Memphis Aquifer Research Study
A deep look into the protective clay layer of our drinking water source

University of Memphis, Center for Applied Earth Science and Engineering Research (CAESER)
Memphis Light Gas and Water (MLGW)

2018-2023
Shelby County, TN
This page is intentionally left blank.
Content

Project location .......................................................... iii

Introduction ......................................................................... 1

Key takeaways ...................................................................... 2

Groundwater Quality and Age-dating ................................. 2

Davis wellfield .................................................................... 3

Mallory and McCord wellfields ......................................... 3

Shaw wellfield .................................................................... 3

Sheahan wellfield .............................................................. 4

Groundwater Modeling ..................................................... 4

Geophysics and Subsurface Mapping ................................. 6

Stream Work and Water Level Surveys .............................. 6

Physical Measures ............................................................

Laboratory tests ............................................................... 8

Conclusions ....................................................................... 8

Research Projects ............................................................ 10
Project location

The project area focused on the MLGW water service area which encompasses Memphis and unincorporated Shelby County to the exclusion of the other major municipalities (Millington, Bartlett, Germantown, and Collierville). Its focus was primarily on the Memphis aquifer and the integrity of its upper confining unit.
In the winter of 2018, the Memphis City Council approved the establishment of a special fund, paid for by the citizens of Memphis and unincorporated Shelby County, to conduct an important scientific investigation on Memphis’ vital drinking water resource, the Memphis aquifer.

The Memphis aquifer was initially discovered in the late 1800s, immediately becoming an extremely important source for clean drinking water, allowing Memphis to survive its worst yellow fever epidemic and regain its charter. Almost 140 years later, the Memphis aquifer still provides exceptional water not only to Memphis citizens but to the entire Mid-South region and beyond. However, our drinking water is threatened in some localized areas by contaminants released during the past 80 years. These contaminants can pass through natural pathways, termed “breaches”, in the confining clay layer overlying the Memphis aquifer. In most places, the confining clay layer protects the Memphis aquifer from infiltrated contaminants and less pure water, but where breaches are present, our drinking water is more vulnerable to contamination.

Memphis has been highly urbanized over the last century, and improper disposal of wastes and increased use of hazardous chemicals in everyday life (particularly post-WWII), resulted in localized areas of contamination that have impacted the unprotected shallow aquifer, the uppermost aquifer in this area. Water from the shallow aquifer can leak downward through these breaches and enter the Memphis aquifer. Water has not always leaked downward though. Back in the late 1800s and early 1900s, flow was upward through the breaches, from the Memphis aquifer into the shallow aquifer. However, extensive pumping from the Memphis aquifer made the water levels in the Memphis aquifer to decline so much that the natural upward flow reversed, allowing the shallow aquifer waters to move down and “recharge” the Memphis aquifer.

This research focuses on the presence of breaches in the confining (protective) clay layer...
their properties and what that means to the bigger picture. These methods included chemical analysis and age-dating of groundwater, numerical (groundwater) modeling, subsurface mapping using historical drilling records, geophysical techniques, physical measurements of water movement and levels, and evaluating the patterns and interactions between streams and the shallow aquifer. Additionally, the impact of breaches to the Memphis aquifer was tested using groundwater models and conducting laboratory experiments. This executive summary discusses the results from the 22 projects performed in this scientific investigation.

Groundwater Quality and Age-dating

The top of the Memphis aquifer comes closer to the Earth’s surface moving eastward through Shelby County, and in Fayette County becomes completely exposed, allowing it to be directly recharged by rainfall. The Memphis aquifer is made mostly of sand and though commonly mistaken as an underground river or lake, the groundwater moves very slowly through the sand. Beneath much of Shelby County, the age of the Memphis aquifer water is 2,000 to 3,000 years old – so old that its chemical signature differs greatly from other sources of water such as streams and lakes, and even that of the shallow aquifer. That difference allows us to identify the presence of a breach near a production (water pumping) well in the Memphis aquifer by looking at the water chemistry. Tied to the chemistry is the age of water.

Memphis aquifer water is 2,000 to 3,000 years old

Surface waters (i.e., streams, lakes) and the shallow aquifer contain modern water (less than 65 years) as identified through environmental tracers like tritium/helium-3 ($^3$H/$^3$He) and sulfur-hexafluoride (SF$_6$). Such comparisons of water chemistries and groundwater age (age-dating) were performed at five of MLGW’s 10 wellfields: Davis, Mallory, McCord, Shaw, and Sheahan.

Key takeaways

- Objective of the project:
  Identify and characterize breaches in the protective clay layer above the Memphis aquifer in Shelby County.

- Prior to this study, there were six suspected breaches (not drilled), and one confirmed breach (drilled). Now, we identified 36 suspected breaches and confirmed six breaches.

- Modern water (less than 65 years old) was detected in the Memphis aquifer water pumped from the Davis, McCord, Shaw, and Sheahan wellfields. Additionally, previous studies also indicated modern water in Lichterman and Allen wellfields. No modern water was found in the Mallory wellfield.

- Updated groundwater flow model (CAESER-II) includes data from field and lab tests that improve matching of past groundwater levels and make future predictions more accurate.

- Groundwater flow model ran hundreds of thousands of scenarios to define the best groundwater production procedures that reduced the threat of modern water in the Memphis aquifer at certain MLGW wellfields.
**Davis wellfield**

In southwest Memphis, Davis wellfield showed mixing of modern waters originating from west and east of the wellfield. To the west, two breaches were verified from other studies by drilling (i.e., known breaches): one off the bluff near the Horn Lake cutoff, and the other at the TVA facility (drilled by TVA consultants). These known breaches allow surface water and shallow aquifer groundwater to enter the Memphis aquifer. East of Davis there is no known breach, although one is suspected through a prior numerical groundwater model and further supported through this study where helium (He) from deep within the Earth seeps upward along a fault within the wellfield. Very little is known about this fault, but faults can either stop groundwater flow or provide a vertical groundwater flow pathway across geologic layers. Mixing percentages of modern water in the western part of the Davis wellfield range from 24 to 46%, which is significant. Keep in mind that 0% within a sample means no modern water from a nearby breach has entered the Memphis aquifer and the water is pristine. However, as the percentage increases so increases the amount of modern water mixing with the older, Memphis aquifer water.

**Mallory and McCord wellfields**

Mallory wellfield is near downtown Memphis and the oldest operating wellfield in town. The analysis of water chemistry and environmental tracers in the Memphis aquifer samples showed no modern water and pristine Memphis aquifer water chemistry. These results mean that there are no nearby breaches affecting the water pumped from the Memphis aquifer in the Mallory wellfield, which is great news. At the McCord wellfield, near the City of Bartlett, data continue to suggest a breach in the area; however, it has not been confirmed. Previous studies suspected a breach in the area due to thinning of the confining clay layer and modern water in samples from several production wells. The current study continued to show the presence of modern water in the Memphis aquifer at three production wells, ranging in mixing percentages of 9 to 25%. Some of the age-dating samples from the McCord wellfield are still being processed, so more information is likely to follow.

**Shaw wellfield**

Shaw wellfield is MLGW’s easternmost major wellfield and is situated within a region where the protective confining unit naturally thins and becomes absent, which is considered the Memphis aquifer recharge zone. Furthermore, the Shaw wellfield is different from other wellfields in that water is pumped from intervals throughout the entire Memphis aquifer (approximately 700 ft thick!) and the underlying Fort Pillow aquifer. Evidence for modern water was only found in two production wells that pump from near the top of the aquifer, with mixing percentages of 9 to 17%. The range of mixing percentages is in part due to considering two possible modern water sources: surface water (i.e., Grays’ Creek) and the shallow aquifer. Of concern, a Superfund site (National Fireworks) with contaminated soil and shallow groundwater is located northwest of Shaw, where the groundwater movement is oriented from them toward Shaw production wells.
Sheahan wellfield

Lastly, Sheahan wellfield near the University of Memphis is one of MLGW’s most extensively studied wellfields. A suspected breach within the middle of the wellfield was verified by drilling, becoming a known breach. This known breach may extend east to Audubon Park where a suspected breach was mapped by an electrical resistivity survey, which allows us to see a couple hundred feet underground. A unique element of the study of the known breach was the collection of sediment from the breach. The sediment was tested in the laboratory to determine its water transmission properties, called hydraulic conductivity (K). Another known breach was found by the Tennessee Department of Environment and Conservation (TDEC) while drilling near the Former Custom Cleaners Superfund site about a mile from the Sheahan water plant. Two other suspected breach were mapped in the northern part of the wellfield using geophysical well logs and to the southeast of the wellfield based on numerical groundwater modeling. This same numerical model included contaminant transport, showing pollution from Former Custom Cleaners moving toward the Sheahan wellfield.

Groundwater Modeling

The complexity of the groundwater system in Shelby County warrants the use of a computer model to represent the simultaneous interactions among the various stressors such as recharge, evapotranspiration, groundwater withdrawal (i.e., pumping), groundwater-surface water exchange, inter-aquifer water exchange, and the mapping of groundwater movement and contaminants over long periods of time. Prior to this study, a model called CAESER-I was developed that captured all these stressors during the period 2005-2016. Under this study, CAESER-I was extended in time to cover from 1960 to 2021, and upgraded to include preliminary results from this study, such as better aquifer characterization (i.e., hydraulic conductivity and storativity), breach conductivity, adjusted recharge, new breach locations (known and suspected through 2022), and pumping. This upgraded model is called CAESER-II. Two key concepts to understand about modeling: (1) a model is only as good as the data that goes into it and (2) each model serves a purpose and there is no model that fits all scenarios.

The new model CAESER-II incorporates better aquifer characterization, new breaches and adjusted recharge.

As mentioned, CAESER-II incorporated better aquifer characterization. This effort was initiated at the start of the study by performing pump tests at four MLGW wellfields and one Germantown wellfield to better estimate two critical variables in groundwater modeling, hydraulic conductivity (again, K) and storativity. Obtaining better estimates of these values is important since a challenge of many numerical models is non-uniqueness. Non-uniqueness means that the same solution can be achieved with various combinations of values; hence, complicating our ability to use the model for value-added decision making. For example, a large
breach with a small $K$ can produce the same flow as a small breach with a large $K$. So, without reducing or eliminating non-uniqueness, we are unable to fully understand the impact of these breaches on our drinking water. This is why it was so critical to calculate the value of $K$ directly from breach sediments in the lab, and additionally to calculate $K$ and storativity from pump test data in the Memphis aquifer. Providing this better-quality data as input to the model increases our trust in the results.

For this study, a variety of models were developed for different purposes, though all have their origin in CAESER-I or -II. One model investigated reducing the threat of modern water reaching MLGW’s production wells and adding to the life (period of operation) of its wellfields by extending wells deeper into the aquifer (and possibly even the much deeper Fort Pillow aquifer) and fluctuating winter and summer production between shallow and deep Memphis aquifer wells, would meet these objectives for certain wellfields (Davis, Allen, Sheahan, Lichterman, McCord, and Shaw). This same model also shows where to drill new production wells to avoid modern water leakage—

—all model scenarios used a technique called particle tracking, which follows the movement of modern water into the Memphis aquifer.

Another model investigated the shallow aquifer, which was once deemed unimportant but now is regarded as a critical factor in both the quantity and quality of water in the Memphis aquifer. In CAESER-I, the shallow aquifer water surface (water table) was mostly flat except near the major streams: Loosahatchie River, Wolf River, and Nonconnah Creek. In Shelby County, the reality is that the water table should more closely conform to the land surface, being of higher elevation under the hills, and sloping down to the streams in the valleys. This model revealed that by incorporating the tributaries to these larger streams in the model, it helped create the hills and valleys expected in the water table. Better representation of the water table by these tributaries also helped determine flow to breaches. Such was the case at MLGW’s Lichterman wellfield in the Hickory Hill area. The original groundwater model incorrectly showed an overestimation of water loss (or absence of water) in the shallow aquifer. The new model predicts water loss to match what is presently observed.

Groundwater models developed in this study

**Model 1.** CAESER-II: Improved and extended model based on CAESER-I.

**Model 2.** Reducing the threat of modern water reaching MLGW’s production wells by identifying optimal pumping placement (depth and distribution).

**Model 3.** Incorporating the influence of tributary streams to improve proper water flow direction in the shallow aquifer.

**Model 4.** Determining the influence of new breaches near the MLGW Sheahan well field on groundwater flow and contaminant transport.

**Model 5.** Contaminant transport model used to derive dispersivity values for the Memphis aquifer.

**Model 6.** Attempts to find a breach (or breaches) based on groundwater ages and mixing percentages.

**Model 7.** Assessing the possibility of filling a breach.
An earlier model (CAESER-I) of the Sheahan wellfield under this study indicated that a larger, more distributed breach system (like a stream system) was required to match the limited historical age-dating data for the wellfield. This concept was refined in CAESER-II to include four breaches (two known, two suspected), and results revealed the likelihood of a third suspected breach southeast of the wellfield. An added feature of this refined model of Sheahan was the simulation of contaminant transport from the Former Custom Cleaners Superfund site near the University of Memphis.

Contaminant transport consists of two different processes: advection and dispersion. Advection can be described as the average movement of contaminants as they are carried by groundwater flow, while dispersion is the spreading out of the contaminant plume as it moves. Dispersion is often used to refine model output to match observed (real) data, but without a specific contaminant plume to match the data to, the dispersion values must be estimated. To derive an appropriate value for dispersivity (used in calculating dispersion), a model was developed of a Collierville wellfield. Though this wellfield is outside the MLGW network, there are two relatively well-defined plumes to use as examples. The model of the TCE (trichloroethylene) and Cr$_6^+$ (hexavalent chromium) plumes revealed dispersivity values ranging from a few meters, to as much as 55 meters, showing the scale dependency of dispersivity, which provides us better precision for this term when predicting threats to our drinking water.

Another model from this study addressed the possibility of finding a breach (or breaches) based on groundwater ages and mixing percentages, with improved probability if both measurements (ages and mixing percentages) were used rather than one. Non-uniqueness was also a challenge that prevented this model from being fully implemented. The problem was the number of breaches and their size are both variable; however, future modeling efforts can build upon these findings and better resolve the issue of non-uniqueness.

The last model was conducted in combination with laboratory measurements. In response to the frequent questions from the public, “Can a breach be filled?”, this study investigated the feasibility of filling a breach. By producing a bentonite (clay) slurry and injecting it into actual breach material (using the material collected from Sheahan wellfield), the study found that a 10% bentonite mixture approximated the estimated range of hydraulic conductivity values of the confining clay, thereby mimicking its protective qualities. Even though actual injection was not performed, different injection thicknesses were investigated using simplified groundwater flow models finding that applying the bentonite mixture to a larger segment did not significantly reduce conductivity and that the bentonite percentage was more important.
Another technique for finding suspected breaches is subsurface mapping. Historically, and in this study, interpretation of lithology (physical characteristics of sediments) depicted in driller’s logs or geophysical logs was completed for each of the wellfields that was analyzed for geochemistry (i.e., Davis, Mallory, Shaw, Sheahan, and McCord). Cross-sections were developed that depict the presence, absence, or thinning/thickening of the various geologic units that make up the shallow aquifer, upper Claiborne confining unit (UCCU), the Memphis aquifer, and if the logs were deep enough, the Flour Island confining unit and Fort Pillow aquifer. Thinning of the UCCU (our protective clay layer) was observed in Davis, Sheahan, McCord, and Shaw wellfields, and the absence of this layer was observed in Davis, Sheahan, and Shaw. Aside from a new borehole drilled near Davis, Sheahan, and McCord wellfields (three total boreholes), these cross-sections relied on existing geophysical logs which varied in quality, depth, and completeness.

When attempting to map the subsurface, sometimes geophysical mapping techniques provide an alternative to drilling, although not all methods are suited for all areas or applications.

GPR was used near Davis wellfield in Ensley Bottoms near the known breach along Horn Lake Cutoff, but it proved ineffective at required depths. On the other hand, ER proved quite effective when the protective clay layer was within 200 feet below ground surface (bgs). It was used (1) to map a suspected ancient channel and breach beneath Audubon Park east of Sheahan wellfield; (2) to refine the boundaries of a suspected breach represented by an anomalous depression in the water table beneath the Fletcher Creek Greenway near the McCord wellfield; (3) to further substantiate a suspected breach from AEM data and previous studies at President’s Island (near Davis and Allen wellfields); and (4) to refine a new suspected breach from AEM data in northeastern Shelby County near Arlington that was later confirmed through drilling.

When investigating the connection between our major streams and the shallow aquifer, EMI was used to
penetrate through the streambed (up to 18 feet bgs) to determine observed losses in stream discharge, such as along Nonconnah Creek near Mount Moriah Road. While the streambed of Nonconnah Creek in the upper reaches is typically underlain by approximately three feet of clay, clay was shown to be absent near Mount Moriah Road using the EMI. Though considered at first to be a breach in the streambed clay, historical aerial imagery showed it to be a borrow pit was constructed.

**AEM was able to penetrate up to 300 feet bgs created a detailed map of the subsurface identifying 23 suspected breaches.**

Another study combined geophysical logs with field mapping of outcrops where our geology becomes exposed at the ground surface for easy observation and three-dimensional subsurface computer modeling. Critical results of the field mapping study showed where the shallow aquifer may have vertical steps, making it less continuous across the county. It also refined the locations of geologic faults identified in previous studies, and refined the three-dimensional subsurface model of the near-surface geology (less than 300 feet). This mapping made it possible to extract the presence of paleo-valleys that could be preferred pathways for groundwater to follow and, where these ancient channels are deeper and having eroded through the confining clay layer, would result in a suspected breach.

The subsurface model provides detailed three-dimensional maps of the confining clay layer, especially in the vicinity of MLGW wellfields and sites with known contamination. These detailed maps can then be used in groundwater flow models to better predict movement of contaminants and protect our water resources near wellfields. This level of investigation is normally done in petroleum exploration to help guide well installation, which costs millions of dollars. The application to groundwater studies is novel and needed given how important our water resources are and costs associated with groundwater clean-up.

Lastly, this study was fortunate to benefit from U.S. Geological Survey (USGS) mapping efforts in the region. The USGS conducted an AEM survey over much of the northern portion of Shelby County, in addition to their regional efforts. With instrumentation suspended from a fixed-wing aircraft, AEM was able to penetrate up to 300 feet bgs with near continuous readings, creating a detailed map of the subsurface and identifying 23 suspected breaches. Though AEM was conducted near the end of this five-year study, one of the suspected breaches from the AEM was drilled through, verifying the absence of a confining clay; subsequently, making it a known breach and supporting the belief that the other 22 suspected breaches identified by the AEM could also be real.

**Stream Work and Water Level Surveys**

Our major streams are expected to be gaining streams, meaning they receive groundwater through direct connection of the streambed with the shallow aquifer, mostly during summer and fall. However, if there is a breach near the stream, it may lose water instead to the aquifer. This phenomenon was investigated for the Loosahatchie River, Wolf River, and Nonconnah Creek by measuring the hydraulic conductivity of their streambeds at various locations and evaluating
downward leakage using a variety of instrumentation. Though much knowledge was gained from the streambed characterization and potential for groundwater-surface water exchange, no suspected breaches were found using these methodologies.

Surface water features such as lakes and streams, play a big role in recharging the shallow aquifer.

In the Fall 2020 and Spring 2021, water level surveys of the shallow aquifer were conducted to identify new anomalous depressions in the water table that would suggest the presence of a suspected breach. Though no new depressions were observed, we did learn that historical surveys (2005 and 2015) and those in this study would be better conducted from mid-November to mid-December and mid-April to early May when groundwater levels are at their lowest and highest, respectively. These surveys also revealed the impact of lost monitoring sites (both private wells and sites monitored by TDEC), which limits our ability to map the water table in detail.

Physical Measures

The shallow aquifer has become a focus of this investigation due to its contribution of water to the Memphis aquifer through breaches in the confining clay layer (UCCU), so how the shallow aquifer receives its water (or recharge) is important. Calculating recharge within an urban environment such as Memphis has numerous challenges, with the largest being the contribution of artificial recharge particularly through leaky underground infrastructure (e.g., sanitary sewer, storm water, water distribution) and irrigation. Even natural recharge to the shallow aquifer from precipitation is difficult because of impervious surfaces and land grading. However, we were able to ascertain plausible recharge rates (0.4 to 7 ft/year) based on the suite of tools used. This suite of tools included: a neutron probe to determine possible pulses of infiltrating water through the subsurface between ground surface and the water table (i.e., unsaturated zone); a fluoride signature in the shallow aquifer as representative of treated water contribution (e.g., lawn and golf course irrigation, distribution line leakage, filling of surface water features); fluctuations in groundwater levels; and leakage estimates from subsurface infrastructure. Though this investigation was not designed to reveal breaches, it provided valuable input for the CAESER-II groundwater model to improve its accuracy and reduce non-uniqueness, also suggesting that surface water features such as lakes and streams, could play a big role in recharging the shallow aquifer, adding more water into the system.

Laboratory Tests

Two laboratory studies were performed under this study: (1) to determine an optimal bentonite mixture for injection into a breach to greatly reduce inter-aquifer exchange (discussed above) and (2) what happens to TCE and Cr6+ when they move through the shallow and Memphis aquifers and through a breach. We found that the presence of iron as Fe3+ and organic carbon had the greatest impact on the mobility of TCE and Cr6+; therefore, future contaminant transport models should consider reactions, such as sorption.
Conclusions

In summary, **22 investigations were completed** over a 5-year period as part of a $5M study paid for by the citizens of Memphis and unincorporated Shelby County sponsored by MLGW and conducted by UoM CAESER. With a focus on the identification of breaches within the confining clay layer and their impact to the Memphis aquifer, this study vastly increased our knowledge on these breaches, expanding the number of suspected breaches from 6 to 36 and having verified through drilling six known breaches (one being an historically identified known breach). Breaches contribute modern water, typically of poorer quality, to the Memphis aquifer. The largest contribution of suspected breaches came from AEM conducted in northern Shelby County north of the Loosahatchie River. As the geology in north Shelby County is not different from the rest of Shelby County, the 23 suspected breaches identified through the AEM may reflect what could be present in the remaining two-thirds of the county, meaning there may be many more breaches. With the Memphis area being heavily urbanized and having occurrences of localized contamination, the continued need to better understand threats to the Memphis aquifer, our primary drinking water source, has been highlighted by this study.

Research Projects

Projects are listed as defined in the contract. For example, Year 1 Deliverable 1 is Project 1-1, Year 2 Deliverable 1 is Project 2-1, so on and so forth.

**Project 1-1**: Determine impact of known breaches in the Sheahan well field, determine presence of new breaches in the well field, and assess impact of Former Custom Cleaners site.

**Project 1-2**: Determine possible new breach locations proximal to the Wolf River by conducting riverbed seepage measurements, performing detailed discharge measurements, and developing well transects to monitor groundwater/surface water exchange.

**Project 1-3**: Perform aquifer characterization across Shelby County to constrain numerical model parameter estimation.

**Project 1-4**: Map potential aquitard breaches in Ensley Bottoms near the Davis well field, TVA, and proximal to the Allen well field using geophysical techniques.

**Project 1-5**: Groundwater pumping optimization to minimize contaminant movement from the water table aquifer to Memphis Aquifer using stochastic modeling.

**Project 2-1**: Use geophysical well records to investigate hypothetical paleo-drainage network atop the upper Claiborne confining unit. This will potentially help identify new breach locations and better inform numerical groundwater flow simulations.

**Project 2-2**: Subsurface mapping of geologic units to identify the presence of aquitard breaches and characterize the hydraulic properties of identified breaches using geophysical techniques in conjunction with other traditional methods.

**Project 2-3**: Conduct multi-scale investigation of surface water-groundwater interactions along the Loosahatchie River and Nonconnah Creek using a variety of methodologies to identify breaches. Incorporate these findings plus those of the Wolf River (Project 1-2) into Shelby County numerical groundwater model.

**Project 2-4**: Development of hypothetical groundwater models focusing on groundwater sustainability and modeling the fate and transport of various contaminants.
while conducting bench scale testing of retardation reactions.

- Contaminant Transport Study.
- Laboratory Work Study.

**Project 2-5:** Build upon Davis well field age-dating results to further refine and quantify source waters to the Memphis aquifer at the Davis well field through sampling water chemistry, groundwater age-dating, characterization of the hydrogeologic properties of a known breach impacting Davis, and development of a conceptual model of groundwater flow for later incorporation into a numerical model.

**Project 2-6:** Determine in-situ riverbed properties (hydraulic conductivity and thickness) for the Loosahatchie River, Wolf River and Nonconnah Creek to further constrain the Shelby County numerical groundwater model and for site-scale hydrogeologic analyses.

**Project 2-7:** Investigate Shaw well field to determine source waters and potential for modern water migration into the Memphis aquifer, development of unconfined conditions and vulnerability to nearby contaminated sites.

**Project 2-8:** Determine recharge mechanisms and rates to the shallow aquifer within Shelby County that contributes to its replenishment and source of additional inflow to the Memphis aquifer through aquitard breaches.

**Project 2-9:** Determine numerical modeling best practice for simulating groundwater conditions in the shallow aquifer that better represent groundwater levels and flow direction, vertical leakage through aquitard breaches, and avoiding inherent cell flooding (too much recharge) and drying (thin saturation depths).

**Project 2-10:** Numerical modeling to correlate age-dating and geochemical observations to known/potential breaches that will include possible paleo-drainage atop the upper Claiborne confining unit.

**Project 2-11:** Formulate and test methodologies to reduce or eliminate preferential inter-aquifer water exchange.

**Project 3-1:** Investigate a suspected aquitard breach near McCord well field by using electric resistivity and possibly other geophysical techniques within available open space. Project to include drilling as well for stratigraphic control.

**Project 3-2:** Investigate Mallory well field to determine source waters and potential for modern water migration into the Memphis aquifer field through sampling water chemistry, groundwater age-dating, mapping of the subsurface stratigraphy, and development of a conceptual model of groundwater flow for later incorporation into a numerical model.

**Project 3-3:** Incorporate more complete age-dating of Sheahan production wells into numerical model to resolve the probable location of breach(es) in the southern portion of the well field with attempted validation through geophysical techniques or drilling of an observation well.

**Project 3-4:** Conduct a county-wide water level survey of the shallow aquifer.

**Project 4-1:** Develop lithologic database of well logs for Shelby County for 3D representation and use for stratigraphic mapping and other upscaling tasks.

**Project 4-2:** Fly AEM (Airborne Electromagnetism) over section of north Shelby County that includes a suspected breach location.