Appendix J

Analysis of Physical Characteristics

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Appendix J1

Hydraulic Conductivity Analysis

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ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
KGS	Kansas Geological Survey
K	Hydraulic Conductivity

1.0 INTRODUCTION

To characterize hydraulic conductivity of the perched water bearing soils at DU01, slug testing was completed at five monitoring wells (CH-MW016, CH-MW018, CH-MW019, CH-MW020, CH-MW021). These wells were selected for slug testing to obtain representative hydraulic conductivity data across and downgradient of Decision Unit 01. Wells where slug testing was completed are screened in undifferentiated deposits of till and stratified drift with screens starting between 5 feet below ground surface (bgs) and 15.5 feet bgs. Slug testing was completed from 21 to 27 June 2017. The slug test analysis is detailed in Subsection 2.1. Two subsurface soil core samples were collected at DU01 and submitted for geotechnical laboratory analysis of hydraulic conductivity following ASTM method D5084 (hydraulic conductivity of saturated porous materials using a flexible wall permeameter). The purpose of the soil core samples was to obtain representative analysis of the permeability of clay layers which underlie the perched water bearing zone. One soil core was collected from soil boring DU01-S009 at 15 to 17 ft bgs and one soil core was collected from soil boring DU01-S015 at 25 to 27 ft bgs. These soil core samples were taken from thick clay layers encountered at these two borings within the perched water bearing zone at DU01. Clay was encountered at soil boring DU01-S009 from 8.5 ft bgs to the total depth of the borehole at 17 ft bgs and at soil boring DU01-S015 from 8.5 feet bgs to the total depth of the borehole at 29 ft bgs. Thick clay layers were generally intercepted at shallow depths in the southeastern portion of the site and at greater depths to the southwest. The soil core samples were collected on 8 June 2017. The geotechnical laboratory hydraulic conductivity of the clay is discussed in Subsection 2.2.

2.0 ANALYSIS

2.1 Slug Test Analysis of Hydraulic Conductivity

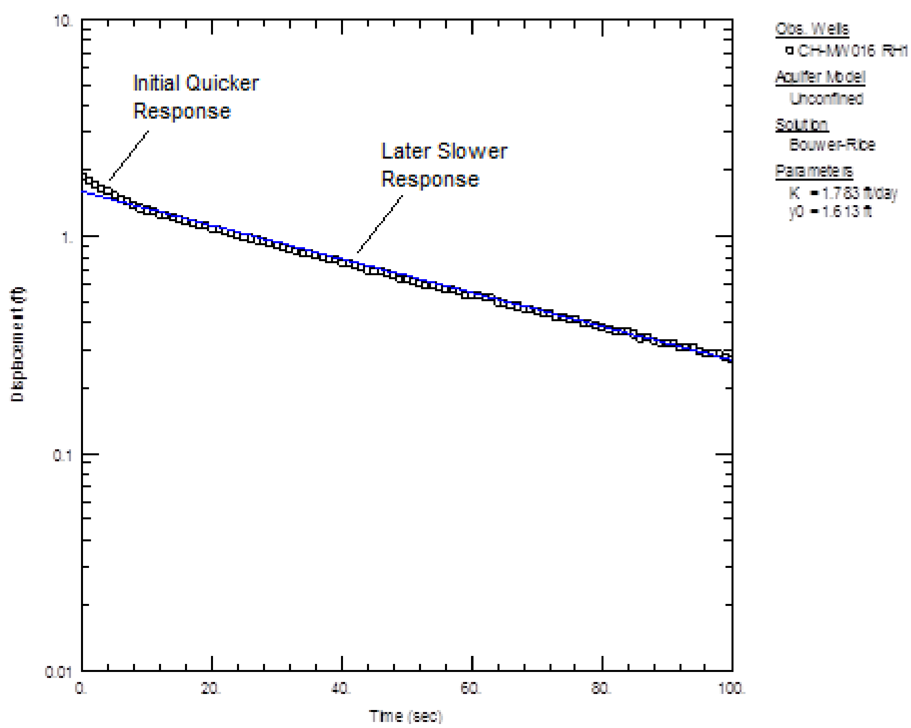
The slug testing was completed in accordance with SOP 3-35 Hydraulic Conductivity (K) Testing. The analysis of the water level response data was completed using Aqtesolve Version 4.5. The data were analyzed with either the Bouwer-Rice model for unconfined aquifers or the Hyder et al. (1994) Kansas Geological Survey (KGS) model for unconfined aquifers, or both. The choice of the model depended on the fit of the solution to the plot of displacement vs. time.

Inputs for the models used in Aqtesolve included well construction details, initial displacement in the water level due to slug movement, static water column height measured from the bottom of the well to the static potentiometric surface, saturated thickness of the aquifer, and vertical-to-horizontal hydraulic conductivity ratio. The saturated thickness of the aquifer was assumed to extend from the static water table to 1 foot below the well. Water at greater depths beneath a well is likely to be inaccessible given the minor water bearing zones and confining beds that comprise the undifferentiated deposits. The vertical-to-horizontal hydraulic conductivity ratio was set at 0.1 to reflect laminations observed in the material over which some of the wells are screened. A well-by-well discussion of slug test analysis follows. Plots of displacement vs. time and model solutions fit to the plots are provided in Attachment 1.

CH-MW016

Three rising and falling heads were performed at CH-MW016. The boring log for this well indicates that the well is screened across sand and clay. Since this well is screened at the water table, only rising head test data were analyzed. The rising head test data showed a quicker response to slug movement followed by a slower response. An example of this is shown in the displacement vs. time plot from the first rising head test below. The plot is constrained to the show the first 100 seconds after the slug was removed.

CH-MW016 Rising Head Test 1



This type of response is known as a double straight line effect and results when filter drainage occurs in a well screened across the water table. The initial quicker response to slug movement is probably due to filter pack drainage, while the slower response that occurs later is more indicative of flow from the aquifer into the well. Analysis of the data from this well focused on the later responses.

Both the Bouwer-Rice model and the Hyder et al. (1994) KGS model solutions fit the plots of displacement vs. time. Estimates of K are representative of glacial till composed primarily of clayey sand with laminations of sand and clay at this well location. The results of both model solutions are presented in the table below.

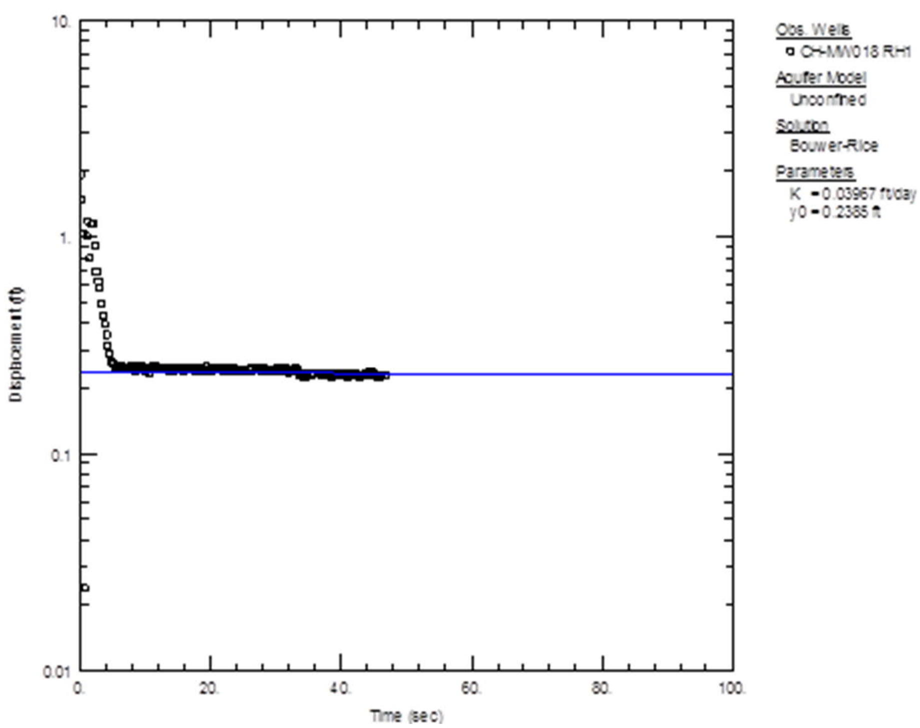
Test	Hydraulic Conductivity (feet/day)	Analysis Method
Rising Head – 1	1.78/2.13	Bouwer-Rice/KGS
Rising Head – 2	1.83/1.89	Bouwer-Rice/KGS
Rising Head – 3	2.04/1.76	Bouwer-Rice/KGS

The average hydraulic conductivity for this well is 1.90 feet/day, which is in the range considered reasonable for silty sand (Freeze and Cherry, 1979).

<u>CH-MW018</u>

Three rising head and falling head tests were performed at CH-MW018. The boring log for this well indicates that the well is screened across silt. Since this well is screened at the water table, only rising head test data were analyzed. Only data from two out of the three rising head tests were analyzable as the second rising head test did not show a decrease in displacement with time. Consistent with CH-MW016, the displacement vs time plots from slug testing of CH-MW018 showed an initial quicker response to slug movement followed by a slower response. An example of this is shown in the displacement vs. time plot from the first rising head test below.

CH-MW018 Rising Head Test 1



The later slower responses were fit with solutions. The Bouwer-Rice model solution fit the plots of displacement vs. time better than the Hyder et al. (1994) KGS model solution. Estimates of K are representative of glacial till composed primarily of silt at this well location. The results of the Bouwer-Rice model solution are presented in the table below.

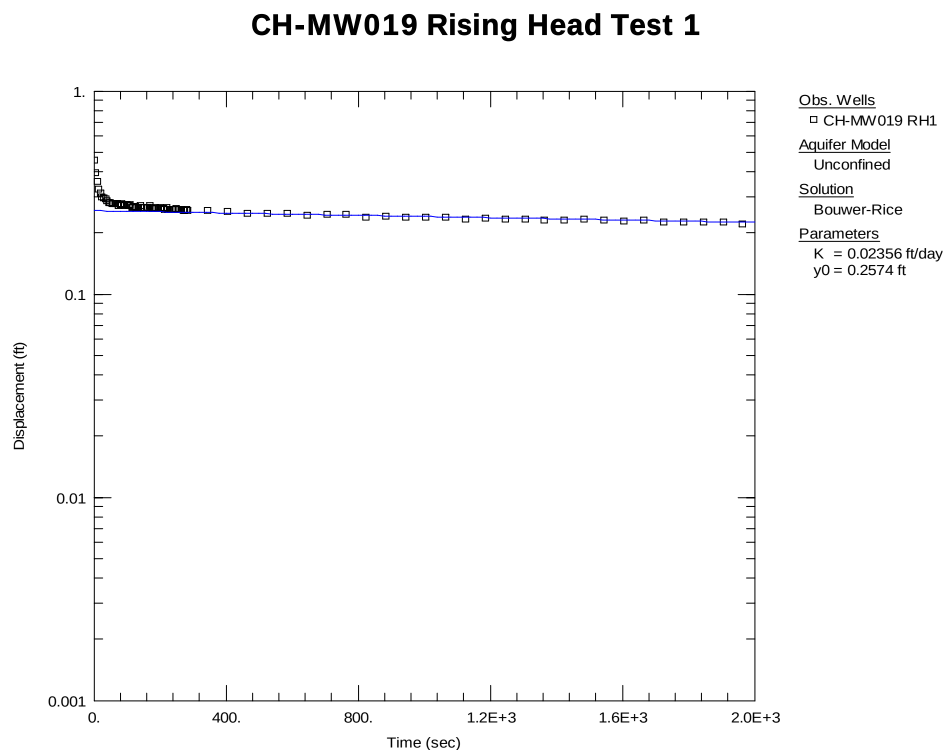
Test	Hydraulic Conductivity (feet/day)	Analysis Method
Rising Head – 1	0.04	Bouwer-Rice
Rising Head – 3	0.02	Bouwer-Rice

The average hydraulic conductivity for this well is 0.03 feet/day, which is in the range considered reasonable for silt (Freeze and Cherry, 1979).

CH-MW019

Two rising head and falling head tests were performed at CH-MW019, however only the rising head tests provided sufficient data for analysis. The boring log for this well indicates that the well is screened across clay. The Bouwer-Rice model solution fit the plots of displacement vs. time better than the Hyder et al. (1994) KGS model solution.

Consistent with CH-MW016 and CH-MW018, response data from CH-MW019 exhibited a double straight line effect. An example of this is shown in the displacement vs. time plot from the first rising head test below.



Initial characterization of the hydraulic conductivity of the formation described by the response selected the steeper slope (higher K) portion of the test. However, well development records indicate the well was pumped dry several times during development with slow recovery. In addition, the boring log indicates the well was completed inglacial till and silt. Because of the response data and evidence of the supporting documents, it is more appropriate that the characterization of the hydraulic conductivity of the formation at CH-MW019 should follow the much slower response.

Estimates of K are representative of glacial till composed primarily of silt and clay at this well location. The results of the Bouwer-Rice model solution are presented in the table below.

Test	Hydraulic Conductivity (feet/day)	Analysis Method
Rising Head – 1	0.02	Bouwer-Rice
Rising Head – 2	0.002	Bouwer-Rice

The average hydraulic conductivity for this well is 0.006 feet/day, which is in the range considered reasonable for glacial till composed of silt and clay (Freeze and Cherry, 1979).

CH-MW020

Three rising head and falling head tests were performed at CH-MW020. The boring log for this well indicates that the well is screened across sand, clayey sand, and silty clay. Since this well is screened below the water table both rising and falling head test data were analyzed. The Bouwer-Rice model solution fit the plots of displacement vs. time of falling head tests better than the Hyder et al. (1994) KGS model solution. Both the Bouwer-Rice model and the Hyder et al. (1994) KGS model solutions fit some of the plots of displacement vs. time of rising head tests. Estimates of K are representative of glacial till composed primarily of sand, clayey sand, and silty clay at this well location. The results are presented in the table below.

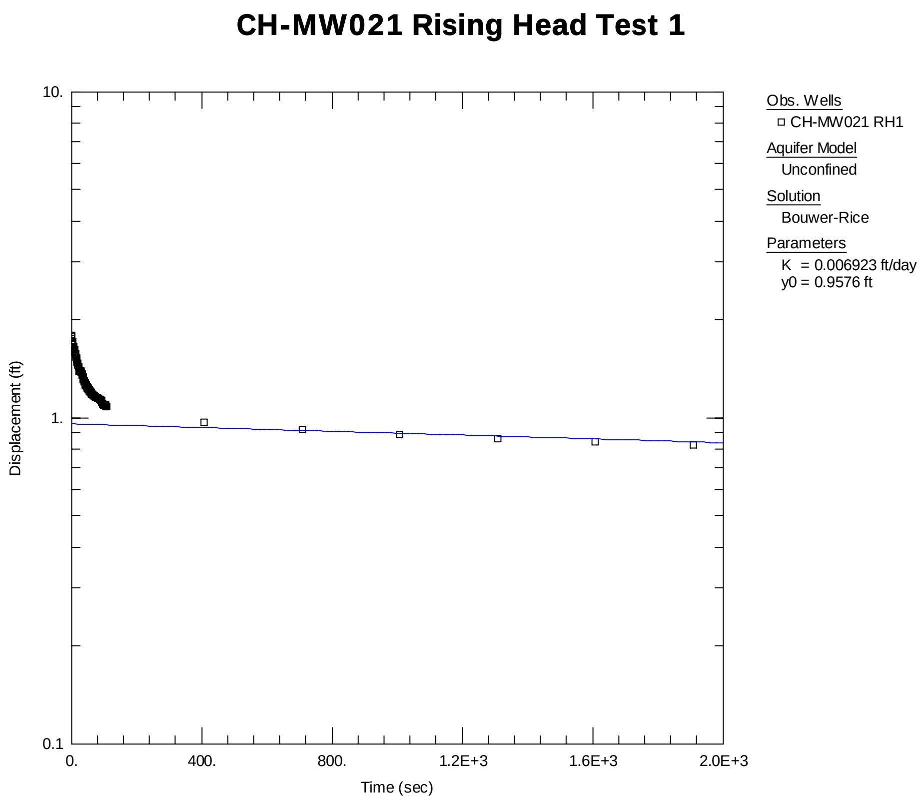
Test	Hydraulic Conductivity (feet/day)	Analysis Method
Falling Head – 1	0.5	Bouwer-Rice
Falling Head – 2	0.5	Bouwer-Rice
Falling Head – 3	0.6	Bouwer-Rice
Rising Head – 1	0.5/0.5	Bouwer-Rice/KGS
Rising Head – 2	0.5	Bouwer-Rice
Rising Head – 3	0.5	Bouwer-Rice

The average hydraulic conductivity for this well is 0.5 feet/day, which is in the range considered reasonable for silty sand (Freeze and Cherry, 1979).

CH-MW021

Two rising head and falling head tests were performed at CH-MW021, however only the falling head tests and one raising head test provided sufficient data for analysis. The boring log for this well indicates that the well is screened across clayey sand and clay. The Bouwer-Rice model solution fit the plots of displacement vs. time better than the Hyder et al. (1994) KGS model solution.

Consistent with other wells, response data from CH-MW021 exhibited a double straight line effect. An example of this is shown in the displacement vs. time plot from the first rising head test below.



Initial characterization of the hydraulic conductivity of the formation described by the response selected the steeper slope (higher K) portion of the test. However, well development records indicate the well was pumped dry several times during development with slow recovery. In addition, boring logs indicate the well was completed inclayey sand and clay. Because of the response data and evidence of the supporting documents, it is more appropriate that the characterization of the hydraulic conductivity of the formation should follow the much slower response.

Estimates of K are representative of glacial till composed primarily of clayey sand and clay at this well location. The results of the Bouwer-Rice model solution are presented in the table below.

Test	Hydraulic Conductivity (feet/day)	Analysis Method
Falling Head – 1	0.01	Bouwer-Rice
Falling Head – 2	0.09	Bouwer-Rice
Rising Head – 1	0.01	Bouwer-Rice

The average hydraulic conductivity for this well is 0.02 feet/day, which is in the range considered reasonable for glacial till to silt (Freeze and Cherry, 1979).

2.2 Laboratory Hydraulic Conductivity Analysis of Clay

Results of the geotechnical laboratory analysis of hydraulic conductivity of the clay core samples following ASTM method D5084 were 3.9 × 10-8 cm/sec at DU01-S009 (15 to 17 ft bgs) and 2.0 × 10-7 cm/sec at DU01-S015 (25 to 27 ft bgs). The measurements are equivalent to 0.0001 ft/day to 0.0006 ft/day, respectively. The low hydraulic conductivity results of the clay support the site conceptual model of clay layers representing confining units in the perched water bearing zone.

2.3 Uncertainties of Hydraulic Conductivity Data

The hydraulic conductivity results of multiple slug tests at each of the five test wells at DU01 were consistent for each well analyzed. This demonstrates the hydraulic response was repeatable at each well and representative of the hydraulic conductivity at that well location. However, the slug test analysis results show that the hydraulic conductivity was variable and ranged at well locations on a sitewide basis from 0.006 feet/day at CH-MW019 to 1.9 feet/day at CH-MW016.

This variability of the hydraulic conductivity values across the site is due to the presence and various thicknesses of interbedded layers of silty sand, silt, and clay layers in the undifferentiated till that contains the perched groundwater. In addition, some areas of the site have soils that have been reworked by previous historic Building 203 development including utilities and UST excavations. The reworked soil may have altered soil permeability and perched water recharge locally at individual wells. Overall, the slug test analysis at DU01 indicates that while there may be localized variability in hydraulic conductivity in soils due to the heterogeneous environment, the soils across the site demonstrate moderate to low permeability.

The data quality of the slug testing results is sufficient for purposes of the Camp Hero RI at DU01. The analysis provides quantitative data of the hydraulic conductivity of the perched water bearing soil units and provides insight into the behavior of perched water and LNAPL observed at DU01.

3.0 REFERENCES

Bouwer, H. and R.C. Rice, 1976. *A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.*

Bouwer, H., 1989, *The Bouwer and Rice Slug Test – An Update: Groundwater, v. 27, p. 304-309*.

Duffield, G.M., 2007. *AQTESOLV for Windows Version 4.0, HydroSOLVE, Inc., Reston, VA.*

Freeze, A. and J. Cherry. 1979. *Groundwater.*

Hyder, Z., J.J. Butler, Jr., C.D. McElwee and W. Liu, 1994. *Slug tests in partially penetrating wells, Water Resources Research, vol. 30, no. 11, pp. 2945-2957*.

Attachment 1

Inputs, Plots of Displacement vs. Time, and Model Solution Fits

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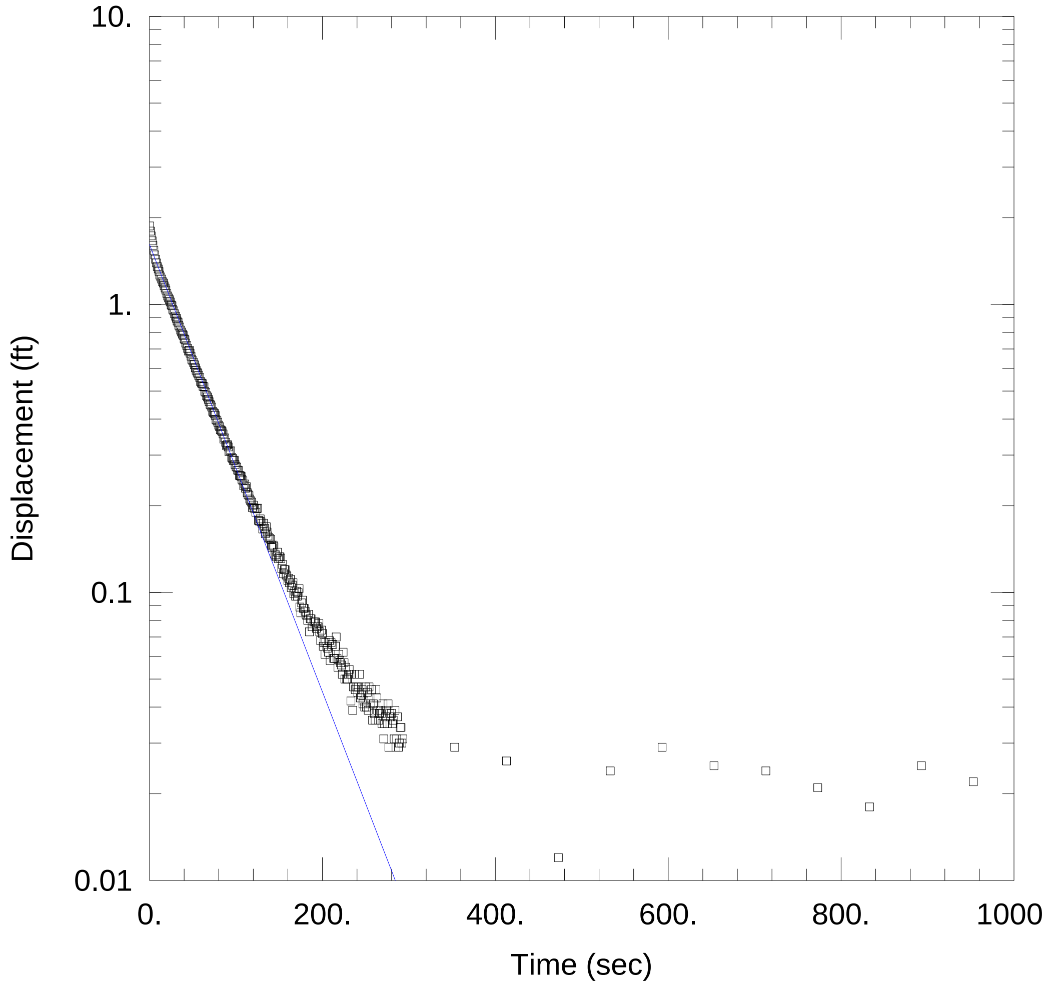


WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH1 BR.aqt
Date: 12/07/17 Time: 14:11:32

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft Anisotropy Ratio (Kz/Kr): 0.1

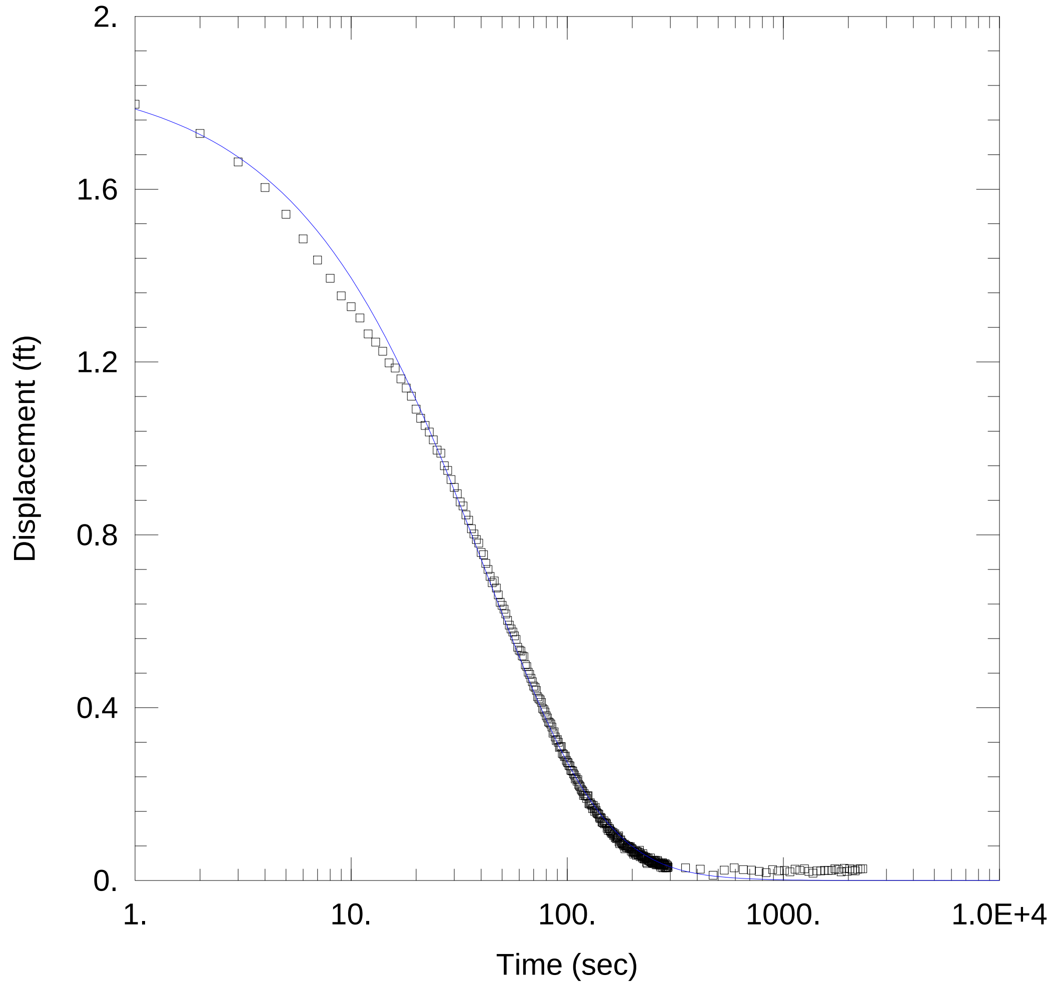
WELL DATA (CH-MW016 RH1)

Initial Displacement: 1.874 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.783 ft/day y0 = 1.613 ft



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH1 KGS.aqt
Date: 12/07/17 Time: 14:11:46

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft

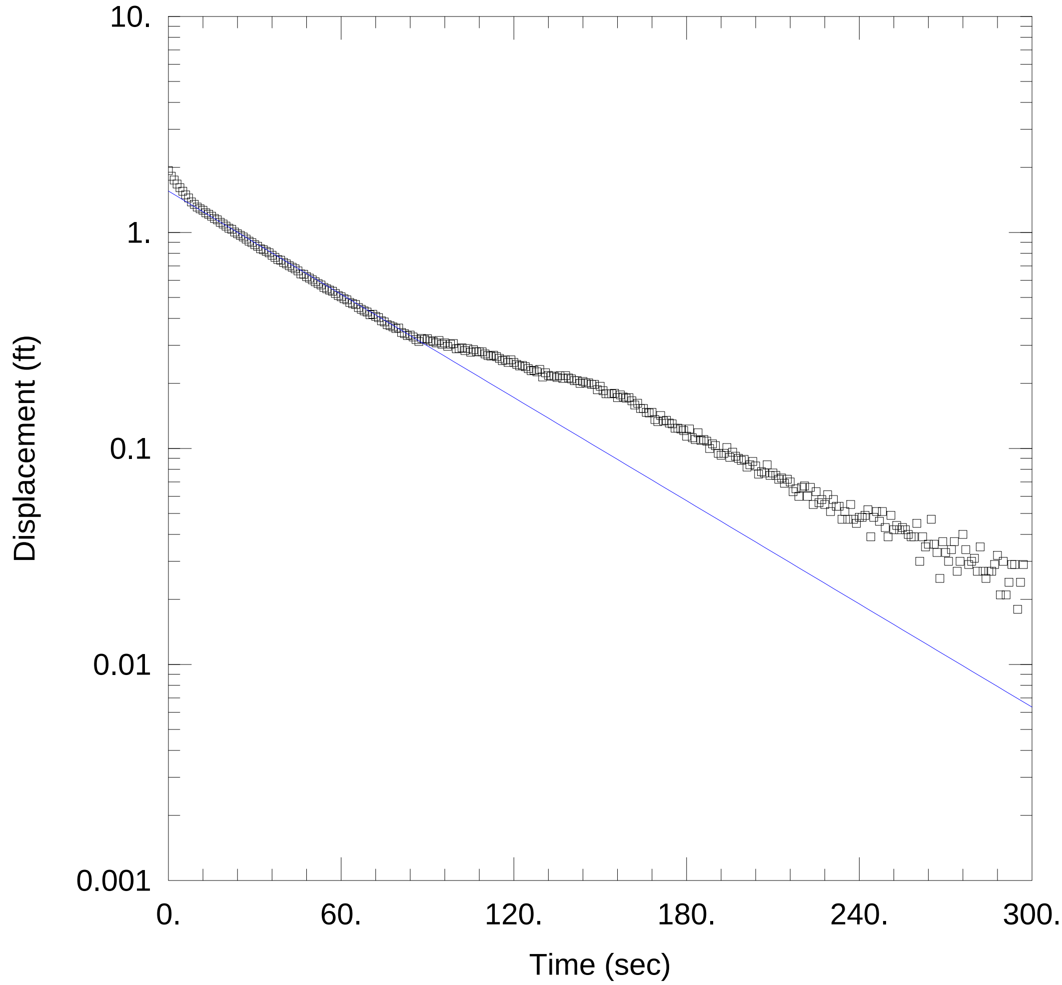
WELL DATA (CH-MW016 RH1)

Initial Displacement: 1.874 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 2.127 ft/day
Kz/Kr = 0.1
Ss = 2.055E-5 ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH2 BR.aqt
Date: 12/07/17 Time: 14:12:19

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft Anisotropy Ratio (Kz/Kr): 0.1

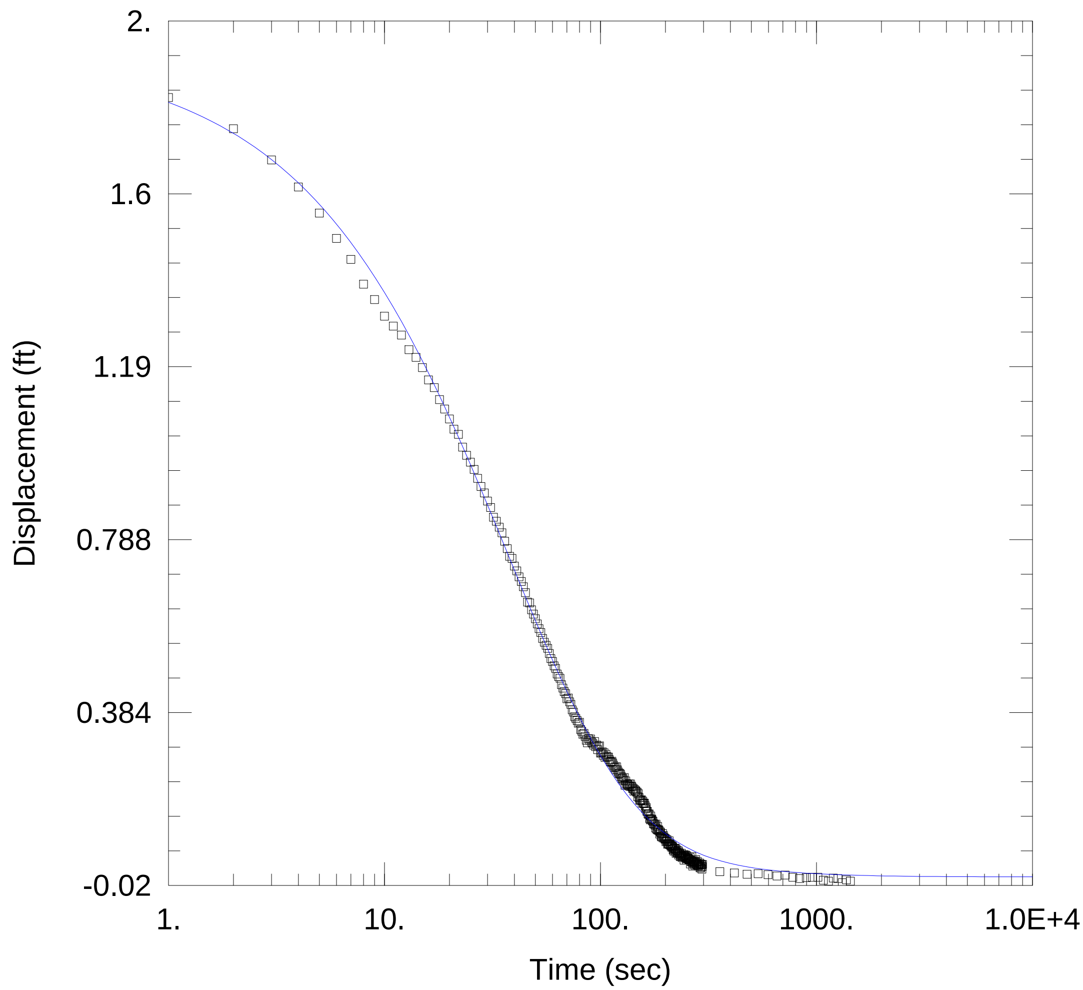
WELL DATA (CH-MW016 RH2)

Initial Displacement: 1.934 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.828 ft/day y0 = 1.553 ft



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH2 KGS.aqt
Date: 12/07/17 Time: 14:12:35

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft

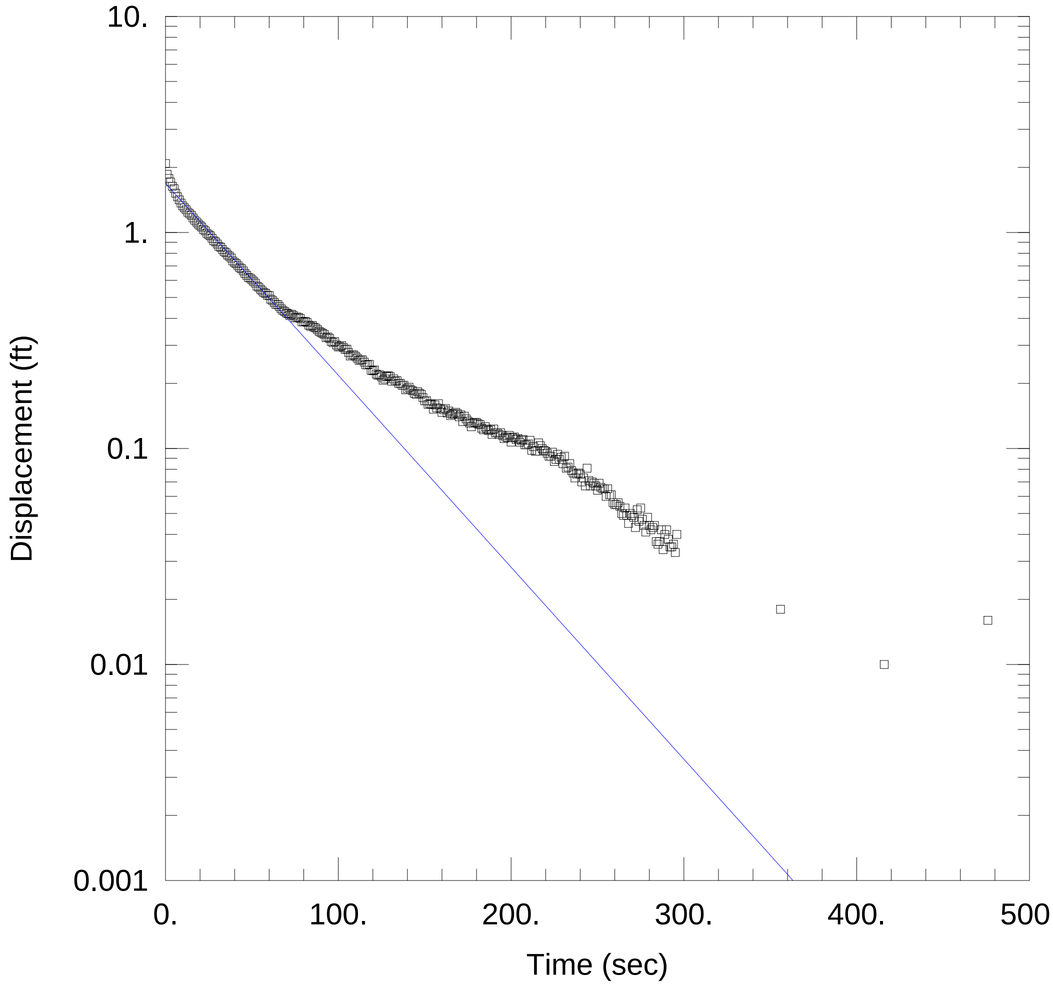
WELL DATA (CH-MW016 RH2)

Initial Displacement: 1.934 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 1.891 ft/day
Kz/Kr = 0.1
Ss = 8.839E-5 ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH3 BR.aqt
Date: 12/07/17 Time: 14:12:56

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft Anisotropy Ratio (Kz/Kr): 0.1

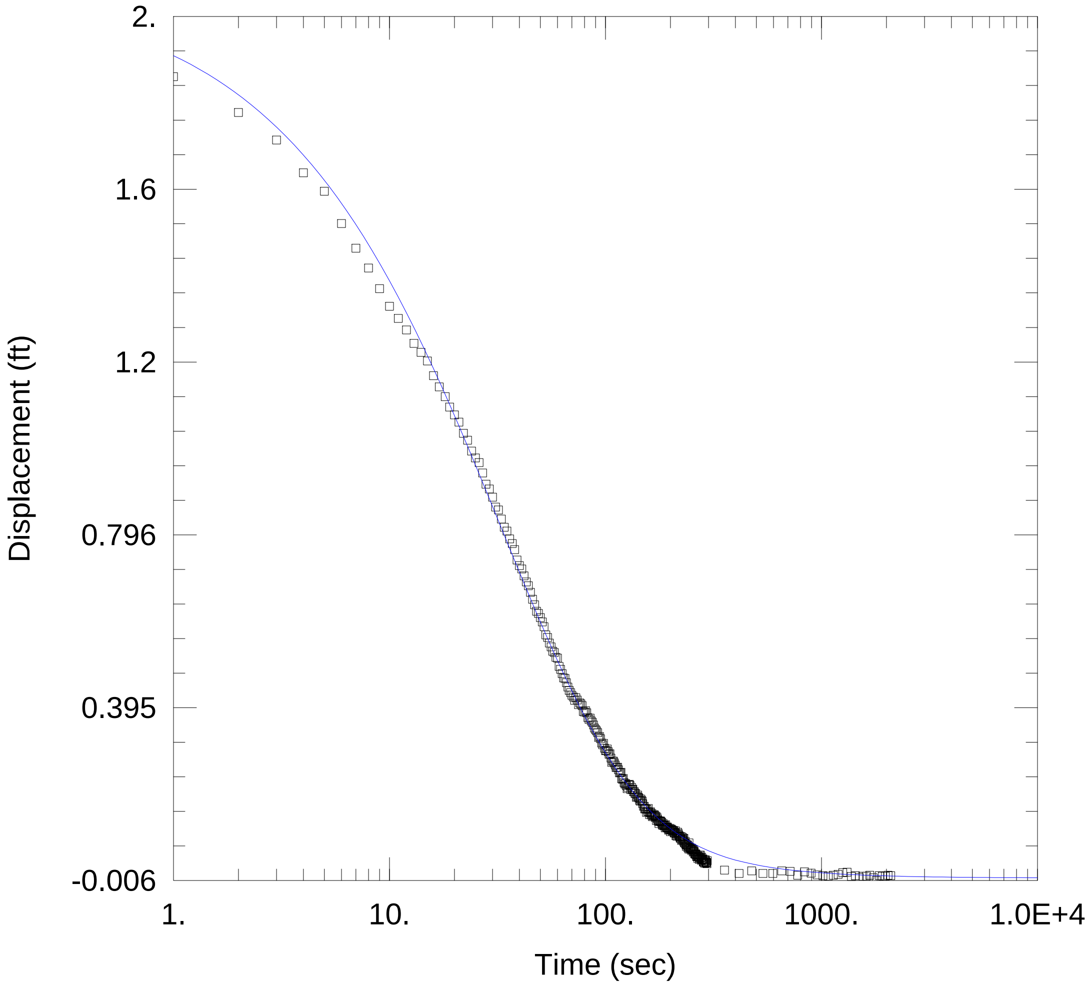
WELL DATA (CH-MW016 RH3)

Initial Displacement: 2.083 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 2.041 ft/day y0 = 1.691 ft



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW016 RH3 KGS.aqt
Date: 12/07/17 Time: 14:13:12

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW016
Test Date:

AQUIFER DATA

Saturated Thickness: 11.72 ft

WELL DATA (CH-MW016 RH3)

Initial Displacement: 2.083 ft
Total Well Penetration Depth: 10.72 ft
Casing Radius: 0.083 ft

Static Water Column Height: 10.72 ft
Screen Length: 10.72 ft
Well Radius: 0.25 ft

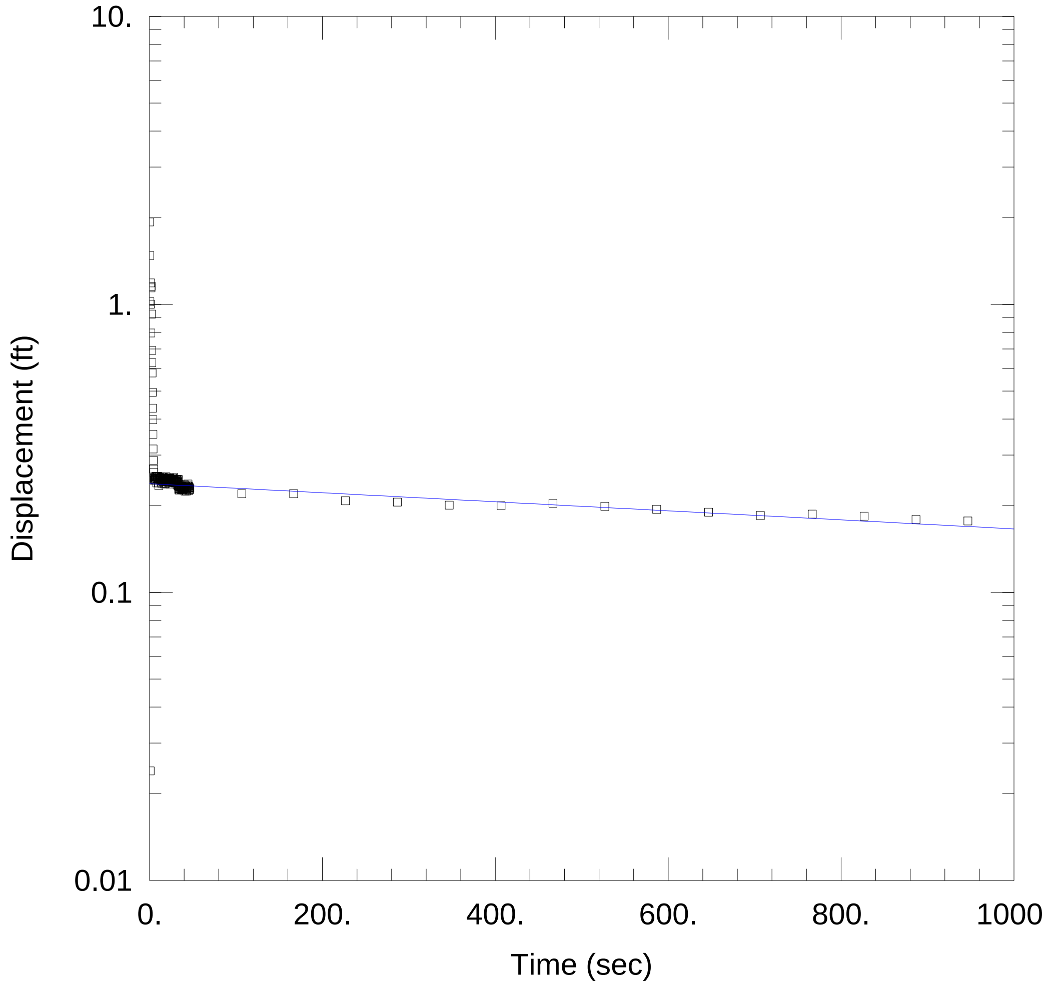
SOLUTION

Aquifer Model: Unconfined

Solution Method: KGS Model

Kr = 1.755 ft/day
Kz/Kr = 0.1

Ss = 0.0002348 ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW018 RH1 BR.aqt
Date: 12/07/17 Time: 14:14:12

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW018
Test Date:

AQUIFER DATA

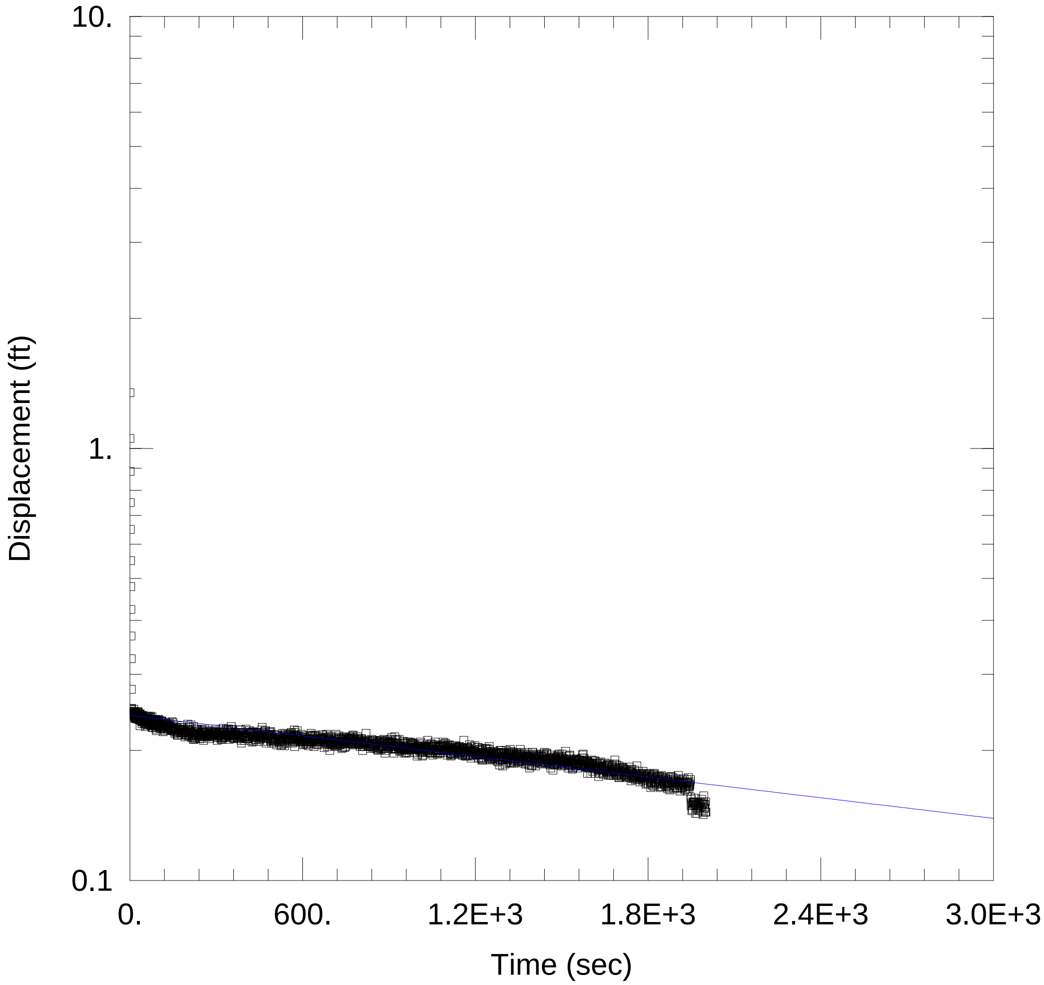
Saturated Thickness: 10.42 ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (CH-MW018 RH1)

Initial Displacement: 1.934 ft
Static Water Column Height: 9.42 ft
Total Well Penetration Depth: 9.42 ft
Screen Length: 9.42 ft
Casing Radius: 0.083 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.03967 ft/day
y0 = 0.2385 ft



WELL TEST ANALYSIS

Data Set: C:\...\CH-MW018 RH3 BR.aqt
Date: 12/07/17   Time: 14:15:18

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW018
Test Date:

AQUIFER DATA

Saturated Thickness: 10.45 ft   Anisotropy Ratio (Kz/Kr): 0.1

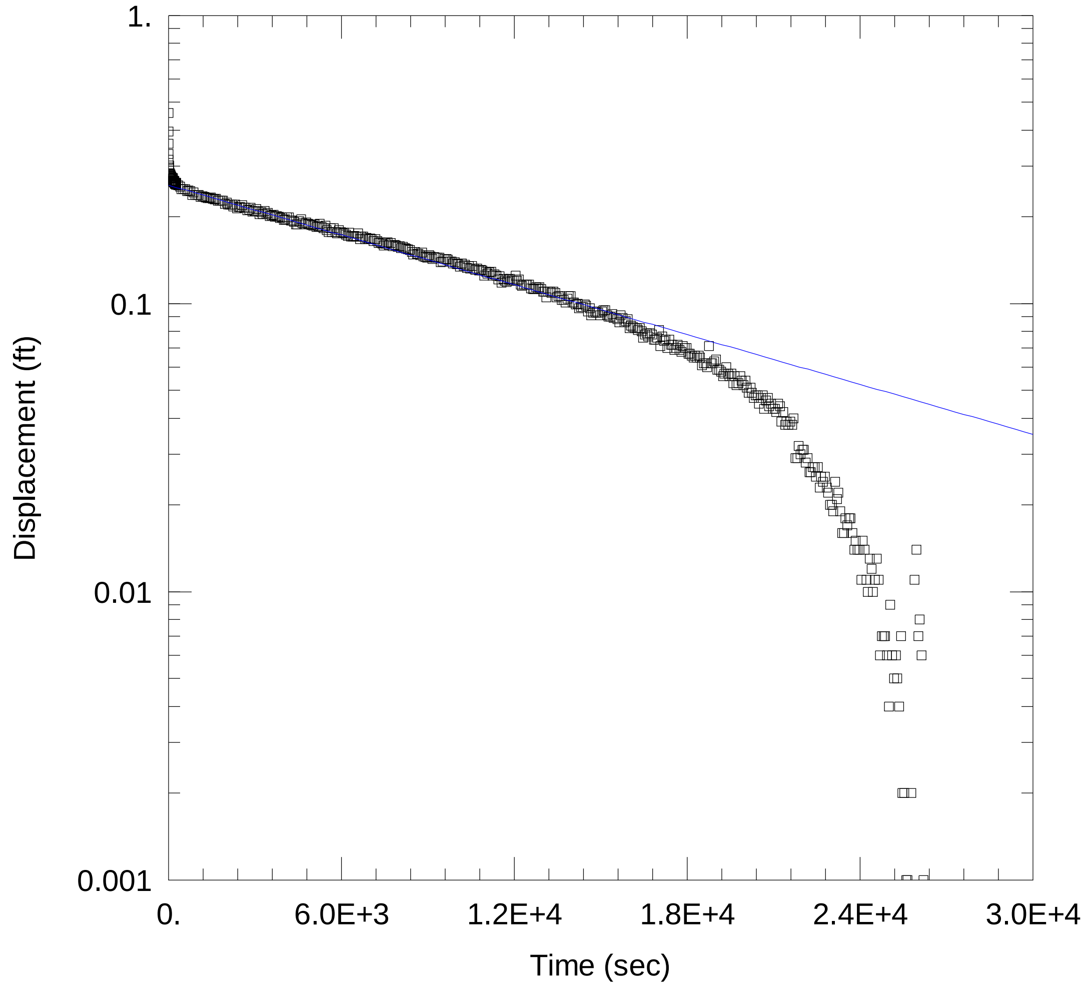
WELL DATA (CH-MW018 RH3)

Initial Displacement: 1.346 ft   Static Water Column Height: 9.45 ft
Total Well Penetration Depth: 9.45 ft   Screen Length: 9.45 ft
Casing Radius: 0.083 ft   Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined   Solution Method: Bouwer-Rice

K = 0.02008 ft/day   y0 = 0.2413 ft



WELL TEST ANALYSIS

Data Set: \...\CH-MW019 RH1 BR.aqt
Date: 10/16/18 Time: 14:04:55

PROJECT INFORMATION

Company: AECOM
Location: Camp Hero
Test Well: CH-MW018
Test Date: 6/22/2017

AQUIFER DATA

Saturated Thickness: 8.44 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (CH-MW019 RH1)

Initial Displacement: 0.459 ft
Total Well Penetration Depth: 7.44 ft
Casing Radius: 0.083 ft
Static Water Column Height: 7.44 ft
Screen Length: 7.44 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.02356 ft/day y0 = 0.2574 ft