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

MLGW Aquitard Study; Contract 12064
PROJECT 1-3 EXECUTIVE SUMMARY

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

Objective

(1) To determine localized aquifer parameters of the Memphis aquifer in Shelby County such as transmissivity and storativity in order to improve the accuracy of numerical model solutions by reducing model non-uniqueness.

Summary

- Groundwater modeling is important to describe and predict the behavior of groundwater flow systems to address issues related to groundwater resources management.
- The limitation of field measurements often leads to parameter non-uniqueness.
  - Non-uniqueness refers to multiple numerical solutions resulting in similarly good matches in every modeled solution which could provide an inaccurate description of the aquifer flow system (Zechman *et al.*, 2006).
  - Non-uniqueness can be reduced by including more parameter data that is based on physical observation.
- Aquifer characterization studies have been performed in Shelby County to ascertain the hydraulic properties of the Memphis aquifer.
  - Values from studies conducted between 1949 to 2002 reported values of transmissivity and storativity with a combined range between 30 to 6,400 m^2/day and 0.0001 to 0.003, respectively.
  - A study by Waldron et al. (2011) that was developed in coordination with the U.S. Geological Survey provided a scoring matrix to assess the quality of the aquifer parameter values (Table 1) and determined that most aquifer tests from previous studies scored poorly.
    - The factors listed in this scoring matrix were used in this study.
  - Locations for most of the historic tests are not specified, instead providing ranges across broad areas such as for a county.
  - Villalpando-Vizcaino (2019) identified this broad range as an obstacle in appropriately representing aquifer parameters in his numerical model of Shelby County.

Table 1. Scoring matrix used to qualitatively assess the reliability of the aquifer parameter data. Retrieved from (Waldron et al., 2011).

Rank Criteria
1. Published or Approved (yes +1) Have the test results been published in a USGS report? If yes, plus 1
2. Multiple pumping wells (yes -2) Are nearby pumping wells affecting the test? If yes, minus 2
3. Other wells on and off (yes -5) Are nearby pumping wells turning on and off? If yes, minus 5
4. Observation wells (unknown -1, no -2) Were water levels monitored in observation wells for the aquifer test? If unknown, minus 1 If no, minus 2
5. Test duration (>24 hours +1, unknown -1, <24 hours -2, <1 hour, -3) If the pumping duration is more than 24 hours, plus 1 If the pumping duration is unknown, minus 1 If the pumping duration is less than 24 hours, minus 2 If the pumping duration is less than 1 hour, minus 3
6. Good supporting information (no -2) Do the records provide good supporting information for the test? If not, minus 2
7. Multiple Analyses (yes +1, no -2) Were multiple analytical methods used in the analysis? If yes, plus 1 If not, minus 2
8. Multiple Wells Analyzed (yes +1) Were analysis conducted on multiple wells for the test? If yes, plus 1
9. Drawdown and recovery analyses (no -2) Were the drawdown and recovery data both analyzed? If not, minus 2

Waldron et al., (2001)

- Pumping tests were determined to be the best methodology to estimate reliable aquifer at a larger area scale.
  - Six pumping tests were conducted from March through May of 2019, in four MLGW well fields (Sheahan, Morton, Davis and Mallory), and one Germantown well field. The latter well field was needed because of a lack of data in southeast Shelby County which is a section of contributing groundwater to Lichterman, Allen and Davis well fields.
    - Selection of wells to be used for characterizing the aquifer were based on three criteria:
      1. Well-distributed across the county;
      2. Availability of an associated observation well screened at a similar interval than that of the production well; and
      3. Observation wells located as distant as possible from the production well to reduce the influence of additional production wells as well as the effects of partial penetration.
    - One well pair was identified in each well field except for Mallory where two pairs were chosen. Therefore, two pumping tests were performed in this well field: one on the

western part of the well field (termed “Mallory W.”), and the other on the eastern part (termed “Mallory E.”).

- A pumping test consists of measuring the water-level response in an observation well imposed by the withdrawal of water in a pumping well (i.e., production well).
  - Pumping tests followed ASTM D4050-14 .
  - Variation in withdrawal rates from a production well was considered low, not varying by more than 10% from the mean discharge.
  - The duration of the test was 48 hours to attain as near a stable water-level as possible (Kruseman and De Ridder, 1994), with an additional 12+ hours prior and after the test to establish a static level and for adequate aquifer recovery (recovery test), respectively.
    - A recovery test consists in measuring the water-level changes after the pumping test has ended.

- Though attempts were made to eliminate pumping from nearby production wells, it was determined that some nearby production wells were actually running during the pumping tests.
  - Information on each neighboring production well was obtained from MLGW's Supervisory Control and Data Acquisition (SCADA) network to determine their exact status during the test period.
  - Discharge rates of the interfering wells were unknown; therefore, it was assumed that their discharge ranged between 1000 – 1500 GPM.
  - Wells that had a notable impact on a test was determined using:
    a) Information on the distance between the production and observation wells and the elevation of the well-screen; and
    b) SCADA information.
  - For example, figure 1 shows the water levels recorded at two observation wells in the Sheahan well field along with nearby production wells that were expected to be off during the pump test, but instead repeatedly came on and off .

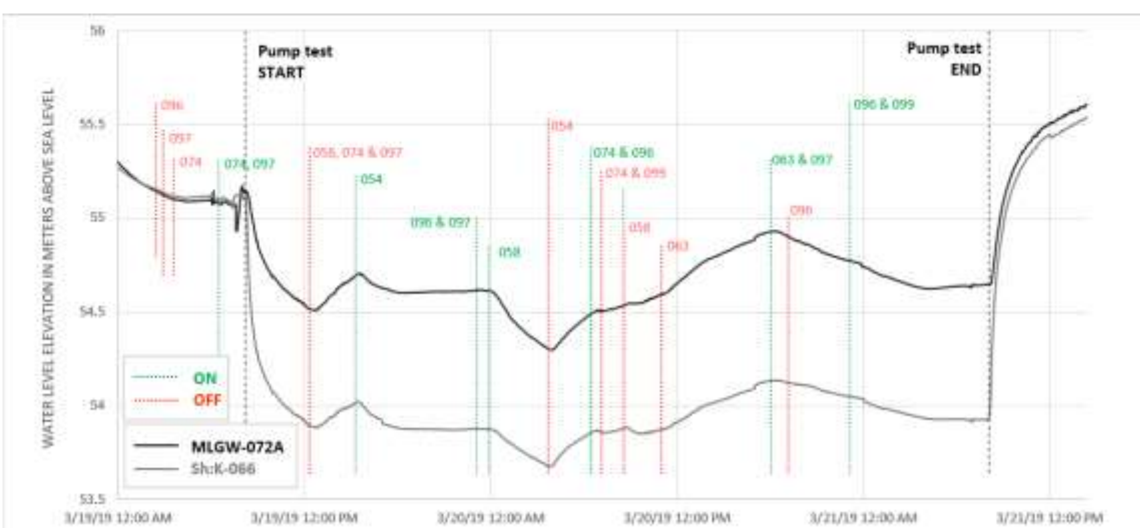

Fig. 1. Water levels observed at wells MLGW-072A and Sh:K-066 during the pumping test at Sheahan.

- The drawdown data collected from each pumping test was plotted against time and analyzed using AQTESOLV.
    - This software package accounts for partial penetration (i.e., well screen does not extend over the entire thickness of the aquifer) and the influence of additional production wells.
    - Each dataset was analyzed using two analytical solutions to identify the solution curve that best fits the data:
        - Theis (1935) solution for confined aquifers
        - Hantush-Jacob (1955) for semi-confined aquifers
    - Analysis of the drawdown curves were constrained to a time window when the interference from other production wells was minimized.
    - The solution curve with the smaller sum of residuals (RSS) (i.e. difference between the observed and simulated drawdowns) was selected.
        - By constraining the analysis to an appropriate time window, the RSS was reduced to more than 98% for most cases.
        - Accounting for the interfering wells in the drawdown analysis, the RSS was reduced by 32-98%.
- **Aquifer parameter results:**
    - The logarithmic plots of the data sets from the pumping tests at Sheahan, Davis, and Mallory showed a decrease in the drawdown rate over time, typical of semi-confined aquifer systems (Dawson and Istok, 1992).
        - This is attributed to downward leakage from the confining unit as these well fields are located near suspected breach locations.
        - As an example, Figure 2 shows the logarithmic plot of the time-drawdown data from the test conducted at Sheahan well field superposed with the solution curves before and after accounting for the influence of other production wells (orange and blue lines, respectively).
            - ➢ The vertical red dashed line in Figure 2 indicates the time-window constrain.

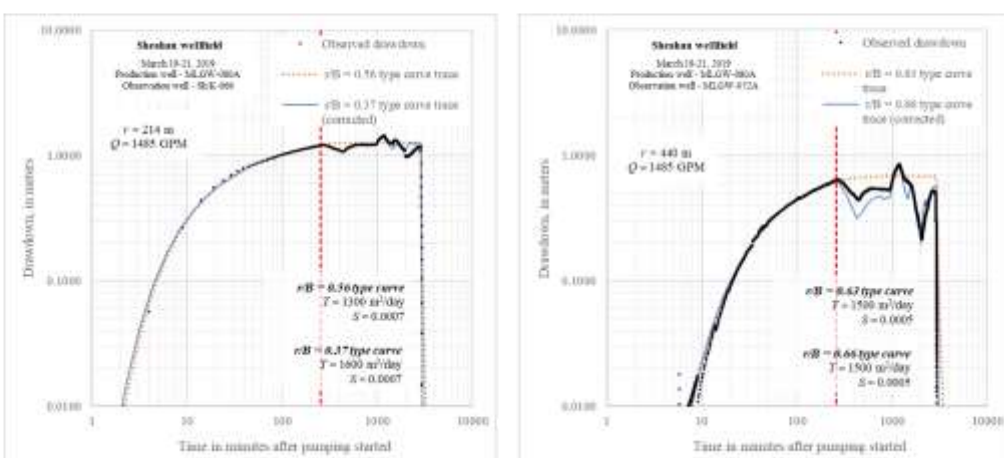

Fig. 2. Hantush-Jacob solution curves for the test performed at Sheahan.

- Estimation of parameters for Mallory W. relied on airline measurements taken at the pumping well, MLGW-001C.
  - Storativity could not be estimated for Mallory W. since the test was performed only on the pumping well (Leven and Dietrich, 2006).
- Morton's drawdown curve was observed to resemble a type curve for confined aquifers despite the influence of interfering pumping wells.

- Resulting solution curves matched well observed drawdown reading from the field; thereby, providing strong confidence in the parameters estimated for these well fields.
- A summary of the aquifer properties determined from this study is presented in Table 2.
  - All values fall within the range reported by previous studies.
  - Values provided in this study (Table 2) varied in less than one order of magnitude within each well field; thereby, providing more localized values across Shelby County.
  - The average value of transmissivity determined for the Memphis aquifer within Shelby County, 2000 m^2/day, falls below the averages reported by previous studies of about 4000 m^2/day.
  - The average storativity of 0.002 estimated in this study is in accordance with the average of previous studies.
  - Most values estimated using recovery data for the tests performed at Sheahan and Mallory fall within the same order of magnitude, adding certainty to the parameters estimated for these well fields.

Table 2. Transmissivity and storativity values estimated from the pumping and recovery tests performed at five well fields.

Wellfield	Average discharge (GPM)	Well	Pumping test: Transmissivity (m^2/day)	Pumping test: Storativity	Pumping test: r/B	Recovery test: Transmissivity (m^2/day)	Recovery test: Storativity
Sheahan	1485	Sh:K-066	1600	0.0007	0.37	1300	0.0005
		MLGW-72A	1500	0.0005	0.66	1500	0.0002
Morton	1420	Sh:P-113	3100	0.009	---	---	---
Germantown	700	Sh:L-089	2500	0.002	---	---	---
Davis	1400	Sh:J-140	2700	0.001	0.36	---	---
		MLGW-401	2800	0.002	0.32	---	---
Mallory W.	1400	MLGW-001C	1800	---	0.09	1700	N/A
Mallory E.	1150	Sh:O-212	600	0.002	0.29	640	0.002
		MLGW-016C	900	0.0006	0.24	900	0.001

N/A – Not applicable

- In addition to the ASTM D4050-14 guidelines, factors outlined by Waldron *et al*. (2011) (Table 1) were also considered to achieve greater confidence in the accuracy and reliability of data collected from the pumping tests.
  - The pumping tests performed in MLGW well fields averaged a score of 10.2 which well surpassed the average score of previous records of 4.1.
- Tests were conducted following a methodology that met the criteria established by Waldron et al. (2011) and addressed the sources of error to achieve improved scores.
  - The tests from this study are considered to have more accurate data than previous studies due to the usage of automatic recording devices and a more rigorous analysis allowed by AQTESOLV.

The estimated values are expected to lead to a better understanding of the Memphis aquifer system in future modeling efforts by reducing model non-uniqueness.

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