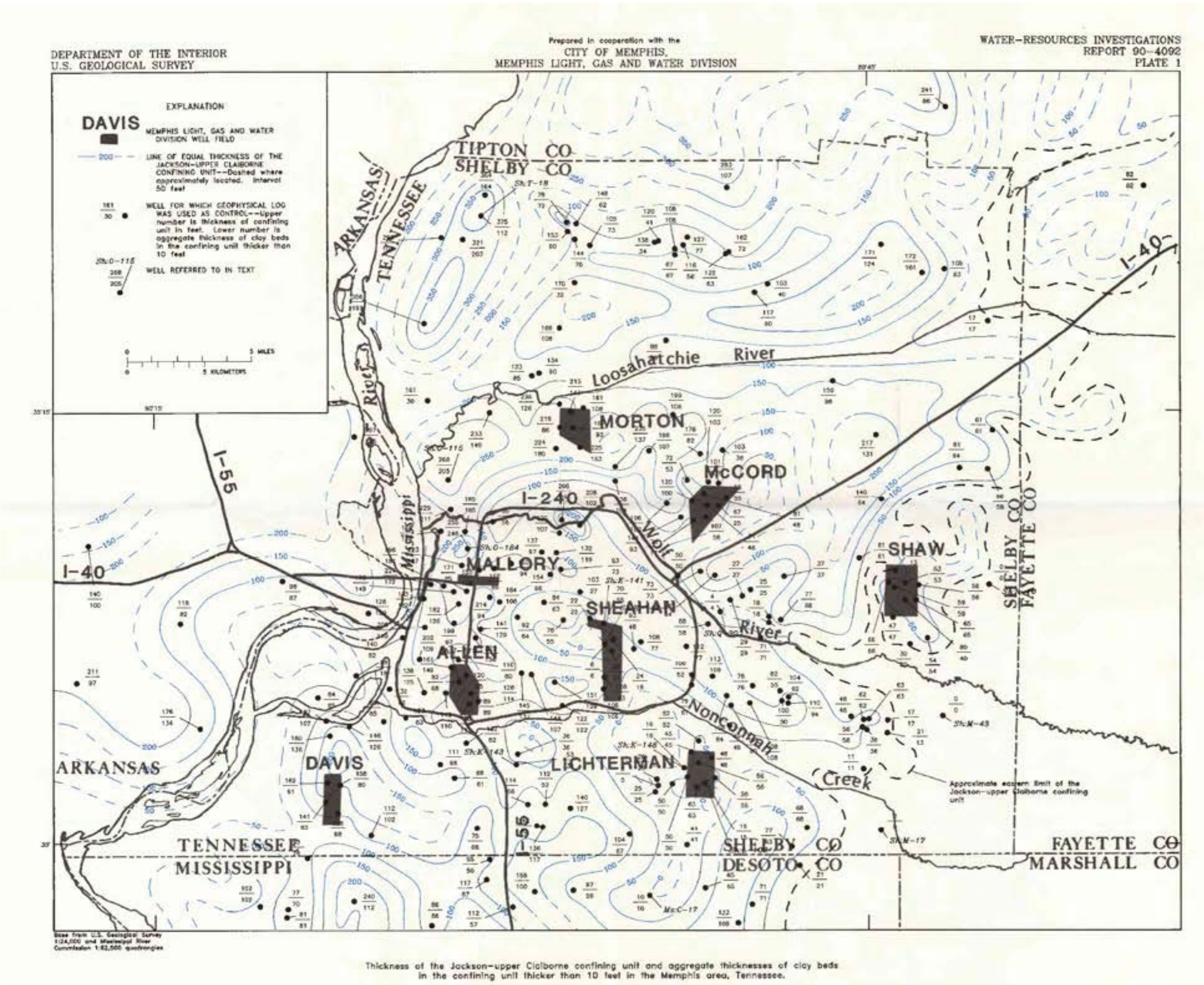

Figure 1. Thickness of Upper Claiborne confining clay with outcrop region of Middle Claiborne shown occurring along eastern Shelby County and into Fayette, Desoto, and Marshall Counties.

15. Lloyd and Lyke (1995) similarly provide in their USGS publication an illustration of the outcrop of section of the Middle Claiborne, and thus show the unconfined region (Figure 2) (Lloyd and Lyke, Figure 126, p. K27). They depict the unconfined region of the Middle Claiborne in West Tennessee passing through Fayette, Haywood, Crockett, Gibson, and Weakley counties, then continuing into Graves, Carlisle, and a small portion of Hickman counties in Kentucky.

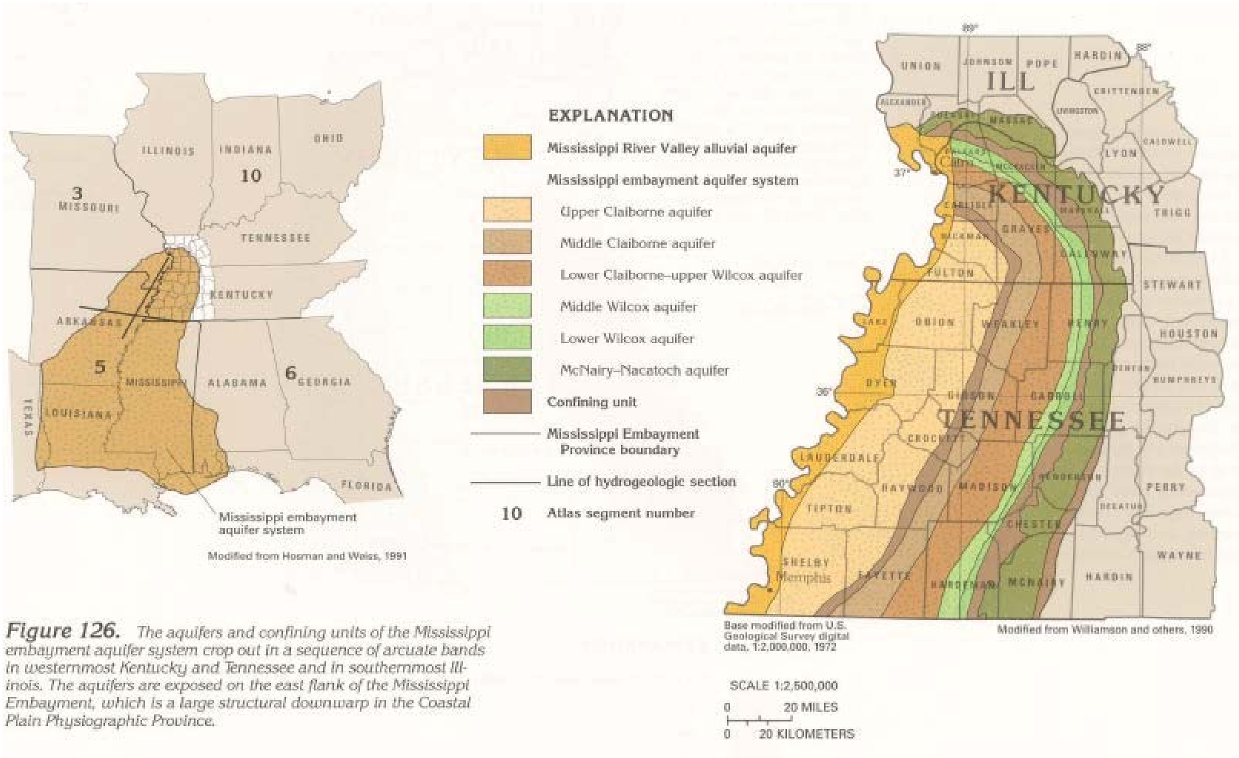

Figure 2. Depiction of extent and outcrop of Middle Claiborne in West Tennessee.

16. Spruill states (at 18) that "maps produced by Criner and Parks (1976) and Reed (1972) only consider groundwater-flow conditions in the <u>confined</u> portions of the aquifer" (emphasis by Spruill). Spruill also states: "It is significant that Criner and Parks only employed data from confined portions of the SMS aquifer system. Problems introduced by mixing water level data for confined and unconfined portions of an aquifer were discussed in my expert report" (p. 11) and "[d]ata for the unconfined aquifer system should <u>never</u> be used to define groundwater flow patterns in the confined portions of the aquifer system which reflect regional flow patterns" (p. 22) (emphasis by Spruill). Based on that view, Spruill states, "Examination of the data sources cited by W&L 2015, and the locations assigned for many of their 'well' data points used to create their Figure 4, reveals that they elected to combine indiscriminately data from confined and unconfined portions of the Sparta-Memphis Sand aquifer. Waldron and Larson's decision to combine these disparate data, in addition to the fundamentally flawed nature of the data itself, render the interpretation of the SMS' pre-development equipotential surface in W&L 2015 meaningless, and also explains why their interpretation is considerably different from that of USGS researchers (e.g., Reed, 1972; Criner and Parks, 1976)." (p. 15) Spruill relies heavily on Reed (1972) and Criner and Parks (1976) for his arguments.

17. Contrary to Spruill's assessment and argument regarding mapping confined and unconfined water levels together, Reed (1972) does in fact map water levels for the Middle Claiborne in the confined and unconfined sections (Figure 3). As shown in the red box, Reed (1972) maps water levels for the Middle Claiborne in Fayette County, Tennessee – shown by Parks (1990) and Lloyd and Lyke (1995) to be unconfined – while also mapping water levels in the confined portion of the Middle Claiborne in Shelby County. Reed (1972) further maps water levels in the Middle Claiborne

throughout West Tennessee and into southwest Kentucky in the same counties listed above minus Graves County, Kentucky (Figure 3, green box). As can be seen, Reed depicts (with the grayed area) the approximate area of the outcrop of the Middle Claiborne and maps a 400 ft water level in this area (Figure 3, blue box).

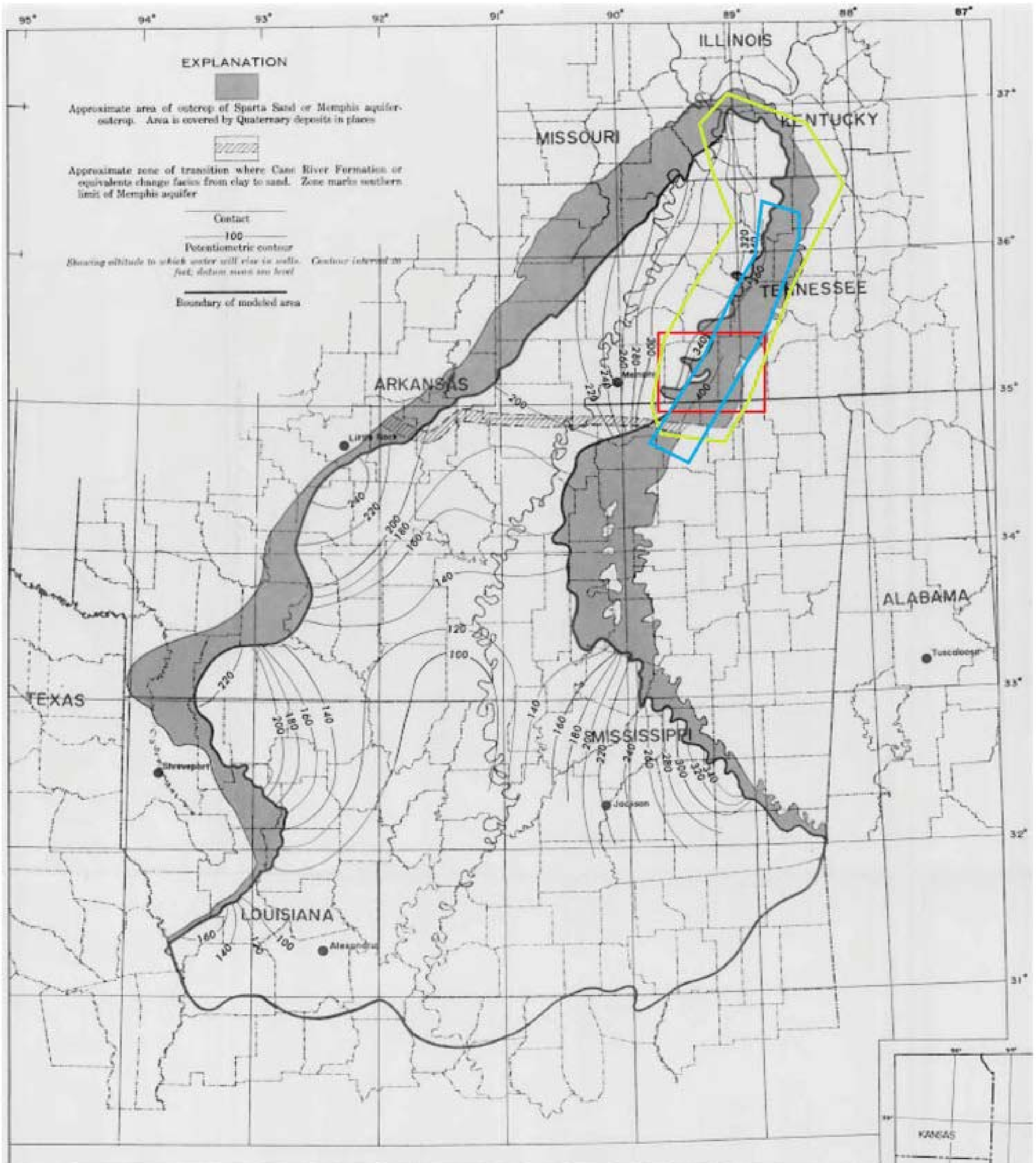

FIGURE 2.—Potentiometric surface of the Sparta Sand and Memphis aquifer in 1886.

Figure 3. Predevelopment potentiometric surface contours of the Middle Claiborne suggested by Reed (1972), including outcrop (unconfined) region of the Middle Claiborne in West Tennessee.

18. Similarly, Criner and Parks (1976) can be seen mapping water levels in both the confined and unconfined regions. Criner and Parks use a well in Fayette County, Tennessee, with the USGS label Fa:R-002. According to Parks (1990),* this well is in the *unconfined* section of the Middle Claiborne residing within a remnant Upper Claiborne clay lens. This well is used in subsequent water level maps of the Middle Claiborne. Further, according to Parks (1990)'s new rendition of the outcrop section of the Middle Claiborne, the eastern water level contours of Criner and Parks (1976) reside in the unconfined section of the Middle Claiborne.

19. Additionally, Parks and Carmichael (1990) mapped the thickness of the Middle Claiborne throughout West Tennessee and depicted on their *Figure 2* (Figure 4) the outcrop (i.e., unconfined section) of the Middle Claiborne residing between two thick black lines. Parks and Carmichael (1990) produce in their subsequent *Figure 3* (Figure 5) the "potentiometric surface" of the Middle Claiborne in 1983. Clearly, water levels are mapped in the confined and unconfined sections of the Memphis aquifer.

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*Each reference to "Parks" among these papers refers to the same W.S. Parks.

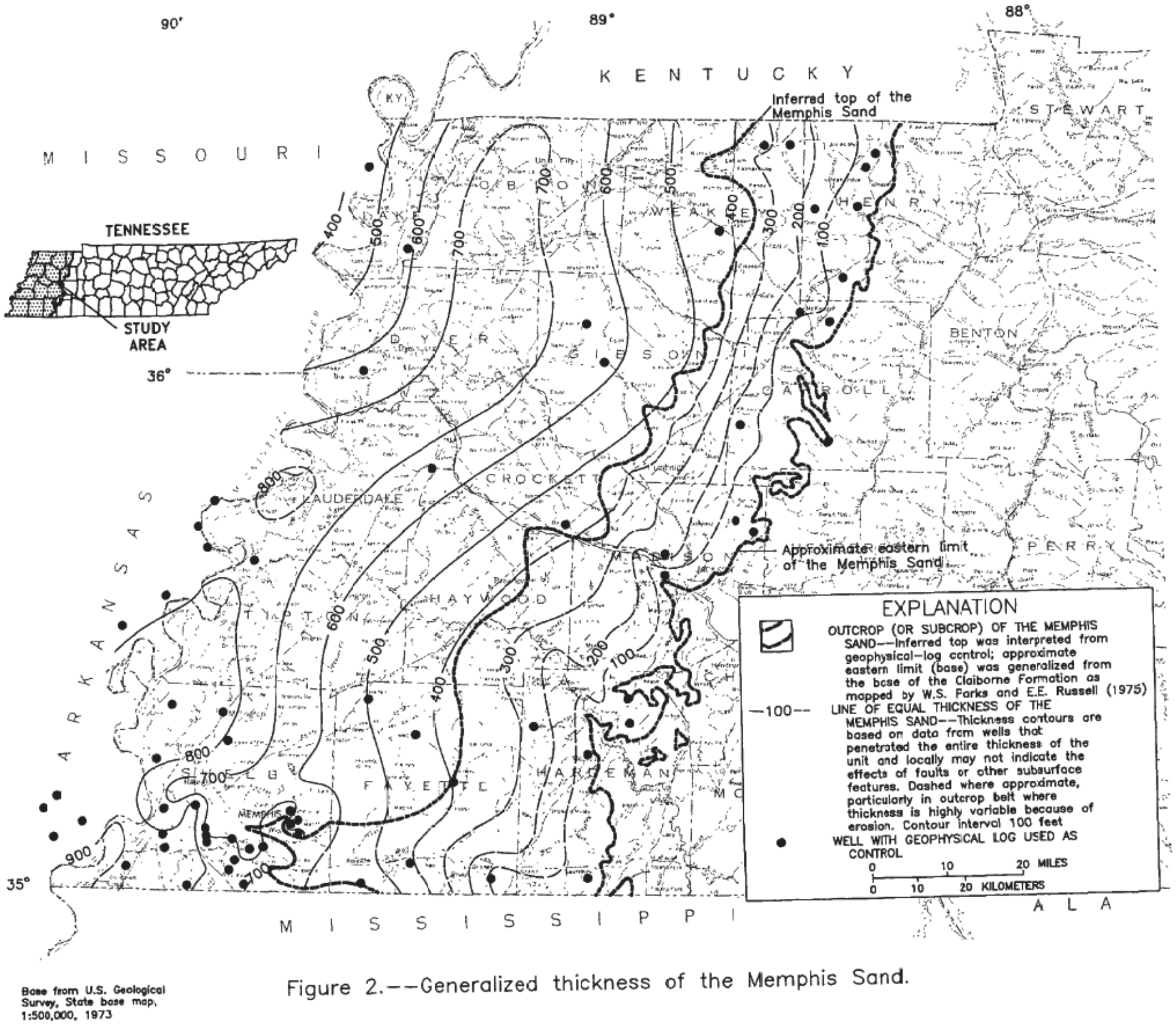

Figure 4. Extent of the Middle Claiborne in West Tennessee, including depiction of the outcrop (unconfined) region of the Middle Claiborne.

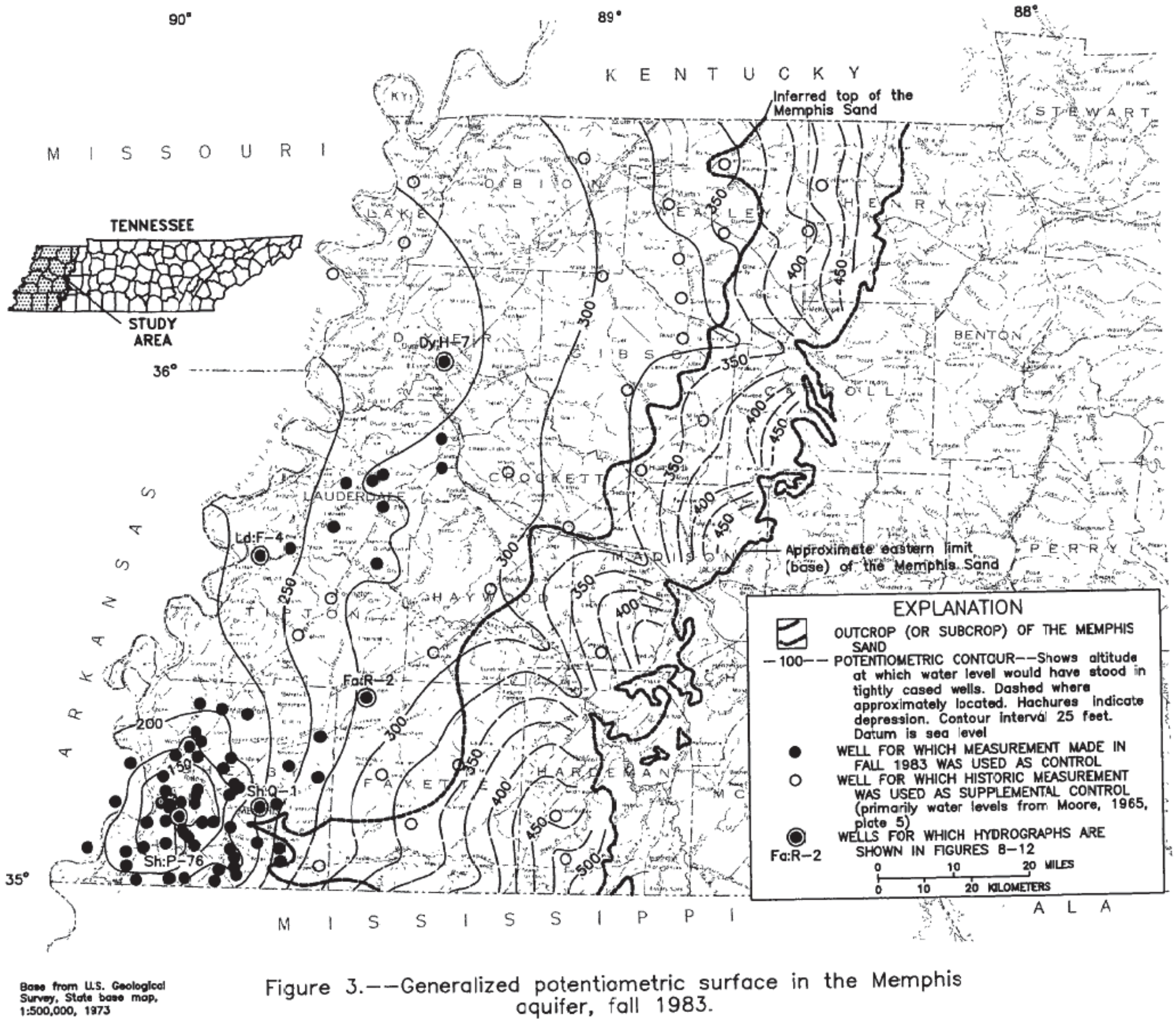

Figure 5. Potentiometric surface of the Middle Claiborne in West Tennessee depicted in the confined and unconfined regions of the Middle Claiborne.

20. Spruill (at 20-22) cites Schrader (2008) in his argument over changes in water levels between 1886 levels as analyzed by W&L and 2007 levels as analyzed by Schrader (2008). Spruill's own argument involves a well in the unconfined portion of the Memphis aquifer (according to Parks, 1990) using a study by Schrader (2008) that, like others, maps water levels in both the confined and unconfined sections of the Middle Claiborne (Figure 6, see grayed areas) in Tennessee and Mississippi. (W&L also use Schrader (2008) in their analysis of comparing groundwater quantities passing from Mississippi into Tennessee.)

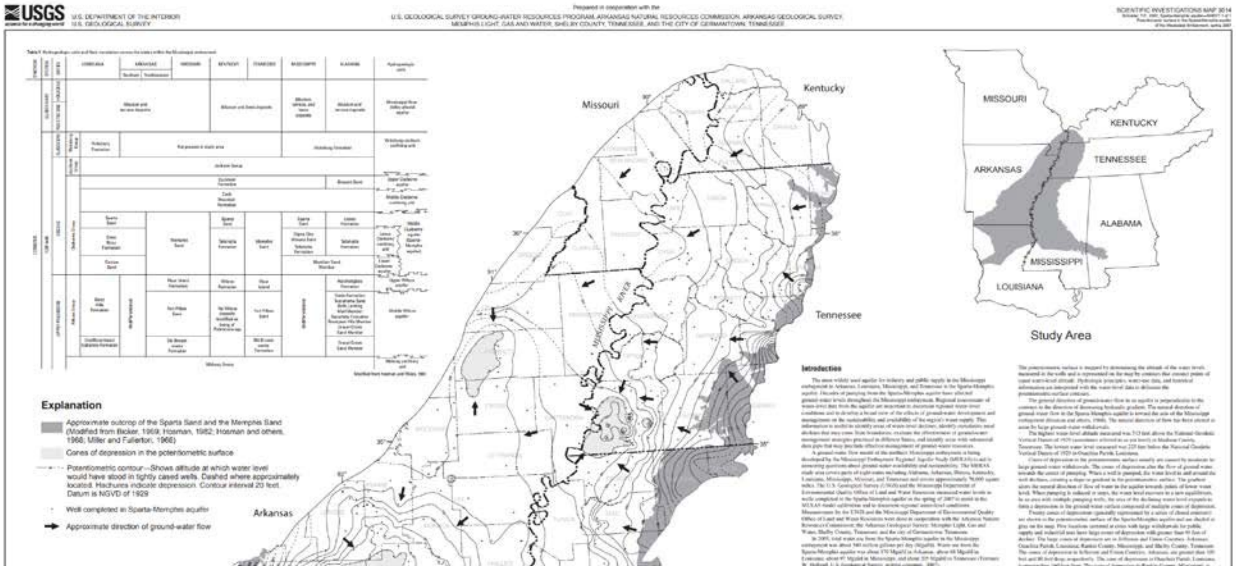

Figure 6. Potentiometric contours of the Middle Claiborne in 2007 mapped within the confined and unconfined regions (lower half of original figure has been cut off).

21. Mapping water levels in the Middle Claiborne confined and unconfined regions is a common practice followed by many of the very USGS authors Spruill cites. W&L followed this ordinary practice in mapping both confined and unconfined regions together.

22. The same practice is followed for other aquifers, as well. For example, Lloyd and Lyke (1995) map water levels in the Lower Wilcox aquifer confined and unconfined portions in West Tennessee in their *Figure 137* (Figure 7), again illustrating the commonality of mapping confined and unconfined water levels together.

<u>Wells Used by Waldron and Larsen Were Recorded in USGS Publications</u>

23. Spruill remarks on the lack of well construction data, arguing that it reduces the reliability of the water level data used by W&L. Although construction techniques were not as well-documented as they would be today, the USGS reported the water levels nonetheless. If the water levels were questionable because of unusual construction in particular wells, it seems unlikely that USGS authors (Fuller, 1903; Crider and Johnson, 1906; Glenn, 1906) would have recorded water levels for scientific purposes, as the USGS is a scientific research and data collection body. Spruill goes on to say (at 18): "Historic records used in W&L 2015 to obtain water level data do <u>not</u> provide <u>any</u> information about well construction and grouting." (emphases by Spruill). [In fact, an early publication by Brown (1947) as part of a Mississippi State Geological Survey lists numerous wells in each county in Mississippi that includes water levels but not a single mention of well construction information (Figure 12).]

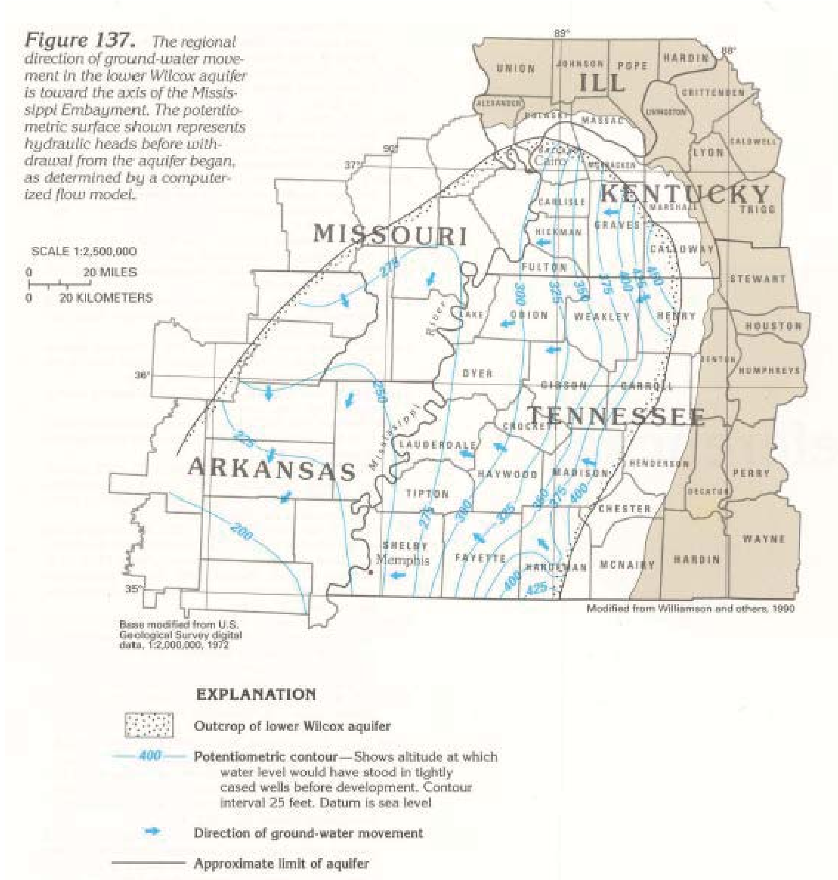

Figure 7. Following the extent and outcrop regions of the Middle Claiborne shown in Figure 2, Lloyd and Lyke (1995) map potentiometric contours within the confined and unconfined regions.

<u>Spruill Overstates the Relative Reliability of Alternative Data</u>

24. Spruill suggests that the data used by Criner and Parks (1976) to construct their predevelopment potentiometric surface are superior to the data used by W&L. However, a number of Spruill's arguments on this point are irrelevant, overstated, or incorrect.

25. Spruill states (at 10) that Criner and Parks (1976) did not include pumpage from a few thousand suburban and rural wells in the vicinity of Memphis and Shelby County, Tennessee; he seems to be suggesting that using these wells would not be relevant because they accounted for a small percentage of overall pumpage volume. However, volume is not the point; the question is what water levels were at the time of predevelopment. At any rate, for this purpose, measurements from these few thousand suburban and rural wells would post-date predevelopment conditions by many years and be less relevant than those measurements used by W&L.

26. Spruill also suggests (at 11) that Criner and Parks (1976)'s data were superior because "[s]ignificantly, C&P only relied upon data from 'observation wells, located at various distances from well fields and away from the estimated center of pumping' (C&P, 1976, page 11)." However, W&L did not focus on obtaining data away from the center of pumping or well fields, because at the

(near-predevelopment) time of the historical data used by W&L there were neither major well fields nor major pumping centers causing potential distortions of water levels.

27. Spruill states (at 11) that Criner and Parks (1976) used water level measurements of six wells that were "'projected backward in time to illustrate the probable original (pre-1886) water level with respect to the land surface' (C&P, 1976, page 11) to illustrate the most likely configuration of the pre-development equipotential surface for <u>hydraulically-confined</u> portions of the SMS aquifer (Figure 3)." However, this statement is incorrect. Criner and Parks (1976) clearly state that only a single well – USGS well Sh:O-124 – was projected back in time. Criner and Parks assumed that it would follow a linear trend over a 41-year span, as shown in Figure 8 (*Figure 3, upper graph*) and Figure 9.

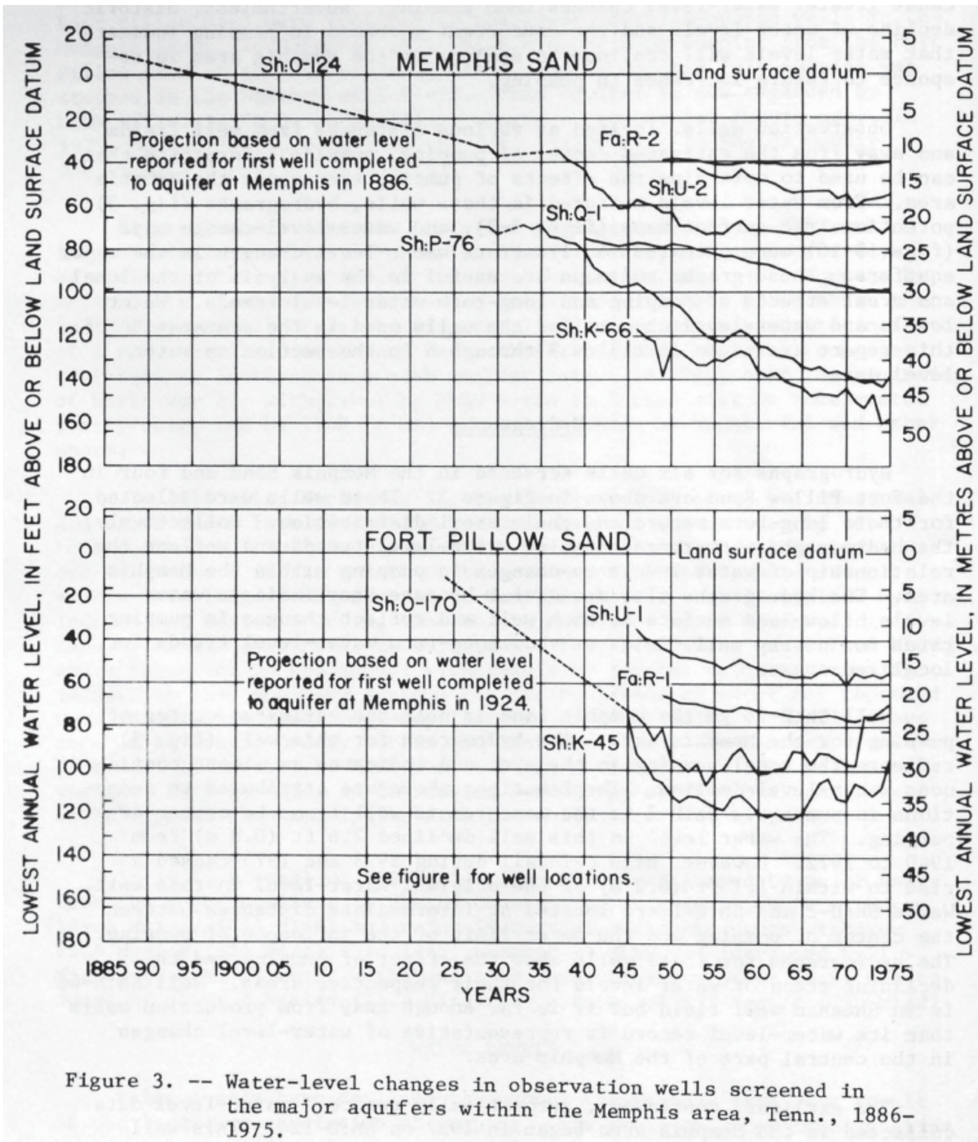

Figure 8. Wells whose hydrographs and water levels were used by Criner and Parks (1976) from predevelopment conditions, and illustration of linear back-projection of Sh:O-124 (tunnel) water level to arrive at estimated predevelopment water level of R.C. G.

> The earliest, continuous, automatically-recorded water-level data collected in the Memphis area began in 1927 on Sh:O-124. This well is near the site of the first well completed to the Memphis Sand in 1886, and for this reason, its hydrograph was projected backward in time to illustrate the probable original water level with respect to the land surface (fig. 3). This projection to an estimated water level

Figure 9. Excerpt from Criner and Parks (1976) regarding back-projection of only Sh:O-124.

28. As noted, Spruill suggests (at 17) that "[m]any 'wells' cited W&L 2015 *are not actually wells*" (emphasis by Spruill). Though this statement is incorrect (as discussed), Spruill argues (at 17) that water level data derived from what he thinks are not wells in W&L renders our analysis invalid. Yet, in fact, the single well Criner and Parks (1976) project backwards in time to define actual predevelopment water level conditions for the region (i.e., Sh:O-124) is not a well, but a water collection shaft (see Figure 10).

> It should be noted that well Sh:O-124 is an inspection shaft to an underground tunnel used in an early water-supply system as a collect- or for water which flowed from several wells screened in the Memphis Sand. Little is known about the tunnel, but it is reported to have been

Figure 10. Excerpt from Criner and Parks (1976, p. 13) on Sh:O-124, the single and only well used to project probable predevelopment conditions.

29. Spruill also questions the reliability of the data used by W&L by stating (at 16): "In addition to their use of ambiguous, uncertain, or clearly defective historic data from wells of unknown construction to develop a map based on those completely unreliable data." Again, however, Criner and Parks (1976), on which Spruill heavily relies, expressly state that Sh:O-124 is of questionable reliability, noting that: (1) Sh:O-124 is not a well but a tunnel (Figure 10); (2) "[l]ittle is known about the tunnel" (Figure 10); and (3) water levels in the tunnel were "anomalously high" and influenced by recharge (Figure 11).

> The hydrograph (fig. 3) and potentiometric-surface maps indicate that the water level in Sh:O-124 is anomalously high and that the tunnel may have become a line of recharge to the Memphis Sand in about 1955.

Figure 11. Excerpt from Criner and Parks (1976, p. 13) on Sh:O-124 and observed anomalously high water levels.

100 GEOLOGY AND ARTESIAN WATER OF THE

TABLE 13—RECORD OF WATER WELLS IN DESOTO COUNTY

No.	Location	Owner or name	Driller	Com-pleted	Dia-meter well (In.)	Depth well (feet)	Depth cased (feet)	Depth to screen (feet)	Length of screen (feet)	Principal water-bearing bed: Thick. (feet)	Material	Geologic form.
1.	SW.1/4, NE.1/4, Sec.24, T.1 S., R. 10 W.	R. P. Harris	Mr. Seay	1921	3	1532	1532	......	60	......	Sand	Lower Wilcox
2.	NW.1/4, NE.1/4, Sec.23, T.1 S., R. 10 W.	T. P. Howard	T. B. Minyard	1926	3(?)	1580	......	......	......	......	Sand	Lower Wilcox
3.	NW.1/4, NE.1/4, Sec.32, T.1 S., R. 9 W.	H. P. Sullivan	C. M. Journey	1935	2	1525	......	......	......	57	Sand	Lower Wilcox
4.	NE.1/4, SW.1/4, Sec.35, T.1 S., R. 10 W.	O. L. Cox		1922	3(?)	1580	......	......	......	......	Sand	Lower Wilcox
4a.	NE.1/4, SW.1/4, Sec.35, T.1 S., R. 10 W.	O. L. Cox	C. M. Journey	1940	3	1541	1541	1499	42	80	Sand	Lower Wilcox
5.	NW.1/4, NE.1/4, Sec.24, T.2 S., R. 10 W.	Mrs. J. C. Brantley	E. S. Archer	......	2½	1460	......	......	20	......	Sand	Lower Wilcox
6.	NW.1/4, NE.1/4, Sec.24, T.2 S., R. 10 W.	Mrs. J. C. Brantley		......	4½	2120	......	......	......	......	......	Lower Wilcox
7.	NW.1/4, NW.1/4, Sec.24, T.2 S., R. 10 W.	W. W. Blythe & others	J. A. Pollard	......	3	1560	......	......	......	......	Sand	Lower Wilcox
8.	SW.1/4, SE.1/4, Sec.32, T.2 S., R 10 W.	I. A. Clement		......	3	1800	......	......	......	......	Sand	Lower Wilcox
9.	NE.1/4, NW.1/4, Sec.15, T.3 S., R. 9 W.	S. B. Dean	C. M. Journey	1938	4	324	324	310	16	29	Sand	Cockfield
10.	NW.1/4, SE.1/4, Sec.13, T.3 S., R. 8 W.	Town of Hernando	Layne-Central Co.	1934	8	250	......	......	......	50+	Sand	Kosciusko
11.	NW.1/4, SE.1/4, Sec.13, T.3 S., R. 8 W.	Town of Hernando	Layne-Central Co.	1940	8	250	......	......	......	50+	Sand	Kosciusko
12.	SW.1/4, NE.1/4, Sec.2, T.4 S., R. 9 W.	Arkabutla K III bore hole		1940	......	365	......	......	......	......	......	Kosciusko(?)

TABLE 13—RECORD OF WATER WELLS IN DESOTO COUNTY—(Continued)

No.	Water Level: + or − meas. pt. (feet)	Water Level: Date measured	Measuring point: Feet above m.s.l.	Measuring point: + or − ground (feet)	Measuring point: Description	Yield Flow	(g.p.m.) Pump	Temp. °F.	Use of water	Other records and general information
1.	7.0	July 15	213	1	Top of well tee	70	10(app.)	......	Dom.	Reported yield when drilled
2.	16.3	July 15	210	0	Top of well tee	......	......	......	Dom.	Reported decline of static head
3.	16.25	July 15	205	0	Top of well tee	......	......	......	Dom.	Static head of 18 feet reported when drilled
4.	18.75	July 15	207	1	Top of 1¼ in. lower tee	......	......	74	Dom.	
4a.	+	May 22	206	0	Level of land at well head	120	......	......	Dom.	4½ in. casing land at 1139 feet 8 in. Reported by driller
5.	16.0	July 15	210	3	Top of well tee	140	......	......	Dom.	Reported yield when drilled
6.	+	......	......	......	......	1	......	......	Aban.	
7.	−18.9	July 15	206	2	Top of well tee	......	......	77	P. S.	
8.	21.85	July 15	205	1.5	Top of well tee	......	......	......	Dom.	
9.	−80.0(app.)	Feb. 22, 1940	301	0	Concrete pump base	25	......	......	Saw Mill	
10.	......	......	......	......	......	250	......	......	P. S.	
11.	......	......	......	......	......	250	......	......	P. S.	
12.	......	......	197.5	......	......	......	......	......	......	

ALLUVIAL PLAIN IN NORTHWESTERN MISSISSIPPI 101

Figure 12. Table 13 for groundwater wells in DeSoto County, Mississippi (Brown, 1947).

30. Spruill states (at 18) that W&L mentioned Well #3 (Forrest City, Arkansas), but did not use it in their analysis; he further suggests that, if W&L had done so, it would reorient the Middle Claiborne predevelopment gradient to be more east-to-west. In fact, however, W&L did incorporate this well into their analysis. The well is on the extreme outskirts of the data area, and there are not enough other data near that well to draw a 2D contour for a single point (following the logic that two points define a line). Figure 13 shows the Forrest City well, which is present in the analysis though not shown on W&L's *Figure 4*.

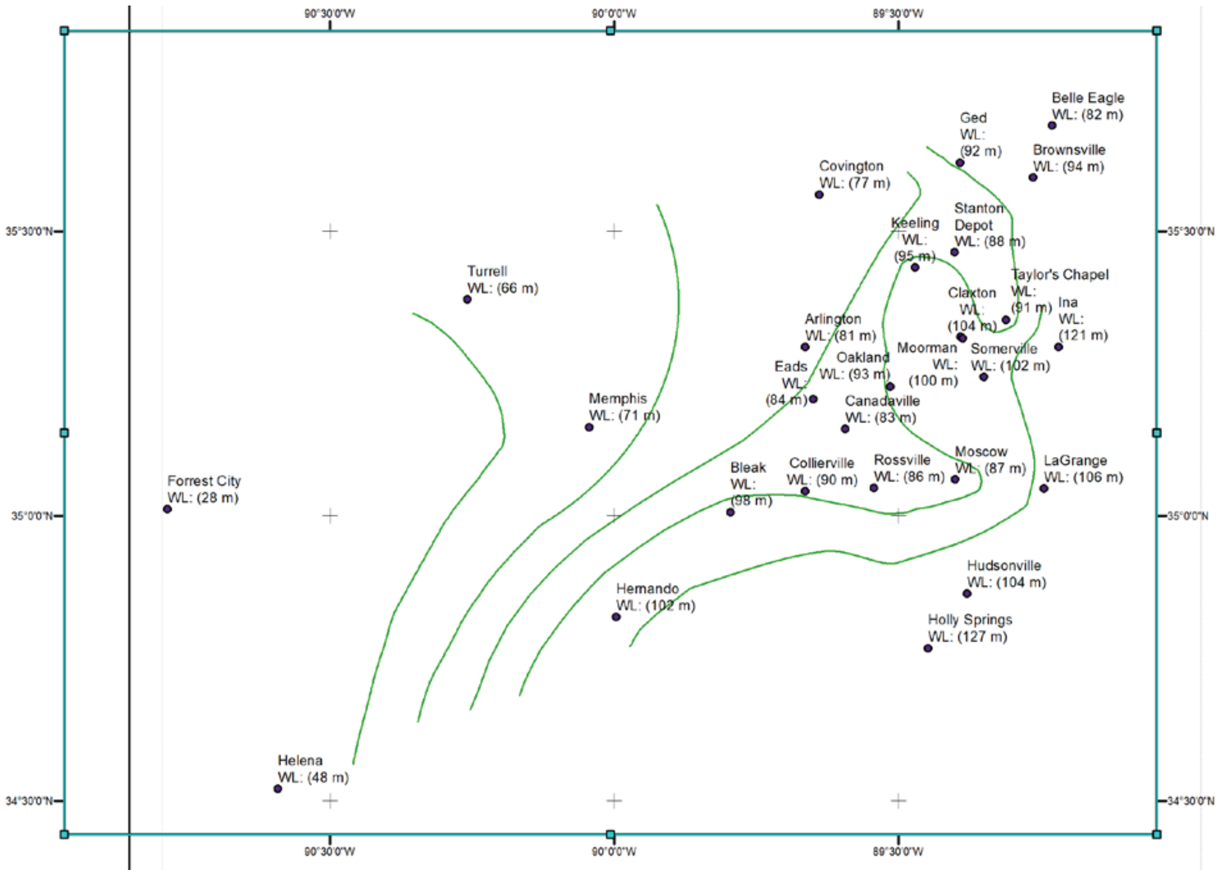

Figure 13. Expansion of W&L wells used for determining predevelopment conditions showing Forrest City, Arkansas, well.

31. Spruill comments on W&L's use of land surface elevations for artesian well conditions, arguing that the resulting water levels are inaccurate. In the case of the historically significant R.C. Graves well in downtown Memphis, W&L extensively reviewed other sources to arrive at the best possible water level elevation for this artesian well (Figure 14). Interestingly, Criner and Parks (1976) use a linear interpolation from a water level reading taken in a tunnel (not a well) in 1927 back over a 41-year span to arrive at their predevelopment water level, yet Spruill does not question the validity of their value.

> The second most accurate elevation was from interpolation of elevation contours mapped by the U.S. Army Corps of Engineers (USACE) during the 1930s (USACE, 1932). Using these older elevation contours was critical in downtown Memphis, Tennessee, where growth and development have greatly altered the landscape. The only well located in downtown Memphis was the Bohlen-Huse well drilled by R.C. Graves in 1886. Glenn (1906) stated that the

Exhibit 24

Tables from Report on Diversion Of Groundwater From Northern Mississippi Due To Memphis Area Well Fields
(Expert Report of David Wiley)

(May 2007)

REPORT ON DIVERSION OF GROUND WATER FROM NORTHERN MISSISSIPPI DUE TO MEMPHIS AREA WELL FIELDS

Prepared For:

Jim Hood, Attorney General of the State of Mississippi

May 2007

Prepared By:

LEGGETTE, BRASHEARS & GRAHAM,, INC.
Professional Ground-Water and Environmental Engineering Consultants
10014 North Dale Mabry Highway, Suite 205
Tampa, FL 33618

TABLES

Table 1 - Water Budget Flows From Desoto & Marshall Counties

Year	Marshall. MS (MGD)	Desoto, MS (MGD)
1886-1924	0.0023	4.18
1924-1941	0.004	9.22
1941-1955	0.007	13.55
1955-1960	0.2	19.946
1960-1965	0.17	22.66
1965-1970	0.133	28.21
1970-1975	0.147	32.22
1975-1980	0.16	33.32
1980-1983	0.161	34.35
1983-1991	0.17	35.38
1991-1993	0.17	35.4
1993-1995	0.168	32.1
1995-2000	0.169	33
2000-2005	0.17	33.1

Table 2 - Pumpage Amounts From Each County

Year	Marshall, MS (MGD)	Tate, MS (MGD)	Tunica, MS (MGD)	Desoto, MS--Pumpage From Model (MGD)
1886-1924	0.1	0.284	0.3553	0
1924-1941	0.232	0.63	0.775	0
1941-1955	0.375	0.94	1.105	0
1955-1960	1.07	2.47	1.99	0.497
1960-1965	1.105	2.65	2.26	0.898
1965-1970	1.221	2.836	2.69	1.23
1970-1975	1.4212	3.44	3.25	4.18
1975-1980	1.47	3.58	3.37	4.18
1980-1983	1.58	3.6	3.28	3.6
1983-1991	1.63	3.65	3.36	3.6
1991-1993	1.62	3.695	3.388	3.6
1993-1995	1.78	4.86	4.031	13.05
1995-2000	1.815	4.97	4.14	13.4
2000-2005	1.822	5.07	4.22	14

Table 3
MEMPHIS LIGHT, GAS AND WATER DIVISION
CITY OF MEMPHIS
Water Pumpage By Stations
Gallons Per Day
1965-2007

	Sheahan	Mallory	Allen	Lichterman	McCord	Davis	Palmer	Morton	LNG.	Shaw	TOTAL	Starting Bates #	Ending Bates #	Monthly or Yearly	Comments (If not raw pumpage data)
Row	41	41	45	44	33	50	48	33	26	33					
Column	25	17	21	29	25	17	24	18	26	32					
1965	17,773,000	13,268,000	22,519,000	4,220,000	14,181,000						71,961,000	MLGW 66416		Yearly	Net Pumpage
1966	16,991,000	12,618,000	22,969,000	9,697,000	13,472,000						75,747,000	MLGW 66417		Yearly	Net Pumpage
1967	15,870,000	12,364,000	22,592,000	13,277,000	13,599,000						77,702,000	MLGW 66417		Yearly	Net Pumpage
1968	15,961,000	12,582,000	23,430,000	14,621,000	14,487,000						81,081,000	MLGW 66417		Yearly	Net Pumpage
1969	15,063,000	11,961,000	23,934,000	16,192,000	15,495,000						82,645,000	MLGW 66418		Yearly	Net Pumpage
1970	15,556,000	11,231,000	27,167,000	16,775,000	16,211,000	3,258,000			101,000		90,299,000	MLGW 66418		Yearly	Net Pumpage
1971	18,332,000	12,953,000	25,420,000	15,585,000	15,930,000	7,487,000			151,000		95,858,000	MLGW 66418		Yearly	Net Pumpage
1972	15,927,000	15,973,000	22,024,000	16,373,000	15,491,000	10,204,000	2,801,000		249,000		99,042,000	MLGW 66419		Yearly	Net Pumpage
1973	17,167,583	18,880,000	21,578,667	18,084,333	17,281,583	10,867,333	2,776,333	1,660,000	174,166		108,469,998	MLGW 67682	MLGW 67741	Monthly	
1974	17,579,833	20,101,500	22,193,750	18,142,667	15,353,667	10,617,083	2,944,833	2,354,083	255,750		109,543,166	MLGW 67622	MLGW 67681	Monthly	
1975	18,130,916	19,148,583	21,276,750	17,378,916	19,111,750	11,688,416	3,047,666	160,500	243,833		110,187,330	MLGW 67562	MLGW 67621	Monthly	
1976	19,007,000	20,641,000	19,947,000	18,148,000	18,721,000	11,370,000	3,158,000	3,000	260,000		111,255,000	MLGW 66420		Yearly	Net Pumpage
1977	18,564,000	22,114,000	21,680,000	18,809,000	19,986,000	13,226,000	3,360,000	5,000	268,000		118,012,000	MLGW 66420		Yearly	Net Pumpage
1978	16,055,000	20,785,000	21,316,000	20,517,000	21,086,000	13,779,000	3,545,000	34,000	361,000		117,478,000	MLGW 67562	MLGW 67848	Monthly	
1979	17,419,000	20,294,000	19,867,000	22,645,000	22,164,000	14,125,000	2,869,000	4,000	327,000		119,714,000	MLGW 67831	MLGW 67835	Monthly	
1980	20,744,000	20,953,000	21,591,000	23,151,000	20,700,000	13,262,000	3,186,000	53,000	343,000		123,983,000	MLGW 67818	MLGW 67882	Monthly	
1981	21,229,000	20,375,000	19,305,000	21,633,000	21,556,000	11,526,000	3,425,000	20,000	339,000		119,408,000	MLGW 67805	MLGW 67809	Monthly	
1982	21,465,000	17,526,000	20,508,000	22,524,000	19,124,000	11,591,000	2,850,000	5,618,000	421,000		121,627,000	MLGW 67791	MLGW 67795	Monthly	
1983	22,914,000	17,338,000	20,947,000	22,163,000	17,269,000	12,705,000	179,000	10,874,000	465,000		124,855,983	MLGW 67778	MLGW 67782	Monthly	
1984	20,743,000	18,693,000	21,102,000	21,850,000	20,772,000	12,244,000	724,000	11,091,000	460,000		127,680,984	MLGW 67765	MLGW 67769	Monthly	
1985	20,499,000	21,784,000	23,607,000	21,550,000	20,764,000	11,294,000	255,000	11,402,000	500,274	-	131,655,274	MLGW 0003		Yearly	Net Pumpage
1986	20,310,411	20,834,795	24,906,027	24,151,781	20,575,068	12,620,548	138,904	12,447,671	554,247	-	136,539,452	GWI 013666	GWI 013684	Monthly	
1987	18,876,438	20,218,082	24,590,411	24,483,562	20,714,795	12,785,753	293,425	12,953,425	530,411	-	135,446,301	GWI 013685	GWI 013722	Monthly	
1988	21,445,479	21,059,178	24,733,973	25,466,575	20,743,562	12,714,521	1,681,096	14,218,082	526,849	-	142,589,315	GWI 012946	GWI 013051	Monthly	
1989	19,761,096	19,727,397	21,925,753	24,121,370	20,559,726	11,349,589	3,776,712	13,705,753	397,260	-	135,324,658	GWI 013082	GWI 013208	Monthly	Some Net pumpage used for Nov - MLGW 00005
1990	21,005,205	19,690,959	24,137,260	23,247,945	19,839,178	10,447,671	4,101,644	12,236,712	434,247	5,867,397	141,008,219	GWI 01321	GWI 013384	Monthly	Net pumpage used for Jan - MLGW 00005
1991	20,998,082	20,714,795	21,012,603	21,771,507	18,516,438	10,135,890	5,079,178	10,465,753	393,151	10,983,562	140,070,959	GWI 012341	GWI 012487	Monthly	
1992	20,023,836	20,626,849	20,444,110	21,130,685	19,223,562	9,701,918	5,337,534	10,458,904	423,014	11,872,603	139,243,014	GWI 012490	GWI 012636	Monthly	
1993	19,548,219	20,222,192	21,248,767	21,801,644	18,483,836	9,960,000	4,808,767	12,719,726	497,534	10,325,479	139,616,164	GWI 012639	GWI 012785	Monthly	
1994	20,627,397	15,901,370	21,576,712	21,936,438	17,695,890	11,866,027	4,938,356	14,360,548	477,260	12,982,466	142,362,466	GWI 012787	GWI 012943	Monthly	
1995	20,570,137	16,029,315	22,800,548	21,915,342	17,398,082	12,569,863	4,903,562	17,106,301	529,589	14,177,260	148,000,000	GWI 011938	GWI 012085	Monthly	
1996	20,170,137	17,329,589	22,532,055	21,929,041	17,373,425	14,135,616	4,668,767	18,168,767	515,342	13,058,630	149,881,370	GWI 012087	GWI 012235	Monthly	
1997	19,556,438	15,529,315	22,114,521	21,377,534	15,968,493	14,602,466	4,284,658	16,915,068	444,384	14,880,000	145,672,877	GWI 012239	GWI 012337	Monthly	Net pumpage used for Sept-Dec - MLGW 00009
1998	21,355,068	17,229,863	22,910,137	23,288,767	15,794,795	15,442,466	4,090,411	17,976,986	419,726	17,894,795	156,403,014	GWI 011534	GWI 011631	Monthly	Net pumpage used for Jan-Apr - MLGW 00009
1999	21,441,370	18,560,548	25,246,575	23,447,397	16,404,932	12,718,356	5,067,945	18,886,027	493,425	19,609,863	161,876,438	GWI 011632	GWI 011767	Monthly	Some Net pumpage used - MLGW 00010
2000	21,641,370	17,321,096	24,287,123	22,502,466	17,129,589	13,992,603	4,998,082	19,012,329	369,315	20,854,521	162,108,493	GWI 011773	GWI 011911	Monthly	Net pumpage used for May - MLGW 00010
2001	19,443,014	17,588,767	19,972,329	19,626,575	16,318,904	17,500,548	4,785,205	17,477,260	446,301	20,248,493	153,407,397	MLGW 00011		Yearly	Net Pumpage
2002	18,140,000	17,300,000	22,000,000	18,550,000	15,550,000	19,000,000	4,525,000	18,000,000	475,000	20,983,333	154,523,333	MLGW2 03771 CD		Monthly	
2003	15,616,666	15,708,333	22,383,333	18,133,333	16,066,667	19,508,333	5,108,333	18,941,667	334,167	20,100,000	151,900,832	MLGW2 03771 CD		Monthly	
2004	15,775,000	16,075,000	21,858,333	17,700,000	16,341,667	19,641,667	5,150,000	18,741,667	400,000	22,666,667	154,350,001	MLGW2 03771 CD		Monthly	
2005	15,266,667	17,141,667	21,675,000	19,158,333	17,700,000	20,225,000	3,383,333	18,783,333	558,333	23,000,000	156,891,666	MLGW2 03771 CD		Monthly	
2006	16,658,333	16,575,000	21,358,333	19,550,000	17,458,333	20,566,667	4,166,667	18,341,667	358,333	21,200,000	156,233,333	MLGW2 03771 CD		Monthly	

Table 4 - Volume of Ground Water Diverted from Mississippi Due to MLGW Pumpage

Year	MGD
1965	13.7
1966	15.2
1967	16.0
1968	16.8
1969	17.2
1970	19.4
1971	20.7
1972	22.0
1973	23.5
1974	23.8
1975	22.7
1976	22.8
1977	24.4
1978	24.5
1979	24.9
1980	26.0
1981	24.5
1982	24.8
1983	24.8
1984	24.8
1985	25.3
1986	26.7
1987	26.6
1988	28.2
1989	26.8
1990	27.1
1991	26.0
1992	25.5
1993	25.7
1994	26.3
1995	24.0
1996	24.5
1997	23.7
1998	25.4
1999	25.9
2000	25.6
2001	24.0
2002	24.3
2003	24.1
2004	23.9
2005	23.8
2006	24.2

Exhibit 25

Tables from Update Report On Diversion And Withdrawal Of Groundwater From Northern Mississippi Into The State Of Tennessee
(Expert Report of David Wiley)

(June 30, 2017)

UPDATE REPORT ON DIVERSION AND WITHDRAWAL OF GROUNDWATER FROM NORTHERN MISSISSIPPI INTO THE STATE OF TENNESSEE

Prepared For:

Jim Hood, Attorney General of the State of Mississippi

June 30, 2017

Prepared By:

LEGGETTE, BRASHEARS & GRAHAM, INC.
Professional Groundwater and Environmental Engineering Consultants
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TABLES

Table 1

MEMPHIS LIGHT, GAS AND WATER DIVISION
CITY OF MEMPHIS
Water Pumpage By Stations
Gallons Per Day
1965-2012

	Sheahan	Mallory	Allen	Lichterman	McCord	Davis	Palmer	Morton	LNG	Shaw	TOTAL	Starting Bates #	Ending Bates #	Monthly or Yearly	Comments (If not raw pumpage data)
Row	41	41	45	44	33	50	48	33	26	33					
Column	25	17	21	29	25	17	24	18	26	32					
1965	17,773,000	13,268,000	22,519,000	4,220,000	14,181,000						71,961,000	MLGW 66416		Yearly	Net Pumpage
1966	16,991,000	12,618,000	22,969,000	9,697,000	13,472,000						75,747,000	MLGW 66417		Yearly	Net Pumpage
1967	15,870,000	12,364,000	22,592,000	13,277,000	13,599,000						77,702,000	MLGW 66417		Yearly	Net Pumpage
1968	15,961,000	12,582,000	23,430,000	14,621,000	14,487,000						81,081,000	MLGW 66417		Yearly	Net Pumpage
1969	15,063,000	11,961,000	23,934,000	16,192,000	15,495,000						82,645,000	MLGW 66418		Yearly	Net Pumpage
1970	15,556,000	11,231,000	27,167,000	16,775,000	16,211,000	3,258,000			101,000		90,299,000	MLGW 66418		Yearly	Net Pumpage
1971	18,332,000	12,953,000	25,420,000	15,585,000	15,930,000	7,487,000			151,000		95,858,000	MLGW 66418		Yearly	Net Pumpage
1972	15,927,000	15,973,000	22,024,000	16,373,000	15,491,000	10,204,000	2,801,000		249,000		99,042,000	MLGW 66419		Yearly	Net Pumpage
1973	17,167,583	18,880,000	21,578,667	18,084,333	17,281,583	10,867,333	2,776,333	1,660,000	174,166		108,469,998	MLGW 67682	MLGW 67741	Monthly	
1974	17,579,833	20,101,500	22,193,750	18,142,667	15,353,667	10,617,083	2,944,833	2,354,083	255,750		109,543,166	MLGW 67622	MLGW 67681	Monthly	
1975	18,130,916	19,148,583	21,276,750	17,378,916	19,111,750	11,688,416	3,047,666	160,500	243,833		110,187,330	MLGW 67562	MLGW 67621	Monthly	
1976	19,007,000	20,641,000	19,947,000	18,148,000	18,721,000	11,370,000	3,158,000	3,000	260,000		111,255,000	MLGW 66420		Yearly	Net Pumpage
1977	18,564,000	22,114,000	21,680,000	18,809,000	19,986,000	13,226,000	3,360,000	5,000	268,000		118,012,000	MLGW 66420		Yearly	Net Pumpage
1978	16,055,000	20,785,000	21,316,000	20,517,000	21,086,000	13,779,000	3,545,000	34,000	361,000		117,478,000	MLGW 67562	MLGW 67848	Monthly	
1979	17,419,000	20,294,000	19,867,000	22,645,000	22,164,000	14,125,000	2,869,000	4,000	327,000		119,714,000	MLGW 67831	MLGW 67835	Monthly	
1980	20,744,000	20,953,000	21,591,000	23,151,000	20,700,000	13,262,000	3,186,000	53,000	343,000		123,983,000	MLGW 67818	MLGW 67882	Monthly	
1981	21,229,000	20,375,000	19,305,000	21,633,000	21,556,000	11,526,000	3,425,000	20,000	339,000		119,408,000	MLGW 67805	MLGW 67809	Monthly	
1982	21,465,000	17,526,000	20,508,000	22,524,000	19,124,000	11,591,000	2,850,000	5,618,000	421,000		121,627,000	MLGW 67791	MLGW 67795	Monthly	
1983	22,914,000	17,338,000	20,947,000	22,163,000	17,269,000	12,705,000	179,000	10,874,000	465,000		124,855,983	MLGW 67778	MLGW 67782	Monthly	
1984	20,743,000	18,693,000	21,102,000	21,850,000	20,772,000	12,244,000	724,000	11,091,000	460,000		127,680,984	MLGW 67765	MLGW 67769	Monthly	
1985	20,499,000	21,784,000	23,607,000	21,550,000	20,764,000	11,294,000	255,000	11,402,000	500,274	-	131,655,274	MLGW 0003		Yearly	Net Pumpage
1986	20,310,411	20,834,795	24,906,027	24,151,781	20,575,068	12,620,548	138,904	12,447,671	554,247	-	136,539,452	GWI 013666	GWI 013684	Monthly	
1987	18,876,438	20,218,082	24,590,411	24,483,562	20,714,795	12,785,753	293,425	12,953,425	530,411	-	135,446,301	GWI 013685	GWI 013722	Monthly	
1988	21,445,479	21,059,178	24,733,973	25,466,575	20,743,562	12,714,521	1,681,096	14,218,082	526,849	-	142,589,315	GWI 012946	GWI 013051	Monthly	
1989	19,761,096	19,727,397	21,925,753	24,121,370	20,559,726	11,349,589	3,776,712	13,705,753	397,260	-	135,324,658	GWI 013082	GWI 013208	Monthly	Some Net pumpage used for Nov - MLGW 00005
1990	21,005,205	19,690,959	24,137,260	23,247,945	19,839,178	10,447,671	4,101,644	12,236,712	434,247	5,867,397	141,008,219	GWI 01321	GWI 013384	Monthly	Net pumpage used for Jan - MLGW 00005
1991	20,998,082	20,714,795	21,012,603	21,771,507	18,516,438	10,135,890	5,079,178	10,465,753	393,151	10,983,562	140,070,959	GWI 012341	GWI 012487	Monthly	
1992	20,023,836	20,626,849	20,444,110	21,130,685	19,223,562	9,701,918	5,337,534	10,458,904	423,014	11,872,603	139,243,014	GWI 012490	GWI 012636	Monthly	
1993	19,548,219	20,222,192	21,248,767	21,801,644	18,483,836	9,960,000	4,808,767	12,719,726	497,534	10,325,479	139,616,164	GWI 012639	GWI 012785	Monthly	
1994	20,627,397	15,901,370	21,576,712	21,936,438	17,695,890	11,866,027	4,938,356	14,360,548	477,260	12,982,466	142,362,466	GWI 012787	GWI 012943	Monthly	
1995	20,570,137	16,029,315	22,800,548	21,915,342	17,398,082	12,569,863	4,903,562	17,106,301	529,589	14,177,260	148,000,000	GWI 011938	GWI 012085	Monthly	
1996	20,170,137	17,329,589	22,532,055	21,929,041	17,373,425	14,135,616	4,668,767	18,168,767	515,342	13,058,630	149,881,370	GWI 012087	GWI 012235	Monthly	
1997	19,556,438	15,529,315	22,114,521	21,377,534	15,968,493	14,602,466	4,284,658	16,915,068	444,384	14,880,000	145,672,877	GWI 012239	GWI 012337	Monthly	Net pumpage used for Sept-Dec - MLGW 00009
1998	21,355,068	17,229,863	22,910,137	23,288,767	15,794,795	15,442,466	4,090,411	17,976,986	419,726	17,894,795	156,403,014	GWI 011534	GWI 011631	Monthly	Net pumpage used for Jan-Apr - MLGW 00009
1999	21,441,370	18,560,548	25,246,575	23,447,397	16,404,932	12,718,356	5,067,945	18,886,027	493,425	19,609,863	161,876,438	GWI 011632	GWI 011767	Monthly	Some Net pumpage used - MLGW 00010
2000	21,641,370	17,321,096	24,287,123	22,502,466	17,129,589	13,992,603	4,998,082	19,012,329	369,315	20,854,521	162,108,493	GWI 011773	GWI 011911	Monthly	Net pumpage used for May - MLGW 00010
2001	19,443,014	17,588,767	19,972,329	19,626,575	16,318,904	17,500,548	4,785,205	17,477,260	446,301	20,248,493	153,407,397	MLGW 00011		Yearly	Net Pumpage
2002	18,140,000	17,300,000	22,000,000	18,550,000	15,550,000	19,000,000	4,525,000	18,000,000	475,000	20,983,333	154,523,333	MLGW2 03771 **CD**		Monthly	
2003	15,616,666	15,708,333	22,383,333	18,133,333	16,066,667	19,508,333	5,108,333	18,941,667	334,167	20,100,000	151,900,832	MLGW2 03771 **CD**		Monthly	
2004	15,775,000	16,075,000	21,858,333	17,700,000	16,341,667	19,641,667	5,150,000	18,741,667	400,000	22,666,667	154,350,001	MLGW2 03771 **CD**		Monthly	
2005	15,266,667	17,141,667	21,675,000	19,158,333	17,700,000	20,225,000	3,383,333	18,783,333	558,333	23,000,000	156,891,666	MLGW2 03771 **CD**		Monthly	
2006	16,658,333	16,575,000	21,358,333	19,550,000	17,458,333	20,566,667	4,166,667	18,341,667	358,333	21,200,000	156,233,333	MLGW2 03771 **CD**		Monthly	

Table 2 - Pumpage Amounts From MLGW and DeSoto County

Year	Shelby County (MGD)	DeSoto County (MGD)
1965	72.1	0.90
1966	75.9	0.90
1967	77.8	0.90
1968	81.2	0.90
1969	82.8	0.90
1970	90.5	1.23
1971	96.0	1.23
1972	99.2	1.23
1973	108.7	1.23
1974	109.7	1.23
1975	110.4	4.18
1976	111.4	4.18
1977	118.2	4.18
1978	117.7	4.18
1979	119.9	4.18
1980	124.2	4.18
1981	119.6	4.18
1982	121.8	4.18
1983	125.1	3.60
1984	127.9	3.60
1985	131.9	3.60
1986	136.8	3.60
1987	135.7	3.60
1988	142.8	3.60
1989	135.6	3.60
1990	141.3	3.60

Year	Shelby County (MGD)	DeSoto County (MGD)
1991	140.3	3.60
1992	139.5	3.60
1993	139.9	3.60
1994	142.6	3.60
1995	148.3	13.04
1996	150.1	13.04
1997	145.9	13.04
1998	156.7	13.04
1999	162.2	13.04
2000	162.4	13.43
2001	153.7	13.43
2002	154.8	13.43
2003	152.2	13.43
2004	154.6	13.43
2005	157.2	13.97
2006	149.8	14.47
2007	151.9	11.09
2008	142.6	10.68
2009	135.9	12.44
2010	147.6	14.44
2011	147.6	13.37
2012	140.7	15.31
2013	132.4	18.27
2014	132.3	17.35
2015	125.6	19.83
2016	123.9	19.83

Table 3 - Volume of Groundwater Taken From Mississippi Due to MLGW Pumpage

Year	MGD	Year	MGD
1965	12.9	1991	25.1
1966	14.5	1992	24.5
1967	15.3	1993	24.8
1968	16.0	1994	25.3
1969	16.5	1995	23.1
1970	18.6	1996	23.5
1971	19.8	1997	22.7
1972	21.1	1998	24.3
1973	22.5	1999	24.8
1974	22.9	2000	24.4
1975	21.8	2001	22.9
1976	21.9	2002	23.2
1977	23.5	2003	23.0
1978	23.6	2004	22.9
1979	24.0	2005	22.7
1980	25.1	2006	21.6
1981	23.6	2007	22.3
1982	23.8	2008	20.5
1983	23.9	2009	18.6
1984	23.9	2010	19.8
1985	24.3	2011	20.2
1986	25.8	2012	18.6
1987	25.6	2013	15.7
1988	27.2	2014	16.2
1989	25.8	2015	14.1
1990	26.1	2016	13.5