TECHNICAL MEMORANDUM

Phase III Subsurface Characterization to Support an Evaluation of Treated Wastewater Infiltration in Gates and Mill City, Marion and Linn Counties, Oregon

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Date: November 15, 2023

This Technical Memorandum (TM), prepared by GSI Water Solutions, Inc. (GSI) and GeoSystems Analysis, Inc. (GSA), summarizes the third phase of a subsurface characterization to evaluate the feasibility of treated wastewater infiltration in Gates and Mill City, Oregon.

1. Introduction

This section summarizes background information about the treated wastewater infiltration project in the Santiam Canyon, including a project overview (Section 1.1) and an overview of the Phase III Subsurface Characterization in Gates and Mill City (Section 1.2).

1.1 Project Overview

The North Santiam Sewer Authority (NSSA) is planning to dispose of treated wastewater by infiltration. Two infiltration facilities are planned—one in the Gates/Mill City area and another in the Detroit/Idanha area (Figure 1). Infiltration facilities will be comprised of rapid infiltration basins and will be authorized by Water Pollution Control Facilities (WPCF) permits from the Oregon Department of Environmental Quality (DEQ).

A phased approach is being used to evaluate infiltration feasibility in the Gates/Mill City area. The phases include:

- **Phase I.** Excavation of test pits and infiltration testing to characterize shallow soils in four study areas.
- **Phase II.** Construction of a single monitoring well and aquifer testing to characterize deep soils in the three study areas that are considered to be the most favorable for infiltration based on the results of Phase I.
- **Phase III.** Construction of two additional monitoring wells, advancement of two temporary borings within the footprint of the planned infiltration basin area, and aquifer testing in the study area that is most favorable to infiltration based on the results of Phase II.

1.2 Phase III Subsurface Characterization in the Gates/Mill City Area

Permitting and design of an infiltration basin requires characterization of soils and groundwater to evaluate whether infiltration capacity at a site is sufficient to meet the projected volume of wastewater that will be infiltrated. In March of 2023, GSI developed a work plan[1] to guide Phase I and Phase II of the subsurface characterization (GSI, 2023a). In April of 2023, an addendum was developed to guide Phase III of the characterization[2] (GSI, 2023b).

In the Gates/Mill City area, the Phase I Subsurface Characterization was completed in March of 2023. The Phase II Subsurface Characterization was completed in July of 2023 at study areas GM1, GM4, and GM5. Based on the results of the Phase II Subsurface Characterization, study area GM1 was selected for the Phase III Subsurface Characterization (GSI, 2023c).

The objective of the Phase III Subsurface Characterization was to collect data that can be used to evaluate infiltration feasibility, inform pollutant fate and transport evaluations, and update previous estimates of groundwater mounding during infiltration. This TM summarizes the: (1) collection and analysis of data during the Phase III subsurface investigation at study area GM1, and (2) updated groundwater mounding modeling to estimate the volume of wastewater that can be infiltrated at Study Area GM1.

This TM summarizes methods (Section 2) and results (Section 3) of the Gates/Mill City Phase III Subsurface Characterization. Finally, this TM provides conclusions and recommendations (Section 4).

2. Methods

This section describes methods used during the Phase III Subsurface Characterization to: (1) locate subsurface utilities (Subsection 2.1), (2) construct monitoring wells (Subsection 2.2), (3) drill temporary boreholes (Subsection 2.3), (4) classify soil physical properties (Subsection 2.4), (5) survey monitoring wells (Subsection 2.5), (6) conduct slug tests to determine aquifer hydraulic conductivity (Subsection 2.6), and (7) estimate the infiltration capacity at the site (Subsection 2.7).

2.1 Utility Locating

Oregon 411 was notified of work activities at study area GM1 and conducted a public utility locate to identify all utilities within 25-feet of the centerline of SE Fairview Street. Additionally, areas chosen for monitoring wells, which were not necessarily within 25 feet of the SE Fairview Street centerline, were located and cleared for subsurface utilities by the private locating company Pacific Northwest Locating, LLC, on August 21, 2023. No utilities were identified along the SE Fairview Street corridor or near proposed monitoring well locations.

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[1] Santiam Canyon Treated Wastewater Infiltration Evaluation Subsurface Characterization Work Plan, dated March 3, 2023

[2] Santiam Canyon Treated Wastewater Disposal – Subsurface Characterization Work Plan Addendum No. 1 (Phase III), dated August 18, 2023

2.2 Monitoring Well Construction and Development

Groundwater monitoring wells were constructed at site GM1 with the objectives of: (1) identifying potential restrictive layers at depth, (2) testing aquifer permeability, and (3) measuring shallow groundwater elevations to develop groundwater elevation contour maps and calculate horizontal hydraulic gradients. Monitoring well borings were drilled with a track-mounted Terra Sonic 150cc Compact Crawler rotosonic drilling rig operated by Holt Services of Vancouver, Washington. Monitoring well borings were advanced to approximately 20 feet below first encountered groundwater. Drilling dates, tooling types, and total monitoring well depths are provided in Table 1. Study area GM1 monitoring well locations are shown in Figure 3.

Table 1. Overview of Monitoring Well Drilling.

Well ID	Drilling Date(s) ¹	Drill Tooling	Total Depth (feet)
GM1-MW1	5/19/2023 – 5/22/2023	6-inch casing, 4-inch core barrel	40
GM1-MW2	8/23/23 – 8/24/23	6-inch casing, 4-inch core barrel	50
GM1-MW3	8/29/23	6-inch casing, 4-inch core barrel	50

Notes

(1) Does not include well completion activities.

Once monitoring well construction was completed, wells were developed using a Waterra Pump System ® with foot valve and surge block. Wells were pumped and surged until at least ten borehole volumes had been removed, turbidity levels in the well dropped below 100 nephelometric turbidity units (NTUs), and water quality parameters stabilized in accordance with Environmental Protection Agency (EPA) well development guidance (Striggow et al, 2008).

2.3 Temporary Borehole Drilling

Temporary boreholes were drilled at site GM1 with the objective of identifying potential restrictive layers at depth. Borings were drilled with a track-mounted Terra Sonic 150cc Compact Crawler rotosonic drilling rig operated by Holt Services of Vancouver, Washington. Once target depth was reached, boreholes were abandoned in accordance with Oregon Water Resources Department regulations and standards.

2.4 Soil Classification Logging

During drilling, GSI personnel continuously logged soils from each borehole in general accordance with the visual-manual method of the Unified Soil Classification System (USCS) (ASTM, 2016). Boring logs are presented in Attachment A and soil classification results are presented in subsection 3.3.

2.5 Monitoring Well Surveying

Monitoring well locations were surveyed by Forty Five North Surveying, LLC on September 5, 2023, using Global Positioning System (GPS) Real Time Kinematics (RTK) methods. Monitoring well elevations were surveyed with an accuracy of within 0.01 feet of each other.

2.6 Aquifer Testing

After monitoring wells were constructed and developed, GSI conducted three successive slug tests (including ‘slug-in’ and ‘slug-out’ tests) at each monitoring well to estimate hydraulic conductivity of the shallow aquifer (i.e., horizontal hydraulic conductivity). Slug testing involves first introducing (slug-in) a solid tapered tube, or slug, into a monitoring well to instantaneously raise the water level in the well, and then removing the slug (slug-out) from the well to instantaneously lower water levels. GSI personnel took manual water level measurements at a predetermined schedule and a pressure transducer was installed beneath the slug to monitor changes in water level every half-second during the tests. Horizontal hydraulic conductivity was calculated using the Hvorslev method for monitoring wells where the aquifer exhibited an overdamped response (Hvorslev, 1951), and the Springer-Gelhar method for monitoring wells where the aquifer exhibited an underdamped response (Springer and Gelhar, 1991).

2.7 Infiltration Capacity Modeling

GSA used the hydraulic conductivity and hydraulic gradient measured during the Phase III Subsurface Characterization to update the preliminary groundwater mounding analysis for Study Area GM1 presented in GSI (2023c). This analysis used the Zlotnik analytical solution for groundwater mounding (Zlotnik et al, 2017) as applied in MOUNDSOLV (Hydrosolv, 2023) to estimate the steady-state groundwater mound that may develop beneath potential infiltration facilities in response to recharge of treated wastewater.

Due to the variability in horizontal saturated hydraulic conductivity (K_{sat}) between monitoring wells at Study Area GM1, three groundwater mounding scenarios were evaluated in MOUNDSOLV. K_{sat} values assigned for each scenario and the associated basis for assigning the K_{sat} values are summarized in Table 2, and model input parameters are summarized in Table 3.

Table 2. Aquifer Horizontal K_{sat} Values

Scenario	Monitoring Well	K_{sat} (ft/day)
Low	GM1-MW3	37.0
Average	Geometric Mean of All Wells	88.2
High	GM1-MW1	163.3

Table 3. Input Parameters Used for Groundwater Mounding Analysis.

Hydraulic Conductivity Scenario	Low (K_{sat} = 37 ft/d)	Average (K_{sat} = 88.2 ft/d)	High (K_{sat} = 163 ft/d)
Recharge Rate ^{1}	0.2375 MGD	0.2375 MGD	0.2375 MGD
Recharge Duration	Continuous	Continuous	Continuous
Infiltration Area ^{2}	2.3 acres	2.3 acres	2.3 acres
Long-Term Infiltration Rate ^{3}	0.90 feet/day	0.12 feet/day	0.03 feet/day
Aquifer Hydraulic Conductivity ^{4}	37 feet/day	88.2 feet/day	163 feet/day
Depth to Water Table (current) ^{5}	15.4 feet bgs	15.4 feet bgs	15.4 feet bgs
Depth to Water Table (after basin construction) ^{6}	14.4 feet bgs	14.4 feet bgs	14.4 feet bgs
Initial Aquifer Saturated Thickness ^{7}	44.6 feet	44.6 feet	44.6 feet
Initial Horizontal Hydraulic Gradient ^{8}	0.0102 feet/foot	0.0102 feet/feet	0.0102 feet/foot

Notes

MGD = Million Gallons Per Day bgs = below ground surface

(1) Projected 2045 effluent generation rate

(2) Selected to be sufficiently large to accept the 0.2375 MGD of treated wastewater

(3) 15 percent of the mean measured near-surface K_{sat} for the study area (GSI, 2023b)

(4) See Table 6 in Section 3.3.2

(5) Depth to groundwater at study area GM1 was measured on May 29, 2023 at monitoring well GM1-MW1.

(6) Assumes a basin excavation depth of 1.0 feet.

(7) Estimated from LINN 1443 (60 feet of unconsolidated sediments – 15.4 feet depth to water = 44.6 feet of aquifer).

(8) Horizontal hydraulic gradient determined based on a groundwater elevation contour map (see Figure 3).

Groundwater mounding simulations were based on the projected year 2045 treated wastewater effluent generation rate of 0.2375 million gallons per day (MGD). For this initial feasibility assessment, the infiltration facility was conservatively assumed to consist of one, square-shaped basin, with a 2.3 acre infiltration area. The long-term infiltration rate was assumed to be 15 percent of the mean measured near-surface K_{sat}, as measured by GSA using a single ring infiltrometer with the lateral divergence correction during the Phase I Subsurface Characterization (GSI, 2023b). A K_{sat} value of 15 percent of the mean measured K_{sat} for the site was used to account for potential surface clogging (EPA, 1984).

Groundwater mounding analysis results are presented in Section 3.6 and in the memorandum completed by GSA available in Attachment C.

3. Results

This section presents the results of Phase III Subsurface Characterization including monitoring well construction (Subsection 3.1), temporary borehole drilling (Subsection 3.2), subsurface geology (Subsection 3.3), groundwater levels, flow directions, and gradient (Subsection 3.4), saturated hydraulic conductivity (Subsection 3.5), and a groundwater mounding analysis (Subsection 3.6).

3.1 Monitoring Well Construction

Construction information for the monitoring wells installed during the Phase III Subsurface Characterization is summarized in Table 4. Monitoring well locations are shown in Figure 3. All monitoring wells were constructed using 2-inch diameter schedule 40 PVC casing and a 10-foot PVC screen with a slot size of 0.010-inches. All monitoring wells were constructed with a 10-20 silica sand filter pack. Boring logs showing well construction and soil types are provided in Attachment A. Cross-section A-A' showing Study Site GM1 geology and groundwater levels is provided in Figure 4.

Table 4. Monitoring Well Construction.

Well ID	Latitude	Longitude	Ground Surface Elevation[2] (ft amsl)	Total Boring Depth (ft bgs)	Screened Interval (ft bgs)	Static Water Level (ft amsl)
GM1-MW1[1]	44.751106°	-122.460697°	851.92	40	30 - 40	829.48
GM1-MW2	44.751044°	-122.462022°	849.77	50	40 - 50	826.78
GM1-MW3	44.749072°	-122.461128°	859.57	50	40 - 50	832.43

Notes

ft amsl = feet above mean sea level

ft bgs = feet below ground surface

(1) Monitoring well GM1-MW1 was constructed during Phase II Subsurface Investigation completed in May of 2023.

(2) Measurements of elevation were taken using the vertical datum NAVD88.

3.2 Temporary Borehole Drilling

Information obtained during drilling of temporary boreholes as part of the Phase III Subsurface Characterization is summarized in Table 5. No sitewide, continuous restrictive layers were encountered in the temporary borings. In temporary boring GM1-TB2, the bottom of the shallow aquifer was encountered at approximately 65 feet bgs, on a layer of silt approximately 20 feet thick.

Table 5. Monitoring Well Construction.

Well ID	Latitude[1]	Longitude[1]	Ground Surface Elevation[1] (ft amsl)	Total Boring Depth (ft bgs)	Depth Groundwater First Encountered (ft bgs)	Depth to Aquifer Bottom[2] (ft bgs)
GM1-TB1	44.750961°	-122.461632°	851	20	18.4	N/A
GM1-TB2	44.750025°	-122.460736°	854	90	20	65

Notes
ft amsl = feet above mean sea level
ft bgs = feet below ground surface
(1) Determined from Google Earth
(2) Aquifer bottom not encountered in GM1-TB1

3.3 Subsurface Geology

Boring logs showing subsurface geology at monitoring wells and temporary borings are provided in Attachment A. Cross-section A-A' showing study area GM1 geology and groundwater levels is provided in Figure 4.

Observations of subsurface geology from monitoring well borings and temporary borings are summarized below:

- In the monitoring well borings completed in the lower terrace area of the site (GM1-MW1 and GM1-MW2) an approximately 1.5 feet thick surficial layer comprised of loose silty gravel was encountered overlying the Quaternary Middle Terrace deposits. The loose nature of this layer and lack of anthropologic materials (e.g., bricks) indicates it is likely a fill layer comprised of reworked native soils from past site activities.
- The surficial fill layer found at monitoring well GM1-MW3, located in the upper terrace area of the site, consisted of 6.5 feet of soft silt with no gravel or sand and contained burnt woody debris and lumber. MW3 soils contained much higher percentages of silt when compared to MW1 or MW2. No infiltration is planned to occur in this area.
- There was a significantly higher ratio of fines found in the upper 5 feet of GM1-MW2 borehole when compared to MW1. Proportions of gravel, sand, and fines between GM1-MW1 and GM1-MW2 were similar below 5 feet bgs.
- The Quaternary Middle Terrace deposits consisted of loose gravels, silty gravels, and sands with lower proportions of silt than observed in surficial layers (see boring logs in Attachment A).
- A significant layer of silt (in excess of 20 feet thick) silt was found at temporary boring GM1-TB2 from 65-feet bgs to 85-feet bgs. This silt layer represents the base of the shallow groundwater system.

3.4 Groundwater Levels, Flow Directions, and Gradient

Table 6 provides groundwater levels at site GM1, and a groundwater elevation contour map is provided in Figure 3. Generally, groundwater flows towards the northwest under a horizontal hydraulic gradient of .0102 feet per foot.

Table 6. Groundwater Levels

Well ID	Depth to Groundwater (feet bgs)	Groundwater Elevation (feet amsl)
GM1-MW1	22.42	829.48
GM1-MW2	22.99	826.78
GM1-MW3	27.14	832.43

Notes

ft amsl = feet above mean sea level

ft bgs = feet below ground surface

(1) At MW1, depth to groundwater was measured on August 29, 2023. At MW2 and MW3, depth to groundwater was measured on September 4, 2023.

3.5 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity is an anisotropic soil property (meaning that hydraulic conductivity may be different in the horizontal and vertical directions) indicating how easily water travels through soil. Due to geologic layering, horizontal hydraulic conductivity may be 10 to 100 times greater than vertical hydraulic conductivity. Horizontal saturated conductivity was measured in the field at GM1 monitoring wells using the slug testing method (see Attachment B for slug testing results).

Water level recovery at GM1 monitoring wells was generally rapid, ranging from less than 30 seconds at GM1-MW1 and GM1-MW2, to about 200 seconds at GM1-MW3. The relatively rapid response indicates that soils at the GM1 site are characterized by a high hydraulic conductivity. Water level response at monitoring wells GM1-MW1 and GM1-MW2 exhibited an underdamped (i.e., oscillatory) response and were analyzed using the Springer-Gelhar (1991) solution for a slug test in an unconfined aquifer. Water level response at monitoring well GM1-MW3 exhibited an overdamped (i.e., straight-line) response and was analyzed by the Hvorslev (1951) solution for a slug test in an unconfined aquifer. Plots of water level versus time during the slug tests are provided in Attachment B. Note on the plots that several tests were not analyzed due to the transducer moving during the test. Horizontal hydraulic conductivity estimates obtained from slug testing at the GM1 site are summarized in Table 7.

Table 7. Slug Test Results.

Well ID	Analysis Method	Result	Figure Reference*	Geometric Mean Horizontal K (feet/day)
GM1-MW1	Springer-Gelhar (1991) Springer-Gelhar (1991)	**Test 1 (in):** 97 feet/day **Test 3 (in):** 275 feet/day	Figure B.1(d) Figure B.1(e)	163.3
GM1-MW2	Springer-Gelhar (1991) Springer-Gelhar (1991) Springer-Gelhar (1991)	**Test 1 (in):** 111 feet/day **Test 2 (in):** 110 feet/day **Test 3 (in):** 120 feet/day	Figure B.2(d) Figure B.2(e) Figure B.2(f)	113.6
GM1-MW3	Hvorslev (1951) Hvorslev (1951) Hvorslev (1951)	**Test 1 (in):** 33.8 feet/day **Test 2 (in):** 57.5 feet/day **Test 3 (in):** 26.1 feet/day	Figure B.3(d) Figure B.3(d) Figure B.3(d)	37.0
			Overall Geometric Mean	88.2

* Available in Attachment B

A geometric mean was calculated by: (1) determining the geologic mean hydraulic conductivity at each monitoring well based on the individual slug tests and then (2) calculating a geometric mean of the geometric means at monitoring wells. This approach is necessary because the hydraulic conductivity values are not independent, identically distributed (iid) values. The overall geometric mean hydraulic conductivity for soils at Study Area GM1 is 88.2 feet per day.

3.6 Groundwater Mounding Analysis

A technical memorandum summarizing the results of the groundwater mounding analysis completed by GSA is provided in Attachment C. A summary of input parameters used for the mounding analysis model is presented in Table 3. Figures showing predicted groundwater mounding in the Gates/Mill City area for each scenario are presented in Attachment C. The model-predicted steady state groundwater mounding results for each scenario is provided in Table 10. Note the depths the groundwater in Table 8 are based on the seasonal high groundwater level measured at monitoring well GM1-MW1 in May 2023 (15.4 feet below current ground surface).

Table 8. Predicted Mounding During Infiltration.

	Hydraulic Conductivity Scenario		
	Low (K_{sat}=37 ft/d)	**Mid (K_{sat}=88.2 ft/d)**	**High (K_{sat}=163 ft/d)**
Maximum Mound Height	13.8 feet above static	5.8 feet above static	3.1 feet above static
Depth to Top of Groundwater Mound (Current Ground Surface)	1.6 feet bgs	9.6 feet bgs	12.3 feet bgs
Depth to Top of Groundwater Mound (Future Ground Surface)	0.6 feet bgs	8.6 feet bgs	11.3 feet bgs

Notes
bgs = below ground surface

The following bullets summarize the results of the groundwater mounding analysis:

- Scenarios using mid and high K_{sat} values showed minimal groundwater mounding (less than 6 feet) and depth to maximum groundwater mound of greater than 8 feet.
- The low K_{sat} value scenario showed increased groundwater mounding (more than 13 feet) and depth to maximum groundwater mound of less than 1 foot under the infiltration basin.

4. Conclusions and Recommendations

The data collected during the Phase III Subsurface Characterization and subsequent mounding simulations indicate that infiltration of the 2045 wastewater effluent generation rate (0.2375 MGD) appears to be feasible at study area GM-1. As a next step, we recommend using the data collected during the Phase III Subsurface Characterization to evaluate the environmental fate of residual pollutants in treated wastewater with the objectives of informing the appropriate permitting framework for the facility (i.e., Water Pollution Control Facilities permit or National Pollutant Discharge Elimination System permit) and evaluating compliance with DEQ's groundwater protection rules and the Three Basin Rule. We also recommend conducting a pilot test as a part of basin construction to refine basin design and collect additional information on aquifer response to infiltration.

5. References

GSI Water Solutions, Inc. and GeoSystems Analysis, Inc. (2023a). *Santiam Canyon Treated Wastewater Infiltration Evaluation Subsurface Characterization Work Plan*.

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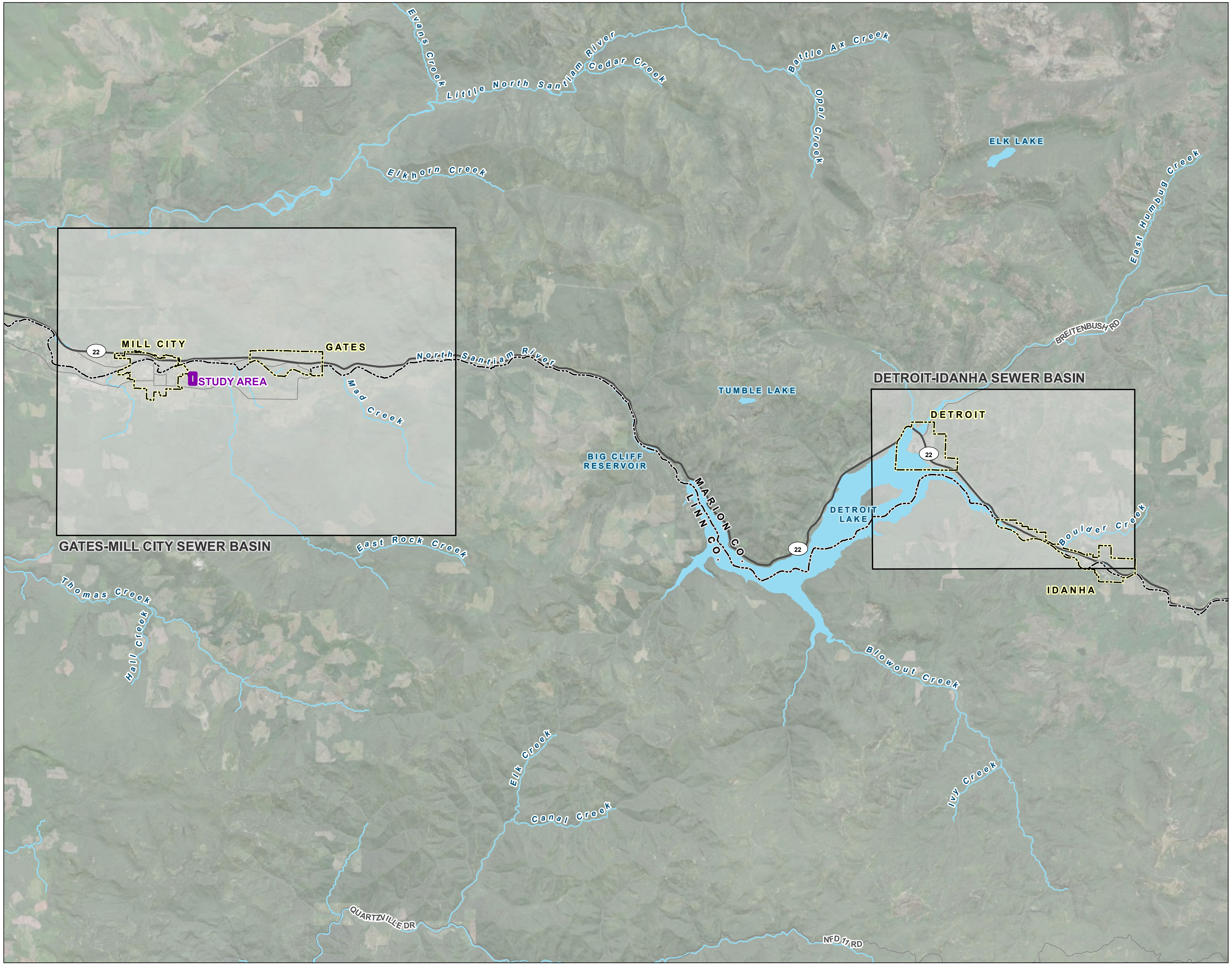
Striggow, B., Quinones, A., and Ackerman, L. (2008, February). *Design and Installation of Monitoring Wells*. (SESDGUID-101-R0). Environmental Protection Agency, Science and Ecosystem Support Division. https://www.epa.gov/sites/default/files/2014-03/documents/appendix_m_monitor_well_installation.pdf

Zlotnik, V. A., Kacimov, A., Al-Maktoumi, A. (2017, May). *Estimating Groundwater Mounding in Sloping Aquifers for Managed Aquifer Recharge*. Groundwater, vol. 55, no. 6, pp. 771 – 930.

FIGURE 1

Project Location Map

Santiam Canyon Infiltration Project
Phase III



LEGEND

- Study Area GM1
- Sewer Basin
- City Boundary
- County Boundary
- Major Road
- Watercourse
- Waterbody

Date: November 8, 2023
Data Sources: BLM, ESRI, ODOT, USGS,
Aerial Photo 2020

GSI Water Solutions, Inc.

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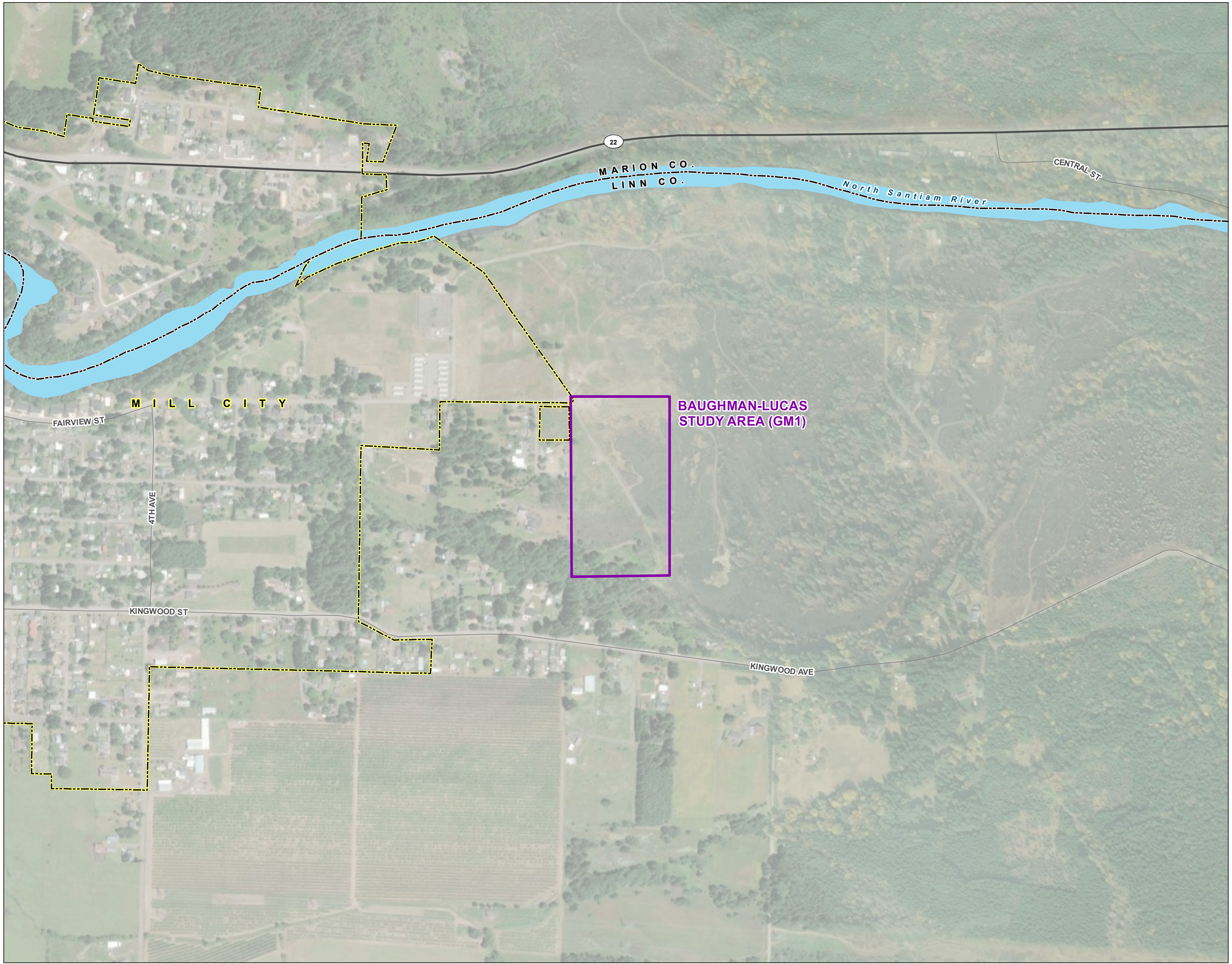

FIGURE 2

Study Site GM1 Location

Santiam Canyon Infiltration Project
Phase III

LEGEND

▭ Study Area

All Other Features

▭ City Boundary

▭ County Boundary

Major Road

Watercourse

Waterbody

N

0 300 600 900
Feet

Date: November 6, 2023
Data Sources: BLM, ESRI, ODOT, USGS,
Aerial Photo 2020

GSI
Water Solutions, Inc.

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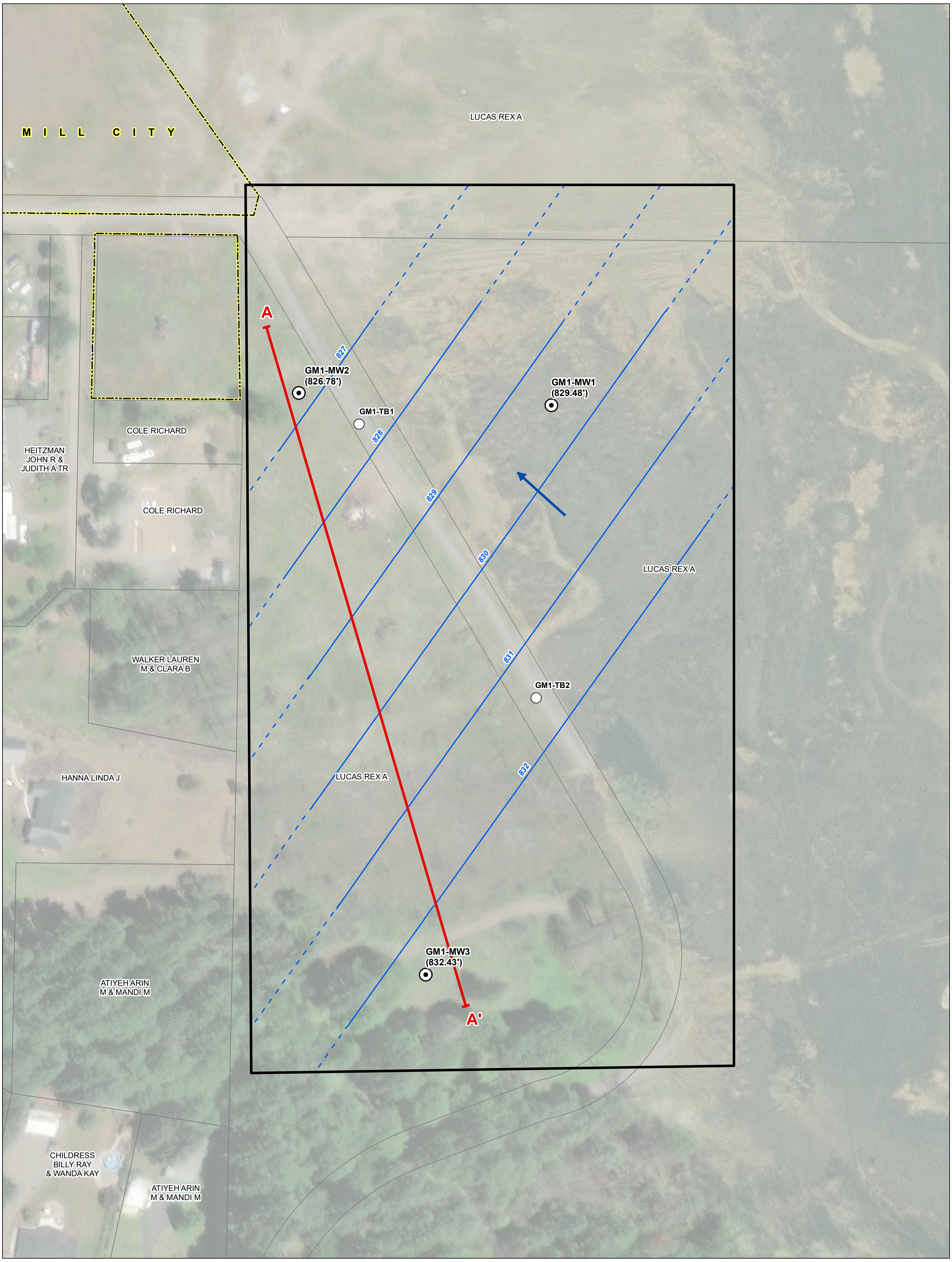

LEGEND

- ⊙ Monitoring Well (Static Water Level)
- ○ Temporary Boring Phase III
- — Groundwater Elevation Contour, feet
- → Groundwater Flow Direction
- ⊢⊣ Cross Section Line

- ▭ Site

All Other Features

- ▭ Tax Lot
- ▭ City Boundary
- ⋀ Major Road

MONITORING WELL	LATITUDE	LONGITUDE	ELEVATION
MW1 (L136274)	N44°45'03.98"	W122°27'38.51"	851.9 feet above mean sea level
MW2 (L136301)	N44°45'03.76"	W122°27'43.28"	849.8 feet above mean sea levell
MW3 (L136302)	N44°44'56.66"	W122°27'40.06"	859.6 feet above mean sea level

NOTE

Monitoring well locations surveyed by FNN Surveying on Septermber 5, 2023.

FIGURE 3

Study Site GM1 Groundwater Elevations

Santiam Canyon Infiltration Project
Phase III

Date: November 8, 2023
Data Sources: BLM, ESRI, ODOT, USGS, Aerial Photo 2020

N

0 60 120 180
Feet

GSI
Water Solutions, Inc.

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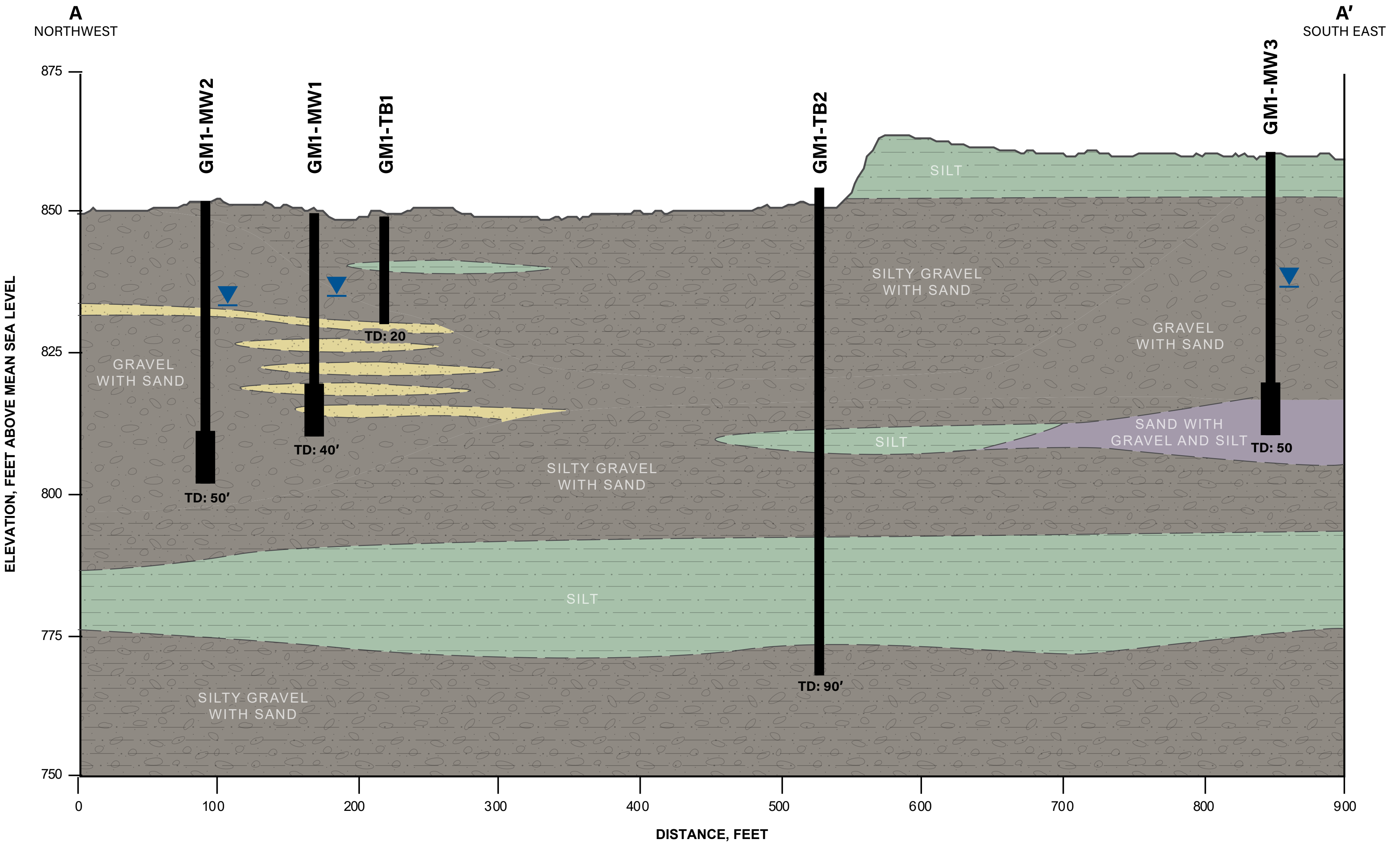

LEGEND

▨ GM: Silty Gravel with Sand
▨ GW: Gravel with Sand
▨ SW: Sand
▨ ML: Silt
▨ SW-SM: Sand with Gravel and Silt

NOTE

TD: Total Depth

FIGURE 4

Study Site GM1 Cross-Section A-A'

Santiam Canyon Infiltration Project
Phase III

GSI Water Solutions, Inc.

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ATTACHMENT A

Boring Logs

GSI Water Solutions, Inc.

LOG ID: GM1-MW1

PROJECT: Santiam Canyon Infiltration Evaluation

GROUND SURFACE ELEVATION AND DATUM: 851 ft NAVD88

BORING LOCATION: Mill City, OR

TOTAL DEPTH (ft): 40

DATE STARTED: 5/19/2023

DRILLING CONTRACTOR: Holt

LOGGED BY: J. Hall

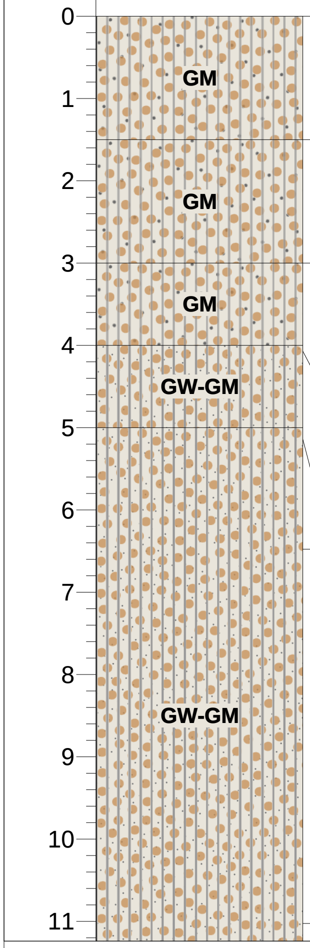
DATE FINISHED: 5/22/2023

SAMPLING METHOD: Continuous Core

DEPTH TO WATER (ft bgs) **FIRST:** 19.5 **COMPLETED:** 14.9

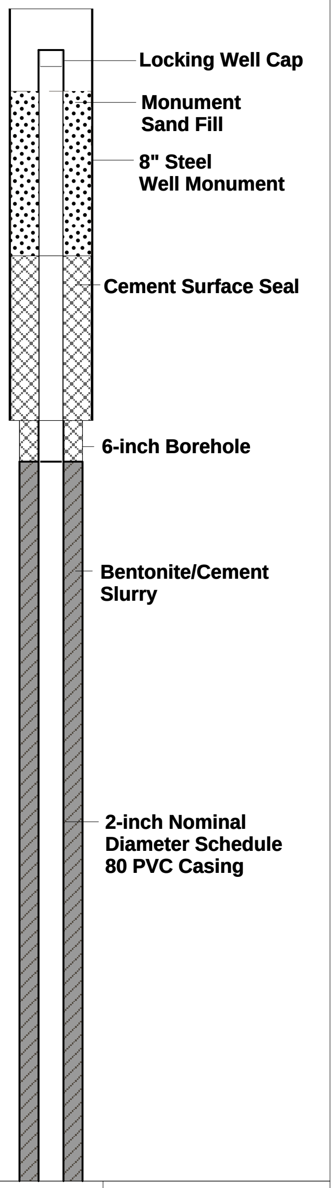
DRILLING METHOD: Sonic

DEPTH (feet)



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
0 - 1.5 ft: Loose, dark brown, dry, silty GRAVEL with sand (GM), organics, sand is very fine to coarse, subangular to subrounded, gravel is fine to coarse, subangular to rounded [FILL]	70	<15	15
1.5 - 3.0 ft: Medium dense, dark brown, moist, silty GRAVEL (GM), organics, medium plasticity, sand is very fine to coarse, subangular to subrounded, gravel is fine to coarse, subangular to subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	50	<10	40
3.0 - 4.0 ft: Loose, dark brown to black, dry to moist, silty GRAVEL with sand (GM), organics, low plasticity, sand is fine to coarse, angular to subrounded, gravel is fine to medium, subangular to subrounded, odor of charcoal [QUATERNARY MIDDLE TERRACE DEPOSITS]	40	25	35
4.0 - 5.0 ft; Very loose, dark grey, dry, well graded GRAVEL with silt and sand (GW-GM), low plasticity, sand is very fine to coarse, subangular to rounded, gravel is fine to medium, subangular to subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	60	30	10
Gray, dry, increase in coarse gravel/cobbles at 6.5 ft			
5.0 - 12.0 ft: Very loose, brown to dark brown to grey, dry to wet, well graded GRAVEL with silt and sand (GW-GM), low plasticity, sand is very fine to coarse, subangular to rounded, gravel is fine to medium, subangular to subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	75	15	10
Increase in moisture (moist to wet) at 11 ft			

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW1

PROJECT:	Santiam Canyon Infiltration Evaluation
BORING LOCATION:	Mill City, OR
DRILLING CONTRACTOR:	Holt
SAMPLING METHOD:	Continuous Core
DRILLING METHOD:	Sonic

GROUND SURFACE ELEVATION AND DATUM: 851 ft NAVD88

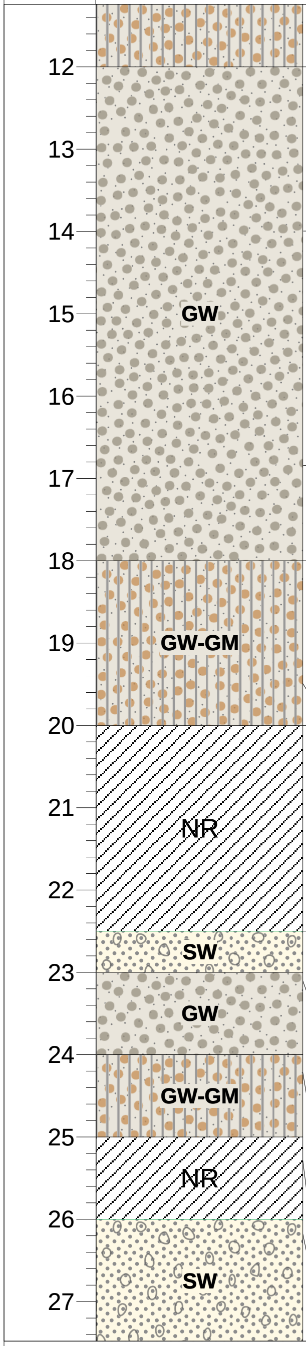
TOTAL DEPTH (ft): 40

DATE STARTED: 5/19/2023

LOGGED BY: J. Hall

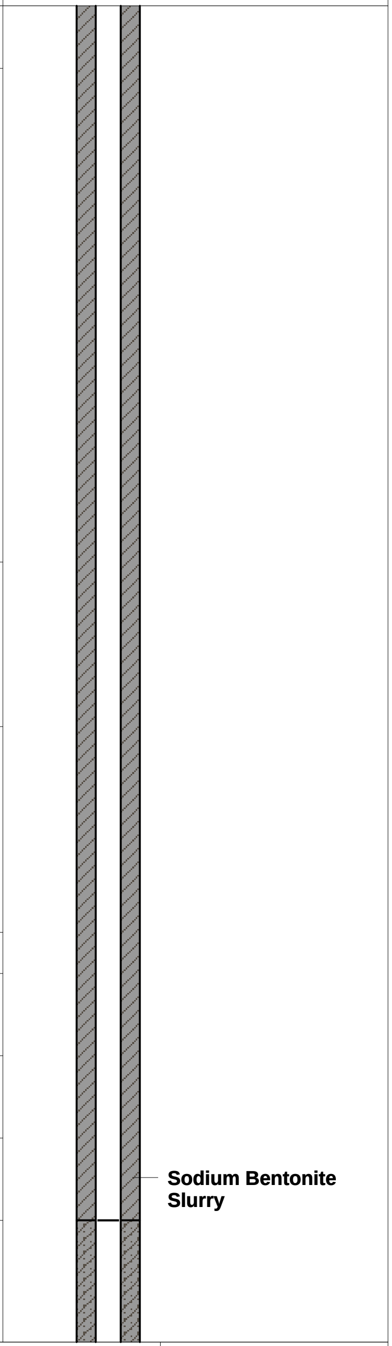
DATE FINISHED: 5/22/2023

DEPTH TO WATER (ft bgs) **FIRST:** 19.5 **COMPLETED:** 14.9



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
Wet at 14.0 ft 12.0 - 18.0 ft: Very loose, dark brown, moist, well graded GRAVEL with sand (GW), low plasticity, sand is very fine to very coarse, subangular to rounded, gravel is fine to coarse, subangular to rounded, cobbles (< 6 inches), subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS] No return from 15 to 20 ft. Recovered with clean-out.	80	15	<5
18.0 - 20.0 ft: Very loose, dark brown, moist, well graded GRAVEL with silt and sand (GW-GM), low plasticity, sand is very fine to coarse, subangular to rounded, gravel is fine to medium, subangular to subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS] Wet at 19.5 ft	70	20	10
20.0 - 22.5 ft: NO RETURN			
22.5 - 23.0 ft: Very loose, dark brown, wet, well graded SAND (SW), low plasticity, sand is very fine to very coarse, subangular to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	0	100	<5
23.0 - 24.0 ft: Very loose, dark brown, moist, well graded GRAVEL with sand (GW), low plasticity, sand is very fine to very coarse, subangular to rounded, gravel is very fine to very coarse, subangular to rounded, cobbles (< 6 inches), subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	50	<50	<5
24.0 - 25.0 ft: Very loose, dark brown, wet, well graded GRAVEL with silt and sand (GW-GM), low plasticity, gravel is very fine to very coarse, subangular to rounded, cobbles <6 in, subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	70	20	10
25.0 - 26.0 ft: NO RETURN			
26.0 - 27.5 ft: Very loose, dark brown, wet, well graded	0	100	<5

AS-BUILT WELL CONSTRUCTION



GSI Water Solutions, Inc.

LOG ID: GM1-MW1

PROJECT:	Santiam Canyon Infiltration Evaluation
BORING LOCATION:	Mill City, OR
DRILLING CONTRACTOR:	Holt
SAMPLING METHOD:	Continuous Core
DRILLING METHOD:	Sonic

GROUND SURFACE ELEVATION AND DATUM: 851 ft NAVD88

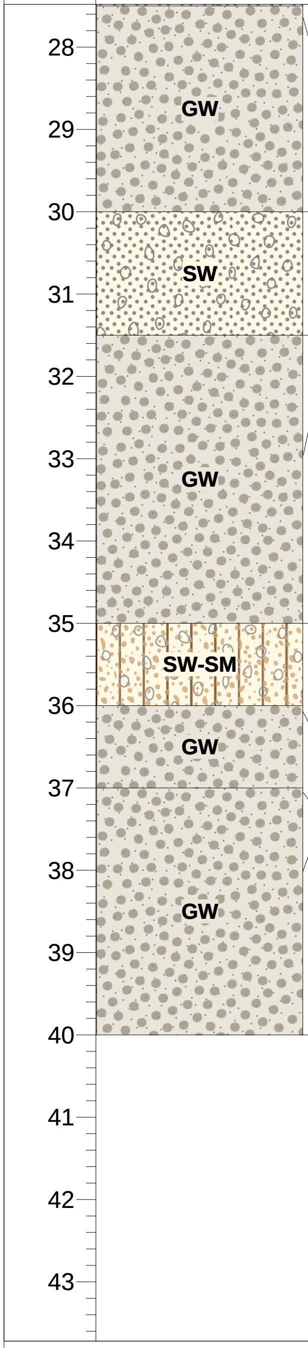
TOTAL DEPTH (ft): 40

DATE STARTED: 5/19/2023

LOGGED BY: J. Hall

DATE FINISHED: 5/22/2023

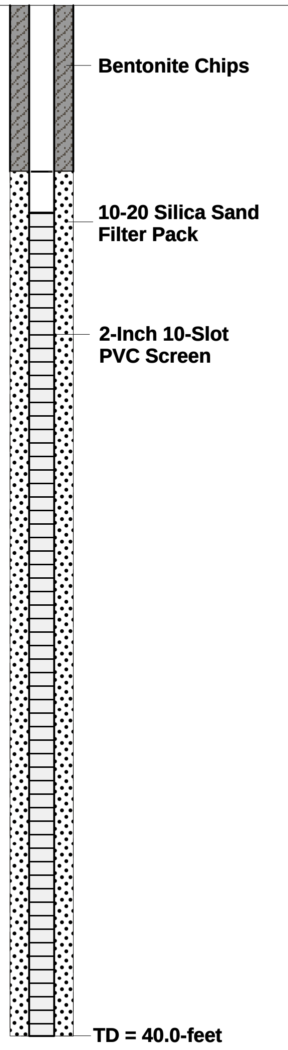
DEPTH TO WATER (ft bgs) **FIRST:** 19.5 **COMPLETED:** 14.9



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
SAND (SW), low plasticity, sand is very fine to coarse, subangular to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]			
27.5 - 30.0 ft: Very loose, dark brown, wet, well graded GRAVEL (GW), low plasticity, sand is very fine to very coarse, subangular to rounded, gravel is fine to coarse, subangular to rounded, cobbles (< 8 inches), subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	100	0	<5
30.0 - 31.5 ft: Very loose, dark brown, wet, well graded SAND (SW), low plasticity, sand is very fine to coarse, subangular to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	0	100	<5
Increase in silt/decrease in gravel at 33.0 ft 31.5 - 35.0 ft: Loose, dark brown, wet, well graded GRAVEL with sand (GW), low plasticity, sand is fine to coarse, subangular to subrounded, gravel is fine to coarse, subangular to rounded, cobbles (< 8 inches), subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	60	40	<5
35.0 - 36.0 ft: Very loose, dark brown to dark gray, wet, well graded SAND with silt (SW-SM), sand is very fine to coarse, subangular to subrounded, gravel is fine to coarse, subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	10	80	10
36.0 - 37.0 ft: Loose, brown to gray, wet, well graded GRAVEL (GW), gravel is fine to coarse, subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	90	<5	<5
Increase in cobbles at 38.0 ft 37.0 - 40.0 ft: Loose, dark brown, wet, well graded GRAVEL with sand (GW), low plasticity, sand is fine to coarse, subangular to subrounded, gravel is fine to coarse, subangular to rounded, cobbles (< 8 inches), subrounded to rounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	60	40	<5

Total Depth = 40.0 ft

AS-BUILT WELL CONSTRUCTION

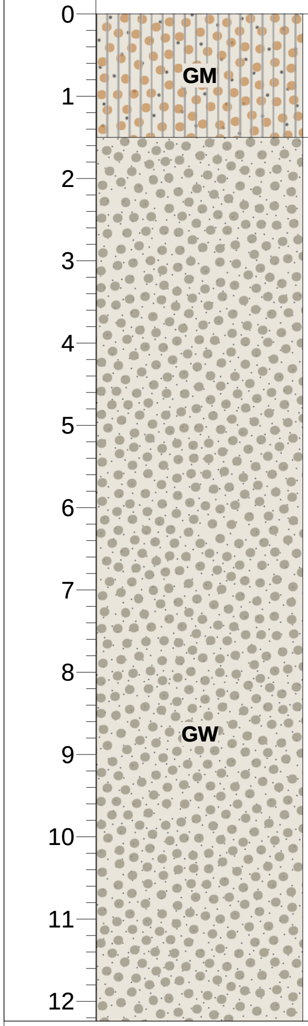


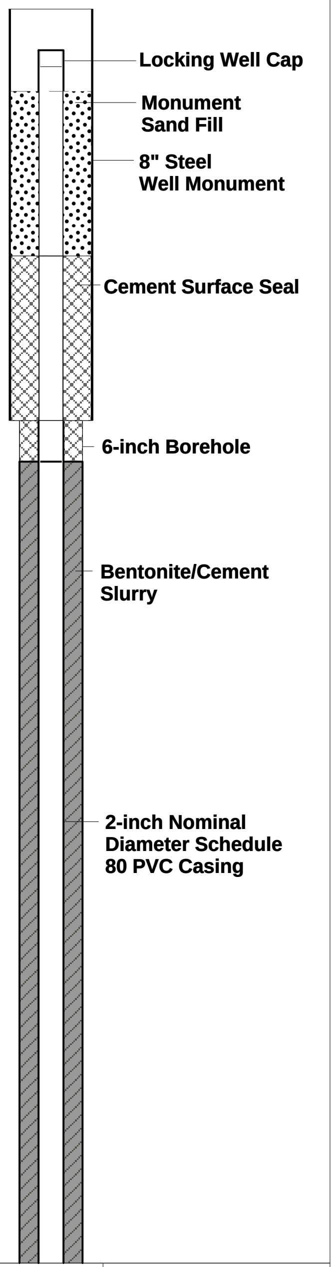
GSI Water Solutions, Inc.

LOG ID: GM1-MW2

PROJECT:	Santiam Canyon Infiltration Evaluation	**GROUND SURFACE ELEVATION AND DATUM:** 849.8 ft NAVD88		
BORING LOCATION:	Mill City, OR	**TOTAL DEPTH (ft):** 50		**DATE STARTED:** 8/23/2023
DRILLING CONTRACTOR:	Holt	**LOGGED BY:** M. Harrison		**DATE FINISHED:** 8/23/2023
SAMPLING METHOD:	Continuous Core	**DEPTH TO WATER (ft bgs)**	**FIRST:** 17.58	**COMPLETED:** 20.98
DRILLING METHOD:	Sonic			

DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**	**AS-BUILT WELL CONSTRUCTION**
0 - 1.5	0.0 - 1.5 ft: Very loose, brown, dry, silty GRAVEL with sand (GM), nonplastic, sand is very fine to coarse, gravel is fine to medium, rounded to subrounded, organics, rootlets [FILL]	60	15	25	
5	Few Cobbles (<5 in) from 5 - 15ft				
1.5 - 12	1.5 - 16.0 ft: Very loose, gray, dry, well graded GRAVEL with sand (GW), sand is fine to coarse, gravel is fine to medium, subrounded to angular [QUATERNARY MIDDLE TERRACE DEPOSITS]	80	15	<5	





LOG ID: GM1-MW2

PROJECT: Santiam Canyon Infiltration Evaluation

BORING LOCATION: Mill City, OR

DRILLING CONTRACTOR: Holt

SAMPLING METHOD: Continuous Core

DRILLING METHOD: Sonic

GROUND SURFACE ELEVATION AND DATUM: 849.8 ft NAVD88

TOTAL DEPTH (ft): 50

DATE STARTED: 8/23/2023

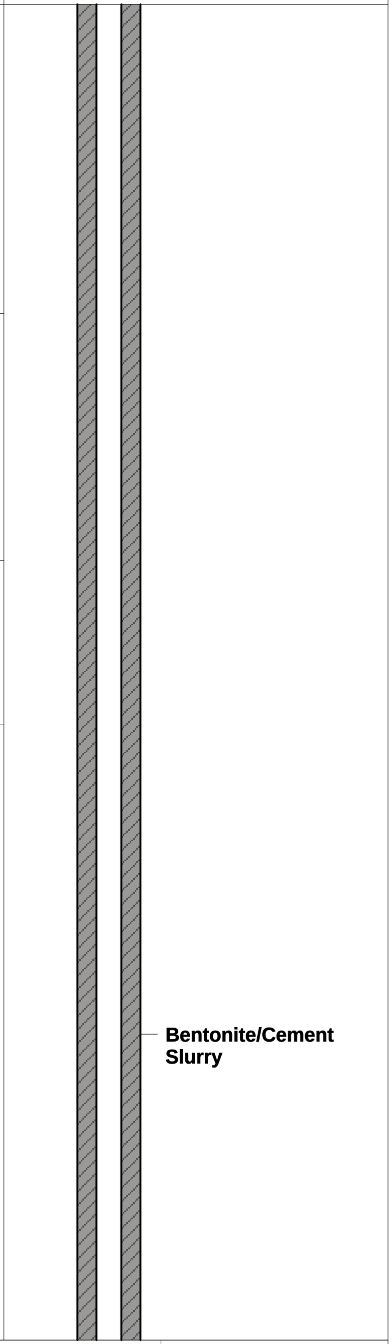
LOGGED BY: M. Harrison

DATE FINISHED: 8/23/2023

DEPTH TO WATER (ft bgs) **FIRST:** 17.58 **COMPLETED:** 20.98

DEPTH (feet)		SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
13 14 15 16		Dry to moist at 13.0 ft and 15.0 ft Wet at 16.0 ft			
17 18 19	GW-GM	16.0 - 19.0 ft: Loose, dark brown, moist to wet, well graded GRAVEL with silt and sand (GW-GM), sand is fine to medium, gravel is fine to coarse, rounded to subrounded, some cobbles (<5 inches) [QUATERNARY MIDDLE TERRACE DEPOSITS]	60	30	<10
20 21	SP	19.0 - 21 ft: Loose, dark brown, wet, poorly graded SAND (SP), sand is fine to medium, gravel is fine to medium, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS] Gravel size increases from 20.0 - 21.0 ft	10	80	<5
22 23 24 25 26 27 28	GW	21.0 - 30.0 Loose, dark brown to gray, wet, well graded GRAVEL with sand (GW), sand is fine to medium, gravel is fine to coarse, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS] Wet from 25.0 - 30.0 ft	60	35	<5

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW2

PROJECT:	Santiam Canyon Infiltration Evaluation
BORING LOCATION:	Mill City, OR
DRILLING CONTRACTOR:	Holt
SAMPLING METHOD:	Continuous Core
DRILLING METHOD:	Sonic

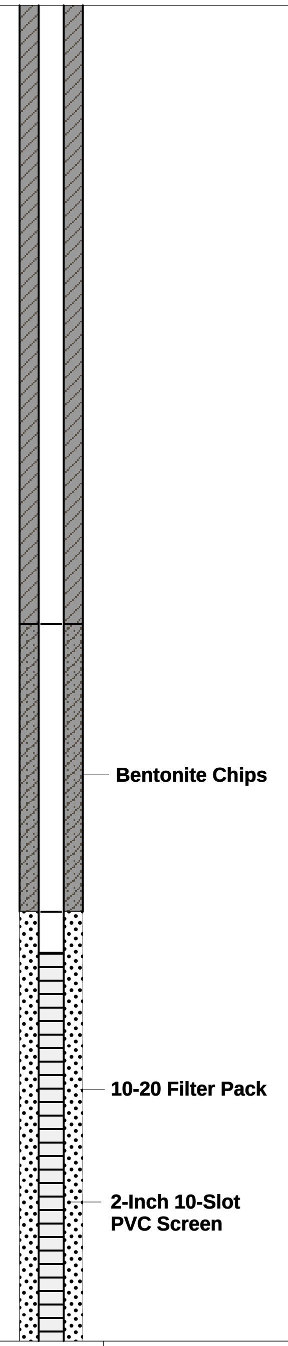
GROUND SURFACE ELEVATION AND DATUM: 849.8 ft NAVD88

TOTAL DEPTH (ft): 50	**DATE STARTED:** 8/23/2023
LOGGED BY: M. Harrison	**DATE FINISHED:** 8/23/2023

DEPTH TO WATER (ft bgs) **FIRST:** 17.58 **COMPLETED:** 20.98

DEPTH (feet)		**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
29					
30 31 32 33 34	GW	30.0 - 35 ft: Loose, dark brown to gray, wet, well graded GRAVEL with sand (GW), sand is fine to medum, gravel is fine to coarse, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	80	15	<5
35 36 37 38 39 40 41	GW	Coarse sand from 37.0 - 38.0 ft 35.0 - 42.0 ft: Loose, gray brown, wet, well graded GRAVEL with sand (GW), sand is fine to coarse, gravel is fine to coarse, subrounded, some cobbles (<4 in) [QUATERNARY MIDDLE TERRACE DEPOSITS]	73	25	<5
42 43 44	GW	42.0 - 45.0 ft: Loose, dark brown, wet, well graded GRAVEL with sand (GW), sand is fine to medium, gravel is fine to medium, subangular [QUATERNARY MIDDLE TERRACE DEPOSITS]	77	18	<5

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW2

PROJECT:	Santiam Canyon Infiltration Evaluation
BORING LOCATION:	Mill City, OR
DRILLING CONTRACTOR:	Holt
SAMPLING METHOD:	Continuous Core
DRILLING METHOD:	Sonic

GROUND SURFACE ELEVATION AND DATUM: 849.8 ft NAVD88

TOTAL DEPTH (ft): 50

DATE STARTED: 8/23/2023

LOGGED BY: M. Harrison

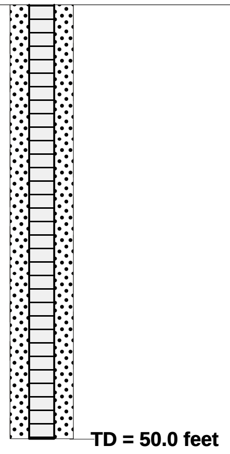
DATE FINISHED: 8/23/2023

DEPTH TO WATER (ft bgs) **FIRST:** 17.58 **COMPLETED:** 20.98

DEPTH (feet)		**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
45 – 48	**GW**	45.0 - 48.0 ft: Loose, dark brown to gray, wet, well graded GRAVEL with sand (GW), sand is fine to coarse, gravel is fine to coarse, subangular [QUATERNARY MIDDLE TERRACE DEPOSITS]	70	27	<5
48 – 50	**GW**	48.0 - 49.0 ft: Loose, dark brown to gray, wet, well graded GRAVEL with sand (GW), sand is fine to coarse, gravel is fine to medium, subangular to angular [QUATERNARY MIDDLE TERRACE DEPOSITS]	54	46	<5

Total Depth = 50.0 ft

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW3

PROJECT: Santiam Canyon Infiltration Evaluation

GROUND SURFACE ELEVATION AND DATUM: 859.6 ft NAVD88

BORING LOCATION: Mill City, OR

TOTAL DEPTH (ft): 50

DATE STARTED: 8/29/2023

DRILLING CONTRACTOR: Holt

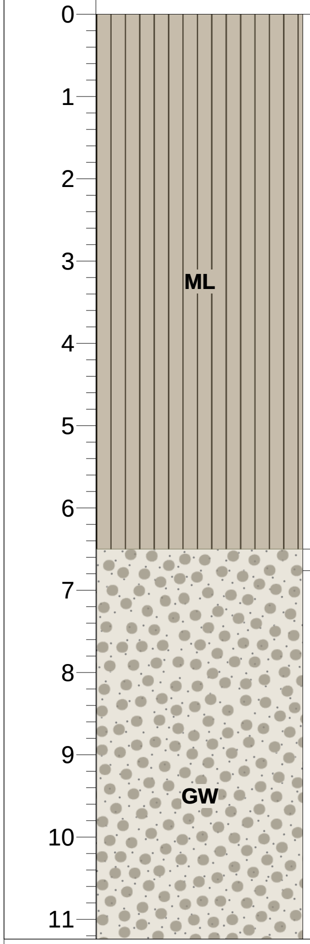
LOGGED BY: M.Harrison, J. Cain

DATE FINISHED: 8/29/2023

SAMPLING METHOD: Continuous Core

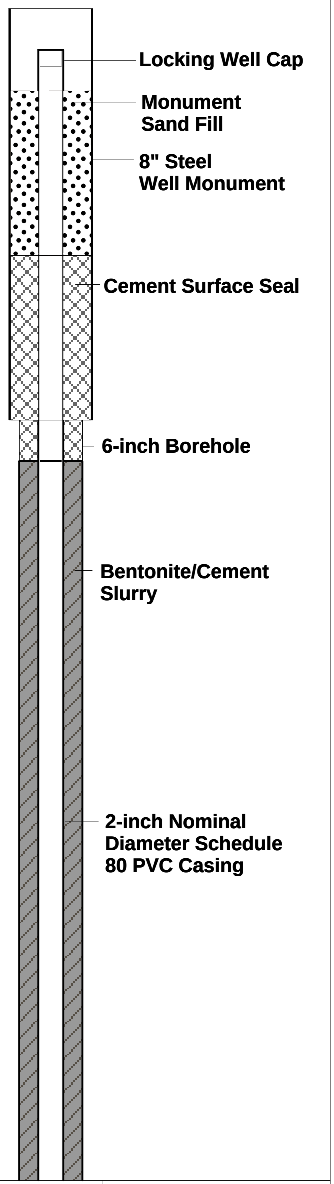
DEPTH TO WATER (ft bgs) **FIRST:** 32.17 **COMPLETED:** 23.17

DRILLING METHOD: Sonic



DEPTH (feet)	SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
0.0 - 6.5	0.0 - 6.5 ft: Soft, brown, dry, SILT (ML), few rootlets [FILL]	0	0	100
6.5	Coarse gravel/cobbles (<4 inches) at 6.5 ft			
6.5 - 12.5	6.5 - 12.5 ft: Loose, gray to brown, dry, well graded GRAVEL (GW), sand is fine to coarse, subangular, gravel is fine to coarse, subrounded to subanglar [QUATERNARY MIDDLE TERRACE DEPOSITS]	84	13	<5

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW3

PROJECT:	Santiam Canyon Infiltration Evaluation
BORING LOCATION:	Mill City, OR
DRILLING CONTRACTOR:	Holt
SAMPLING METHOD:	Continuous Core
DRILLING METHOD:	Sonic

GROUND SURFACE ELEVATION AND DATUM: 859.6 ft NAVD88

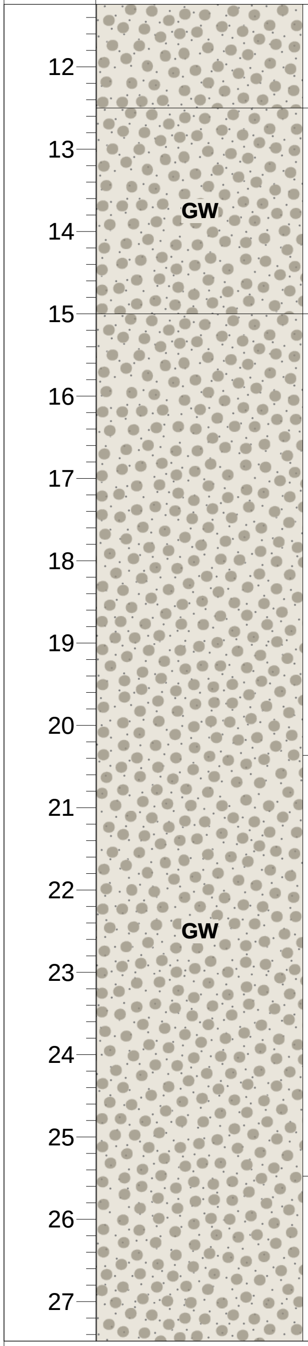
TOTAL DEPTH (ft): 50

DATE STARTED: 8/29/2023

LOGGED BY: M.Harrison, J. Cain

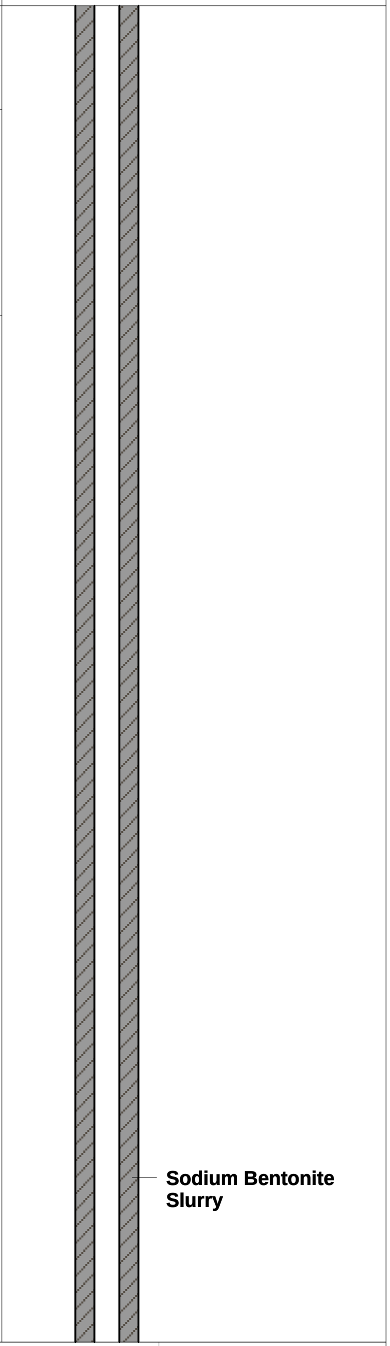
DATE FINISHED: 8/29/2023

DEPTH TO WATER (ft bgs) **FIRST:** 32.17 **COMPLETED:** 23.17



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
12.5 - 15.0 ft: Loose, gray to brown, dry, well graded GRAVEL with sand (GW), sand is medium, gravel is fine to coarse, subangular, some cobbles (<4 inches) [QUATERNARY MIDDLE TERRACE DEPOSITS]	67	28	<5
Moisture and cobbles increase downward from 20.0 - 25.0 ft			
15.0 - 30.0 ft: Loose, gray to brown, moist, well graded GRAVEL with sand (GW), sand is medium to coarse, gravel is fine to coarse, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	81	17	<5
Sand coarsens downward from 25.0 - 30.0 ft			

AS-BUILT WELL CONSTRUCTION



LOG ID: GM1-MW3

PROJECT: Santiam Canyon Infiltration Evaluation

BORING LOCATION: Mill City, OR

DRILLING CONTRACTOR: Holt

SAMPLING METHOD: Continuous Core

DRILLING METHOD: Sonic

GROUND SURFACE ELEVATION AND DATUM: 859.6 ft NAVD88

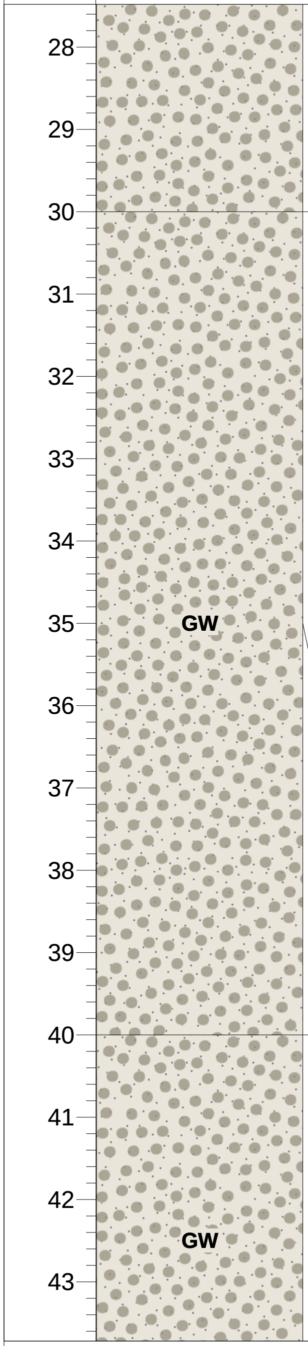
TOTAL DEPTH (ft): 50

DATE STARTED: 8/29/2023

LOGGED BY: M.Harrison, J. Cain

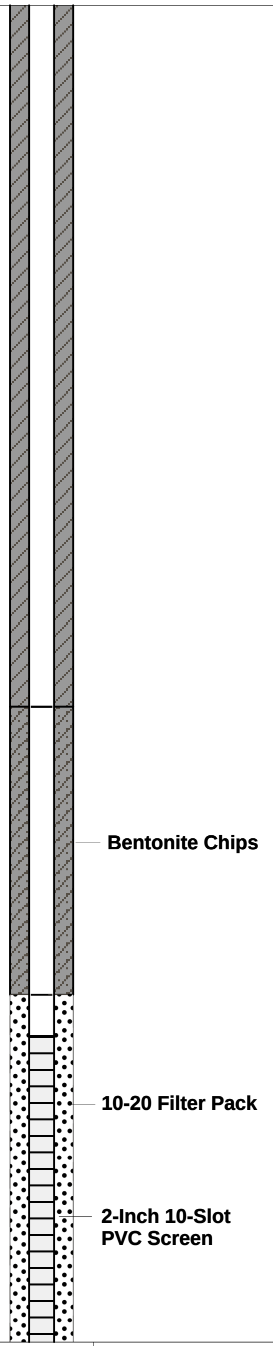
DATE FINISHED: 8/29/2023

DEPTH TO WATER (ft bgs) **FIRST:** 32.17 **COMPLETED:** 23.17



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
30.0 - 40.0 ft: Loose, gray, wet, well graded GRAVEL with sand (GW), sand is medium, gravel is fine to coarse, subrounded, some cobbles (<4 inches) [QUATERNARY MIDDLE TERRACE DEPOSITS] Increase in sand at 35.0 ft	70	25	<5
40.0 - 45.0 ft: Loose, gray to brown, wet, well graded GRAVEL with sand (GW), sand is fine to medium, gravel is fine to coarse, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	60	32	8

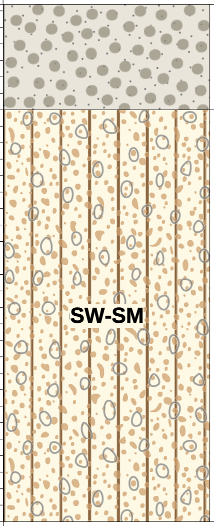
AS-BUILT WELL CONSTRUCTION



GSI Water Solutions, Inc.

LOG ID: GM1-MW3

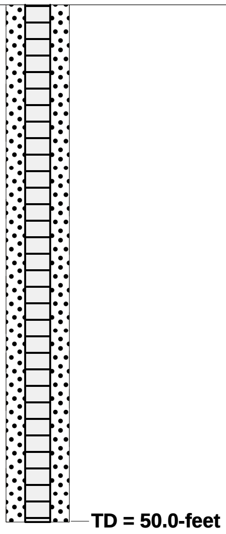
PROJECT:	Santiam Canyon Infiltration Evaluation	**GROUND SURFACE ELEVATION AND DATUM:** 859.6 ft NAVD88		
BORING LOCATION:	Mill City, OR	**TOTAL DEPTH (ft):** 50		**DATE STARTED:** 8/29/2023
DRILLING CONTRACTOR:	Holt	**LOGGED BY:** M.Harrison, J. Cain		**DATE FINISHED:** 8/29/2023
SAMPLING METHOD:	Continuous Core	**DEPTH TO WATER (ft bgs)**	**FIRST:** 32.17	**COMPLETED:** 23.17
DRILLING METHOD:	Sonic			



DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
44–45				
45–50	45.0 - 50.0 ft: loose to medium dense, gray to brown, wet, well graded SAND with silt and gravel (SW-SM), sand is fine to medium, gravel is fine to coarse, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	29	61	10

Total Depth = 50.0 ft

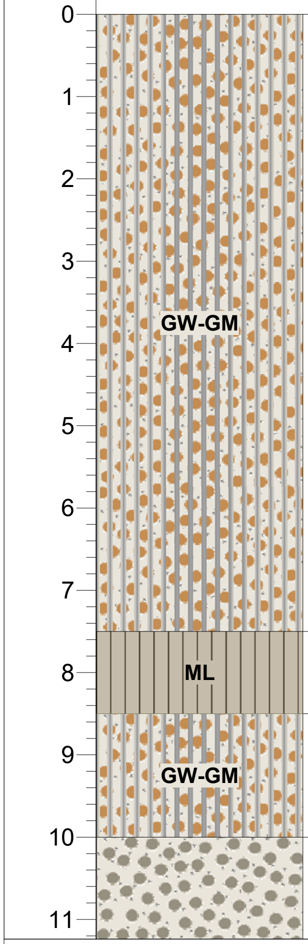
AS-BUILT WELL CONSTRUCTION



GSI Water Solutions, Inc.

LOG ID: GM1-TB1

PROJECT:	Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 20	**DATE STARTED:** 8/21/2023
BORING LOCATION:	Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur	**DATE FINISHED:** 8/21/2023
DRILLING CONTRACTOR:	Holt	**DEPTH TO WATER (ft bgs)** **FIRST:** 18.4	**COMPLETED:** N/A
SAMPLING METHOD:	Continuous Core		
DRILLING METHOD:	Sonic		



DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
0 - 7.5	0.0 - 7.5 ft: Loose, light brown to gray, dry to moist, well graded GRAVEL with silt and sand (GW-GM), sand is fine to medium, few cobbles (<4 inches) [QUATERNARY MIDDLE TERRACE DEPOSITS]	82	18	13
7.5 - 8.5	7.5 - 8.5 ft: Soft, dark brown, dry to moist, SILT (ML) [QUATERNARY MIDDLE TERRACE DEPOSITS]	<5	<5	97
8.5 - 10.0	8.5 - 10.0 ft: Loose, gray, dry, well graded GRAVEL with silt and sand (GM), sand is fine to medium, gravel is fine to coarse, subangular, some cobbles (<4 inches) [QUATERNARY MIDDLE TERRACE DEPOSITS]	70	15	15

LOG ID: GM1-TB1

PROJECT:	Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 20		**DATE STARTED:** 8/21/2023
BORING LOCATION:	Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur		**DATE FINISHED:** 8/21/2023
DRILLING CONTRACTOR:	Holt	**DEPTH TO WATER (ft bgs)**	**FIRST:** 18.4	**COMPLETED:** N/A
SAMPLING METHOD:	Continuous Core			
DRILLING METHOD:	Sonic			

DEPTH (feet)		**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
12 13 14 15 16 17 18 19 20	**GW**	10.0 - 20.0 ft: Loose, gray, dry, well graded GRAVEL with sand (GM), sand is fine to medium, gravel is fine to medium, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	73	22	<5
21 22 23 24 25 26 27		Total Depth = 20.0 ft			

LOG ID: GM1-TB2

PROJECT: Santiam Canyon Infiltration Evaluation

BORING LOCATION: Mill City, OR

DRILLING CONTRACTOR: Holt

SAMPLING METHOD: Continuous Core

DRILLING METHOD: Sonic

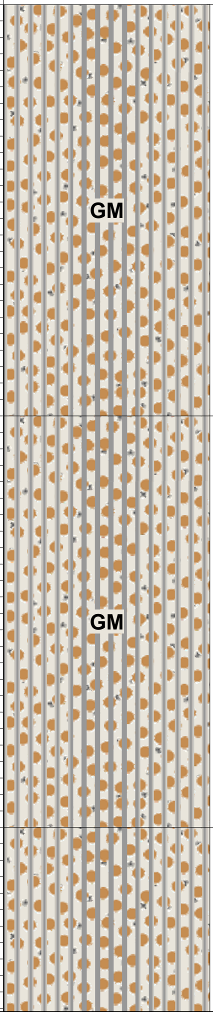
TOTAL DEPTH (ft): 90

DATE STARTED: 8/21/2023

LOGGED BY: M. Harrison, C. Kambur

DATE FINISHED: 8/22/2023

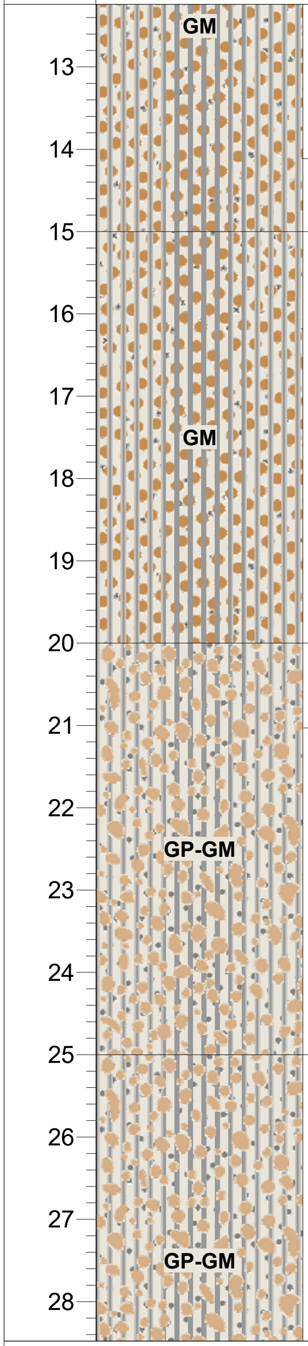
DEPTH TO WATER (ft bgs) **FIRST:** 20 **COMPLETED:** N/A



DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
0–5	0.0 - 5.0 ft: Loose, gray to brown, silty GRAVEL with sand (GM), sand is fine to medium, gravel is subangular, cobbles are subangular, topsoil contains rootlets [QUATERNARY MIDDLE TERRACE DEPOSITS]	65	20	15
5–10	5.0 - 10.0 ft: Loose, light gray, dry, silty GRAVEL with sand (GM), sand is fine to medium, subrounded, cobbles are fist-shaped [QUATERNARY MIDDLE TERRACE DEPOSITS]	70	15	15
10–12				

LOG ID: GM1-TB2

PROJECT:	Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 90	**DATE STARTED:** 8/21/2023
BORING LOCATION:	Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur	**DATE FINISHED:** 8/22/2023
DRILLING CONTRACTOR:	Holt	**DEPTH TO WATER (ft bgs)** **FIRST:** 20	**COMPLETED:** N/A
SAMPLING METHOD:	Continuous Core		
DRILLING METHOD:	Sonic		

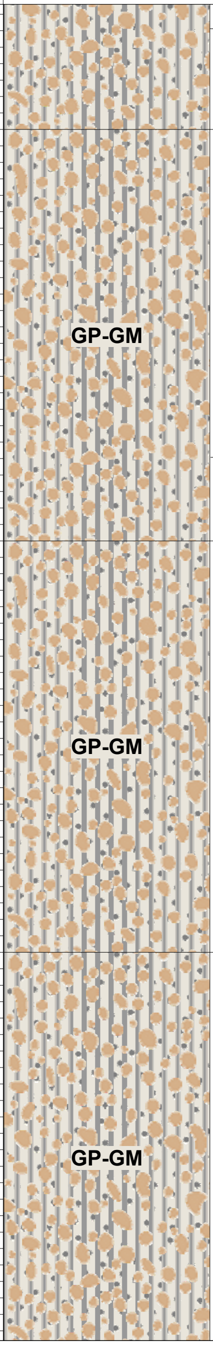


DEPTH (feet)	SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	% GRAVEL	% SAND	% FINES
10.0 - 15.0	10.0 - 15.0 ft: Loose, gray to brown, wet, silty GRAVEL with sand (GM), sand is fine to medium, gravel is subangular, cobbles are subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS] Sands appear to fine downwards from 10.0 - 15.0 ft	76	14	10
15.0 - 20.0	15.0 - 20.0 ft: Loose, gray to brown, wet, silty GRAVEL with sand (GM), sand is fine to medium, gravel is subangular, cobbles are subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	80	10	10
20.0 - 25.0	Sands appear to slightly fine downwards from 20.0 - 25.0 ft 20.0 - 25.0 ft: Loose, gray to dark gray, wet, poorly graded GRAVEL with silt (GP-GM), sand is medium to fine, gravel is fine to coarse, gravel is subangular to subrounded, cobbles are subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	88	<5	10
25.0 - 30.0	25.0 - 30.0 ft: Loose, gray to dark gray, wet, poorly graded GRAVEL with silt (GP-GM), sand is medium to fine, gravel is fine to coarse, gravel is subangular to subrounded, cobbles are subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	78	10	12

GSI Water Solutions, Inc.

LOG ID: GM1-TB2

PROJECT:	Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 90	**DATE STARTED:** 8/21/2023
BORING LOCATION:	Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur	**DATE FINISHED:** 8/22/2023
DRILLING CONTRACTOR:	Holt	**DEPTH TO WATER (ft bgs)** **FIRST:** 20	**COMPLETED:** N/A
SAMPLING METHOD:	Continuous Core		
DRILLING METHOD:	Sonic		



DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
29	Matrix fines downwards from 25.0 - 30.0 ft			
30–35	30.0 - 35.0 ft: Loose, gray to dark gray, wet, poorly graded GRAVEL with silt (GP-GM), sand is medium to fine, gravel is fine to coarse, gravel is subangular to subrounded, cobbles are subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	85	8	7
34	Sand content increases downwards from 30.0 - 35.0 ft			
35–40	35.0 - 40.0 ft: Loose, gray to dark gray, wet, poorly graded GRAVEL with silt and sand (GP-GM), gravel is fine to coarse, gravel is fine to coarse, subrounded, cobbles are subangular, less cohesive than 30-35 ft sample [QUATERNARY MIDDLE TERRACE DEPOSITS]	90	5	5
40–45	40.0 - 45.0 ft: Loose, gray to dark gray, wet, poorly graded GRAVEL with silt (GP-GM), sand is fine to medium, gravel is fine to coarse, subrounded, cobbles are subrounded, sandy matrix, silty matrix fines downward [QUATERNARY MIDDLE TERRACE DEPOSITS]	63	12	25

LOG ID: GM1-TB2

PROJECT: Santiam Canyon Infiltration Evaluation

BORING LOCATION: Mill City, OR

DRILLING CONTRACTOR: Holt

SAMPLING METHOD: Continuous Core

DRILLING METHOD: Sonic

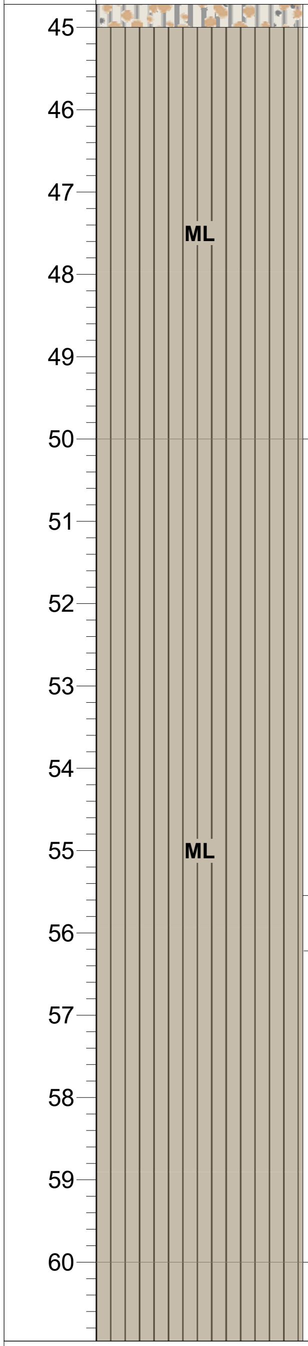
TOTAL DEPTH (ft): 90

LOGGED BY: M. Harrison, C. Kambur

DEPTH TO WATER (ft bgs) **FIRST:** 20 **COMPLETED:** N/A

DATE STARTED: 8/21/2023

DATE FINISHED: 8/22/2023



SAMPLE DESCRIPTION Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
45.0 - 50.0 ft: Medium hard to hard, gray-olive, moist, gravelly SILT (ML), gravel is subrounded, few cobbles, subangular, some clay [QUATERNARY MIDDLE TERRACE DEPOSITS]	35	10	55
55.0 - 60.0 ft: Medium hard to hard, light gray to gray-olive, moist, gravelly SILT (ML), gravel is subrounded, cobbles are subangular, more clay than 45.0 - 50.0 ft [QUATERNARY MIDDLE TERRACE DEPOSITS] Matrix coarsens downwards from 55.0 - 60.0 ft Gravel is more abundant from 55.0 - 60.0 ft	50	10	40

LOG ID: GM1-TB2

PROJECT:	Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 90	**DATE STARTED:** 8/21/2023
BORING LOCATION:	Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur	**DATE FINISHED:** 8/22/2023
DRILLING CONTRACTOR:	Holt	**DEPTH TO WATER (ft bgs)** **FIRST:** 20	**COMPLETED:** N/A
SAMPLING METHOD:	Continuous Core		
DRILLING METHOD:	Sonic		

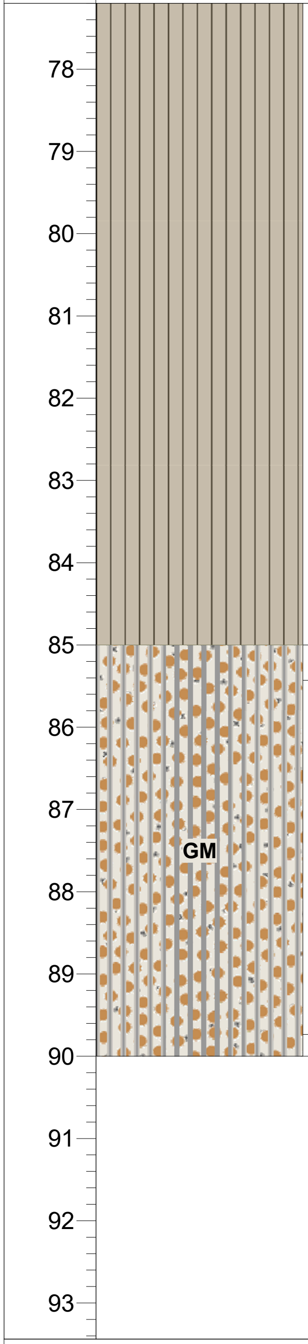
DEPTH (feet)		**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
61 62 63 64	ML	60.0 - 65.0 ft: Medium hard, olive-gray, moist, silty GRAVEL with sand (GM), sand is fine to medium, gravel is fine to medium, subrounded [QUATERNARY MIDDLE TERRACE DEPOSITS]	65	15	20
65		3.0 - 4.0 in clasts and weathered mafic material at 65.0 ft			
66 67 68 69 70 71 72 73 74 75 76 77	ML	65.0 - 85.0 ft: hard, brown, moist, SILT (ML) [QUATERNARY MIDDLE TERRACE DEPOSITS]	<5	<5	100

GSI Water Solutions, Inc.

LOG ID: GM1-TB2

PROJECT: Santiam Canyon Infiltration Evaluation	**TOTAL DEPTH (ft):** 90		**DATE STARTED:** 8/21/2023
BORING LOCATION: Mill City, OR	**LOGGED BY:** M. Harrison, C. Kambur		**DATE FINISHED:** 8/22/2023
DRILLING CONTRACTOR: Holt	**DEPTH TO WATER (ft bgs)**	**FIRST:** 20	**COMPLETED:** N/A
SAMPLING METHOD: Continuous Core			
DRILLING METHOD: Sonic			

DEPTH (feet)	**SAMPLE DESCRIPTION** Flow, color, weathering, grain size, vesicles primary and secondary minerals, alterations	**% GRAVEL**	**% SAND**	**% FINES**
85.0 - 90.0	Coarsens downward from 85.0 - 90.0 ft 85.0 - 90.0 ft: Loose to medium dense, dark brown to gray-olive, slightly moist to moist, silty GRAVEL with sand (GM), gravel is subangular, cobbles are subangular [QUATERNARY MIDDLE TERRACE DEPOSITS] Cobbles present at 90.0 ft	51	15	34



Total Depth = 90.0 ft

ATTACHMENT B

Slug Testing Memo

TECHNICAL MEMORANDUM

Aquifer Permeability Estimates in Study Area GM1, Gates/Mill City Sewer Basin, Linn County, Oregon

To:	File
From:	Matthew Kohlbecker, RG / GSI Water Solutions, Inc.
Date:	September 20, 2023

1. Introduction

GSI Water Solutions, Inc., (GSI) conducted slug testing at three monitoring wells in Study Area GM1, which is a candidate for infiltration of treated wastewater in Mill City, Oregon. The purpose of the slug testing was to estimate the hydraulic conductivity of saturated soils in the study area. Hydraulic conductivity is a property of soils that describes the ease at which a fluid moves through the pore space. The estimates of hydraulic conductivity will be used to: (1) predict the groundwater mounding that occurs during the infiltration of treated wastewater at proposed Rapid Infiltration Basins (RIBs) using an analytical model, and (2) run contaminant fate and transport models to evaluate the fate and transport of residual constituents in the treated wastewater.

The monitoring wells were installed in Study Area GM1 as part of a subsurface characterization in August 2023. The monitoring wells are completed in a shallow, unconfined aquifer. In addition, the monitoring well screens remained saturated for the duration of the slug tests. Boring logs and well construction diagrams for the monitoring wells are provided in the main text of this report.

This technical memorandum provides methods and results of slug testing conducted at monitoring wells GM1-MW1, GM1-MW2, and GM1-MW3 in Study Area GM1. Note that slug tests at monitoring well GM1-MW1 were previously analyzed in GSI (2023). This technical memorandum presents a re-analysis of the slug tests at GM1-MW1 based on a clearer understanding of aquifer response to slug testing gained from the GM1-MW2 and GM1-MW3 slug tests.

2. Methods

A slug test involves: (1) introducing or removing a solid cylinder into a monitoring well to instantaneously raise or lower the water level in the monitoring well, and (2) monitoring the recovery of the water level to the static (pre-test) condition. Slug tests were conducted in general accordance with the *Santiam Canyon Treated Wastewater Disposal – Subsurface Characterization Work Plan*, dated March 3, 2023, and the *Santiam Canyon Treated wastewater Disposal – Subsurface Characterization Work Plan Addendum No. 1 (Phase III)*, dated August 18, 2023.

For each slug test, water level recovery was recorded every 0.5 seconds with a non-vented Solinst pressure transducer and datalogger. Although non-vented transducers record both water pressure and barometric pressure, it was not necessary to subtract out barometric pressure effects due to the rapid recovery of water levels to the static level.

Each slug test consisted of monitoring water level response due to raising the water level ("Slug-In Test") and lowering the water level ("Slug-Out Test"). Three tests were conducted at each well. Water level responses exhibiting an underdamped (i.e., oscillatory) response were analyzed with the Springer-Gelhar (1991) solution for a slug test in an unconfined aquifer. Water level responses exhibiting an overdamped (i.e., straight-line) response were analyzed by the Hvorslev (1951) solution for a slug test in an unconfined aquifer.

3. Results

Plots of water level versus time during the slug tests are provided in Figures B.1(a) and B.1(b) for GM1-MW1, Figures B.2(a) through B.2(c) for GM1-MW2, and Figures B.3(a) through B.3(c) for GM1-MW3. Water level recovery was generally rapid, ranging from less than 30 seconds in monitoring wells GM1-MW1 and GM1-MW2, to about 200 seconds at GM1-MW3. The relatively rapid response indicates that soils at Study Area GM-1 are characterized by a high hydraulic conductivity. Note on the plots that several tests were not analyzed due to the transducer moving during the test.

Water level response at monitoring wells GM1-MW1 and GM1-MW2 exhibited an underdamped (i.e., oscillatory) response and were analyzed using the Springer-Gelhar (1991) solution for a slug test in an unconfined aquifer. Water level response at monitoring well GM1-MW3 exhibited an overdamped (i.e., straight-line) response and was analyzed by the Hvorslev (1951) solution for a slug test in an unconfined aquifer. Hydraulic conductivity estimates from the slug tests are summarized in Table 1.

Table 1. Slug Test Results.

Well ID	Analysis Method	Result	Figure Reference	Geometric Mean Horizontal K (feet/day)
GM1-MW1	Springer-Gelhar (1991) Springer-Gelhar (1991)	**Test 1 (in):** 97 feet/day **Test 3 (in):** 275 feet/day	Figure B.1(d) Figure B.1(e)	163.3
GM1-MW2	Springer-Gelhar (1991) Springer-Gelhar (1991) Springer-Gelhar (1991)	**Test 1 (in):** 111 feet/day **Test 2 (in):** 110 feet/day **Test 3 (in):** 120 feet/day	Figure B.2(d) Figure B.2(e) Figure B.2(f)	113.6
GM1-MW3	Hvorslev (1951) Hvorslev (1951) Hvorslev (1951)	**Test 1 (in):** 33.8 feet/day **Test 2 (in):** 57.5 feet/day **Test 3 (in):** 26.1 feet/day	Figure B.3(d) Figure B.3(d) Figure B.3(d)	37.0
			Overall Geometric Mean	**88.2**

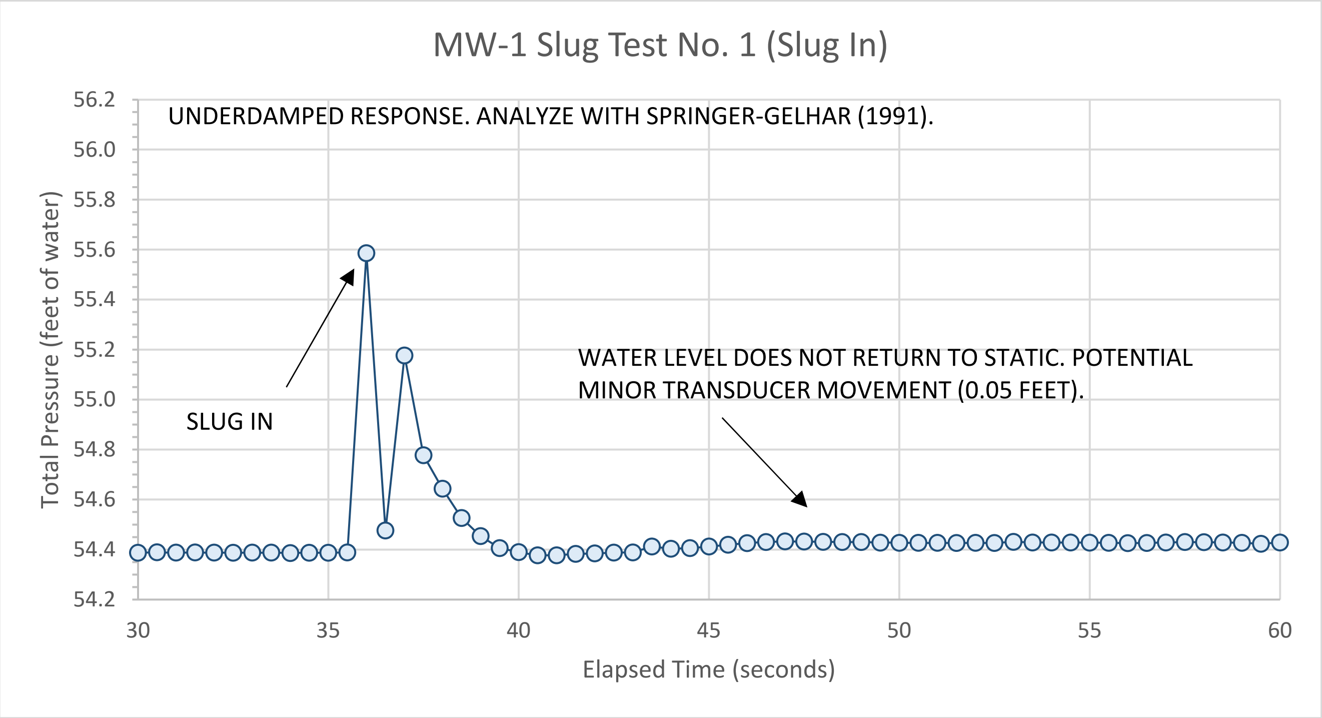
The hydraulic conductivity of the aquifer at Study Area GM1 ranges from 37 feet per day to 163 feet per day, with a geometric mean of 88.2 feet per day. Note that hydraulic conductivity in the area where treated wastewater is to be infiltrated (i.e., in the lower-elevation area around GM1-MW1 and GM1-MW2) is higher, ranging from about 114 feet per day to 163 feet per day. This trend in hydraulic conductivity is consistent with coarser, higher conductivity sediments being deposited close to a river.

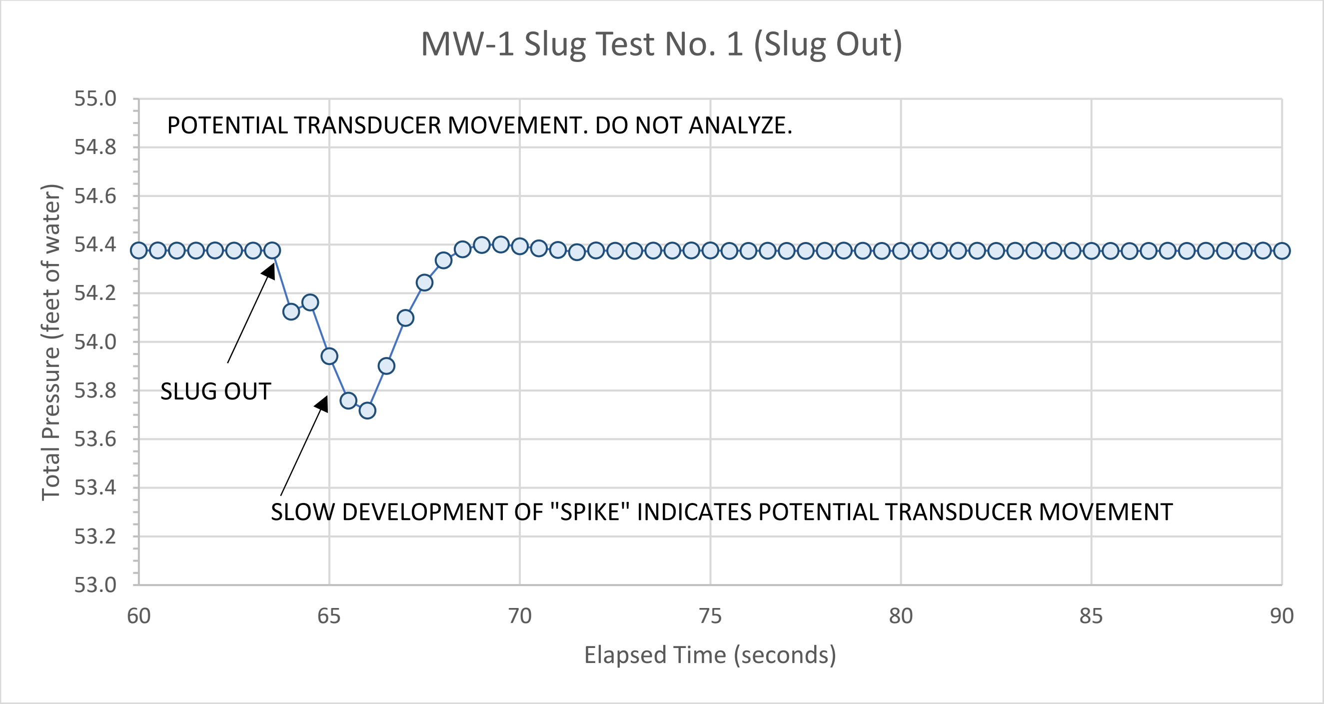
4. References

GSI. 2023. Phase II Subsurface Characterization to Support an Evaluation of Treated Wastewater Infiltration in Gates and Mill City, Marion and Linn Counties, Oregon.

Hvorslev, M. J. 1951. Time lag and soil permeability in ground-water observations. Bulletin No. 36, Waterways Exper. Sta. Corps of Engineers, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

Springer, R. K. and L. W. Gehlar. 1991. Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug tests with oscillatory response, Cape Cod, Massachusetts. U.S. Geological Survey Water Resources Investigations 91-4034, pp. 36-40.





Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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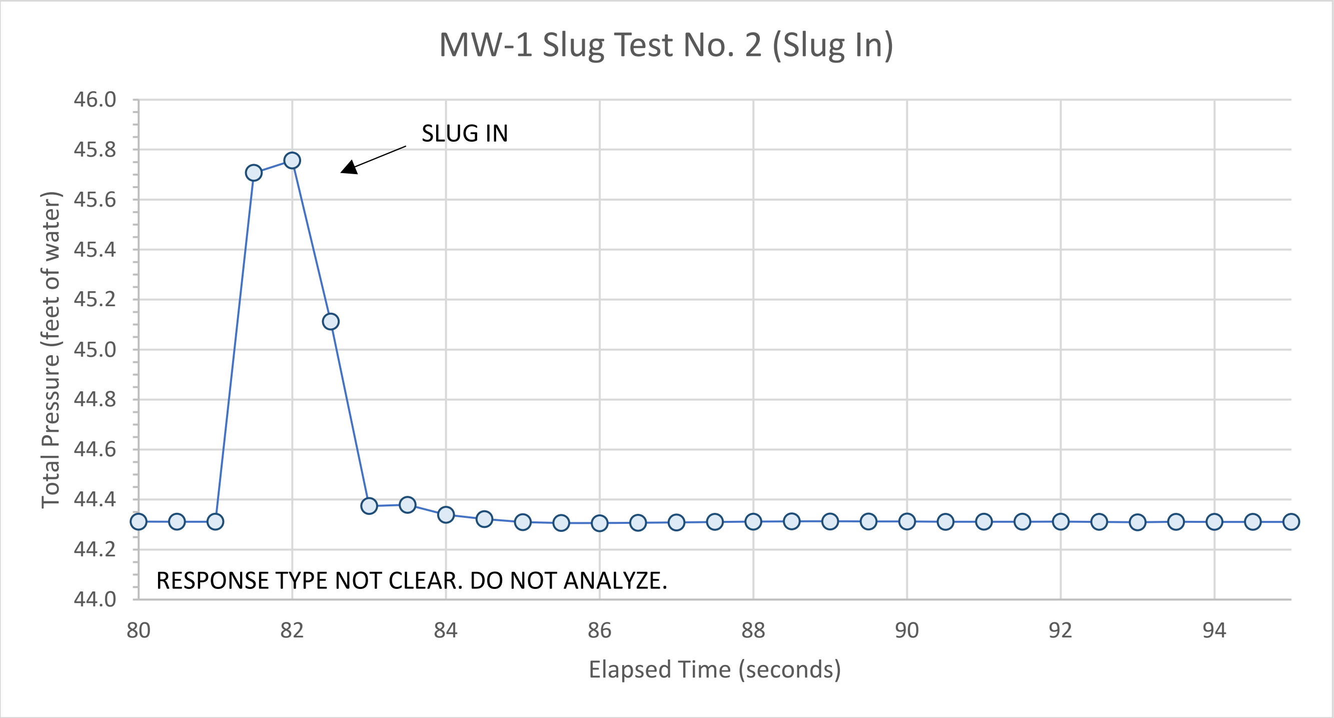
Figure B.1(a)

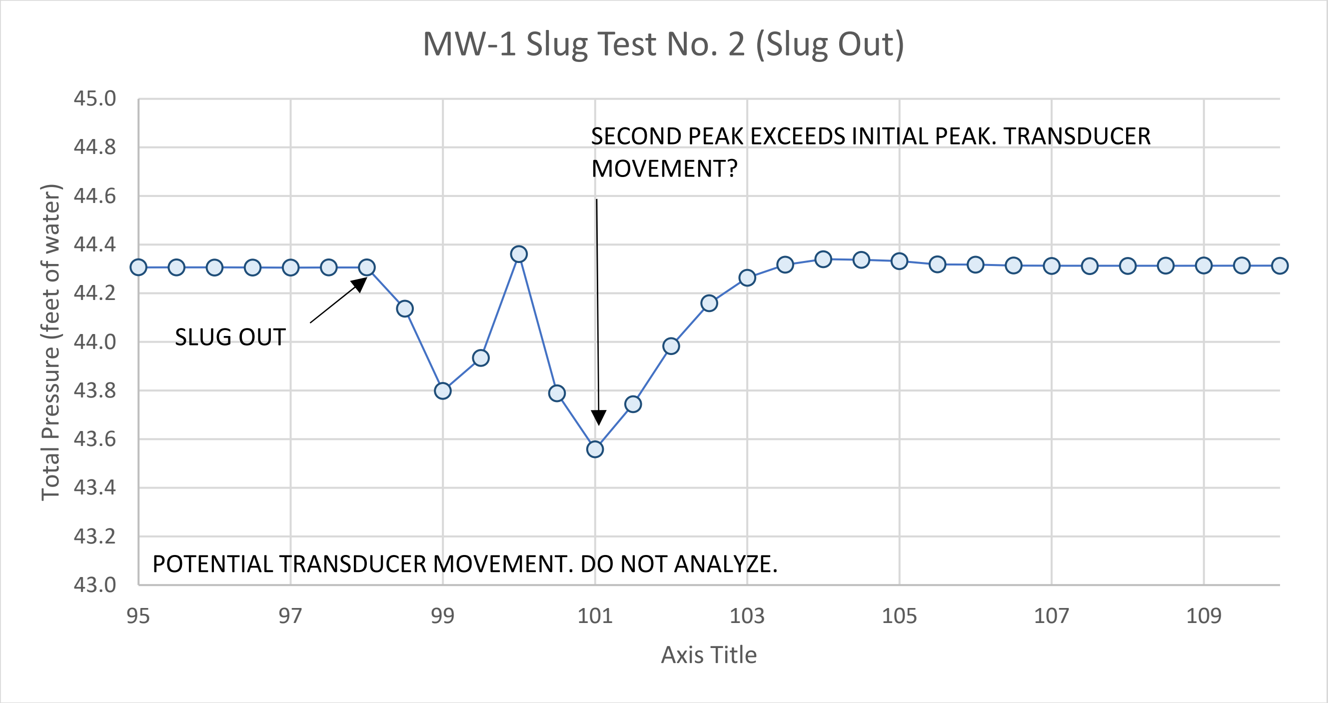
GM1-MW1 Slug Test 1

Gates/Mill City Phase II Subsurface Characterization


MW-1 Slug Test No. 2 (Slug In)

SLUG IN

RESPONSE TYPE NOT CLEAR. DO NOT ANALYZE.


MW-1 Slug Test No. 2 (Slug Out)

SECOND PEAK EXCEEDS INITIAL PEAK. TRANSDUCER MOVEMENT?

SLUG OUT

POTENTIAL TRANSDUCER MOVEMENT. DO NOT ANALYZE.

Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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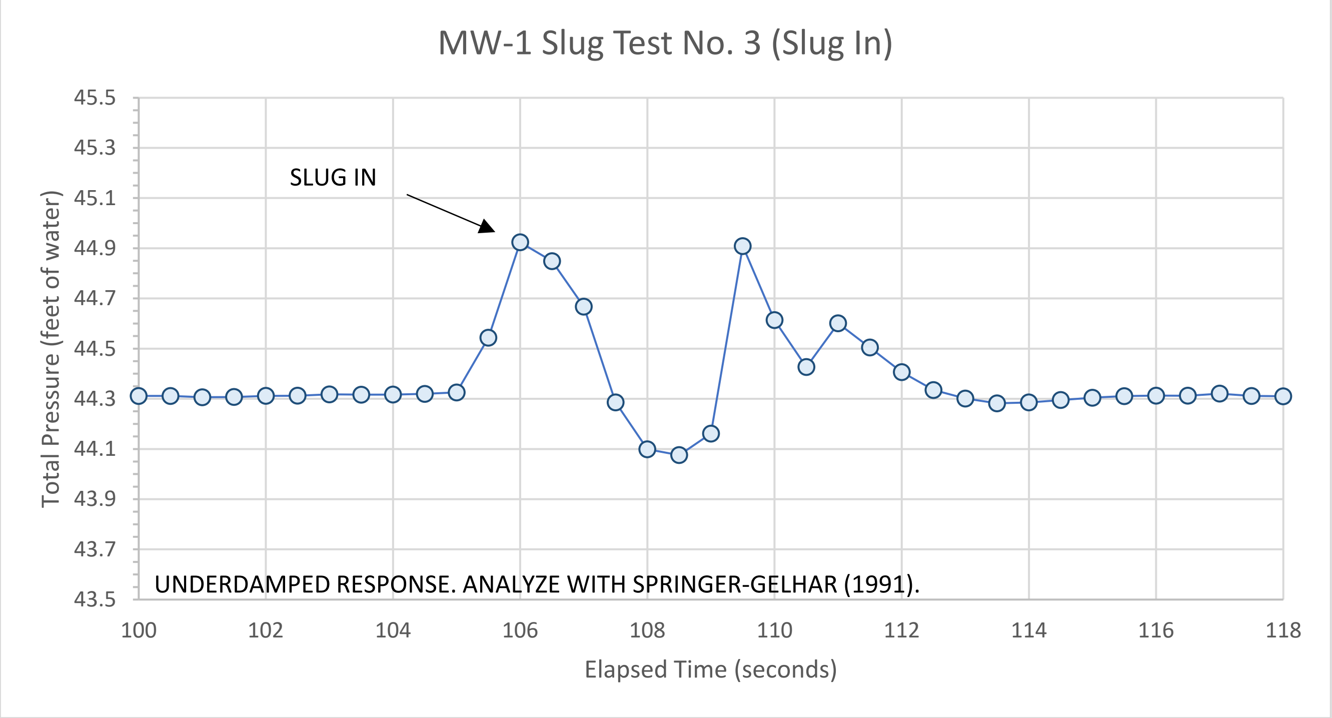
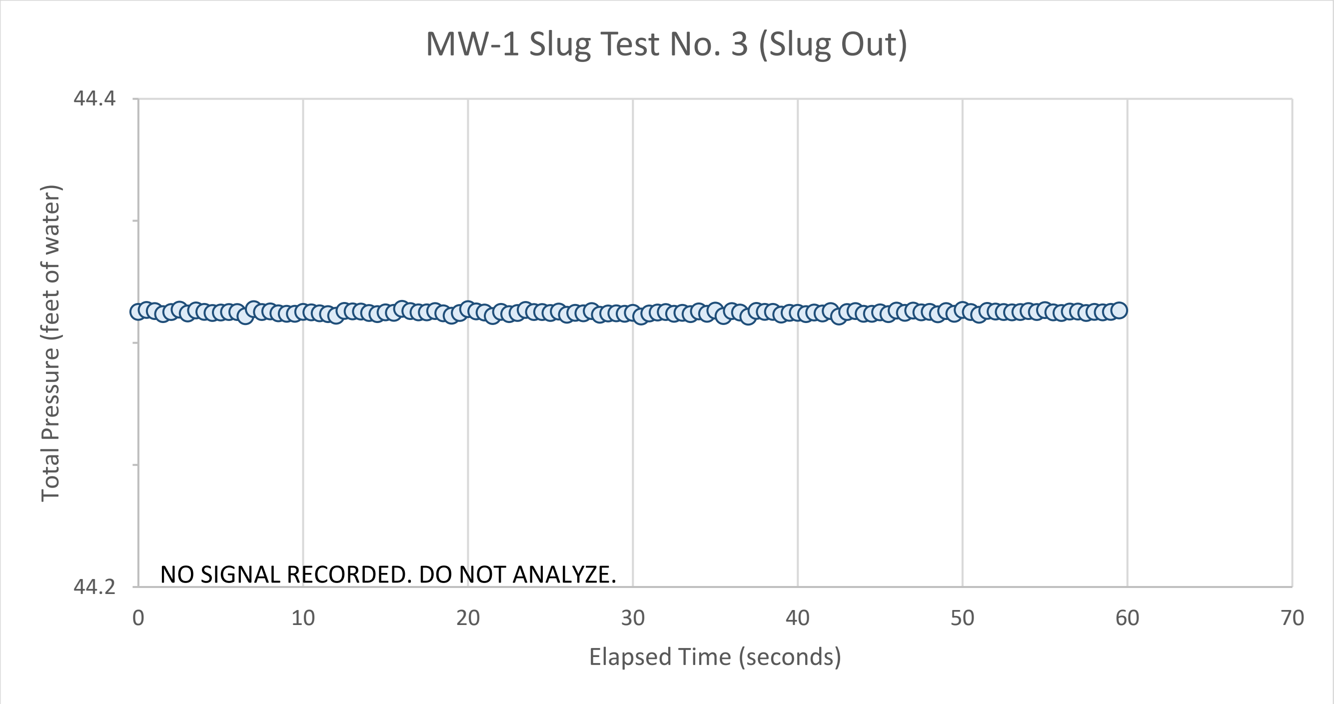
Figure B.1(b)

GM1-MW1 Slug Test 2

Gates/Mill City Phase II Subsurface Characterization





Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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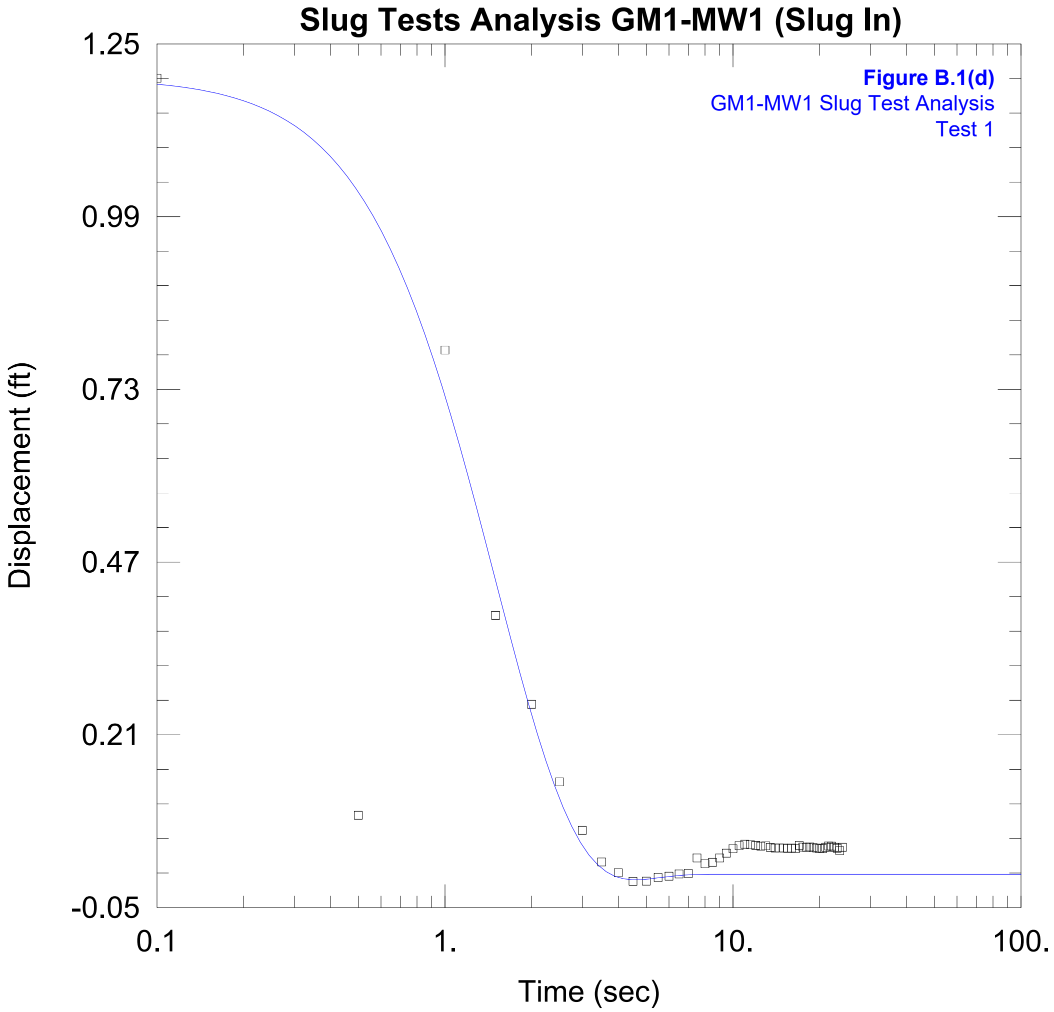
Figure B.1(c)

GM1-MW1 Slug Test 3

Gates/Mill City Phase II Subsurface Characterization



WELL TEST ANALYSIS

Data Set: P:\...\GM1-MW1-ST1-INa.aqt
Date: 09/18/23 Time: 12:35:07

PROJECT INFORMATION

Company: Gates Mill City Infiltration
Client: Keller Associates
Project: 464.020
Location: Mill City, Oregon
Test Well: MW-1
Test Date: 6/8/2023

AQUIFER DATA

Saturated Thickness: 24.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-1)

Initial Displacement: 1.198 ft
Total Well Penetration Depth: 24.6 ft
Casing Radius: 0.083 ft
Static Water Column Height: 24.6 ft
Screen Length: 10. ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 97. ft/day
Le = 19.6 ft

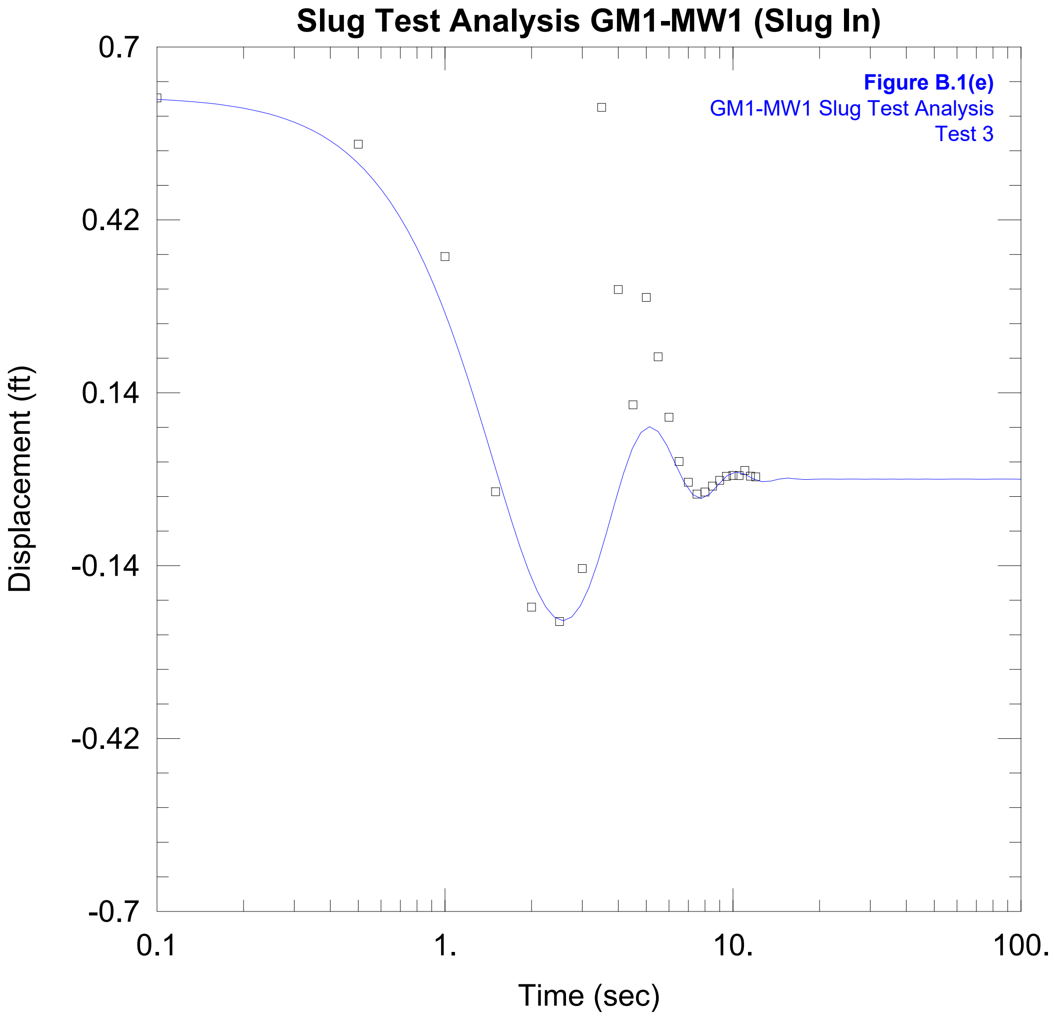


Figure B.1(e)
GM1-MW1 Slug Test Analysis
Test 3

WELL TEST ANALYSIS

Data Set: P:\...\GM1-MW1-ST3-INa.aqt
Date: 09/18/23
Time: 13:54:04

PROJECT INFORMATION

Company: Gates Mill City Infiltration
Client: Keller Associates
Project: 464.020
Location: Mill City, Oregon
Test Well: MW-1
Test Date: 6/8/2023

AQUIFER DATA

Saturated Thickness: 24.6 ft
Anisotropy Ratio (Kz/Kr): 1.

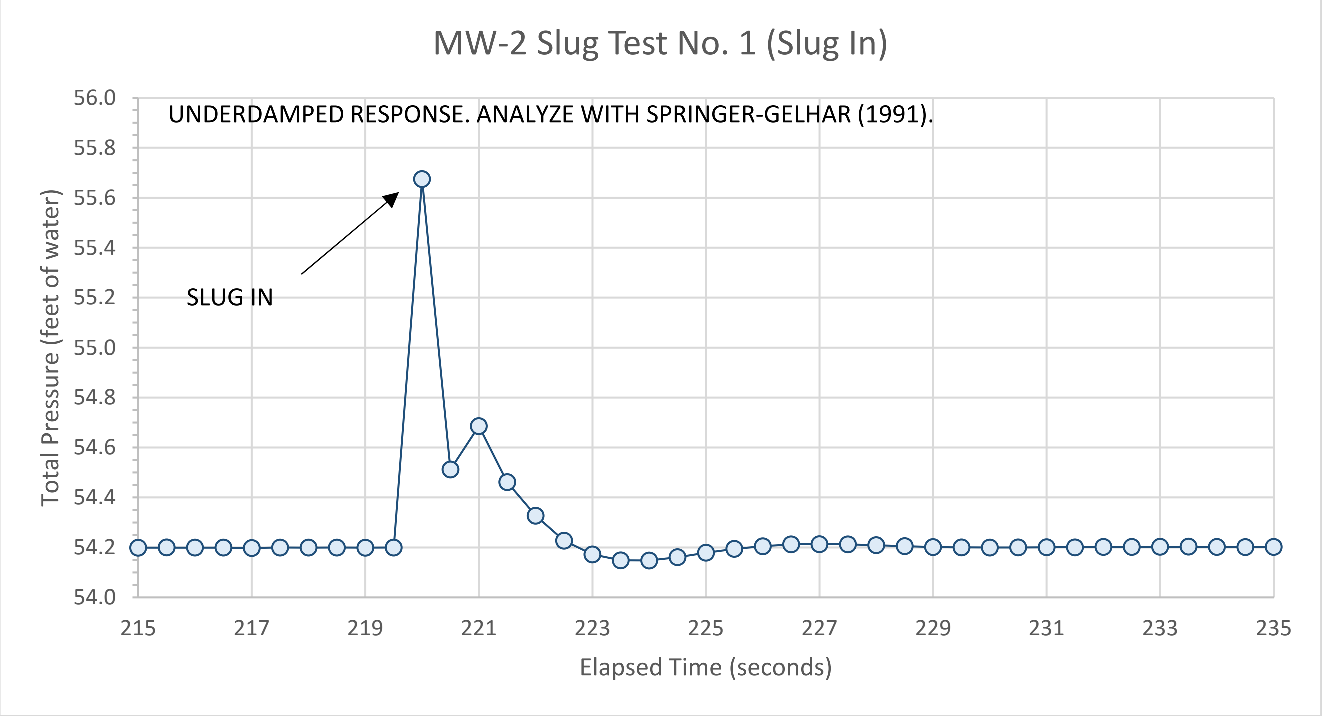
WELL DATA (MW-1)

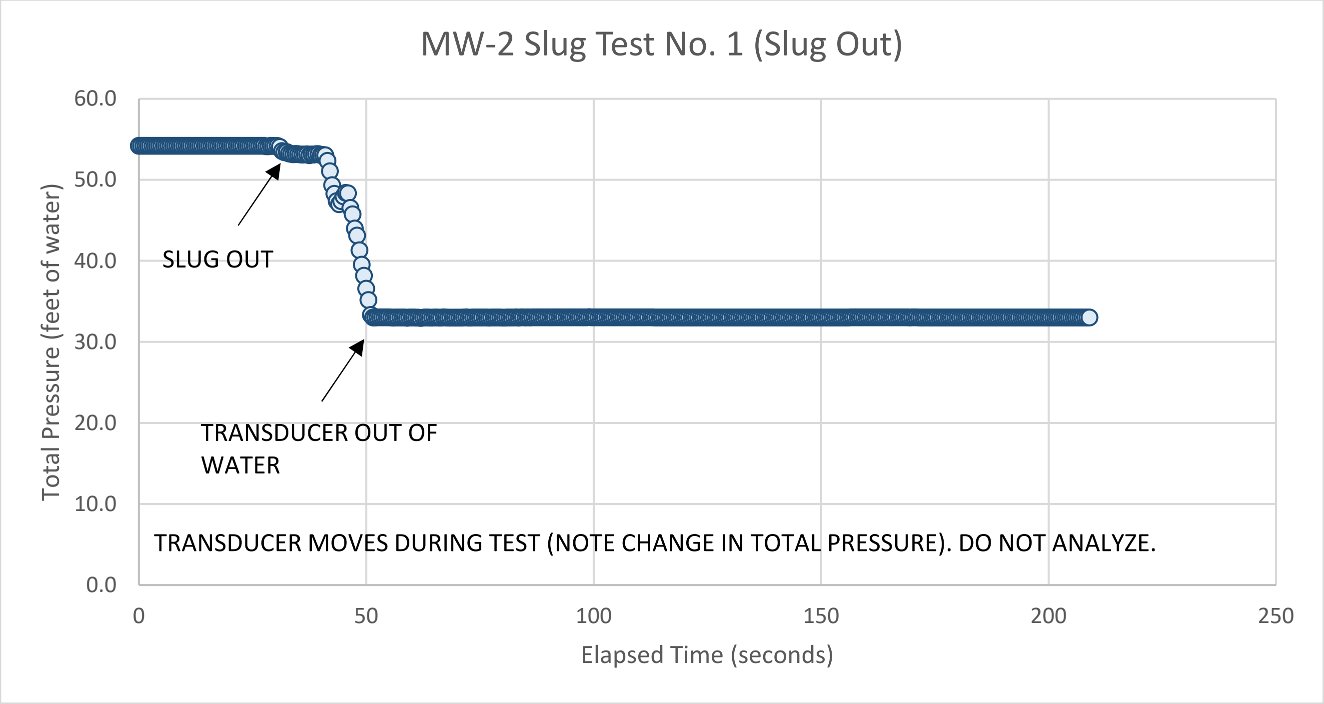
Initial Displacement: 0.62 ft
Total Well Penetration Depth: 24.6 ft
Casing Radius: 0.083 ft
Static Water Column Height: 24.6 ft
Screen Length: 10. ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 275. ft/day
Le = 19.6 ft





Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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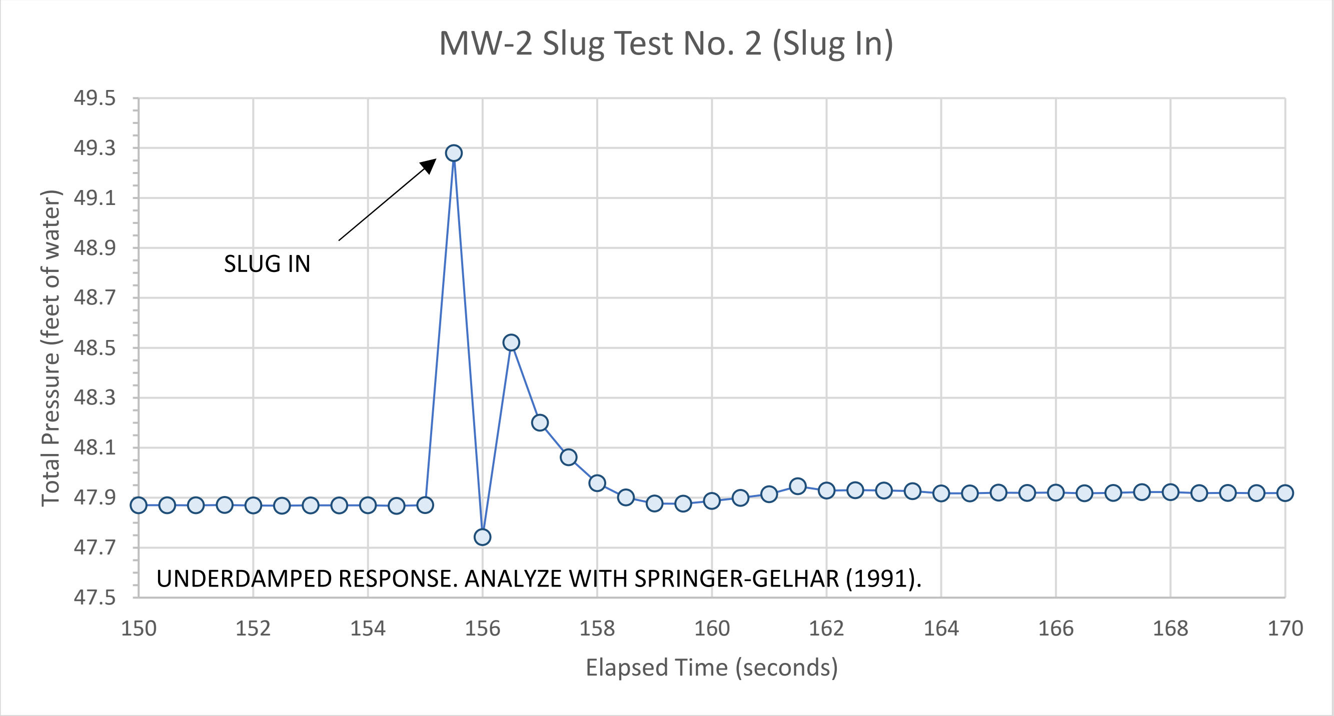
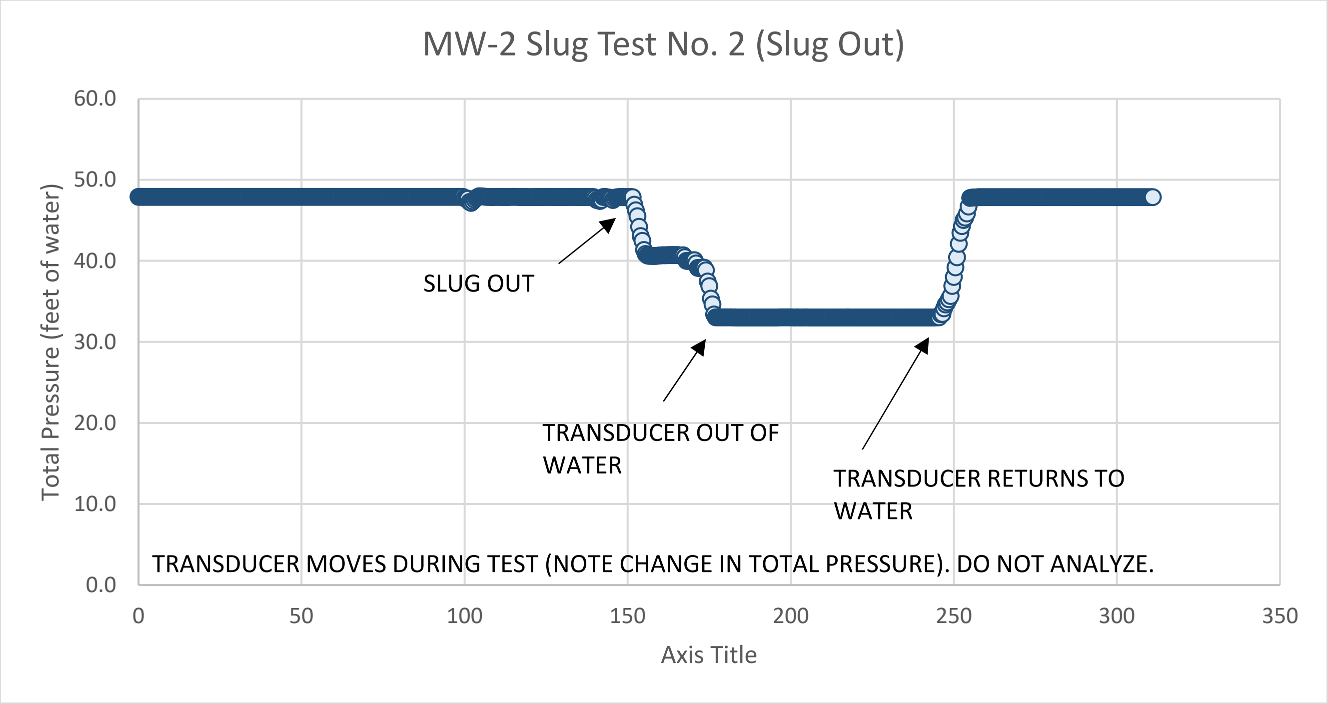
Figure B.2(a)

GM1-MW2 Slug Test 1

Gates/Mill City Phase II Subsurface Characterization





Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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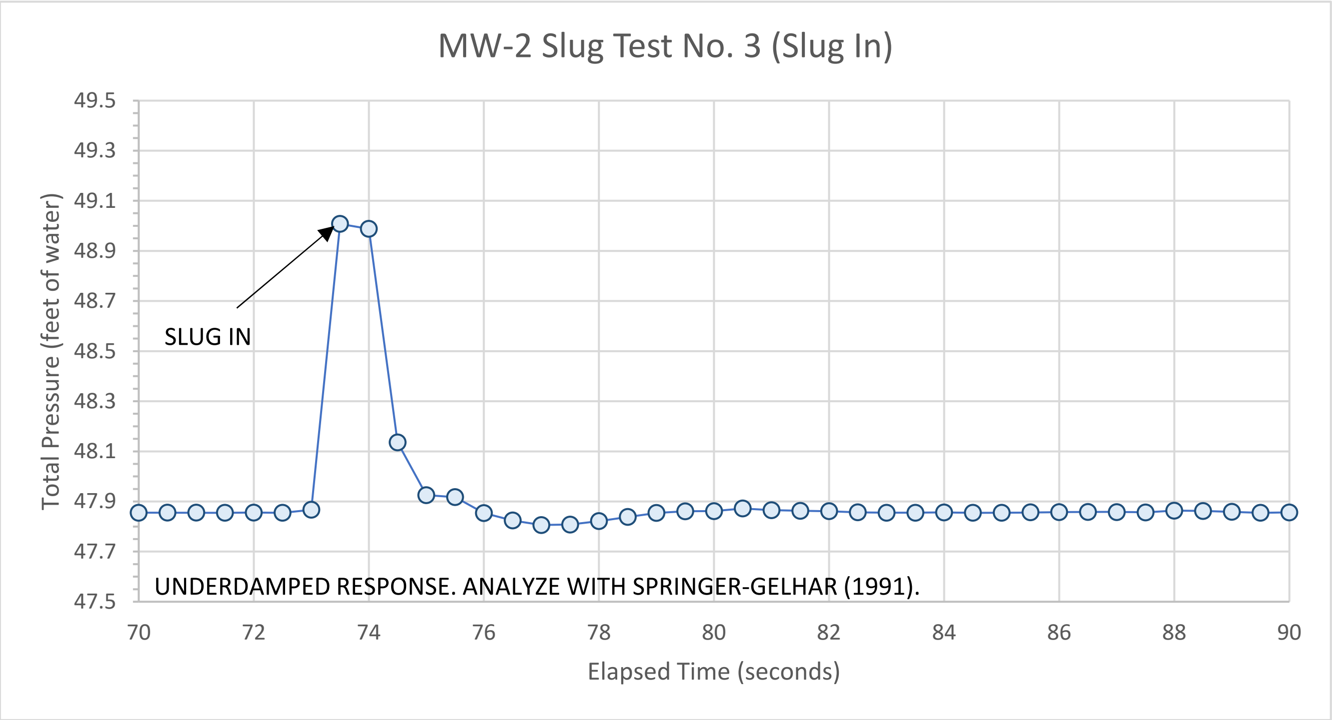
Figure B.2(b)

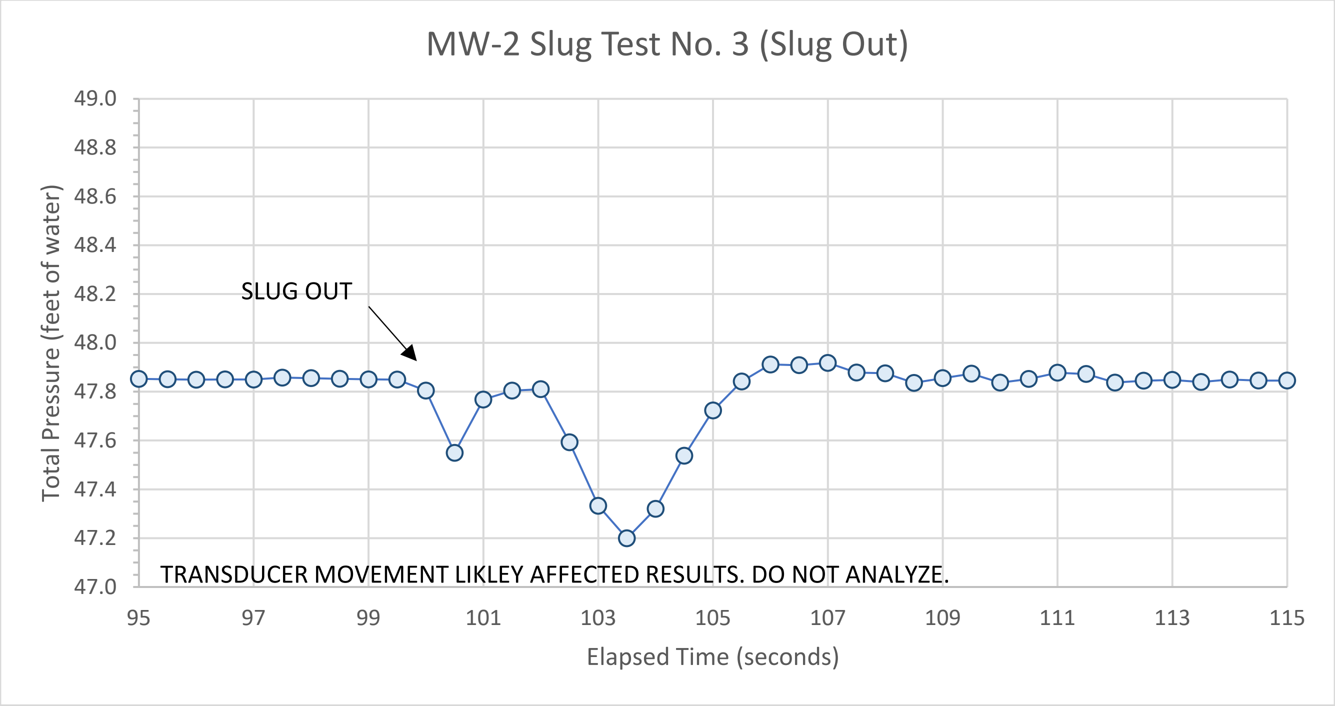
GM1-MW2 Slug Test 2

Gates/Mill City Phase II Subsurface Characterization



SLUG IN

UNDERDAMPED RESPONSE. ANALYZE WITH SPRINGER-GELHAR (1991).



SLUG OUT

TRANSDUCER MOVEMENT LIKLEY AFFECTED RESULTS. DO NOT ANALYZE.

Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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Figure B.2(c)

GM1-MW2 Slug Test 3

Gates/Mill City Phase II Subsurface Characterization

Slug Test Analysis GM1-MW2 (Slug In)

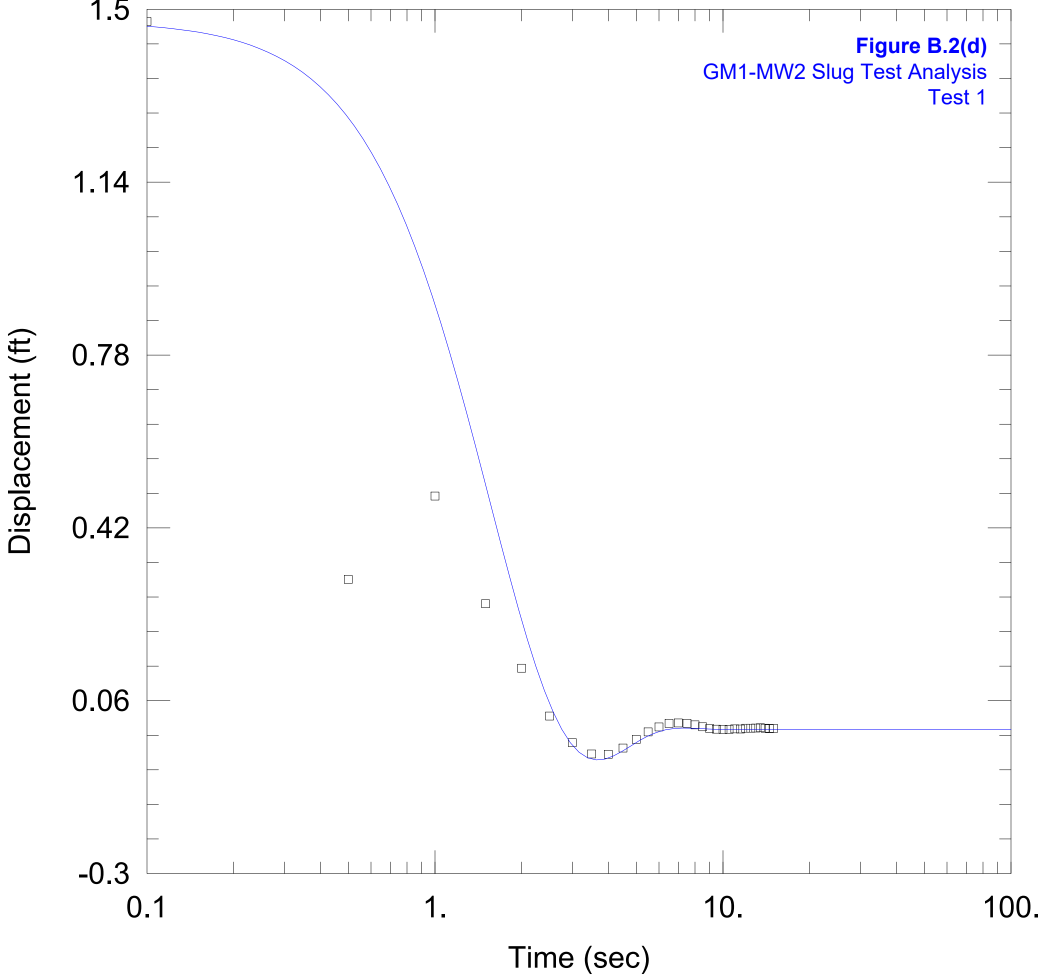


Figure B.2(d)
GM1-MW2 Slug Test Analysis
Test 1

WELL TEST ANALYSIS

Data Set: P:\...\GM1-MW1-ST1-INa.aqt
Date: 09/15/23 Time: 16:26:36

PROJECT INFORMATION

Company: Gates Mill City Infiltration
Client: Keller Associates
Project: 464.020
Location: Mill City, Oregon
Test Well: MW-2
Test Date: 9/4/2023

AQUIFER DATA

Saturated Thickness: 27.01 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (GM1-MW2)

Initial Displacement: 1.475 ft
Static Water Column Height: 27.01 ft
Total Well Penetration Depth: 27.01 ft
Screen Length: 10. ft
Casing Radius: 0.083 ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 111. ft/day
Le = 22.01 ft

Slug Test Analysis GM1-MW2 (Slug In)

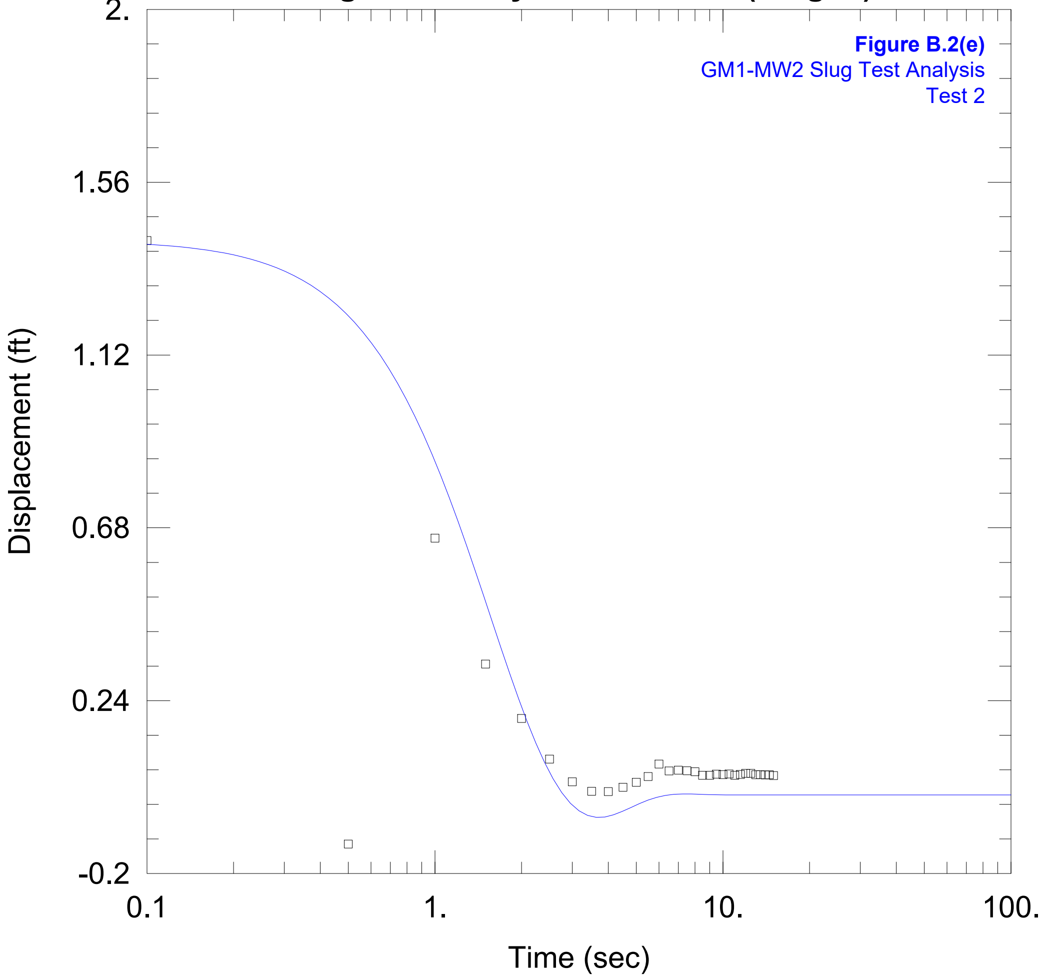


Figure B.2(e)
GM1-MW2 Slug Test Analysis
Test 2

WELL TEST ANALYSIS

Data Set: P:\...\GM1-MW2-ST1-INa.aqt
Date: 09/15/23 Time: 16:40:44

PROJECT INFORMATION

Company: Gates Mill City Infiltration
Client: Keller Associates
Project: 464.020
Location: Mill City, Oregon
Test Well: MW-2
Test Date: 9/4/2023

AQUIFER DATA

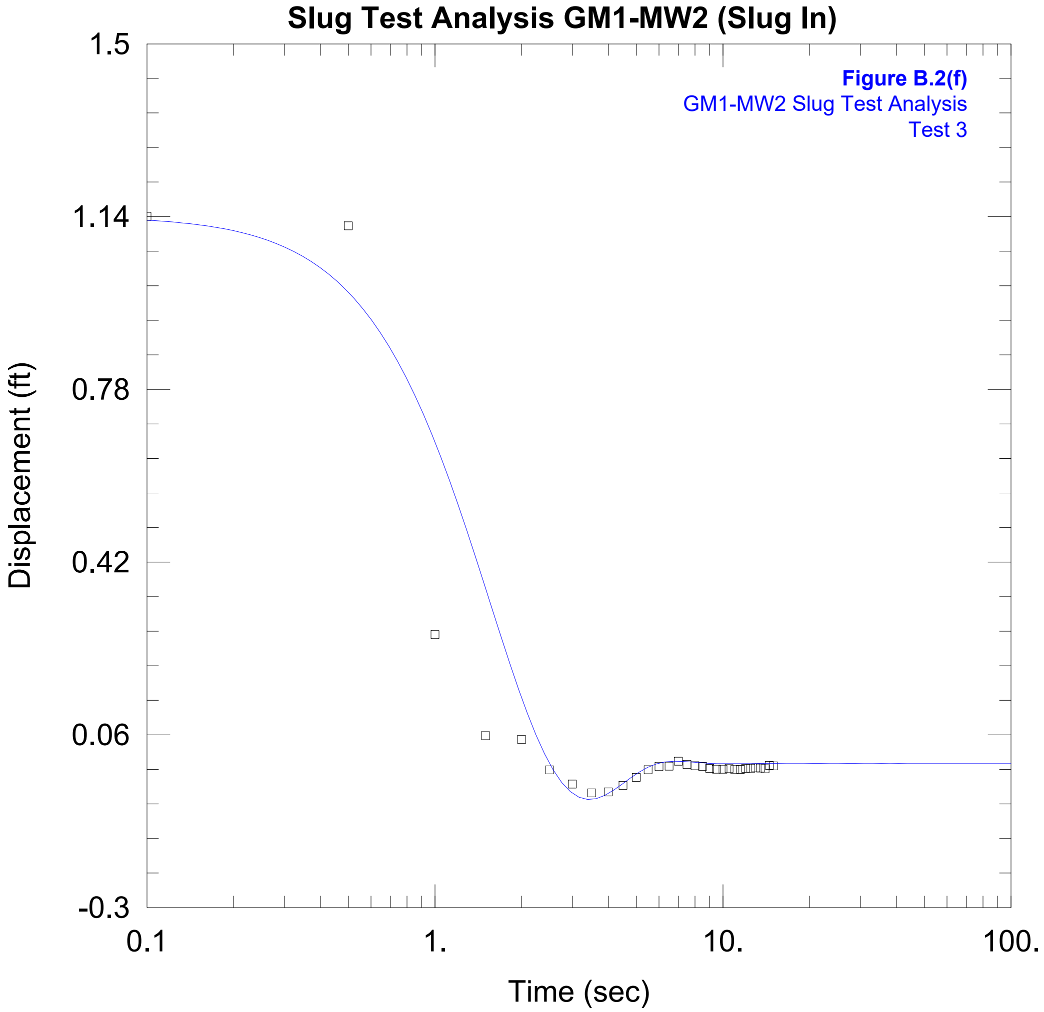
Saturated Thickness: 27.01 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2)

Initial Displacement: 1.412 ft
Total Well Penetration Depth: 27.01 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.01 ft
Screen Length: 10. ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 110. ft/day
Le = 22.01 ft



WELL TEST ANALYSIS

Data Set: P:\...\GM1-MW2-ST3-INa.aqt
Date: 09/15/23
Time: 16:56:38

PROJECT INFORMATION

Company: Gates Mill City Infiltration
Client: Keller Associates
Project: 464.020
Location: Mill City, Oregon
Test Well: MW-2
Test Date: 9/4/2023

AQUIFER DATA

Saturated Thickness: 27.01 ft
Anisotropy Ratio (Kz/Kr): 1.

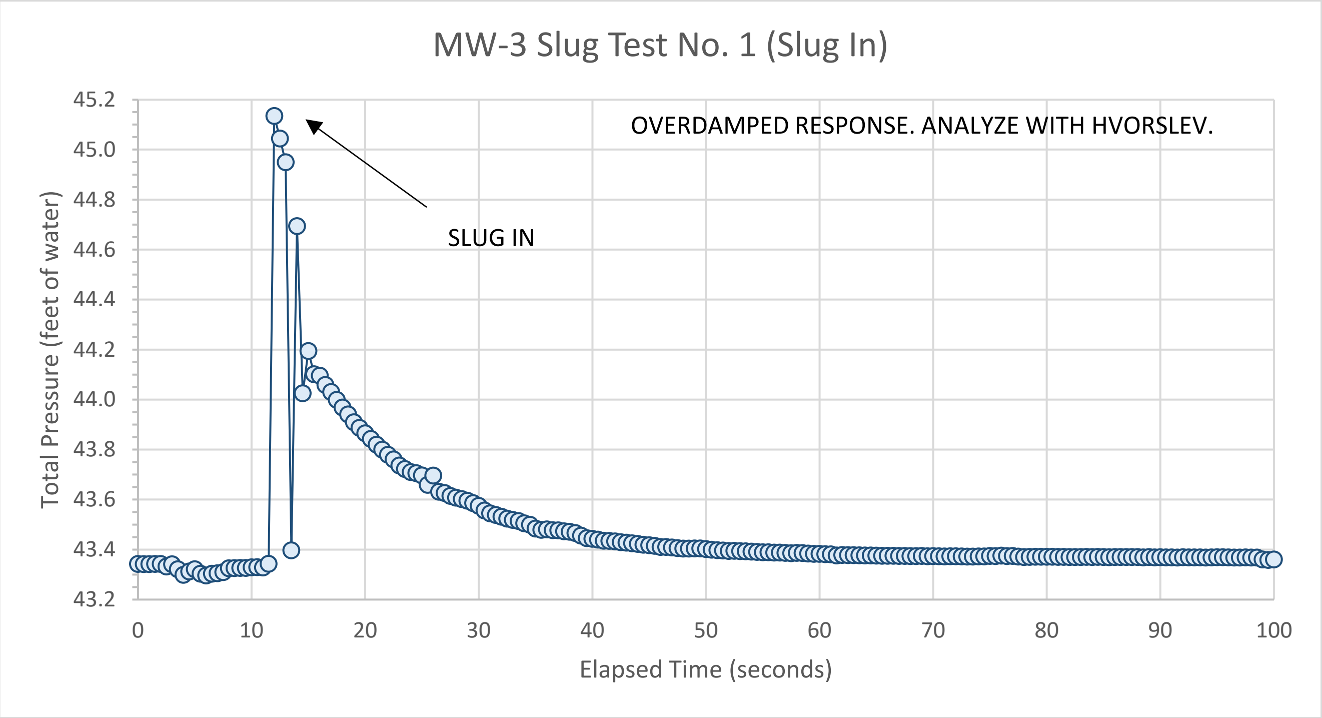
WELL DATA (MW-2)

Initial Displacement: 1.141 ft
Static Water Column Height: 27.01 ft
Total Well Penetration Depth: 27.01 ft
Screen Length: 10. ft
Casing Radius: 0.083 ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

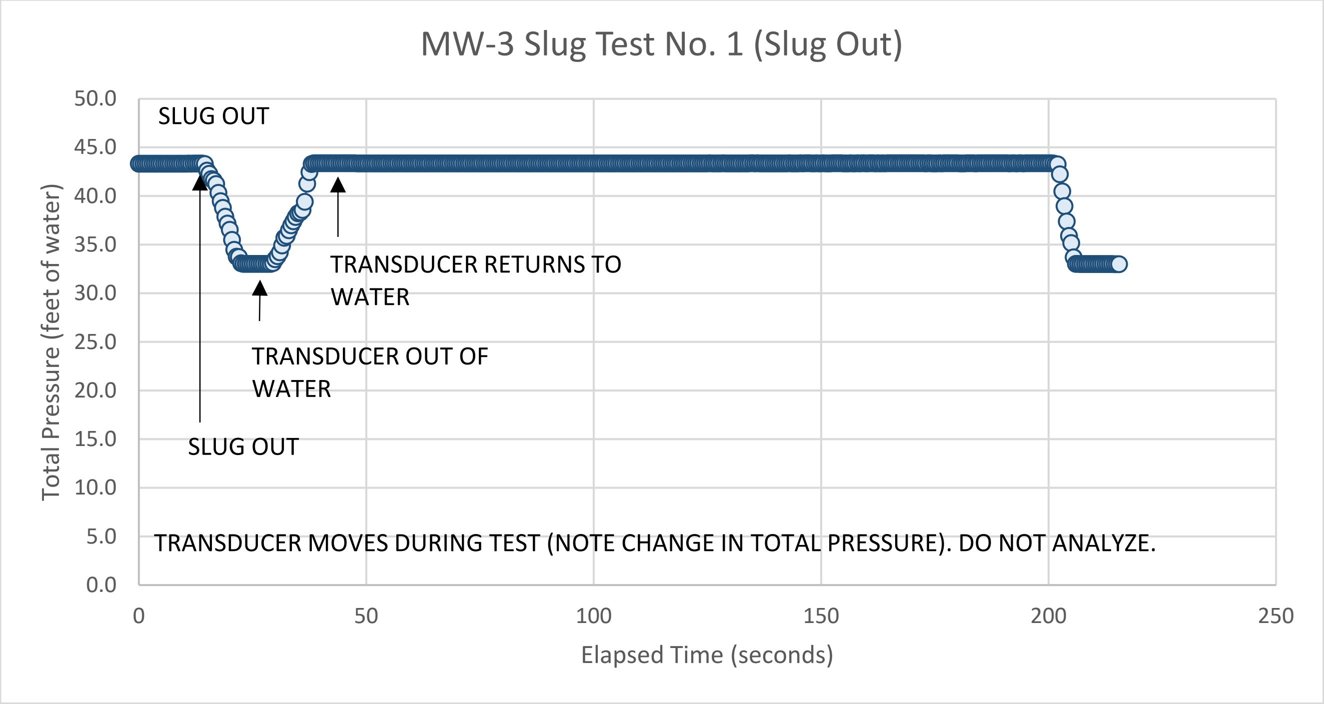
K = 120. ft/day
Le = 22.01 ft



MW-3 Slug Test No. 1 (Slug In)

OVERDAMPED RESPONSE. ANALYZE WITH HVORSLEV.

SLUG IN



MW-3 Slug Test No. 1 (Slug Out)

SLUG OUT

TRANSDUCER RETURNS TO WATER

TRANSDUCER OUT OF WATER

SLUG OUT

TRANSDUCER MOVES DURING TEST (NOTE CHANGE IN TOTAL PRESSURE). DO NOT ANALYZE.

Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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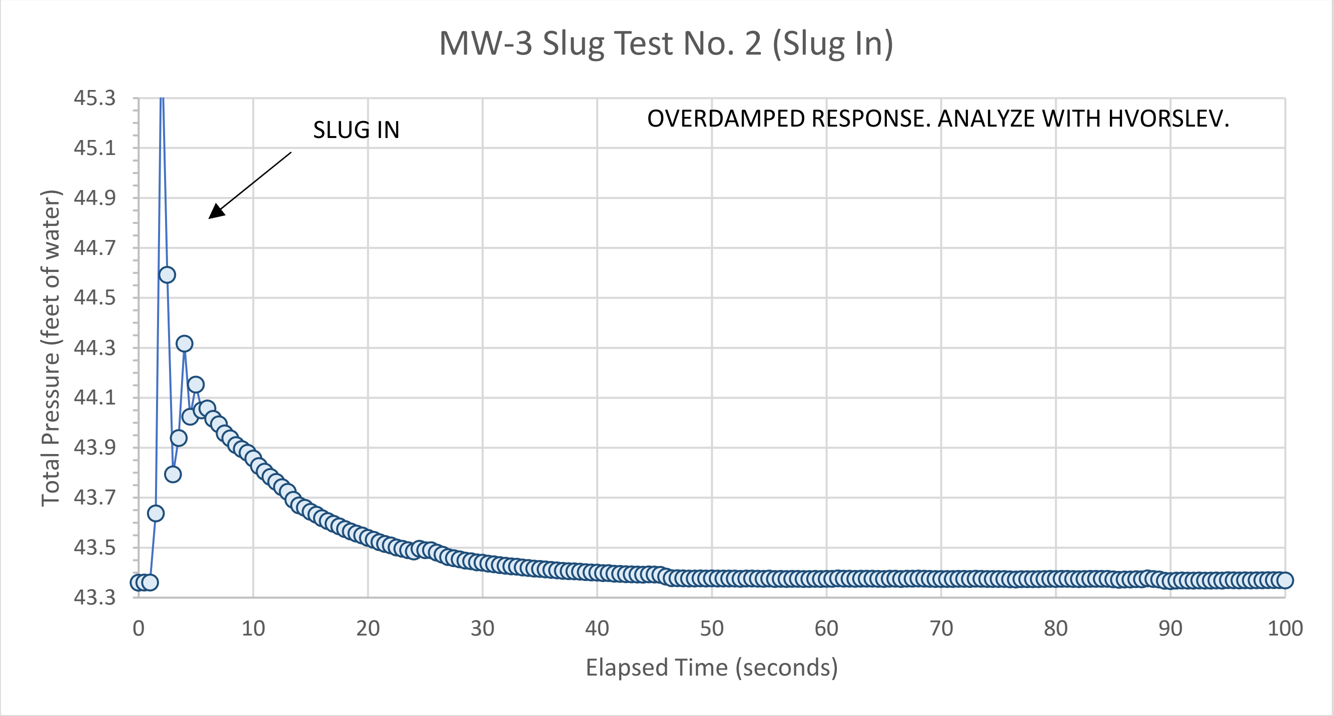
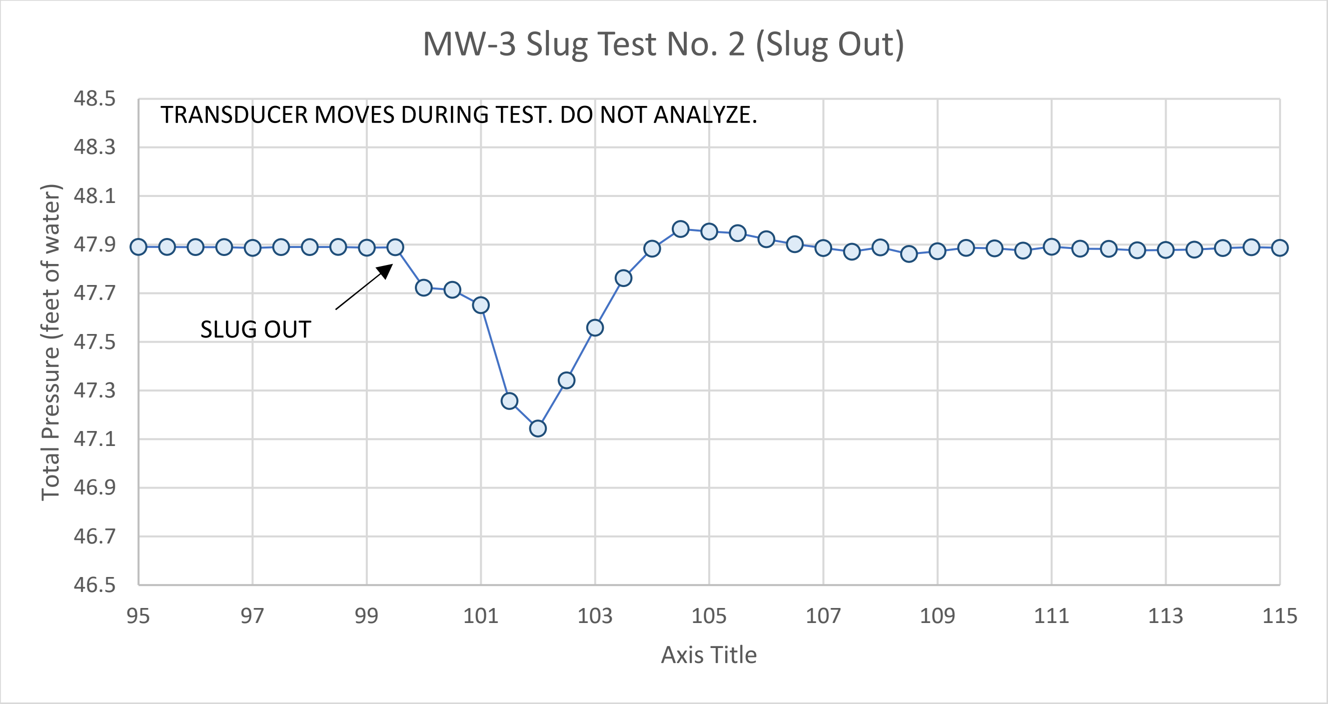
Figure B.3(a)

GM1-MW3 Slug Test 1

Gates/Mill City Phase II Subsurface Characterization





<u>Notes:</u>

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

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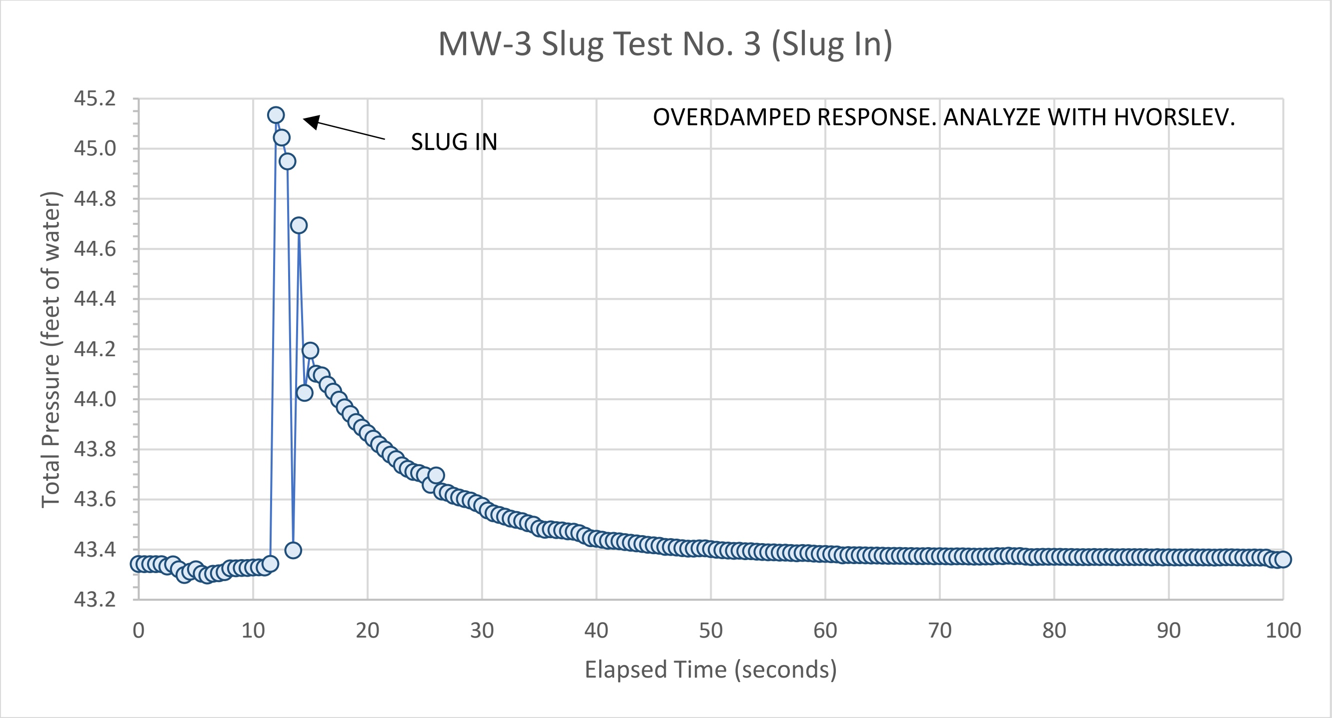
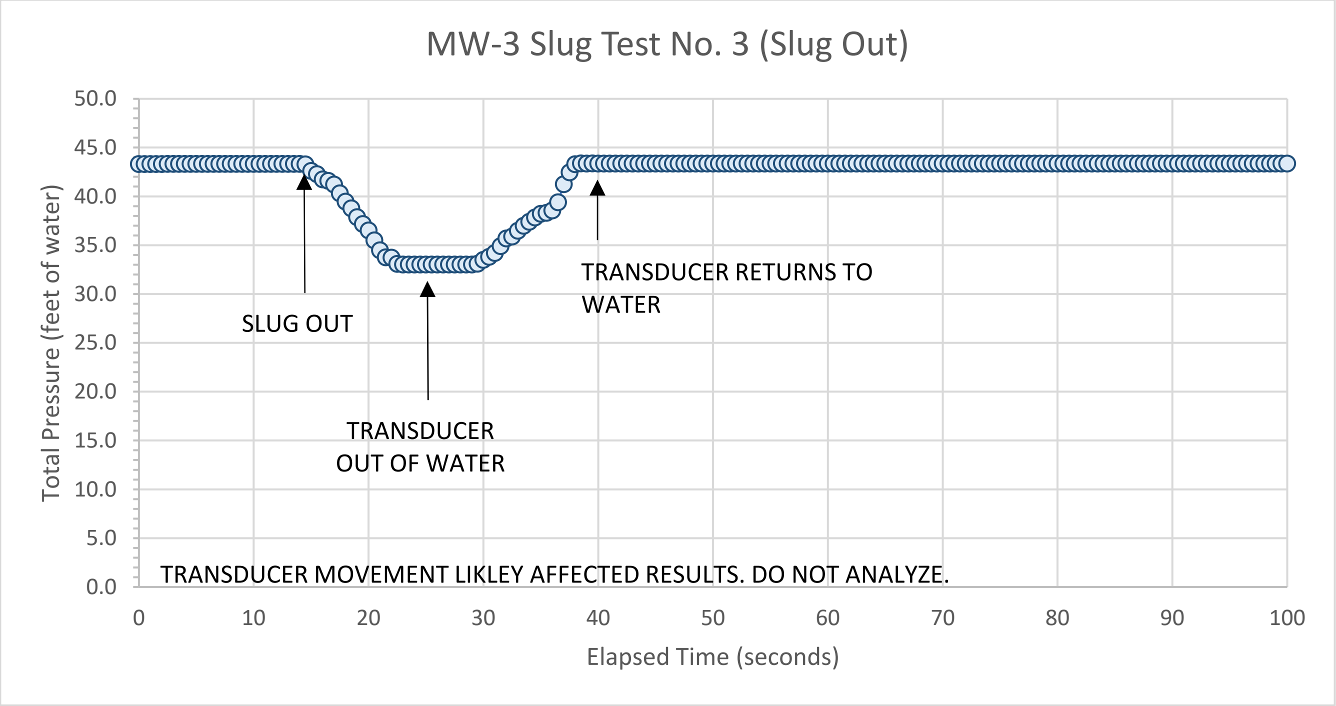
Figure B.3(b)

GM1-MW3 Slug Test 2

Gates/Mill City Phase II Subsurface Characterization





Notes:

(1) "Total Pressure" includes water pressure above transducer and barometric pressure.

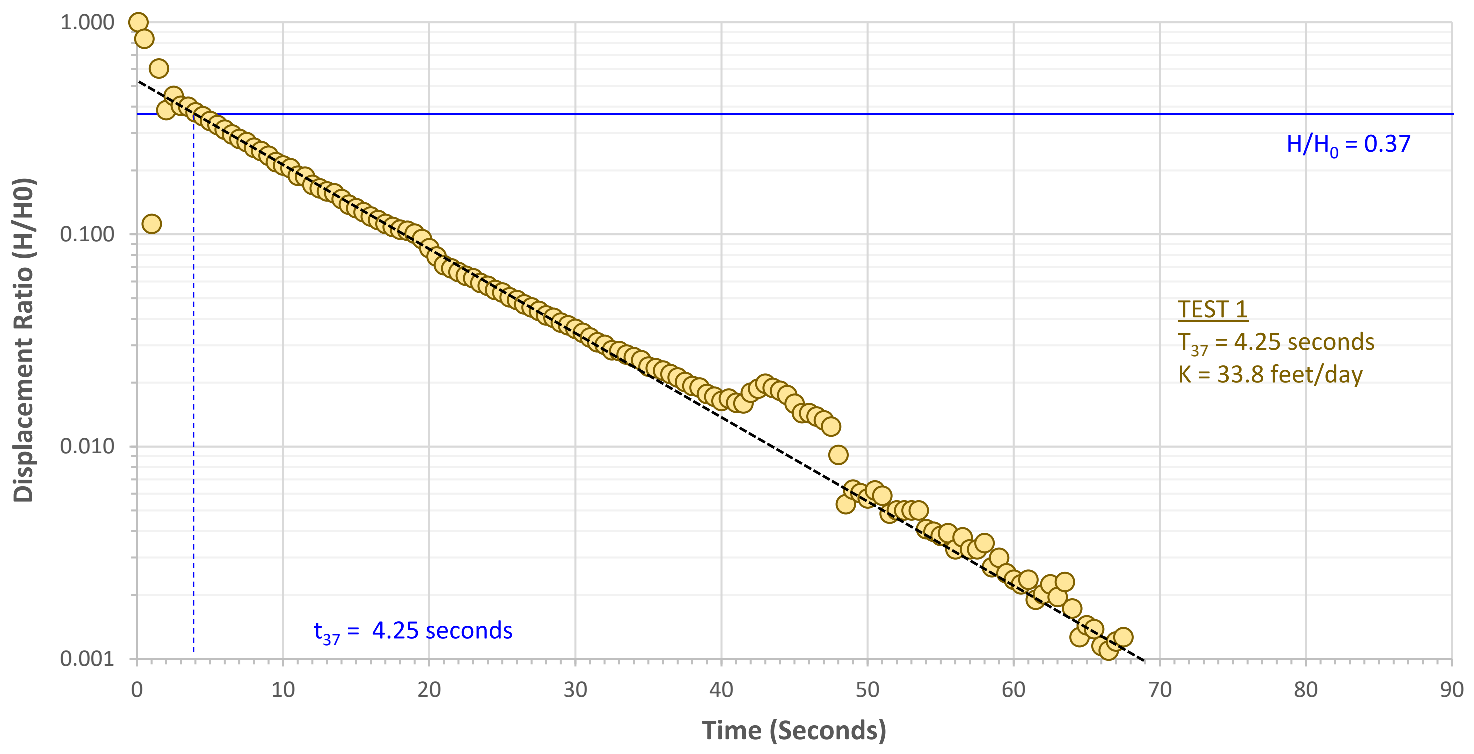
GSI Water Solutions, Inc.

Figure B.3(c)

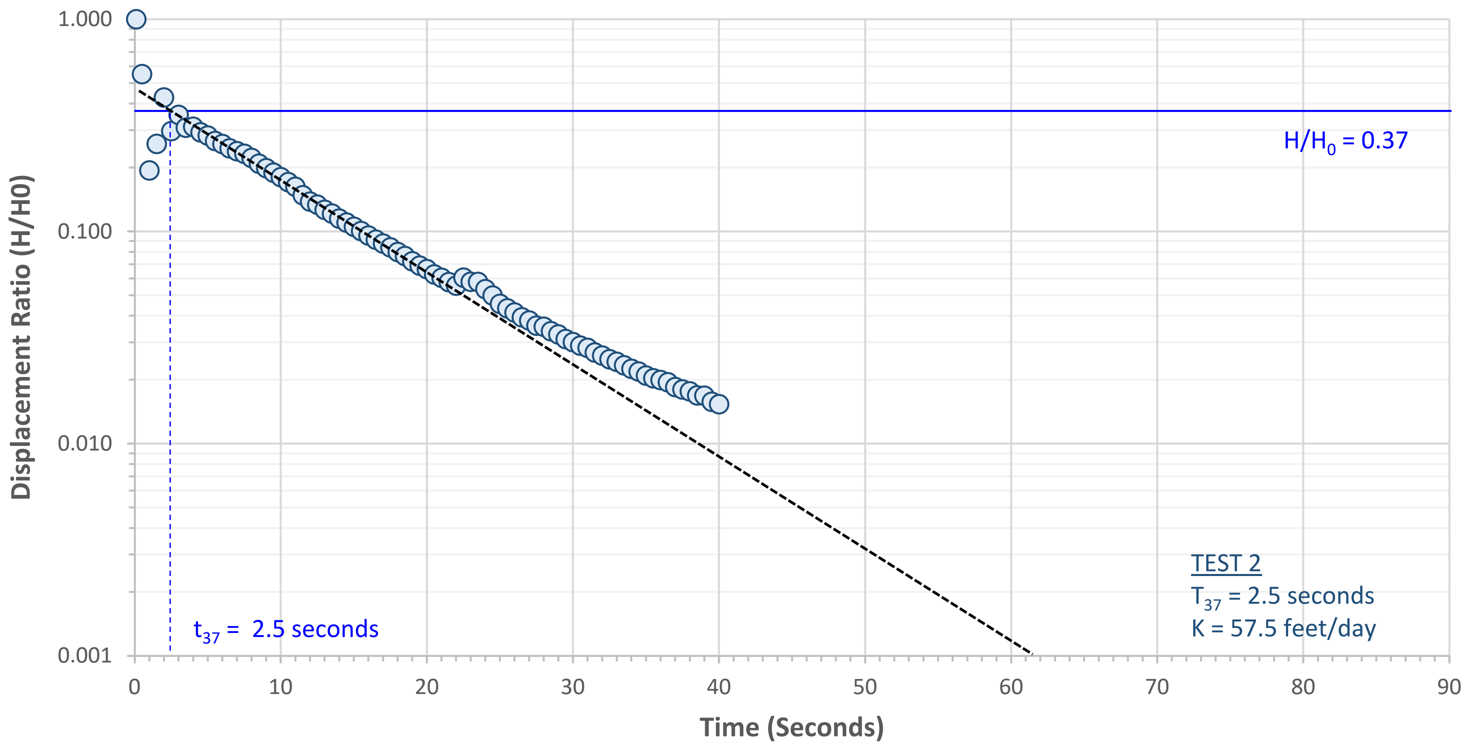
GM1-MW3 Slug Test 3

Gates/Mill City Phase II Subsurface Characterization

Slug-In Test No. 1



Slug-In Test No. 2



Slug-In Test No. 3

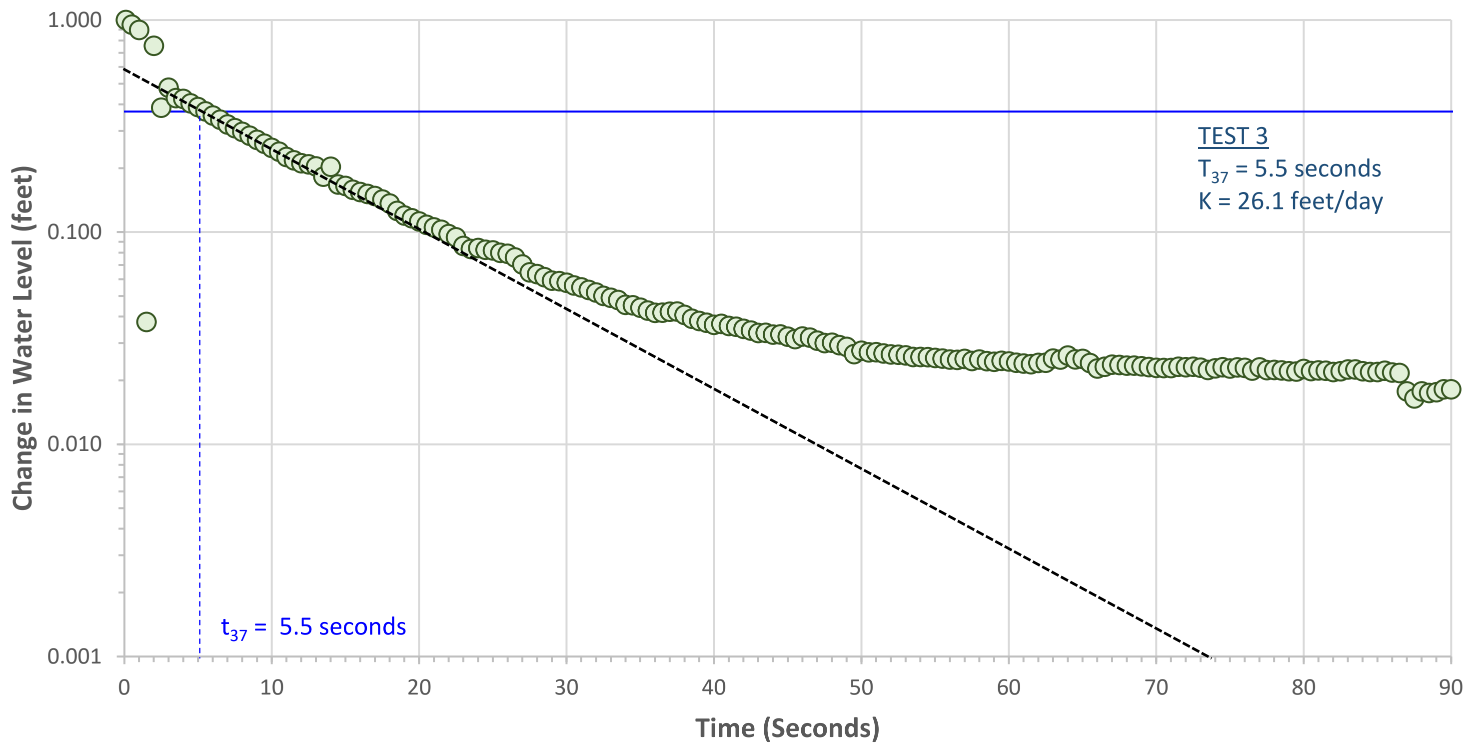


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Figure B.3(d)

GM1-MW3 Slug-In Test Analyses

Santiam Canyon Treated Wastewater Infiltration Evaluation

ATTACHMENT C

Groundwater Mounding Analysis

GeoSystems Analysis, Inc.
Innovations in Hydrology

MEMORANDUM

November 3, 2023

TO: Matt Kohlbecker, GSI Water Solutions, Inc.

FROM: Jason Keller, GeoSystems Analysis, Inc.

CC: Scott Waibel, GeoSystems Analysis, Inc.

RE: Gates – Mill City Site GM1 Groundwater Mounding Analysis

INTRODUCTION

Geosystems Analysis, Inc. (GSA) conducted a groundwater mounding analysis for the alluvial aquifer beneath Gates and Mill City, Oregon in support of the treated wastewater infiltration feasibility assessment being completed by GSI Water Solutions and Keller and Associates. Groundwater mounding beneath a potential infiltration basin location at site GM1 (Figure 1) was simulated for three measured horizontal saturated hydraulic conductivity (K_{sat-h}) scenarios.

A subsurface characterization program was completed by GSI and GSA, consisting of shallow (i.e., test pit) and deep (i.e., borehole) soil texture characterization, depth to groundwater measurements, soil saturated hydraulic conductivity (K_{sat}) measurements, and aquifer horizontal saturated hydraulic conductivity (K_{sat-h}) measurements (GSI/GSA, 2023; GSI, 2023). Information collected from the subsurface characterization program was applied in the groundwater mounding analysis presented herein.

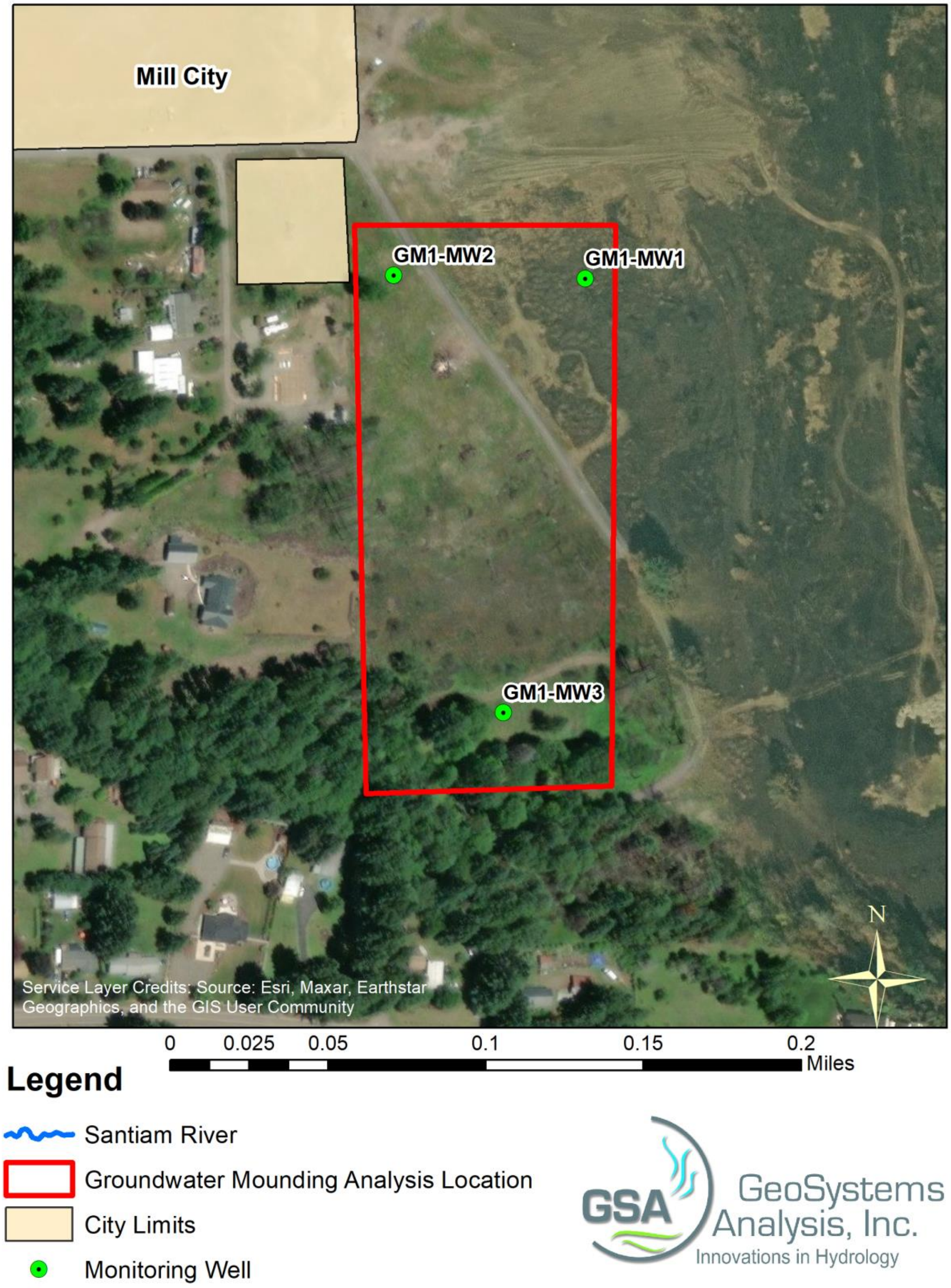


Figure 1. Potential infiltration basin location at GM-1

METHODS

The Zlotnik (2017) analytical solution for groundwater mounding as applied in MOUNDSOLV (Hydrosolve, 2023) was used to estimate the steady-state groundwater mound that may develop beneath the potential infiltration facility at site GM1 in response to recharge of treated wastewater. The Zlotnik analytical solution considers both horizontal and dipping aquifers that are assumed to be of infinite extent, homogenous, and isotropic. Required steady-state model parameters include:

- Recharge rate and duration.
- Recharge basin infiltration area and orientation.
- Aquifer horizontal saturated hydraulic conductivity (K_{sat-h})
- Aquifer initial saturated thickness
- Aquifer gradient (dip and flow direction)

The recharge rate was set equal to the projected year 2045 effluent generation rate of 0.2375 million gallons per day (MGD) (M. Kohlbecker, personal communication, April 12, 2023) and was assumed to be continuous in time. For this initial feasibility assessment, the infiltration facility was assumed to consist of one, square shaped basin with a 2.3-acre infiltration area (K. Stewart, personal communication, October 9, 2023). Preliminary basin designs consist of six independently operated, and adjacent smaller basins with a total infiltration area of 2.3 acres. The basins are proposed to operate on a two-day wastewater application rotation between basins. The proposed short rotation cycle and proximity of the basins to each other is hydraulically similar to infiltrating over one 2.3-acre basin. The 2.3-acre infiltration area is sufficient to infiltrate 0.2375 MGD assuming a long-term infiltration rate equal to 15 percent of the mean measured near surface K_{sat} for the site (GSA, 2023) to account for potential surface clogging.

Aquifer K_{sat-h} values were assigned from aquifer slug test measurements performed by GSI (GSI, 2023). A range of aquifer K_{sat-h} values were simulated to represent measurement uncertainty and spatial heterogeneity in K_{sat-h}. Initial (pre-infiltration) depth to groundwater and aquifer saturated thickness was estimated from observed depth to groundwater measured by GSI on May 29, 2023 and GSI observed depth of a thick, fine textured hydrostratigraphic unit during monitoring well installation that may act as the lower boundary of the alluvial aquifer system. The regional aquifer gradient and direction was calculated by GSI from static groundwater levels measured on August 29 and September 4, 2023 at the three on-site monitoring wells. The depth to groundwater used the earlier May 29th measurement to conservatively assess when groundwater conditions will be shallower, relative to the late summer measurements. Groundwater mounding model parameters that are the same for each scenario (static parameters) are summarized in Table 1. The K_{sat-h} value assigned for each scenario is shown in Table 2.

Table 1. Groundwater mounding model parameters applied for all scenarios

Static Model Parameter	Value
Recharge Volume	0.2375 MGD
Recharge Duration	Continuous
Infiltration Area	2.3 acres
Long Term Infiltration Rate	0.32 ft/day
Depth to Water Table[1]	14.4 ft
Aquifer Initial Saturated Thickness	44.6 ft
Aquifer Gradient	0.01
Aquifer Flow Direction	N 53° W

[1] Measured depth to groundwater was 15.5 ft, assumes constructed basin floor will be 1 foot below original ground surface

Table 2. Aquifer horizontal saturated hydraulic conductivity values

Scenario	Monitoring Well	K_{sat-h} (ft/day)
Low	MW3	37.0
Mid	Geometric Mean MW1, MW2, MW3	88.2
High	MW1	163.3

RESULTS

Site GM1 model predicted steady-state maximum mound height above the pre-infiltration water table and depth to the mound below the assumed 1-foot deep infiltration basin floor are presented in Table 3 for all three $K_{sat\text{-}h}$ scenarios. Model predicted steady-state mounding extent for the scenarios is provided in Figure 2 through Figure 4. Using the lowest $K_{sat\text{-}h}$ value of 37.0 ft/day (Low Scenario) produced a predicted steady-state maximum mound height of 13.8 ft above the pre-infiltration water table, equivalent to 0.6 ft below the basin floor. A $K_{sat\text{-}h}$ value of 88.2 ft/day (Mid Scenario) produced a predicted steady-state maximum mound height of 5.8 ft above the pre-infiltration water table, which is 8.6 ft below the basin floor. A $K_{sat\text{-}h}$ value of 163.3 ft/day (High Scenario) produced a predicted steady-state maximum mound height of 3.1 ft, which is 11.3 ft below the basin floor.

Table 3. Site GM1 model predicted steady-state maximum mound height and depth below surface

Scenario	$K_{sat\text{-}h}$ (ft/day)	Maximum Mounding Height (ft above pre-infiltration water table)	Depth to Maximum Groundwater Mound (ft bgs)
Low	37.0	13.8	0.6
Mid	88.2	5.8	8.6
High	163.3	3.1	11.3

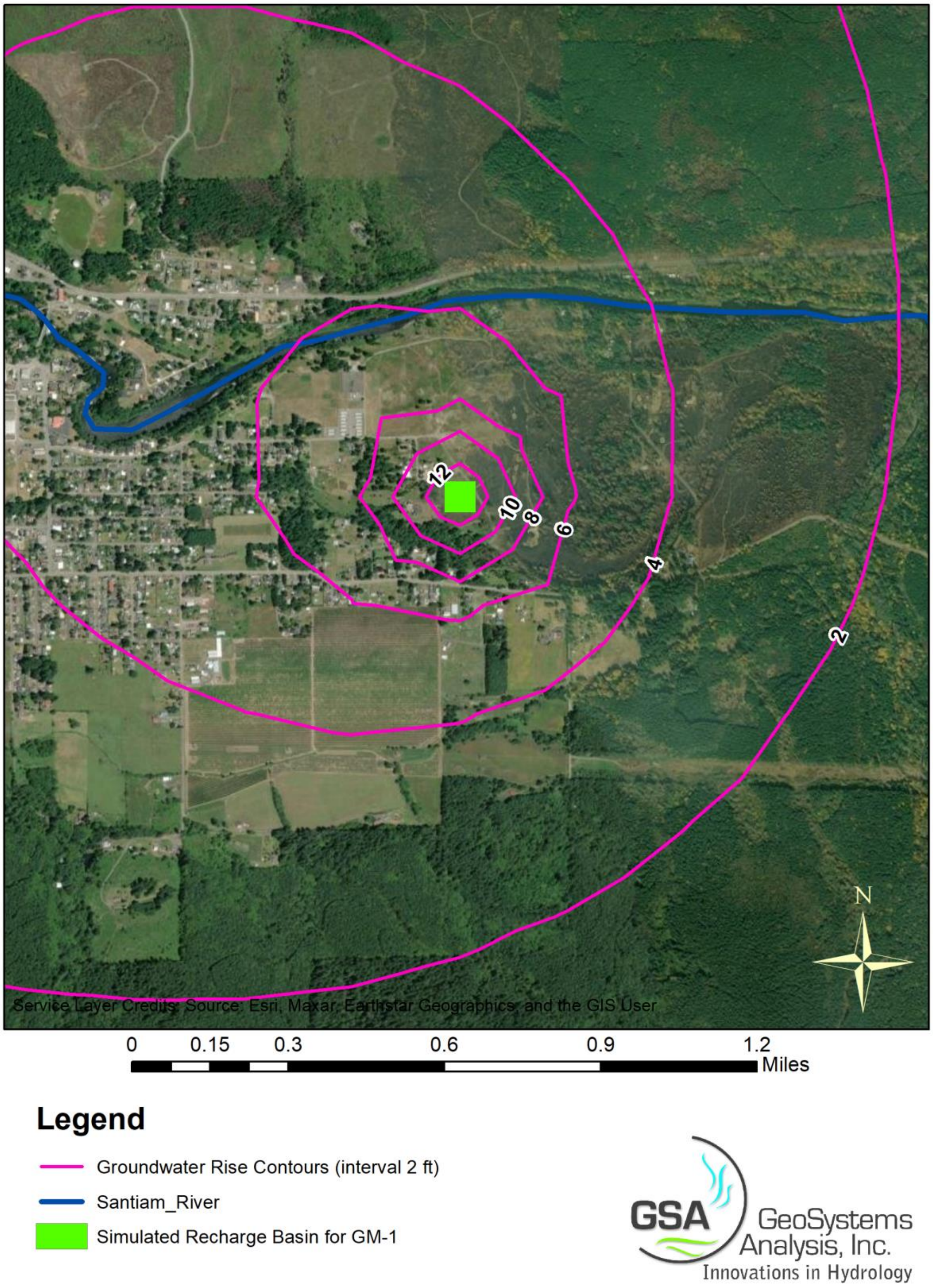
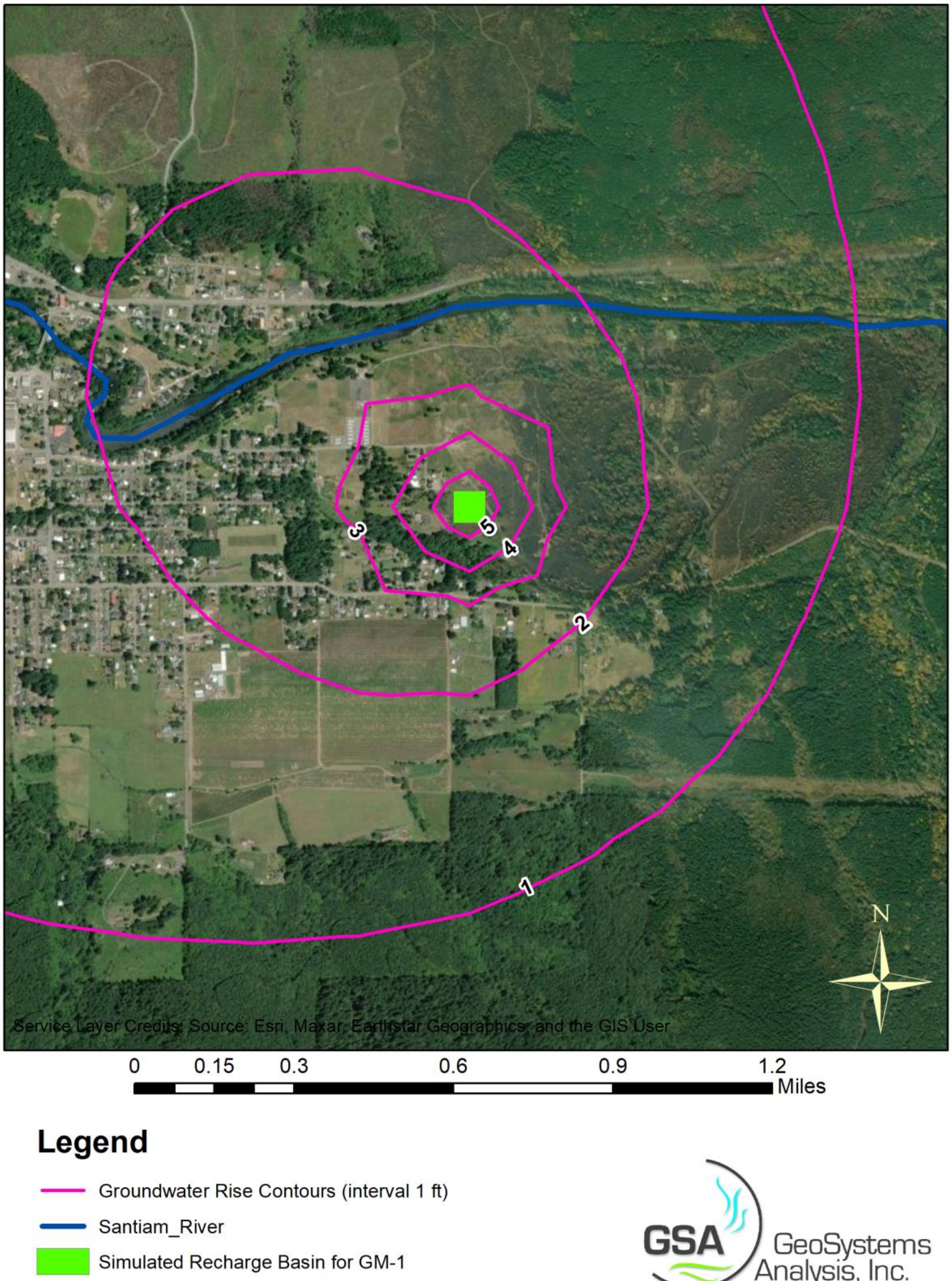
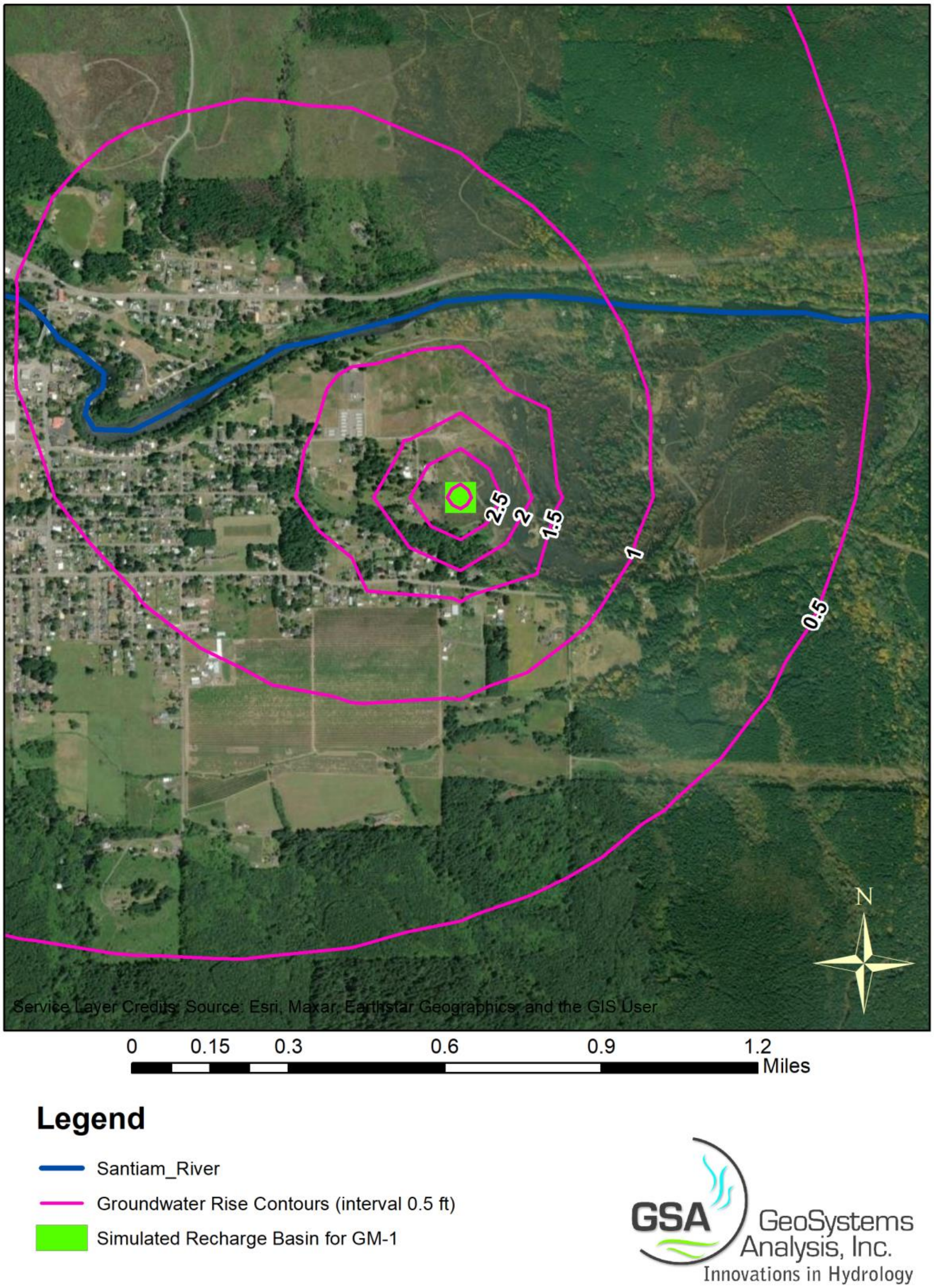


Figure 2. Predicted steady-state groundwater mounding extent for K_{sat-h} = 37.0 ft/day



Service Layer Credits: Source: Esri, Maxar, Earthstar Geographics, and the GIS User

Figure 3. Predicted steady-state groundwater mounding extent for K_{sat-h} = 88.2 ft/day



Service Layer Credits: Source: Esri, Maxar, Earthstar Geographics, and the GIS User

Figure 4. Predicted steady-state groundwater mounding extent for $K_{sat\text{-}h}$ = 163.3 ft/day

CONCLUSIONS

A steady-state mounding analysis was performed for site GM1 applying low, mid, and high K_{sat-h} values representing the range of measured K_{sat-h}. The mounding analysis assumed a 2.3-acre recharge basin infiltration area and a recharge volume of 0.2375 MGD. Model predicted steady-state groundwater mounding was 3.1 ft to 13.8 ft above the pre-infiltration water table, with mounding height increasing with decreased K_{sat-h}. Assuming a 14.4 ft depth from the basin floor to the pre-infiltration water table, the predicted depth to the groundwater mounding was 11.3 ft to 0.6 ft bgs. Due to the predicted potential for shallow mounding beneath the basin, which may reduce basin infiltration rates, GSA recommends additional aquifer characterization be performed to resolve uncertainty in aquifer Ksat-h or a long-term infiltration pilot test be completed to assess aquifer mounding response.

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GSI, see GSI Water Solutions, Inc.

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Zlotnik, V.A., Kacimov, A. and A. Al-Maktoumi, 2017. Estimating groundwater mounding in sloping aquifers for managed aquifer recharge, Groundwater, vol. 55, no. 6, pp. 797-810.