THE UNIVERSITY OF MEMPHIS
Center for Applied Earth Science and Engineering Research

MLGW Aquitard Study; Contract 12064
PROJECT 1-2 EXECUTIVE SUMMARY

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.*

Objective

(1) To locate losing reaches along the Wolf River during low-flow condition at a coarse scale.
(2) To use different techniques (seepage meters, temperature sensors, piezometer, and differential stream gaging) to investigate riverbed seepage in potentially losing areas, identified from broader scale study.
(3) To monitor water levels of the Wolf River, the unconfined aquifer (shallow aquifer), and the confined Memphis aquifer to confirm the potential presence of a breach nearby.

Background

- The presence of a breach in the upper Claiborne confining unit (UCCU) is usually indicated by an abnormal depression in the shallow aquifer due to a downward vertical gradient and inter-aquifer water exchange between the shallow and the Memphis aquifers (Graham and Parks, 1986; Parks, 1990; Narsimha, 2007; Bradshaw, 2011; Gallo, 2015). When a breach is in close proximity to a river, it may locally depress the water table resulting in a directional movement of water (a loss) from the river toward the breach.
- This research hypothesizes that identifying losing reaches along the Wolf River under low-flow conditions can serve as a proxy for locating nearby UCCU breaches.
- This study was based on three phases. Phase I was focused on cost- and time-effective methodologies to cover the full 49 km of the Wolf River within Shelby County. For Phases II and III, more resources were allocated to allow for finer scale and more robust research methods such as using OTT current meters to measure discharge and drilling to observe groundwater gradients. Phases II and III locations were guided by Phase I results and historical data.

Phase I: Full Reach Scale

- The cost-effective seepage meter design included a seepage bucket (5-gallon bucket), a seepage bag (catheter bag) with a valve, and a housing or shelter for the bag (5-gallon bucket).
- Seepage meters were deployed in the lower 49 km of the Wolf River at a spacing of 100 m for a total of 400 data points.
- The gain or loss seepage rate at each location was calculated based on the change in weight of the seepage bag. Results are shown in Figure 1.
    - The average seepage rate for the first 14 km (upstream section in east Shelby County) is 4.7 g/min, whereas it is 13.2 g/min for the channelized downstream section: a significantly different value according to a t-test (p value < 0.0001).
    - The higher gain rate in the lower reach might be due to augmented connectivity between the Wolf River and the underlying aquifer after the channelization process, as suggested by Yates et al. (2003).

- The upper 14-km reach lies within the unconfined portion of the Memphis aquifer (Parks, 1990) where losing conditions or lower seepage rates are expected.

Figure 1. Calculated seepage rate for seepage meter measurements (100-m spacing) conducted in the lower 49 km reach of the Wolf River within Shelby County, Tennessee. Three areas (A, B, and C) have been enlarged to clearly show the rates and direction (gain/loss).

- The area near the closed landfill in Shelby Farms Park was examined in more detail since previous studies strongly suggest the presence of a breach nearby (Graham and Parks, 1986; Parks, 1990; Gentry *et al.*, 2006; Waldron *et al.*, 2009; Schoefernacker, 2018) with a documented decrease in discharge by Bradley (1991). The present seepage meter data does not conclusively reflect a losing pattern in this area; however, it does contain a single losing point (see Figure 1 inset B).
- A series of spatial analyses were conducted which shows spatial patterns in seepage rates whereby the lower seepage rates (lower gains) are clustered together.
- Three sub-reaches were chosen as close as possible to potential breach locations for further, detail study based on the spatial analyses and site accessibility – this is discussed more in the Phase II section below.
  - Area downstream of Austin Peay Highway (**Area A** in Figure 1)
  - Area near the closed landfill in Shelby Farms (**Area B** in Figure 1)
  - Area near Lansdowne Park at Germantown (**Area C** in Figure 1)

Phase II: Sub-Reach Scale

Phase II: Results

- Downstream area of the Austin Peay Highway (Area A)
  - Seepage meter deployment of over 36 data points in a closely spaced grid structure shows seven losing points and 29 gaining points.
  - The average seepage rates are lower near the left bank. The topography of the right bank is steeper. Potential for vertical hydraulic gradient between the river and the unconfined aquifer is lower at the left bank in comparison to the center and the right bank.
  - Vertical hydraulic gradient and temperature were measured at the depth of 30 cm and 80 cm from streambed at each data points using piezometers and temperature sensors (iButtons) respectively.
    - The observed differences in temperature are less than 1° C, which lies within the measurement accuracy of the iButtons that were used (± 1° C).
    - Head differences measured with piezometers were very low at most locations (only a few millimeters at most).
    - Low correlation was observed while comparing the vertical hydraulic gradient and temperature profile with the seepage rates.
  - Differential stream gaging using the OTT meters was conducted at this location on 8/10/2020, over a 930-m reach that incorporates the seepage grid.
  - The upstream discharge was 8.59 m^3/s and the downstream discharge was 8.61 m^3/s. Given the measurement uncertainty of 3%, this difference is negligible; thereby, indicating no decernable gain or loss.
- Area near the closed landfill in Shelby Farms (Area B)
  - Seepage meter deployment of over 45 data point in closely spaced grid structure shows two losing points and 43 gaining points.
  - The vertical hydraulic gradient was measured at a depth of 100 cm from the streambed. Comparing seepage rates with this vertical hydraulic gradient shows a low correlation value.
  - The average seepage rates are lower near the right bank and seems to be gaining less which might be due to the presence of a depression in the unconfined water table on that side; hence, reflecting the effects of the known breach near the right bank (Graham and Parks, 1986; Parks, 1990; Waldron et al., 2009; Schoefernacker, 2018).
  - Differential stream gaging was conducted at this location on 8/11/2020, over a 970 m-long reach which includes the above seepage grid.
    - The upstream discharge was 8.36 m^3/s and the downstream discharge was 8.55 m^3/s. The difference of 0.19 m^3/s in discharge lies within the measurement uncertainty of 3%, which suggests that this reach cannot be definitively described as gaining or losing.
    - The existing, known breach near the right bank might influence this reach minimally, or else the reach is losing to shallow aquifer due to the *more distant* breach, while at the same time gaining on its left bank such that there exists no overall net gain.
- Area near Lansdowne Park at Germantown (Area C and Figure 2)

- Seepage meter deployment of over 42 data points in closely spaced grid structure shows six losing points and 36 gaining points.
- Comparing seepage rates with the vertical hydraulic gradient (measured at 100 cm depth) and temperature profile (measured at depths of 20 cm, 60 cm, 100 cm below the streambed, as well as in the mid-section of the water column) shows low correlation.
- Differential stream gaging was conducted at this location on 8/6/2020, in a reach of length 820 m between Transects 1 and 2 shown in Figure 2.
    - The upstream discharge was 9.74 m^3/s and the downstream discharge was 9.31 m^3/s.
    - Considering standard normal distribution of the measured discharges, the overlapping area between two normal distributions (centered about the gaged discharges at two cross-sections) was computed as a way to check whether the discharges at the two cross-sections are significantly different. Even though the difference of 0.43 m^3/s lies within the measurement uncertainty of 3%, these two discharges are significantly different with only a 14% overlap in area between the two normal distribution.
- Another differential stream gaging was also conducted on 8/5/2020, over a reach of length 890 m between Transects 3 and 4 in Figure 2.
    - The upstream discharge was 9.94 m^3/s and the downstream discharge was 9.85 m^3/s. The difference between these two discharges is negligible.
- When comparing the discharge near Lansdowne Park (at transect 1, 2, 3, and 4) to the continuous measurements at the U.S. Geological Survey (USGS) gage (1.7 km to 3.8 km downstream), it was observed that the discharges measured near Lansdowne Park were significantly higher (3.6 to 7.8 % higher) than the discharge recorded by USGS gage, which suggests that the Wolf River is mostly losing along these reaches.

Figure 2. Location of well cluster, seepage meter grid, and stream gaging transects along the reach near Lansdowne Park in Germantown

Phase II: Conclusions

- In general, a high spatial variation in seepage rates is observed at the finer spatial measurement scale indicating high variation in vertical exchange fluxes. This large spatial variability might be due to heterogeneity in hydraulic conductivity or vertical hydraulic gradient, local hyporheic exchange (that usually occurs in upper layers of unconsolidated streambeds), or due to the fact that the seepage measurements are performed at a very small spatial scale.
- The differential stream gaging data only show small differences between upstream and downstream cross-sections in most cases. Though this may the reality of the system under the conditions observed, other reasonings include simultaneous gain of water from one bank and loss to the other bank where there a breach exists or reach lengths are too short to capture any losing/gaining signal.
- Comparing seepage rates with piezometer and temperature profile data yields low correlation values, which could be due to the issues associated with each individual method and its application.

Phase III: Monitoring River Stage and Groundwater Levels

- Based on the results of Phases I and II, a location near Lansdowne Park in Germantown was chosen to continuously monitor the changes in river stage and head in both the shallow and Memphis aquifers.
- A stilling well in the Wolf River as well as a monitoring well cluster (i.e., one well screened in the shallow aquifer and the other well in the Memphis aquifer) were installed in close proximity along the Germantown Greenway.

Phase III: Results

- The borehole log for the new monitoring well (GGMW2) shows a 55 ft (17 m) thick clay layer (UCCU) at this location starting at a depth of 50 ft (15 m). This evidence disagrees with the notion that this river segment lies in an outcrop zone at least at this specific point, as suggested by Parks (1990) and Larsen (personal comm.). However, this does not discard the potential existence of a breach or an outcrop zone somewhere nearby owing to the high spatial heterogeneity in clay thickness as evident, for example, in the area near the closed landfill in Shelby Farms (Parks and Mirecki, 1994; Gentry et al., 2006).
- A limited timeframe of data collected from the monitoring wells and stilling well are shown in Figure 3. The river gains during base flow conditions and temporarily converts into a losing system during large flow events.
- The Memphis aquifer did not show any significant response to the high flow events during the study period. The response of the Memphis aquifer at this location needs further investigation using data over a longer duration.
- When comparing the water levels observed in the well cluster with the water-table maps in the literature (Narsimha, 2007; Ogletree, 2016), significant differences in the unconfined aquifer water levels were found. The unconfined aquifer water levels are about 15 ft below the interpolated data obtained from the Ogletree (2016). The observed differences between present water levels, as observed in this study, and those from historical map are possibly due to the addition of new data points as discussed by Ogletree (2016).

- Other sub-reaches need to be further investigated using additional and improved methodologies to confirm losing conditions, before drilling additional observation wells.

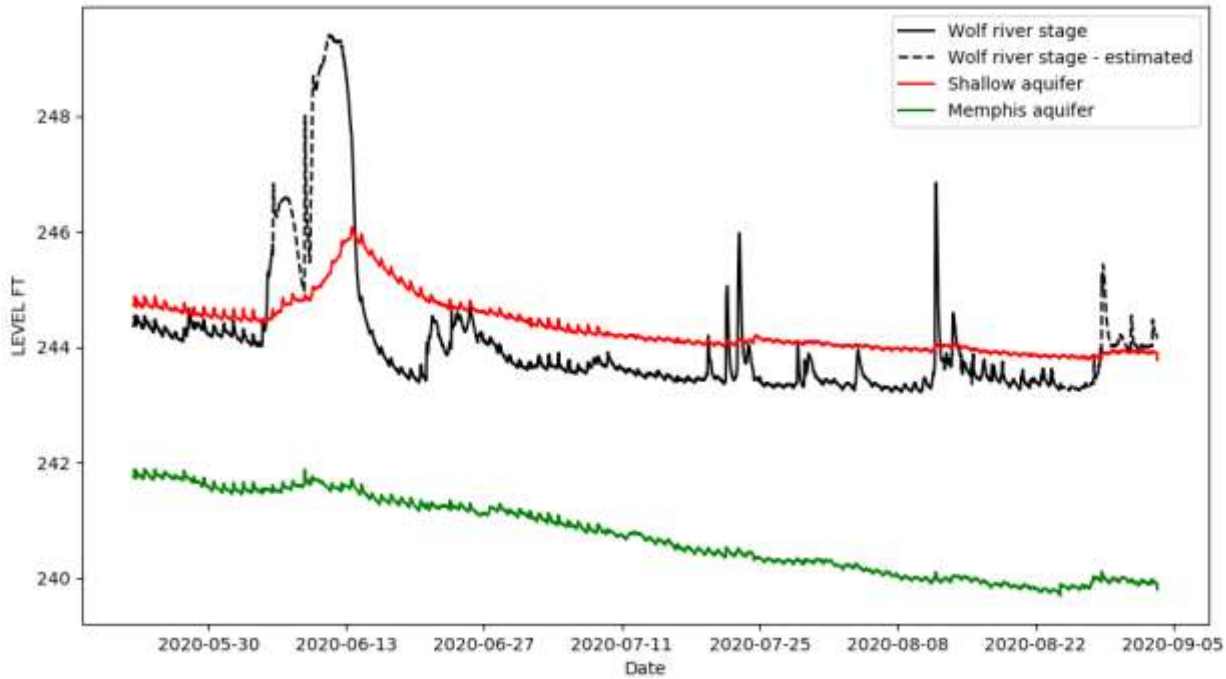

Figure 3. Comparison of time series for the Wolf River stage, the elevation of the water table in the unconfined aquifer, and the potentiometric surface of the Memphis aquifer from wells located near Lansdowne Park in Germantown.

References

Bradley, M.W., 1991. Ground-Water Hydrology and the Effects of Vertical Leakage and Leachate Migration on Ground-Water Quality near the Shelby County Landfill, Memphis, Tennessee.

Bradshaw, E.A., 2011. Assessment of Ground-Water Leakage through the Upper Claiborne Confining Unit to the Memphis Aquifer in the Allen Well Field, Memphis, Tennessee. University of Memphis, Memphis, TN.

Gallo, H.G., 2015. Hydrologic and Geochemical Investigation of Modern Leakage beneath the McCord Well Field, Memphis, Tennessee. University of Memphis, Memphis, TN.

Gentry, R., L. McKay, N. Thonnard, D. Larsen, and J. Anderson, 2006. Novel Techniques for Investigating Recharge to the Memphis Aquifer. American Water Works Association.

Graham, D.D. and W.S. Parks, 1986. Potential for Leakage among Principal Aquifers in the Memphis Area, Tennessee. doi:10.3133/wri854295.

Larsen, D., S. Schoefernacker, and B. Waldron, 2017. A Report on the Results of a Groundwater Vulnerability Study in Shelby County, Tennessee. Memphis, TN. Unpublished Work. Personal Communication.

Narsimha, V.K.K., 2007. Altitudes of Ground Water Levels for 2005 and Historic Water Level Change in Surficial and Memphis Aquifers, Shelby County, Tennessee. University of Memphis.

Ogletree, B.., 2016. Geostatistical Analysis of the Water Table Aquifer in Shelby County, Tennessee. University of Memphis, Memphis, Tennessee.

Parks, W.S., 1990. Hydrogeology and Preliminary Assessment of the Potential for Contamination of the Memphis Aquifer in the Memphis Area, Tennessee. doi:10.3133/wri904092.

Schoefernacker, S., 2018. Evaluation and Evolution of a Groundwater Contaminant Plume at the Former Shelby County Landfill, Memphis, Tennessee. University of Memphis.

Waldron, B.A., J.B. Harris, D. Larsen, and A. Pell, 2009. Mapping an Aquitard Breach Using Shear-Wave Seismic Reflection. Hydrogeology Journal 17:505–517.