APPENDIX D

Aquifer Hydraulic Testing Methods and Results

D. Aquifer Hydraulic Testing Methods and Results

This appendix describes the methods and results conducted to document hydraulic characteristics of the shallow water-bearing unit at the Harris Avenue Shipyard site (Site). The hydraulic data were collected to assist the Port of Bellingham's selected cleanup construction contractor with design of their dewatering approach for soil excavation within the Site's Cleanup Area 2 (CA 2). The testing included both continuous water level monitoring in two shallow monitoring wells adjacent to the CA 2 excavation area (MW-2A and MW-12)[1] as well as hydraulic conductivity (K) testing (slug testing) of the two wells. Each data collection activity is described below.

D.1. Continuous Water Level Monitoring

Continuous water level monitoring was performed in monitoring wells MW-2A and MW-12 to document groundwater elevations and the magnitude of tidal influence on them. The monitoring wells were equipped with a downhole pressure transducer/data logger to allow automated collection of water level data on a 6-minute interval throughout the 5-day monitoring period of April 28 through May 3, 2022. The 6-minute interval matches that used by the National Oceanic and Atmospheric Administration (NOAA) for tidal stage readings. The closest NOAA tide station to the Site is at Cherry Point, approximately 14 miles northwest of the Site. The tidal stage data from that station were obtained for inclusion and evaluation with the groundwater level data. A barometric pressure data logger was also installed on Site to allow the groundwater level data to be corrected for changes in atmospheric pressure throughout the study.

Figure D.1 depicts the continuous water level data from the two wells and from the Cherry Point tidal station; the groundwater and tide level data are plotted on separate y axes, with different scales, for presentation purposes.

The groundwater levels at both wells show a definitive tidal influence with very little time lag from changes in tidal stage. The groundwater levels at well MW-12S, located west of CA 2, show a somewhat greater magnitude of tidal response (up to 3 feet) than does MW-2A located east of CA 2 (up to 2 feet). That is even though well MW-12S is located slightly farther inland from the shoreline (as defined by the mean higher high water [MHHW] elevation contour) than is well MW-2A—approximately 32 feet versus 20 feet inland, respectively. The difference in tidal response (tidal efficiency) is likely attributable to more permeable aquifer conditions in the MW-12A area (as is indicated by slug testing data described in Section D.2) and/or a more hydraulically open shoreline structure (e.g., rip rap versus solid bulkhead) in the MW-12A area.

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[1] Each well is located between the planned CA 2 excavation and the Site's Bellingham Bay shoreline (refer to figures in main body of this report).

D.2. Hydraulic Conductivity (Slug) Testing

Aspect performed slug testing in wells MW-2A and MW-12 to estimate the hydraulic conductivity (K) of the shallow water-bearing zone near the planned CA 2 excavation. A slug test produces a change in water level within a well and measures the rate of return to the static water level (SWL). This rate of water level change in the well is used to compute the K of the water-bearing zone.

D.2.1.1. Slug Test Methods

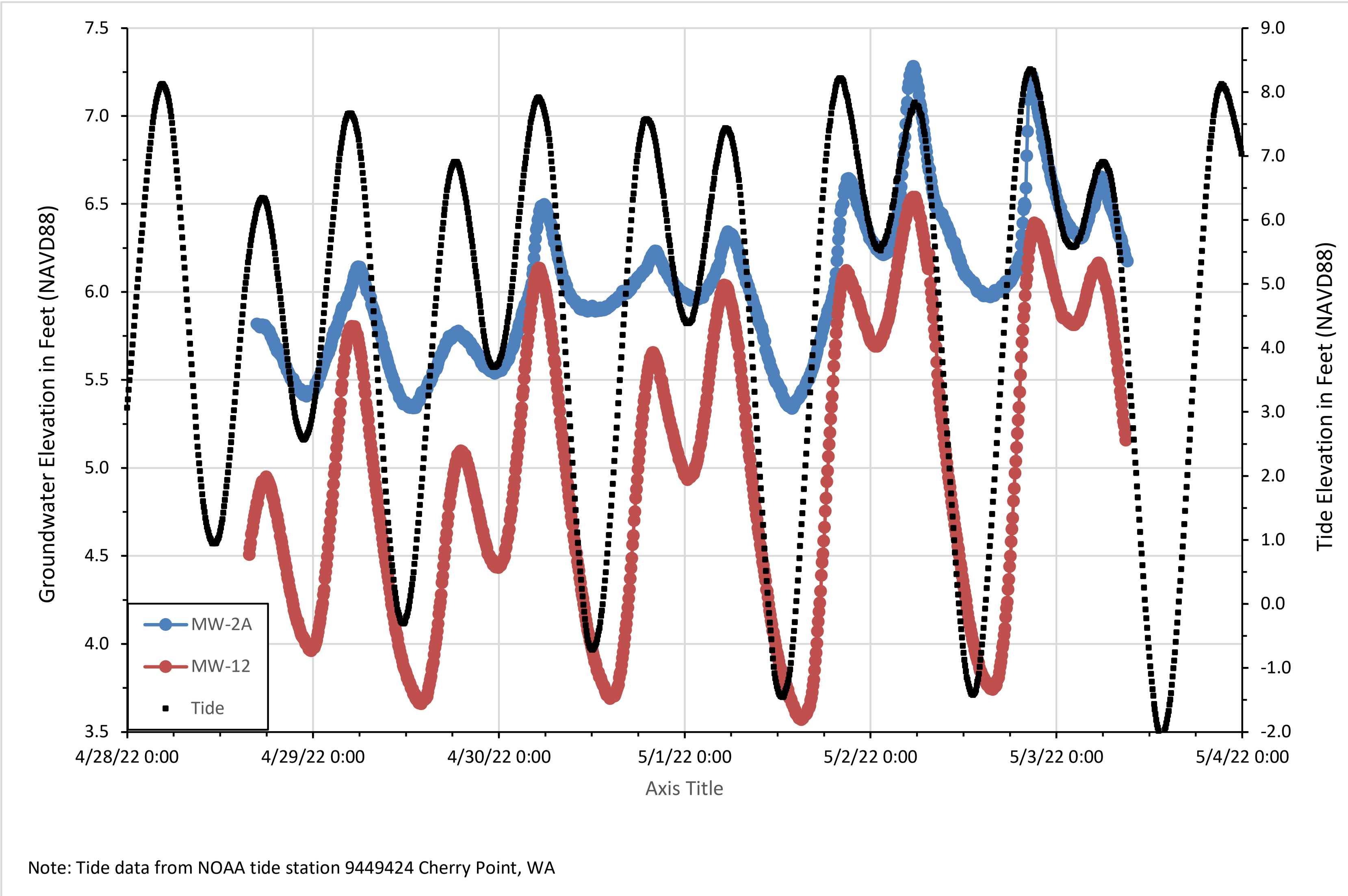
A slug rod (a solid cylinder of known volume suspended with a fiberglass cable) was used to displace water in each well. Prior to the rising-head slug test, the slug rod was inserted into the water column and the water level was allowed to return to SWL. Then the test was performed by rapidly removing the slug rod from the water, causing the water level to rapidly fall before rising back to the SWL over time. To verify the precision of the results, the test was performed three times at each well. To evaluate the results for dependency on hydraulic head, the rising head tests were performed with two slug rods of at least two different lengths in each well. Falling head tests (when the slug is rapidly submerged in the water column) are not valid in wells where the water level intersects the screen interval and therefore were not used in the analysis.

The water levels in the wells during testing were measured using a vented pressure transducer and collected electronically on a data logger set to a nearly continuous time interval (1 second or less). Water levels were measured manually with an electronic tape before and after testing was completed to confirm transducer readings and determine tidal-induced change during the test duration.

D.2.1.2. Slug Test Results

After reviewing the slug test data, we estimated K using the Bouwer & Rice method for unconfined aquifer conditions as updated (Bouwer, 1989[2]). Table D.1 summarizes the well parameters and resulting K estimates for the replicate tests, and the geometric mean of the replicates, for each well. The resulting K estimates from replicate testing were consistent at each well, and the geometric mean value for the two wells were 1 and 12 feet per day (4×10^{-4} to 4×10^{-3} centimeters per second) in wells MW-2A and MW-12, respectively. The geometric mean estimate for the shallow water-bearing zone across the CA 2 area (combining data from both wells) is 3 feet per day (1×10^{-3} centimeters per second). These estimates are consistent with the silty sands described within the monitoring well screen intervals.

[2] Bouwer, H., 1989, The Bouwer and Rice Slug Test – an Update, Ground Water, Vol. 27, No. 3, May-June 1989.



Note: Tide data from NOAA tide station 9449424 Cherry Point, WA

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V:\210195 Harris Ave Shipyard Remedial Design\Deliverables\2023.02 EDR\Draft\App D_Aquifer Testing Data\Fig D.1 WL Data plot

Figure D.1.
Groundwater Level (MW-2A, MW-12) and Tide Elevation Data, 4/28-5/3/2022

Table D.1. Aquifer Hydraulic Conductivity Estimates from Slug Tests

210195 Harris Ave Shipyard Site, Port of Bellingham

Monitoring Well	MW-02A			MW-12		
Well Depth in Feet	11.9			15.0		
Screen Length in Feet	10.0			10.0		
Depth to Screen in Feet	4.0			5.0		
Depth to Aquitard in Feet	14			25		
Depth to Water in Feet bTOC	9.10			10.03		
Depth to Sandpack in Feet	3.0			3.0		
Slug Displacement (Ho) in Feet	0.81	0.95	0.44	0.54	1.06	1.07
Porosity (n)	0.30			0.30		
Radius of Casing (rc) in Feet	0.08			0.08		
Radius of Borehole (rw) in Feet	0.35			0.35		
Saturated Aquifer Thickness (H) in Feet	**4.9**			**15.0**		
Saturated Well Thickness (Lw) in Feet	**4.9**			**5.0**		
Effective Radius (reff) in Feet	**0.206**			**0.206**		
Effective Screen Length (Le) in Feet	**4.9**			**5.0**		
Slug Size	*2.5' x1.7"*	*2.5' x1.7"*	*1.5' x1.7"*	*1.5' x1.7"*	*2.5' x1.7"*	*2.5' x1.7"*
Rising/Falling Head Test	*Rising*	*Rising*	*Rising*	*Rising*	*Rising*	*Rising*
Fully Submerged Sandpack	*No*	*No*	*No*	*No*	*No*	*No*
Transiently Exposed Sandpack	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Transiently Exposed Screen	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Partially Submerged Screen	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Bouwer and Rice Analysis Parameters						
Normalized Head at t1 (y1) in Feet	**0.21**	**0.18**	**0.26**	**0.30**	**0.35**	**0.32**
Time - t1 in Seconds	**66**	**58**	**54**	**27**	**30**	**31**
Normalized Head at t2 (y2) in Feet	**0.19**	**0.17**	**0.23**	**0.18**	**0.22**	**0.20**
Time - t2 in Seconds	**147**	**184**	**146**	**50**	**55**	**56**
Calculated K in cm/sec	**3E-04**	**2E-04**	**3E-04**	**5E-03**	**4E-03**	**4E-03**
Calculated K in ft/day	**0.8**	**0.6**	**0.7**	**13**	**11**	**11**
Geometric Mean K in ft/day	**1**			**12**		
Site Geometric Mean K in ft/day	**3**					
Screened Interval Soil Type	SP + ML			SW + ML		

Notes:

Data analysis by method of Bouwer and Rice (1976; 1989).

For each well, analyses are run for three individual tests and geometrically averaged.

Bold values are entered from field data and other values are calculated.

All depths are below ground surface