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Western Sector Injection Well Performance Testing

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August 10, 2018

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EXECUTIVE SUMMARY

A total of eight short duration injection tests were conducted on wells at the M-Area Western Sector In-Situ Chemical Oxidation (ISCO) test site. For each injection event, approximately 200 gallons of water were 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 drain 5000 gallons of water in less than 24 hours in all wells. The estimated injection capacity of each well tested is shown in Table E-1.

Table E-1. Injection Capacity of ISCO Injection Wells

Well Name[1]	Average Injection Capacity[1] (gpm)
WSI001B	19.7
WSI001C	6.5
WSI002B	19.1
WSI002C	6.0
WSI003B	23.2
WSI003C	3.8
WSI004B	5.9
WSI004C	7.0

[1]Under gravity flow conditions.

Data from the injection tests were analyzed to estimate hydraulic conductivity. The average hydraulic conductivity of the “B” wells was determined to be 2.8E-03 cm/sec and that of the “C” wells was determined to be 3.6E-04 cm/sec. These hydraulic conductivity values are lower than previously reported values for the Lost Lake Aquifer. Due to uncertainties associated with the injection testing, these values should be viewed primarily as localized measurements that provide an indicator of the variation in hydraulic conductivity in the aquifer sediments. The results of this testing suggest the “B” well screens are hydraulically isolated from the “C” well screens and that the “B” wells are screened in a more transmissive zone of the aquifer.

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LIST OF ABBREVIATIONS

ACP	Area Completion Projects
ISCO	In-situ chemical oxidation
LLAZ	Lost Lake Aquifer Zone
SRNL	Savannah River National Laboratory
PCE	Tetrachloroethylene
SCDHEC	South Carolina Department of Health and Environmental Control
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
TA	Temporary Authorization
TCE	Trichloroethylene

1.0 Background

Groundwater in the Western Sector of M-Area is contaminated with chlorinated ethenes including trichloroethylene (TCE) and tetrachloroethylene (PCE). In March of 2016 the South Carolina Department of Health and Environmental Control (SCDHEC) approved a temporary authorization (TA) allowing SRNS to evaluate in situ chemical oxidation (ISCO) technologies to address the high concentration of dissolved phase volatile organic compounds and any residual dense non-aqueous phase liquid present in the Lost Lake Aquifer Zone (LLAZ) in A/M Area. As a result, a pilot test is planned for the LLAZ to assess the remediation potential of in-situ chemical oxidation. During the pilot test, potassium permanganate and sodium persulfate injection solutions will be injected into each of eight new oxidant injection wells (up to 5000 gals/well). The objective of the pilot test is to assess the ability of the selected oxidants to diminish concentrations of TCE, PCE, and daughter products that are present in the groundwater system at this location.

Oxidant injection wells were installed in four locations (two injection wells screened in separate intervals in each of the four cluster locations) distributed in a line on approximately 25 foot centers transverse to the prevailing groundwater flow in the Lost Lake aquifer zone (LLAZ) (Figure 1). Each location consists of two clustered wells. The wells are constructed of 2 inch diameter PVC with a 15 foot screened interval. Wells with the suffix “C” are shallow and screened near the top of the LLAZ while “B” wells are deeper. Well construction details are provided in Table 1.

At the request of Area Completion Projects (ACP), Savannah River National Laboratory (SRNL) conducted injection well performance testing on the eight oxidant injection wells identified in Table 1. The project was conducted in accordance with test plan SRNS-RP-2018-00198 (Dixon, 2018a). The purpose of the testing was to determine the injection capacity of each well under gravity flow conditions.

2.0 Objectives

The objective of the injection well testing was to determine the injection capacity of each well. For the purposes of this test, injection capacity was defined as the volume of water injected in a well per unit time under gravity flow conditions. 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 a total of eight injection wells (Table 1). The overall approach for the testing was to inject a volume of water (~200 gal) 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 slug testing prior to the oxidant injection pilot test (SRNS,2017). Pressure response was monitored in the injection well being tested and neighboring injection 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 2 presents a generalized conceptual model for the injection well performance testing. The test assembly used for the injection well performance tests is shown in Figure 3. Prior to the start of testing, a water tank was loaded empty into the bed of a 1-ton pickup truck. The truck and tank were weighed empty. The tank was then filled with approximately 200 gallons of potable water and weighed again to confirm the amount of water in the tank. Once at the test site, the truck was located near the well head and positioned such that the height of the bottom of the tank was as close as possible to the height of the well. The tank was connected to the well head using flexible hose and a well head assembly. A valve was used to control flow of water from the tank to the well. A data logging pressure transducer was installed in the tank to monitor the water level in the tank as it drained. This information was used along with the geometry of the tank to estimate the average injection flow rate.

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. When the head increase associated with injection dissipated and the water level in the well returned approximately to the original static condition, the test was considered complete.

4.0 Results

Eight oxidant injection wells (Table 1) were tested to determine injection capacity. Results from the injection tests are presented in Table 2. It is important to note that the oxidant solutions have properties different than water and may have different injection rates and times compared to those determined in this testing. Approximately 200 gallons were injected in each well under gravity flow conditions. With the exception of WSI003C and WSI004B, it took 10 minutes or less to empty the tank (under gravity flow conditions) into each injection well ("B" and "C" screens). During each injection test, a head increase in the injection well was observed as the flow rate into the aquifer through the well screen was less than the injection flow rate. This excess head was monitored with a pressure transducer and was used to establish a criteria for determining when the test was complete. An injection test was considered complete when the excess head in the injection well decreased to within 1% of the static pretest water level. Using this criteria, the excess head due to injection in WSI001B, WSI002B, and WSI003B returned to static pretest conditions in 11 minutes or less (Table 2). Compared to the other "B" screened wells, WSI004B was an anomaly requiring 36.5 minutes for the excess head to dissipate to within 1% of the pretest water level. For the "C" screened wells, WSI001C, WSI002C, and WSI004C required 37 minutes or less to return to pretest water levels. WSI003C was an anomaly for the "C" screened wells. WSI003C required 56.6 minutes to return to pretest conditions. In general, it took considerably less time for the excess injection head to dissipate in the "B" screened wells. This was expected since these wells are screened in a more permeable portion of the LLAZ.

The average injection capacity was calculated for each well by dividing the volume of water injected by the amount of time required for the excess head to dissipate as previously described (Table 2). Excluding WSI004B, the average injection capacity of the "B" screened wells was determined to be about 20 gpm under gravity flow conditions. Likewise for the "C" screened wells, the average injection capacity was determined to be about 6.5 gpm, excluding WSI003C.

Figure 4 through Figure 19 present the pressure responses observed due to injection in each of the test wells. The ordinate of the hydrographs represents the depth to water below the top of casing. The results are presented in this way so that wellbore storage can be easily assessed visually. Wellbore storage is created when the flow rate into the well exceeds the flow rate out of the well into the aquifer. It is identified graphically as the initial increase in head associated with gravity driven injection. With the exception of WSI004B, wellbore storage in the "B" screened wells ranged from 20 to 35 feet above the static water level. The hydrograph for WSI004B (Figure 16) shows that the well casing filled completely before draining to a depth of about 60 feet for the remainder of the test. This produced a pressure response different than observed for the other injection wells. This suggests there may be an issue with WSI004B (i.e. construction or development) that cannot be identified based on the results of this test. Nevertheless, WSI004B appears hydraulically connected to WSI003B (Figure 16). Wellbore storage for the "C" screened wells was greater than observed for the "B" screened with WSI002C and WSI003C filling almost completely during the injection tests. These results are consistent with the assumption that the "C" screens are in a less permeable portion of the aquifer.

Figure 4 through Figure 19 show that wells screened in the same zone are hydraulically connected. For example, Figure 5 shows that injection in WSI001B produced a measurable pressure response in WSI002B. Likewise, Figure 7 shows that injection in WSI001C produced a pressure response in WSI002C. In contrast, Figure 9 shows that injection in WSI002B did not produce a pressure response in WSI002C. Similar results were observed for other pairs of "B" and "C" wells. Therefore, it appears that the "B" and "C" screens are not hydraulically connected.

4.1 Hydraulic Conductivity

The data from the injection tests were analyzed using the program AQTESOLV, which is a program designed for pump test analysis (Geraghty and Miller Inc., 1999). A type curve matching procedure was employed using a model for leaky aquifers with partially penetrating wells. The model used was developed by Hantush and Jacob (1955) and Hantush (1961a and b) to analyze data from pumping tests in leaky aquifers.

Parameters used in the Hantush-Jacob model for leaky aquifers include the saturated thickness of the aquifer, the thickness of the overlying confining layer, and the zone of penetration of the pumping and observation well (or wells). A lithologic cross-section of the ISCO site was used to establish the aquifer thickness and the confining layer thickness (Figure 20). Screened intervals were determined from well construction details (Table 1).

Soil boring MW29SB was taken at the ISCO test site (Figure 20) and it was used to establish that the Lost Lake aquifer is approximately 45 ft thick at the ISCO test site. The aquifer is overlain by the Green Clay confining zone which is approximately 11 ft thick at the test site. The aquifer is bounded at the bottom by the Crouch Branch confining unit which is approximately 3 ft thick at MW29SB.

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 for those wells where the time to empty the tank was comparable to the time for head to dissipate in the well. The validity of this assumption is less certain for cases where there is a substantial difference between the time to empty the tank and the time for head to dissipate in the well. Nonetheless, the total volume of water injected in all cases was comparable to the volume calculated based on the average flow rate from the tank.

AQTESOLV simulations were performed on the data from injection tests at WSI001B, WSI001C, WSI003B, WSI003B, WSI004B, and WSI004C. Results from WSI002B and WSI002C were not analyzed because there was no response in the observation wells used for these injections (Figure 8 through Figure 11). For the WSI002 cluster, one well was used for injection and the other was used for observation to assess whether the "B" and "C" screened intervals were hydraulically connected. As previously mentioned, the "B" and "C" screens appear to be isolated from each other.

Results from the AQTESOLV simulations are presented in Table 3 and Figure 21 through Figure 26. The results corroborate the assertion that the "B" wells are screened in a more permeable portion of the aquifer than the "C" wells. The hydraulic conductivity estimated from the "B" wells ranged from 1.9E-03 cm/sec to 3.4E-03 cm/sec. The hydraulic conductivity estimated from the "C" wells ranged from 2.5E-04 cm/sec to 4.2E-04 cm/sec. These values are somewhat lower than average values reported by Dixon (1E-02 cm/sec, 2018b) and Geraghty and Miller (2E-02 cm/sec 1987). Differences observed may be attributed to uncertainties in the injection testing which include assumptions made regarding the injection flow rate and the small injection volume for each test. As previously mentioned, the injection flow rate was assumed to be equal to the tank flow rate since it was not practical to measure the actual injection rate into the well. Also, by comparison to the pumping tests conducted by Dixon (2018b) and Geraghty and Miller (1987), the injection tests interrogated a small volume of the aquifer. For example, the total volume of each injection test was approximately 200 gallons compared to approximately 730,000 gallons for the pumping test conducted by Dixon (2018b).

5.0 Conclusions

A total of eight short duration injection tests were conducted on wells at the ISCO test site. For each injection event, approximately 200 gallons of water were 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 main objective of this project was to assess whether it was hydraulically feasible to inject up to 5000 gallons per day under gravity flow conditions. The results of this analysis show that it is hydraulically feasible to gravity drain 5000 gallons of water in less than 24 hours in all wells.

Data from the injection tests were analyzed to estimate hydraulic conductivity. The average hydraulic conductivity of the “B” wells was determined to be 2.8E-03 cm/sec and that of the “C” wells was determined to be 3.6E-04 cm/sec. These hydraulic conductivity values are lower than previously reported values for the Lost Lake Aquifer. Due to uncertainties associated with the injection testing, these values should be viewed primarily as localized measurements that provide an indicator of the variation in hydraulic conductivity in the aquifer sediments. The results of this testing suggest the “B” well screens are hydraulically isolated from the “C” well screens and, that the “B” wells are screened in a more transmissive zone of the aquifer.

6.0 References

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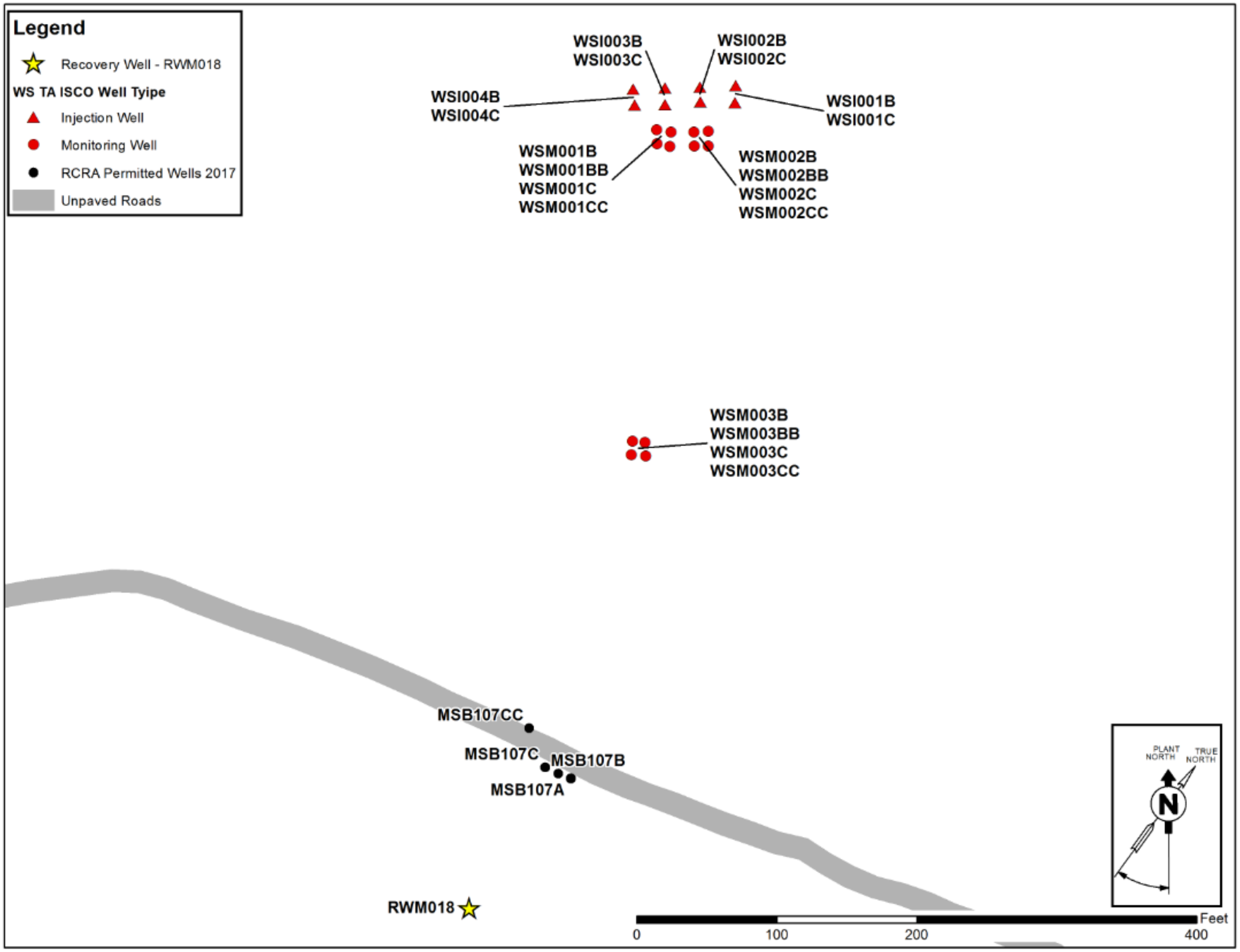

Figure 1: Location of Oxidant Injection Wells (WSIxxx).

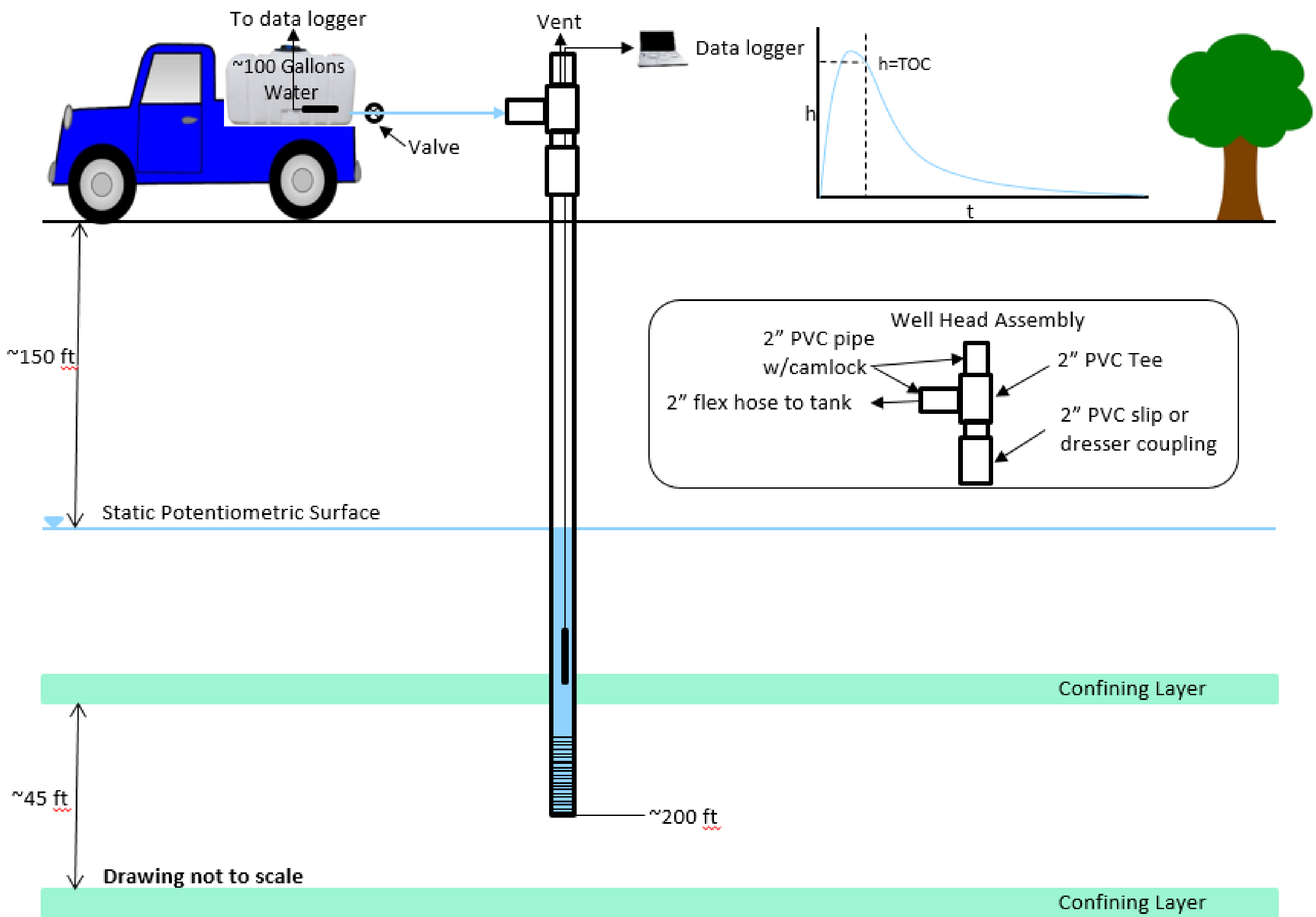

Figure 2: Generalized Conceptual Model for Injection Well Performance Testing.

Figure 3: Injection Well Test Configuration

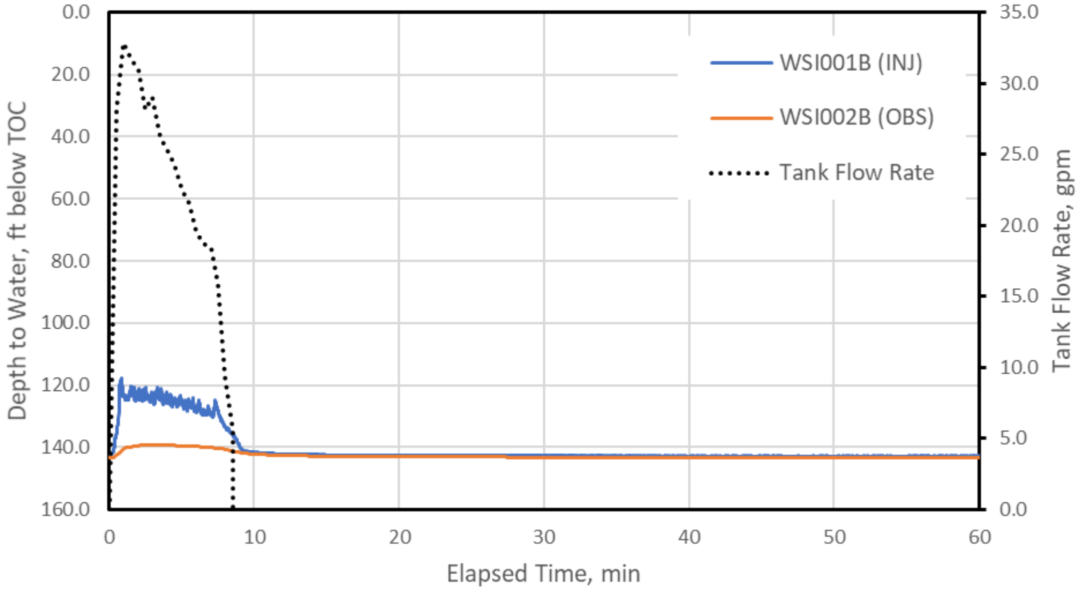

Figure 4. Hydrograph Showing Aquifer Response at WSI002B Due to Injection in WSI001B.

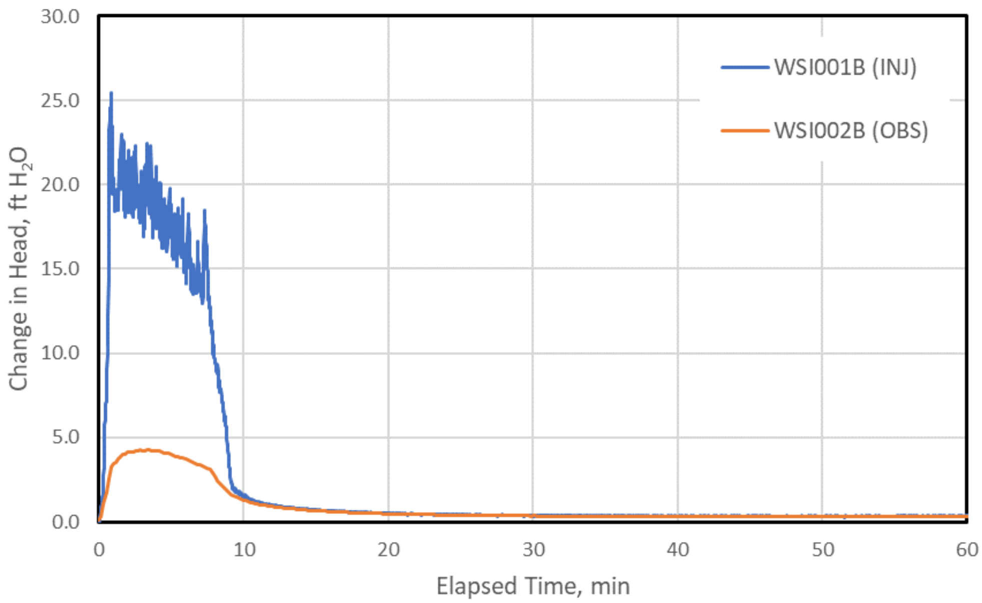

Figure 5. Pressure Response Observed in WSI002B Due to Injection in WSI001B.

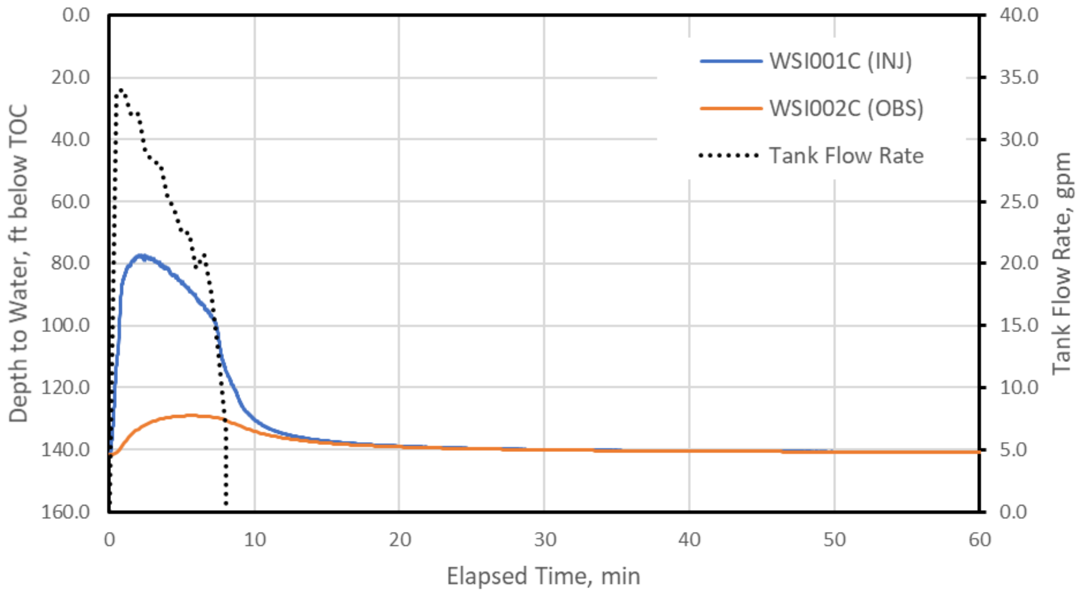

Figure 6. Hydrograph Showing Aquifer Response to Injection in WSI001C.

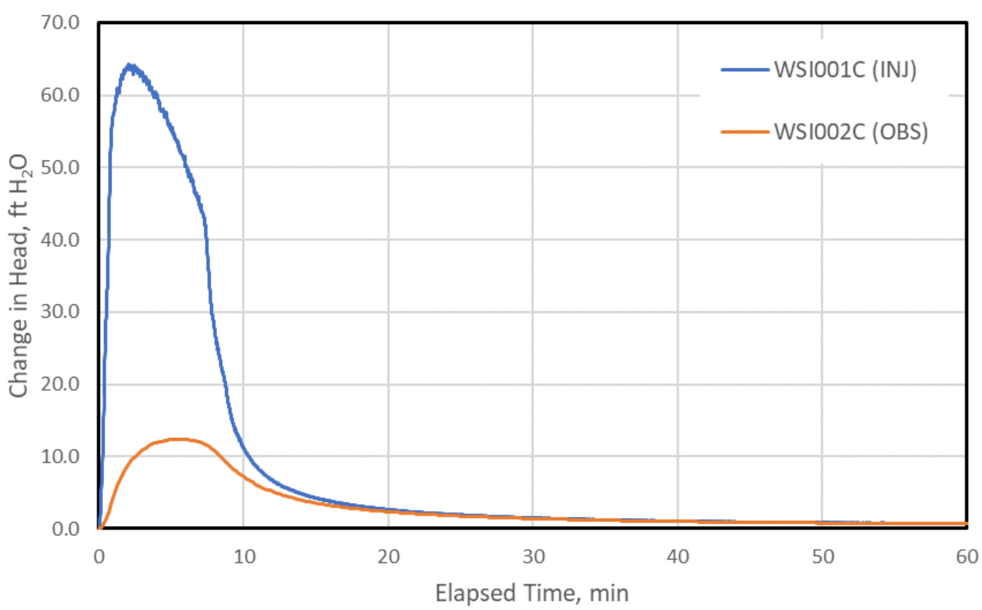

Figure 7. Pressure Response Observed in WSI002C Due to Injection in WSI001C.

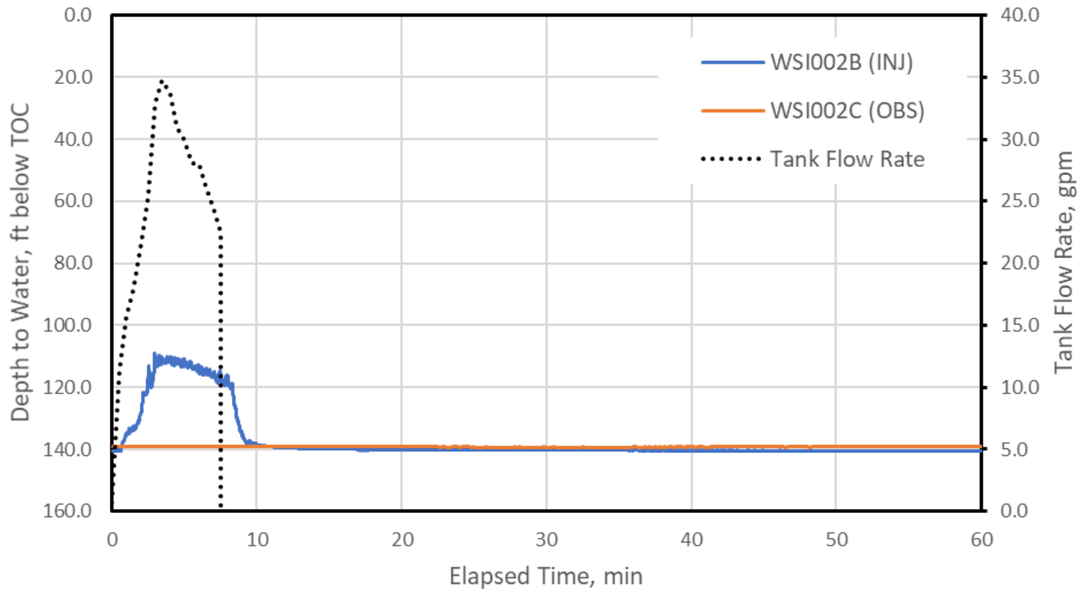

Figure 8. Hydrograph Showing Aquifer Response to Injection in WSI002B.

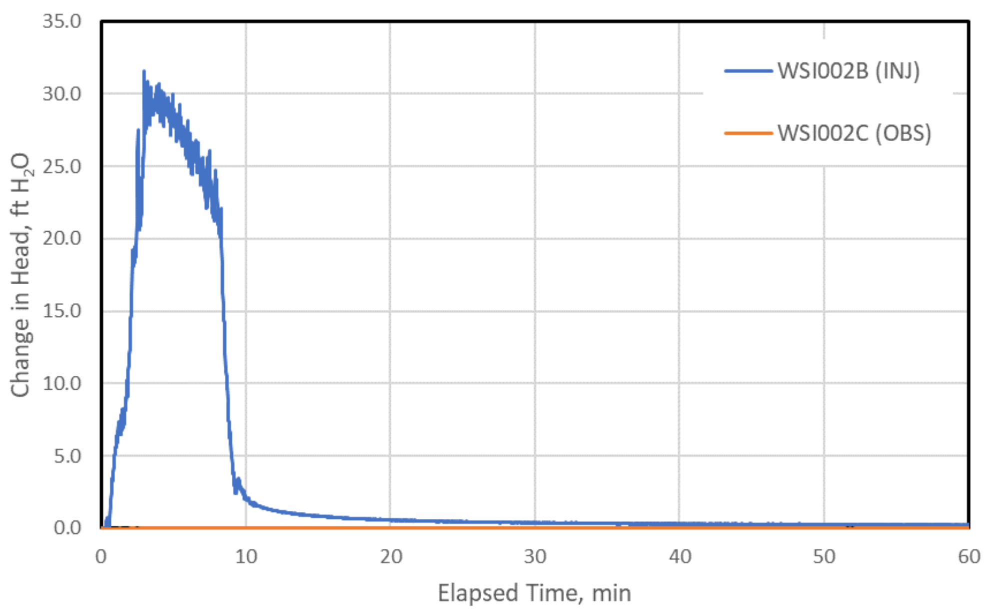

Figure 9. Pressure Response Observed in WSI002C Due to Injection in WSI002B.

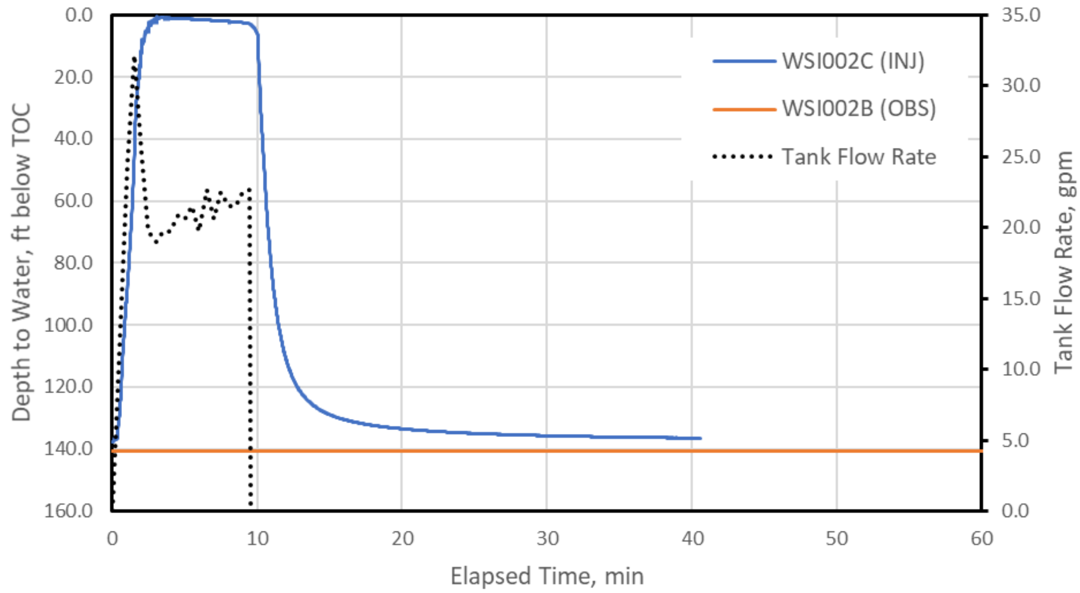

Figure 10. Hydrograph Showing Aquifer Response to Injection in WSI002C.

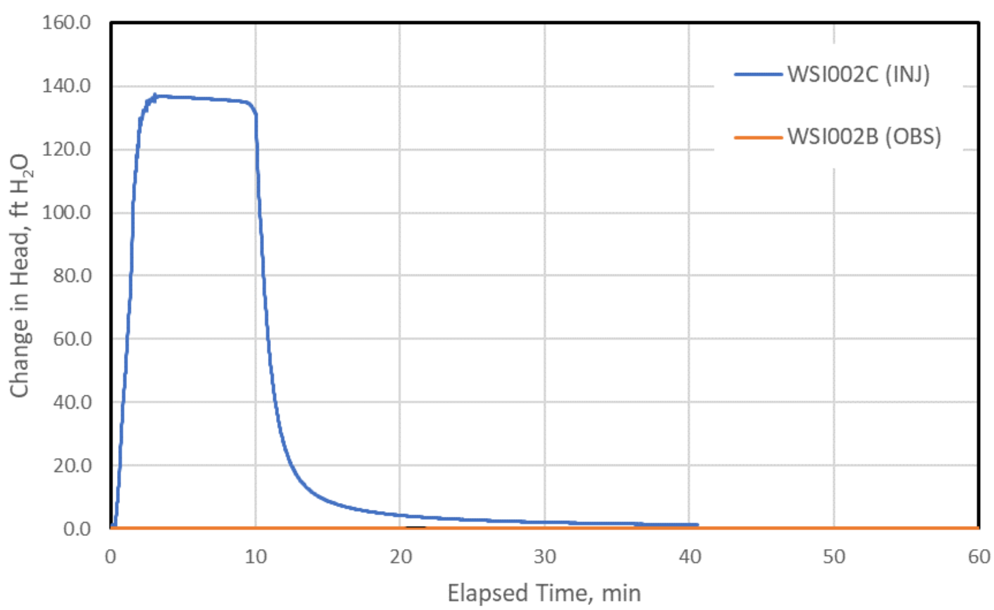

Figure 11. Pressure Response Observed in WSI002B Due to Injection in WSI002C.

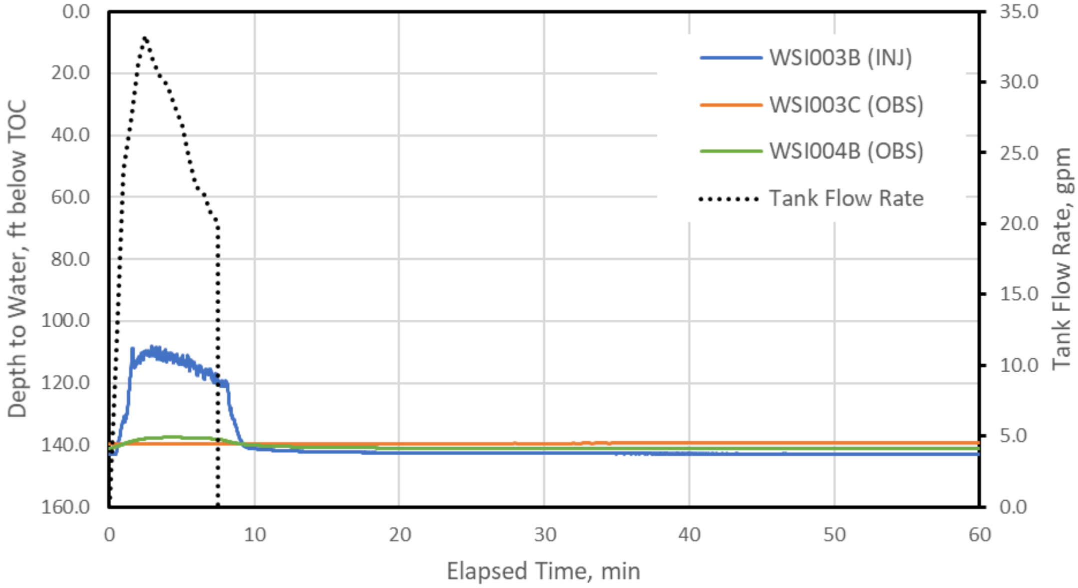

Figure 12. Hydrograph Showing Aquifer Response to Injection in WSI003B.

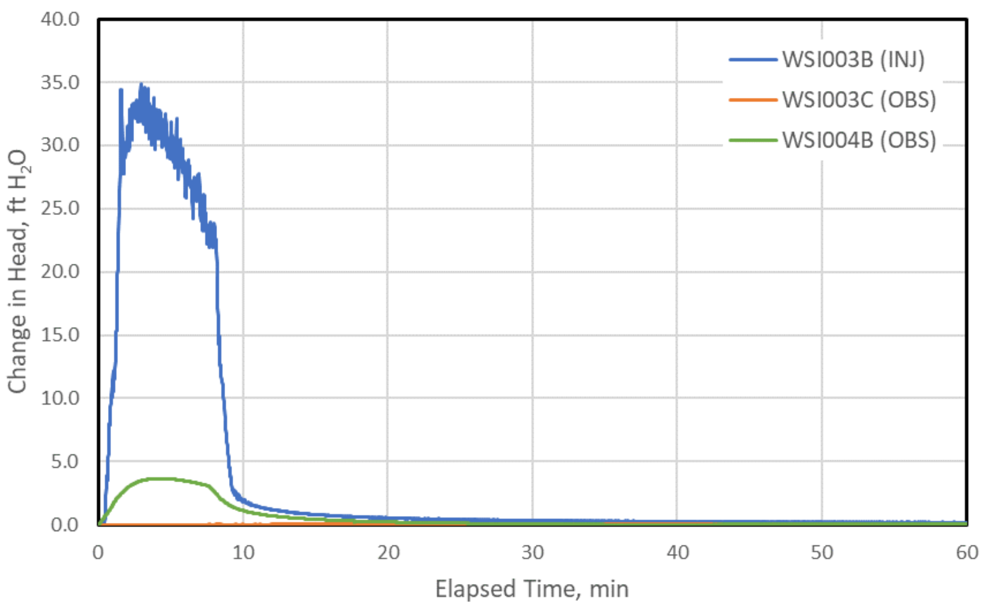

Figure 13. Pressure Response Observed in WSI003C and WSI004B Due to Injection in WSI003B.

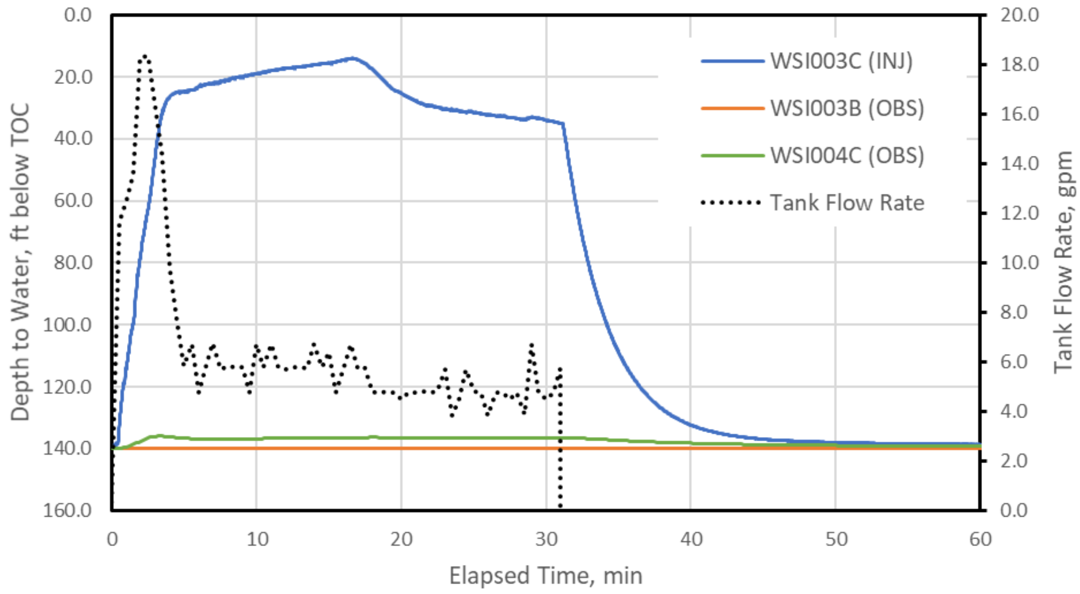

Figure 14. Hydrograph Showing Aquifer Response to Injection in WSI003C.

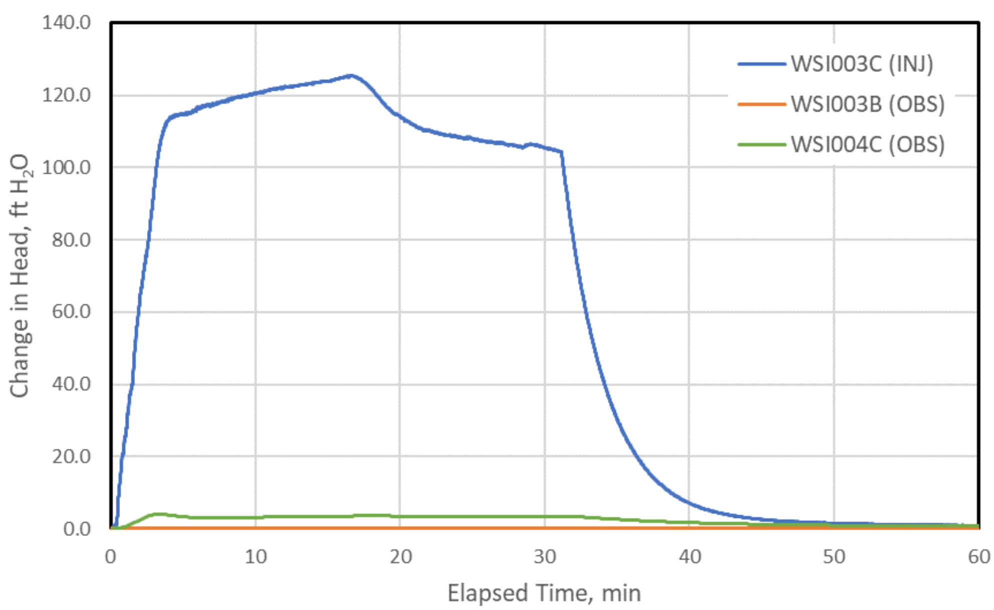

Figure 15. Pressure Response Observed in WSI003B and WSI004C Due to Injection in WSI003C.

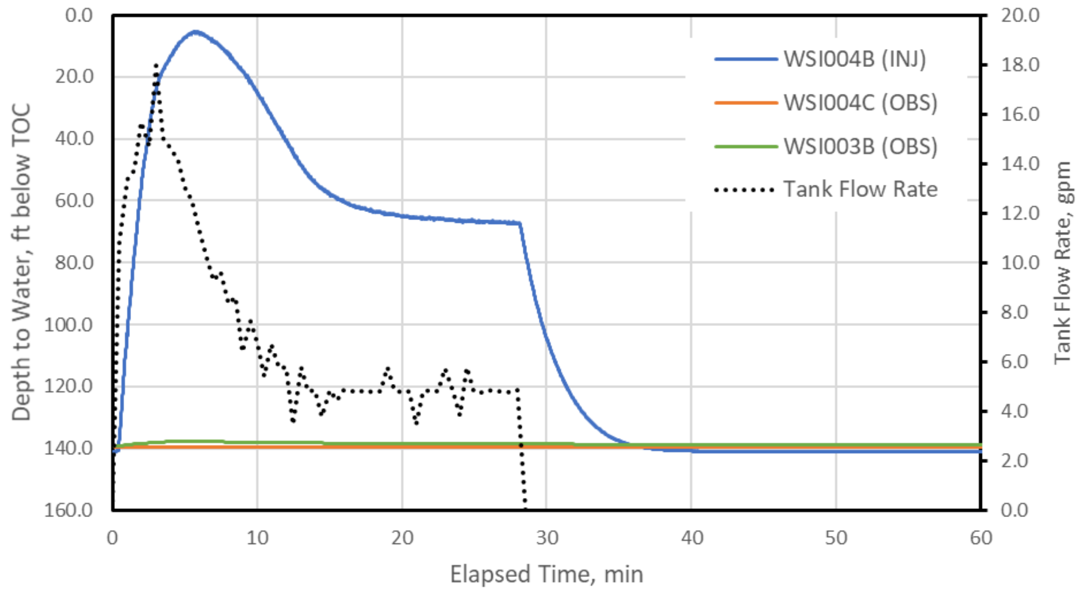

Figure 16. Hydrograph Showing Aquifer Response to Injection in WSI004B.

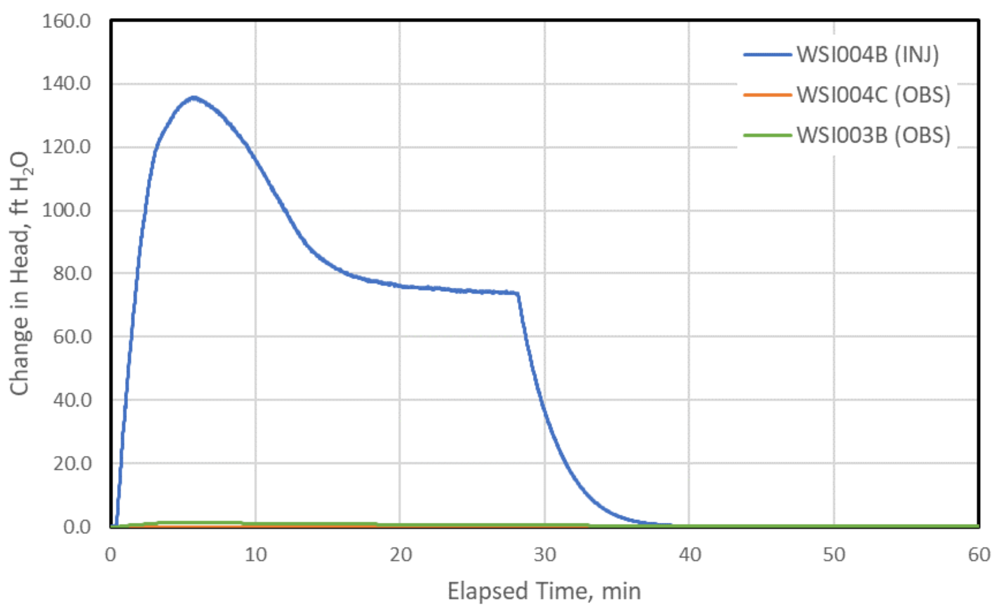

Figure 17. Pressure Response Observed in WSI004C and WSI003B Due to Injection in WSI004B.

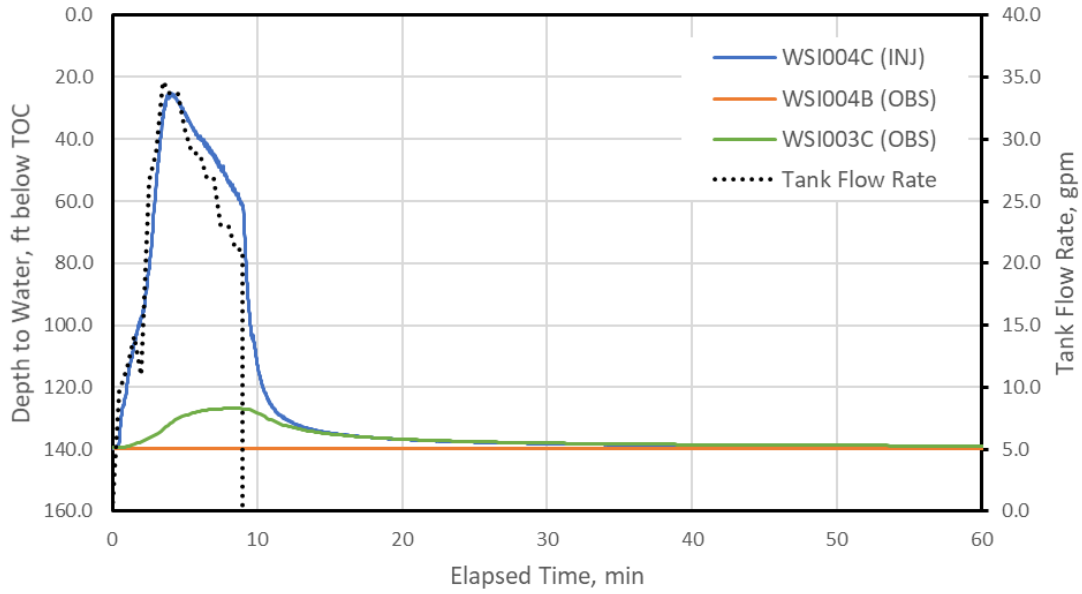

Figure 18. Hydrograph Showing Aquifer Response to Injection in WSI004C.

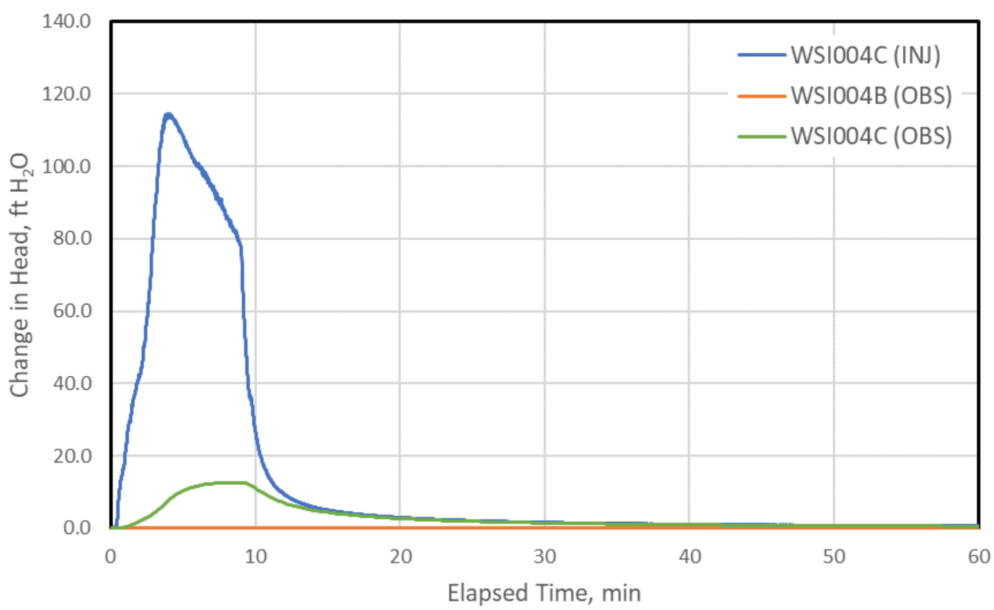

Figure 19. Pressure Response Observed in WSI003B and WSI004C Due to Injection in WSI004C.

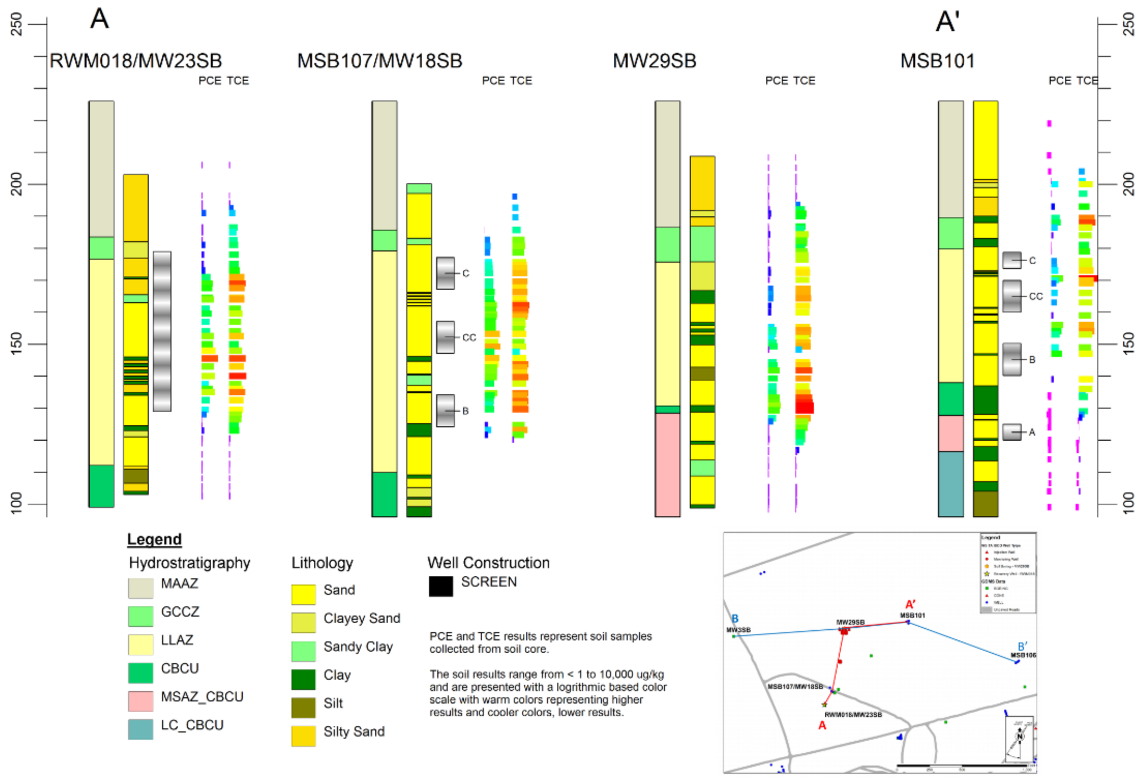

Figure 20. Lithologic Cross-Section of ISCO Site.

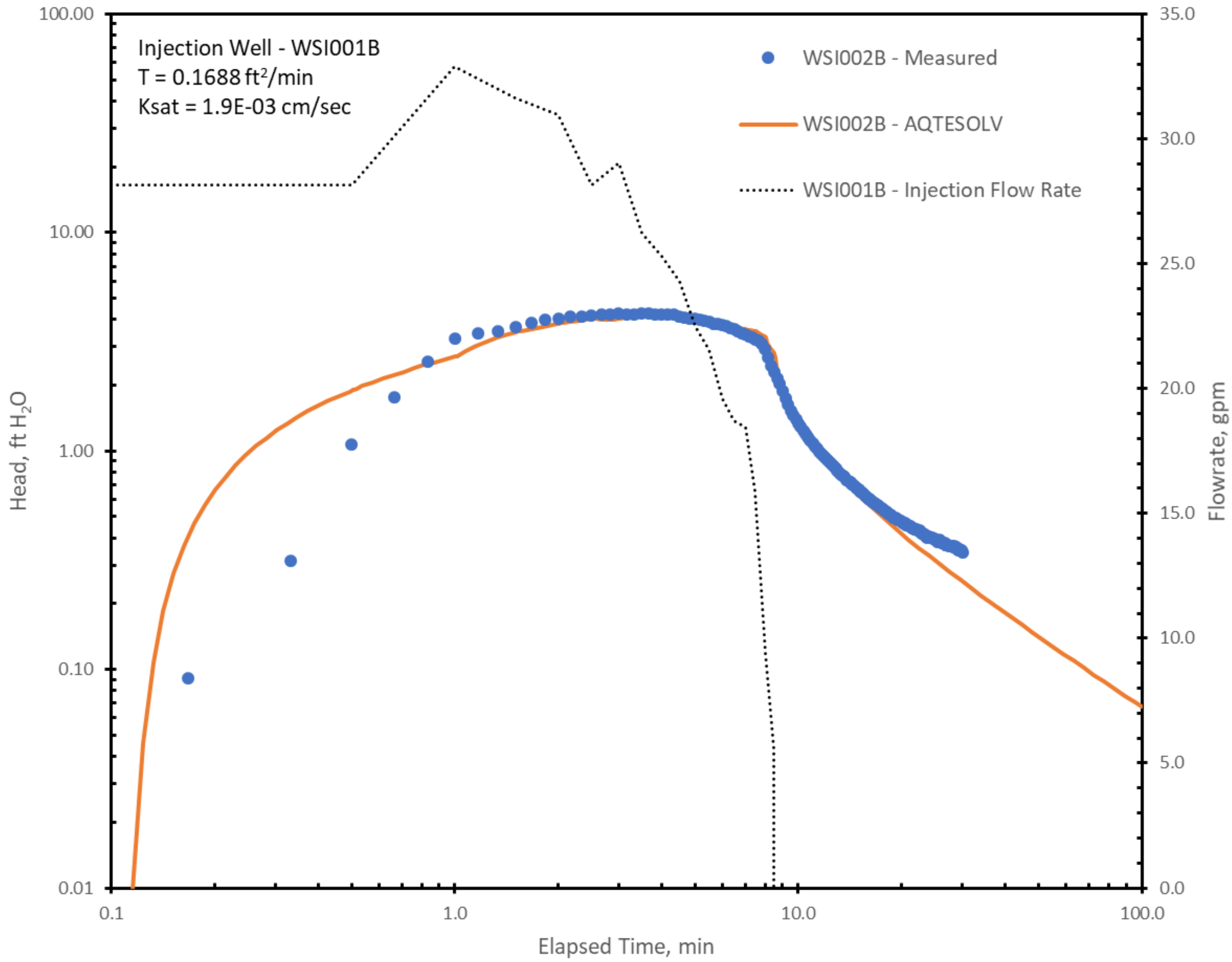

Figure 21. Head Change as a Function of Time for WSI002B in Response to Injection in WSI001B.

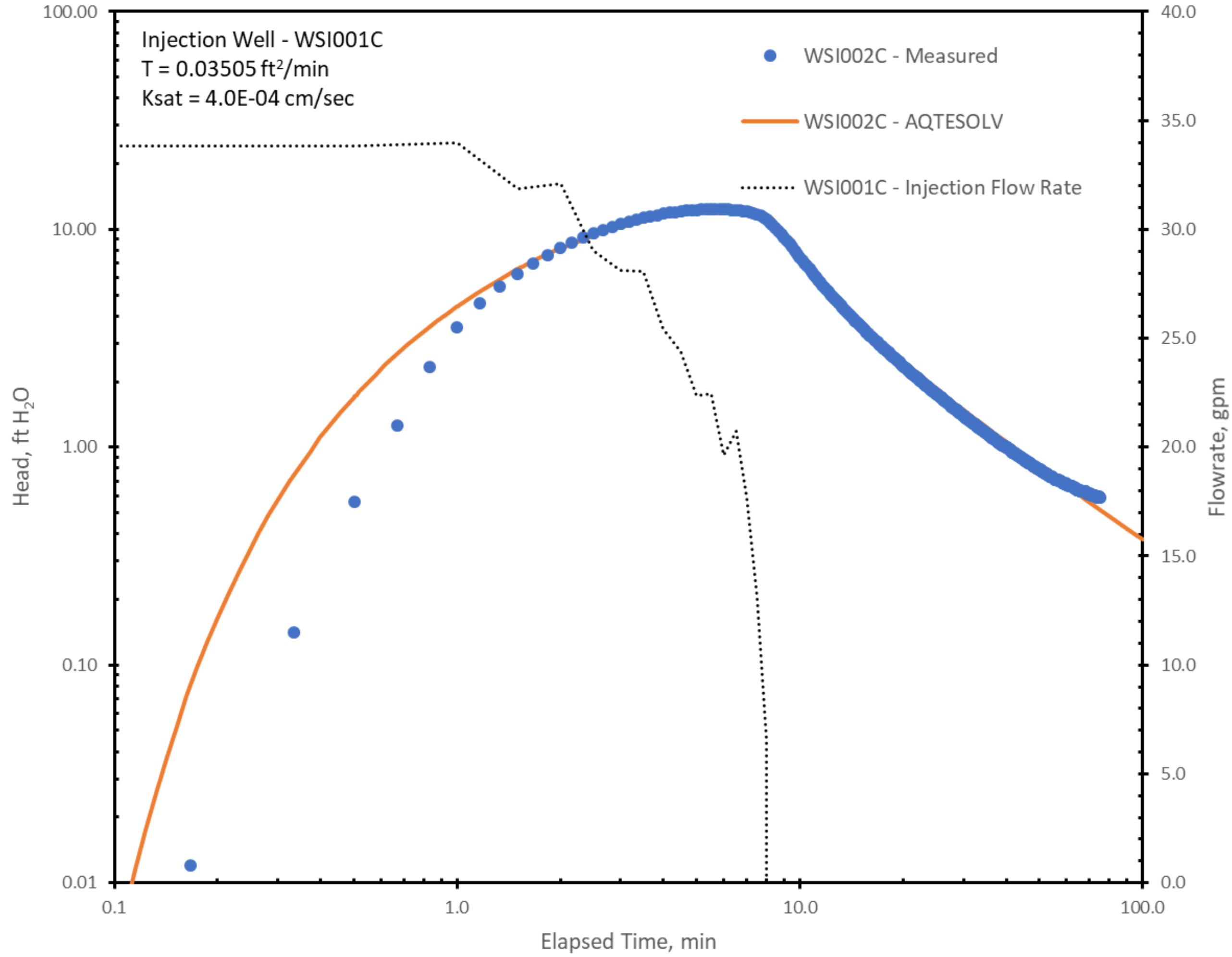

Figure 22. Head Change as a Function of Time for WSI002C in Response to Injection in WSI001C.

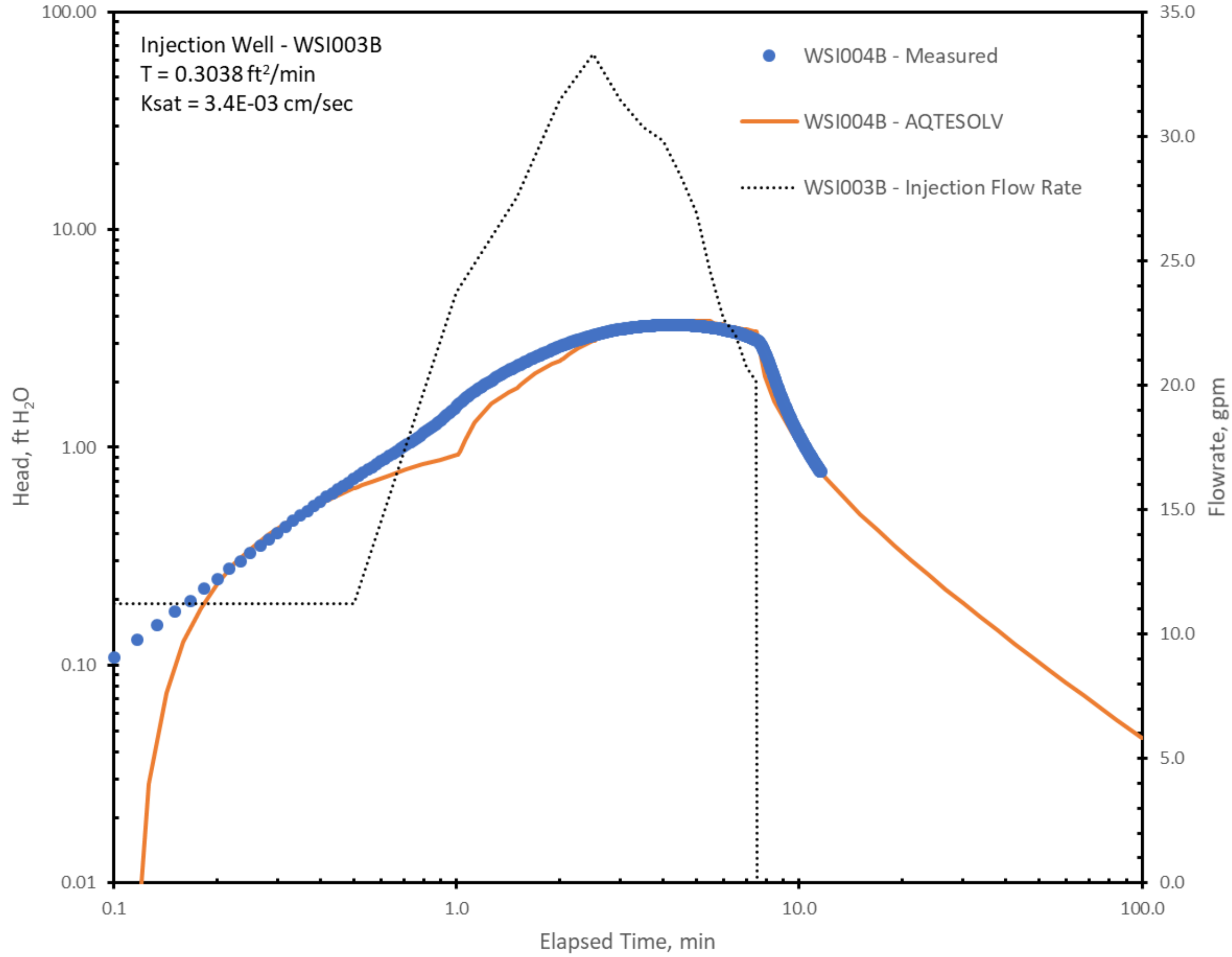

Figure 23. Head Change as a Function of Time for WSI004B in Response to Injection in WSI003B.

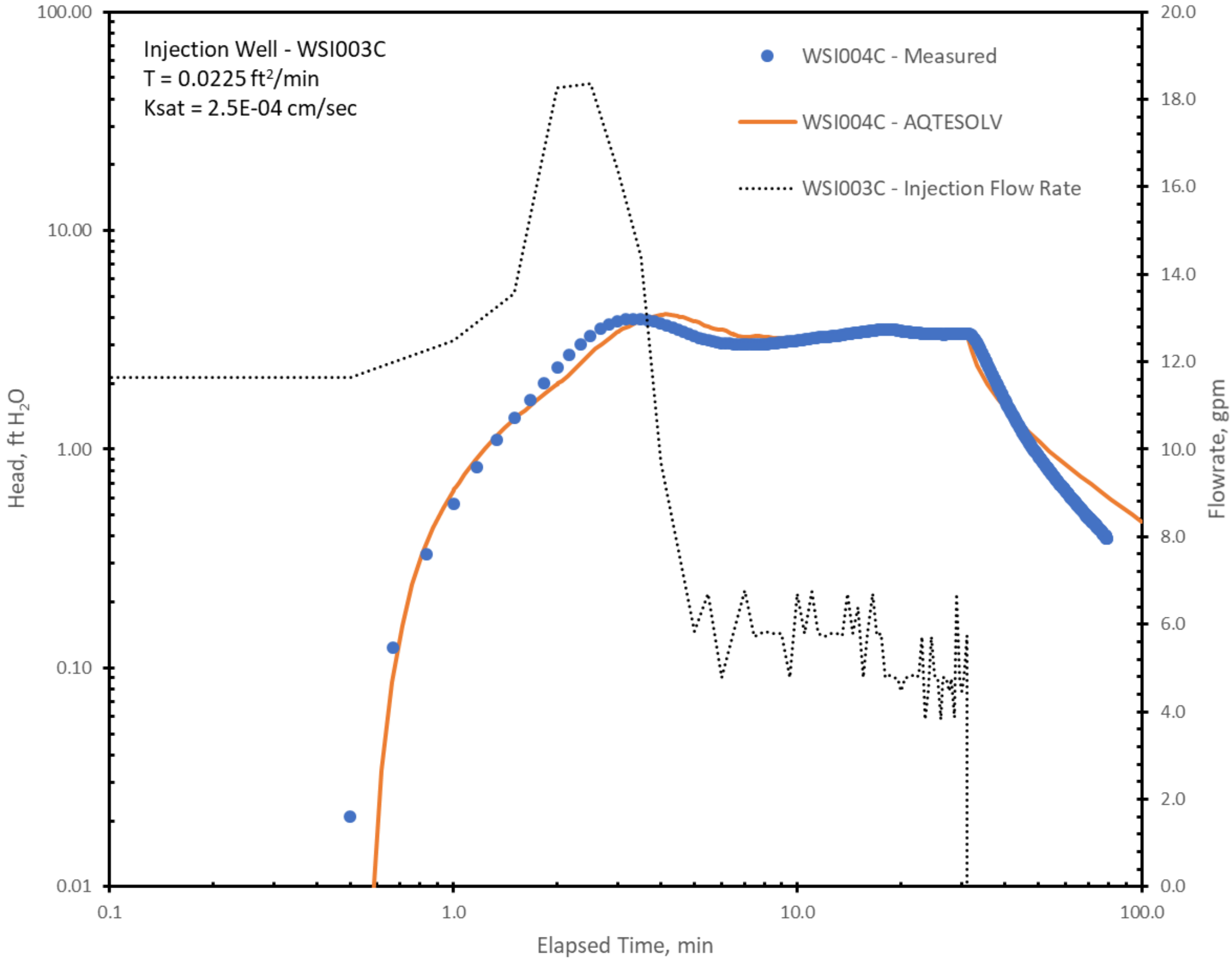

Figure 24. Head Change as a Function of Time for WSI004C in Response to Injection in WSI003C.

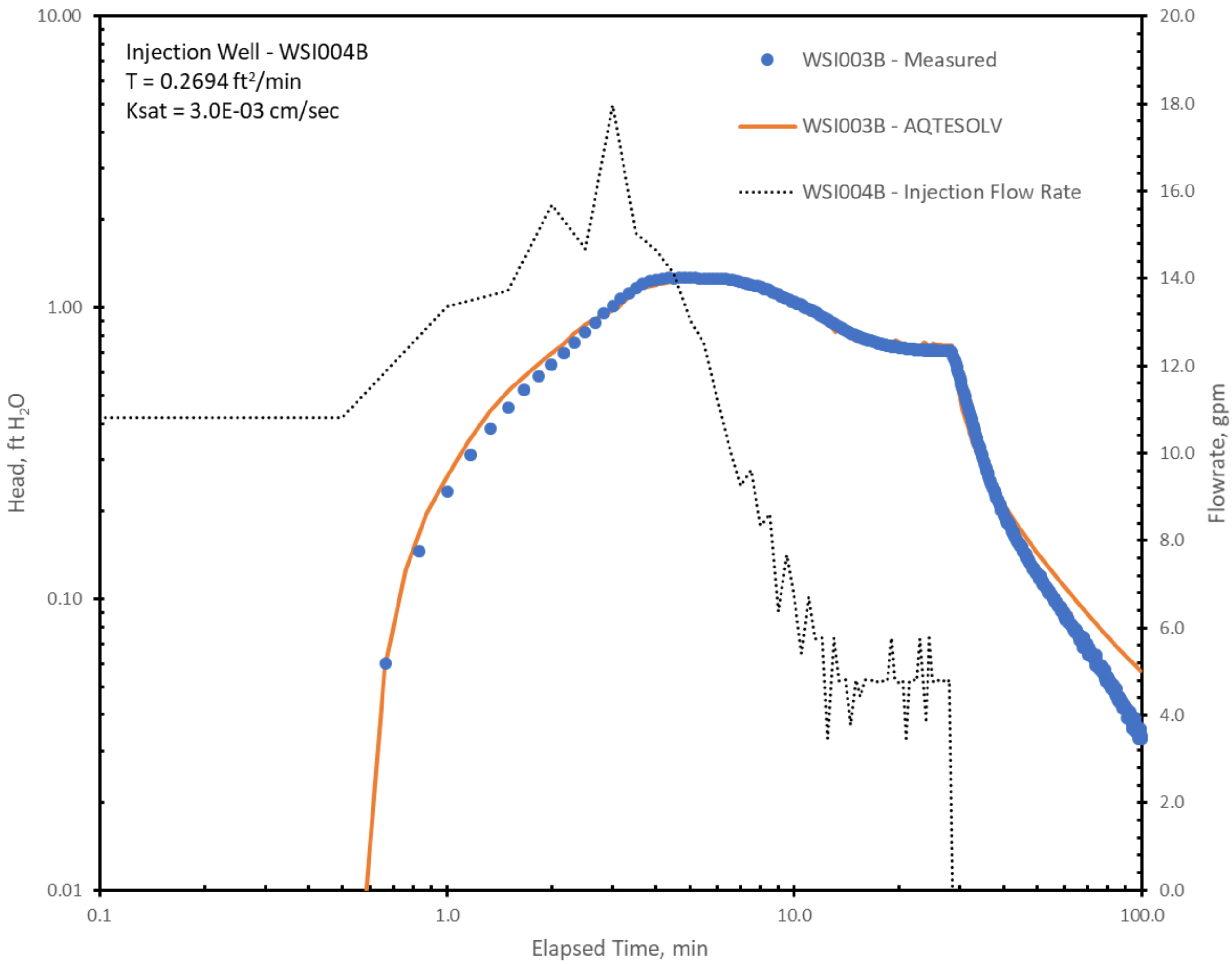

Figure 25. Head Change as a Function of Time for WSI003B in Response to Injection in WSI004B.

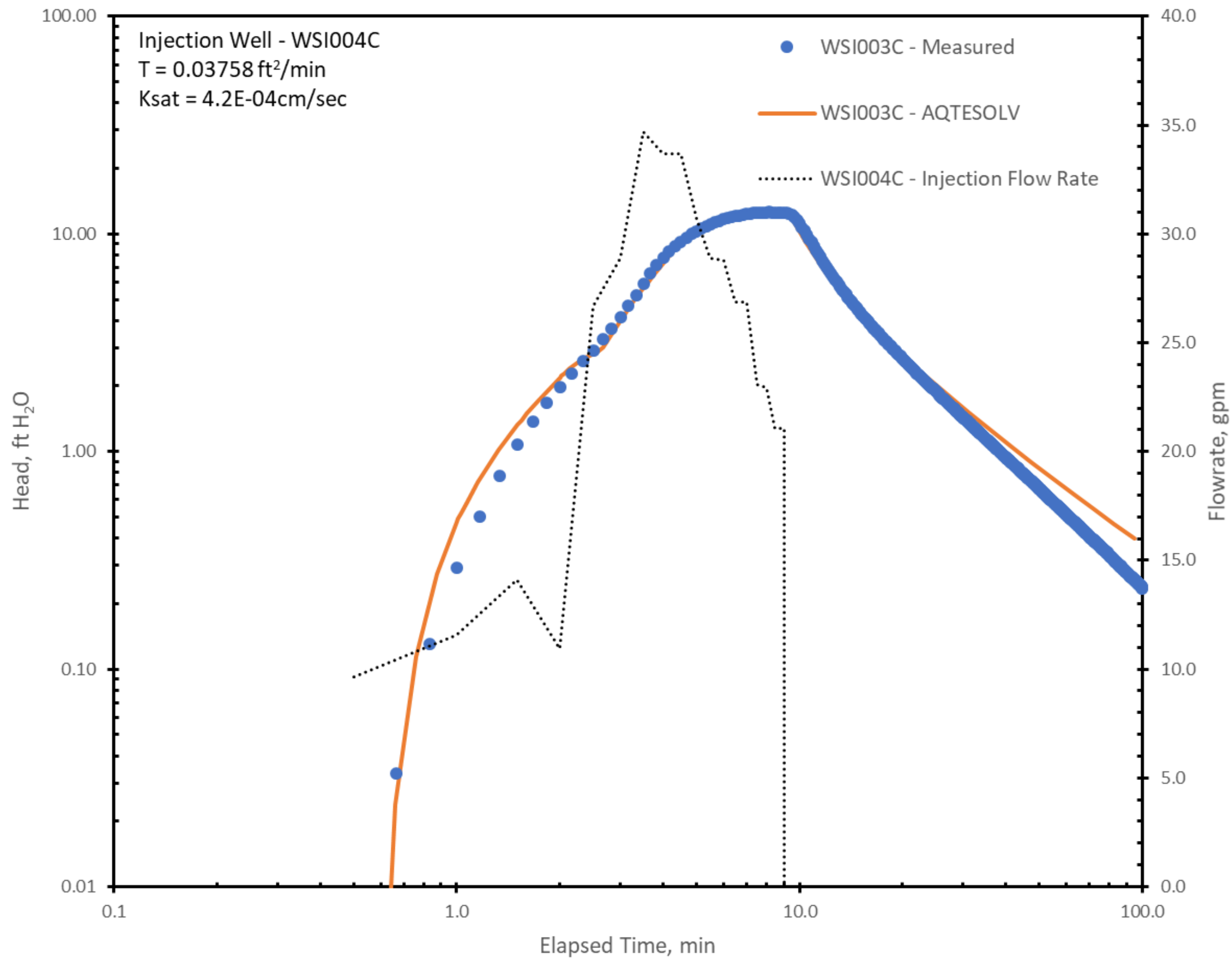

Figure 26. Head Change as a Function of Time for WSI003C in Response to Injection in WSI004C.

Table 1: Construction Details for the Oxidant Injection Wells.

Well Name[1]	Estimated Depth (ft bgs)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Aquifer Zone
WSI001B	217.2	194	209.0	Lower LLAZ
WSI001C	186.7	171.3	186.3	Upper LLAZ
WSI002B	211.5	196.2	211.2	Lower LLAZ
WSI002C	189.6	174.3	189.3	Upper LLAZ
WSI003B	211.0	195.7	210.7	Lower LLAZ
WSI003C	189.0	173.7	188.7	Upper LLAZ
WSI004B	212.0	196.3	211.3	Lower LLAZ
WSI004C	189.8	174.5	189.5	Upper LLAZ

[1]All wells are constructed of 2" PVC with 15' screens.

Table 2. Field Data Collected During Injection Well Testing.

Well Name[1]	Injection Volume (gals)	Tank Average Flow rate (gpm)	Average Pressure In Well (psig)	Time to Empty Tank (min)	Time for Head to Dissipate[1] (min)	Average Injection Capacity[2] (gpm)	Time Required for 5000 gals[3] (hours)
WSI001B	201	23.7	8.6	8.5	10.2	19.7	4.2
WSI001C	201	23.7	22.8	8.5	31.2	6.5	12.9
WSI002B	216	24.0	11.2	9.0	11.3	19.1	4.4
WSI002C	225	22.5	58.5	10.0	37.4	6.0	13.8
WSI003B	216	27.0	12.2	8.0	9.3	23.2	3.6
WSI003C	213	6.9	49.2	31.0	56.6	3.8	22.1
WSI004B	216	7.7	45.4	28.0	36.5	5.9	14.1
WSI004C	225	25.0	41.2	9.0	32.0	7.0	11.8

[1]Time for excess head due to injection to dissipate to within 1% of static water level.
[2]Injection capacity based on total injection volume and the time required for head to dissipate.
[3]Time required to inject 5000 gallons under gravity flow conditions based on injection capacity.

Table 3. Hydraulic Properties of the Lost Lake Aquifer in the Immediate Vicinity of the Western Sector Oxidant Injection Site.

Injection Well	Observation Well	T (ft^2/min)	Ks (cm/sec)
WSI001B	WSI002B	0.1688	1.9E-03
WSI001C	WSI002C	0.03505	4.0E-04
WSI002B	WSI002C	-	-
WSI002C	WSI002B	-	-
WSI003B	WSI004B	0.3038	3.4E-03
WSI003C	WSI004C	0.0225	2.5E-04
WSI004B	WSI003B	0.2694	3.0E-03
WSI004C	WSI003C	0.03758	4.2E-04

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