In the Matter Of:

STATE OF MISSISSIPPI vs

STATE OF TENNESSEE, ET AL

143, Original

PROCEEDINGS

May 20, 2019

IN THE SUPREME COURT OF THE UNITED STATES

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STATE OF MISSISSIPPI,

Plaintiff,

v. No. 143, Original

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

Defendants.

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May 20, 2019

9:03 a.m.

ON BILL OF COMPLAINT

Before:

HON. EUGENE SILER,

Special Master.

APPEARANCES

BARRETT LAW GROUP, P.A.
Attorneys for Plaintiff
BY: DAVID M. MCMULLAN, JR.

DANIEL COKER HORTON & BELL, P.A.
Attorneys for Plaintiff
BY: C. MICHAEL ELLINGBURG
LARRY D. MOFFETT

NEAL & HARWELL
Attorneys for Plaintiff
BY: CHARLES BARRETT

A P P E A R A N C E S (continued)

KELLOGG, HANSEN, TODD, FIGEL & FREDERICK
Attorneys for Defendant State of Tennessee
BY: DAVID C. FREDERICK
JOSHUA D. BRANSON
T. DIETRICH HILL
GRACE W. KNOFCZYNSKI

HERBERT H. SLATTERY III
Attorney General for Defendant State of Tennessee
BY: BARRY TURNER

BAKER, DONELSON, BEARMAN, CALDWELL & BERKOWITZ
Attorneys for Defendants City of Memphis, Tennessee and Memphis Light, Gas & Water Division
BY: LEO M. BEARMAN
DAVID L. BEARMAN
KRISTINE L. ROBERTS

BRUCE A. McMULLEN
Attorney for Defendants City of Memphis

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EXAMINATION

PLAINTIFF EXHIBITS

(In open court)

(Case called)

THE COURT: Okay. I'm glad to see all these experts with us and everything else, but anyway, we're finally to it. And what we'll try to do, my goal is to find the facts, determine the law, and send it to the Supreme Court and not bring it back. So we don't want any remand in this case, and so I'm going to be very liberal in allowing evidence to come in. I might strike it later, but our goal is to provide something for the Supreme Court to make its ruling. And so they found somebody who would try it, and that's me.

And we can be very informal in this matter. We want to follow the rules of evidence, obviously. If we have to, we can move witnesses around and move the lawyers around. And the biggest problem we will have, of course, is the stamina of all of us in trying this case. So as we go along, you can remind me of any kind of rulings we may have made in the past, and go from there.

And I will try my best to be fair to all of the parties. I have tried cases as a Court on the District level on several occasions, and so I'm familiar with how you do these things. And I have dealt with water rights. I have dealt with ownership of property and property fines in Kentucky and places like that.

So with that, I guess we need to let the counsel identify themselves for the record, so that you -- so I'll do -- I may forget who everybody is sometimes, but let's go from there, and then we will start with our opening statements, unless there are other matters that need to be brought to the attention of the Court.

Okay. For the plaintiff?

MR. ELLINGBURG: Good morning, your Honor. My name is Mike Ellingburg; I am lead counsel for the State of Mississippi. My actual name is C. Michael Ellingburg, but I go by "Mike."

THE COURT: Okay.

MR. ELLINGBURG: Would you like me to introduce the other counsel?

THE COURT: Sure.

MR. BARRETT: Your Honor, I'm Charles Barrett from the Neal & Harwell firm here in Nashville for Mississippi.

MS. RAY: Jacqueline Ray for the Mississipi Attorney General's office.

THE COURT: All right. Is that it?

MR. MOFFETT: Larry Moffett on behalf of the State of Mississippi.

MR. McMULLAN: Good morning, your Honor. David McMullan for the State of Mississippi.

MR. FREDERICK: For Tennessee, your Honor, David Frederick.

MR. BRANSON: Good morning, your Honor. Josh Branson, also for the State of Tennessee.

MR. HILL: Your Honor, Dietrich Hill for the State of Tennessee.

MS. KNOFCZYNSKI: Grace Knofczynski, also for the State of Tennessee.

MR. L. BEARMAN: Good morning, your Honor. I'm Leo Bearman, representing, along with my cohorts, the City of Memphis and the Memphis Light, Gas & Water Division.

MR. D. BEARMAN: Good morning, your Honor. David Bearman, representing the City of Memphis and Memphis Light, Gas & Water Division.

THE COURT: All right.

MS. ROBERTS: Good morning, your Honor. I'm Kristine Roberts, also representing the City of Memphis and Memphis Light, Gas & Water Division.

THE COURT: Is there anything in housekeeping or other problems that you need to bring up to the Court before we get started? Is the United States on telephone now, does anybody know?

MR. FREDERICK: Your Honor, David Frederick for Tennessee. United States has indicated it's okay not being on the phone. They'll review the transcripts as they become available.

THE COURT: So that's resolved?

MR. FREDERICK: Yes.

THE COURT: Thank you.

MR. BARRETT: Your Honor, we have a few slides to use in opening. Could we turn on the system?

THE COURT: You sure may.

All right. Are we ready? Have we set a limit of time on the opening statements?

MR. ELLINGBURG: Yes, your Honor. 15 minutes each.

THE COURT: We've got a lot to cover in this case.

All right. You may proceed for the great State of Mississippi.

MR. ELLINGBURG: Thank you, your Honor.

I'd like to open up by stating that the law to us is clear. Mississippi has declared as its public policy, consistent with its contained sovereignty under the Constitution, that all water, whether occurring on the surface of the ground or underneath the surface of the ground, declared to be among the spaces publicly for the state. And the state holds them in public trust.

This idea is not unique to Mississippi. Tennessee has done what is the equivalent; somewhat different language in its statute, but it has declared the public policy of Tennessee to be part of the waters and of the State. And so both states claim all the water in their boundaries.

Now, you're going to hear a lot of testimony about hydrology, hydrogeology, and the earth and formation and all those things which are really relevant to this case. But in the end, this case is about groundwater that was naturally occurring in the state of Mississippi, within the area of its boundaries for thousands of years before it was actually formed as a state. And groundwater that could be -- that was in a volume essentially equivalent that didn't change under the conditions of nature. And groundwater that would have remained in Mississippi but for the pumping of the defendants in this case.

It's important to understand at the outset that groundwater flow can't really be compared to surface water flow. I've put a slide up which is one of the exhibits in the case, and what the slide shows is the travel time, if you will, between the time that surface water enters a groundwater system and the time that it is discharged from that system.

And I don't know if your Honor can see this clearly, but the slide shows -- and this is something that is in groundwater hydrology courses and teaching -- but it shows that you have an unconfined water surface at the top. That's what we call the water table, which you have confined aquifers below it.

This case is about the confined aquifer in northwest Mississippi. And so, as it shows on the slide, it takes either years in some cases -- and it depends on the specific geology, which you'll hear a lot about -- or it takes decades, or in some cases it takes centuries for groundwater, from the time it enters the ground until the time that it is discharged from confined aquifer.

Now, if you want to compare that to what the Supreme Court's previously dealt with, if you dropped your water ski -- although I don't know if anybody skis on the Mississippi River, but if you dropped it in the channel on the Mississippi River, a day later you'd find you're about 50 miles away. So when you think about water in a river flowing, you can think about that ski moving 50 miles in a day.

Well, there's really nothing on this chart that would indicate you would expect confined groundwater, from the time it enters the confined formation until the time it naturally discharges, to take less than decades. So that's an important distinction.

Now, the City of Memphis has been pumping water for a long time. I forget the exact day; I think they say 1886. But the United States Geological Survey has been paying attention. They've done their job, and there is -- I found a report in 1906 when they're talking about Memphis pumping. And they became active over the years, and they reported on numerous occasions what the status was, because the amount of water being pumped in the Memphis-Shelby County area was increasing as the 20th century moved forward.

And in 1958 there was significant increases in the amount pumped. So -- in the 1950s. So in about '58, '59, USGS started a study of the impacts on the groundwater system within Tennessee.

Now, I think it's important to note at this point that before this, we've seen nothing that would indicate that the pumping that was taking place in Shelby County was having any material impact on any groundwater available in Mississippi. So they started these studies as a result of significantly increased pumping, and those studies are ultimately reported in Joint Exhibit J22, J58, and I'm going to show you a few of the things that it says in those studies.

The first one is in J22. And these are two clips. And this is in 1964, after they've conducted this study of what the conditions -- and the information they collected, I believe, in 1960. And it makes it very clear that they are drawing water out of areas within Tennessee.

If you go to that second paragraph, it says that the -- "The present 1960 rate of withdrawal is about 150 million gallons a day."

Now, this is 135, of which is pumped from -- what they call the 500-Foot Sand here, but it will consistently be referred to as the Memphis Sand.

And that was all pumping in Shelby County. It wasn't just the Mississippi line, okay? I mean, Memphis, Light, Gas &

Water.

But it says, of the inflow that was coming into these wells, that about 45 percent was from the east, so that would be in Tennessee. About 20 percent from the south; that would have been out of Mississippi. And then about 15 percent from the north, also in Tennessee. And about 10 percent or less from the west.

Now, there was another study that was done -- now, this study we just looked at, J22, was done in cooperation with Memphis Light, Gas & Water. There was another study done that was in cooperation with the State of Tennessee, and that is Exhibit J58.

Chuck, put that up. Thank you.

Now, this one is -- it goes through the same types of analysis. And here they're talking about Memphis. The area -- what they call the Memphis area, which is essentially Shelby County; some north, some east, and a little down in Mississippi a few miles.

And I think this particular quote is important in context. It says that "Future development should be undertaken with the full knowledge that the net increase in pumping will be offset by an increase in inflow of groundwater from other states." So at a decrease in the base flow of streams. But they are acknowledging here that they will be taking more water out of Mississippi if they increase the pumping.

Now, with that information in hand, MLGW planned a new wellfield. And that wellfield, they did a study before it actually started, but they had already planned it, I believe. But being this period between 1959, 1965, reported. So that study, they wanted to look at how far they would be pulling water from not just -- well, from the length of the entire circular area of that wellfield, and that is J59.

And if you would put that up.

This is a study of the Lichterman field, that's not yet started pumping, or is about to start pumping. And they're talking about something you will hear about a lot, which is cone of depression which is the area from which a well can actually capture water. And they estimate about 20 miles.

Now, the reason that's significant is where they put these wellfields. Now, before Lichterman was put in, when they had these studies from both the USGS, both the Tennessee -- with Tennessee and with the City of Memphis and Memphis Light, Gas & Water, if you'll look at the slide, these are the wellfields they had pumping. And so the Lichterman field isn't on here.

If you would pull the next slide.

So with the information that they had at that point in time, they decided they would build a wellfield -- they were already pulling water out of Mississippi; they decided they'd build a wellfield closer to Mississippi, so they built the

Lichterman field. But they didn't stop there.

If you go to the next slide.

That Lichterman was in '65. In 1970, they're still increasing their pumping, and so they build the Davis field, which is even closer to Mississippi. And they've also now added one to the northeast. And then finally in 1971 they built the Palmer field, which is even -- it's small, but it's even closer to Mississippi.

So what we have is a situation where, because the Memphis area was studied so thoroughly, Memphis Light, Gas & Water in Tennessee, they knew exactly what they were doing. And it was not something that had to be done. The fact is that a -- as the proof will show, wells, wellfields, at the time all this was done, were -- could be planned; the area from which they withdrew water could be estimated, and the ability to avoid taking water from someone else was always available.

Now, the last thing that kind of fits into this is that north of Memphis -- and you're going to see the geology, and you're going to see the testimony, but south in Mississippi, the water quality, the level of water availability, all decreases.

North of Tennessee, they have an abundance of water. I mean, in all of west Tennessee. So North Memphis, they have an abundance of water. So had these wells been placed after they'd gotten the information they received further to the north, and there had been a systematic effort made in -- by the City of Memphis and Shelby County, there wouldn't be any significant water being moved out of Mississippi. But you'll see the scientific testimony. And it's clear.

The water -- the groundwater in Mississippi, as groundwater in Tennessee, was predominantly moving at the rate -- at a rate measured in decades and centuries and thousands of years across each state from the outcrop area, which is to the east. And that water was entering the surface, and it was meandering and finding its way down as shown on the prior slide, and it was staying within the respective states in terms of the amount of water. There was some little bit here and some little bit there, but until pumping the amount of water available in Mississippi, in Tennessee and Shelby County, the amount of water residing in Mississippi was not -- the available water.

Now, that doesn't say the water doesn't move; it does move, ever so slowly. And so we'll put on some evidence about that. The reality is this is -- case is about water that was available in Mississippi under natural conditions, was not shared with anybody, and had been appropriated or taken by pumping. And they didn't need it. They didn't have to do it. It was avoidable. They had alternative sources to the north, and surface water.

Thank you, your Honor.

THE COURT: May I ask a quick question. I know it's an opening statement, but what sort of remedy are you asking for?

MR. ELLINGBURG: Well, in this particular case, the Court has bifurcated the proceedings, so that there was a -- this hearing is about the question of whether there was a right to take the water. Mississippi's position is that the -- that the water within its earth, which is what this is, is its -- under its right to regulate, control, or preserve for its citizens. As is the water that naturally resides in Tennessee, and that neither State has a right to appropriate the other State's water. And that's really the question.

THE COURT: Okay. So we'll do this in a bifurcated style to determine whether they're liable, and then we go into some sort of a remedy hearing, or what?

MR. ELLINGBURG: Yes, your Honor, that's what I understand, was that your order set this hearing up for the purpose of determining the right to the water, if you would.

THE COURT: Okay.

MR. ELLINGBURG: Thank you.

THE COURT: Are you all going to have separate opening statements?

MR. FREDERICK: Yes, your Honor, we will. This is David Frederick. I'll open for Tennessee. And Mr. Bearman for Memphis and MLGW.

Your Honor, this hearing is focused on the sole and what we believe to be the dispositive question of whether the aquifer is an interstate water resource. As the Special Master has already recognized, equitable apportionment is the only litigation remedy for an interstate water resource that is not governed by an interstate compact.

The evidence will show that the aquifer is an interstate resource, and that the Special Master was correct, that Mississippi has pleaded its way out of court by disclaiming and claimed for equitable apportionment. And equitable apportionment applies equally to groundwater, especially when, as the evidence will show here, that groundwater is connected to interstate surface water.

Mississippi and Tennessee do not have an interstate compact concerning the aquifer; nor do any of the other eight states under which the aquifer flows. So we're in an area where, if you determine that the aquifer is an interstate aquifer, the case is over, because Mississippi has disclaimed a right to interstate water through the legal means that the Supreme Court of the United States has recognized.

That is an equitable apportionment. Their complaint says they are not seeking an equitable apportionment, and your preliminary decisions, your Honor, have ruled that if the resource is an interstate resource, then the case should be over.

So we view your fact-finding in this phase of the hearing to be directed to the sole question: Is this aquifer an interstate resource? And if you find that it is, the evidence overwhelmingly shows that -- and in fact Mississippi's counsel has just conceded in his opening that this is interstate water -- the case should be over. And we would ask for you to make a recommendation to the Justices that the complaint be dismissed with prejudice.

Mississippi argues that State law claims are overriding their disclaimer of equitable apportionment, but what is important is that they made a conscious decision to avoid an equitable apportionment.

Why? Why did they do that? Because they are not able to prove the key elements of an equitable apportionment: Substantial injury by clear and convincing evidence; justification for an equitable decree that would preclude its demand for hundreds of millions of dollars in money damages; an evaluation of the broader regional water system that would include not just Mississippi and Tennessee's pumping, but also the substantial pumping in other states that are on top of this aquifer throughout the Mississippi Embayment.

Nor can they address the reliance interests of Tennessee and Memphis in protecting its historical water supply, which originates with the very first well, in the 1880s. In fact, an equitable apportionment, if done fully the way the Supreme Court has done equitable apportionments, very likely would be leading to bigger and much more complicated litigation, and the result could mean that Mississippi would be worse off.

So instead, what they're trying to do is to use Mississippi tort law to ask Tennessee to pay it hundreds of millions of dollars, because it cannot meet the requisites of an equitable apportionment for the proper and fair sharing of an interstate water resource.

We're going to ask you, your Honor, to keep the focus on the threshold question of whether the aquifer is an interstate aquifer. All of the maps of the aquifer will show it to be a large multi-state resource. Mississippi spent half of its time in its opening talking about Memphis's intent, but the intent is irrelevant. The question before you is whether this water resource is an interstate water resource, and we believe the evidence will show overwhelmingly that it is.

If we were having an equitable apportionment, we would have plenty to say about all the evidence that they want to introduce that's irrelevant to the question you have said is the sole dispositive question for this hearing. But we directed our discovery at the question that you said we should be focusing on, which is whether or not this is an interstate resource. And we would ask you to confine what we're doing in this hearing to the limited topic that you set out in your 2016 decision, because that's what we relied on in determining the scope of the discovery in this case.

Now, counsel says the US Geological Survey has, quote, done their job; but all of the USGS maps of this aquifer show it to be an interstate aquifer going underneath eight different states. Our trial presentation will demonstrate that Mississippi cannot meet its burden because the Middle Claiborne Aquifer, including the groundwater, is interstate.

In your decision on summary judgment, Judge Siler, you identified four reasons why the aquifer is an interstate water resource: The aquifer theory, the pumping effects theory, the natural flow theory, and the surface connection theory. The evidence is going to show through expert testimony, maps, and other documents, that Tennessee will establish that all four of those theories for why this is an interstate aquifer are correct and provable.

Let's start with the first one, the aquifer theory. Tennessee's expert, Steve Larson, will testify that from a hydrogeological perspective, an interstate aquifer is a single continuous hydrogeological unit extending beneath multiple states, in which an action in one state can affect water in another state. The aquifer in question here is called the Middle Claiborne.

Now, to be sure, it's given local names in different parts of the country where it underrides, but the US Geological

Survey identifies it as a single aquifer. And it lies underneath eight different states, six of whom are not defendants in this lawsuit. Those states are Illinois, Missouri, Kentucky, Arkansas, Louisiana, and Alabama, in addition to Tennessee and Mississippi.

Now, every relevant study is going to show that the Middle Claiborne extends beneath those eight states. There is no barrier restricting the lateral flow of water at the Mississippi/Tennessee border, and this image here shows you the different levels of sand at different elevations within the groundwater system of the Middle Claiborne Aquifer.

And what this shows is that the sand levels do not change at state boundaries; they cross state boundaries. And the water that is encapsulated within this -- these geological structures do not have a change either. And so what's important to understand is that it is a single resource. It is water in its geological formation, and they are in sands from which the water can be pumped. But it is a single resource.

The second theory that we are going to present is called the pumping effects theory. The opening conceded that 20 percent, according to one very rough estimate made 50 years ago, of water came from Mississippi. That concession ends the case, because that demonstrates that through the natural effects of physics, pumping in one state will affect the groundwater movement in another state.

Now, what they're going to talk about, and you're going to hear a lot of testimony about cones of depression. And this diagram shows you where some of the most significant cones of depression are in the region that is within the Middle Claiborne Aquifer.

And if you look at this diagram, your Honor, you're going to see that the cones of depression are actually larger in Arkansas, and in Arkansas, the boundary with Louisiana, and even in south central Mississippi, than they are up in Memphis.

Think about that. They're pumping out, and the cones of depression are larger in adjoining states than what they're accusing Tennessee of in this case. And those cones of depression cross state boundaries and affect the flow of water between Louisiana and Mississippi and between Arkansas and Mississippi.

So when you look at the very right cone of depression, up in the Memphis area, and you compare the sand level and density, you will see that the cones of depression in these other states is much more significant. That's from pumping. And the evidence is going to show that it is the pumping effects theory that is causing these cross-boundary flows of water.

Now, the third theory that we will explore with you is called the natural flow theory. And Steve Larson will testify that no water, including the water that Mississippi claims is, quote, intrastate, will remain under Mississippi permanently.

As your 2018 opinion at page 19 has already recognized, Mississippi's experts have adopted a predevelopment flow map showing all the water leaving Mississippi. This is from the plaintiffs, this exhibit. And all those arrows show that water was leaving Tennessee and Mississippi and flowing toward the Mississippi River and under the Mississippi River into Arkansas, or in some instances -- and you noted that it was being -- it was going from Mississippi into Tennessee itself; that's the famous yellow triangle in which Mississippi's conceded that under predevelopment conditions, water was already flowing to the north out of Mississippi and into Tennessee.

The fourth theory that we're going to present evidence on is the surface connection theory. Mr. Larson also will testify about the interconnection of the aquifer to interstate surface water. Now, it's undisputed that the Middle Claiborne is part of the larger Mississippi Embayment Regional Aquifer System. It contains multiple interstate aquifers that are separated by confining layers.

You're going to hear a lot about layers in the testimony this week, your Honor, but it's also undisputed that the aquifer is connected to interstate surface streams. And this diagram here shows you the boundaries of the Middle Claiborne Aquifer. And then the blue are all the rivers, the surface streams that flow into the Mississippi River, but in various forms create recharge for the Middle Claiborne Aquifer.

And that recharge source is very important from the interstate river network. And because of that, what the Supreme Court's cases have said is that if there is a dispute between one state and another that deals with the surface water and groundwater, it should be addressed through an equitable apportionment, not through the use of one State's tort law to claim that another State owes it hundreds of millions of dollars.

Now, we don't think you're going to need to get into the predevelopment, but you're going to hear a lot about it anyway, and let me just give you some sense of what you're going to hear in terms of testimony: That even if no water flowed across Mississippi into Tennessee under natural conditions, the aquifer would still be an interstate resource, for all the reasons I've discussed and that we're going to prove.

You're not going to need to go back into the 1880s, your Honor, and try to reconstruct through historic maps and age information what the state of predevelopment pumping was. That's not necessary to the question that you have before you which is: Is this aquifer an interstate resource?

However, if you decide you want to look at that, we have probably the world's foremost expert on this aquifer, Brian Waldron, who spent more -- thousands and thousands of hours studying the Middle Claiborne Aquifer. And he's going to testify to you, and he's going to show you, based on the most precise data possible, which way the water was flowing in the predevelopment state.

And this diagram, which we'll have him walk through when he testifies, is going to show that water was leaving in significant amounts, northward into Tennessee and then thereafter into Arkansas.

As I say, I don't think you're going to have to decide that in order to resolve the case. But we're going to present that evidence to you, because you've indicated you want to have a full evidentiary record.

Both Mr. Larson and Dr. Waldron will testify that all of the maps and models of the predevelopment potentiometric surface will indicate natural interstate flow in the Middle Claiborne Aquifer. And why is that? Water is not static. Water is constantly moving. When it rains, the water seeps through to the ground. When it seeps into the ground, it seeps into places where it moves, but it is always moving. There is no such thing as static water.

Now, you've already indicated at the pleading stage that the yellow triangle from Mississippi's expert does not help their case, because it shows that even in predevelopment conditions, there was some water that was moving across State boundaries. And of course the effect of the pumping has altered that, the evidence is going to show that less water is moving now, after development, than before development.

Think about that. They brought this tort suit on the theory that Tennessee is doing something wrong by having water go across the boundaries. The evidence is going to show, in fact, that Mississippi's pumping has slowed down that intra-aquifer flow across the state lines.

Now, Mississippi's evidence is not going to demonstrate that the water in the aquifer is intrastate. They've got a couple of theories that they're going to trot out, based on what they have done in their pleadings.

One of them is that there are in fact two aquifers, not one. As simply a new characterization of a long established hydrogeological fact, where there's no physical barrier to prevent the flow of water. You'll hear something about a facies change. This is a geological formation that is south of the border between Tennessee and Mississippi. But there is an uninterrupted layer of primarily sand that saturated with water, and that is the Middle Claiborne Aquifer.

We're going to ask you to reject their repeated attempts to characterize this aquifer as an intrastate water resource. They'll probably give you hours of testimony about the velocity and movement and residence time of the aquifer water. All of that is irrelevant. It's irrelevant because water constantly moves. They cannot prove that any water would stay in Mississippi forever, and that Tennessee has somehow gotten water that would have stayed in Mississippi forever.

Similarly, they're going to talk a lot about Memphis's groundwater and pumping management practices. Those might be relevant if we were having an equitable apportionment. But they already disclaimed we're not doing an equitable apportionment. So when we listen to their testimony, it will all be geared toward an irrelevancy to what you are charged with deciding after this hearing.

And that is: Is the aquifer an interstate water resource? It is a single, continuous, hydrogeologic unit extending beneath multiple states, in which pumping in one state can, through the natural laws of physics and hydrology, affect water in another state. And the predevelopment flows are unnecessary to that conclusion, but they nonetheless further support the claim that the aquifer is an interstate water resource.

Thank you, your Honor.

THE COURT: Thank you.

You may proceed on behalf of the City of Memphis and Memphis Light, Gas & Water.

MR. L. BEARMAN: Thank you, your Honor.

MR. ELLINGBURG: Excuse me, your Honor. Before we proceed, I wanted to make one request.

THE COURT: Sure.

MR. ELLINGBURG: I know it's unusual, but we agreed to 15 minutes, and I pretty much pushed myself through 15 minutes. And Mr. Frederick just took about 19. And so when Mr. Bearman finishes, I'd like just a few minutes. I won't necessarily even take four minutes.

THE COURT: Okay. If you can stick to the limits. I'm not keeping track of your time. I hope you are keeping track of your own time.

All right, Mr. Bearman.

MR. L. BEARMAN: Good morning, your Honor. If you will allow me, I'd like to introduce my cohorts and people that are working with me.

First, my son, David Bearman, partner; secondly, Kristine Roberts, partner; third, our paralegal, Kathy Hughes, who is back there; and fourth, what they now call a litigation support specialist, your Honor, which, I take it means he can work a computer. His name is Cole Taylor.

Also, if your Honor will allow me to introduce Ms. Cheryl Patterson, who is vice president and general counsel of the Memphis Light, Gas & Water Division back there. And Ms. Charlotte Knight Griffin, who is manager of the legal services at the Memphis Light, Gas & Water Division. And finally, Mr. Bruce McMullen, who is City Attorney of the City of Memphis.

Thank you, your Honor. I appreciate that.
THE COURT: Glad to have them along.
MR. L. BEARMAN: Your Honor, we adopt of course what points have been made by Mr. Frederick.
I was going to start, but he's made the point before, and it's significant that Mississippi ignores what your Honor has designated as what we're doing here today; namely, on page 36 of your Honor's opinion, an evidentiary hearing on the limited issue of whether the aquifer and the water constitutes an interstate resource is appropriate.
Okay. That's what we've -- I assume are going to do, and it's significant, as I say, that Mississippi has ignored that and began talking about intentional actions. We're not anywhere near that, as Mr. Frederick points out.
Now, your Honor is going to need, I suggest -- although your Honor may already be aware of some of the geography that's going to be alluded to in this case -- can your Honor see that poster board over there?
THE COURT: Yes, I can.
MR. L. BEARMAN: Good. I apologize for not putting it up on all kinds of screens here, but I've won a lot of cases on poster board, your Honor, so I'll keep trying it this way.
Your Honor, the key area in this -- obviously Arkansas, Tennessee, and Mississippi; but the key area of focus here is Shelby County, Tennessee, right in the southwest corner

of Tennessee. And Memphis, Tennessee, is of course located in Shelby County, and your Honor can see that part. And just south of Shelby County, in Mississippi, is DeSoto County.

Your Honor may hear other counties mentioned: Marshall County and Benton in Mississippi, and perhaps Fayette and Hardeman in Tennessee. But the focus your Honor is going to find, and what I suggest is the appropriate proof, is Shelby County and DeSoto County, and of course the Mississippi River that runs down the side.

Now, your Honor also needs to be aware, I suggest, of certain nomenclature, if your Honor will allow me. If the aquifer that we're talking about is the light-blue shaded area, your Honor's already seen that on the screens, but that is known generally as the Middle Claiborne Aquifer. The Middle Claiborne Aquifer.

Now, your Honor, also needs to know, because you'll hear this, I suggest, as the testimony goes on, some people have called the aquifer in Tennessee the Memphis Sand Aquifer. Some people in Mississippi have called the aquifer the Sparta Sand Aquifer. Some people have called it the MSSA, Memphis Sand/Sparta Sands Aquifer.

The fact is that those words are interchangeable, and they all stand for the Middle Claiborne Aquifer, which is what we're talking about today; is that an interstate resource? Your Honor is going to find that the answer is yes.

But here is some of the proof that I suggest your Honor is going to want to mark, number one -- and this point has been made well by Mr. Frederick, and I'm not going to overdo it, but it's important, because these are crucial issues.

The aquifer underlies eight states, and your Honor can see that on the poster board, in the light blue area: Missouri, Kentucky, Tennessee, Arkansas, Mississippi, Alabama, and Louisiana. That is certainly one added factor that indicates that the Middle Claiborne is in fact an interstate resource and interstate aquifer.

Your Honor will also find -- and the reason I'm making these points, let me say in advance, these points that I say are proof are going to be undisputed, in my judgment, undisputed, that it underlies eight states; that before pumping, groundwater naturally flowed across state lines, including flowing from Mississippi into Tennessee and also, your Honor will find, as the proof goes on, from Tennessee into Arkansas. And so that, your Honor will find, is also going to be undisputed.

The third point is that pumping in one state impacts the flow of groundwater in the same aquifer in other states. And that of course is one of the reasons we're in this courtroom today. And that is, it's -- it is quite undisputed that pumping in Tennessee will affect groundwater in

Mississippi.

And let me add, your Honor, because it's important, pumping in Mississippi will affect groundwater, the same groundwater, in Tennessee. So that is one of the additional factors.

And finally -- not finally. I'm sorry. The aquifer is hydrologically connected with interstate rivers. That's going to be undisputed as well. Your Honor has seen designation of that on the screen earlier from Mr. Frederick.

One of the main rivers in this area that your Honor will find is connected to is the Wolf River, which runs -- starts in Mississippi and runs in Tennessee and then into the Mississippi River.

Now, there are two other points in addition to that that I think your Honor will find important. There is no physical barrier -- I'll repeat: No physical barrier along the Mississippi Tennessee boundary -- that impedes groundwater from crossing the State line.

In other words, there is no -- rephrase it -- there is no physical barrier that impedes this groundwater moving interstate from Mississippi to Tennessee, from Tennessee to Mississippi. That will be undisputed.

And as also has been alluded to, the groundwater -- this is not -- your Honor, this is not a Mississippi bathtub. This water is constantly moving. This water in the aquifer is constantly moving in the Middle Claiborne, to some extent. And it is recharging constantly. It is moving in and out of Mississippi, and in and out of other states.

So I think your Honor will find that with these facts that I have set out being undisputed in the record, I think your Honor will conclude, undisputed in the record, the plaintiff's position in this case is going to be not only unworkable but illogical; and that the proper way, as indicated by Mr. Frederick, and we concur, is if this is -- and we certainly view it as an interstate resource, then equitable apportionment is the solution.

The solution from Mississippi will be, if their position is upheld, their position will involve dozens and dozens of lawsuits around the country from areas where the aquifer is underlying more than one state. It's untenable and it's illogic, and so we ask your Honor to answer that question that your Honor posed as yes. This is an interstate resource. So is the aquifer water. So is the water. And we think the proof will be clear and undisputed.

Our expert, Mr. David Langseth, will testify in the case. Your Honor will find him to be highly competent, highly learned, two degrees from the University of Minnesota, a master's and doctorate from MIT, and he will support the positions that we have reiterated to indicate that in fact this is an inter -- interstate -- I'm sorry, interstate resource.

So that will be our proof, if the Court please. And when it's concluded, your Honor will be strongly persuaded.

Thank you.

MR. ELLINGBURG: Excuse me. You said I could have just a few minutes.

THE COURT: Okay. Makes no difference if you save it. He got 19, so you get 4 minutes

MR. ELLINGBURG: Yes, sir. This won't take long.

What the proof's going to show is that the defendant's case is based on undisputed generalizations, labels that weren't necessarily included as part of the report, and if they were, they were just titles and characterizations.

That's what their case is all about. Mississippi's case is about the signs, and the reason it's been the signs is very clear. This issue has never been addressed by the Supreme Court. And groundwater is simply not surface water. And all of these efforts to make it look the same are going to disappear during the course of this case.

The reality is that groundwater is -- the availability of it, the quality of it, is different in virtually every location on the earth, including within the Mississippi Embayment. There are some common characteristics; we don't deny that. There are -- you know, certainly geology didn't stop at the State line.

The case isn't really about the geology; it's about the water. And this -- in this case, this is a mixed question of law and fact. It's a question that has to be decided under the United States Constitution. I mean, states' rights have been eroded, but as recently as the last year, the Supreme Court has reaffirmed the state sovereignty over the waters within its borders.

And that's what this case is about. This case is about Mississippi's right to protect, preserve, control the taking, regulate groundwater within its borders. And it has been denied that right by the attitude of its neighboring state, which said, "We can pump it, and so it's ours."

And it didn't have to be pumped from there. So they're -- this is an issue not about generalizations, characterizations, high-level labels. It's about the groundwater in this area, what its natural condition is, and about the fact that it's being pumped by another state out of Mississippi, and Mississippi has a constitutional right to regulate and control it, before the Supreme Court.

Thank you.

THE COURT: Thank you.

Well, are we ready to put on any testimony?

MR. ELLINGBURG: Yes, your Honor.

THE COURT: Are you planning on putting on joint purposes defense now, later on, or is Memphis and Tennessee going to have separate witnesses?

MR. FREDERICK: We'll have separate witnesses, your Honor.

THE COURT: All right.

Okay. Are you ready, Mississippi?

MR. D. BEARMAN: Your Honor, just as a housekeeping matter, the Court -- this is my -- an issue with me personally is my hearing is a little difficult. Would it -- if it's not too much trouble, to ask your Honor to bring the microphone a little bit closer --

THE COURT: Okay.

MR. D. BEARMAN: -- to you; and perhaps on the podium, too, if your Honor would not mind.

THE COURT: Sure.

MR. D. BEARMAN: Thank you, your Honor.

THE COURT: Can you hear that? Is that better?

MR. D. BEARMAN: Absolutely.

THE COURT: Thank you for bringing it to my attention. I have the same problem sometimes, if people don't get close to the mics.

Okay. Yes.

MR. D. BEARMAN: May I move the microphones together, or -- Mr. Ellingburg, if you wouldn't mind.

THE COURT: We want everybody to hear what we're saying.

MR. D. BEARMAN: Thank you, your Honor. I appreciate that.

THE COURT: Okay. You may call your first witness for Mississippi.

MR. ELLINGBURG: Thank you, your Honor.

THE COURT: Are you all keeping track of your time now that -- for the whole part of your case, as we talked about before?

MR. ELLINGBURG: Yes, we'll keep the time -- track of the testimonial time, and we have parties who will agree to mediate at the end of the day.

The State of Mississippi would like to call as its first witness Dr. Richard Spruill.

THE COURT: Do we have a clerk here to swear him in? I guess I can do this now.

DR. RICHARD SPRUIL,

called as a witness by the Plaintiff,

having been duly sworn, testified as follows:

MR. ELLINGBURG: Your Honor, before we start, I would like to ask if it would be acceptable -- certainly not the whole time, but we're going to use a lot of illustrations to show some issues. Could it be acceptable for Dr. Spruill at times to step down and point at the screen?

THE COURT: Oh, yeah, sure. That would be fine.

MR. ELLINGBURG: Thank you, your Honor.

THE COURT: You're going to use the screen primarily

for your exhibits?
MR. ELLINGBURG: Yes, your Honor. You'll see them up there also, and you should have a book of them.
THE COURT: Yes, I have.
MR. ELLINGBURG: Thank you. I have a propensity to sometimes get a little too loud, so I try to keep it away from me. But I'll try to keep that down.
THE COURT: It's okay. I never complain about somebody speaking too loud.
MR. ELLINGBURG: Thank you, your Honor.
Before we start, I'd like to say that Dr. Spruill's résumé or curriculum vitae has already been submitted to the Court.
THE COURT: Sure.
MR. ELLINGBURG: It is Docket Number -- let's see. It's Docket Number 73. We're not going to go through the entire contents of it, but I am going to -- I'll try to get some highlights on his background. I think it's important.
THE COURT: All right. I don't think there's any objection on the other side.
MR. FREDERICK: No objection, your Honor.
THE COURT: Okay. All right. Go ahead. You may hit some high points.
MR. ELLINGBURG: Thank you.

DIRECT EXAMINATION
BY MR. ELLINGBURG:
Q. Would you state your name.
A. My name is Richard Kent Spruill.
Q. And what is your residence address?
A. I reside at 4100 Timberlake Drive, in Grimesland, North Carolina.
Q. And what is your profession?
A. I'm a geologist and hydrogeologist.
Q. Is there -- is there a difference between geology and hydrogeology?
A. I think that geology is a more general term. There are many different types of geologists: Mineralogist, petrologist, and so forth. And I have trained as a geologist first, and then added additional training that I think qualifies me to specialize in the study of water.
So I think that's the difference between the two. I'm a specialist as a geologist who understands something about groundwater and surface water.
Q. Do you -- would you -- briefly, what is your educational background?
A. I studied geology at -- master's -- undergraduate at master's level down at East Carolina University and the south coastal plains of North Carolina, and I then enrolled in the PhD program at the University of North Carolina at Chapel Hill,

where I studied geology and isotope geochemistry.
Q. And did you have any further studies that related specifically to groundwater hydrology?
A. Well, throughout my three-degree program, I was fortunate to take some courses in hydrogeology at both the undergraduate and graduate level. But I didn't find the subject at that time to be something that I wanted to adopt, because I was fascinated by isotope geochemistry.
And so I started teaching at East Carolina University in 1979, and mainly taught courses in mineralogy and petrology and isotope chemistry. But at that time the university offered me the opportunity to go back to North Carolina State University, in addition to everything else I was doing at the university, and take courses with a renowned hydrogeologist named Ralph Heath, who was a retired US Geological Survey hydrogeologist. So I trained extensively with him.
Q. Just for a moment, before we go there, can you hear me, Dr. Spruill?
A. Yeah. It just shakes me up. The sound all of a sudden comes here, and I think it's the judge. Sorry.
Q. What I was going to ask is, what made Ralph Heath somebody you went to study under?
A. Well, Ralph Heath, in my opinion, is one of the preeminent hydrogeologists who ever worked for the US Geological Survey. In addition to being a North Carolinian and graduate of

University of North Carolina Chapel Hill, he worked throughout his career as a high-level district chief at the US Geological Survey.

But what was more important to me is that he wrote a couple of books that I think serve as the foundation for modern applied hydrogeology, and these are water supply papers. And so I had been fortunate to read those papers and was fascinated by his approach to evaluating groundwater hydrology, especially.

Q. Yes, I believe one of those has been marked as a joint exhibit. I'm not sure of the number at this moment, but it's Basic Groundwater Hydrogeology, right?

A. Basic Groundwater Hydrology.

Q. Hydrology. And so what -- would you describe briefly your studies with -- under Dr. Heath -- I mean, under Mr. Heath?

A. Mr. Heath.

So I had an opportunity to go to NC State and attend his class in the school of engineering, where he taught after his retirement, and as a return to the great Tar Heel state. And that first course was an advanced course in applied hydrogeology. And so I studied that semester with him and became fascinated with the subject because of his approach.

Following that first semester, I feel that I established a bond with Ralph Heath, and we worked together to begin to evaluate some issues that he thought were critical issues that he could perhaps pass along to me as a budding hydrogeologist in North Carolina.

Q. Did you work with him on any specific projects in North Carolina?

A. That first year we wrote a research proposal to I think the Water Resources Research Institute to evaluate how water moves in certain parts of the bedrock aquifer system in the Piedmont of North Carolina. And we were successful in getting funding, and we installed wells. And he mentored me throughout that first early project.

Q. How much of this was fieldwork and how much of it was classwork?

A. About half and half.

Q. Okay. And what is the value of the fieldwork?

A. Well, I've always been a field-oriented person, and so the value of the fieldwork to me was to learn a lot of the techniques. And I was never exposed to that as more of an academic-style geologist, and that is dealing with well -- learning how to design and construct wells, and learning how to take measurements in wells, and doing the kinds of things that I call applied hydrogeology.

Q. So what did -- what effect --

THE COURT: You're taking your coat off?

THE WITNESS: Yes. It's warm in here.

BY MR. ELLINGBURG::
Q. Richard, would you like some water?
A. I'd love some -- I have some right here.
Q. You ready?
A. Yes.
Q. Before I move on, I'd like to step back just a little bit.
Is there anything about your CV that needs to be changed?
A. Yes.
Q. And what is that?
A. After 39 years, which equates to almost 80 semesters, I retired last year from East Carolina University. I don't think that's indicated on this; I didn't update it on this résumé. So I'm officially retired from ECU, after almost 40 years, effective September 1st of 2018.
Q. Is that the only change you need to make?
A. As far as I know.
Q. Okay. Now, after you worked with Ralph Heath, did you take any actions that were motivated by that work with him?
A. It's a funny question.
Q. Did you shift your focus? You said earlier you --
A. I shifted my focus both at the university and both outside the university to really getting involved in to the groundwater issues that are significant in the coastal provinces of the Carolinas and all the way down to Florida.

And one of the most important things that I started to do early on was Ralph had made me aware of the very large cone of depression that was generated by pumping from the major coastal plain cities of North Carolina and the impacts it was having on the groundwater system. And so he and I developed a series of presentations that I gave over a multi-year period to try to convince the State to take some action with respect to the impacts that our use of groundwater from certain aquifers on the coastal plain was having.

Q. What was your concern about those cones of depression?

A. Well, the cone of depression and what we call the Cretaceous aquifer -- that's a geological time period for materials that are deposited during the time of the dinosaurs, 100 or more million years ago -- was that the larger cities of the coastal plain, Greenville, Kingston, Jacksonville, were taking large quantities of water from the groundwater system. And then that result was that a large cone of depression was generated. Water levels were declining, and perhaps more significance, there was evidence that groundwater flow patterns were altered, and saltwater intrusion was occurring in response to those large-scale withdrawals.

Q. And so what action did the State take, if any?

A. The State didn't take any action for a long period of time. But after giving more than 100 presentations and working with lots of different groups, the State of North Carolina finally

passed the Central Coastal Plain Capacity Use Area, which governed the withdrawal of water in a roughly 15-county area -- slightly larger than that, actually -- and forced the reduction by 75 percent, with respect to the volume of water that the water -- major water purveyors were removing from the groundwater system.
Q. Was that to protect the sustainability of the system?
A. Absolutely.
Q. Okay. Now, after -- I got a little off course, but after you studied with Ralph Heath, did you start your own business?
A. I started my business a year or -- a year or so later.
Q. And what is that business?
A. My business is called Groundwater Management Associates, Incorporated.
Q. Is that where you are now?
A. Yes.
Q. Okay. So you started it in 1986?
A. About 1986.
Q. And could you describe what the resources you currently have are at Groundwater Management and Associates.
A. Groundwater Management Associates is a small company. I have two offices. I have an office in Apex, North Carolina, which is a suburb of Raleigh, and I have an office there in Greenville. The office in Apex is housed by my partner, who is a world-class engineer. And he has geologists and other staff

members in that office. And I keep all of the geologists and most of the CAD operators and so forth in the Greenville office, because I am a geologist; and our company, we separate the geological and the engineering services.
Q. Are you a licensed geologic -- geologist?
A. Yeah, I'm a real proud licensed geologist, professional geologist in North Carolina, Number 942.
Q. Have you done any work with any national associations relating to testing and groundwater hydrology?
A. I'm not sure what you're asking, but early on in my career at ECU, I became fascinated with the concept of professional licensure, mainly because professional licensure at its core is protective of the health, welfare, and safety of the public. And so I became involved in professional licensure by being appointed by the Governor to the North Carolina Board for Licensing of Geologists. And I was on that board for six years, and shared the board for the last three years of my tenure on the North Carolina Licensing Board.
Q. Is there a national board?
A. There isn't a national board, but through my experiences on the North Carolina Board for Licensing of Geologists, I really got interested in how we can impact the profession through the development of the national examinations that every geologist has to pass in order to become licensed.
So I got involved in what's called ASBOG. It's a

terrible acronym, but the acronym is A-S-B-O-G, and it stands for the National Association of State Boards of Geology. And what it does is design, build, administer, score, and report the national examinations that every geologist has to suffer through if they want to be licensed in the United States. And we also administered this exam in Canada.

And this whole thing fascinated me so much that I contributed about 17 years of my career to it, involving moving up through the executive committee to become the president of ASBOG in the year 2010, 2011.

Q. Did they -- does ASBOG identify subject matter specialists or experts?

A. Yes. So the structure of ASBOG is in which one subject matter experts in specific disciplines are designated by the organization, and the organization brings those subject matter experts together to craft the exam and to evaluate the results of scoring of the exam.

Q. Okay. Could you run -- were you a subject matter expert?

A. I was a subject matter expert for 17 years.

Q. In what area?

A. In the areas of mineralogy, petrology, geochemistry, and groundwater hydrology. The surface water hydrology.

Q. Okay. Back to, I guess, the timeline a little bit here.

After you formed -- well, GMA, how many licensed professionals do you have at GMA now?

A. Oh, boy. So one -- one professional engineer. One professional engineer who's also licensed as a geologist. And approximately 13 licensed professional geologists.
Q. Okay. And what is your role at GMA, or Groundwater Management Associates, with regard to the work that's being done there in the area of groundwater and groundwater and hydrology and groundwater development?
A. So my company has two divisions. It has an environmental division; it has a water resources division. And I have well-trained hydrogeologists heading up both those divisions. Then we have the engineering division. What I do is I oversee the work in both of those divisions that is hydrogeological in nature but not engineering part of it, the company.
So I serve as sort of an oversight person, reading all the reports, etc. But since my retirement from the university, at night, I only had one job instead of two. I've become fascinated again with getting back out into the field, doing the things that really applied to other geologists actually do.
Q. So what kind of projects does Groundwater Management Associates handle with regard to groundwater and its development and use?
A. So that would be the water resources division of the company. We're involved in the -- the evaluation and management of groundwater resources through the -- throughout just about any place that you can manage. And we are real

specialists in how to design wells and wellfields and managed groundwater resources in an effective way.
Q. What part does sustainability of the groundwater resource and availability play in the work you do in the groundwater area?
A. I don't think you can have a company like Groundwater Management Associates without a heavy emphasis on sustainability. Sustainability is the one issue that Ralph Heath preached throughout my wonderful time with him before he passed away. So it's a real serious issue for us, is dealing with the issue of sustainability.
Q. And from the management standpoint, what are you looking at on your projects oftentimes?
A. From the management perspective, what we're doing is actually designing wellfields and testing and developing wellfields, which end up in municipal water supplies for small towns, big towns. But we also do a tremendous amount of work in support of the groundwater resource issues associated with large-scale withdrawals from mining operations.
Q. Okay. I'm going to move forward. You in the courtroom -- and I made this comment that groundwater wasn't like surface water. Could you tell me, what is groundwater?
A. Groundwater is that water which occurs in the core spaces or fractures in naturally occurring material below the land surface.

Q. Okay. Does it flow underground, like a river?
A. Rivers flow on the land surface in channels of their own creation, in my opinion. Rivers don't find channels and flow in them. Rivers generate the channels after water accumulates on the land surface following precipitation.
Groundwater is different, in that water falling on the land surface percolates through portions of the groundwater system, where the groundwater system then becomes saturated; then groundwater then flows at pretty low flow rates through and around, mostly around, individual particles in the subsurface.
Q. Okay. Let me show you something. I'm going to put a slide up and ask if this helps you explain by looking at groundwater.
This slide is a slide, proud to say, from Ralph Heath's water supply paper 220, that's designed at sort of the introductory level to make the point that groundwater occurs in the pore spaces around rings of naturally occurring material. And this particular diagram, which Ralph referred to as primary openings, those are the pores around sediment after it forms.
The whole idea was these would be sand-sized particles, and sand-sized particles are illustrated or defined by definition in the upper left-hand corner of the left-hand figure with the simple scale one millimeter. Millimeter is about, as you know, the thickness of your little fingernail. About the thickness of your little fingernail.

And so this is a blowup, so that sand-sized particles can be easily observed. And the blue-green color on this diagram is simply designed to get across the point that water fills these pore spaces as part of groundwater, and that water flows through and around -- around these particles in response to certain physical forces.

Q. Okay. So those -- those sand particles shown in that case would generally be about the size, in terms of thickness, of your fingernail, or smaller?

A. About the thickness of your little fingernail. Not the length of your little --

Q. That little bitty part.

A. Mm-hmm.

Q. Okay. Let's -- let's go to the next -- now let me ask you, is this -- is this an -- what kind of material, geologically is this? Sand, you said; what is that?

A. Sand. Sand is a geological term that is a size term, not a composition term. People confuse all the time sand. Sand can be composed of any naturally occurring material, as long as the grain size is between a 16th of a millimeter and 2 millimeters.

Q. Okay. I'm going to put up another slide here, and that we'll be referring to on occasion.

What does the slide show?

A. So I want to know, how this can work? Can I walk down to the slide? I'm capable of speaking pretty loud.

THE COURT: Sure.
THE WITNESS: So this is the 1922 Wentworth scale that --
Q. Speak up some more.
A. This is the 1922 Wentworth scale used by geologists from the Journal of Geology quite some years ago, and it is the -- sort of the fundamental scale that geologists use to talk about the gradational sizes of naturally occurring materials.
Now, just hit a couple highlights. Materials that are less than 1/256th of a millimeter are referred to by geologists as clay. 1/256th of the thickness of your fingernail is really, really tiny, and that material is called clay.
We actually use the word "mud" as a scientific term. I know it sounds like a child's term, but we actually use "mud" to describe these particles of both silt and clay. Any particle that's between 1/256th of a millimeter and a 16th of a millimeter, this size range is referred to as silt. So silt is bigger than clay.
Q. But it's still 1/16th the size, thickness of your fingernail?
A. Yeah. It's less than 1/16th the size of your little fingernail.
So clay, really, really tiny; silt, also tiny. Geologists are fond of actually saying you can -- if you were to chew on a piece of clay, you wouldn't be able -- it wouldn't

be pretty, but silt would be slightly gritty. You can hardly even see these particles with some analytic magnification. Anything bigger than a 16th of a millimeter but smaller than 2 millimeters -- that's two times the thickness of your little fingernail -- is called "sand," regardless of its composition. It could be gold sand; it could be quartz sand. "Sand" is a size term.

I think it's important to note that we also subdivide sand to the different types of particles; for example, very fine sand, fine sand, medium sand, coarse sand, etc.

Any particle bigger than two millimeters, regardless of its composition, is called gravel. And there are subdivisions of gravel: Granule, pebble, cobble, and boulder. These terms -- clay, mud, silt, sand, and gravel -- are used exclusively by geologists to indicate that the particles aren't stuck together. They're unconsolidated materials.

If you stick the particles together, you form a rock, so we will say it's lithified. For example, if you take some gravel which is bigger than 2 millimeters, and you in the natural environment cement the grains together, maybe by groundwater percolating through it, the resulting rock would be called "conglomerate." If you stick the sand grains together by natural processes, it would be called a sandstone. It would be called a sedimentary rock. If you -- and etc. Silt stone, and a clay stone or a mud stone would be the lithified equivalent of these unconsolidated materials indicated on this chart.

Q. Okay. And this is a -- this is the chart -- it says at the bottom, but it's hard to read; it's a scale of grade or class terms for clastic sediments?

A. Sediments.

Q. So what is a clastic sediment?

A. Clastic sediments are those that are derived from the weathering breakdown of pre-existing materials into discrete particles without being dissolved first. So these are -- these are fragments of other minerals, in many cases.

Q. So how does this relate to the earth under northwest Mississippi, west Tennessee and throughout the Mississippi Embayment?

A. Well, materials that make up the Mississippi Embayment are not lithified, and so they would be composed of varying compositions of clay, silt, sand, and some gravel in some locations.

Q. Okay. So this is the earth basically on the Mississippi Embayment?

A. It is.

Q. And the earlier slide showing the big blowup of the sand, the groundwater we're talking about is water that is in the spaces between those -- these particles in the ground?

A. That's correct.

Q. Thank you.

Now, the term "aquifer" is thrown around a lot. In fact, the representation has been made that the entire Mississippi Embayment is one totally hydraulically related aquifer. So what is an aquifer?

A. I use the Heath's definition of an aquifer that I've used in the past 20-some years. An aquifer is a rock or sediment layer capable of transmitting usable quantities of water.

Q. And if -- is there -- are there different kinds of aquifers?

A. We classify aquifers differently --

Q. Okay.

A. -- based on lots of different hydraulic properties.

Q. Are there any fundamental large classifications?

A. Yes. Yes.

Q. What are they?

A. Those classifications, in my mind, would be a simple one: Unconfined aquifers and confined aquifers would be the two fundamental types.

Q. Okay. Do you -- I'd like to put a slide up and ask you if you could explain what the differences in the ground --

THE COURT: We'll take a short recess at this time.

MR. ELLINGBURG: Thank you.

THE COURT: We'll take a ten-minute recess.

(Recess)

THE COURT: You may continue with your witness.
MR. ELLINGBURG: Thank you, your Honor.
BY MR. ELLINGBURG:
Q. Backing up just a little bit, earlier I asked you if there were different types of aquifers in terms of their -- and I meant to ask you in terms of their geological materials. And I'm sorry I wasn't clear about that; but could you explain what the different groupings of aquifers are in terms of geological materials.
A. So we had evolved, I thought, to a discussion of the types of aquifers and unconsolidated materials. And I had described those as confined and unconfined.
Q. Right.
A. But on a broader scale, there are rocks and there are sediments. I've described sediments -- clay, silt, sand, gravel -- and there are aquifers in those. But rocks can also be aquifers. There are three rock types: Igneous rocks, I-G-N-E-O-U-S, metamorphic, and sedimentary rocks. I actually gave an example of sedimentary rocks in the previous example, where I pointed out that sand can become sandstone. And sandstone is a sedimentary rock.
Igneous, metamorphic, and sedimentary rocks can be considered aquifers. Many times igneous and metamorphic rocks have water in fractures and cracks rather than in the pore spaces between grains. But you can have pore spaces that have

water in them, and sedimentary rocks, like sandstones and silt stones.

And so that's a general discussion of the three different types of rocks, in fact, that they can be aquifers, and are important aquifers in many places around the country and the world where we don't have sediment or sedimentary aquifers.

Q. So in the fractured rock aquifers, do you -- do those sometimes, I guess, does the water over millions of years erode some of the fractures away?

A. Groundwater velocity is so low, in my opinion, in these kinds of rocks, that there's no erosion. But mineral precipitation in response to changes and conditions in the fractures can be a problem.

Q. Okay. Well, that was kind of an aside. What kind of aquifer system do you have in the area of North Mississippi and West Tennessee?

A. Those aquifers that we seem to be talking about here today are composed of unconsolidated sedimentary materials. They're composed of kinds of particles I've described: Silt, clay, sand, etc.

Q. And when we look at some of these early slides, we'll see an area, and it will say "sand," okay? And within the geology of Northwest Mississippi and West Tennessee, when it says "sand," is that like the sand I get at the Home Depot? Comes

in a bag, it's all nice, regular, and sorted, and same size and everything?
A. It can be. But most geologists, I think, agree that naturally occurring materials tend to be less than perfect. They tend to be a little messy. They tend to have some variation in grain size. For example, a sand can have -- can be characterized as poorly sorted, which means that it could have fine sand mixed in with the coarser sand. It could be a silty sand.
So as a general rule, when you see the words on a map, "sand," most geologists would take that to mean that there's a preponderance of sand-sized particles; but there could be other things in it and still classify it as a sand.
Q. Okay. So the maps are the generalization?
A. They are.
Q. Okay. Now, in terms of the recovery of groundwater, or in terms of the presence of groundwater, where it's found, you put a slide up that says "Aquifers and confining beds." Could you explain to us what that shows.
A. Yes.
I'm going to move down again. I don't have a lot of experience with this. Is that too loud?
THE COURT: That's fine.
THE WITNESS: Is it okay without it?
THE COURT: It's better if you have it.

THE WITNESS: Okay. So this figure is also from Ralph Heath; probably no surprise. Probably no surprise. Thank you. Is from his Basic Groundwater Hydrology textbook.

And what it shows is the difference between aquifers and confining beds. And so just to give you some understanding of what's going on here, this is a geological cross-section of the earth. So the land surface would be here.

And just to get things going, we'll subdivide the groundwater system into two zones: The unsaturated zone and the saturated zone. And in the unsaturated zone, there is water, but the pore spaces aren't completely filled with water. It's not saturated. The unsaturated zone overlies the saturated zone, and by definition, the saturated did -- in the saturated zone, all the pore spaces are filled with water, hence they're saturated.

In this illustration I try to distinguish between two types of unconsolidated aquifers, the unconfined aquifer and the confined aquifer, but I throw in the issue of a confining bed. Confining beds are materials that have -- can have a lot of water in them, but they don't transmit the water very readily. So while clay actually has more water in it, and more pore space, the pore spaces aren't as interconnected, and it's hard to get water to flow through clay. So we say clay can be confining; that is, it can be the boundaries between the different types of the groundwater system.

Above a confining layer, the first confining layer that we find below the land surface, we usually find an unconfined aquifer system. It's not confined above, but it's confined below.

Below it, we define confined aquifers. And confined aquifers are usually confined above and below, even though there's no confinement shown on this particular diagram.

So there's an important distinction between unconfined aquifers and confined aquifers, that are really the result of the presence of this confining bed. When water falls on the land surface as precipitation, some of it runs off and becomes the water that will breach the rivers; but a lot of the water -- some proportion of the water seeps underground and goes down and saturates the pore spaces. And so while it's not completely obvious in this diagram, every pore space between this -- below this line, between the pore spaces in the clay and pore spaces in the sand, are completely saturated with water. Every pore space below that line, every pore space in all these different units, is completely saturated with water.

If you were to go out into the unconfined aquifer and put in a well, and put some pipes in the ground to keep it from collapsing, and put some slots there that we call screens, that will allow the water to come in but not let the sand in this case come in, the water would rise to the height of the saturated zone -- unsaturated zone, more or less.

And I say "more or less" because of the presence of this thing called a capillary fringe. And the capillary fringe is perhaps one of the most complicated parts of the groundwater system, because there the water is under tension caused by the attraction of water molecules for each other and the water molecules for grades of sand.

And so the water actually in this capillary fringe is at less than atmospheric pressure, and it can't come into the well. So we say, for all practical purposes, the water table is the boundary between the saturated zone and the unsaturated zone at the base of the capillary fringe.

If you put a well into the unconfined aquifer and ask yourself the question, "Well, where is the top of the aquifer?" Well, it's there.

And so the water table, the water table in an unconfined aquifer does not rise above the top of the aquifer at the well. The top of the aquifer at this well is there. The water is going to be here. This is the kind of well you'd see out in Mom and Pop's farm, with an old pumphouse and a hand crank and a bucket to get the water out of the ground.

When we developed the ability to drill deeper holes, we realized we can drill into the deeper aquifers and get water which is often not always a higher quality.

So I'll move on, then, to some discussion about the confined aquifer, in which case I'm showing it as a sand. And

I show it uniform in composition, but it could be variable.

And so in this case, if we put in a steel pipe with slots in it, so that the water can come into the well but the sand can't, we would find a situation, in real simple, terms like this: The water level in this well will rise above the top of this aquifer. At this well.

In other words, the water level could rise all the way to here, in this generic example. So when the water level in that well rises above the top of the aquifer in that well, we call it a confined aquifer well. And the general terminology is "Artesian well."

Sometimes particularly the water surface in this well, the standing water level in this well is above the land surface, and it will flow freely, and it's called a free-flowing Artesian well. I'll show you one later.

Many times, however, the water level in a well attached to this aquifer is above the top of the aquifer but below the land surface.

An important point about confined aquifers is that the water in the pore spaces is under pressure. And you tap this aquifer, the water will rise to a certain height, that can be related to sea level.

So sea level is down here. We would say, "Oh, it's up -- a hundred feet up to this surface," or to this height in this well, and so that is the potential that this water has to rise to that height. So we call it, in general terms, the potentiometric surface.

Q. And those wells -- in that case there's no pumping; this is just a hole in the ground. Right?

A. These are holes in the ground, in which we would install things to keep them from collapsing. And so, yes, these are wells that do not have pumps, and that I would call a monitoring well.

Q. Okay. All right.

A. I'm monitoring things in the groundwater system, like heights of the water table, or height to which water would rise in this aquifer, called the potentiometric surface.

Q. Okay. So the water in the water table is essentially -- so the water in the water table is at a level that is confined by atmospheric pressure?

A. The water in the water table is actually at greater than atmospheric pressure, because atmospheric pressure exists in this well. So if the water here is at greater than atmospheric pressure, it can come into the well. The water in the capillary fringe is at less than atmospheric pressure, so it can't overcome atmospheric pressure, so it remains in the groundwater system.

Q. But everything in the confined aquifer is residing under pressure?

A. Yes. Yes.

Q. And that pressure is higher than atmospheric pressure, on average?
A. Yes.
Q. And that's what shows an Artesian well?
A. By definition -- my definition of an Artesian well is one in which the water in the well rises above the top of the aquifer at the well.
Q. Thank you. Let's move to the next slide.
        And I'm going to ask you, we have those clay layers in that last slide; and what does this show? That shows one --
A. Can we go back one slide?
Q. What --
A. Are you talking about this clay layer?
Q. Yes, that one. Let's go to the next slide.
A. Okay.
Q. And so what does it show?
A. This slide shows a more realistic depiction of a groundwater system. A groundwater system usually is not just one unconfined aquifer overlaying a confined aquifer. It's probably more common to find a series of confined aquifers stacked one on top of the other, with intervening clay layers, that we would call confining beds; or it could be silt layers that we call confining beds.
Q. So in this particular depiction, you have these dotted lines. What are they showing?

A. This particular figure, from -- also from Ralph Heath, is designed to educate people about the functions of the groundwater system, which are to store water, to transport water, and to treat water. Those are the three functions of the groundwater system.

And so the predominant thing that you get from these arrows is that well water stored underground, with a molecule of water at this location, can, given existing conditions within these aquifers, follow this line, moving across confining layers at a really slow rate, and then moving through the groundwater system before ultimately discharging to some area that we call the discharge area, which could be a creek, a river, or even the ocean.

Q. Okay. So when you talk about groundwater coming in, say, in this case, it doesn't show one other layer; but when it comes into the confined aquifer system, it will then follow a path. Now, you've got some -- or Mr. Heath put some -- put some time scales that are pretty generic on there?

A. Yeah.

Q. But could you explain why those time scales are there, what they show?

A. So what Ralph has always emphasized is that the residence time of water in different aquifers is different. And as a general rule, groundwater flows from recharge areas, indicated by this, to discharge areas in both the shallow aquifers and the deeper aquifers.

But the amount of time required for a molecule of water to flow from recharge areas to discharge areas varies pretty dramatically. In the unconfined portion of the groundwater system, travel times -- that's the amount of time a molecule of water stays in the groundwater systems -- could be measured in days, or weeks, or even years. But for deeper groundwater systems -- and I'm talking about systems where the aquifers are thousands of feet, for example, below the land surface -- water can require -- a molecule of water can require centuries or even millennia to move from the recharge area, where it ultimately could be discharged in the discharge areas.

So this is an indication of a really, really slow velocity of water in the groundwater system.

Q. And those things, what's called the travelers time?

A. Travelers time or residence time.

Q. Or residence time. What determines -- just generally, at this point, what determines those? Is it the makeup of the material? What is it?

A. It's a wide variety of factors. The travel time, for example, in this aquifer would be a function of the permeability of all the materials through which it flows. It has to flow through this material. It has to flow through this clay and through this material. And each of these could have different abilities to transmit water, which is what we call

permeability.
Q. Okay. So --
A. So that would be a factor.
The other factor could be the pressures that are operating in the system, that are the driving force for water through these systems.
Q. And these are all natural systems?
A. These are just generic -- it's a portrayal of kind of a generic system that would be considered natural.
Q. Focus on concepts?
A. Pardon?
Q. To help us understand the concepts?
A. Absolutely.
Q. Okay. Now, let's move -- in the last two slides, these aquifers were like flat; were like a cake, except for the top, where somebody messed up the icing.
Let's move to the next one. Are there different-sized aquifers than that?
A. Yeah. I think Ralph was a master of moving from the simple to the complex, so in his text he always started out with horizontal layers. But we recognize that many layers that we call aquifers in confining beds can have an inclination, and so the logical next step would be to show an aquifer here, called the confined or Artesian aquifer, that actually has an inclination relative -- relevant to showing in a flat

orientation a horizontal orientation.

So in this case I'm actually showing a confining layer down here that's nonporous -- I don't know if that's spelled correctly -- and an aquifer sitting on top of it with a confining layer.

And the purpose of this slide, in my mind, is to illustrate this concept that aquifers can become inclined when it rains, and what we call the recharged area of the confined aquifer. It's -- water can percolate down. And by the way, I would perceive that that's an unconfined portion of the groundwater system. And where the clay picks up, it becomes confined, and water flows down the confined aquifer system, because it's under pressure.

And the only way you can see that pressure is to put in a margin well here, that lets the water come in here, the pressure rises to there, you would say, relative to sea level, there's its pressure; there's its potentiometric surface in feet.

And if you were to come over here, somewhere else and do it, what you would find is that at this location for this diagram, the pressure would be lower; so groundwater moving in the direction of decreasing pressure, down the axis of this confined aquifer.

Q. Okay. Now, we're talking in this case about -- these are some general concepts. Now we're talking about aquifers,

systems, and units within the Mississippi Embayment, right?
A. Mm-hmm.
Q. Talking about -- put the next slide up.
Now, what is that?
A. This is a -- this is a map by Clark, et al., 2011, you see, and it shows the general location of the northern part of the Mississippi Embayment, the part of the Mississippi Embayment in Mississippi and Louisiana up into Tennessee, Arkansas, and so forth.
Q. Okay. Now, as a geologist, could you give us some history as to how the Mississippi Embayment was formed, and why that is important in this case?
A. So the Mississippi Embayment is a rather large sedimentary structure that is what I would describe as a synclinal form, which means it's a downwarping. And this downwarped geological feature, which is part of the Gulf Coastal Region, began forming, in my opinion, about 100 or so million years ago, during Cretaceous time.
Q. Let's go to the next slide.
Okay. So what are you showing here?
A. Okay. And so this is a --
Q. Tell us how many years we're talking about here.
A. Okay. I call this a paleogeographic map. It shows the geography a long time ago, hence "paleo" to geographic. And so 75 million years, according to this artist's rendition, who was

also a geologist, the Gulf of Mexico and -- which is here, and the Gulf states at the East Coast of the United States, and indeed the central part of the United States, was inundated by a great sea. And that's because sea level was a whole lot higher than it is today.

And so this embayment, this low spot -- which has a really interesting geological history, which I'm sure you don't know about -- formed in response to some kind of tectonic forces as a sedimentary basin, that it's a low spot. And in this time, late Cretaceous, 75 million years ago, and before a sea occupied this area.

And so you can imagine, 75 million years ago, a river flowing down here -- oops.

Q. Got ahead of you.

A. It moved.

Q. I'm sorr.?

A. A river flowing down. And in this area, a complex land surface with some beaches all along there, these would be late Cretaceous beaches, and there would be dinosaurs walking around there instead of people. And offshore, there would have been other types of sediment deposited, and maybe some barrier islands; I see a few barrier islands in there, for example.

And so in Cretaceous time, the Mississippi Embayment was inundated by the ocean. And the net result would be some layers today that geologists would say are Cretaceous in age, because they formed in this area 75 million years ago.

In the last 75 million years, sea level has been rising and falling pretty dramatically. It gives new meaning to global climate change and global warming. Here the climate was a lot different than it is today, and you can imagine that all of Eastern North Carolina, for example, where I live, was underwater, and most of Mississippi was underwater.

The point here is that during these times, sediment layers were being deposited. And their complexity is enormous. There were beach sands, deposits like estuarine deposits of mud, silt and clay, all kinds of complexity in this geological environment, just during this time.

And what I think it would show in the next slide would be that as time progresses, to 65 million years ago, the ocean, which covered pretty far up on the continent and now regressed off the continent, and so those layers that could have been deposited up into here now might eroded by rivers, and some of it could be eroded away, and now new material is being deposited down here that has a slightly different age. It would be called Tertiary, or 65 million years ago, etc.

And then if we progress just a little bit more, Paleocene time, which is 60 million years ago, the sea had regressed pretty far off. So those sediments are still there in large part; those Cretaceous sediments are still there. But they could have been impacted by the fact the sea level has fallen, and rivers are cutting down into the land surface and changing those, the compositions of those materials.

But then, at about the end of this time period, about 56 million years ago -- and I think this was listed as 50, but about 56 million years ago -- the climate of the earth changed dramatically, and it launched what we geologists call the Eocene time period, a word for 56 million years ago to about 33.9 million years ago. The climate of the earth changed dramatically. And the glaciers melted. And there was no Arctic and no Antarctic at the time, and all of that water went into the ocean again, and it inundated the land surface, and once again flooded the land surface all the way up to the present-day position of Memphis and beyond.

And I think it's really important, if you want to understand this stuff, to know that this is just a snapshot, one time frame, within a 25-million-year period that we call "Eocene." And during this time, sea level rose and fell throughout all this time. The intermediate level age aquifers or layers that make up the Mississippi Embayment today were formed in this kind of a protrusion of the ocean up onto the continent during that time. So you would say they are Eocene formations, geological formations.

Q. And so are you saying that there was a beach up here somewhere?

A. I think there was a delta up here, bringing sand down from the Mississippi River, all of its tributaries, and depositing it, the sand at this particular time in the Eocene there.

And I can imagine sand being deposited and distributaries and all kinds of interesting bodies, and clay being deposited over here. So tremendous complexity.

And then further offshore, right in this area, I actually see barrier islands. So there could be beaches of sand there, and sand dunes, and all kinds of material being deposited behind it.

So the net result is that if you find a lot of geological formations that are that age, Eocene, but they have tremendous lateral and vertical grading.

Q. Now, when you say grading, what sediments were being deposited?

A. Sand, silt, clay, and probably some gravel layers associated with the primary channel of the major rivers flowing down from the north.

Q. Okay. And is there some reason that they wouldn't be uniform?

A. I think geologists look at an environment like this and see ultimate complexity. If you were at this location up here, you'd be in a delta not unlike the delta south of New Orleans today. And if you came down the Mississippi River, you'd see splays of the river going off in different directions. By the time you get down to here, you'd see kind of an estuary out there; you might be able to see Gulf Coast-type barrier islands with big sand dunes on them. And then the beach, and then more sand deposited here, silt and clay being deposited out here.

So my point in showing you this is, this is the reality of the formation of geological materials. We don't get the same geological material formed over really large areas except under some different geological circumstances. And I'm showing for this region at this time.

Q. Would this generally -- you're saying that the level of the ocean would move up and move down, but would this generally show where what's been called by many geologists the Southern Mississippi Embayment was primarily being formed, of the South Mississippi Embayment --

A. I think you would see sediments of the middle and upper part of the Mississippi Embayment here, as well as a lot of settlement in the Mississippi Embayment in the Gulf Coast region, and the Atlantic Coast region also.

Q. Thank you. Next slide.

What does this show?

A. This just shows the natural progression of the earth as the climate changed, and sea level rose and fell after a -- towards the end of the Eocene.

Towards the end of the Eocene, something interesting really happened; that is, the earth cooled dramatically. So at the beginning of the Eocene glaciers melted; sea level rose.

By the time we -- again, close to the end of the Eocene, which is around 30, 40 million years ago, glaciers started to form once again in the polar regions, and so sea level fell, because you had to have the water from the ocean to make the glaciers.

It shows, then, that you would be left here, in this area, with a thick several-thousand-foot section of sediments that formed from Cretaceous to Eocene, but now sea level has fallen, and those sediments are exposed at the land surface, and rivers are migrating across them.

Q. Is there anything other than just the ocean going up and down that impacted the way the sediments got formed?

A. There could be all kinds of things. They could actually be sand dunes in here; they could be river channels and floodplains as rivers flood their channels and migrated across their floodplains.

Q. Did river flow have any impact?

A. River flow could clearly impact the sediments of the Mississippi Embayment by constantly eroding through them at different times through geological history.

Q. Okay. Let's go to the next one.

This is just another one?

A. Just another slide to show this complex change through time, shows how the shoreline is going to change.

Where I live, in Eastern North Carolina, was still underwater 25 million years ago, and coastal Louisiana and

Mississippi was underwater.
Q. What about the next one: Let's look to the next one.
A. Same thing. Sea level rises and falls, and the sea level change is the norm, rather than the exception, in the way geologists perceive the history of the earth. And it shows that you could have had rivers of different composition flowing from different areas up in the area now known as the Mississippi Embayment.
And we're almost done with these slides.
Q. Next one.
A. 8 million years ago, still a higher stand of sea level than we see today. And then 3 million years ago, most of the present-day area of the Mississippi Embayment was clearly a highland, the sea trends had regressed. And then this is the -- what happened about a couple million years ago up to about 126,000 years ago, and that is the global climate changed dramatically, and water piled onto the continents as ice two miles thick, and inundated the continent with ice.
And today all those ice sheets are gone, and this is what North America looks like today.
Q. So that's what we have now?
A. Yes, that's what we have now. And you actually can kind of see the outline of the Mississippi Embayment here, because the materials are different than the materials of the Appalachian and the Ouachita.

Q. So the Mississippi Embayment is filled with sediments that were laid down over this long period of time under these conditions?
A. That's an accurate description.
Q. Okay. Now, how does -- from the geologist-hydrogeologist standpoint, the history you've just given: Why is it important?
A. It's important because you just have to think, if you're a geologist, about complexity and about the different geological environs that existed in this area over that roughly hundred-million-year period that resulted in that almost unfathomable difference in the environments of deposition and the changes in the materials that existed in this area through that time.
Q. I'm going to show you a slide that has been used a lot in this case. And it's a -- it's something you even used in your report. And when I'm looking at this, it appears to me that we got something called Middle Claiborne, which is an underground sea full of water, and it's just all flowing in these nice uniform directions of these arrows. Is that what it really looks like underground?
A. Well, I think this is designed to be a generalization that can lead to the type of interpretation that you just made. But I would say that just because there's an arrow there doesn't mean that it's a flowing river of water underground. These

arrows are giving us an indication of the direction of groundwater flow, not the rate of groundwater flow.

And the overall concept here I think is a good one, because it portrays that these sediments are formed in a basin that has sort of a north/south axis, and that there are multiple layers, like the bottom ones of Paleocene, and the top ones are really young, and there are different names applied to the different geological formations that occur in the Mississippi Embayment.

But I certainly agree that you can't look at this diagram and see rivers of water underground; you have to look at these arrows in terms of direction of groundwater flow.

Q. Okay. Well, about -- I'm not looking right now for a specific, but what kind of timetable are we looking at on this map from the time water enters the Middle Claiborne, as shown, to the time that it makes that turn to go up?

A. Are you talking about in this area, where it turns and goes up?

Q. Yeah.

A. So up here, the Middle Claiborne not only thins, but it gets close to the land surface. So groundwater moving up in this area of an outcrop area could enter and exit the groundwater system in a matter of days, weeks.

Q. And the unconfined?

A. And the unconfined portions up here in the outcrop area.

But once the water gets into the part of the system.
Q. The confined part?
A. Into the confined part, travel time is now measured by centuries and millennia. Thousands of years.
Q. So this would go back -- that water from the out -- once it gets into the confined portion of the aquifer, it would take it thousands of years to even get to the bottom; is that right?
A. Thousands and ten -- and tens of thousands of years.
Q. Okay.
A. Millennia.
Q. Also this particular diagram, you know, it's got that middle area called the Middle Claiborne.
A. Mm-hmm.
Q. Is the Middle Claiborne an uninterrupted body of sand?
A. No. No. It's characterized by significant lateral and vertical variability.
Q. And this is exaggerated scale, it says on there, right?
A. It says "Not to scale," and so the vertical scale would be different from the horizontal scale. So slight exaggeration.
Q. Right. Okay. So what -- let me ask you, you said -- are there any other recognized formations within the Middle Claiborne that aren't shown on this map?
A. Okay. This particular -- this is not a map; it's a cross-section -- shows an interpretation by some well-respected hydrogeologists, Arthur & Taylor, 1990, not of the formations

but the lumping of formations together in what are called aquifer systems, or aquifer units, or hydrologic units.

And so when you asked me the question about formations, make sure that you understand, the geologist thinks about a formation different from a hydrologic unit, and these -- this stacking of these materials is designed to portray the Mississippi Embayment hydrologic system.

Q. Okay.

A. Geologists look at big systems like this because they have something in common. They formed in the last hundred million years the same general structural feature. But we hydrogeologists like to subdivide things in different layers, different systems, in this case within the bigger system, and then we use the term "hydrologic unit."

Q. Okay.

A. And so these are hydrologic, hydrogeologic units of the Mississippi Embayment Groundwater System.

Q. Okay. And how --

A. But your question to me was, are there variations even within this hydrologic unit? And my answer is yes.

Q. Okay. Could we -- let's pull up the next slide.

Do you recognize that, Dr. Spruill?

A. Yes.

Q. This is the -- a chart that you see everywhere in the literature for this region that's been worked on by geologists

for years. It's called the hydrogeologic and geologic units and their correlation across the states within the Mississippi Embayment Regional Aquifer Study.
Q. Now, let me make it clear, this particular slide has removed the last column, which we'll show in a minute.
A. I took the last column off.
Q. To just talk about the geology?
A. Yes. What you see here is geology, and you add hydrogeology on the right-hand side when you put it back together.
Q. Okay. So --
A. Should have lifted some weights before I came, because it's heavy.
Q. Tell me, what geologic formations do you see on that map that are in the state of Tennessee in the Eocene time period?
A. Okay. So this diagram shows what geologists refer to as the Cenozoic, one of the major subdivisions of geological time; and then the tertiary; and then it shows the Eocene -- remember, that's about 56 million years ago, and that would be about 33 million years ago or so. So all of the formations listed right in here are Eocene in age. These are older Eocene, and these are younger Eocene.
So you asked me specifically, if you went to Mississippi today and wanted to see the things that geologists call formations, which are mappable units -- we're not thinking

about water; we're talking about mappable geological units.
Q. So what is a mappable geological unit?
A. A unit that has sufficient thickness and characteristics that a well-trained geologist would recognize it in different locations as the same unit.
Q. Okay. Does that mean that its composition within that formation is the same as it was?
A. Not necessarily. It can change, but it has characteristics and thickness that would be recognized by a trained geologist as something that's mappable.
Q. Okay.
A. Recognizable.
Q. Go ahead.
A. So in -- with respect to the Eocene, and the great State of Mississippi, you would expect to find at the base of the Eocene something called a Meridian Sand member. You might find the Tallahatta Formation, the Winona Sand, the Zilpha Clay, the Sparta Sand, the Cook Mountain Formation, and the Cockfield Formation stacked one on top of the other. And you might see that in some parts of Mississippi, but you might not find it everywhere in Mississippi.
Q. Okay.
A. In the great State of Tennessee, you would expect to find at the same location a geological formation called the Memphis Sand. And the Memphis Sand is represented by this rectangle.

On top of the Memphis Sand would be the same formation, and the same two formations that represent well per part of the Eocene, of the Claiborne group. Claiborne is a group of formations.

Q. Okay. It's not a formation?

A. It's a group of formations.

Q. Okay. And this lists the formations, right?

A. These are geological formations. The Memphis Sand is a geological formation.

Q. Geologically, are there further breakdowns within these formations?

A. Oh, yeah. Geologists then go from -- from group to formations to members, and even submembers, but they're not -- that level of detail is not shown on this document.

Q. This, again, is a generalization?

A. It's a pretty good generalization.

Q. Okay. Now, let's put the next slide up.

Now, what -- this is the slide out of the USGS MERAS study. So what has been added in that last column?

A. I added back in the hydrogeological units, just for sake of clarity. Geologists look at these on the basis of their compositions. And then geologists come in, hydrogeologists and others, and say, "Well, wait a minute; what about the ability of these formations to transmit water? Let's lump those formations together that have similarity, say, of age and position, and have the same tendency to transmit water; let's lump them together as a hydrogeologic unit," as shown in the heading at the top.

Q. So what is a hydrogeologic unit?

A. Okay. A hydrogeologic unit is a subdivision of an aquifer system. This is the aquifer system.

Q. The whole thing?

A. All of this. This is the aquifer system. Hydrogeologic units are subdivisions of aquifer systems, based on their similarity of ability to transmit water -- or their inability, so to speak -- to transmit water.

So hydrogeologic units can be things like the Upper Claiborne Aquifer. And it can also -- hydrogeologic unit can also be the Middle Claiborne Confining Unit, and I talked about confining units before.

Q. So a hydrogeologic unit includes both aquifers and confining units?

A. In this classification of hydrogeologic units, you can find confining layers or confining units that are part of the system, and you can find different types of aquifers with different names as hydrogeologic units.

Q. So they've lumped together or put together multiple formations?

A. Multiple formations can be lumped together in a single hydrogeological unit, or it can be a single geological formation that makes up a hydrogeologic unit.

For example, as a general rule, the Cockfield Formation, over a really large area, Cockfield Formation is called the Upper Claiborne Aquifer. And there isn't a lot of name change from state to state.
Q. Okay. But these hydrologic units, I've got to make sure I'm clear: Do they include the confining layers?
A. A hydrogeologic unit may be a confining unit. It may be a group of aquifers lumped together, called an aquifer unit.
Q. Okay. On the right-hand side -- on the -- in that particular section you're looking at, the Sparta Sand and the Memphis Sand?
A. That would be here and here.
Q. Between that line and the bottom line, the Memphis Sand?
A. Mm-hmm.
Q. Over to the right, in the hydrogeologic unit, it's got those funny lines. What do they mean?
A. Those are lines that geologists draw to represent, in my opinion, some level of uncertainty about exactly where these boundaries are, timewise, and how we've decided to lump some of these different things together. And it can also show, when the line is vertical, it has this variability, that sometimes this exists in an aquifer, as an aquifer unit, and sometimes it doesn't.
Q. Okay.
A. It can come and go in this particular geologic environment.

Q. Okay. Where is the Tallahatta Formation in the Memphis Sand?
A. Say that again?
Q. Where is the Tallahatta Formation -- I see that in Mississippi. Where is it in the Memphis Sand?
A. Geologists don't recognize the Tallahatta Formation as part of the Memphis Sand.
Q. What about the Zilpha Clay, or Zilpha?
A. The Zilpha Clay, of Eocene age, is not recognized as part of the Memphis Sand in this correlation chart.
Q. Is it recognized in this --
A. It's recognized in Mississippi as a geological formation and part of a hydrogeological unit called the Lower Claiborne Confining Unit.
Q. Okay. So it's a confining layer?
A. It's part of a confining layer.
Q. Oh. And so if we just decided we were going to disregard the -- we were going to mix it all up, and we were going to call them the same thing, what would be the thickness of the Memphis Sand in Tennessee?
A. From the literature, I understand that the Memphis Sand is probably on the order of 250 meters thick, which would be over 700 feet thick.
Q. Okay.
A. But variable in thickness. So if you went to the east, it

would become thinner.
Q. Right. What about the Sparta Sand in Mississippi?
A. Appreciably thicker, appreciably thinner in the -- in the Mississippi, especially in Northern Mississippi, but attained some slightly greater thickness in Southern Mississippi.
Q. Okay. So this -- these Zilpha Clay, the Winona Sand, the Tallahatta formation, those aren't in Tennessee?
A. My opinion is they do not exist in Tennessee.
Q. Okay. Now, this chart does refer to the Middle Claiborne Aquifer, right?
A. Yes.
Q. And is that anywhere on the geology part of the table?
A. No. The word "Claiborne" is a word that's used to describe a group of geological formations without regard to its ability to transmit water. So hydrogeologists simply took this name and added a "Middle" designation to it, and the word "aquifer," and said, "Oh, some of these formations are capable of transmitting usable quantities of water and should be lumped together in something called a Middle Claiborne Aquifer."
Q. But that's a hydrogeological term?
A. It's a hydrogeological term.
Q. And it includes both the confined aquifer, which can produce water, right?
A. Yes.
Q. Okay. And it includes the confined layers, which were

predominantly clay. Does anybody --
A. I don't agree with what you just said, so --
Q. Well, the confining units are of lower permeability, right?
A. That's correct.
Q. Does anybody drill wells in the confining units to produce water?
A. Yes. What -- I've always said throughout my career that one man's confining layer is another man's aquifer. For example, here in Mississippi, there's a sequence of formations that are relatively low in their ability to transmit water; but in the middle, there's a discontinuous sand called Winona Sand. And if a small company or residences or somebody wanted some water, they could probably get some water out of it. But by and large that's not a major aquifer, so it's lumped in -- this is really important -- it's lumped in with the Lower Claiborne Confining Unit.
Q. So it's inside the confining unit?
A. It is part of the confining unit.
Q. Okay. So -- but it's kind of walled off, generally?
A. Sealed off vertically, and then in many cases horizontally.
Q. Okay. So it wouldn't -- it wouldn't be providing water to the Memphis Sand?
A. I can't say whether or not -- where it ends, in this direction, whether it actually intersects the Memphis Sand or not. I don't have that level of detail. Sorry.

Q. Tell me what the significance is of the name being -- of the name "Middle Claiborne Aquifer" being the hydrologic unit aquifer.
A. The Middle Claiborne Aquifer is a very important aquifer in the Mississippi Embayment, which is Lower Eocene in age, which has different geological formations that make it up. And geologists have called these different geological formations different aquifers.
But Middle Claiborne Aquifer is incredibly complex, as is indicated by this particular pattern here, which is hard for some people to understand. I would like to point out that when other geologists started coming up with these names, they decided that they would name an aquifer like this, like the Lower Claiborne Aquifer, and the confining bed above it, they would call it the Lower Claiborne Confining Unit.
Q. Okay.
A. So if there's an aquifer called the Lower Claiborne Aquifer here, its confining layer is called the Lower Claiborne Confining Unit.
Q. Are you saying that there can be multiple aquifer units within different aquifers or multiple aquifers?
A. There could be multiple aquifers within a hydrogeological unit, multiple aquifers. So the concept is system, Mississippi Embayment. Hydrogeologic unit, these subdivisions, aquifers.
Q. Okay. So the aquifers are what would be identified in the

geology part; that's where they would be found?
A. Well, the formation, the formation, the Memphis Sand carries no connotation of its ability to transmit water, other than it's a sand. So what hydrogeologists would do -- and look, it's not shown on this diagram -- is they'd simply say the Memphis Sand has the ability to transmit usable quantities of water; it's an aquifer.
Q. Well, are there any -- what aquifers are there in that area in Tennessee?
A. In Tennessee, the aquifer is called the Memphis aquifer.
Q. Okay. In Mississippi, is there a different recognized aquifer?
A. In Mississippi, the aquifer is called the Sparta Aquifer of the Middle Claiborne Aquifer system of the Mississippi Embayment Aquifer System.
But there's also another aquifer of Eocene age in Mississippi that is called the Lower Claiborne Aquifer, and it has in Mississippi a Lower Claiborne Confining Layer on top of it, and it's called these formations.
Q. Okay. And so does the Lower Claiborne Aquifer exist in Tennessee?
A. My opinion is that the Lower Claiborne Aquifer does not exist in Tennessee.
Q. Okay.
A. Typically. Maybe right along the border at some spot we

don't know about, but no.
Q. Well, from the hydrogeologic standpoint, are the Sparta Sand and Memphis Sand different aquifers?
A. The Memphis Sand, in my mind, and Sparta Sand are different aquifers that have been assigned to the same aquifer hydrogeology unit.
Q. But in terms of the -- it is a recognized separate aquifer, Sparta Sand?
A. In my mind, yes.
Q. In your mind? I mean, is it or isn't it?
A. It is -- I perceive -- I would classify the Memphis Sand as a different aquifer from the Sparta Sand.
Q. Okay. And this would mean the entire aquifer system on this chart?
A. Well, not really. There's some over stuff down here that doesn't show up on this chart, but it's usually pretty deep and pretty hard to get to, so most hydrogeologists just kind of focus on this.
Q. Well, is this intended to be a depiction of an entire aquifer system?
A. The majority of the younger part of the aquifer system.
Q. Okay. Let's go to the next slide.
Can you tell me, is this depicted on the last two documents we've looked at, or is this another layer down?
A. To me, this is an attempt to portray in a geological

cross-section all those words that we see in that table.
Q. Okay.
A. It's a way to get people to understand what all those words mean in terms of how aquifers in confined layers are stacked one on top of the other.
Q. Okay. Now you said the Sparta Sand is separate in Mississippi or the Memphis Sand. Can you show even how you would indicate that?
A. The words "Memphis Sand" and "Sparta Sand" will not show up on this diagram. But here's the difference: This is a geological cross-section that you would get if you went way up north of Memphis, almost in Kentucky; split the earth right here, and split it all the way down to Southern Mississippi, and lifted it up and looked at it from the side.
And what you would see is that the geological formations are getting thinner up here, but in the vicinity of the Tennessee-Mississippi State line, there's a lot of interesting geological things going on.
So this diagram shows -- as I know, the interest is in the Middle Claiborne Aquifer; it shows a thick Middle Claiborne Aquifer. And it shows, right here, this area that doesn't have the blue color --
Q. The white part of the ragged edge?
A. The white part of the ragged edge is called a Lower Claiborne Confining Unit. So this thing is a Lower Claiborne

Confining Unit, and it dies out or pinches out in Northern Mississippi. When a geological formation pinches out in the subsurface, and we can't see it down there, we simply show a symbol that kind of looks like a flame, and we say that in this general area, this thing pinches out. This thing disappears. Could have been by erosion, or it could have just never been deposited there.

So what's really critical is that the Middle Claiborne Aquifer right here is real thick; probably it's 1,000 feet thick. But right here, there's a fundamental change, and a lot of clay is found in this middle section. And so that's called the Lower Claiborne Confining Unit.

Q. And what is above the Lower Claiborne Confining Unit?

A. Geologists have stipulated that at this boundary -- and this is a diffuse boundary, the transition from the Middle Claiborne Aquifer occurs. And instead of calling it the Memphis Aquifer, we'll call it the Sparta Aquifer, Memphis Sand, Sparta Sand, Memphis Aquifer, Sparta Aquifer.

Q. And I think you've said that an area in between the State line and the beginning of the Lower Claiborne Confining Unit has been referred to as a transition zone?

A. Yeah, transition zone. Would be best if I could draw it, but I can't do; but that squiggly line there, representing a facies change, the change in the subsurface from predominantly sand to a lot more clay to a predominance of clay as you go in

this direction.
Q. Okay.
A. So we call that a facies change. And so it's not a sharp line; rather, it's a boundary that you can see if you look down from the surface, if you could see into the subsurface.
Q. Okay.
MR. ELLINGBURG: Excuse me, your Honor, can we put up something so he can draw what he's talking about?
THE COURT: Sure.
(Discussion held off the record)
BY MR. ELLINGBURG:
Q. Dr. Spruill, we've been talking about this transition zone.
A. Yes.
Q. Could you draw an illustration of it? Because we don't know exactly what it looks like.
A. So on this limited space I have, I'm going to try to draw the geology right at this area of the Tennessee/Mississippi line. But if you would, I'm just going to reverse it, to make it a little bit easier to label, because I'm right-handed.
So here I'm going to draw the land surface, and there's going to be the Tennessee --
Q. You might turn it just a little bit more so the judge can see it.
THE COURT: I can see it. I can see it.
A. There's the Tennessee/Mississippi line on the land surface.

For example, there's a tree, so that's the land surface. Down beneath the land surface, hundreds of feet, there's the top of a series of geological formations that represent a horizontal line.

And so now this is the south and this is the north. And down in the subsurface, further down, a thousand feet or more, there's another boundary. And this boundary represents the lower part of the Eocene, the sediments and geological formations during Eocene.

And somewhere right in here, near Mississippi -- might make that smaller -- because the northern border of Mississippi, here's what you have. (Indicating.)

You have a preponderance over here of sand. And you have sand over here -- and I'm speaking in real general terms first -- and you have some sand over here. And I'm not saying that this sand is exactly like this sand; I'm just saying right now, it's sand.

Q. By "this" and "this" --

A. I'm not saying that the dots that I'm putting here under "Tennessee" are the same as the dots I'm putting here in terms of grade size.

Q. Maybe a different mixtures of --

A. Different mixture, different amount of clay, which I haven't shown, and so forth. So I'm just kind of working towards the major points.

Down in Mississippi, not far from the Tennessee border, you can find the layer of sand -- and frankly, I don't think we know enough about it to know how far it extends in a north/south direction, but it's referred to in that previous chart as part of the Lower Claiborne Confining Layer.

On top of it is some clay. We use this symbol for clay, because that's what's geologists do.

So what we have here is a layer that starts to appear as you go southward into Mississippi. That doesn't exist in Tennessee, in any information I've ever seen. And this thing has a name. And this thing has a name, and this one and this one have a name.

Q. Okay.

A. So if you go back and look at that chart -- which is now gone, so could we go back one slide, please.

I draw now the Memphis Sand, and this is the Memphis Sand, or the Memphis Aquifer. And I draw this sand, which I'm going to call the Sparta Sand.

This geological formation and this geological formation have specific names in this chart. And they are part of hydrogeologic units. This Zilpha Clay, Winona Sand, Tallahatta Formation, are part of what's called the Lower Claiborne Confining Unit. That's this thing.

Q. By "this thing," you're pointing to --

A. The Lower Claiborne Confining Unit.

Q. -- the chart?
A. Strange thing in the chart for --
Q. That's under "Hydrogeologic Units"?
A. This thing is a hydrogeologic unit, called a Lower Claiborne Confining Unit. So if you have a Lower Claiborne Confining Unit, by definition, there's going to be a Lower Claiborne Aquifer. So this thing is the Lower Claiborne Aquifer.
Q. Okay.
A. Lower Claiborne Aquifer, Lower Claiborne Confining Unit, Sparta Sand of the Middle Claiborne Aquifer, Memphis Aquifer Sand of the Middle Claiborne Aquifer.
So if you have a Middle Claiborne Aquifer -- here it is.
Q. Just pausing for one second, so you're saying that a hydrogeologic unit can have -- and in this case does have -- multiple aquifers; is that correct?
A. Yes. A hydrogeologic unit called an aquifer can have multiple aquifers.
Q. Okay.
A. Multiple names for aquifers, for example. Types of aquifers.
Q. But the hydrogeologic name is depicting something different than the aquifer names?
A. It's a bigger classification. It's a classification for a

group of aquifers or a group of confining layers.
Q. Okay.
A. So if you take the position of the Lower Claiborne Aquifer Confining Layer, this thing, and you show where it sort of starts to really get thick and where it disappears, and then you project that up to the surface, like this -- just a theory -- right here, you're projecting it up to the surface, and then draw it across the land surface where it occurs, you would say that everything in this zone called -- I'll call it the transition zone, "TZ," the transition zone, everything in this zone is transitioning from what you have over here to what you have over here. That's why it's called a transition zone.
Q. Okay. And is that -- as you move closer to Tennessee, is it all pure sand?
A. No. Mixed in with the Memphis Sand or some sand -- some clay layers, as we all know, and mixed in with the Sparta Sand are some clay layers. But in addition, the Memphis Sand has some really nice sands in it. The sands tend to get smaller in size, and could tend to get more clay mixed in when you go in this direction, and that's well known.
And so at some point right in here --
Q. When you said the sands get smaller in size, and there's more clay as you go in the direction you were pointing, the direction from Tennessee to Mississippi; is that correct?
A. More clay, smaller grain size of the sand.

Q. Okay. Now you just drew a line on there. And if you --
A. Okay. So --
Q. You can put an arrow or something. I mean, and -- but we just need to make sure we know what you're talking about.
A. In this direction.
Q. Okay.
A. In this direction, the --
Q. Well, what is that?
A. The coarser grain materials that make up the Memphis are getting smaller as you go in this direction, and you're getting more clay in the aquifer.
Q. Now, remind us: If you have smaller grains instead of larger grains, what does that do?
A. It would affect the ability of the material to transmit water. So it would have a different permeability here than here.
Q. Is it lower with the smaller grains, or higher?
A. As a general rule.
Q. Okay. Okay. Are you finished with that?
A. I am, except that this transition zone -- I keep pointing out that the transition zone, lots of things happen. One, the Memphis Sand transitions to the Sparta Sand, and the Memphis Aquifer becomes the Sparta Aquifer of the Middle Claiborne. The -- that's true because the thickness is dramatically less, and the grain size decreases, and more clay enters the picture

as you go in that direction; that is, to the south.
The Lower Claiborne Confining Layer does not exist north of the transition line, the Lower Claiborne Aquifer does not exist north of the transition line, according to all the information that I see in our reports and literature.
Q. Okay. Does that have anything to do with the hydrogeologic properties of the aquifer in those locations?
A. The dramatic thinning of the Memphis Sand Aquifer to the Sparta Sand Aquifer is significant in itself, because thinned aquifers have different ability to transmit water relative to thick aquifers.
Q. Okay.
A. In addition, the transition from lower -- to smaller grain sizes as you go to the south would have a profound impact on the ability of aquifer materials to transmit water.
Q. This transition zone, its exact location certainly on this map has not been identified, has it?
A. Let's see.
Q. I mean, they show it on the -- on the border, the change?
A. I've seen it on a lot of different figures.
Q. Well, let me show you some, okay?
Let's go to the next slide, Charles. And just leave that there. We'll figure out how we're going to deal with that on the record.
A. Is this okay?

Q. Yes. Okay.
Now, what does this slide show?
A. Okay. This is a mat from MERAS, which is a USGS report. I forget the date. But what this map shows is the states of Louisiana, Mississippi, Tennessee, and so forth. And it is a map designed to use colors to show the thickness of the Middle Claiborne Aquifer.
In the Middle Claiborne Aquifer is the Sparta Sand --
Q. You mean the hydrogeologic unit?
A. Hydrogeologic unit.
Q. Okay. It's designed to show both the Sparta Sand and the Memphis Sand, which is part of the hydrogeologic unit.
Q. Okay.
A. And it shows in color the different colors of the thickness. For example, the white color right here, up in west -- Southwestern Tennessee indicates a thickness of up to 1,100 feet. The green color and the yellow colors would indicate thicknesses of no greater than about 400 feet.
And so what's conspicuous is this line running across the land surface here, on this map view, in which the Middle Claiborne Aquifer is really thick up there, and suddenly becomes thin at that line. And that line is indicated as the facies transition, that line.
Q. That's what you were drawing?
A. As the transition zone.

Q. Okay. And the -- I think the brown color shows that you have, what, 601 to 800 feet?
A. Well, color shows an aquifer unit whose thickness would range from 600 to 800 feet, approximately.
Q. Okay. And then the darker kind of sand color, that shows 4 to 600 feet?
A. This shows 4 to 600 feet.
Q. Okay. So --
A. Yes, this color.
Q. So where do you see either the brown color, 6 to 800 feet, or the lighter sand color, 4 to 600 feet, or the white, 800 to 1,000 feet: What do you see there, below the transition zone in North Mississippi?
A. I don't see it in North Mississippi. I don't see it until you go much further south. I don't see it in Northern Mississippi at all. I don't see the -- if you're asking me about the brown and light colors indicate great thickness, I don't see that in Northern Mississippi. I see it in Southern Tennessee, Western Tennessee, and maybe just across the border, because this is a very irregular pattern we're showing with some uncertainty.
Q. But that -- that sand map of the USGS and MERAS, you've shown the digital map north of that transition zone extends pretty much all the way up through West Tennessee, doesn't it?
A. Extends all the way up to approximately here, according to

this map. That's the end of that zone, where the thickness would be up to 800 feet.
Q. Okay. So it extends up there -- it looks like Kentucky and a little bit of Missouri?
A. Yes.
Q. Okay. Now let's go to the next map.
What does this show?
A. This map is also in the MERAS report, and it shows the thickness of the Lower Claiborne Confining Unit. And the Lower Claiborne Confining Unit, referring to my sketch, is this clay layer, this persistent thick clay layer that you find down in Mississippi but don't find over in Tennessee.
Q. Now, you were just referring to the hand-drawn sketch that you put on the whiteboard with the detailed picture?
A. That's right. I was referring to the Lower Claiborne Confining Layer.
Q. Okay.
A. And the fact that it disappears here -- well, it's portrayed on this diagram as the thickness of the Lower Claiborne Confining Unit, in feet. And here it's saying that this is the extent of the Lower Claiborne Confining Unit and that small yellow -- red line.
So this small red line says that right there, it exists to the south of the line, does not exist to the north of the line, as I -- as suggested in my hand-drawn sketch. The

Lower Claiborne Confining Unit does not exist north of the transition zone.

Q. All right. Right at the Tennessee/Mississipi State line?

A. Which is that.

Q. And by "that," you're pointing at that -- the very top of the colored part of this particular slide, that ends right at the edge of the Mississippi/Tennessee State line, right?

A. That is correct. I'm pointing at this light red line that parallels the Mississippi/Tennessee line east of the Mississippi River, off to the edge of the Mississippi Embayment.

Q. Thank you. Let's show the next slide.

Now, what is shown on this slide?

A. This is the thickness of the Lower Claiborne Aquifer. By reference, the Lower Claiborne Aquifer is this thing.

Q. This thing you're pointing to -- you're drawing?

A. This thing on my drawing being the --

Q. The space beneath the confining unit that disappears in the transition zone?

A. It is a hydrogeologic unit beneath the lower confining layer called the Lower -- Lower Aquifer, Lower Claiborne Aquifer.

Q. All of that would be part of a hydrogeologic unit, as is the rest of the formations?

A. This is a hydrogeologic unit. This is a hydrogeologic unit. This is a hydrogeologic unit. It gets thicker as you go in that direction.

Q. But it includes the confined ones?

A. Hydrogeologic units, including the confining layers. I would like to do this. (Indicating.)

That's a hydrogeologic unit.

Q. Okay. Now, you -- what you've done now is you've just taken a red Magic Marker, and you have drawn off an area below the Lower Claiborne Confining Unit, and then you put some kind of hatch lines across it. And you're saying that is a what?

A. This is a depiction on this geological cross-section of the nature and extent vertically, laterally, of the Lower Claiborne Aquifer.

Q. Okay.

A. I'm showing it does not exist to the north of the transition zone.

Q. Right.

A. I would then show, using a blue line that outlines the Lower Claiborne Confining Unit, illustrate that it can have variable thickness, but it does not extend to the north of the transition zone.

Q. Okay.

A. And then finally, and I think this is critical, the Middle Claiborne Aquifer, composed of the Sparta Aquifer and the Memphis Aquifer, is all of that.

Q. Okay. That's the hydrogeologic unit?
A. That's the hydrogeologic unit composed of the Memphis Aquifer, transitioning to the Sparta Aquifer, all called part of the hydrogeologic unit called the Middle Claiborne aquifer.
Q. Okay. Let's go to the next slide.
Now, what did you -- what do you want to show in this slide? Or is it just the language, primarily, this -- what is this slide?
A. This is the potentiometric surface of the Sparta Sand and Memphis Aquifer as portrayed in 19- -- 1886, projected in 1886, by the researcher Reed. I guess it's published in 1972. And this particular figure shows running across the -- in an east/west direction across the state of Mississippi a pattern -- it's hard to estimate its width, but several miles wide, extending for a substantial distance across the northern part of the state. And it's called the approximate position of the transition, where things change.
Q. Okay.
A. And if you read the statement in this caption, which he wrote, and the explanation, it says this zone I'm pointing to, called this transition zone, marks the southern limit of the Memphis Aquifer.
Q. So in this USGS report, he's identified the bottom line in that transition zone between the Memphis Sand Aquifer and the Sparta Sand Aquifer?

A. Yes.
Q. Okay.
A. Showing it not only in the confined portions of the aquifer, but also in the unconfined portions of the aquifer, indicated by this darker pattern.
Q. Right. What is that gray area on that map?
A. So remember, the geological formations in the Mississippi Embayment are down to what they did -- from the east to the west, from the west to the east. So they come up close to the land surface, they outcrop; you can actually go and see them. They're not covered by clay. And so geologists would call this the outcrop area, where you could actually go and see it, Fort Dodge underground to the west.
Q. And is that where the water that migrates from the surface primarily comes from?
A. Primarily. Not all of it, but primarily.
Q. All right. So that gray area, the outcrop area, is on that -- is where the -- that kind of I guess is very bended-down sort of U-shaped -- whatever comes to the surface?
A. Yes. Yes.
Q. Okay. And that's where the water originally came from, on the whole, during predevelopment conditions, and found its way down into the system?
A. Even in modern times, this is a major area of recharge of the deeper aquifers, because when it rains here, it can enter

directly into the aquifers without having to go across the clay layer.
Q. Now, we've mentioned that it moves. Do you have, or have you looked at approximately how long it would take that water entering that recharge area, or the outcrop, to be discharged from the confined Middle Claiborne Aquifer -- or Middle Claiborne hydrogeologic unit in Mississippi?
A. Travel times in an aquifer composed of this type of material could be measured in terms of inches per day. Most likely in terms of inches per day. An inch a day might be a good average value, because it's not all sand; some of it's clay. And so at an inch per day, it would take about 30 -- it would take about a couple hundred years to move a mile. And an inch per day, or once it gets into this aquifer, is moving down through the aquifer, would travel -- reasonable -- reasonable estimates would be, oh, 150, 180, 200 years to travel a mile, depending on the specifics of the aquifer at this location.
Q. Okay. So those -- that water, those water molecules entering that outcrop are going to be within that formation for a very, very long period of time?
A. Especially in human terms; very, very long period of time.
Q. Human terms, right, at least 200 years?
A. Per mile.
Q. Per mile. Okay.
A. Per mile. Per mile of travel.

Q. Thank you.

MR. ELLINGBURG: Your Honor, would this be a good time to break for lunch?

THE COURT: Okay. It may be appropriate. We will recess until 1:15; is that okay with people?

All right. We'll come back at 1:15. Court stands in recess.

(Luncheon adjournment)

AFTERNOON SESSION
1:15 p.m.
THE COURT: You may resume your direct examination.
MR. ELLINGBURG: Thank you, your Honor.
BY MR. ELLINGBURG:
Q. Okay. Going back to kind of pick up, a little overlap. Can you hear me?
A. Yes.
Q. Can everybody hear me? Can you hear me now? Thank you. Okay.
Dr. Spruill, we were talking before lunch, and it is kind of an extension leading into the next area, but of the aquifers, in the Middle Claiborne Hydrogeological Unit, do those aquifers contain areas that are confined and also areas that are unconfined?
A. Yes.
Q. Where -- I've put a map up here. Can you show us where the unconfined areas are? The map is --
A. Yes.
Q. And just try to be a little clearer than we have been. This is a digital map from the USGS MERAS report, titled "Surficial Geography of the Mississippi Embayment Region Aquifer Study Area." Is that correct?
A. Yes. This is surficial geology; that which you can see at the surface, not necessarily what you could see below the land

surface. So this map predicts with -- or shows with different colors the different hydrogeologic and geologic units in this part of the Mississippi Embayment.

Q. And can you tell me where the outcrop areas are?

A. Well, since this is a surface geological map or surficial geology, these patterns would represent where you can see these units exposed at the land surface, and hence they would be the outcrops.

For example, this -- this color, I guess, which is sort of a brown-orange color, according to the chart, would be the outcrop area for what's called the Middle Claiborne Aquifer (Memphis Sand). And in contrast, the blue area, the blue area is south of it, south of this -- of roughly east-west trending line that parallels the border some distance below the Tennessee/Mississippi border is labeled "Middle Claiborne Aquifer," and in parentheses, "Sparta Sand."

Q. Okay. And then what does the green show?

A. The green area I'm quite sure shows the -- what they call the undifferentiated Claiborne group; that is other geological formations elsewhere in the Claiborne group.

Q. And in West Tennessee, appears that you have those two formations, the outcrops for the Memphis Sand and the outcrop for the undifferentiated Claiborne?

A. At the land surface, yes.

Q. At the land surface. And then in Mississippi, what do we

have in terms of outcrop areas?
A. We have a wide range of geological formations. Some of the color patterns are hard for me to see up here. I suspect, maybe Lower Claiborne Confining Layer disappeared -- disappearing Sparta Sand, disappearing, and then disappearing here at this east-west trending line south of the border.
Q. And by "east-west trending line," you're talking about the bottom of the orange section that covers all West Tennessee?
A. I am.
Q. Okay.
A. And then in the green, some up -- the Claiborne group, undifferentiated, which I would assume is younger in age than the Sparta Sand, and then this very large color pattern here.
Q. And is that representative of the eastern boundary of the Mississippi Embayment in the entire Embayment on the east side?
A. More or less. The -- yeah, this is a study outlined in red, and I would assume that this is -- this line I'm illustrating is east of the study area of the Mississippi marks the west -- eastern limit of the geological units of the Mississippi Embayment that are exposed at the land surface. Hence they are outcrops.
Q. So how does surface water or surface precipitation find its way into the confined aquifers in the two -- in both Mississippi and in Tennessee?
A. Well, I'm fond of saying that water moves into and out of

aquifers from all directions. But the preponderance of water, in my opinion, in these confined aquifers, this part of the Mississippi Embayment, probably enter the -- does enter the aquifer system in the unconfined portions of the aquifer, where a substantial part of that water is discharged locally to creeks and rivers, and some percentage finds its way down into the confined aquifers, confined aquifer flow.
Q. Okay. Is the outcrop and the unconfined portion of the aquifer the same thing?
A. Generally speaking, yeah. I would say that.
Q. In this case?
A. Yes.
Q. Okay. Do you have some slides to show generally how water moves from the outcrop into the confined aquifer system?
A. Yes.
Q. And what was this?
A. This is a -- the first of a series of slides designed to show, hypothetically, flow paths in the confined portion of the groundwater system in an area of Northwestern Mississippi and over into the State of Tennessee. And so on this map, that gives you some indication of land forms, so that you can see some elevation over here as relative to the flat terrain here associated with the position of the Mississippi River.
I've indicated with letter "A" that in Mississippi, the beginning of a -- what I call a line of section extending

upward into Memphis, terminating at A prime geologists call this "the line of section." And the concept is that -- try to envision lifting up the earth along this line of section and seeing what's below the surface of the earth in terms of the geological formations, etc.
Q. And have you prepared some slides to illustrate that?
A. Yes.
Q. Now, the slides we're going to show, they're not to scale, are they?
A. Not to scale.
Q. And they don't depict specific flow directions; is that correct?
A. They're designed to illustrate how groundwater flows through the unconfined and confined portions of the aquifer.
Q. Okay. And they -- and they depict what would be natural for -- in the absence of any pumping; is that correct?
A. That's correct.
Q. Well, let's put the first slide up. Now, would you explain what this shows.
A. Okay. This is a -- what I call a groundwater residence time slide, which sort of starts the process. I point out that it's not to scale. Inset, once again, is the line of section, so that the line of section would begin at A, would be analogous to this point on the left-hand side of the diagram of the land surface, and the red line running across the land

surface would intersect the Tennessee/Mississippi line there and there. And I'm indicating inner section of this Mississippi/Tennessee border, with the red line on the map view and on the cross-sectional view.
Q. Thank you.
What part of the -- if you would describe what's shown, in terms of -- again, in illustrative form, in terms of the earth in that area, before moving to the next slide.
A. I'm describing a geological formation similar to the Memphis Sand and the Sparta Sand, with -- represented by this pattern of closed circles, representing sand of varying sizes, and maybe use some gravel with some interlayers of clay.
I'm showing that this continuous layers in this general -- general diagram that does not -- displays how an aquifer can be inclined from the land surface, getting deeper below the land surface off to the left here.
On top of the sand layer, I'm showing some layers of clay, which would effectively confine below and confine above. These are the extending gray layers that I'm showing, effectively confine the aquifer. Within the aquifer and down dip in the aquifer, I'm showing a transition zone between mostly sand. And we pick up a layer of clay and other materials here, predominantly clay I'm showing on this generalized diagram.
Q. That's the dark part within the confined aquifer?

A. That's this dark part that's -- it has this kind of flame-looking pattern on the right hand, in down inside the combined aquifer.
Q. To the left?
A. To the left.
Q. Okay. And what are those cone-shaped-looking things at the very top that come from the surface, or below the surface, it looks like?
A. Well, they are -- is this going to work? That thing is really, really heavy and hard to hold and deal with.
Can you hear me if I speak without it?
Q. Can I -- why don't you use this -- which I haven't broke it entirely yet, and see if that helps. And I'll speak louder in the mics, which I will lean in and move for David's benefit. You better put it up real close.
A. Yes, sir. How does that work? Good? Okay.
So would you repeat your question? I'm sorry.
Q. What are the cone-shaped figures within that slide that start at or near the surface and come down?
A. These are my attempt, as not such a good artist, to portray that there are variations in the materials above this confined aquifer that could be filled with geological material of different composition than that which surrounds it.
Some people might say, well, this could be an erosional window. It could be a paleo channel caused by the

prior position of a river migrating across this area, and then the backfilling of that river channel with gravel.

And I'm proud to illustrate that some of them actually could reach the confining layer, and that's the case of the middle one, it actually provided a breachment of the confining layer, whereas the other two, I didn't show them breaching the confining layer, but my concept was to get across the idea that these aquifers aren't just beautifully confined everywhere. There are places where the confining layer thins and it's more permeable, and there are places where the confining layer is actually breached by erosion, paleo channels and things of that nature.

Q. So does that depict the actual complexity, or is it just something used to illustrate --

A. Just an -- just to get across the idea of some of the complexity involved in these kinds of geological systems.

Q. We'll go to the next slide.

Okay. So what have you shown here?

A. The next slide is a blowup. Take this rectangle and draw an arrow to the formation to say that --

Q. Now, you're referring to the rectangle in the lower right-hand corner, which is a blowup of some geologic material, and it's an arrow pointing to what you have defined as the confined aquifer illustration. Correct?

A. I'm sorry.

Q. I'll try to stop dropping off at the end.
THE COURT: I'm sorry, I didn't hear. Did somebody say something?
MR. ELLINGBURG: The court reporter -- I'm dropping my voice.
Q. Go ahead, Mr. Spruill.
A. I agreed with your more detailed analysis of my description that this box is a representation of material from the confined portion of the aquifer. And I've enlarged it, but it's not to scale. And the blue line here represents -- the blue line in the rectangular box represents a concept of how a molecule of water might move through the geological materials in the confined aquifer. It can't move through the sand grains or the silt grains. It's required to move around the sand grains as it flows in a given direction, in this case from the top of this rectangle to the bottom left of this rectangle.
Q. Is the next slide -- let's show the next slide. Okay.
So if you would now, I think this would be easier to follow. We've blown up the small box from the prior one, and the top says "Illustrative path of groundwater through sand." And then at the bottom it says "Groundwater flow direction." Is that correct?
A. The bottom says "Groundwater flow direction," which really doesn't have an arrow on it, but it would indicate the groundwater flow direction was to the lower left of this box.

Q. Okay. Now, would you describe what you -- what that is illustrating?
A. So once again, I tried to illustrate a not-to-scale sand grains. But if these were sand grains, then they would, by definition, between a 16th -- be between a 16th of a millimeter and 2 millimeters. So there's some small sand grains and some larger sand grains within this -- within this unit.
A molecule of water entering this segment of the groundwater system might follow this flow path as it flows around --
Q. Now, "this flow path," you're talking about the blue line?
A. This blue line.
Q. Okay.
A. I've illustrated here with my finger, following a blue path as it goes from the upper part of the diagram to the lower left.
Another molecule of water in really close proximity to this molecule of water might follow a slightly separate circuitous path as it flows through these materials, but the general pattern would be for the water that enters this part of the aquifer system alert -- or this porous media to flow along tortuous flow paths, as I've illustrated in this diagram.
Q. Okay. And as you said, some of that water comes in at the very top of the arrow is -- may very well follow a different path now?

A. That's correct.
Q. And we're talking about very, very small amounts of water?
A. Well, we could be talking about very large amounts of water flowing through a sand, a sand body, at a very slow rate.
Q. Okay. And this particular diagram, the water flowing on that path is the -- a small amount of water, isn't it?
A. I'm simply trying to illustrate the path and direction that a single molecule of water might follow as is flowing through the groundwater system.
Q. Okay. Now, as far as these sand particles, why aren't they all uniform?
A. The nonuniformity of grain sizes in the geological environment, to me, is the rule, not the exception. There are certainly some fairly uniform geological deposits that we find in nature. I would hold up a sand dune deposit, for example, as one in which many of the grains are about the same size, but most geological formations have a variety of particles within them.
Q. Okay. If we could move to the next slide.
So now what are we showing here?
A. Just the same slide over again, but I had this idea that you could get across how aquifers become charged with water by recognizing precipitation. So these were rain drops at the top, above the land surface, so precipitation. These little dots falling on the land surface either runs off the land

surface, evaporates, transfers, or enters the groundwater system.
Q. Okay. And so what's -- let's put the next slide.
A. So we get across this concept of travel time and residence time in the groundwater system, trying to illustrate that as water moves into the groundwater system, it might take a series of days for water to flow from recharge areas to discharge areas in the unconfined portions of the groundwater system.
Q. Okay. So this is the unconfined portion?
A. Well, it could be the unconfined system. Clearly over here the system might be slightly confined, but I'm saying consistent with what Ralph tells us, that in the upper parts of the groundwater system, it's not unusual to have water that can move through the groundwater system and discharge over distances of -- over time frames of days.
Q. Okay. So let's move to the next slide.
A. The next slide, I'm just trying to get across the idea of the slow movement of water through the groundwater system. So now movement of a molecule of water might require a time frame of ten years to move some reasonable distance through the groundwater system, measured in feet to miles.
Q. Now, are you in the confined part of the aquifer now?
A. I'm defining now the flow down in the confined portion of the groundwater system.
Q. Okay. That's not in the outcrop area?

A. No, it's in the groundwater system. But it's confined.
Q. Can we kind of follow that particle along?
A. Sure. So follow that particle along, travel time of 100 years might be shown in this general sketch, followed by more travel time of 1,000 years. Flows slowly through the individual pore spaces at rates measured in inches per day.
Q. This is all under natural conditions?
A. This is all under natural conditions.
Q. All right. Let's move to the next one.
A. And then the next one, just a final illustration to show that groundwater in the groundwater system has been shown to be old. It takes a long time for water to reach the deeper parts of our groundwater system.
In the coastal plain of North Carolina, where I live, we know that the water in the deeper aquifers is almost 20,000 years old. So as it moves from the land surface across this long history, it resides in the groundwater system as it's slowly moving through the system for incredibly long periods of time.
Q. Okay. And this is all looking at the water as it moves from the outcrop area of recharge down in the system?
A. Yes.
Q. And through the system?
A. Yes.
Q. Thank you.

Now, I think you may have mentioned this earlier, but what is the approximate rate in the actual Sparta Sand and North Memphis Sand in Tennessee, both the actual natural -- under natural conditions, the actual estimated rate of movement of the water?
A. Well, it depends on a lot of different factors, whether you talk about water moving through some of these clay lenses or water moving through sands. But I've stated already I think a reasonable value is, for velocity of groundwater in the groundwater system, is inches per day.
Q. Okay. Which would convert to how many feet a year?
A. At an inch -- at an inch per day, I'll have to do that calculation.
And that would be 365 inches in a year, 30 feet. Maybe the width of this room in here.
Q. About 30 years?
A. In a -- in a year, 30 feet.
Q. 30 feet in a year?
A. 30 feet a year, which would be about the width of this room, I would suppose, though I haven't measured it.
Q. If we change that from a year to the time it would take for it to travel from the outcrop down through the aquifer, under natural conditions, for a mile, about how long would that take?
A. Thirty feet a year; 30 into 5,280 is around 200.
Q. Okay. Thank you.

A. Around 200 feet of travel in about a year.
Q. Okay.
A. So --
Q. Is 200 feet in a year what you meant to say?
A. I think about a mile, travel about a mile in about -- 200 days, 187 days or something, however you calculate.
Q. Is that years or days a mile?
A. I'm sorry. So we're talking about the amount of time it takes to travel an inch. That was about an inch a day.
Q. Right.
A. So to travel a mile would probably take around 200 years, 185 years, 200 years. We're talking about a mile.
Q. Okay.
A. I'm sorry for the confusion.
Q. Okay. I just wanted to make sure we had it clear.
So in your illustration, what would be the approximate time from the area of recharge in the outcrop to the discharge of the groundwater? Although I know you're not showing the discharge point.
A. It depends on too many factors for me to answer that, because the discharge area for all parts of the groundwater system is not the same. But I would say that we know that residence times in the groundwater system could be measured in thousands of years. It can also take thousands of years for it to move upward across confining layers and into other aquifers

before finally being discharged.

Not all groundwater discharge is locally; some groundwater can actually flow in circuitous paths and flow, for example, down the axis of the Mississippi Embayment before it discharges much further away.

Q. So if you give it 10, 20, 50, 100, 200, 300,000 years, it will get out?

A. It will get out over a long period of time.

Q. Okay. Now, I want to compare this inch a day to some surface water.

A. Okay

Q. Okay. And so I'd like to look at the next slide.

Now, could you tell me what you're showing here.

A. I took a map of the Mississippi River, looked for some velocity data on the website, that is a government website, shown in the lower left-hand corner. And I chose three locations to illustrate the velocity of water, and fluvial system -- river system.

So I chose first --

Q. Let's pause for just a second. This is something that you actually culled data from the government site www.mps.gov/mississippi/riverfacts; is that correct?

A. Yes, sir.

Q. And you used that to calculate what you're about to show us; is that correct?

A. Yes.
Q. And did you also use the map from americanrivers.org/river/mississippi?
A. Yes.
Q. Okay. Now go ahead and explain to us what it shows in terms of the travel time of the surface water in the Mississippi River.
A. This map, I use flyins that my daughter helped me with. And I picked three locations. I flew in the position of the Mississippi River headwaters up in Minnesota, indicated by the uppermost box. I flew in locations of the Memphis -- Mississippi River in Memphis, Tennessee, indicated by this box, this arrow pointing to Memphis. And I selected New Orleans, Louisiana, indicated in this box, and an arrow indicating New Orleans.
          And using this information, I've simply calculated or simply related to you the velocity of water in the river. And this is sort of an average velocity, so I've been -- the headwaters of the Mississippi River in Minnesota, a more reasonable velocity would be about 1.2 miles an hour. And you can translate that into miles per day, so that would translate to about 28.8 miles per day of movement of the water in the river.
Q. Okay.
A. And you can contrast that with an increase in velocity

further downstream in the mighty Mississippi of about two miles per hour and a velocity of almost 50 miles per day. And further south, velocity could increase to 3 miles per hour, which would translate to a velocity of about 72 miles per day.
Q. Okay. So the water flowing at Memphis, how many miles per hour did you say that was?
A. About 50 miles per day. Per day.
Q. About 50 miles per day. Okay. And I think you said that -- let's see. In a year, an inch a day for groundwater, the groundwater might travel about 50 -- about 30 feet?
A. I used that example.
Q. Okay. And so the amount of water that flows down the Mississippi River within a reasonably short period of time would be a great deal more water than would flow through this aquifer system in 20, 30, 40 years?
A. That would be an understatement.
Q. Understatement. Okay. Thank you.
Now, the Mississippi River obviously is not representative of all rivers?
A. Definitely not.
Q. Okay. But in terms of flow rates, if we come down to, say, a stream or small tributary river, would the flow rate again be measured in -- more likely in miles a day?
A. Could be, or at least hundreds of feet per day.
Q. At least?

A. Hundreds.
Q. Well, a small trickling stream might only go hundreds or thousands of feet a day, but most significant tributaries have significant surface water velocities.
Q. Okay. Now, what can you, as a hydrogeologist, tell us about the flow direction of groundwater in the unconfined and confined portions of an aquifer such as the one you illustrated earlier?
A. Generally, groundwater in the -- well, I would say generally that groundwater in the unconfined portions of the groundwater system is typified by complex flow patterns, and then the deeper parts of the groundwater system is typified by more consistent regional flow patterns. But both of them can -- both -- in both examples, the flow patterns can be complex.
Q. Let's look at the next slide.
If you would explain what that shows.
A. Okay. This is a slide from the freshman textbook that I used, called Tarbuck and Lutgens, 2010 publication, and it shows a land surface typified by a couple of rivers, a major river, a stream and a couple of lakes here, clearly labeled, with some interstream areas with higher topography.
And the general concept here is that we would see what I call local versus regional flow patterns. I'll describe what I mean.

The unconfined aquifers, typified by a water table -- that's the boundary between unsaturated and saturated conditions, and that water table generally mimics the land surface. And what I mean by that is where the land surface is low, like next to streams, the water table is low; and where the land surface is -- has the higher elevation, the water table has a higher elevation.

So it -- I always say that the water table in the unconfined aquifer is a subdued reflection of the land surface. The inclination --

Q. Why do you say it's a subdued reflection?

A. Because the water table here, if you just notice, is a relatively flat surface; some inclination, but it doesn't have the same curvature.

Q. Now, you're pointing to the first -- it looks like kind of an upward-curved area to the right of the river, on the left of your drawing; is that correct?

A. That's correct.

Q. Okay. And --

A. Same thing would be true in any part of the surficial aquifer on this document.

Q. Okay. Because you have a whole series of lines that show water basically entering at the surface and then discharging into the surface water, correct?

A. Yeah. These are general flow lines. It's really important for everybody to realize that it doesn't just rain up here. Water doesn't just enter the aquifer here. Water enters the aquifer everywhere when it rains. It also covers the land surface, and there's infiltration.

But this is -- the concept here is just one of understanding how local flow patterns develop in the unconfined portions of the groundwater system, where water -- groundwater flows from interstream areas, as a general rule, downward before it takes the turn, and actually flows upward and discharges to local discharge areas like lakes and rivers.

Q. So on your slide, you have light blue lines at the top --
A. Mm-hmm.
Q. -- that were -- you've been pointing to in your description?
A. Yes.
Q. So what are the red lines, the red --
A. The red lines indicate that you can have multiple scales of groundwater flow patterns as you transition from an unconfined aquifer system to a confined aquifer system. And the idea of this diagram is that these clay lenses that actually have breaches in them are confining layers for a deeper aquifer system that is confined.

And so I'm illustrating a shallow aquifer flow pattern, an intermediate groundwater and what's called the subregional groundwater flow pattern, indicated by the red

lines.
And then some of this groundwater must make it into the confined aquifer system in areas like this. Otherwise we would never have consistent volumes of water, under nonpumping conditions, flowing through our groundwater system.
Q. Thank you.
Now, the next line, if you would pull the next slide, then let's look back, and if you would tell me what you want to show.
A. I use this slide all the time to indicate what's necessary to really understand the general groundwater flow patterns in the unconfined portions of the groundwater system. And it's quite a complex diagram that shows the land surface, the top of the diagram indicated by the word "land surface." And it shows the water table that would develop in this area following precipitate, long-term precipitation and the establishment of a groundwater system. And it shows the position of the water table with this dotted line, that's at some distance from the land surface and is mimicking the land surface.
Q. If I could just get -- before we move on, it says "Modified from Winter, et al. '98."
A. Mm-hmm.
Q. Is that a USGS publication?
A. I don't remember if it's USGS or not.
Q. Okay.

A. I don't remember.
Q. But that's a published document that has been taken from -- and what is the purpose of this slide?
A. The purpose of this slide for me always is to get people to understand how you determine groundwater flows down in a recharge area in an unconfined aquifer, then flows laterally, and then can actually flow upward.
I'm always frustrated when people say groundwater flows in response to gravity. If groundwater flows in response to gravity, it's hard to get groundwater to flow upward in the face of just the gravitational force. And so what geologists have come to recognize is that the lines of equal pressure in the unconfined system are complex and variable, and that what you need to do, if you really want to understand how groundwater flows in the unconfined system, is to use a series of monitoring wells, which are on this diagram called piezometers. I equate monitoring wells with piezometers, and there may be some differences, but I'm talking about a well that we can install that can measure the pressure over a short vertical distance. It doesn't have a pump in it.
Q. So none of those are pumping; they just measure pressures at specific locations?
A. That's correct.
Q. And depths?
A. And depths.

Q. Okay.
A. So all of these are designed with what I call short screens. In other words, I only want to measure the pressure at that spot. So I'm going to put 40 feet of screen in it. So by having a piezometer at sea, for example, that extends to a depth of -- to this depth, by measuring the water level in this well, which would rise to about 80 feet -- there's 80 feet -- I can measure the pressure in this well, and I can construct this surface, called the potentiometric surface or the pressure surface; a line of equal head within the aquifer itself.
So the concept here is an important one. If you go anywhere else on this diagram in this area, and you drill a well to 80 feet, I expect the water in that well with a short screen to rise to 80 feet above sea level.
Similarly, if I put in a shallower well, I would measure a pressure of 90 feet. Put in a shallower well still that has a short screen in it, I measure a pressure of 110 feet.
By putting in these wells, we can construct these lines. We don't construct these lines and then put in the wells.
Q. So how are those used to determine direction?
A. Groundwater flows in the direction of decreasing pressure, at right angles to lines of equal pressure. These are lines of equal pressure in the subsurface. Groundwater flows at right

angles to lines of equal pressure, in the distribution of decreasing pressure.

So this area, the pressure I'm showing in the upper right-hand corner is 120 feet; here, along this blue flow line, it's 110, 100, 90.

So we know that groundwater has to flow at right angles to those lines of equal pressure, and in the direction of which the pressure is decreasing. And so what we do as hydrologists is we define the recharge area. We define the recharge area of aquifers as those places where there is an increase in pressure -- sorry, a decrease in pressure with increasing depth, and decrease in pressure with increasing depth. And we say that's a recharge area.

Our opinion as hydrologists is that you can't walk out on the land surface and just say, "That's a recharge area." You might be right. But a recharge area is that part of the groundwater system where, with increasing depth, there's a decrease in pressure.

Q. Why can't you just look at a geological map and some data you get and say, "Well, this is how the groundwater is flowing in the unconfined aquifer"? Why can't you do that?

A. Too complicated. Groundwater is not just flowing horizontally in the groundwater system. It has a downward flow compound, and in some places near horizontal flow compounded into others, and a upward flow compounded into other places.

For example, if you were to go to this location, which I've labeled "B" on this diagram, and put in two, three, four wells -- as many as you want, as long as they have short screens -- at this particular location, you would measure the same pressure. And so the line of equal pressure is vertical, which means that the flow pattern is at right angles to that line. And so I'm showing you this blue line, a right-to-left groundwater flow.

So groundwater enters an unconfined aquifer system here, flows horizontally at the boundary between -- at this subboundary I call the groundwater recharge boundary right there, and then from here over towards a stream, there might be a creek or a river here.

Q. Okay.

A. The groundwater system is different. So if I put in a deep well, I get a pressure of 20.

Q. All right.

A. If I put in an intermediate well I get a pressure of 10. Well, that means that with increasing depth, the pressure increases. So the deeper I go in the groundwater system, the greater the pressure. Groundwater flows in the direction of decreasing pressure, at right angles to lines of equal pressure; 30 feet of pressure, 20 feet of pressure, 10 feet of pressure. It's that pressure gradient that's driving this water upward, so it discharges.

Notice this: There's recharge in the groundwater system everywhere. When it rains, water infiltrates the groundwater system. And so we define groundwater discharge areas as the area where there is an upward decrease in pressure and upward flow, and here a downward flow and a downward decrease in pressure.

And recharge areas and discharge areas are defined on this, not necessarily topography.

Q. Okay. We've talked about that a lot now. Let's -- we've talked also about confined aquifers, and we've talked about unconfined aquifers. The question is, how do you get water out of a confined aquifer for use?

A. More often than not, it has to be done by designing, drilling, constructing a well into that aquifer and removing that water from that aquifer. Unless it's a free-flowing Artesian aquifer, you remove it by pumping.

Q. Okay. Let's go to the next slide.

What does this slide show, Dr. Spruill?

A. It's a picture of a typical well.

Q. At the top it says -- the title says "Supply Well"?

A. Okay. So it says Supply Well, Multiscreen, Gravel Pack. But it's a figure that I took -- no surprise -- from Ralph Heath's classic groundwater supply book, the groundwater hydrology book. And so it shows the construction details for a multiscreen, gravel pack, supply well.

Q. Okay. And is that representative of the wells that are typically used to commercially pump water?
A. These are the types of wells that I design and supervise the construction of or the removal of water pump -- mostly for a larger-type well, based on the style of pump that I see here.
Q. Okay. And so the top -- top surface, it shows sand, right?
A. Up at the surface it shows a layer of sand underlain by a layer of clay, another sand, layer of clay, sand, clay.
Q. Is this well producing any water on that top layer of sand?
A. No. We're intentionally precluding that upper sand that I'm pointing to here now. That's just the first sand that you encountered in this particular situation below the land surface, by taking special precautions to seal it off by putting in a casing and using cement. We only use Portland cement, or we could use other types of materials that have really low permeability, to prevent or preclude not only the migration of water from the sand into the well, but also the migration of water down the well from one layer surface towards another. We call that grouting.
Q. Okay. So you've -- this illustration shows two additional sand layers and shows a total of three clay layers, is that correct?
A. That's correct.
Q. So there's multiple zones of sand that this well is penetrating?

A. Yeah. And that's pretty common. It's wonderful to find a single sand that will produce the amount of water that you need, but most often you'll find the sand layer, and you'll put a solid piece of casing into the subsurface in this hole and allow -- put into the design some openings here that might be 20/1,000ths of an inch, or something like that, that will allow the water from the sand to come in and preclude the sand from coming in. It will also put maybe a gravel pack illustrated by this, so the material that we generated put underground.
Q. Before you drill this well, how do you determine the potential zone of sand in the subsurface that you might be trying to obtain the water from?
A. Well, a lot of ways to do that. One would be to rely on what people have already learned from drilling wells at a given location, is go to the literature, go to more purveyors, find out what's known about the groundwater system, and begin to get a picture of what's underground.
The second way would be to go to the literature. There's a tremendous amount of literature in some locations in this country, and other locations we don't know much about the groundwater system at all. But ultimately we use what I call the great truth machine. And the great truth machine is a drill rigger. And you can stand at the land surface and pontificate about what's underground all you want to, but you really don't know the details until you drill a hole in the

ground.

And so we would pick a spot and drill an exploratory hole in the ground. It would be called a pilot hole. And while we're drilling the pilot hole, a good geologist would stand there with his or her hand lens and study the materials that are coming up while we're drilling this hole, and develop a picture in their mind of what's underground from looking at the cuttings. And on the basis of that, then you have this initial picture of where some units underground might be potential good candidates for construction of well screens that will allow you to tap that water anywhere there are places that would be problematic, because you don't want these teeny clay-sized particles to come into your well.

Q. So the water is not coming in the entire well depth; it comes into the screens?

A. If you construct it that way, water will come in through the areas that are opposite screens, and for short distance above and below that through the gravel path.

Q. Okay. And once you've -- once you drill the well, is there information you can obtain from down in the well before you start pumping it?

A. We're in an age of electronics, and so we have these sophisticated instruments that we use that you can generally describe as geophysical logging tools. I spent a tremendous amount of my career learning how to deal with these geophysical

logging tools and interpret the results of them.
Q. Okay. Let's look at the next slide.
A. Okay.
Q. Could you tell us the next slide, which on the bottom it says "Figure 9, Geologic Section C-C Tennessee Valley Authority, Allen Combined Cycle and Allen Fossil Plants Area."
Is that what this slide was taken from?
A. That's exactly what it says.
Q. Okay. And is this -- is this from the area where the -- or near the Davis wellfield?
A. Yes. Yes, it is.
Q. Okay. Can you tell us what that log shows.
A. Well, there are a series of logs here. And so just to lay the groundwork, in this diagram there's a vertical scale indicating the altitude in feet above sea level, NGBV. This is altitude relative to sea level.
(Reporter interruption)
A. There's a vertical scale showing depth below sea level in feet; minus 100, minus 600 feet below sea level.
The land surface or the approximate land surface is shown as this subhorizontal line, and there is a break over here in topography, and there's more topography or more elevation in the land surface on the right-hand side of the diagram.
I selected this diagram because it illustrates the

kind of geophysical logs that you would see in the Memphis Sand, as indicated by this -- these two words. So in this diagram, someone has --

Q. The two words you pointed to are over to the right box, with the various explanations at the very top; it was "Memphis Sand"?

A. "Memphis Sand" is shown on this diagram in at least two places. It's shown at this location right above the word "Explanation," and it's also shown on the extreme right of the diagram, about a third of the way down the document.

Q. So go ahead. So what does it actually show, that you're trying to illustrate?

A. So you had asked me about geophysical logging techniques and how they're used and what they tell us. I would just pick, for the sake of brevity, a well that was drilled at the location here, called PW1, right in the center of this diagram. And I interpret that this horizontal -- this vertical line, the dark black vertical line represents more or less the center of a well. And after a hole in the ground was drilled, and they kept it from collapsing by, say, keeping heavy drilling mud in it, someone lowered a geophysical logging tool down to the bottom of the well.

One of the logging tools -- and there are many that we could utilize -- would be what's called a gamma logging tool. Gamma rays are part of the natural electromagnetic spectrum, like X-rays and visual light, etc. Naturally occurring formations give off varying amounts of gamma radiation.

Sands composed of quartz predominantly tend to not produce much gamma radiation. Clay fine-grain material, that tends to be heteromineralogic, tends to be composed of several different minerals, some of which give off gamma rays.

Then that distinction between a formation that doesn't produce a lot of gamma rays and one that does produce a lot of gamma rays is applicable to this diagram, because it shows --
Q. Here you're pointing again to PW1.
A. I'm pointing to PW1. I'm going to focus all my discussion on PW1 for the time being.
Q. Okay.
A. And in this diagram, I'm just going to start at the Memphis Sand Cook Mountain sand boundary, and show that the gamma radiation, NGR -- natural gamma ray -- NGR log shows a variation from -- kicks to the right, to the left, right again, left again. And so I'm following with my finger down the water hole, showing the differences and variation of the amplitude of this gamma ray log.
Q. So would you convert that the layers of --
A. So based on my experience with these kinds of geophysical logs, I would make the generalization that this zone, from right above 300 feet below sea level, is sand.
Q. That's basically 250 to 350?

A. Okay, if you want that level of specificity, I can provide it. And so I see that minus 250, minus 300 sand.
Q. Okay.
A. And then I see a clay layer that extends downward probably to about 350 feet. Another small sand, maybe 350, 360, something like that. Another clay layer that would take me down to 400 feet. Below that, another sand layer, maybe 400 to 440 feet below land surface, underlain by clay, underlain by now pretty thick-looking sequence of sand, that just happens to be around 500 feet below sea level.
And -- but even with, then, this layer of sand that I see from about 500 feet below sea level to nearly 800 feet below sea level, I see indication of gamma emissions that could represent different compositions of the sand, but could also represent clay layers.
Q. Okay. And so in terms -- just in general terms, would you describe this as a simple area, in terms of subsurface geology?
A. I would describe it as relatively complex. It's not in one homogeneous sand body from top to bottom. It's typified by sand layers and intervening layers of lower permeability. I would know or have a good feel for whether this is -- what type of sand this is and what type of finer-grain material this is if I was paying special attention while we were drilling this hole initially.
Q. And all those things go into how much water can be produced

from those various -- we'll call them zones?
A. Well, yeah, the hydrogeologists would be faced with the wonderful of task of deciding -- well, it could build a well screen, or something like this, or screen in this unit, excluding these finer-grain materials. Or you would want to build a well that has screens set in a few of these sands, and so you might actually do an exploratory program where you design some wells to test these individual zones for yield and water quality.
Q. Based on what you know about the geology in this area of the Mississippi/Tennessee border, if you moved from that location, say, to the east or the southeast 200 yards, would you expect to see exactly the same thing?
A. Not exactly the same thing. I think there's some generalities. I would think that -- a pervasive and significant sand layer might be able to trace that across some areas, but there would be local variations within even that thicker sand deposit.
Even looking at this sight, looking rather at PW1 over to PW -- PW2, all the scales and the geophysical log are not the same. I can see some variations in the composition of the earth materials from this position to this position, over whatever horizontal this distance this is, and I forget, including the horizontal scale.
Q. Thank you.

But this isn't -- this isn't pure sand down there you're pointing to?
A. "Pure sand" meaning sand all one size and nothing else?
Q. Or all sand and no clay.
A. It's definitely not all sand and no silt or clay.
Q. So this is --
A. It's sand interlayered by lower permeability or finer-grain materials, in my opinion.
Q. Okay. Thank you.
Now, on this slide there is another -- is there another feature, geological feature of the clay?
A. Well, there are a couple geological features. The one of most interest to me as a field geologist, because I spend a lot of time unpacking these kinds of structures, is the fault that's indicated on the east side of the diagram by the vertical dash-dot-dash-dot line that's located here.
And it has the two arrows down and up, which indicate someone -- someone's interpretation of the relative movement along this feature, which is -- and this diagram, classified as a fault. A fault is a line -- is a boundary between parts of the earth that have moved relative to each other.
And so the location of the work done in this location is that the top of the Memphis Sand, which is shown here on the left side of this fault, disappears and shows up on -- maybe a little more than 100 feet, just -- about 100 feet higher on the

right-hand side of the fault. So the implication is that this block went up on the right, and this block on the left went down.

Q. And so would you expect the geology to be somewhat different at the same location below sea level to the right?

A. No. It's -- things are going to be different by 100 feet, just based on the fault; and they could be different just based on their lateral change relative to some other location on the diagram.

Q. So is the Memphis Sand a simple sand formation?

A. Memphis Sand is a complex geological formation, with sand layers and intervening lower-permeability layers, and some relatively thick and very nice sand layers.

Q. So I forget what you called test wells. What did you call them? Test wells?

A. I call them -- well, that I put a pump in a test well. If I don't put a pump in, I call it a what -- if I put a pump in a well, I call it a test well, or production well. If I don't put a pump in it and just measure things, I call it a monitoring well.

Q. So just explain, I guess, briefly: Why do you drill test wells at all?

A. In an unknown area, you can drill a test well, and you can learn a tremendous amount about the geological formations at reduced expense and reduced liability. Risk, I might say.

Suppose I never drilled in this location at all. I might decide to drill a small-diameter hole and put in a 4- or 6-inch diameter casing with screens. Or I might, after running the geophysical log to the core hole, put in a 40-foot screen, and I might just pull it up little bit at a time, testing these different zones in the subsurface.
Q. So what kind --
A. Or yield.
Q. -- of information could you obtain from the test well, as a hydrogeologist planning wellfields or well -- individual wells?
A. Other than first I'd be able to interpret -- obtain information about the yield of the individual zones that I've been testing. That is, how many gallons a minute do I think I could get out of it? I would gain valuable information about the quality of the water in the individual zones if I tested them individually.
Q. Okay.
A. But more importantly, if I employ some really sound aquifer test procedures and analyses, I can begin to determine the hydraulic properties of the aquifer.
Q. Okay. And why is it important to know the hydraulic properties of the aquifer at that point, before the well is drilled?
A. Well, modern wellfield design has to be based on really detailed knowledge of the hydraulic properties of the aquifer

in which you're going to install wellfields.
Q. Okay. And when you say "modern," how long has that been around?
A. Well, we've known about a lot of these techniques for evaluating the groundwater system, really, since the 1800s. But our knowledge was of a meager kind, and we had a few basic equations like the -- like Darcy's Law and the 10 Equation, but the whole science of hydrology and hydrogeology and aquifer understanding revolutionized in the 1930s, with the advent of -- sorry, with the publication of papers by the US Geological Survey, and a man named CB Tatis in 1939, in which he described the impacts on the groundwater system associated with withdrawal of water.
Q. Okay. Let's move to Slide 43. I think we've seen this before, and I just want to ask you a few questions about it.
A. I'm ready.
Q. Okay. Now, briefly again, we touched on it earlier, what is the potentiometric surface?
A. Potentiometric surface is the indication of -- an indication of the pressure in an aquifer at the spot where you measure it. I measured the pressure of this aquifer by tapping the aquifer with a monitoring well that doesn't have a pump. I record the height of the water standing in this well, and relate it to sea level.
And so we relate the pressure of the aquifer, the

potential of the aquifer, to the height of the water that would rise in a well that taps the aquifer location. If I put a well in the same aquifer in this location, and the water is moving, then by definition the potentiometric value of the terminal will not be the same.
Q. So can you map potentiometric pressures in an aquifer system or in --
A. We can, and I --
Q. -- hydrogeologic --
A. We can, and that's a significant thing that hydrogeologists do, is to put monitoring wells into aquifer systems, measure the head in the aquifer system relative to sea level, and then contouring or evaluating the differences in head in the groundwater system. Mainly for the purposes of determining direction of groundwater flow and hydraulic gradient.
Q. Okay. So what information can get -- can you get from a pot map in terms of direction of flow?
A. Well, I don't use the term "pot map," because it will get you in trouble at the university, so I use the word "potentiometric surface map." I don't know what you're talking about. Little levity here.
A pot map is a abbreviation of potentiometric surface map.
Q. So potentiometric surface map?
A. Potentiometric surface map is a map indicating the

variation in the pressure in an aquifer as a function of different positions in the aquifer. And so once you know some of these numbers, by putting in a well, measuring that height relative to sea level, and you have a bunch of those numbers, you can start to contour.

Contours are lines of equal pressure. And once you have those contours, you can begin to figure out the direction of groundwater flow in the aquifer as well as the steepness, the inclination of a potentiometric surface.

Q. So it will help you determine both the direction of the groundwater at that point in time and the slope?

A. And the slope, but it will also give you an incredibly valuable piece of information about how far the potentiometric surface is above the top of the aquifer. And later on, I hope I'll talk about available drawdown.

Q. We'll --

A. So that number right there, the distance from the potentiometric surface to the top of the aquifer, really also important.

Q. Let's look at the next slide.

Now, what are you showing in this slide, that's entitled "Cone of Depression"?

A. This is a figure from Ralph Heath, shows both the unconfined aquifer system, which I don't want to say anything about, and the confined aquifer system in the right-hand block.

And the major point of this discussion would be to get across the idea that once you drill and constructed a well, if you want to get water out of that well, the only way you can do it is by lowering the pressure in that well. Before any pumping is done, the pressure would rise to the height of the potentiometric surface, and is shown as this horizontal line located parallel with the land surface, this particular diagram, and so labeled "Potentiometric Surface," that line.
Q. Okay. There's an edge of that potentiometric surface?
A. There's a what?
Q. Seems like there's an edge on the surface; I mean, is that curved line? What does that reflect?
A. So when you put a pump in the well, and geologists always indicate "cubed," which indicates we are taking water out at some number of gallons per minute; that's the flow rate. So when you're taking water out of this well, this water level is going to fall. When the water level falls, the pressure in the aquifer in the vicinity of the well decreases, and that causes water to flow towards the well.
And so there are lots of important things about this diagram. One is, Ralph developed a tendency early on in his writing that he could show a circle to represent a molecule of water. And so all he's showing here is that a molecule of water will flow towards the well from this side of the well, this side, and actually it will flow radiantly toward the well

in this case.

And so when you remove water from a well, the pressure in the aquifer next to the well decreases, and that pressure propagates -- pressure decline propagates outward.

Q. And that's a confined aquifer?

A. This is a confined aquifer.

And the net result is a lowering of the potentiometric surface, in this case well above the top of the aquifer. And it has the shape of a cone.

You really can't see it here so much, but you can imagine this thing is a three -- as a three-dimensional theoretical feature, and it's cone-shaped; it's roughly circular in this case, centered on the well. And it represents a lowering of the pressure in the vicinity of the well. And hydrologists call it the cone of depression, but it's the cone of depression in the potentiometric surface. Groundwater flows in the direction of decreasing total pressure.

So look, the pressure here now, which was at the original and potential surface, is lower, but the pressure here is even lower. So groundwater flows in the direction of decreasing pressure; it must flow from right to left towards the well.

The opposite is true over here. The pressure here is high -- I'm talking about the left-hand side of this diagram -- and the pressure here is lower. So groundwater will flow in

the direction of decreasing pressure towards the well.
Q. Okay. So the well is creating negative pressure in the area of the pumping?
A. It's reducing the pressure.
Q. Okay. The pulling down of pressure, and it's pulling that water out of the confined aquifer?
A. Right. But the flow is not like here; the flow is down here, in the confined aquifer. But the pressure surface, which you really can't see unless you put in the well, is above the aquifer.
Q. But why isn't the water coming out of the confined aquifer? I don't see any water coming out of that -- the aquifer; I just see the dotted lines involved.
A. The water is flowing in this direction in response to pumping, entering the well and going up to the pump. And the pump is stabilizing the water level here for a time, and probably increasing with increasing pumping time. So water is coming out of the confined aquifer and leaving the well.
Q. What does "drawdown" mean?
A. "Drawdown" is a hypogeological term used specifically and often to hydrologists to represent the difference in pressures at different distances, specified distances and specified times.
For example, if I've just pumped this well at 300 gallons a minute for four hours at a distance of 12 feet

from this well, I could measure the difference between the original potentiometric surface and the potentiometric surface that the cone can calculate that in feet. And I might say, "Well, the potentiometric surface has been lowered at that distance, at that pumping rate, at that time, by four feet."

Q. Okay.

A. That's called drawdown. Drawdown in a cone of depression is greater near the well and less further and further from the well.

Q. Okay. So the change in pressure created by the pumping of the well is pulling water in from all directions toward the well?

A. Yes, in the confined aquifer.

Q. In the confined aquifer.

A. Yeah.

Q. Now, what is total available drawdown?

A. Total available drawdown is a very important hydrological concept that says measure the pressure surface relative to the top of the aquifer --

Q. Okay.

A. -- and convert that number to feet.

For example, if sea level is here, and the potentiometric surface is above sea level, and the top of the aquifer is 60 feet above sea level, 100 minus 60, there would be 40 feet of total available drawdown. Total available drawdown is simply the distance from the potentiometric surface to the top of the aquifer.

Q. How does it affect the amount of water you can pump out of a well?

A. That's a really great but complicated question. And in the great Tar Heel state, we're not allowed to pump water level over the top of our aquifer. So if we use that as an example, if I put a pump in this well and I continue to pump the water level down, I'm going to be limited in terms of how much I can pump the water level down in my state to the top of the aquifer.

So if I know how many feet that is, if it's 40 feet or 100 feet, it's some number, I know how much I can lower the water level in my well. And I'm going to assume the water level is going to be lowest in my well, unless depressed outside the well.

So then I'm going to calculate something called the specific capacity of the well; that's how much water you can get out of a well at a given flow rate, relative to the drawdown at a specific time and specific distance.

I know it's a lot.

Q. Okay. But let's just pause for a second, and we'll come back to this, maybe.

Within that cone of depression, if I drop another well, can I recover as much water as I could before this well

was put in?
A. No.
Q. Why?
A. You reduce the total available drawdown. So you're saying if I put -- would have put in a well right here, at the location of this level arrow --
Q. Yes, sir.
A. -- the total available drawdown at this location, if I put in another well within the cone of depression, that's been reduced by the difference between the original potentiometric surface and the position of the cone of depression at that distance.
Q. Okay. And so dropping the pressure down to the confined aquifer within the area of the cone of depression of that well, I have reduced the amount of water someone else could pump out of it?
A. The maximum amount they could pump out.
Q. Okay. Thank you.
A. Yep.
THE COURT: I think we'll stop for a short recess. We'll have a ten-minute recess.
(Recess)
THE COURT: You may proceed with your witness.
BY MR. ELLINGBURG:
Q. Are you ready, Dr. Spruill?

A. Yes.
Q. Oh, okay.
Dr. Spruill, earlier we talked about how you determined the direction of groundwater flow at an unconfined aquifer at some point. And I don't want to revisit that. But it looked like I forgot to ask you about how you determine the flow on direction of groundwater in a confined aquifer, and if that's different than an unconfined aquifer.
A. In a confined aquifer, if you want to determine the direction of groundwater flow, you need at least three wells, in my opinion, that do not have pumps in them, called hydro wells, in which you measure the elevation of the water in the monitoring wells and then the head, and then you can start to get a feel for direction of groundwater flow. That gives you a general understanding of which way groundwater is flowing.
If you want to determine the direction of groundwater flow with any reasonable degree of accuracy, it requires a fairly large number of monitoring wells, or a monitoring well network, such that you can measure the head at each of those wells and the pressure at each one of those wells, and then use those data to determine direction of groundwater flow.
Q. So what influences the direction of groundwater flow in a confined aquifer?
A. A lot of different things. The inclination of the aquifer, its dip, relationship between recharge areas and discharge

areas would be two of the key factors. The amount of recharge that you get into the aquifer within control flow through the aquifer, and under nonpumping conditions you can establish a state of equillibrium in which water flows from the recharge areas to the discharge areas, say, at an inclined aquifer system.

So those would be some of the factors that would control the direction of flow.

Q. Can you -- have you developed an opinion, based on everything you studied, of the flow direction of the groundwater in a confined portion of the Mississippi aquifer system before it was ever pumped?

A. The Mississippi Embayment Aquifer System?

Q. Yes, within the State of Mississippi.

A. I would have to describe it in the general terms indicated on an earlier illustration for the entire Embayment; that basically water flows from the outcrop areas to the east, with a generally westward groundwater flow pattern, increasing downward into the aquifer before the -- before there's a transition from downward movement to upward movement towards recharge areas to the west, or even to the south.

Q. And within that confined portion of the aquifer system within the State of Mississippi, I think you've given us some estimates of how long it takes the groundwater to move?

A. Yeah. I've indicated several times that groundwater moves really, really slowly, and its long path from recharge to discharge areas could be -- could literally be thousands or tens of thousands of years.

Q. Okay. And so that would be true without regard to which direction that water was flowing, wouldn't it; that it would be under natural conditions, that it would take many, many years to cover short distances? Is that correct?

A. Correct.

Q. Thank you.

Now, you said that -- you talked about a discharge area. Does the water in the confined aquifer under -- or did the water in the confined aquifer under natural conditions ultimately discharge from the State of Mississippi?

A. Yes. Water that knows the aquifer -- hydrologists are fond of saying what goes down must come up; water that goes down into these inclined aquifers eventually discharges from those aquifers. Some discharge location could be a creek or river. It could ultimately be an area near the ocean.

Q. With regard to substantially all of the water in the State of Mississippi in the confined aquifer, when it enters -- does the water under natural conditions -- strike that. Let's start over.

Under natural conditions, when we talk about equilibrium, what are you talking about?

A. Oh, an interesting concept of a balance in the groundwater system. Geologists would say that when a groundwater system is in steady state, that the amount of water entering the groundwater system is balanced by the amount of water exiting the groundwater system. So the equipotential surface remains relatively constant through time.

So that doesn't mean that you can't have an increase in wet periods and a decrease in dry periods. But effectively, a nonpump groundwater system, disregarding any major changes in precipitation from time, will be in balance, and we say that the recharge is balanced by the discharge, so the equipotential surface of the water table would remain relatively constant through time.

Q. So absent, in the State of Mississippi, or absent pumping, the groundwater in the confined aquifers in the State of Mississippi and Northwest Mississippi would remain as an essentially constant amount of groundwater, varying with, as you said, the weather and all; but if you looked at the pressures in the confined aquifer, they would not be changing material over time. Is that correct?

MR. BRANSON: Your Honor, objection. We've tried to be very spare with our objections today, but he's leading the witness with these types of questions, and we'd ask for a more open-ended question.

THE COURT: (Inaudible)

(Reporter interruption)

MR. ELLINGBURG: The judge instructed me not to lead him; is that right?

THE COURT: We of course know we're not before a jury, so it's not so bad. But when that objection is made, let's try to obey it.

MR. ELLINGBURG: I understand. And thank you.

BY MR. ELLINGBURG:

Q. I'm trying to understand what you see below the surface in the groundwater system before any pumping was taking place within the State of Mississippi. And could you try to make that clear for me, because I'm not -- obviously not learned in all this.

A. If you had a -- an aquifer, and it was at equilibrium, so that the amount of water entering the aquifer is about the amount of water leaving the aquifer, and on any given day that aquifer had a billion gallons of water in its pore spaces, you would say that enough water would have to enter the aquifer and exit the aquifer on a daily, monthly, yearly basis to maintain that constant volume of water within the aquifer.

Q. And with regard to the specific confined aquifer system in North Mississippi, would you expect over the last several hundred years for that volume or that level of potentiometric surface to change materially, absent pumping?

A. Absent pumping? No.

Q. And why is that?

A. Well, absent pumping, a groundwater system would -- in the absence of significant climate change, like changes in precipitation -- be in a balance, where the amount of water entering the aquifer is balanced by the amount of water exiting the aquifer. We would say discharge is balanced by recharge, and we would have a relatively constant volume of water in the aquifer as the water slowly moves from the recharge areas through the confined aquifer to the discharge areas.
Q. And again, you're defining "slowly" in terms of what?
A. I'm always defining "slowly" in terms of groundwater velocities, which are measured in inches or fractions of a foot --
Q. Which converts to thousands?
A. -- a day.
Thousands of years of travel time.
Q. Okay.
A. Right.
Q. But the water -- but the system is, unless someone intercepts that water that would otherwise be discharged; then that water is going to remain in that system?
A. Right.
Q. Thank you.
Or at least that volume of water, because the specific molecules are turning over in this process?
A. That's the point. It's not the same molecules of water;

it's the same number of molecules of water.
Q. Thank you.
Now, before pumping, is there another groundwater formation in Mississippi to which the confined aquifer would discharge water?
A. I'm sorry, I didn't understand that question.
Q. I said is there another aquifer system that a -- above the confined aquifer involved in this case to which that natural discharge would go before it was ever pumped?
A. If we're talking about the Memphis Aquifer and the Sparta Aquifer of the Middle Claiborne hydrologic unit --
Q. Yes.
A. -- it's overlain by confining layers and other potential aquifers that would receive water by upward movement in discharge areas in response to those head gradients, so water can flow out of the confined aquifer upward, across confining layers and other aquifers, before it's ultimately discharged.
Q. Okay. What aquifers overlie the area near the Mississippi River in the State of Mississippi that would ultimately receive groundwater that was being discharged, if it were not intercepted, and that are commonly used?
A. In Tennessee or Mississippi?
Q. In Mississippi.
A. In Mississippi, on top of the Sparta Sand Aquifer, there is the Middle Claiborne confining unit, and its geological

formation is the Cook Mountain Formation, and it's considered to be a confining unit. Above that in Mississippi is a relatively thin aquifer called the Upper Claiborne Aquifer. And its geological formation is called a Cockfield Formation. And then there's the Jackson Formation and the Vicksburg Formation, both of which are considered confining layers.

And on top of that, in some places there is a relatively young sedimentary sequence called alluvium, that's really related to more recent geological times and association with deposition relative to Mississippi -- the Mississippi River system and its changing position through time.

Q. Is that the Mississippi Alluvial Aquifer?

A. It's called the Mississippi River Valley Alluvial Aquifer, in terms of the hydrogeologic unit. And the geological formation would be called alluvium terrace and deposits.

Q. Thank you. So before pumping this water we're talking about, that had moved through the thousands of years and was ultimately discharged, was some of it going into that alluvial aquifer?

A. I believe that it is.

Q. Okay.

A. The geological reports that I've seen show some discharge upward across confining layers and into the Mississippi Alluvial Aquifer and in tributaries and into Mississippi.

Q. Thank you.

Now I'm going to move back to the cone of depression. And my question here is whether the -- the radial extent away from the well and the cone, can that radial extent be reasonably estimated or calculated?
A. Yes. It can be kind of generalized. For example, at a given pumping rate, the cone of depression in an unconfined aquifer will generally be not as large radially as that in a confined aquifer, and you can sort of generalize depths of the cone of depression in that way. But the best way to determine the configuration, size, and shape of the cone of depression is from either determining directly, by having an adequate number of observation wells near a production well, and/or calculate it using modern equations.
Q. Okay. And the calculations are dependent on the -- on the amount of information you have, and they are a kind of a homogenization of everything within the cone, I would think?
A. I'm not sure what you mean, but you can't calculate the size and shape of the cone of depression unless you know the hydraulic properties of the aquifer in the vicinity of the well that you're talking about, or the aquifer that you're talking about.
Q. But if you know those hydraulic properties and that cone of depression and the size of it, the reach, if you will, from the well out are you able -- could that be reasonably calculated?
A. Oh, yes.

Q. Now, how do you do that?
A. I'm not sure what your question is. Do you mean how do you get the answer to the question of what are the hydraulic properties, or how do you calculate it once you know them? The hydraulic properties.
Q. I think you said you have to determine the hydraulic properties, so I guess, how do you determine the hydraulic properties?
A. Okay. My opinion is that you can look at a geological material and estimate its hydraulic property, at least one of them; that's called permeability. But the way that hydraulic properties of aquifers are determined are from modern tests that we call aquifer tests. Aquifer tests involve putting in a production well and removing water from that well at constant rate, and measuring the rate of decline of water level in that well, and knowing the rate of decline and the pumping rate.
You can calculate one of the important hydraulic properties, called transmissivity, in the aquifer. But transmissivity of an aquifer can be calculated directly and determined directly from a test in a single well, single production well; but if you really want to determine the nature and extent of the cone of depression, you also have to determine something called storage coefficient.
Storage coefficient cannot be determined from a single well test. In other words, you can't put in a production well

like the one I'm pointing to, of this diagram on page 44, and test it at constant rate and determine storage coefficient. Instead, you have to have that well, and another one that will be in the cone of depression, that's used to monitor the rate of decline of water level in that well in response to a constant rate withdrawal of water from that production well.

So we need a production well, and a monitoring well nearby. And from those data we can calculate storage coefficients. Armed with transmissivity and storage coefficient, we can calculate the theoretical limit of the cone of depression, and you can tell me how long you want to pump that water; in other words, if you want to pump it for one day or one year, I need to know that before I can calculate how big the cone of depression is.

Q. What is permeability?

A. Permeability is a term that geologists use generally, but prefer a better term, called hydraulic conductivity. But I'll just use the word "permeability."

Permeability, or hydraulic conductivity, is the -- is a measure of the ability of a naturally occurring material in this case to transmit water. It's a measure of the ease with which that material transmits water.

Q. Do different materials have different permeabilities?

A. One of the things that fascinates me most about hydraulics is that permeability of naturally occurring materials varies over 12 orders of magnitude. I find nothing else in nature that has that much variability as a single concept.

Hydraulic conductivity, as shown in this slide.

Q. Now, you just put a slide that's titled "Igneous and Metamorphic Rocks"?

A. No, that's not the title. That's a category within the body of the feature. This is a figure from --

Q. No surprise: Ralph?

A. And it shows different rock types and different sediment types as a function of a quantified permeability, a measure of permeability.

So I can give you a couple of examples.

Q. Okay.

A. On this axis, there are different ways that geologists deal with these units. They're units of metric meters per day, they're units of standard unit speed per day, and they're old units by the US Geologic Survey, gallons per day per foot squared.

I'm just going to focus on units of feet per day -- and by the way, it's not velocity; it looks like it, but it's not.

The ability or the ease with which water flows through naturally occurring materials is defined with a number, and that number has units of feet per day; but it's really a volume of water that can be transmitted through this material under certain conditions. And they give you an indication of that, a material that we call clay, and we all remember is less than 1/256 of a millimeter, has a permeability on average of 10 to the -6 and 10 to the -7 cubic feet of water that can pass through --

(Reporter interruption)

A. I'm a simple guy; it's a measure of the volume of water that can be transmitted through the material. One times 10 to the -7 cubic feet of water is a thimbleful of water. It's not much water at all; you can hold it in the palm of your hand.

So that's one times 10 to the -7 cubic feet of water would be transmitted by a clay. If you take the same amount of earth material and make it a lean sand, or coarse sand, meaning all the particles are about the same size, 10-squared cubic feet of water would pass through that same area of the material.

So sand has a permeability one, two, three, four, five, six, seven, eight -- nine orders of magnitude higher; it has nine orders of magnitude greater ease of transmission of water than clay. Clay, then, doesn't easily allow water to be transmitted through it. But it's not impermeable; it's just very restrictive.

And so this is the concept of permeability, the ability of a naturally occurring material in this case to transmit water.

Q. So what is storage coefficient? You mentioned that earlier.
A. Storage coefficient is the thing that separates hydrogeologists from wannabes. Storage coefficient is the most difficult concept that you can possibly imagine, because in confined -- can we go back one slide?
In confined aquifers, when we take water out of these pore spaces and the water flows to the well, the pore spaces are still completely filled with water. When we take water out of a confined aquifer, the pore spaces are still completely filled with water. Which is absolutely fascinating to me.
And so what we've learned is that the water in these confined aquifers is under pressure; and in a given volume, then, in the aquifers, in a given volume there's more molecules of water, because the water is slightly compressible; just like air is compressible, water is slightly compressible.
So in the pore spaces down there, we can put a bunch of extra molecules. And when we lower the pressure, the water expands. We can take a few of those extra molecules out.
I would give the analogy of a car tire, a car tire that has 15 pounds per square inch of air in it, thus its pressure is filled with air. You can put some more air in that car tire, and it's still filled with air, and you can jack the pressure up to 30PSI. How do you do that? You just compress the molecules a little bit. But if you'll recall, when you put

more molecules in a tire, the tire gets a little bit bigger. So in an aquifer --

Q. A confined aquifer?

A. In a confined aquifer, the water is under pressure. And that pressure allows more water molecules to be in a given volume, but it also pushes the grains a little bit apart, and now there's more space for those water molecules.

So it wasn't recognized until the 19- -- late '20s and 1930s in this country that aquifers are elastic and that water is slightly compressible, and that you can put more into an aquifer and take water out of a confined aquifer and it will still be filled with water. You can put some molecules of water already in a confined aquifer. It's full of water; just put some more in it. You can do that by compressing the water and moving the grains apart just a little bit.

So in answer to your question, I'm sorry, we have come to understand that storage coefficients for an aquifer is a number. It is the volume of water that you can put into the pore spaces or take out of the pore spaces for a given volume of the aquifer per foot of head change. If you want to take water out of the pore spaces, lower the head. If you want to put water in the pore spaces, increase the head.

We put water in the confined aquifers all the time that are already filled with water, and we just pack them full of molecules of water.

Q. Okay. So was that the area of the cone of depression, even though if you looked at it, it's still filled with water, there is in fact less water than there was before? Is that correct?
A. Absolutely true. There's less water within the cone of depression and those pore spaces than there was before the cone of depression generated, but the pore spaces are still filled with water.
Q. Right. And is that why the total available drawdown you described earlier is less; you can produce less water than you could have outside the cone of depression within the cone of depression?
A. In effect, yes.
Q. Okay. Sir, can you -- to determine the size of the cone of depression, do you need a storage coefficient?
A. My opinion is that if you want to determine the size of the cone of depression at a specified time, you have to have the storage coefficient. There are older equations that say, "I can tell you what the size of the cone of depression is going to be way out in the future, when everything is stabilized." But if you ask me, how big is the cone of depression after one day or ten days or a year, you have to have the storage coefficient.
Q. Okay. And do you need actual pumping information?
A. You need information from aquifer tests that accurately give that storage coefficient for the region in the vicinity of

the well.
Q. Thank you.
Okay. I'm going to show you another document which, on the bottom, indicates that it is taken from --
A. This one up here? Oh.
Q. At the bottom it says "Distance from center of pumping in Lichterman wellfield in feet."
No, that's not the next one? Going back. I missed one. Okay.
This one says "Wellfield design." Could you explain this to me, and how you use it, and what it's used for.
A. Yes, sir. This is another figure from Heath, and -- who would have thunk it? Living with this figure, because this is the basic tool that you use to design wellfields; that is, the areas composed of one or more wells.
And so what you would do in this case is actually use the value of transmissivity for an aquifer and storage coefficient for an aquifer. And if I said to you, "Well, I'm going to tell you the size of the cone of depression after a time of 365 days," I could calculate, using a real simple equation, this number.
And this number, which I've called R-subzero, or radical R-subzero, is 90,600 feet. And so if I pump an aquifer whose hydraulic properties are 5,000 feet square per day for transmissivity, and 5 times 10 to the -4 per storage

coefficient, for one continuous year, the cone of depression would extend outward at a homogeneous and isotropic acclimate to 90,600 feet.
And so that's the first aspect of this design, is that the calculation is done to get that number, which I then apply here at 90,000 feet.
Q. Okay. And so --
A. 90,000 feet is about 19 or -- 19 to 20 miles.
Q. So that shows the distance of the cone from the well or the wellfields?
A. Yeah, so -- yes. It would say if I put a well at this location, or at any location, the distance to the place where there would be no impact, theoretically, would be 90,600 feet, equal to R-subzero.
Q. And that's under stated specific properties?
A. Yeah, you change these numbers and change this time, you change that value.
Q. So all those things -- so it all depends on the specific geology within the area of the cone?
A. Depends on the hydraulic properties in the vicinity of the cone.
Q. And how did you say you can determine those?
A. You put in a production well with an observation well. You have to have that observation well. Pump that well probably for 24 hours, and the presence of that observation well,

measure the rate of decline. Use the Tatis -- T-A-T-I-S -- nonequilibrium procedures developed in the 1930s to calculate T and S for any time -- sorry, to calculate T and S, and then you use modifications of that equation to calculate R-subzero.

Q. Okay. Thank you.

Now I'll ask you to go to the next slide. So could you explain to the Court what this slide shows.

A. This is another of those plots, and I'm sorry, on the previous plot I failed to point out that this scale is a logarithmic scale.

So here is a graph showing distance from the center of a pumping well -- this happens to be in the Lichterman wellfield -- in feet. So it says, okay, if you're 1,000 feet away from a pumping well, or 10,000 feet or 100,000 feet away from a well, and that well is pumping, how big would the cone of depression be?

And so we've said so far that the theoretical size of the cone of depression, its radius or diameter is a function of transmissivity, storage coefficient, and time. But the cone of depression has another dimension, and that's its depth. How much drawdown do you have in the well, or in the aquifer next to the well? And that is a function of the pumping rate in gallons per minute.

And so here's an example from the literature report back from the 1960s on the well that was pumped that

Lichterman -- or some theory about it, that says that if you pump a well at 6,000 gallons a minute, which is a really high pumping rate, the cone of depression, the drawdown will extend outward to about 100,000 feet. And at a distance of about -- 1,000, 2,000 -- at a distance of 3,000 feet, you'd have about 22 feet of drawdown.

The cone of depression would extend outward to 100,000 feet, and this is the amount of drawdown you would have at the 2,000 feet; but if you increase the pumping rate to 14,000 gallons per minute from 6,000 gallons per minute, it doesn't influence the theoretical limit of the cone of depression. It causes more drawdown at the well and immediately adjacent to the well.

So at 1,000, 2,000, 3,000 feet, instead of having 22 feet of drawdown at 6,000 gallons a minute, at the same distance, 2,000 feet, you would have 55 feet of drawdown.

So the cone of depression size is independent of the pumping rate. The depth is a function of the pumping rate.

Q. Now, I think earlier you testified what transmissivity was; is that correct?

A. We didn't say much about it. I used the term but didn't talk about it very much, so I talked about the term "permeability" or "hydraulic conductivity."

And that's a really great term, but it indicates how much water would flow through a small cross-sectional area of an aquifer. So hydrologists found it more convenient to say, "Well, let's just multiply the permeability." That's that thing that varies over 12 orders of magnitude by the thickness of the aquifer.

So transmissivity is equal to hydraulic conductivity or permeability times aquifer thickness. In hydrology, we say -- and I think my students memorized -- TKB, T is transmissivity, K --

(Reporter interruption)

A. K, hydraulic conductivity, times B, aquifer thickness.

So you imagine how much water would flow through a little cross-sectional area by how many cross-sectional areas there are. That's the thickness of the aquifer. It's a better measure of the ability of the aquifer to transmit water than is just permeability.

Q. Based on that, is the Sparta Sand in Mississippi either more or less transmissive than Memphis Sand is?

A. If you assume equal permeability in the Memphis Sand and the Sparta Sand, because the Sparta Sand is thinner, it by definition has a lower transmissivity. My studies show that from the literature, that there's also a difference in permeability in some parts of the Sparta and Memphis Sands. So the Memphis Sand generally has a higher trans -- sorry, higher permeability than does the Sparta Sand.

So if you combine those two factors for the Sparta

Sand -- reduced thickness, reduced permeability -- it has a lower transmissivity than the Memphis Sand.
Q. Thank you.
And I think you said that as you increased pumping rates, the -- what happens isn't so much the extent of the cone as it is the amount of total available drawdown reduction; is that correct?
A. The theoretical limit of the cone of depression, its diameter, independent of the pumping rate. It's a function of transmissivity, storage coefficient, and how long you've been pumping.
Q. And it's 19 or 20 miles, generally?
A. For a lot of confined aquifers, that's a good starting number, yeah, 90,000 at the end of a year of pumping.
Q. Okay. Thank you.
So what is a wellfield?
A. A wellfield is one or more wells drilled for the purpose of supplying water demands of some organization -- individuals or organization. So it is in effect one or more wells.
Q. So what is wellfield design?
A. Well, wellfield design, as I envisioned it, is a -- is a process of learning everything you can about an aquifer: Its depth, its thickness, its permeability, its storage coefficient; all those properties. Its water chemistry.
And armed with that information about its hydraulic

properties, it's designing one or more wells that will collectively produce the volume of water needed by the client, while minimizing the impact to the groundwater system or the impact to adjacent property owners.
Q. Okay. Are those impacts something that you always factor into your wellfield designs?
A. I certainly -- I certainly try. It's a fundamental part of wellfield design, as I learned from Ralph Heath.
Q. Is the creation of the cone of depression something you take into account when you are engaged in wellfield design?
A. You have to understand the size and depth of the cone of depression to do an adequate job of wellfield design. And that's because when you drill one or more wells, if one well happens to be within the cone of depression of the other, you have to factor in well interference.
Q. So we've put up another slide. Does this slide address the issue of cone -- or well interference?
A. Yes, it does.
Q. And could you tell us what it shows.
A. This slide from Ralph Heath is designed to illustrate the concept of well interference in its simplest form. So this upper slide, the slide is divided into two parts: An upper sequence and a lower sequence. And in the upper sequence, we're showing a confined aquifer in blue, with arrows in it. And the arrows in the confined aquifer are pointing towards

Well A, indicated here, and a little bit of water shown coming out of it, so it's pumping.
Q. And this slide is titled "Well Interference"?
A. "Well Interference."
And so the concept here is that if you pump Well A at some rate, it will generate a cone of depression illustrated by the words "Cone of Depression with Well A Pumping." And so it will generate a cone of depression that looks like this, and the cone of depression will extend out to here. I'm showing out to the right, under the words "Static Potentiometric Surface."
And water will flow in the aquifer rate leading by the water standing and the aquifer materials contracting. And we're taking the water out of the aquifer, but the pore spaces are filled.
And so imagine that you turn on Well B, Well B, and Well A was not on. Well B, if this aquifer is the same across this area, Well B would create a cone of depression that is identical, if you use the same pumping rate and pump it the same amount of time. And so the cone of depression, if Well B were pumping and Well A were idle, is the dash line.
What's critical about wellfield design is this: If you go to put two wells, one within the cone of depression of the other, you have to know how much drawdown is going to occur at each of these wells caused by each of the other wells.

I can illustrate that in this real simple way: Well A pumping causes that much drawdown -- I'm indicating the distance between the potentiometric surface and the potentiometric surface for Well A.

Well B pumping causes the same amount of drawdown as Well A. Halfway between the two wells, Well A causes a substantial amount of drawdown; Well B causes the same amount of drawdown. And so the resultant -- we call it the resultant, the combination of those drawdowns, is shown in the second diagram.

And so instead of just having this pumping water level in this well, I've got to add the additional drawdown in Well A caused by pumping at Well B. And so the drawdown will be lower. And it's designed to show that in this second or bottom sketch, that Well A, the drawdown is lower in that well -- greater in that well than it is in Well A pumping alone.

Q. Go ahead. Is there anything you can do to minimize the radial extent and the depth of a well's cone of depression?

A. As a factor in wellfield designs, or --

Q. Yes, we're still on wellfield design.

A. Okay. So the closer you put these wells together, the closer the spacing of these two wells in this theoretical wellfield design, the greater the drawdown that is caused at each well.

So if you want to minimize the depth of the cone of depression, one of the things you can do is move the wells further apart. By moving the wells further apart, you minimize the amount of drawdown in each well. That doesn't minimize the size of the cone of depression; it minimizes the depth of the cone of depression.

So that's one thing you can do. So you're asking, what can you do to minimize the cone of depression?

Q. The extent and the depth.

A. Okay. Minimizing the extent of the cone of depression is different from minimizing the depth of the cone of depression. So if you'll allow, I'll just take them one at a time.

If you want to minimize the extent of the cone of depression -- that is, R-subzero; how far it extends out from the well -- pump the well for a shorter time period. You can't change the transmissivity or storage coefficient of the aquifer, but you can reduce the pumping time. How big the cone of depression is is a function of T and S of the aquifer and how long you pump it. The longer you pump it, the bigger it gets. Reduce the pumping time, you reduce dramatically the theoretical limit of the cone of depression, or its radius.

If you want to reduce the depth of the cone of depression, or the drawdown that you have in these individual wells and the aquifer in the vicinity of the wells, then there are lots of things that you can do. You can move the wells further apart. You can pump the wells at a lower pumping rate, measured in gallons per minute. You can alternate the wells, so that one's pumping for a while, and then you turn it off and let the other one pump.

Those are some of the key things that you can do to minimize the nature and extent, the size and the depth of the cone of depression.

Q. In an aquifer system, or a hydrogeologic system, where you have multiple formations, can you do anything to reduce the size or the depth of the cone of depression?

A. I'm not sure what you're asking. But if you have at your disposal more than one aquifer, or more than one permeable zone in an aquifer, you can minimize the size and the shape of the cone of depression by developing some of your wells in different parts of that aquifer, or wells in different aquifers. And that would certainly minimize the cone of depression, compared to putting two wells, one inside the cone of depression of the other.

Q. Now, once the cone of depression has been created, is it possible to shrink it?

A. Yes, it is.

Q. Why is that?

A. Because of the natural recharge of aquifers. So if the operation of a well is such that a cone of depression has been generated, and the aquifer hasn't been harmed -- that is, it hasn't been pumped so hard that the grains of sand, for example, can't -- can't be pushed apart again; that is, if it's compressed by too much pumping over a long period of time -- unless that's happened, when you stop pumping, the rate of water level recovery, the rate at which the pressure will return, is a sort of reversed image of the rate at which it declined, associated with the onset of pumping.

And so the cone of depression will recover itself in an amount of time more or less equal to the amount of time it took to develop that cone by pumping.

Q. Do you have any specific examples where this has been done that you were directly involved in?

A. The best example I would give, and the one I'm most proud of is the Central Coastal Plain of North Carolina, where they produced literally hundreds of feet of drawdown in a really large cone, and as a result of the efforts -- mainly I could credit Ralph Heath; I was the spokesperson, but he was the brains -- we convinced the State that that wasn't a tolerable situation. And so the State stepped in and said, "Okay, in this multicounty area, you got to stop pumping so much water from the aquifer."

So we said -- so the State said, "How much do we need to stop pumping?"

And we said, "75 percent reduction in the volume that you're taking."

And the water purveyor said, "Unfunded mandate, unreasonable expectations."

So we said, "Okay, let's do it over a 16-year period. Let's start reducing 25 percent, another 25 percent, another 25 percent, until we got to 75 percent."

And as we reduced our reliance on that aquifer, under State mandate, the water levels recovered, and are continuing to recover today, some 20 years after implementation, or 17 years after implementation, I think, of that program.

So, yes, we got a lot of recovery early, and we're still continuing to recover. But what that required is that people who were using that particular aquifer -- and it was all of us in the Central Coastal Plain -- had to find alternative sources of water.

Q. Using another aquifer or surface water?

A. We went to surface water in some cities, other aquifers in other cities, and developed alternative sources of water, because of the requirement that you can no longer pump that volume of water from that aquifer or those aquifers.

Q. In your work in this case, have you been become familiar with the groundwater production activities of Mississippi Light, Gas & Water?

A. I've studied it as much as I can.

Q. Could you give us -- could you provide us kind of a brief overview, then -- I think you put some slides together on this?

A. A brief overview.

Q. Tell us what's the first slide -- go ahead. Give the brief overview.

MR. BRANSON: Sorry, your Honor. Before we get into this, we wanted to renote our relevance objection to this. In reliance on your ruling in this case, we have not focused our discovery on MLGW's pumping activity. So we think it's prejudicial to allow it in. It's not relevant. If it is going to come in, we'd ask for a continuing objection and have the ability to move to strike it.

THE COURT: And I'm sure what the -- go ahead. Anyway ...

MR. ELLINGBURG: This is clearly relevant, because Memphis and Tennessee, and Memphis Light, Gas & Water, have all taken the position that if you pump anything in Tennessee, it necessarily takes water out of Mississippi. And it is fundamental -- that's fundamentally scientifically unsupportable.

And that's one of the things we've been building up to, is this point. So the pumping that was done by MLGW, and the way that pumping was increased, and the way it located its wellfields, shows that that was an -- and the rest of the testimony I believe will show that that was an avoidable -- and I think that you can't -- they can pump the water. It doesn't necessarily have the impact.

And this case is not about the sand; it's about the water. And our position is that they have taken Mississippi water. They say, "Well, it's not Mississippi water, because if anybody pumps, Mississippi loses water."

That's just not so. So it is relevant.

MR. L. BEARMAN: I want to join in with the objection, your Honor, and point out an additional point. This is well beyond the scope of the pleadings and beyond the scope of the lawsuit.

THE COURT: So I agree -- I'm going to overrule the objection that you make, put it in subject to it being stricken.

MR. ELLINGBURG: Yes, your Honor.

And I will point out one thing at this juncture in response to Mr. Bearman's statement. The order entered of Court, which has been characterized by defendants with some liberality, specifically says that evidence which you would envision could be relevant would have to be with historical flows of the water.

Now, the historical flows of the water, as we have been showing, laying the foundation to show, is directly impacted by the pumping. And so it falls within this category of the historical flows between states, which is one of the comments in your order, as long as -- as well as the geology and the hydrogeology, which is what we've been focusing on.

THE COURT: All right. You may proceed.

MR. ELLINGBURG: Thank you.
BY MR. ELLINGBURG:
Q. So, Dr. Spruill, you've prepared some slides which show a progression -- okay. You were about to give a brief overview of the pumping by MLGW --
A. Okay.
Q. -- in Shelby County, Tennessee?
A. Okay. MLGW, according to my research, operates one of the largest artesian wellfields in the country. They withdraw water from approximately 160 wells and 10 different wellfields in the county -- that's Shelby County -- and they have produced over the years variable amounts of water, starting back into the 1800s -- I don't remember the exact dates, but the mid-1800s -- producing water from a series of wells and wellfields, progressing up to as high as 150 million or so. I think the current withdrawals from the ten wellfields is probably in the vicinity of 120, 24, 23 million gallons of water a day.
So they -- they are a large purveyor of water, extracting water from the Memphis Aquifer, from ten different wellfields. They provide that water for the use of the people in the region.
Q. And does that cone of depression extend beyond the City of Memphis?
A. Today?

Q. Yes.
A. Clearly. The cone of depression of a single well, pumping this aquifer for a long period of time, would extend outward --
Q. Okay. So let's --
A. -- 15 to 20 miles, and extend beyond the City of Memphis.
Q. Now you've provided some slides that show the progression to how we got where we are today in terms of wellfields?
A. Okay.
Q. What does this first slide show?
A. Just prepared a slide that shows that Memphis Light & Gas -- Memphis Light, Gas & Water wellfield comprised of -- a well system comprised of one, two, three, four -- four wellfields: The Mallory, Allen, Sheehan, and McCord wellfields, up to the year 1958.
Q. And did you track the additional wellfields?
A. I did. I thought it was very interesting to see the historical development of additional wellfields.
And so the next slide, from 1965, shows that in addition to those initial four wells that -- whose names I mentioned, the Lichterman wellfield was brought online, and according to my records the first pumping was probably in 1965.
Q. And what is the next progression -- now, the Lichterman field is -- I think we've already moved to the next one, but the Lichterman field is -- or you can see on the map, it's located closer to the Mississippi border; is that correct?

A. Yeah, it's -- most of the wells are between, say, two and four miles from the border between Tennessee and Mississippi.
Q. Now, is that the wellfield from which you obtained the information of the projected pumping, in terms of the size of the cone of depression, from Lichterman?
A. Yes.
Q. Okay. And so you said the cone of depression would extend about 20 miles; is that correct?
A. Right. Right. At the increased -- at the pumping rate projected by the USGS geologists that did that work, they projected a cone of depression extending outward to approximately 20 miles.
Q. Thank you.
Now, what's the next wellfield?
A. The next field -- wellfield that comes online, according to my data, is the Davis wellfield, in about 1970.
Q. And is that the one that's been added to the lower left-hand corner?
A. Yes, it is.
Q. And then were there any other wellfields added?
A. Yeah, at this -- about the same time, the LMG facility -- and that would be up in the northeast corner of that facility, right underneath the bar scale -- LMG, I think, facility came online, started pumping around 1970.
Q. And were any other wellfields constructed after Lichterman,

in addition to Davis, close to the Mississippi/Tennessee border?
A. Yeah, this slide shows the development of a Palmer wellfield, somewhere around '71 or '2.
Q. Now, that bright line -- the dark line across there, underneath the Palmer wellfield, it says "Tennessee/Mississippi"; is that the Tennessee/Mississippi State line?
A. Yes, it is.
Q. And I think earlier Mr. Bearman put a map up that showed that -- this is Shelby County, Tennessee, and immediately below it, where you can see the eastern boundary of Shelby County on that slide, and then immediately below that is DeSoto County, Mississippi, is that correct?
A. Correct.
Q. Now, do all these wellfields pump from the Memphis Sand?
A. As far as I can determine, yes, they do.
Q. Do they all have the same number of wells?
A. They do not.
Q. They don't?
A. Some have a small number of wells; some have as many I think as 20 wells or so.
Q. Do they all produce the same volume of water?
A. No. No.
Q. Let's go to the next slide, because I think I focused on

these close to Mississippi, but I think there's some more wellfields there.
What's the next slide? Does that show the addition of another wellfield?
A. I'm sorry, I'm confused. Yeah, this would show, I think, the 1973 addition of the Morton wellfield.
Q. Which is to the north of Memphis?
A. That would be correct.
Q. Or at least to the north of the existing wellfields.
A. Except -- with the exception of LMG.
Q. Right.
And would you go one more slide.
Okay. And so does this show the addition of the Shaw wellfield?
A. Yes, it shows the addition of the Shaw wellfield in 1990.
Q. And so those are the wellfields you referred to a little bit earlier, when you were talking about the total number now?
A. Yes. Shows the ten wellfields that I mentioned earlier.
Q. Now, do you know how far those three southernmost wellfields are from the Mississippi/Tennessee border?
A. Yeah. I mean, I'd -- I took the time to calculate those distances. I don't have that chart with me, but I know generally how far those wells -- wellfields are.
Q. Okay. And I think the parties have agreed they're generally within two to three miles; is that correct?

MR. ELLINGBURG: Is that not the stipulation, David? What is the stipulation?

MR. D. BEARMAN: I don't have it. I don't have it.

MR. ELLINGBURG: We can move on.

Q. Do you have a slide, or would you give a slide that shows the actual Palmer wellfield?

A. The Palmer wellfield is shown as Slide 55.

Q. So how many wells did it have?

A. I count five wells in the Palmer wellfield. And by my calculation, these wells are about three-quarters of a mile from the Tennessee/Mississippi border.

Q. Now, do you have a slide showing the Davis wellfield?

A. This is a slide of the Davis wellfield.

Q. How many wells does it have?

A. I'm convinced that it has eleven wells. And these wells are approximately two miles from the border. I don't remember the exact numbers, but about two miles from the border.

Q. Okay. Did you provide us with a slide of the Lichterman well?

A. Yes. And this is that figure, and it shows approximately 20 wells. About 20 wells, and by my calculation, these wells range from about two to about four miles from the Tennessee/Mississippi border.

Q. Now, did you -- did you add a scale to Slide -- the slide of the Lichterman wellfield?

A. I did, because maps without scales drive me up the wall.
Q. And so where did you get the information to add a scale to it?
A. I went to the USDS, found latitude and longitude values for the individual wells, and had my GS specialist in my company take those coordinates and then do our GIS magic and calculate the distance from those wells to the border.
MR. BRANSON: Your Honor, I'd have to object to this as well. None of this information he's cited was in his expert reports. We haven't deposed him on this. We haven't taken discovery on it. It sounds like he's done this after the depositions.
MR. L. BEARMAN: Same objection.
MR. ELLINGBURG: Your Honor, there's been continuing work on this case. This is a matter of great importance, and I don't -- we're not in a case where somebody is saying they're bringing in a new doctor on the eve of the trial. This information is all relevant to these inquiries.
MR. BRANSON: Your Honor, I have no idea if this is accurate or not. We haven't had a chance to test it. The whole point of discovery and a scheduling order is so that we're all on the same page and we're prepared for the hearing. If it's done after discovery closed, I don't think it should be allowed here.
THE COURT: I'm not sure I see that, but I'm going to

let it come in.

Overruled. Overrule the objection, and you may proceed.

MR. ELLINGBURG: We'd also like to offer at this time Exhibit P57, which is not a joint exhibit, but which has an explanation of the scale and how it was added, using USGS data.

THE COURT: Okay. Any objection?

MR. ELLINGBURG: I'll provide it to the parties.

THE COURT: I'll let it be introduced at this time, subject to later change.

MR. BRANSON: Your Honor, can I just note a continuing objection to these, so I don't have to keep saying that.

THE COURT: Yes. You'll have a chance to strike it.

MR. L. BEARMAN: Same thing.

THE COURT: Okay.

We'll take a short break at this time. Ten minutes.

(Recess)

THE COURT: The witness may take the stand.

MR. L. BEARMAN: Your Honor, can I add to the objection: No proper foundation has been laid for this testimony.

I know I heard your Honor rule; I just want to make clear --

THE COURT: Okay. Yes. Your objection is well taken. It's overruled.

Go ahead.
BY MR. ELLINGBURG:
Q. Dr. Spruill, in your notebook, you have Exhibit P57. Correct?
A. 157?
Q. P57.
A. Oh, 57. Yes. Yes, I see it.
Q. Okay. And can you explain to us what is shown in Exhibit P57.
A. That --
Q. This one. The one in your notebook has more than one page.
A. Oh. Okay. So are you asking me about this figure? I'm sorry.
Q. No, excuse me. No. On P57 relates to --
A. I think it's Number 58.
Q. Look at P57 in your notebook.
Are you looking at it?
A. Yes.
Q. Does it have more than one page? If it does, it's good.
A. Well, I just have something called P57, page one of four.
Q. Right. Do you have four pages as part of P57?
A. No. Well, hold on.
Q. Let me hand this to you.
A. Okay.
Q. Because it is a four-page document, and I think that was an

error.

MR. ELLINGBURG: Did you all get four pages?

MS. KNOFCZYNSKI: Yes.

A. Oh, I see what you're talking about. That's further along than I thought. Sorry.

Q. Okay. So now do you see Exhibit P57?

A. I do.

Q. And can you tell me what's on the three pages after the slide we've shown that you discussed.

A. Oh, those are -- those are some latitude and longitude values for wells, by number. In the different wellfields, Palmer, Davis, and Lichterman wellfields.

Q. Now, was that used to prepare the images and to give the testimony you gave with regard to the location of those wells?

A. It was only used to prepare a figure called P57, that has a scale on it. So I used those data --

Q. Okay.

A. -- with the GIS specialists in my company to pinpoint the location of those wells, and just do the simple calculation of how far is it to the border?

And then we said, "Well, we love maps with scales on them, and the maps don't have scales on them; that's not good. So let's put a bar scale on it."

So we generated that bar scale that you see in the lower right-hand corner.

Q. Okay.

MR. ELLINGBURG: So that -- for P57, Plaintiff's Exhibit, which we'd like to offer along with -- we'd like to offer the full copy of P57 into the record to show the basis, the dermination of the scale.

THE COURT: It's been tendered to the other side before this trial?

MR. ELLINGBURG: Yes, your Honor.

MR. BRANSON: We have the same objection. You've already heard it, your Honor.

THE COURT: I'll overrule the objection. But it may be placed in evidence at this time.

(Plaintiff's Exhibit 57 received in evidence)

BY MR. ELLINGBURG:

Q. I just want to make sure, is that the information used to apply that scale?

A. Yes.

Q. Pull up the next slide. No, wait a minute, I've got my -- all right.

Before we move on, did you use P57 in any way to calculate the scale added to this map?

A. I used the latitude and longitude numbers for the individual wells that we recovered from the USGS -- some USGS website; I don't remember which one.

And the position of the Mississippi/Tennessee line, which you can also get from websites, to not only calculate the distance from the border to the individual wells, but to generate a map scale, to simply say on this map one inch equals about half a mile.

Q. Okay. And did you determine the distance between the map -- the wells using that scale?

A. I'm sorry, did I determine what?

Q. Did you determine the distance between the wells in the wellfield using the scale?

A. Just generally, I mean, you can look at the -- now the -- you can look at the bar scale at the bottom, and you can determine that a lot of the wells there in Lichterman, relative to each other, might be a quarter of a mile, 13 -- 1,300 or so feet.

Other wells, from the northwest to the southeast -- there seem to be kind of two clusters here; one on the northwest, one on the southeast. Those wells would be further apart by a distance easily measured with a reasonable bar scale.

Q. Thank you.

Earlier we talked about the shrinking of the cone of depression, and I think you discussed the possibility of limiting the amount of time that wells in the wellfield were pumped; is that correct?

A. I did. I did say that.

Q. What if you just turned all the wells off? Would that have any impact on the well -- on the cone?
A. It will eliminate the cone, the cone -- eliminate it in large part relatively rapidly, and the final recovery of the -- of the artesian pressure would occur over a period of -- of years after that, but it would recover, in my opinion.
Q. So you could recover the original predevelopment pumping pressures if you turned off all the wells?
A. All the wells.
Q. Yeah?
A. Yeah. Yes.
Q. Thank you.
A. I'll add something to that. I said before, the withdrawal of water from confined aquifers can result in nonelastic behavior of an aquifer. I don't think that's the case for the Memphis Sand. I don't think the sand -- I think the Memphis Sand behaves elastically, and that is, if you -- so there's no damage, no substantial damage or subsidence that I can see so far.
So I just want to qualify that.
Q. Thank you.
Have you had and used some information relating to the volume of groundwater being pumped from these wells and others in wellfields?
A. I'm aware of the numbers, of millions of gallons per day

withdrawn from the wellfields, and I've looked at those numbers.

Q. So do you have before you Exhibit P157? That's in your notebook; it's the last, I believe.

A. Yes, I do.

Q. If you would turn back to -- or let's -- we're going to go back -- we'll give it to you -- to slide -- the slide showing the wellfields. Slide 54. It's up there? Okay.

Can you summarize the groundwater production from the Davis field, using the --

A. Through time, or just the most recent number?

Q. No, not...

A. So Davis -- according to this P157 chart, the Davis wellfield, there in the southwestern portion of Shelby County, came online in about 1970. And the early production figures show about 3.2 million gallons of water per day. And it began to increase through time, achieving -- I would say a maximum, in the 2005/2006 time frame, of about 20.8 million gallons of water per day from that wellfield. And the 2016 total for Davis suggests 14.98 million gallons of water per day from that wellfield.

Q. Thank you. Can you do the same for Palmer?

A. Palmer, I think, came online around 1972, and it has consistently produced between about 2.8 and 4 million gallons of water a day. So the first year of record that I find

suggests about 2.8 million gallons of water, and the highest that I think I remember seeing was a little over 5 million gallons of water a day from that wellfield. And the 2016 -- yeah, 2016 wellfield production is recorded as 3.68, roughly, million gallons per day.
Q. And finally, what about Lichterman?
A. Lichterman I believe came online in 1965, and it -- it started off in around 4.2 million gallons per water -- 4.2 million gallons of water per day. And probably the highest production from it occurred in the late 1980s, around 25 million gallons of water per day. And in 2016, the reported value is 18.5 million gallons of water per day production from the total wellfield.
Q. What about MLGW's overall pumping volumes?
A. These records indicated on this chart started 1965, and they indicated at that time total MLGW pumping was about 71.96 million gallons of water per day. And it increased, and sort of seemed to cap out in the 162 million gallon-per-day range around year 2000. And today -- and 2016, the value is 123 -- 123. I think it's -- I think it's 123.9, roughly, million gallons of water per day.
Q. So which of the MLGW wellfields have been the largest groundwater producers in recent years?
A. "Recent years" meaning last --
Q. Last time you remember them.

A. Okay. So in 2016, the largest producers were Allen at 14, Lichterman at 18, McCord at 14, Davis at almost 15, Morton at almost 16, and Shaw at almost 20.
Q. Thank you.
MR. ELLINGBURG: Before I move on, may I approach the witness, your Honor?
THE COURT: Yes, you may.
BY MR. ELLINGBURG:
Q. Doctor, you should take a few minutes, and all I'd like you to do is authenticate, verify, that the series of slides which I'll identify are slides that came out of your report; they're figures within your report.
The first one is Figure 1. Is that a figure that came out of your report?
A. Yes.
Q. Figure 2?
A. Yes.
Q. Is that a -- which is marked as P192; Figure 1 was marked as P191.
Figure 3, which is marked as P193, is that a --
A. Yes.
Q. Okay. Figure 4, which is marked as P194 --
A. Yes.
Q. -- is that one of yours?
A. Yes.

Q. Figure 5 is marked as P195; is that one of yours?
A. Yes.
Q. Figure 8, which is marked as P198: Is that one of your figures?
A. Yes.
Q. Figure 9, which is marked as P199: Is that one of your figures?
A. Yes.
Q. Figure 10, marked as P200: Is that one of your figures?
A. Yes.
Q. Figure 11, marked as P201: Is that one of your figures?
A. Yes.
Q. Figure --
MR. BRANSON: We're just -- for the record, we're happy to stipulate; you don't have to keep --
MR. ELLINGBURG: There was an authenticity objection to these.
MR. BRANSON: I think, if all you're doing is saying that these figures on the exhibit list are actually in his expert report, we will stipulate to that.
MR. ELLINGBURG: Okay.
MR. BRANSON: I don't --
MR. D. BEARMAN: We agree.
MR. ELLINGBURG: Thank you.
THE COURT: This is what he's been testifying to,

mostly? All these exhibits are what we saw?
MR. ELLINGBURG: These are figures that came from his original report back in 2000.
THE COURT: If there's no objection, they may be admitted.
MR. ELLINGBURG: And so they go from P191 to P208.
MR. BRANSON: And, your Honor, to be clear, we have our evidentiary objections we submitted to you on these, but I'm just stipulating to the fact that they actually are in his expert report.
THE COURT: No authenticity, but you don't give up your objection on relevancy.
MR. BRANSON: Thank you, your Honor.
MR. D. BEARMAN: Thank you, your Honor.
THE COURT: They will be admitted.
(Plaintiff's Exhibits P191 to P208 received in evidence)
MR. ELLINGBURG: Your Honor, for the purposes of preserving the sketch and making the transcript somewhat more understandable, based upon the testimony, we had someone take a color picture of what he drew on the whiteboard. And this goes to his testimony, and we wanted to submit that for the record, for clarification.
MR. FREDERICK: Can we put an exhibit number or something on that, counsel, so that we can at least know what

we're talking about?

MR. ELLINGBURG: Sure. We also took a better picture.

THE COURT: No objection, that will be filed, subject to the relevancy.

MR. ELLINGBURG: And the other thing that we'd like to do is to put some exhibit numbers on the slides, so that they can -- again, so the record can be followed.

MR. BRANSON: Which slides are you talking about?

MR. ELLINGBURG: The ones used with Dr. Spruill's testimony.

MR. BRANSON: The ones that were not on the exhibit list before the hearing, that we didn't get until Friday, I think we would have an objection to them being submitted as exhibits.

MR. D. BEARMAN: Absolutely agree, your Honor.

MR. ELLINGBURG: Can we mark them for identification, your Honor?

THE COURT: Sure, they may be.

MR. ELLINGBURG: Thank you. And so we'll put stickers on those after we finish today --

THE COURT: All right.

MR. ELLINGBURG: -- and submit them to the Court.

BY MR. ELLINGBURG:

Q. Dr. Spruill, do you have any opinions on the impact of -- if any -- on the pumping in Shelby County, Tennessee, and including the MLGW pumping operations on the Middle Claiborne Hydrologic Unit within the State of Mississippi?

A. The creation of a cone of depression associated with pumping 120-plus million gallons of water a day, to me, is undeniable. The cone of depression would be large, and it would be relatively deep, depending on the hydraulic properties of the aquifer.

And so my general statement would be I would anticipate the development of a large, a really extensive and reasonably deep cone of depression, based on what I understand about hydraulic properties of the aquifer, and what I've read from the literature and from reports that I've read that deal with estimation or calculation on the size of the cone of depression associated with pumping that much water from an aquifer from ten wellfields located in their current positions.

Q. Thank you.

Do you have an estimate of about how far that cone of depression extends into, or could have been determined to extend into the State of Mississippi?

A. Makes sense to me that for wells located within a couple miles of the Mississippi/Tennessee line, that a cone of depression of 20 miles, theoretical limit of the cone of depression of 20 miles would be very reasonable.

And so that would put an impact south of the Tennessee/Mississippi border of on the order of 15 to 18 miles, and that's with respect to the theoretical limit of the cone of depression, with respect to the depth of the cone. I can only rely on the reports that are related to modeling to estimate the amount of well-level change or reduction in pressure you would have down in Mississippi.

Q. Based on the modeling which you've seen -- which would include USGS models, right?

A. Right.

Q. Do you have an estimate of what the drawdown impact could have been anticipated to be in one in the cone of depression created by the MLGW wells?

A. I can only rely -- since I didn't do the modeling, I can only rely on what I see in terms of model results or model outputs from models like those done by Dave Wiley at LBG, and earlier models that were done by the USGS that attempted to predict or to show the cone of depression at different times against different pumping rates.

And so a generality is that there's a 20-foot cone -- 20-foot drawdown area that extends over -- appreciably over large parts of DeSoto County, and that drawdowns of 20, 40, maybe even 60 feet up near the border of Tennessee and Mississippi are shown on some of those -- those maps, both as -- taking the different surface maps, and then subtracting the equipotential surface map from the calculated cone of depression, you get a drawdown map. So I've seen both of those

that indicate that general size.
Q. In addition to what you've seen from -- I think you said LB -- what --
A. LBG is the -- I'm sorry, is the old name for Dave Wiley's company, Leggette Broshears Graham, a Florida-based hydrogeology firm.
Q. I think in addition to those models, have you looked at model results from -- published by USGS?
A. Yes.
Q. Are those part of the basis of your opinion?
A. Yes.
Q. And so how long have you actually been planning wellfields?
A. I designed my first wellfield in 1989 -- sorry, late in 1988, into '89 and 1990, at the city of Washington in North Carolina. The original Washington.
Q. Have you designed any wellfields specifically for the purpose of limiting the amount of the -- or limiting the depth of the cone of depression for a public utility or other entity?
A. I would like to think I've never designed a wellfield without that information. That would be my hope.
Q. And how many wellfields would you say you've designed, an estimate?
A. I've designed and worked on over -- well, hundreds of wells in my career. I don't have an exact number. But wellfields, 20, 30, or more.

Q. Thank you.
What are the remaining known or obvious impacts in Mississippi that have been reported in the USGS documents that you've seen?
A. I'm not sure what you're asking me.
Q. I'm asking if USGS for modeling has indicated that the pumping would be coming out of Mississippi if MLGW proceeded as they planned?
A. I guess two -- yes. The answer would be yes. I've seen reports, examples.
Q. Right.
A. I recall the 1965, I think, report by Moore from the US Geological Survey, who indicated that continued development of -- development of supplies, development of wellfields, and especially in that area closest to the border, could cause water to flow from other states and could be problematic.
I specifically recall -- and I just focused on, because I love the report -- the work done by a USGS gentleman, whose name escapes me, on the Lichterman wellfield about the same time, about 1965, in which he did calculations indicating the nature and the extent of the cone of depression, and where he predicted cones extending outward in the 20-mile range.
Q. What are the specific changes to the groundwater system in the Middle Claiborne and Mississippi, within the cone of depression that you discussed, created the Memphis wellfields?

A. Generally speaking, the development of a cone of depression of this magnitude will change groundwater and flow patterns. It will affect pressures within the cone of depression. It can and generally does cause changes in direction of groundwater flow that can be significant.

It has always the result of decreasing the pressure, and hence reducing the total available drawdown within the cone of depression. And so if the cone of depression extends outward for a reasonable distance, or for any distance within that cone of depression, there is a -- an absolute reduction in the amount of total available drawdown.

And I'm speaking just generally now, so in the vicinity -- within the cone of depression, or as a result of the cone of depression, you have to anticipate potential water quality issues that result when you create a pressure gradient between different parts of the system, so that if you lower the water level in an aquifer by a cone of depression, the overlying and underlying aquifers that have their own pressure regimes can begin to respond by pushing water in the direction of reduced pressure, which is in the cone of depression.

And so water quality changes are something we always think about when we think about developing a developed cone of depression by leakage across, say, windows or breaches in the confining layer by faulting, and things of that nature.

Q. Now, in your answer you said something can happen. Based

on the work you've done, do you know whether the total available drawdown has been reduced within the state of Mississippi as a result of the pumping in Shelby County, particularly MLGW?
A. Based on the drawdown map and the equipotential surface maps that I've seen, the total available drawdown in Mississippi has been reduced by pumping from across the border.
Q. Has the cone of depression created by the pumping in Shelby County and by MLGW caused any change in the natural flow path of groundwater within the confined aquifer unit within Mississippi?
A. Again, if you look at equipotential surface maps, based on actual data, and then say for predevelopment conditions, or within the cone of depression as model, for example, it's clear that groundwater flow patterns have changed such that water that naturally resided in Mississippi is moving towards -- has moved towards or is continuing to move towards the State of Tennessee, unless the cone of depression is eliminated or lessened.
Q. Okay. Within a confined aquifer, what was the predevelopment direction?
A. In Mississippi?
Q. Yes.
A. Generally to the west.
Q. And how has that direction been changed as it shows up on a

map?
A. Maps that I see -- and obviously not all maps show the same thing, but there is a shift towards a more northerly flow pattern in the vicinity of the Tennessee and Mississippi border.
Q. Based on your testimony earlier with regard to total available drawdown, has the amount of water that can be produced from the Middle Claiborne hydrologic unit in the state of Mississippi been reduced by the pumping in Shelby County and by MLGW?
A. I would have to base my answer to that on the drawdown map that I have observed from the Wiley study that shows, say, by way of example, 40 feet of drawdown in the northern part of DeSoto County and south of the border. 40 feet of reduction and total available drawdown would be then implied by the drawdown map showing a 40-foot drawdown.
Putting that in perspective, if you have a well at that location that's capable of producing 10 gallons a minute for every foot that you lower the water level, then reducing the total amount available drawdown by 40 feet would reduce the ability -- would reduce the capacity of that well, maximum capacity, by 400 gallons a minute.
Q. And is that because of this movement of some of the molecules of water out of the pore spaces?
A. It means that the amount of water in storage in these

completely filled pore spaces has been reduced materially by the reduction it had within the cone of depression up -- at that value. I gave a value of I think 40 feet, so 40 feet of pressure reduction would result in a loss of 400 gallons a minute maximum capacity of a well --

Q. Within your example?

A. Within my example.

Q. Okay. Are there any other impacts that relate to -- on the production of groundwater in Mississippi that arise from the reduction in total available drawdown?

A. I would have concerns, based on my experience, that if you had a well within the cone of depression that I've stipulated, this cone of depression that has maybe 20, 40, 60 feet of drawdown, if somebody else had a well within that cone and they were producing a given amount of water, it's entirely conceivable that the cost of pumping that water to the surface, it is reasonable to assume that the cost of pumping that water to the surface increases, because now, instead of pumping against the high water level, they're pumping against a lower water level.

As we all know, the definition of work is moving an object over a distance. So that pump has to move the water over a greater distance; it has to do more work, so it caused that water purveyor more money.

Throughout my career, I've been involved in situations

like this, where the pump that was installed was perfectly capable of producing a given amount of water against that head, that pressure; but when the pressure was lost, that pump could no longer produce the same amount of water, so the pump had to be replaced.
Q. So that's a possible example. But in the case of actually pumping --
THE COURT: Just a minute.
MR. L. BEARMAN: We're now talking about what's possible, which is inadmissible, in my judgment. We are also speculating, if the Court please. And while I understand your Honor's ruling, I think this has gone beyond the pale.
MR. ELLINGBURG: Which is the reason I was about to ask him to clarify that further, without talking about --
THE COURT: The point is well taken. But I'll let you proceed, and overrule the objection. But don't get into possibilities; do probabilities, if you can.
BY MR. ELLINGBURG:
Q. Dr. Spruill?
A. Yes, sir.
Q. Is there any impact on the cost of producing water from a -- within a cone of depression, where you have to pump out of that cone, as distinguished from pumping at conditions outside the cone?
A. Absolutely.

Q. And what is the cost?
A. Increased cost of lifting water to the surface against -- against a reduced water level in a well at that same rate.
Q. And what amount -- the actual well itself, did it have to go deeper?
A. It's possible that the --
Q. Not possible?
A. It's probable -- well, okay. Depending on the pump setting, depending on the pump setting, you may have to lower the pump to achieve the same flow of water, gallons per minute.
Q. Okay. So that was "may," and again, that's speculative. But if you have to pump from the deeper depth because of all the circumstances, does that cost any more money?
A. Certainly. Yes.
Q. And how about -- do you have any idea how much more it costs?
A. Under the calculation years ago that shows if you lift a -- I don't want to give this example.
Q. Then don't.
A. It costs more money to lift water over a greater distance.
Q. Okay.
Also, I want to make sure I understand that earlier in your answer -- I'm not sure how you phrased it, but is it your opinion that the pumping -- do you have an opinion as to whether the pumping in Shelby County and by MLGW has withdrawn

any groundwater through Mississippi?
A. The modeling results and reports that I see, that show the cone of depression and changing flow lines, say to me that groundwater that originally was residing in Mississippi has changed directions, in some locations moving towards the Mississippi and by -- some of that water has moved across the border.
Q. And do you -- when you say "the model results," are you talking about the USGS models included in that?
A. Both the USGS model and recent modeling efforts.
Q. Thank you.
Now, you mentioned earlier some water quality issues resulting from the lowering of the pressures within the Middle Claiborne Hydrological Unit; is that correct?
A. Yes.
Q. Have you seen evidence of that?
A. I've read lots of papers outlining the migration of water in response to the development of the cone of depression downward from overlying units and through confining beds and breaches in confining beds, through things that are variably referred to as paleo channels, windows, thinning -- areas of thin confining beds, etc.
Q. And when you say you've read papers, do you have an opinion based on the information, scientific information available, as to whether that has taken place?

A. Yeah, I think it's a lot of really nice work that involves the use of isotopes and looking at the introduction of human contaminants, human-related contaminants, into the groundwater system.
Q. Dr. Spruill, you said, I think it's nice work. My question is, do you have an opinion, based on the scientific information you reviewed?
A. Yeah, I have an opinion.
Q. Yes?
A. Contaminants have moved downward through these features that I described.
Q. Or younger water?
A. Or younger, uncontaminated water, into the aquifers within the cone of depression.
Q. Yes.
MR. L. BEARMAN: Do I understand, your Honor, that we have a continuing speculation objection as well?
THE COURT: I understand that. I'll let it be introduced. You may reserve your right to strike it.
BY MR. ELLINGBURG:
Q. I think you said yes; is that right?
A. I said yes.
Q. And what is the opinion?
A. The opinion is clear. There's lots of scientific evidence, based on constituents that show up at production wells that are

not part of the confined aquifer system, that have come from demonstrably younger water making its way down through these special areas within the overlying materials that are making their way into the groundwater system.

It is well documented. It's not speculation. It's well documented that there are windows that allow or facilitate the migration of younger water that may be anthropogenically -- may be contaminated with human-related constituents; for example, gasoline. Constituent of gasoline, benzene, or something else that might come up --

Q. We don't need to talk about what may happen.

A. Okay.

Q. But has there been downward migration?

A. Yes.

Q. And is it your opinion that that's the...

A. Yes.

Q. And that is -- and why is that as it relates to the cone of depression?

A. The establishment of a cone of depression changes the pressure environment and increases the rate of downward migration of water from overlying units within the cone of depression.

Q. Thank you.

Would you put the last slide up there.

This is a document taken from hydrogeology of the

principal aquifers in relation to faults to interaquifer leakage in the Memphis area. Have you seen this before?
A. Yes.
Q. And what is it that is significant on this slide that you'd like to talk about, and how does it relate to your opinion?
A. This figure, from a report by the USGS, shows the position of the ten wellfields. There's Davis. I'm pointing to Allen, Sheahan, Lichterman; can't see Palmer because of the timing.
But it shows the area where the confining unit is thin or absent. And it shows the areas where the confining unit is thin or absent most conspicuously, and most understandably, in the confining -- in the unconfined portions of the aquifer, where it's expected to be absent.
But it shows the position of areas in some cases closely related to the position of the wellfields, where there is thinning of the confining unit or the confining unit is absent. And so those would be places where the confined aquifer would be -- is less protected from downward migration of water than areas where these windows or thin areas don't exist.
Q. Okay. So those are the windows you were talking about; would that also -- does that have any relation to the paleo channels?
A. I don't know whether these are paleo channels, ancient channels that form when sea level fell, rivers cut deeper, sea

level rose, the channels were filled with gravel and sand. I don't know whether they are paleo channels or whether they are areas where simply there's a thinning of the confining bed on top of the aquifer. But they are recognized as areas -- and these are the ones that were recognized, I guess, up to this point in time.

Q. Thank you.

Would you put Slide 23 back up.

We discussed this slide earlier on, did we, Dr. Spruill?

A. Yes.

Q. Do you have an opinion as to whether there is available groundwater that can be produced within the State of Tennessee far enough from the border of the State of Mississippi that would have no significant impact on channels?

MR. BRANSON: Your Honor, I just note a foundation objection to that question. There's been no evidence that Dr. Spruill has studied that question.

THE COURT: I'll overrule it, but you may put it in.

BY MR. ELLINGBURG:

Q. Before we do that, do you recall being asked questions in the deposition by Mr. Branson in which he asked how the cone could be mitigated?

A. Yes.

Q. And you stated that wells could be placed further to the

north?
A. Yes.
Q. Okay. That said, do you have an opinion as to whether there is an adequate supply of water, based upon the US Geological Survey's mapping, north of Memphis to meet the needs in Tennessee without any significant impact on channels?
A. Yes, I have an opinion. This map shows the thickness of the Middle Claiborne Aquifer. North of the transition zone, the Middle Claiborne Aquifer unit is composed of the Memphis Sand Aquifer.
North of the facies line, I think that it's called, the facies transition that's shown on this map, there's an indication that the Memphis Sand, well north in Tennessee and east of the Mississippi River, contains a thickness of 600 feet or higher, which is an appreciable sand thickness. And so the transmissivity of that aquifer would be an important question, because transmissivity is not just aquifer thickness, but it's also permeability times aquifer thickness.
And so I base my opinion on a report prepared in the 1960s by Moore, in which he presented a map of zones of transmissivity for this particular area that we're describing; that is, the area north of Memphis, east of the Mississippi River, and well to the west of the -- of the unconfined portions of the system.
I cannot tell you what individual yields from wells

would be, but my opinion is that that's a zone capable of sustaining significant quantities of water from wells or wellfields.
Q. And based on the Moore --
A. Based on the Moore study.
Q. And on channels?
A. And on this, it shows a significant thickness.
Q. Give me a moment.
MR. ELLINGBURG: Excuse me just a moment.
THE COURT: Yes.
MR. ELLINGBURG: Trying to find our copy of the joint exhibits.
THE COURT: All right.
MR. BRANSON: Mike, do you have a particular one you're looking for?
MR. ELLINGBURG: Yes. I'd like to see Joint Exhibits 58 and 59.
THE COURT: Why don't we just recess until tomorrow, and you can see if you can find that and answer anything else, or ask any questions, and then have cross-examination tomorrow.
Yes.
MR. BRANSON: Your Honor, I have something I'd like to raise briefly before we recess. Dr. Spruill has not addressed today -- and I understand he's probably not going to on direct -- the predevelopment of flow map generated by Dr. Brian

Waldron, who we're planning to call. And this was an extensive subject of discovery; 70, 80 pages of expert reports were devoted to it. Both experts were deposed on it.

I don't know if they're planning to do Dr. Spruill's criticisms of Dr. Waldron on rebuttal or not, but I would ask that if they are, that we -- that you instruct them to do it on direct, so that we can only have Dr. Waldron testify once. I don't want to have him testify, then get critiqued, and then have to come testify again.

So I just wanted to raise that issue.

THE COURT: Okay.

MR. ELLINGBURG: Your Honor, this issue was first raised today, and we have planned to direct -- to present our evidence in that fashion. We will follow the typical rule, that you have direct and that the other side has a response, and then if you need it, you have rebuttal. And so we'd like to hear what he has to say first, before we know whether we have to put any testimony on.

MR. BRANSON: Judge, there's no mystery about what our expert is going to say. He published an academic paper that all five experts in this case have talked about. There are literally 70 pages of expert reports exchanged on it. It goes to a core thing that I understood your Honor wanted evidence on, which is the historical flows in the aquifer between the states.

We think that it needs to be part of the case in chief. There's no good reason to have both witnesses testify twice about it when we could just do it once.

MR. ELLINGBURG: Well, there's no reason for it to be testified to twice. I mean, we don't know what Dr. Waldron is going to say about it and how that examination is going to go. We can't make a decision as to whether we want to put Dr. Spruill on to respond any of it; he may say something about Dr. Spruill.

There's a reason that this has always been done this way, which is that you put on your witnesses, they put on theirs, and then if you need to, you put on rebuttal.

And so we object to having to ask him questions about something that we may not even need to ask him questions about.

THE COURT: Well, what we'll do, we won't decide that issue today, but we'll decide it in the morning. And it may be that if you don't cover -- make their expert go, if they want to, or if you expect to put Dr. -- what's his name, Moore?

MR. BRANSON: No, our expert is Dr. Waldron, your Honor.

Just to be clear, he's testifying -- Mr. Frederick presented his map of the aquifer in his opening statement, and he's going to testify based on an academic paper that all five experts have discussed about the predevelopment cross-border flows in the aquifer.

So we're not letting him go. My point is that Dr. Spruill submitted essentially this entire expert report criticizing Dr. Waldron's map. Both of them were deposed about it. There's just no good reason to do this piecemeal and force both of these gentlemen to testify twice. It just makes sense.

THE COURT: Well, put it in tomorrow; then you can hold your witness over, or you can put it in later, if it's a proper report. But if it doesn't come in, I don't see any reason for you to have your expert here.

MR. BRANSON: Your Honor, this is -- to be clear, our expert is independent of Dr. Spruill. Our expert has published a map about predevelopment flows in the aquifer, which I understood your Honor wanted evidence on in this hearing, the extent of historical flows between states. And so it's an affirmative part of our case.

THE COURT: So you want to use him anyway?

MR. BRANSON: We're going to use him anyway.

MR. ELLINGBURG: As he said, it's an affirmative part of their case.

THE COURT: Well, we'll try to figure that out. I never had that come up before. But we'll see about it now, and we'll talk about it tomorrow.

MR. FREDERICK: Your Honor, the main point is that if we could finish this week, by having efficiency with the witnesses --

THE COURT: That's correct.

MR. FREDERICK: -- that's a net good for everybody.

THE COURT: Sure.

MR. FREDERICK: And so having Dr. Spruill address all the issues that he opined about in his expert report once, and then we just have one cross-examination of him, I'm sure he would appreciate that. And then having Dr. Waldron talk about his information and then not have to come back two days later to address any issues that Dr. Spruill might testify about specifically to Dr. Waldron.

We're just trying to make the hearing more efficient.

THE COURT: I understand that. I'm not sure that I can look at it in a vacuum, frankly, because you're going to put your man on, and if he doesn't testify about it, you may not have any problem whether it's done. We'll just have to be as flexible as we can about it.

MR. BRANSON: Your Honor, the other -- the only other thing I had is my experience in these -- in trials has been that when a witness is still live on the stand when we break for the day, such as Dr. Spruill is now, that attorneys should not be talking to the witness about the substance of their testimony, and that would apply to both sides. I just wanted to see if that was your understanding as well.

THE COURT: What do you say?

MR. ELLINGBURG: We have no objection to that.

THE COURT: All right. That's my direction, then. Don't talk to your witness until we get back tomorrow and put him on the stand.

Is there anything else to take up?

MR. ELLINGBURG: The only thing I can say about that is that we have not planned on putting on testimony by him directly about Dr. Waldron. And so if the Court were to require us to put testimony on for him before we've heard Dr. Waldron testify, we'd have to do some more work.

That's part of the reason we're objecting to this being brought up today. They've brought up almost every imaginable thing they wanted to during the pretrial, and so it's hard for me to see how they can justify today telling us that one is going to change the historic rule of the progress of trial with regard to our witness, and then not let us -- you know, not even let us talk to him if we're going to have to do that.

You know, I just think that -- we don't mind not talking to him, but we would have to talk to him if we were going to have him testify with regard to --

THE COURT: Well, if you don't plan to do it, don't change it, and we'll just wait to see what he testifies about, and we'll -- I'll rule after that.

MR. BRANSON: And your Honor, just to be clear, if there ends up being rebuttal testimony criticizing our expert, we would move for leave to have a surrebuttal and have our expert respond to the criticisms.

THE COURT: I'm not sure whether rebuttal will pass, or surrebuttal, but we'll pass that also.

MR. ELLINGBURG: Thank you, your Honor.

MR. BRANSON: Thank you, your Honor.

THE COURT: If there's nothing else, this Court will be in recess until 9:00 a.m.

(Adjourned until May 21, 2019, at 9:00 a.m.)

STATE OF TENNESSEE:

COURT REPORTER'S CERTIFICATE

I, PATRICIA A. NILSEN, Licensed Reporter for the State of Tennessee, CERTIFY:

1. The foregoing deposition was taken before me at the time and place stated in the foregoing styled cause with the appearances as noted;

2. Being a Court Reporter, I then reported the deposition in Stenotype to the best of my skill and ability, and the foregoing pages contain a full, true and correct transcript of my said Stenotype notes then and there taken;

3. I am not in the employ of and am not related to any of the parties or their counsel, and I have no interest in the matter involved.

WITNESS MY SIGNATURE, this, the_____ day of _________________, 2019.

____

PATRICIA A. NILSEN, RMR, CRR, CRC
TN Licensed Court Reporter
LCR Number: 717
Expiration: 6/30/2020

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