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# Southern Sector Humate Injection Well Performance Testing


**K. L. Dixon**


August 29, 2019


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# EXECUTIVE SUMMARY

Three short duration injection tests were conducted on wells at the humate test site. For each injection event, potable water was gravity drained into the well casing. Pressure response was monitored in the injection well and these data were used to estimate the injection capacity of each well. Injection capacity was calculated by dividing the average injection flow rate by the head increase observed in the injection well. Nearby injection wells were used as observation wells and data from these wells were used to estimate the local hydraulic conductivity.

The results of this analysis show that it is hydraulically feasible to gravity inject water into the test wells. The estimated water injection capacity of each well as determined by injecting potable water is shown in Table E-1. It is important to note that these short duration tests utilized water and not the humate solution that will ultimately be injected into the aquifer. The results of these tests do not account for physical or chemical processes that may occur over longer time scales. Injection well performance typically declines over time due to water-chemistry issues, air entrainment, and aquifer clogging (Driscoll, 1987). Therefore, these results should be viewed as optimistic estimates of injection capacity.

Table E-1. Injection Capacity of Humate Test Wells[1]

| Well Name | Average Water Injection Capacity[1,2,3] (gpm/ft) |
|---|---|
| SSM001B | 0.7 |
| SSM037B | 0.8 |
| SSM040CC | 1.0 |

[1]Using potable water.
[2]Under gravity flow conditions.
[3]Gallons per minute per foot of head increase.

Data from the injection tests were analyzed to estimate local aquifer properties. Transmissivity values for all tests ranged from 0.62 to 1.07 $ft^2$/min with an average value of 0.805 $ft^2$/min. Hydraulic conductivity was calculated by dividing transmissivity by the aquifer thickness (53 ft). Hydraulic conductivity ranged from 16.7 to 29.2 ft/day with an average value of 21.9 ft/day. Storativity values ranged from 0.0001 to 0.001 with an average value of 0.0006.

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| | |
|---|---|
| ~ | approximate, approximately |
| EC&ACP | Environmental Compliance and Area Completion Projects |
| CBCU | Crouch Branch Confining Unit |
| GCCU | Green Clay Confining Unit |
| gpm | gallons per minute |
| HWMF | Hazardous Waste Management Facility |
| LLAZ | Lost Lake Aquifer Zone |
| PCE | Perchloroethylene |
| PVC | Polyvinyl Chloride |
| SCDHEC | South Carolina Department of Health and Environmental Control |
| SRNL | Savannah River National Laboratory |
| SRS | Savannah River Site |
| TCE | Trichloroethylene |
| UIC | Underground Injection Control Permit |
| VOC | Volatile Organic Compound |

## 1.0 Introduction

Groundwater in the Lost Lake Aquifer Zone (LLAZ) in the Southern Sector of the M-Area Hazardous Waste Management Facility (HWMF) is contaminated with chlorinated ethenes including trichloroethylene (TCE) and tetrachloroethylene (PCE). Environmental Compliance and Area Completion Projects (EC&ACP) is evaluating the extraction and injection of amended groundwater for evaluation as a corrective action for the LLAZ in Southern Sector (SRNS, 2019). During the evaluation, groundwater will be extracted from the lower portion of the LLAZ using the lower screen of groundwater recirculation well SSR001 (Figure 1). It will then be amended with humate, macronutrients, and an antifoam agent, and subsequently injected into the LLAZ using three nearby injection wells (SSM001B, SSM037B, and SSM040CC).

The injection wells are installed in the LLAZ near groundwater recirculation well SSR001 as shown in Figure 1. Wells SSM001B and SSM0037B are constructed of 2-inch diameter PVC with a screened interval of ~5 feet. Well SSM040CC is also constructed of 6-inch diameter PVC and has a screened interval of ~20 feet. Well construction details are provided in Table 1.

At the request of EC&ACP, Savannah River National Laboratory (SRNL) conducted short duration injection well performance testing on the three humate injection wells identified in Table 1. The project was conducted in accordance with test plan SRNS-RP-2019-00101 (Dixon, 2019). The purpose of the testing was to estimate the water injection capacity of each well under gravity flow conditions.

## 2.0 Objectives

The objective of the injection well testing was to determine the water injection capacity of each well. For the purposes of this test, injection capacity was defined as the average injection flow rate divided by the head increase observed in the test well in response to injection. A secondary objective of the testing was to estimate the hydraulic conductivity of the Lost Lake Aquifer in the immediate vicinity of the injection wells.

## 3.0 Test Methods

Injection tests were conducted on three wells screened in the LLAZ at the humate test site (Figure 1, Table 1). Figure 2 shows the relative screen placement of the wells at the humate test site. The overall approach for the testing was to inject a volume of water (~350 to 400 gallons) into each well one at a time and monitor the pressure response of the aquifer as a function of time. SCDHEC authorized the injection of potable water as part of well testing prior to the humate injection test (SRNS, 2019). Pressure response was monitored in the injection well being tested and neighboring wells. Data collected from the transducers were used to calculate injection capacity and to estimate the hydraulic conductivity of the aquifer in the immediate vicinity of the injection well.

### 3.1 Test Configuration

Figure 3 presents a generalized conceptual model for the injection well performance testing. A water truck with a nominal 500-gallon tank was used to supply potable water for the injection testing. Potable water for all testing was obtained from SRS Building 772-7B. The water tank was equipped with a valve and flow totalizer. A flexible hose was used to connect the water tank to the well. The flexible hose was inserted directly in the well casing to allow water to flow freely into the well casing. Based on previous injection testing in the LLAZ in Western Sector (Dixon, 2018), it was determined that a well head assembly was not needed for this project. The purpose of the well head assembly is to extend the well casing above the level of water in the tank to prevent overflowing conditions for wells screened in lower permeability formations. The well head assembly can present challenges with venting the air that is displaced by the injected water. Elimination of the well head assembly simplified testing by allowing the displaced air to freely vent to the atmosphere.

Each injection well (Table 1) was tested one at a time. The pressure response in the aquifer due to injection was monitored in the injection well being tested and in at least one neighboring injection well. When the test setup was complete, the valve on the tank was opened and water gravity drained into the well. The pressure response in the injection well was monitored on a laptop computer. An injection test was considered complete when the excess head in the injection well decreased to within 1% of the static pretest water level. The average injection capacity was calculated by dividing the average injection flow rate by the average head increase observed in the test well. This is analogous to specific capacity for a pumping well where extraction flow is divided by drawdown as measured in feet of head.

## 4.0 Results

The three wells that may be used for humate injection were tested to determine injection capacity (Table 1). Results from the injection tests are presented in Table 2. It is important to note that the humate solution may have properties different than water and may have different injection rates compared to those determined in this testing. The results presented here should be viewed as optimistic. The injection capacity of a well typically declines over time due to issues such as water-chemistry, air entrainment, and aquifer clogging (Driscoll, 1987). The influences of these processes are not reflected in the results of these short duration tests.

### 4.1 Water Injection Testing

Approximately 389 gallons of potable water were injected into SSM001B under gravity flow conditions (Table 2; Figure 4 and Figure 5). The flow rate as determined from the flow totalizer readings was 11.4 gpm. For SSM001B, it took 35 minutes to empty the tank and 36.9 minutes from the start of injection for the excess head to dissipate to within 1% of the pretest water level. The average water injection flow rate of SSM001B was determined to be 10.6 gpm. During injection, head increases in the injection well until the flow out of the well equals the flow into the well. For SSM001B, the average head increase due to injection was 14.8 feet. This yields an injection capacity of 0.7 gpm/ft for SSM001B. A pressure response was observed in all three observation wells (SSM037B, SSM037C, and SSM040CC) due to injection in SSM001B (Figure 5). This indicates that all four wells are hydraulically connected.

Approximately 392 gallons of potable water were injected into SSM037B under gravity flow conditions (Table 2; Figure 6 and Figure 7). The flow rate as determined from the flow totalizer readings was 10.1 gpm. For SSM037B, it took 40 minutes to empty the tank and 40.9 minutes from the start of injection for the excess head to dissipate to within 1% of the pretest water level. The average injection flow rate of SSM037B was determined to be 9.6 gpm under gravity flow conditions. The average head increase in SSM037B due to injection was 12.7 feet. This yields an injection capacity of 0.8 gpm/ft for SSM0037B. A pressure response was observed in all three observation wells (SSM001B, SSM037C, and SSM040CC) due to injection in SSM037B (Figure 7).

Approximately 343 gallons of potable water were injected into SSM040CC under gravity flow conditions (Table 2; Figure 8 and Figure 9). The average flow rate as determined from the flow totalizer readings was 6.9 gpm. A larger hose (2-inch) was used to inject into SSM040CC than the 1-inch hose used for the other wells. The larger hose required a combination of fittings that ultimately resulted in a lower injection rate than for the other wells. For SSM040CC, it took 60 minutes to empty the tank and 62.3 minutes from the start of injection for the excess head to dissipate to within 1% of the pretest water level. The average injection flow rate of SSM040CC was determined to be 5.5 gpm under gravity flow conditions. The average head increase was 5.5 feet. This yields an injection capacity of 1.0 gpm/ft for SSM0040CC. A pressure response was observed in all three observation wells (SSM001B, SSM037B, and SSM037C) due to injection in SSM040CC (Figure 9).

**4.2 Local Aquifer Hydraulic Properties**

The data from the injection tests were analyzed to determine the local hydraulic properties of the LLAZ at the humate test site. Each injection test was comparable to a short duration aquifer pumping test. For the injection test analysis, injection flow rate was substituted for pumping rate and pressure increase was used instead of pressure drawdown. This allowed for analysis using traditional methods derived for pumping test analysis.

The LLAZ is a semi-confined aquifer bounded by the Green Clay Confining Zone (GCCZ) on the top and the Crouch Branch Confining Unit (CBCU) on the bottom (Dixon, 2018). The aquifer was estimated to be 53 ft thick in the test area. Although the LLAZ is a semi-confined aquifer, the Theis solution for non-leaky, confined aquifers was used to analyze the injection test data (Theis, 1935; Hantush, 1961a and b). The more relevant assumptions of the solution include that the aquifer is of infinite areal extent, it is homogeneous and uniform in thickness, and that the diameter of the well is small so that storage in the well may be neglected. A non-leaky, confined solution was selected because the injection tests were low volume and short duration (< 1hr). This type of test would not be expected to provide a meaningful estimate of aquitard leakage. In cases where leakage is negligible (either due to aquitard properties or test constraints), both the non-leaky confined aquifer solution (Theis, 1935) and leaky, confined aquifer solution (Hantush and Jacob, 1955) yield essentially the same result for aquifer transmissivity.

For each injection event, the injection flow rate was assumed to be adequately represented by the flow rate of water out of the tank. This approximation is reasonable when the time to empty the tank is comparable to the time for head to dissipate in the well. This was the case for each of the injection tests (Table 2).

The pressure response from each injection test was analyzed separately in AQTESOLV (Geraghty and Miller Inc., 1999). The results of these analyses are presented in Table 3 and Figure 10 through Figure 17. Transmissivity values for all tests ranged from 0.62 to 1.07 $ft^2$/min with an average value of 0.805 $ft^2$/min ($\sigma$ =0.137 $ft^2$/min). Hydraulic conductivity was calculated by dividing transmissivity by the aquifer thickness (53 ft). Hydraulic conductivity ranged from 16.7 to 29.2 ft/day with an average value of 21.9 ft/day ($\sigma$ = 3.7 ft/day) which is comparable to a clean sand (Freeze and Cherry, 1979). Storativity values ranged from 0.0001 to 0.001 with an average value of 0.0006 ($\sigma$ =0.0004). The results compare favorably to those reported by Dixon (2018) for the LLAZ as determined from a pumping test at RWM018. Dixon (2018) reported an average transmissivity of 0.816 $ft^2$/min and an average hydraulic conductivity of 21.4 ft/day. White and Hiergesell (1997) reported a hydraulic conductivity of 25.4 ft/day from aquifer testing at airlift recirculation well SSR012, which is located nearby. During a 72-hour pumping test at RWM-16, Hiergesell (1993) also observed an average (n=3) hydraulic conductivity of 25.4 ft/day using the Hantush method of analysis.

## 5.0 Conclusions

Three short duration water injection tests were conducted on wells at the humate test site. For each injection event, potable water was gravity drained into the well casing. Pressure response was monitored in the injection well and these data were used to estimate the injection capacity of each well. Nearby injection wells were used as observation wells and data from these wells were used to estimate local hydraulic conductivity.

The results of this analysis show that it is hydraulically feasible to gravity inject water into the test wells. The water injection capacity of the wells ranged from 0.7 to 1.0 gpm/ft. It is important to note that these short duration tests utilized water and not the humate solution that will ultimately be injected into the aquifer. The results of these tests do not account for physical or chemical processes that may occur over longer time scales. Injection well performance typically declines over time due to water-chemistry issues, air entrainment, and aquifer clogging (Driscoll, 1987). Therefore, these results should be viewed as optimistic estimates of injection capacity.

Data from the injection tests were analyzed to estimate local aquifer properties. Transmissivity values for all tests ranged from 0.62 to 1.07 $ft^2$/min with an average value of 0.805 ft2/min. Hydraulic conductivity was calculated by dividing transmissivity by the aquifer thickness (53 ft). Hydraulic conductivity ranged from 16.7 to 29.2 ft/day with an average value of 21.9 ft/day. Storativity values ranged from 0.0001 to 0.001 with an average value of 0.0006. Lower hydraulic conductivity values were associated with the upper portion of the aquifer and were attributed to aquifer heterogeneity.

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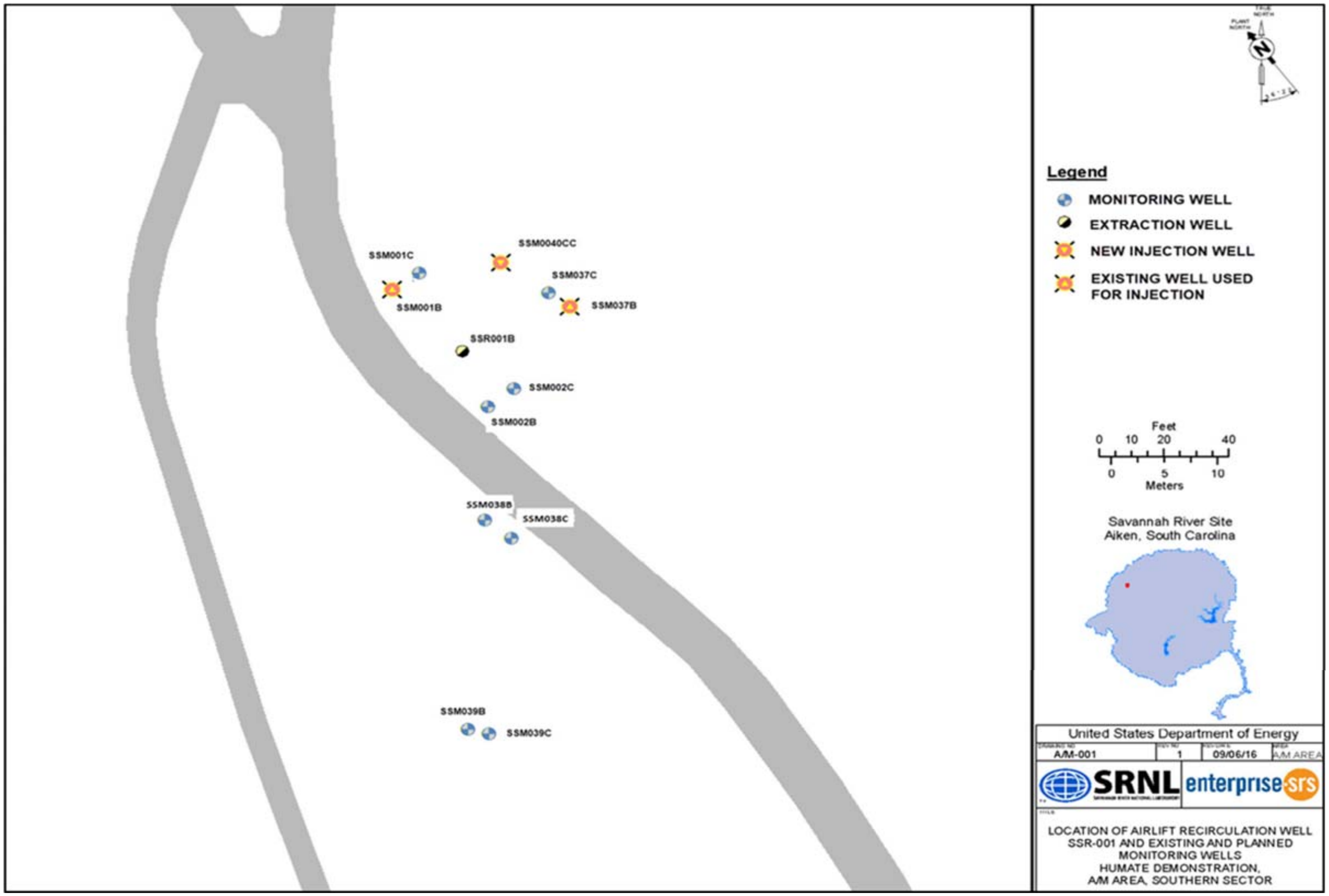


**Figure 1: Location of Injection Wells.**

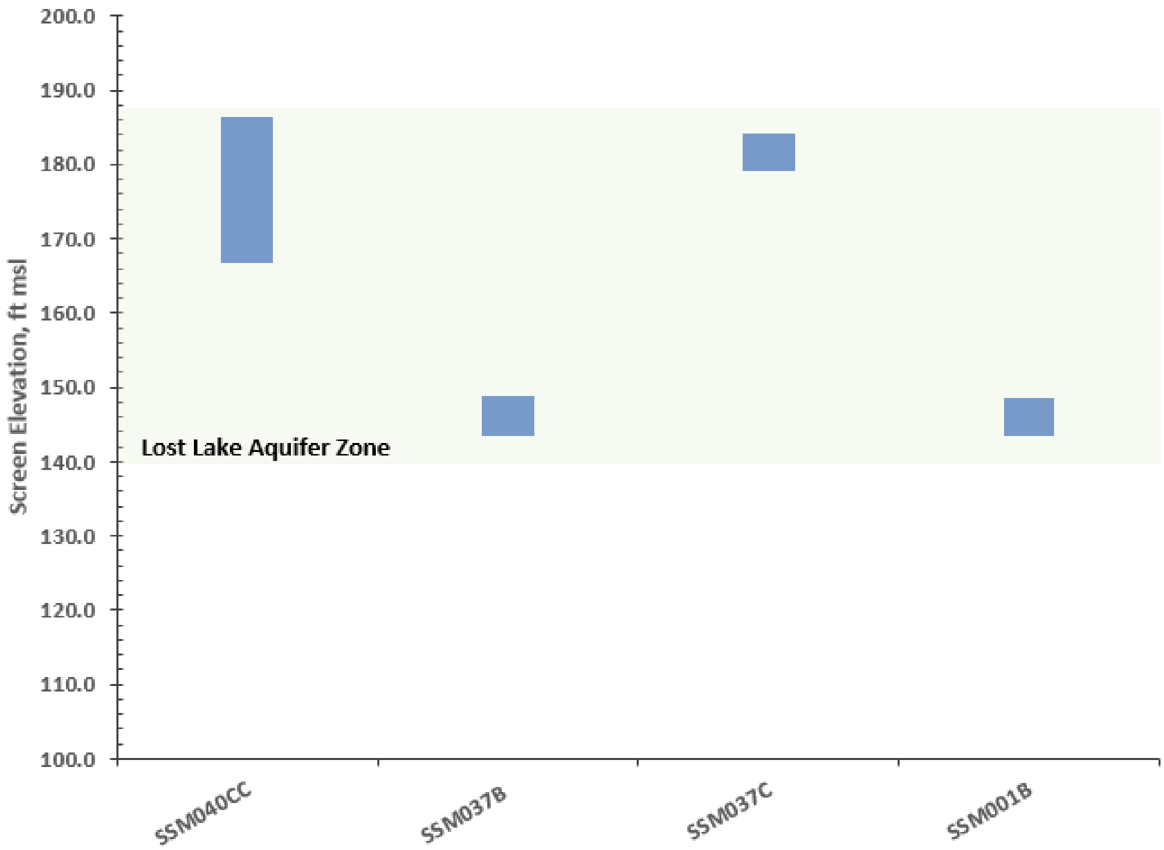


**Figure 2. Screen Placement of Humate Test Wells**

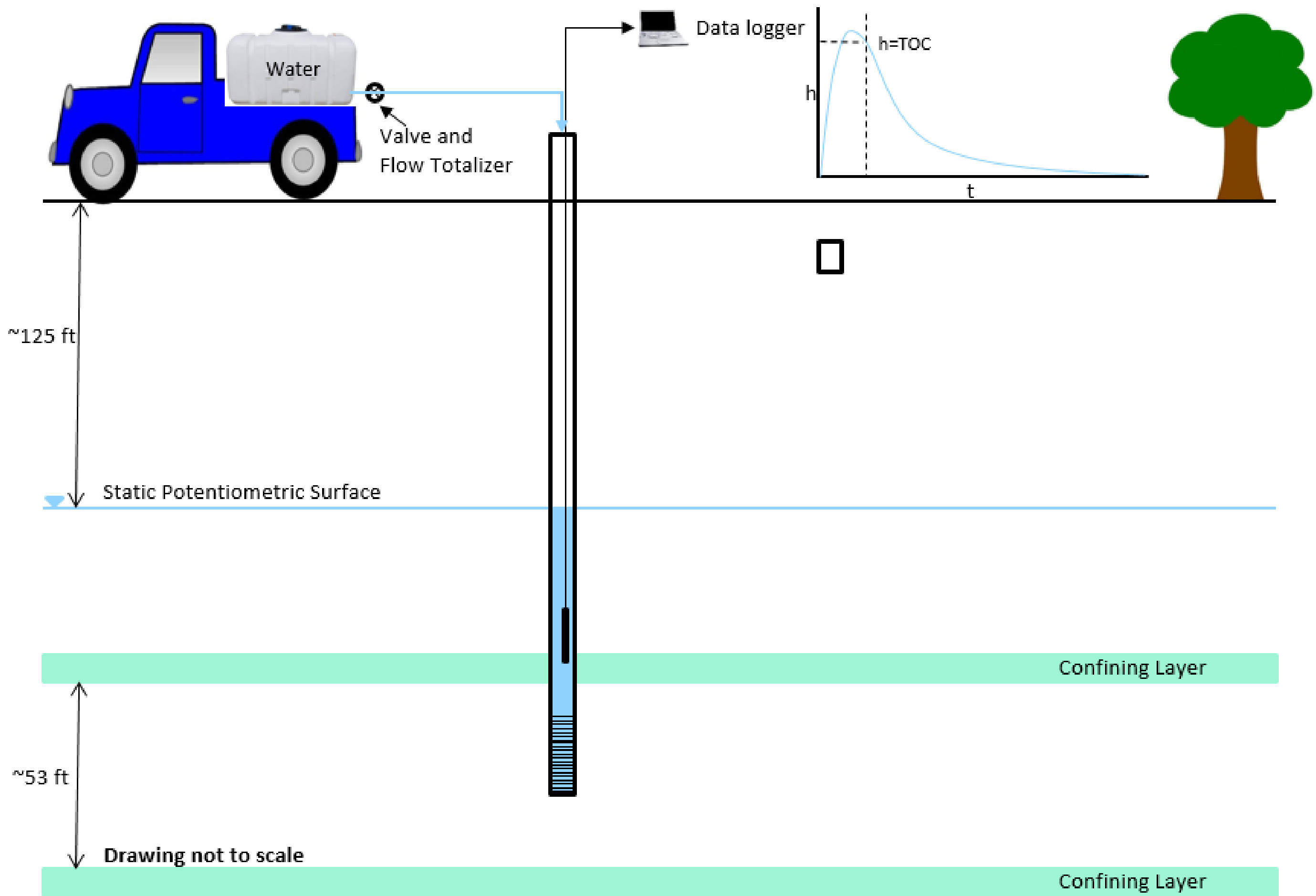


**Figure 3: Generalized Conceptual Model for Injection Well Performance Testing.**

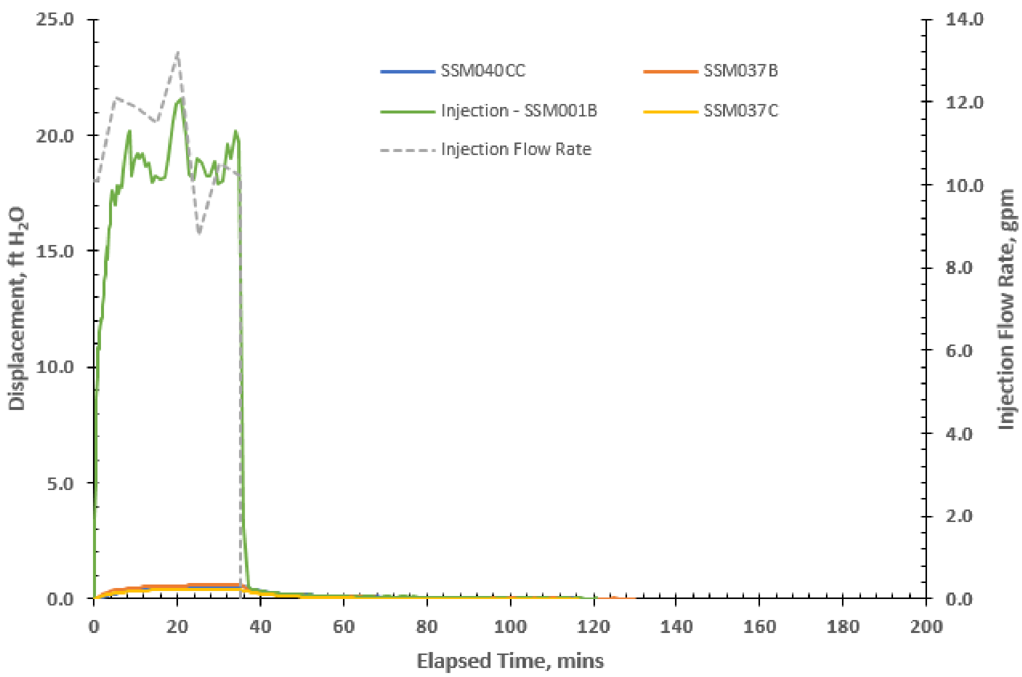


**Figure 4. Aquifer Response Due to Injection at SSM001B.**

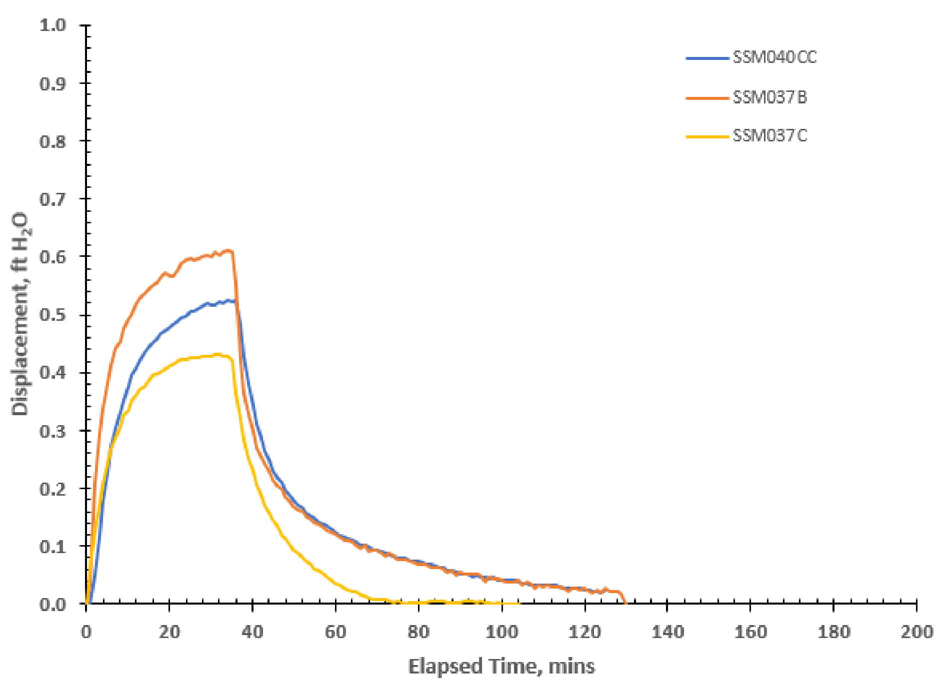


**Figure 5. Pressure Response in Observation Wells Due to Injection at SSM001B.**

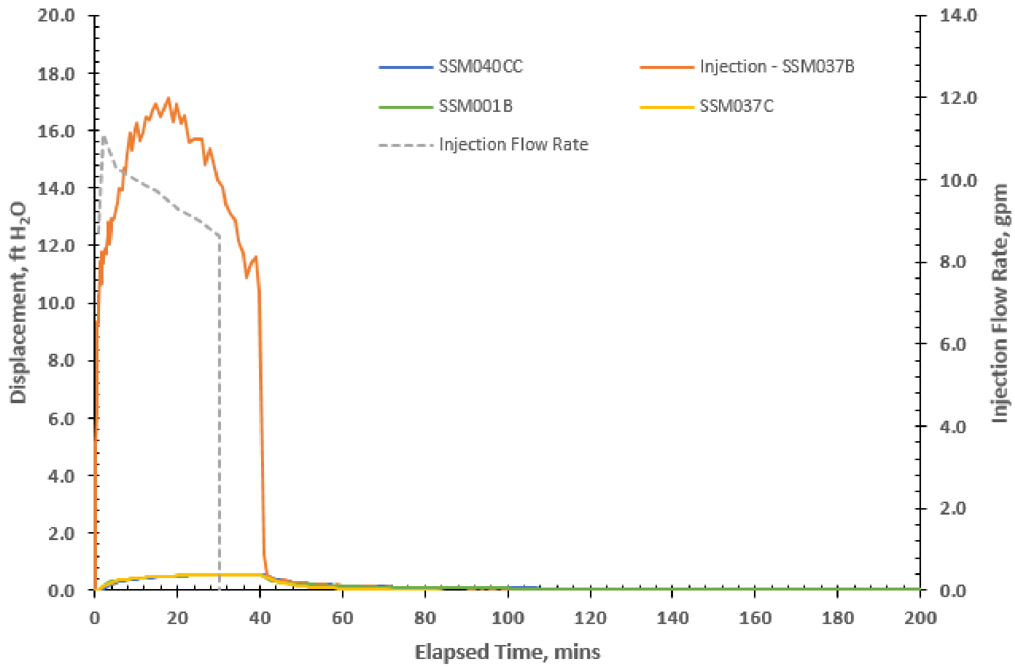


**Figure 6. Aquifer Response Due to Injection in SSM037B.**

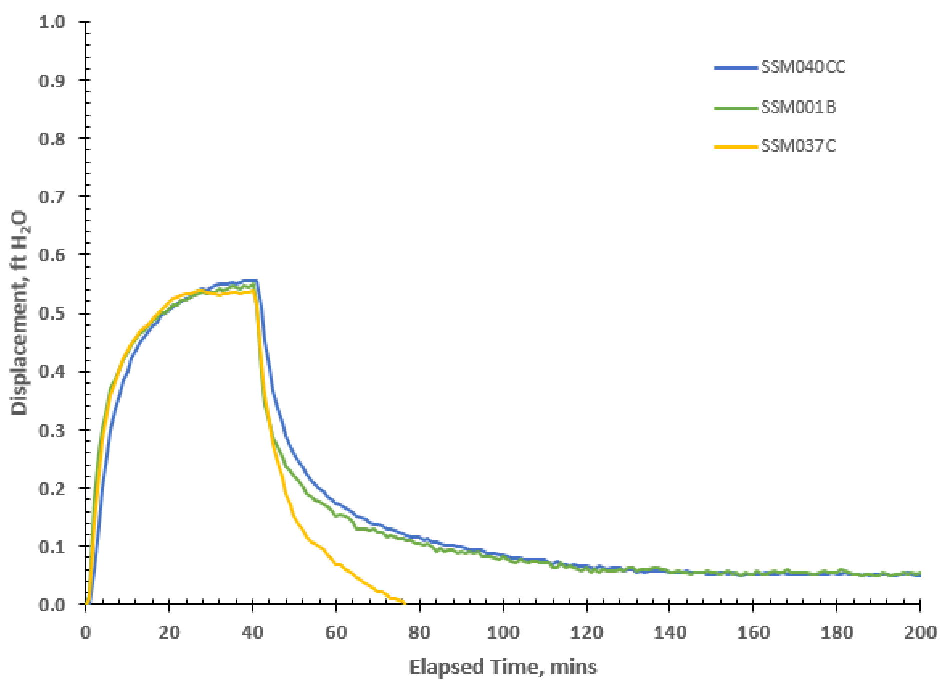


**Figure 7. Pressure Response in Observation Wells Due to Injection in SSM037B.**

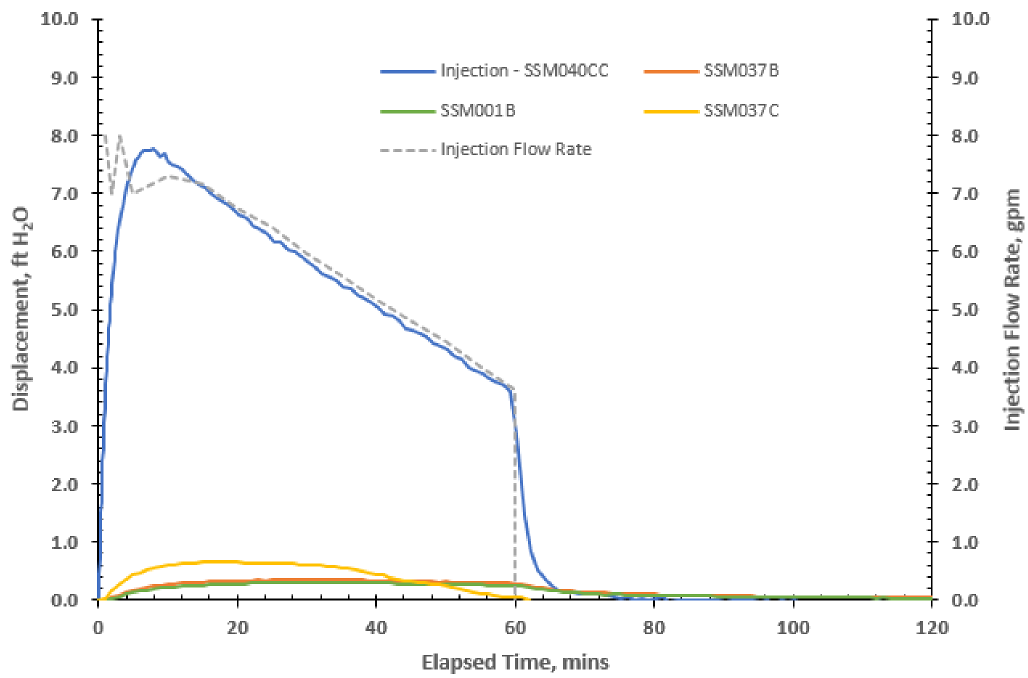


**Figure 8. Aquifer Response Due to Injection in SSM040CC.**

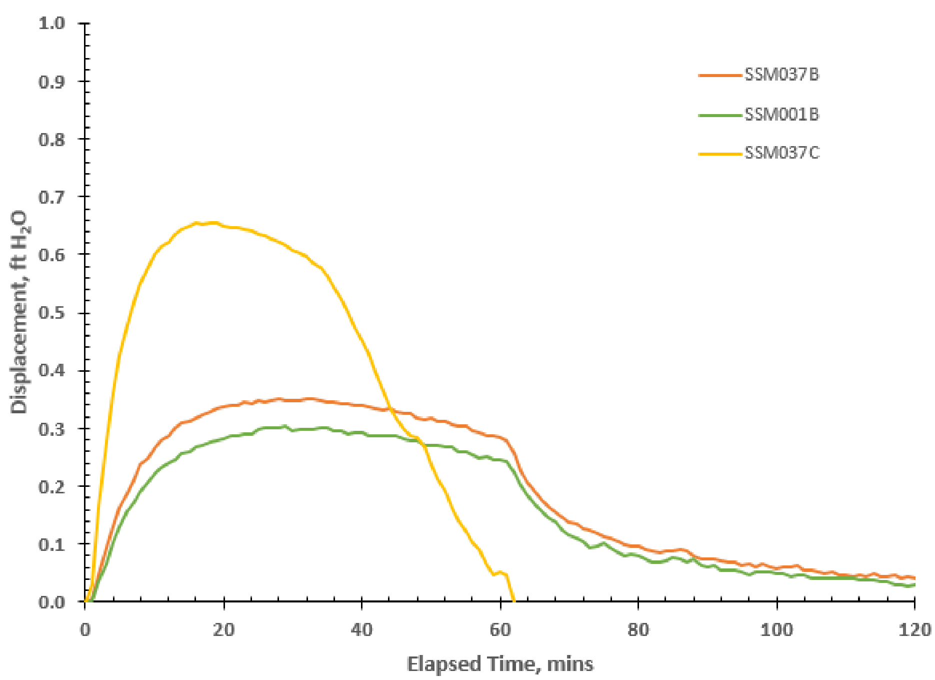


**Figure 9. Pressure Response in Observation Wells Due to Injection in SSM040CC.**

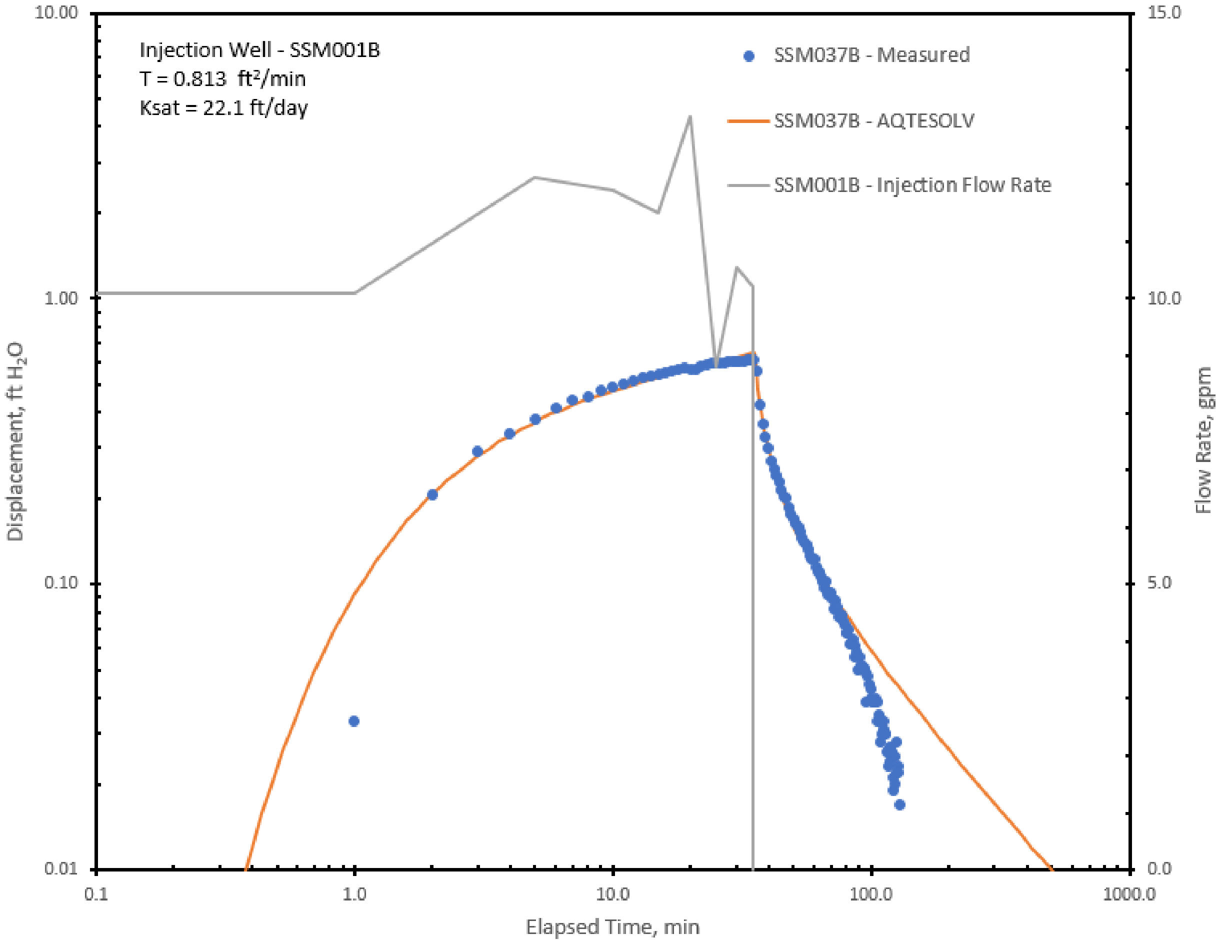


**Figure 10. Displacement as a Function of Time for SSM037B due to Injection in SSM001B.**

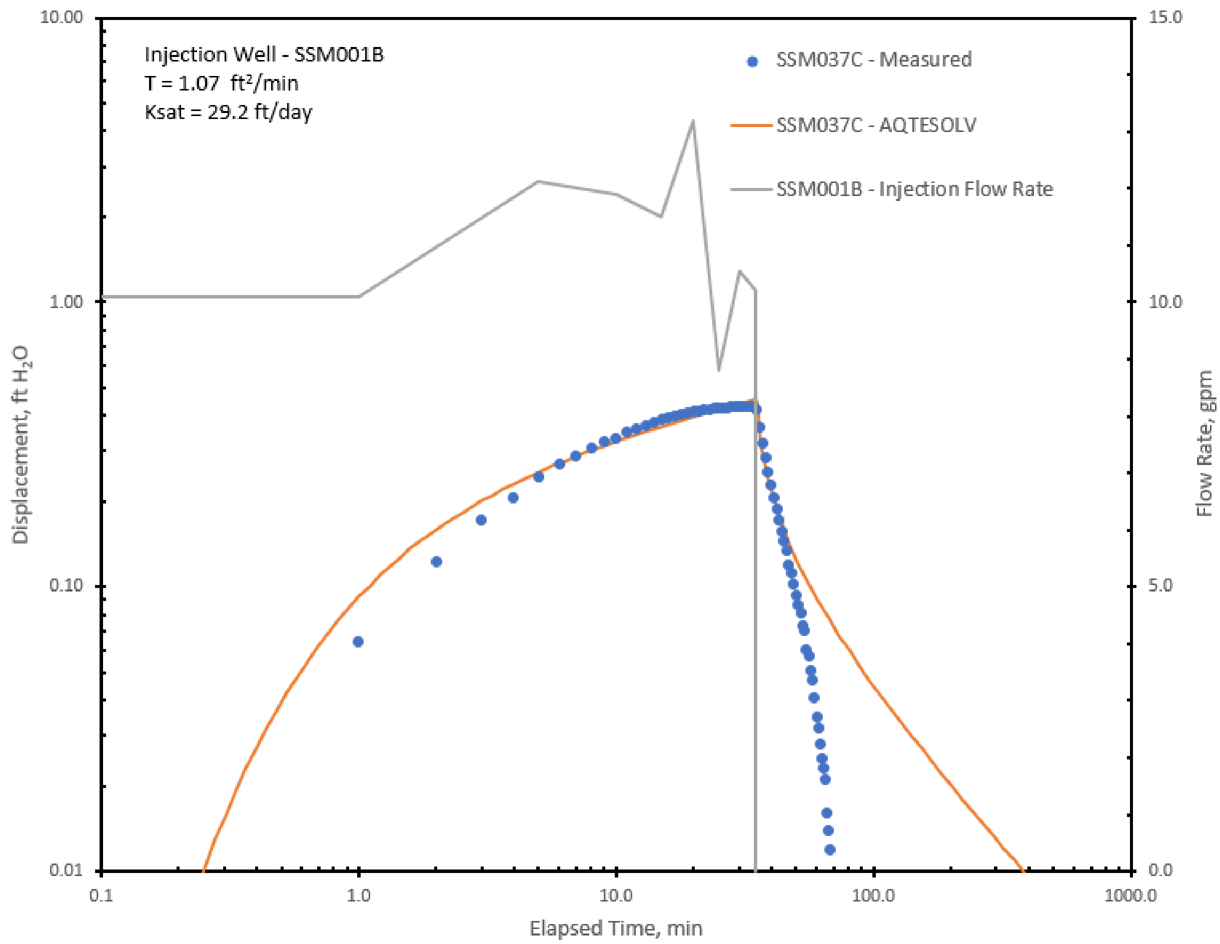


**Figure 11. Displacement as a Function of Time for SSM037C due to Injection in SSM001B.**

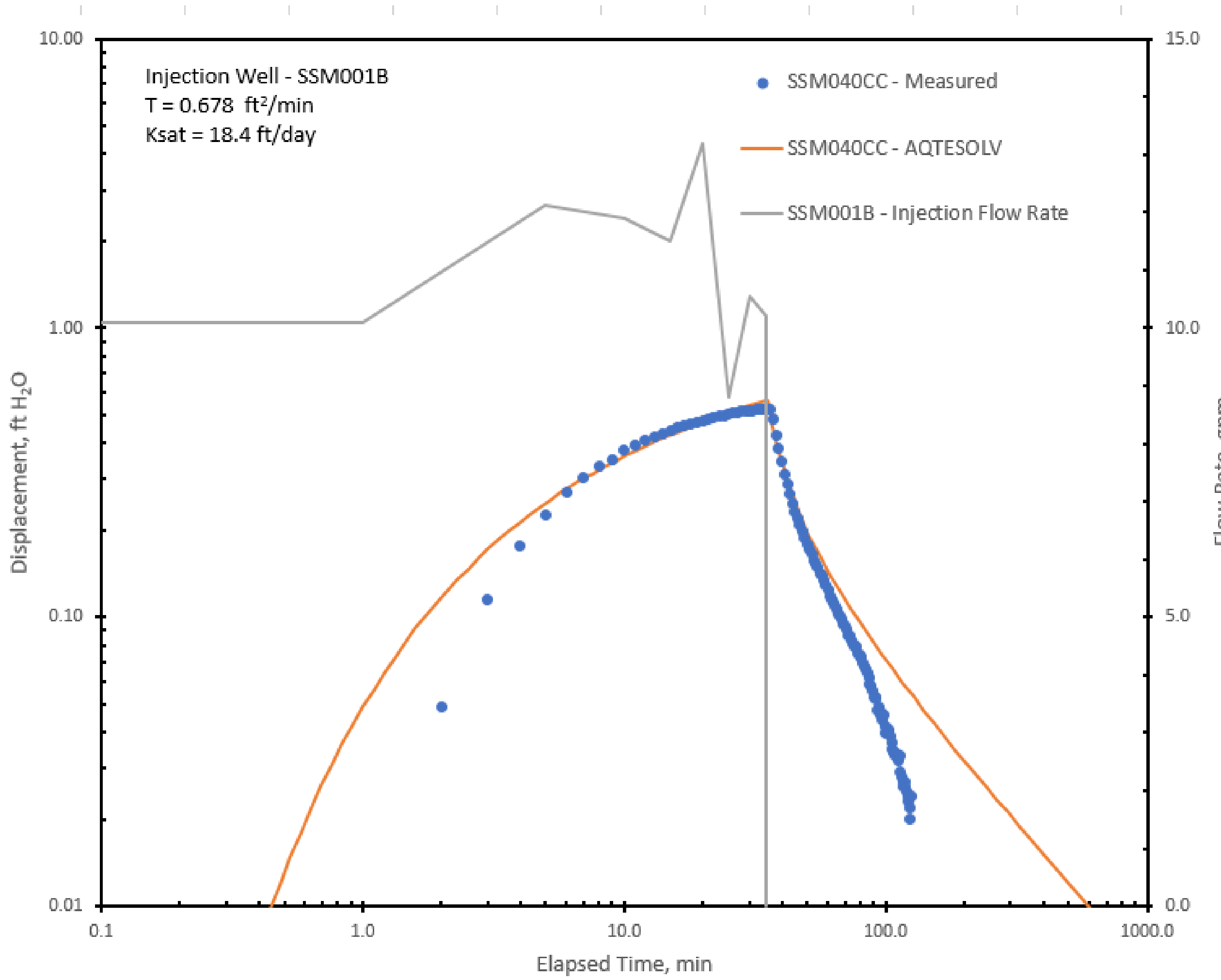


**Figure 12. Displacement as a Function of Time for SSM040CC due to Injection in SSM001B.**

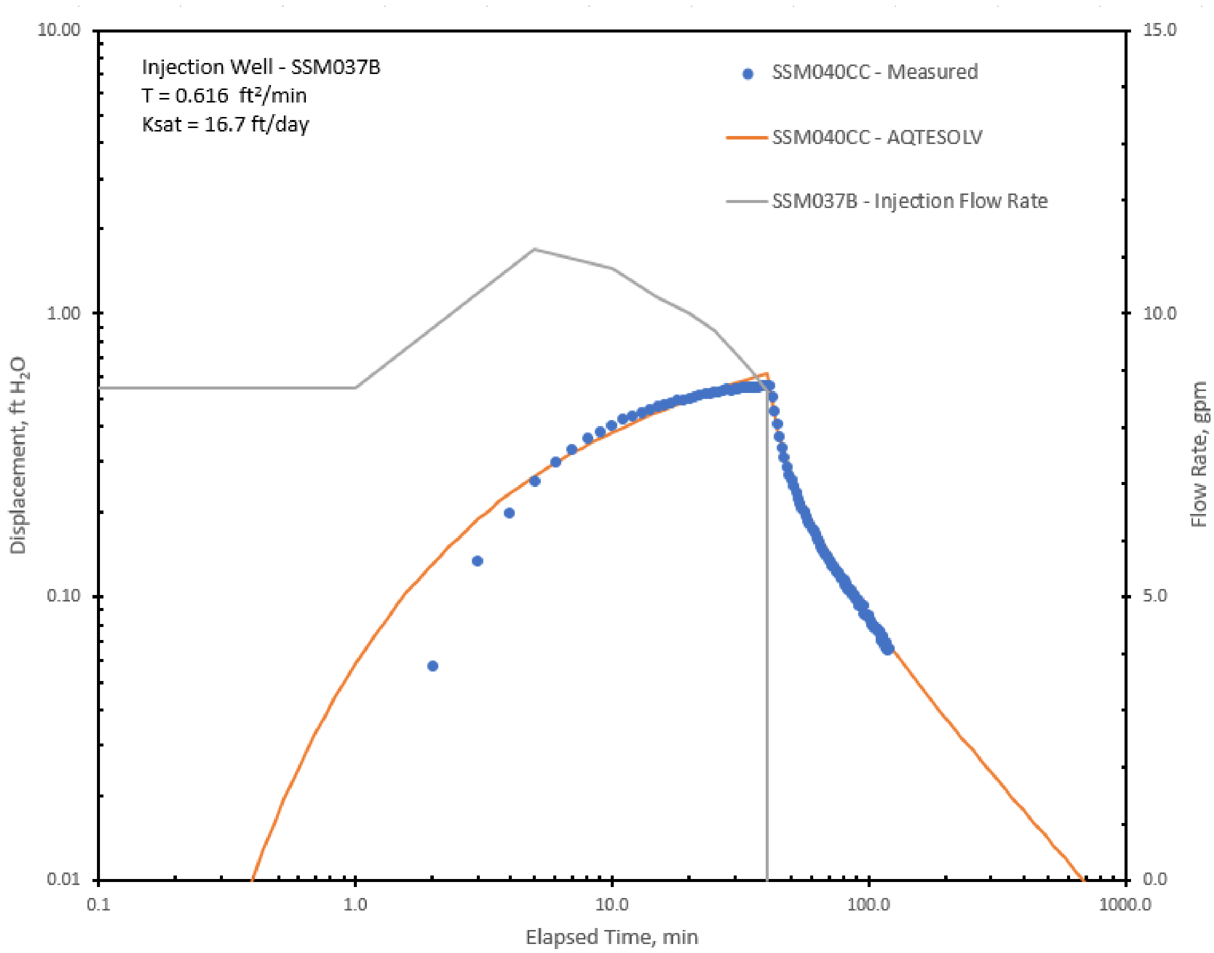


**Figure 13. Displacement as a Function of Time for SSM040CC due to Injection in SSM037B.**

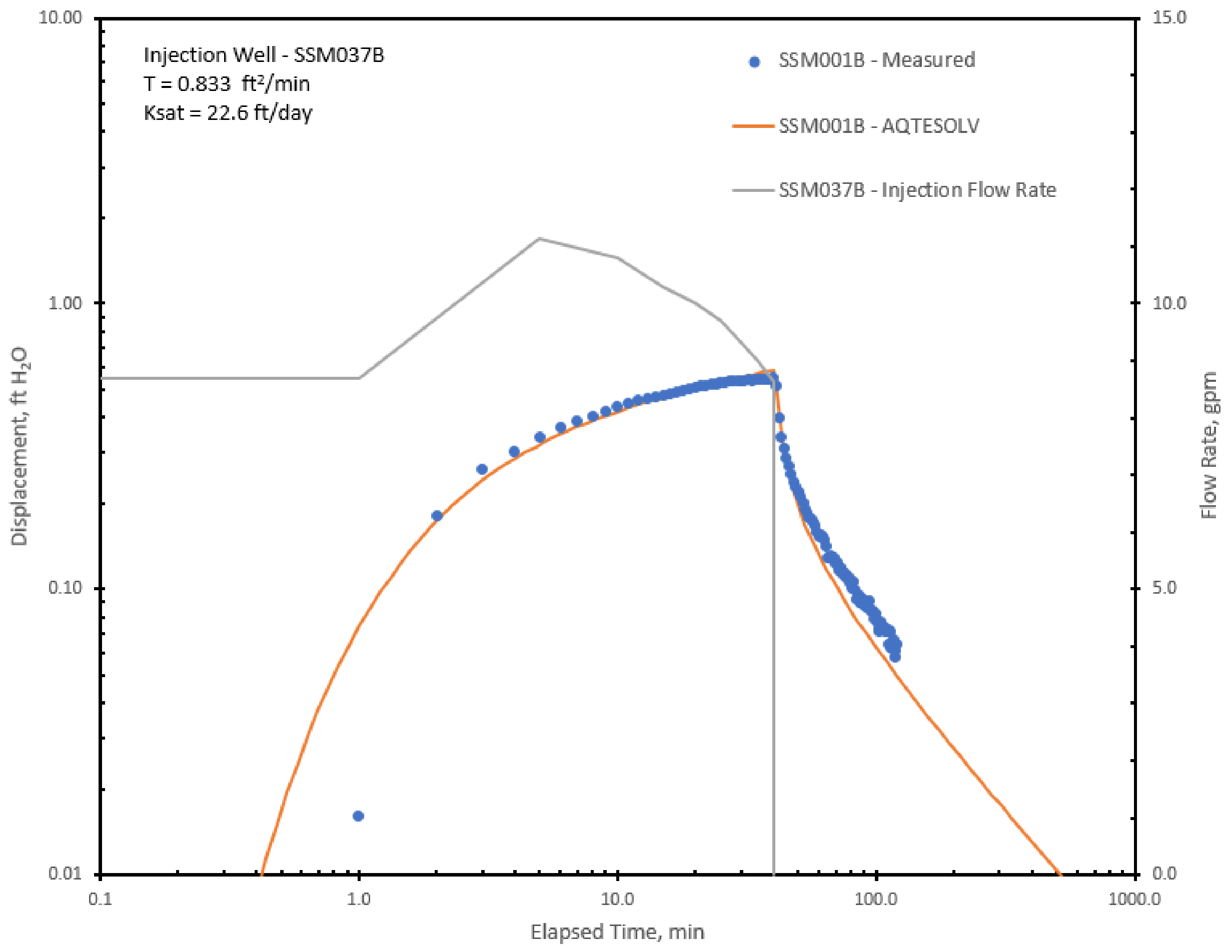


**Figure 14. Displacement as a Function of Time for SSM001B due to Injection in SSM037B.**

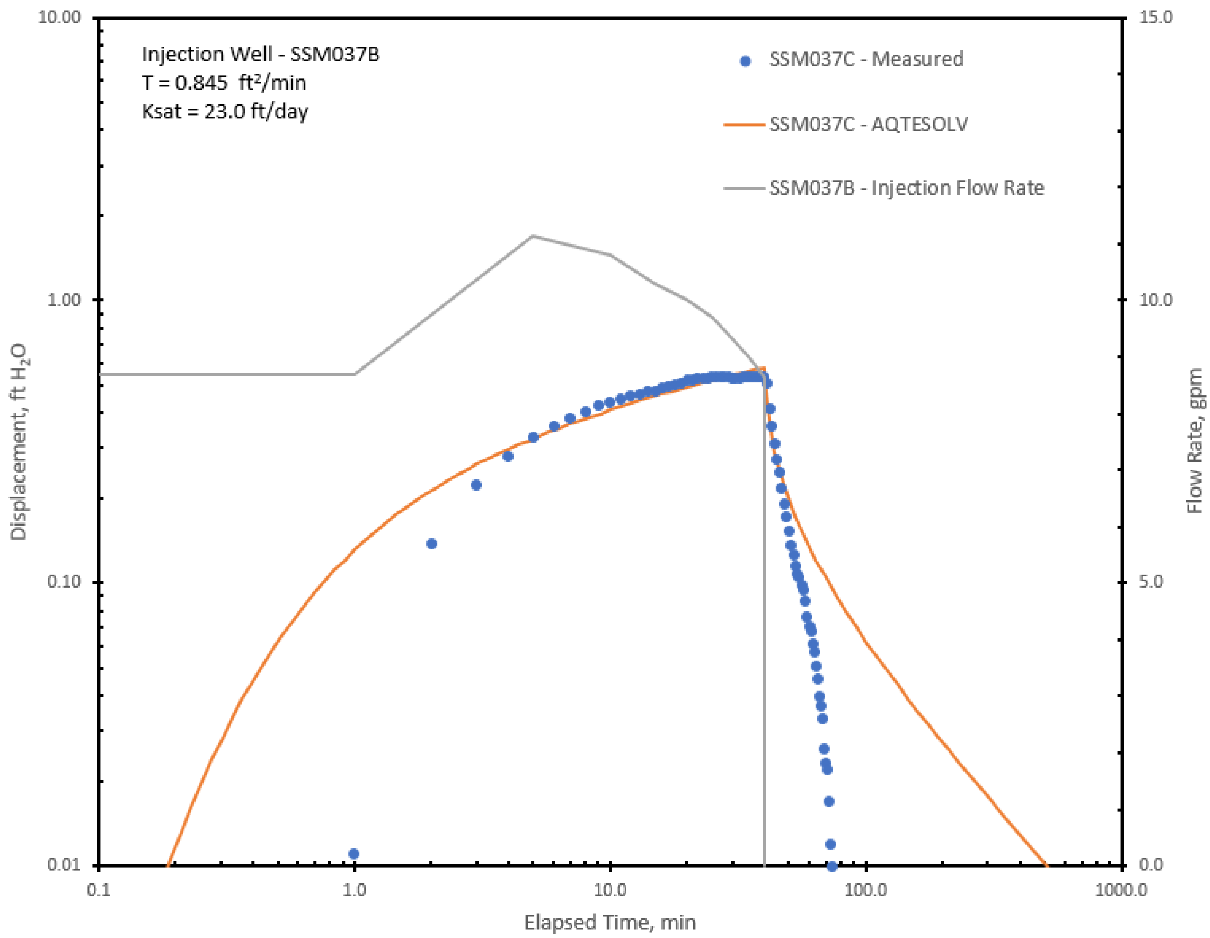


**Figure 15. Displacement as a Function of Time for SSM037C due to Injection in SSM037B**

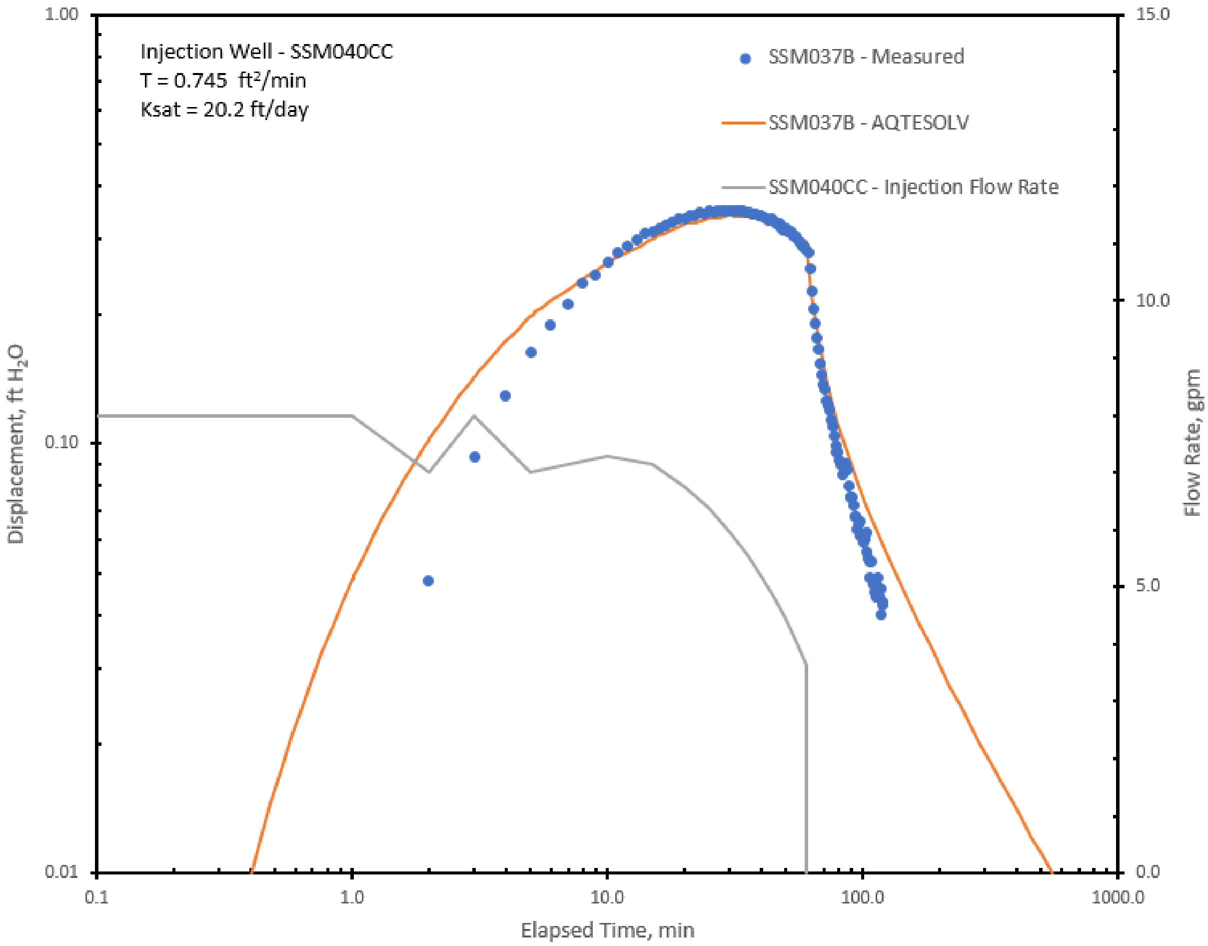


**Figure 16. Displacement as a Function of Time for SSM037B due to Injection in SSM040CC.**

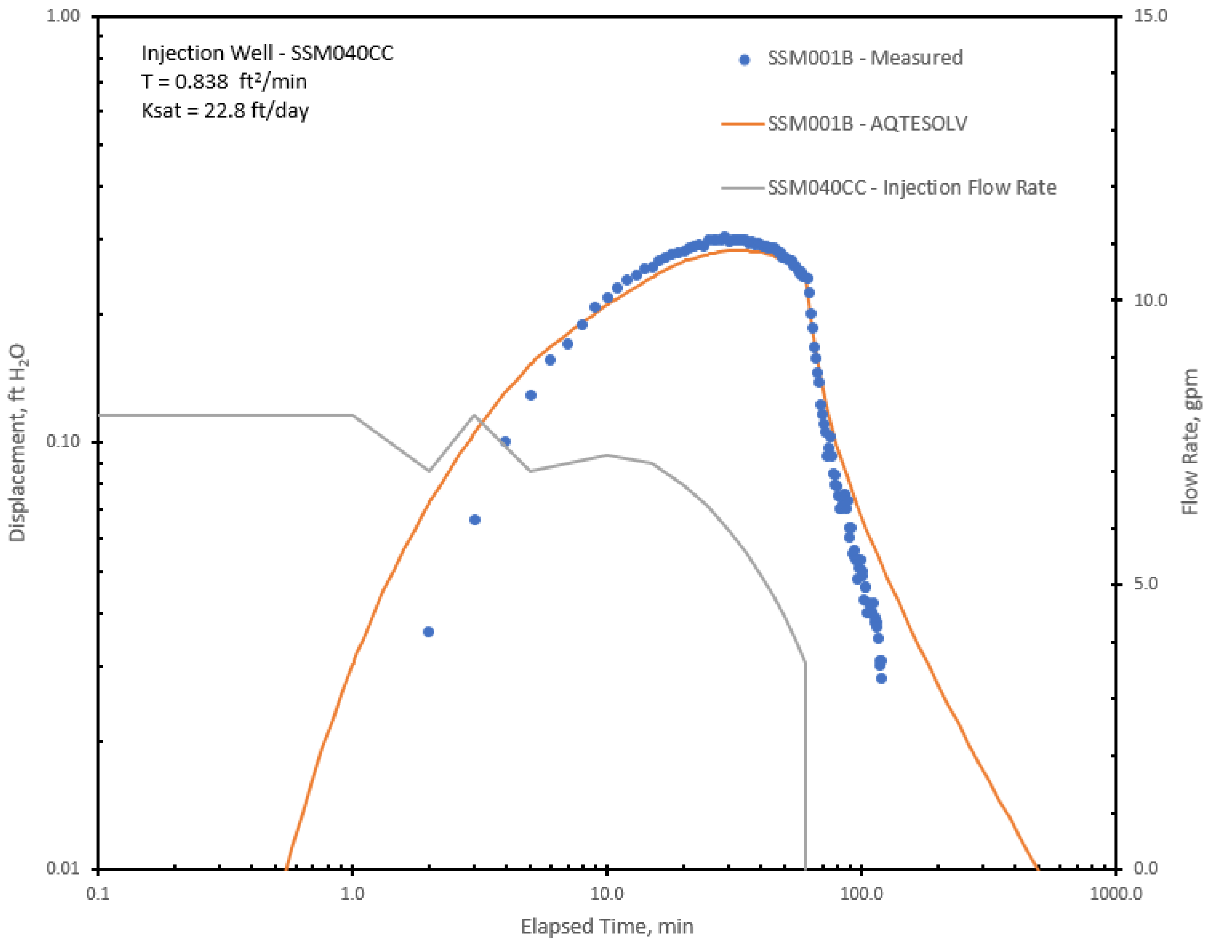


**Figure 17. Displacement as a Function of Time for SSM001B due to Injection in SSM040CC.**

**Table 1: Construction Details for the Extraction, Injection and Monitoring Wells (SRNS-RP-2019-0046).**

| Well ID | Purpose During Injection Testing | SRS Northing | SRS Easting | Casing Diameter | Screen Zone Top | Screen Zone Bottom | Aquifer |
|---|---|---|---|---|---|---|---|
| | | *(ft)* | *(ft)* | *(in.)* | *(ft msl)* | *(ft msl)* | |
| SSM001B | Injection | 97,301.8 | 48,239.9 | 2 PVC | 148.5 | 143.5 | Lower LLAZ |
| SSM037B | Injection | 97,266.6 | 48,281.9 | 2 PVC | 148.8 | 143.8 | Lower LLAZ |
| SSM037C | Monitoring | 97,272.9 | 48,278.3 | 2 PVC | 184.2 | 179.2 | Upper LLAZ |
| SSM040CC | Injection | 97,290 (Estimated) | 48,270 (Estimated) | 6 PVC | 184 | 164 | Upper/Middle LLAZ |

**Table 2. Field Data Collected During Injection Well Testing.**

| Well Name | Injection Volume (gals) | Tank Average Flow rate (gpm) | Average Head In Well (ft $H_2O$) | Time to Empty Tank (min) | Time for Head to Dissipate[1] (min) | Average Water Injection Flow Rate[2,3] (gpm) | Average Injection Capacity (gpm/ft) |
|---|---|---|---|---|---|---|---|
| SSM001B | 389.3 | 11.4 | 14.8 | 35 | 36.9 | 10.6 | 0.7 |
| SSM037B | 391.9 | 10.2 | 12.7 | 40 | 40.9 | 9.6 | 0.8 |
| SSM040CC | 343.0 | 7.0 | 5.5 | 60 | 62.3 | 5.5 | 1.0 |

[1]Time for excess head due to injection to dissipate to within 1% of static water level.

[2]Using potable water.

[3]Average injection flow rate determined by dividing total water injection volume and the time required for head to dissipate.

[4]Average injection capacity determined by dividing average injection flow rate by average head increase observed in well.

**Table 3. Local Hydraulic Properties of the Lost Lake Aquifer in the Immediate Vicinity of the Humate Injection Site.**

| Injection Well | Observation Well | T ($ft^2$/min) | Storativity | Ks[1] (ft/day) |
|---|---|---|---|---|
| SSM001B | SSM040CC | 0.678 | 0.0003 | 18.4 |
| SSM001B | SSM037B | 0.813 | 0.0011 | 22.1 |
| SSM001B | SSM0037C | 1.073 | 0.0001 | 29.2 |
| SSM037B | SSM001B | 0.833 | 0.0012 | 22.6 |
| SSM037B | SSM0037C | 0.845 | 0.0010 | 23.0 |
| SSM037B | SSM040CC | 0.616 | 0.0003 | 16.7 |
| SSM040CC | SSM001B | 0.838 | 0.0004 | 22.8 |
| SSM040CC | SSM037B | 0.745 | 0.0003 | 20.2 |
| **Average** | | **0.805** | **0.0006** | **21.9** |
| **Median** | | **0.823** | **0.0003** | **22.4** |
| **Standard Deviation** | | **0.137** | **0.0004** | **3.7** |

[1]Based on an aquifer thickness of 53 ft.

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