Appendix 3F
Groundwater Flow Model

Table of Contents

TABLES

FIGURES

ATTACHMENTS

1.0 SUMMARY

A groundwater flow model was developed to simulate groundwater flow in the Area of Investigation (AOI) using MODFLOW, a finite-difference, three-dimensional (3D), numerical groundwater flow model developed by the United States Geological Survey (USGS). MODFLOW is widely accepted and commonly used for modeling groundwater flow.

Local information including weather data, AOI geologic and hydrogeologic data, and April 2013 groundwater and surface water elevations were input into the model. The model was calibrated to these conditions and then verified using October 2013 groundwater and surface water elevations. Statistical evaluations of MODFLOW output indicate good statistical agreement between modeled and observed groundwater conditions in the AOI.

The groundwater flow model demonstrates that groundwater in the AOI is dominated by recharge from precipitation at the park and that very little groundwater flows into the AOI from upgradient areas. It also shows that most groundwater from the AOI upland discharges to Lake Union near the shoreline, and that groundwater discharge to the lake decreases substantially with distance from the shoreline.

The groundwater model output was used to develop a water balance for the AOI, estimate groundwater flux at the sediment mudline, and estimate groundwater velocity at the Lake Union shoreline. Water balance, flux, and groundwater velocity parameters will be used to develop and evaluate cleanup alternatives during the feasibility study.

2.0 INTRODUCTION

A numerical groundwater flow model was developed for the AOI (Figure 3F-1) using MODFLOW to:

- Simulate groundwater flow,
- Evaluate the water balance,
- Estimate groundwater flux at the sediment mudline, and
- Estimate shoreline groundwater velocity.

2.1. Physical Setting

The AOI upland occupies the former Brown's Point, a prominent natural point on the north shore of Lake Union (Figure 3F-1) in Seattle, Washington. The primary geologic units in the AOI include fill, recent lacustrine, Vashon recessional and advance outwash, and Pre-Fraser glacial till.

- Fill material (Af) was deposited during development of the area. Upland and shoreline areas were filled to level the ground and increase land area. Fill is the surface layer on most of the AOI upland and varies in thickness with an average thickness of about 10 feet. Fill is thicker at Kite Hill and near the shoreline. In most of the uplands, fill lies directly on top of the till.
- Recent lacustrine (Ql) deposits are the lake sediments in the in-water portion of the AOI and contain a high proportion of fine grained and organic matter. In some areas of Lake Union, silty and clayey recessional glaciolacustrine deposits (Qvrl) are locally present above outwash. These deposits date from late in the Vashon glaciation and early Holocene when there was still abundant glacial sediment

entering the lake. Glaciolacustrine deposits generally are composed of fine-grained mineral sediment, in contrast with the subsequently deposited recent lacustrine deposits that contain a high proportion of organic matter.

- Vashon recessional and advance outwash (Qvr and Qva) are present above the glacial till beneath part of the upland and in-water portions of the AOI. Outwash is overlain by recent lacustrine deposits in Lake Union, and by fill on the uplands and in-water areas on the lake shore and lake slope areas of the AOI.
- Pre-Fraser glacial till (Qpgt) is a thick, laterally extensive unit that underlies the younger geologic units AOI. It is present throughout the AOI and is exposed at the ground surface near the center of the AOI upland.

Average annual precipitation in Seattle, measured between 1948 and 2018, is 37.5 inches (National Climatic Data Center). The results of detailed hydrogeologic investigations indicate that most groundwater at the Gas Works Park Site (GWPS) originates from precipitation that infiltrates the ground at Gas Works Park (upland) and discharges into Lake Union through fill and glacial outwash units in a radial pattern roughly perpendicular to the Gas Works Park shoreline. AOI geology and hydrogeology is presented in more detail in Section 3.0 of the Remedial Investigation (RI) Report.

2.2. Background

Previous investigations and studies included the following groundwater flow models:

- Simulation of the effect of pumping rates on proposed extraction well systems using the WELFLO model (HDR 1989),
- Two-dimensional flow and contaminant transport modeling (SSPA 2006) (Attachment 3F-1),
- Three-dimensional groundwater flow model using MODFLOW (Aspect 2007), and
- Three-dimensional flow model using MODFLOW (Aspect et al 2012).

2.3. 2016-2018 Groundwater Flow Model

A finite-difference, 3D groundwater flow model was developed using MODFLOW to simulate groundwater flow in the AOI in 2016 and revised in 2018. The framework for the model was based on previous groundwater modeling and the current geologic and hydrogeologic interpretation of the AOI (GWSA Technical Team 2011a, b, c; Aspect et al. 2012). The 2012 model geology (e.g., known extents of each geologic unit) was updated to include information from soil borings and shoreline monitoring well borings completed during the 2013-2014 supplemental investigation (RI Appendix 2A). Hydrogeologic parameters for each geologic unit also were updated following field tests performed in 2013. The groundwater model was calibrated to groundwater levels measured in April 2013 to simulate a wet-weather condition and verified using groundwater levels measured in October 2013. The sections below describe in more detail the model construction, calibration and validation procedures, and results.

3.0 MODEL CONSTRUCTION

3.1. Model Grid

The MODFLOW groundwater model domain included the AOI and additional area outside the AOI to limit the effect of model boundary conditions on modeled groundwater flow in the AOI (Figure 3F-1). The model boundary extends from North 34th Street into Lake Union roughly paralleling the AOI boundary. The model grid consists of 26 layers, including model Layer 1, placed above the topographic surface (upland) and bathymetric surface (submerged), to represent the boundary condition of Lake Union (Table 3F-1). Subsequent layers represent the geology in the model and vary in thickness from 4 inches to 10 feet, with thinner layers shallower in the model, and thicker layers at depth. Each model layer is discretized into square cells measuring 20 feet by 20 feet horizontally, with the model grid x-axis oriented east-west and the y-axis oriented north-south.

3.2. Model Geology

The geologic interpretation presented in the RI Report and summarized above in Section 2.1 was used to develop the model geology. More than 400 borings were completed in both upland soil and offshore sediment, and geologic unit contact elevations from each boring were interpolated using the natural neighbor method included in GMS 10.0 (Aquaveo 2015) to create the surface of each geologic unit. The geologic units represented in the groundwater model include fill (Af), recent lacustrine (Ql), Vashon recessional and advance outwash (Qvr and Qva), and Pre-Fraser glacial till (Qpgt). Vashon recessional and advance outwash units were combined into a single hydrostratigraphic unit in the model. The ground surface of the model was constructed using topographic and bathymetric data. Cross-sections produced from the model geology were compared to cross-sections produced during the RI to ensure continuity. Geologic cross sections of the model are shown on Figures 3F-2 through 3F-5.

3.3. Hydrogeologic Parameters

Hydraulic flow parameters are illustrated on Figure 3F-6. Lake Union and groundwater heads measured on April 22 and October 14, 2013, in a subset of wells shown on Figure 3F-7, were selected for modeling. The wells were selected to include a spatially balanced mix of wells. Wells farther upland were emphasized in the calibration well set because they are less controlled by the Lake Union boundary condition than wells near shore. Well construction details, including the geologic unit screened by each well used for modeling, are presented in Table 3F-2; additional well construction details are provided in Table 3J-1 of Appendix J.

Horizontal hydraulic conductivities of the geologic units were estimated from slug tests and/or pump tests on wells screened in each geologic unit (see Figure 3F-8). A horizontal/vertical anisotropy ratio for each geologic unit was applied to estimate vertical hydraulic conductivity for the units. Hydraulic conductivity of the recent sediment unit was developed during previous modeling work by S.S. Papadopulos & Associates, Inc. (SSPA) using void ratio to extrapolate a hydraulic conductivity value. This value was verified using the Kozeny-Carman equation, which relates soil grain size distribution and porosity to hydraulic conductivity (Hussain and Nabi 2016). Hydraulic conductivities used in the model are presented on Table 3F-1.

3.4. Harbor Patrol Bulkhead

A shoreline bulkhead constructed of driven sheet piles was installed on the Seattle Harbor Patrol property in June 2017. The bulkhead configuration was updated in the model in 2018 (post calibration) to better represent the sheet pile wall as installed.

4.0 BOUNDARY CONDITIONS

At the model domain boundary, boundary conditions are assigned to represent regional groundwater flow conditions including areas where water is expected to flow into or out of the model domain, and areas where no flow is expected. Boundary conditions applied to the model were selected based on the best available information regarding regional groundwater flow.

4.1. Northern Boundary

The northern boundary of the model was defined as a constant head boundary to represent the groundwater heads (elevations) in wells along North 34th Street, north of the AOI (Terra Associates 2002; Sound Earth Strategies 2014) (Figure 3F-9). Groundwater heads from these wells indicate groundwater levels are a muted reflection of the topography. The northern boundary condition water levels were adjusted during model calibration as noted in Section 6.0.

4.2. Northeastern and Western Boundaries

The northeastern and western boundaries of the model domain were defined as no-flow boundaries because they are parallel to the interpreted groundwater flow direction from upland areas toward Lake Union.

4.3. South and East Boundaries

The south and east boundaries of the model were defined as no-flow boundaries because they are beyond the AOI and far enough offshore to not be influenced by groundwater flowing from Gas Works Park or other upland lakeshore areas.

4.4. Lake Boundary

Lake Union water elevations are controlled at the Lake Washington Ship Canal and vary throughout the year from approximately 19.5 to 22 feet (United States Army Corps of Engineers [USACE] Locks datum). The lake elevation during April 2013 was approximately 22 feet USACE; therefore, a constant head of 22 feet was applied to the lake boundary condition (model Layer 1) during model calibration. The lake elevation of 20.8 feet USACE in October 2013 was applied to the lake boundary condition during model validation.

4.5. Recharge Surface Boundary

Recharge was applied to permeable grass-covered and landscaped areas within the AOI upland (Figure 3F-10). Paved or covered surfaces were assumed to have negligible recharge. Areas of ponding and high stormwater runoff within the model domain were identified by field observation during rain events. These observations were used to identify areas with lower infiltration rates than surrounding areas.

Recharge was estimated by calculating an AOI-wide water balance, where recharge was equal to precipitation minus losses due to evapotranspiration and runoff. Values for precipitation were estimated using weather data (NOAA 2018) as described in subsection 4.5.1. Values for evapotranspiration and runoff were estimated using the Western Washington Hydrologic Model 2012 (WWHM) and site-specific soil and average slope condition as described in subsections 4.5.2 through 4.5.4. The areas where recharge was applied, and recharge values used in the MODFLOW model are shown in Figure 3F-10. The majority of the AOI upland had a recharge rate of 15 inches per year, but areas where ponding water was observed and landscaped areas in parking lots were assigned lower recharge rates.

4.5.1. Precipitation Values

Average annual precipitation measured between 1948 and 2018 for Seattle is 37.5 inches (National Climatic Data Center), with approximately 2.5 inches falling in April (an equivalent April precipitation rate of 30 inches per year, or approximately 0.007 feet per day). In April 2013, 3.54 inches (approximately

0.010 feet per day) of rain fell (National Oceanic and Atmospheric Administration at Discovery Park [NOAA 2018]) indicating that April 2013 was unusually wet compared to average conditions. October 2013 precipitation estimates used for the October 2013 verification run were also higher than typical because record rainfall of 4.87 inches (approximately 0.014 feet per day) was recorded in September 2013 (NOAA 2018). To account for actual (higher-than-typical) precipitation which contributed to recharge and corresponding groundwater elevation changes, precipitation measurements for the 30 days prior to synoptic water level measurement dates (April 22, 2013 and October 14, 2013) were used as model inputs: 0.013 feet per day (April) and 0.012 feet per day (October).

4.5.2. Evapotranspiration Rates

Evapotranspiration rates were estimated using modeled values from WWHM and historical measured evaporation rates. April evapotranspiration rates predicted from the WWHM model ranged from 18.7 to 19.2 inches per year, and annual evapotranspiration rates ranged from 14.7 to 15.2 inches per year.

The average corrected pan evaporation rate for April was 27 inches per year, and the annual rate was 24 inches per year at the Western Regional Climate Center's (WRCC's) Seattle Maple Leaf station from 1941 to 1960. Because pan evaporation measures evaporation from a surface of pooled water, correction factors are used to convert pan evaporation measurements to corresponding evapotranspiration in a lawn setting. Literature suggests a correction factor of 0.7 should be used for the Puget Sound region (Richardson et al. 1968).

4.5.3. Soil Moisture Deficit

Soil moisture deficit is defined as the available water storage in the soil layer. Because the steady-state calibration was performed using data from April during wet-weather conditions, the soil moisture deficit was assumed to be zero.

4.5.4. Runoff Losses

Runoff losses occur one of two ways: precipitation that falls on sloped areas can directly runoff into Lake Union, or flow to the park stormwater system including catch basins and perforated below-grade collection piping. Runoff losses were estimated to be approximately 25 percent of precipitation (WWHM 2012).

5.0 SOLUTION TECHNIQUE

The MODFLOW groundwater flow package used to solve the groundwater flow equation was the Newton (NWT) solver package using the Upstream Weighting (UPW) groundwater flow package. The NWT solver with the UPW groundwater flow package handle cell drying and rewetting situations better than previous solvers and is often more stable during model convergence and calibration.

6.0 MODEL CALIBRATION AND VALIDATION

6.1. Model Calibration

The groundwater flow model was calibrated to fit observed groundwater elevations by varying hydraulic conductivity (horizontal and vertical), recharge, and northern boundary constant head values within ranges of expected values. These parameters were varied during calibration using a combination of manual changes and the Parameter Estimation code (PEST), which uses a predictive analysis algorithm to find the set of variables that best fits observed values. Horizontal hydraulic conductivities and vertical anisotropy for each layer were allowed to fluctuate within a range of expected values to find the value that best fit hydraulic conductivities estimated from field tests. Similarly, recharge and the northern boundary constant head values were constrained during calibration to a moderate range of values estimated based on modeling (WWHM for recharge, as discussed in Section 4.5) or field measurements.

The modeled value for groundwater elevation was taken from the model layer that coincided with the saturated screen midpoint of each well. The geology present in the model at the saturated screen midpoint location was compared to the boring log geology to verify that the model represented the correct geologic units at each location.

The steady-state flow model was calibrated to a lake level of 22 feet and groundwater levels measured on April 22, 2013, from a subset of wells (i.e., calibration wells) shown on Figure 3F-7. The water levels and the final calibration values for hydraulic parameters in the model are presented in Tables 3F-1 and 3F-2. Modeled groundwater levels were compared to measurements from monitoring wells. Modeled versus observed heads for April 2013 conditions were contoured and are presented on Figure 3F-11, and also compared with a 1:1 line to show the model's goodness-of-fit (Figure 3F-13).

One way of evaluating the performance of MODFLOW as a simulation of real-world conditions is to examine its mass balance error. The mass balance error is defined as the difference between total predicted inflow and total predicted outflow generated by the model divided by either total inflow or total outflow and expressed as a percentage. Ideally, the mass balance error should be much less than 1 percent. The model calibration has a mass balance error of 0.0013 percent, which meets this criterion. The overall groundwater flow conditions are summarized on Figure 3F-14.

The evaluation of the "goodness-of-fit" for the final calibration consisted of a combination of qualitative and quantitative measures and targets, including the following:

- *Qualitative measures* – Modeled groundwater gradients and contours (both horizontal and vertical) should adequately simulate known values. Head contours and flow patterns must be reasonably similar to those based on measurements (Barnett et al. 2012); comparison of measured and modeled groundwater table contours for April 2013 (Figure 3F-11) show that this is the case. Model parameters (e.g., hydraulic conductivities, recharge) that serve as the basis for head or flow predictions should fall within measured or expected ranges; Table 3F-1 shows that model calibrated hydraulic conductivity values fall within the range of field-measured hydraulic conductivity values for each hydrostratigraphic unit.
- *Quantitative head measures* – Various statistical parameters, as shown in Table 3F-2, were used to evaluate model calibration.
  - The regression coefficient (R^2) measures the variation in modeled output that can be described by the model (Walpole and Meyers 1978). The R^2 for the calibration well data set is 0.88, meaning 88 percent of the variation in groundwater elevation data was captured by the model.
  - The root mean squared errors (RMSEs) can also be evaluated, providing a comparison of modeled versus observed values. The final calibration RMSE was 0.79 feet, or, as a percent of head variation in calibration wells, approximately 7.9 percent.
  - The mean residual head was 0.34 feet, and the absolute residual head was 0.72 feet.

Model calibration results indicate the model is adequately capturing the groundwater flow across the GWPS.

6.2. Model Validation

The model was validated by simulating October 2013 groundwater conditions and comparing the results to measured values collected on October 14, 2013. October was selected as the validation month because groundwater levels were measured in October 2013, and October is typically drier and groundwater levels are lower than in April. The only values that were varied between the April calibration and October validation model runs were:

- *Lake level boundary condition* – The lake level for October 2013 was measured to be 20.8 feet USACE.
- *Northern head boundary condition* – The northern constant head boundary was lowered by 1.5 feet from April conditions (as determined by measured groundwater levels).

October 2013 recharge was assumed to be equal to April 2013 recharge due to unusually high rainfall in September. The amount of precipitation that fell in the 30 days before the April 22, 2013, measurement event was approximately equal to the amount of precipitation that fell in the 30 days before the October 14, 2013, measurement event (0.013 feet per day versus 0.012 feet per day).

The performance of the October model was evaluated in the same manner as the April-calibration model – it adequately simulated groundwater conditions on October 14, 2013, based on a comparison of modeled versus measured groundwater elevations (Table 3F-2) and groundwater table contours (Figure 3F-12).

Quantitative measures indicate favorable performance of the October model:

- *Mass Balance Difference* – 0.0004 percent (substantially less than 1).
- Regression coefficient – R^2 value was 0.95 (close to 1).
- RMSE – The root mean squared error was 0.70 feet.
- *Residual Head* – The mean absolute residual head was 0.52 feet.

The October validation run adequately described simulated groundwater conditions on October 14, 2013, based on the model results and residual analysis. Validation results are tabulated in Table 3F-2. Overall groundwater flow conditions for October are summarized on Figure 3F-17.

Good agreement between measured and modeled conditions for the October model validates results from the April model.

7.0 MODEL RESULTS

The groundwater model output was used to develop a water balance within the AOI, estimate groundwater flux at the sediment mudline, and estimate groundwater velocity at the Lake Union shoreline.

The model demonstrates that groundwater flow at Gas Works Park is dominated by recharge from precipitation. Groundwater is recharged from precipitation on to large, vegetated areas of Gas Works Park that are more pervious than surrounding areas. Upgradient of the park, buildings and paved areas predominate the landscape and limit recharge into surrounding upland areas. Upgradient areas also are underlain by shallow glacial till that further limits groundwater throughflow. Groundwater flow conditions for April 2013 show that more than 98 percent of estimated groundwater discharge to the lake originated from recharge at the park (Figure 3F-14).

As illustrated on Figures 3F-14 through 3F-17, groundwater flow is predominantly within the fill and outwash units, and more than 92 percent of groundwater discharges within approximately 100 feet of the shoreline. This near-shore discharge area, defined as the “groundwater discharge zone,” encompasses the area where groundwater flowing through the fill and the outwash at the shoreline discharges. The volume of groundwater discharging to the lake decreases substantially with distance from the shoreline.

The calibrated model was used to estimate groundwater flux at the shoreline and to the lake mudline for baseline flow conditions, as shown on Figures 3F-16 and 3F-17.

8.0 REFERENCES

Aquaveo. 2015. GMS 10.0 Groundwater Modeling Interface. Aquaveo, Provo, Utah.

Aspect Consulting, LLC, GeoEngineers. Inc., Anchor QEA, LLC, and Floyd|Snider. 2012. Groundwater Flow Model Memorandum, Draft Groundwater Flow Model Construction and Calibration, Gas Works Sediment Area, Seattle, Washington. Memorandum to John Keeling, Ching-Pi Wang and Maura O’Brien, Washington Department of Ecology. March 2.

Barnett, B., L.R. Townley, V. Post, R.E. Evans, R.J. Hunt, L. Peeters, S. Richardson, A.D. Werner, A. Knapton, and A. Boronkay. 2012. Australian groundwater modelling guidelines. Waterlines Report Series No. 82. National Water Commission, Canberra. June 2012.

Washington Department of Ecology. 2015. Cleanup Levels and Risk Calculation website. MTCA default values. Available at https://fortress.wa.gov/ecy/clarc/CLARCHome.aspx.

Environmental Protection Agency (EPA). 2015. Superfund Soil Screening Guidance Technical Background Document, Part 5 (Chemical-Specific Parameters). U.S. Environmental Protection Agency, available at http://www.epa.gov/superfund/superfund-soil-screening-guidance; https://semspub.epa.gov/work/11/175235.pdf. Accessed 2015.

Gelhar, L.W., C. Welty, and K.R. Rehfeldt. 1992. A Critical Review of Data on Field-Scale Dispersion in Aquifers. Water Resources Research 28(7):1955-1974.

GWSA Technical Team. 2011a. Regional Geologic Setting Memorandum.

GWSA Technical Team. 2011b. Revised Geologic Conceptual Site Model Package, Gas Works Sediment Area.

GWSA Technical Team. 2011c. Revised Hydrogeologic Conceptual Site Model.

GWSA Technical Team. 2012. Draft Groundwater Flow Model Memorandum.

Hong, L. and R. Luthy. 2006. Final Report – February 3, 2006. PAH Partitioning in Black Carbon-impacted Sediments from Lake Union. Stanford University, Department of Civil and Environmental Engineering, Stanford, California.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meyland, and E.M. Michalenko. 1991. Handbook of Environmental Degradation Rates. Chelsea, Michigan: Lewis Publishers.

Hussain and Nabi. 2016. F Hussain and G Nabi, Empirical Formulae Evaluation for Hydraulic Conductivity Determination Based on Grain Size Analysis. Pyrex Journal of Research in Environmental Studies, Vole 3 (3) pp. 026-032. http://www.pyrexjournals.org/pjres. March 2016.

NOAA. 2018. National Oceanic and Atmospheric Administration, National Centers for Environmental Information, Land-Based Station Data, https://www.ncdc.noaa.gov/data-access/land-based-station-data, accessed January 2018.

Richardson, D., J.W. Bingham, R.J. Madison, and R. Williams. 1968. Water Resources of King County, Washington, Geological Survey Water-Supply Paper 1852. U.S. Government Printing Office, Washington, DC. Available at http://pubs.usgs.gov/wsp/1852/report.pdf.

Sound Earth Strategies. 2014. Draft Remedial Investigation and Feasibility Study Report Avtech Property 3400 Wallingford Avenue North. January 10, 2014.

SSPA. 2006. North Lake Union Groundwater Modeling Memorandum. From Michael J. Riley to Dan Baker. S.S. Papadopulos & Associates, Inc., Olympia, Washington. March 23, 2006.

Terra Associates, Inc. 2002. Preliminary Geotechnical Report, 3333 Wallingford Avenue North Building Seattle, Washington, August 21, 2002.

Troost, K.G. and D.B. Booth. 2008. Geography of Seattle and the Seattle area, Washington, Geological Society of America. In: Baum, R.L., J.W.Godt and L.M.Highland, (eds), Landslides and Engineering Geology of the Seattle, Washington, Area. Geological Society of America Reviews in Engineering Geology XX:1–35.

Walpole and Myers. 1978. Probability and Statistics for Engineers and Scientists, R. Walpole and R. Myers. Macmillan Publishing, New York.

Western Regional Climate Center (WRCC). 2015. Comparative Data for the Western States. Washington State Monthly Average Pan Evaporation Data. Accessed 2015. http://www.wrcc.dri.edu/htmlfiles/westevap.final.html#WASHINGTON.

Western Washington Hydrology Model (WWHM. 2012. WWHM2012, prepared for the Washington State Department of Ecology, by AQUA TERRA Consultants and Clear Creek Solutions, Inc., 2012. https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals/Western-Washington-Hydrology-Model.

Zheng, C. and P.P. Wang. 1999. MT3DMS, A modular three-dimensional multi-species transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems; documentation and users guide. Contract Report SERDP-99-1. Prepared for U.S. Army Corps of Engineers, Washington, DC.

Table 3F-1

Hydraulic Parameters for Steady-state Flow Model

Gas Works Park Site

Seattle, Washington

Hydrostratigraphic Unit[1]	Parameter	Hydraulic Conductivity							
		Field-test Values[4]						Model Calibrated Values	
		Minimum		Maximum		Geometric Mean			
		(cm/sec)	(ft/day)	(cm/sec)	(ft/day)	(cm/sec)	(ft/day)	(cm/sec)	(ft/day)
Fill	Kx	7.15E-03	20	6.00E-02	170	1.92E-02	54	8.11E-04	2.3
	Kx/Kz	--	--	--	--	--	--	2	2
Recent Lake Sediments[2]	Kx	--	--	--	--	--	1	3.88E-04	1.1
	Kx/Kz	--	--	--	--	--	--	10	10
Outwash[3]	Kx	9.35E-05	0.27	2.00E-02	57	2.04E-03	5.8	4.69E-03	13.3
	Kx/Kz	--	--	--	--	--	--	5	5
Glacial Till	Kx	1.50E-05	0.04	6.67E-04	1.9	2.43E-04	0.69	6.70E-05	0.19
	Kx/Kz	--	--	--	--	--	--	104	104

Notes:

1. See Figures 3F-2 through 3F-5 for cross-sections showing typical hydrostratigraphic unit distributions within the model layers and domain (cell by cell). The constant head boundary condition that represents Lake Union was assigned in Layer 1. Values of 22.0 and 20.8 feet (USACE Locks datum) were used for the lake water elevation for April 22 and October 14, 2013, respectively.
2. Lake sediments horizontal hydraulic conductivity was estimated from void ratio (SSPA 2006) and verified using the Kozney Carman equation.
3. Outwash hydrostratigraphic unit represents both recessional and advance outwash deposits.
4. See RI Report Table 3E-2 for available hydraulic conductivity values per well (for wells that were field-tested [slug or pump tests]) for each hydrostratigraphic unit.

-- Not measured

cm/sec = centimeters per second

ft/day = feet per day

Kx = horizontal hydraulic conductivity

Kz = vertical hydraulic conductivity

Kx/Kz - anisotropy (unitless)

USACE = U.S. Army Corps of Engineers

Table 3F-2

Model Calibration and Validation Results for Calibration Wells

Gas Works Park Site
Seattle, Washington

Well ID[1]	Saturated Well Screen Midpoint (feet USACE)	Geologic Unit of Screened Interval[3]	Observed vs. Modeled Groundwater Elevations (April 2013)			Observed vs. Modeled Groundwater Elevations (October 2013)		
			Observed Groundwater Elevation (feet USACE) (April 22, 2013)	Modeled Groundwater Elevation (feet USACE)	Residual (feet) (Observed minus Modeled)	Observed Groundwater Elevation (feet USACE) (October 14, 2013)	Modeled Groundwater Elevation (feet USACE)	Residual (feet) (Observed minus Modeled)
AGI-2_metro	18.49	Qvr	21.97	22.28	-0.31	20.99	21.09	-0.10
DW-05	-1.06	Qva	21.91	22.50	-0.59	20.97	21.35	-0.38
MLU-1_metro	19.07	Qvr	22.01	22.36	-0.35	20.65	21.19	-0.54
MW-03	30.75	Qpgt	33.42	32.36	1.06	31.18	31.89	-0.71
MW-03D	-17.17	Qpgt	24.13	25.32	-1.19	23.23	24.35	-1.12
MW-09[2]	18.55	Qva	27.39	25.87	1.52	24.94	25.05	-0.11
MW-14	19.85	Fill	21.97	22.81	-0.84	21.91	21.67	0.24
MW-17	19.24	Fill	21.91	22.80	-0.89	20.88	21.66	-0.78
MW-23	-7.70	Qpgt	21.80	22.36	-0.56	21.76	21.21	0.55
MW-26	21.00	Qpgt	25.12	26.19	-1.07	23.32	25.50	-2.18
MW-26_metro	17.60	Qpgt	21.97	22.20	-0.23	20.98	21.01	-0.03
MW-27	21.92	Qpgt	29.75	28.31	1.44	26.67	27.65	-0.98
MW-28	15.60	Qpgt	22.98	23.4	-0.42	22.00	22.53	-0.53
MW-30	14.91	Qpgt	23.49	24.19	-0.70	23.08	23.16	-0.08
MW-31	1.08	Qpgt	25.00	24.20	0.80	24.06	n/a	n/a
MW-33S	19.26	Fill	21.81	22.69	-0.88	21.77	21.58	0.19
MW-34S	20.22	Fill	21.80	23.15	-1.35	21.11	22.83	-1.72
MW-36D	-1.56	Qvr	21.73	22.68	-0.95	20.85	21.65	-0.80
MW-36S	14.53	Fill	21.74	22.52	-0.78	20.90	21.51	-0.61
MW-39D	7.59	Qva/Qpgt	21.74	22.40	-0.66	20.88	21.29	-0.41
OBS-1	16.28	Fill	21.71	22.09	-0.38	20.86	21.19	-0.33
OBS-3	20.47	Fill	23.05	23.23	-0.18	22.05	22.43	-0.38
PZ-03	18.54	Qvr	22.28	23.12	-0.84	21.11	21.98	-0.87
PZ-05	15.75	Fill	21.76	22.50	-0.74	20.89	21.35	-0.46
PZ-09	19.26	Qvr	24.26	23.65	0.61	22.78	22.58	0.20
RW-01	19.41	Qvr	24.01	23.69	0.32	22.42	22.63	-0.21
TDW-1	-15.10	Qva	21.86	22.21	-0.35	20.98	21.05	-0.07
TSW-1	18.02	Fill	21.81	22.23	-0.42	20.91	21.08	-0.17
TDW-3	-9.87	Qva	21.79	22.37	-0.58	20.76	21.23	-0.47
TSW-3	19.03	Fill	21.77	22.23	-0.46	21.59	21.13	0.46
				Statistical Metrics	**April Statistics**			**October Statistics**
				Mean Absolute Residual (Head)	0.72			0.52
				Root Mean Square Error (RMSE)	0.8			0.7
				Regressional Coefficient (R^2)	0.88			0.95

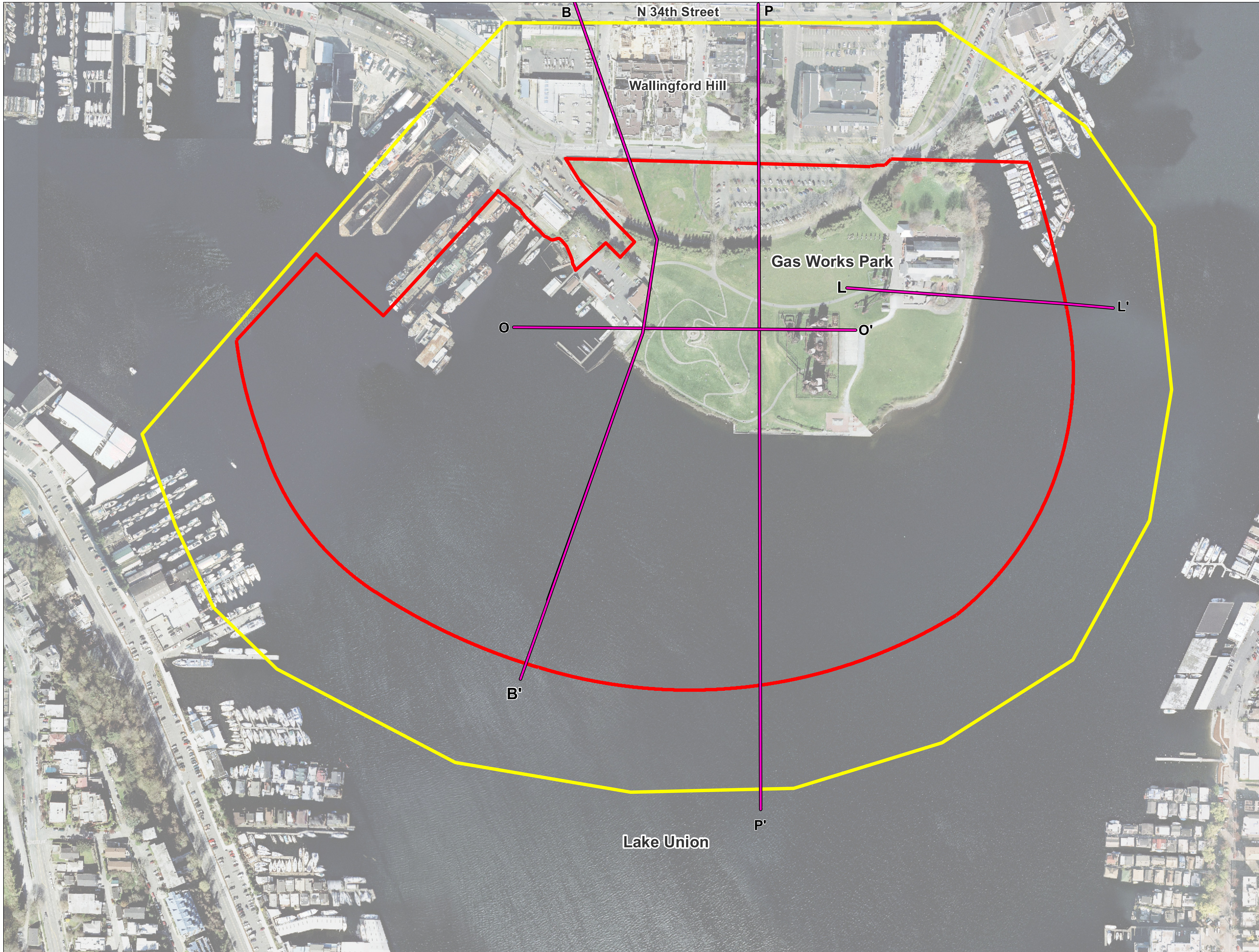
Notes:

[1] Well locations shown in RI Report Figure 5-21 and appendix Figures 3F-11 and 3F-12.

[2] Well contains light nonaqueous phase liquid (LNAPL). Water elevation corrected using LNAPL specific gravity of 0.92 (PTS Laboratories result for MW09-130415-LNAPL).

[3] Geologic unit referenced from RI Appendix Table 3J-1, or interpolated from isopach and structural contour figures 3B-2 through 3B-5 from RI Appendix B (for wells MW-26_metro, AGI-2_metro, and MLU-1_metro). See Note 4 of Table 3J-1 for information regarding wells screened over multiple geologic units (where applicable).

Qpgt = Pre-Fraser glacial till
Qva = Advance outwash
Qvr = Recessional outwash



Legend

- Area of Investigation (AOI)
- Groundwater Flow Model Domain Boundary
- Cross-Section Location

Notes:

1. Basemap 2005 USGS aerial photograph. Does not show current conditions.
2. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

DISCLAIMER: This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. The locations of all features are approximate. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

N W E S

0 300 600

Feet

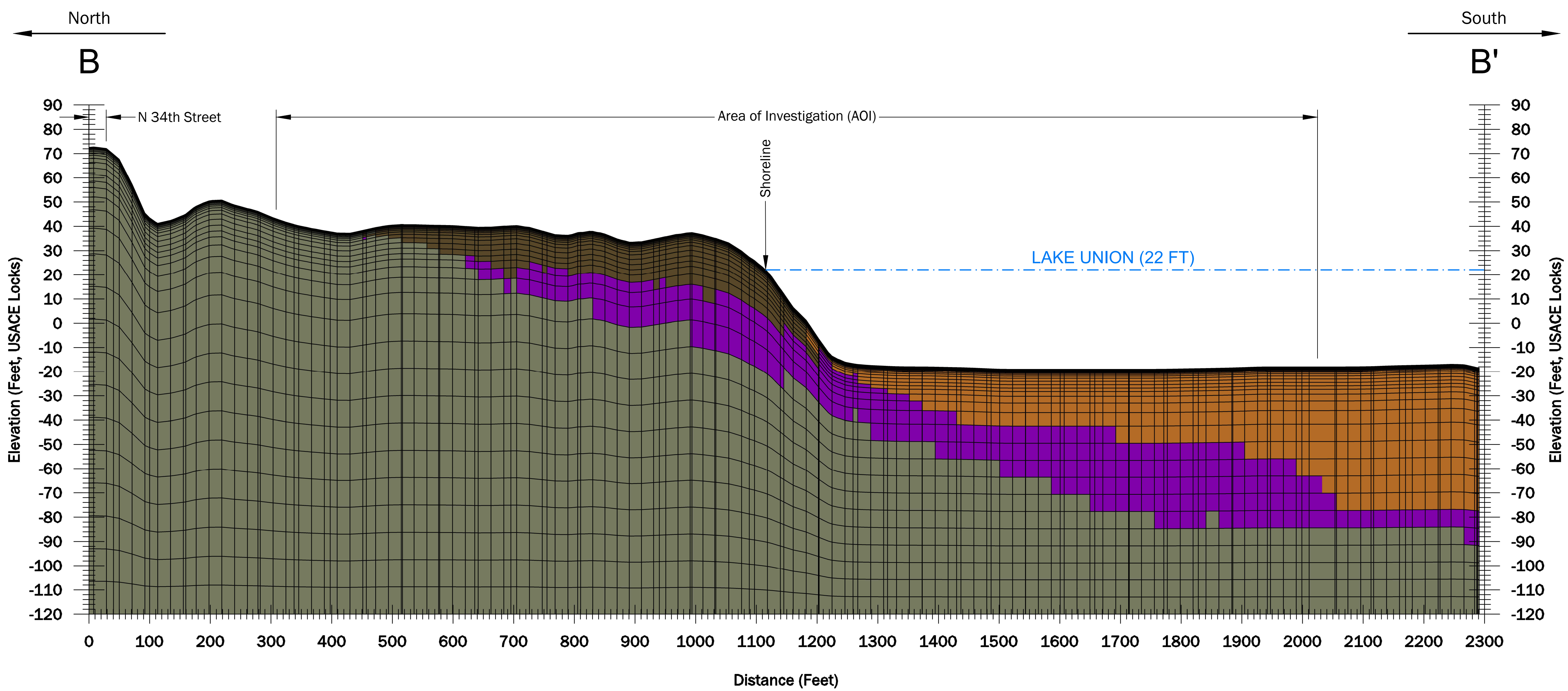
Groundwater Flow Model Domain

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-1

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\0186846_01_F3F-1_GroundwaterFlowDomain_modified.mxd Map Revised: 13 December 2021 maugust



Notes

1. See Figure 3F-1 for Cross Section Locations.

Hydrostratigraphic Units

- Af - Fill
- Ql - Recent Lacustrine Deposits
- Qvr and Qva - Vashon Recessional and Advance Outwash
- Qpgt - Pre-Fraser Glacial Till

100 0 200

Scale in Feet

Vertical Exaggeration: 4x

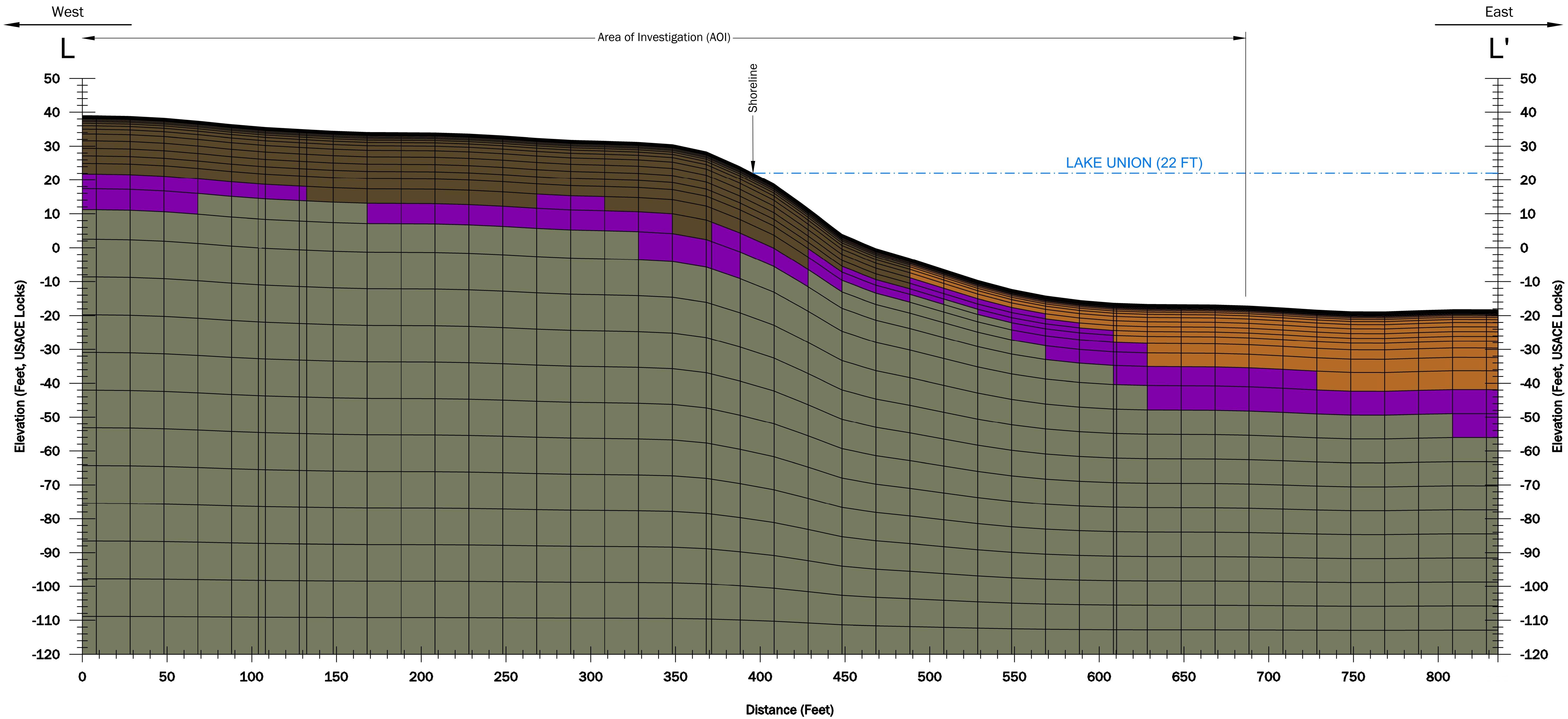
Representative MODFLOW Grid Cross-Section B-B'

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-2

P:\0\0186846\01\CAD\Task 1636 RI\01 Internal Review\Appendix 3F\018684601_Task1636_GW Modeling xSections.dwg TAB:3F-2 (BB) Date Exported: 05/20/19 - 17:42 by cstickel



Notes

1. See Figure 3F-1 for Cross Section Locations.

Hydrostratigraphic Units

- Af - Fill
- Ql - Recent Lacustrine Deposits
- Qvr and Qva - Vashon Recessional and Advance Outwash
- Qpgt - Pre-Fraser Glacial Till

30 0 60

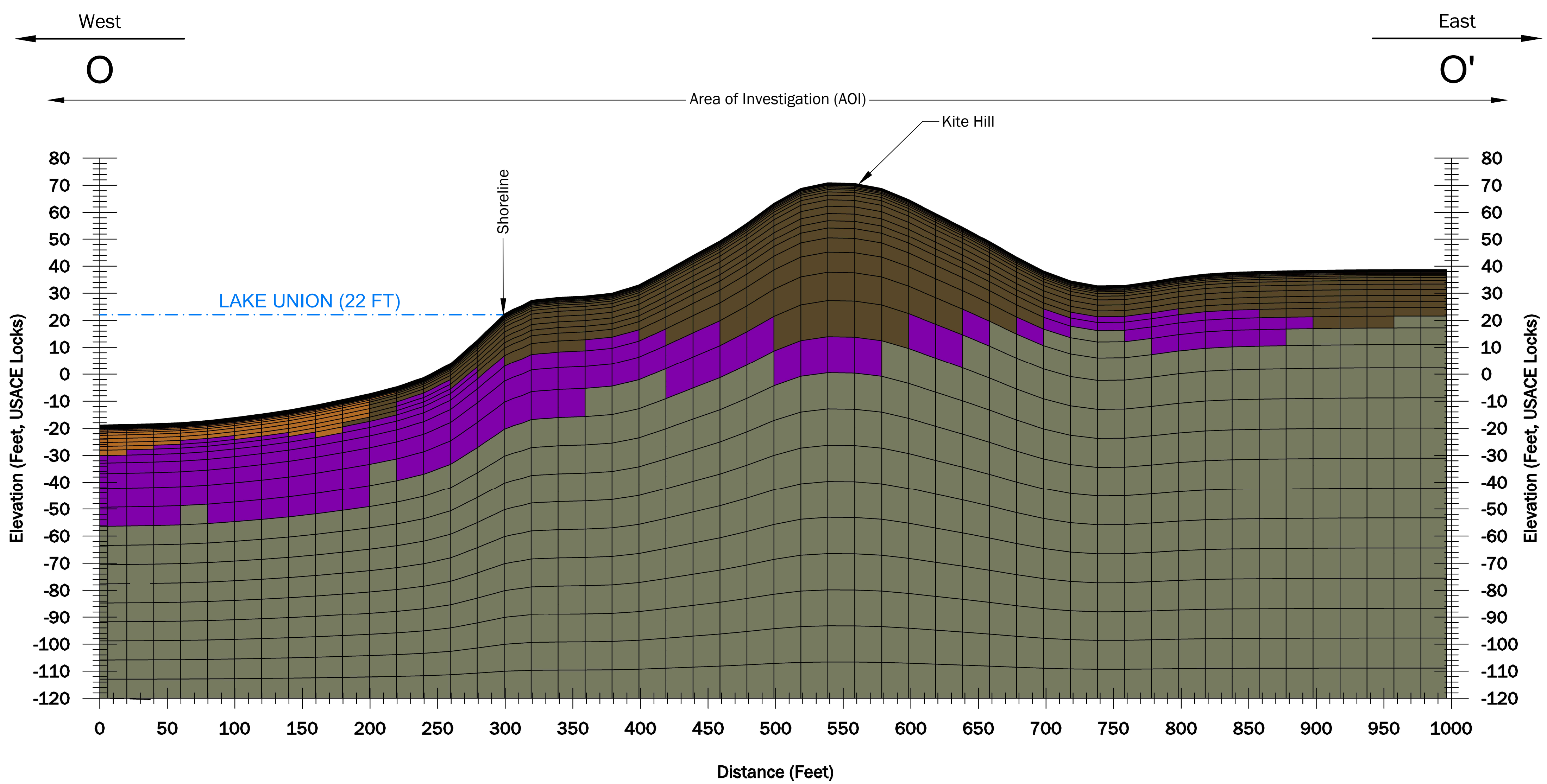
Scale in Feet
Vertical Exaggeration: 2x

Representative MODFLOW Grid Cross-Section L-L'

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-3



Notes

1. See Figure 3F-1 for Cross Section Locations.

Hydrostratigraphic Units

- Af - Fill
- Ql - Recent Lacustrine Deposits
- Qvr and Qva - Vashon Recessional and Advance Outwash
- Qpgt - Pre-Fraser Glacial Till

50 0 100

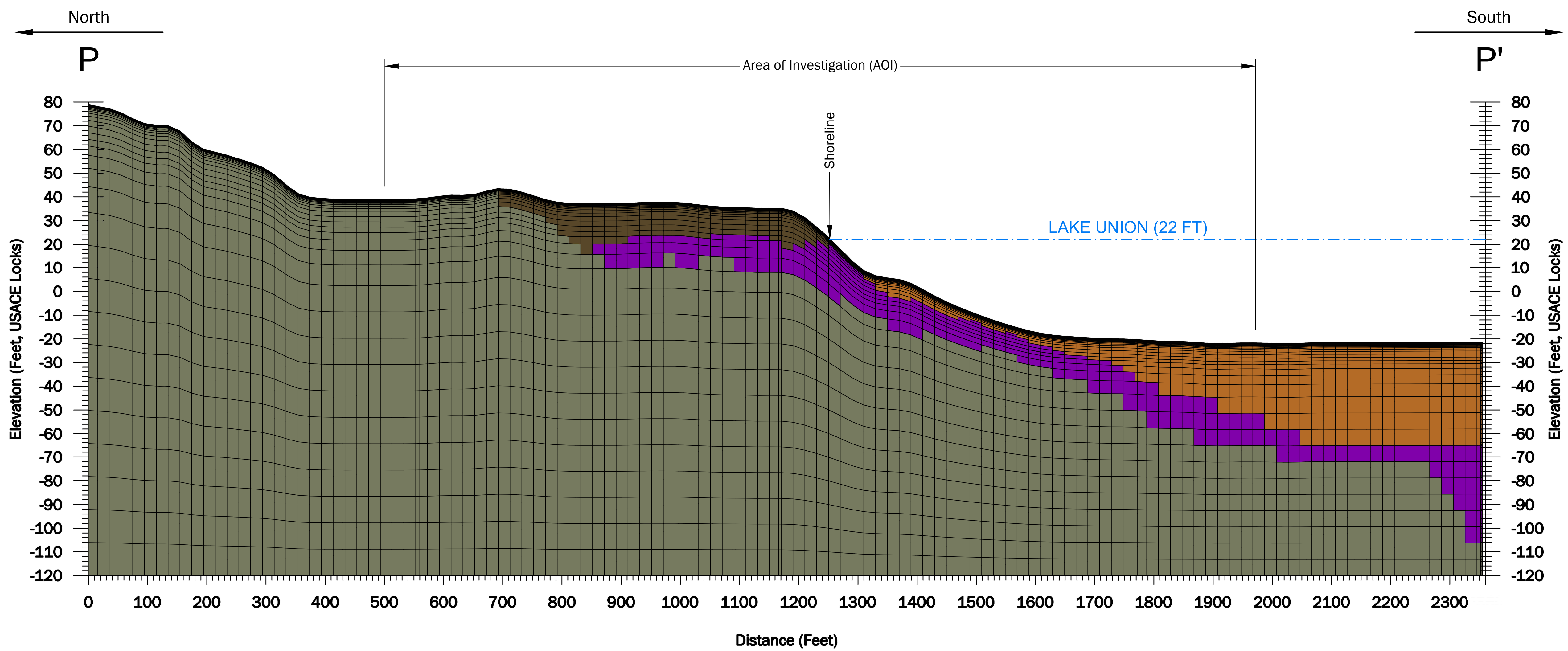
Scale in Feet
Vertical Exaggeration: 2x

Representative MODFLOW Grid Cross-Section O-O'

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-4



P:\0\0186846\01\CAD\Task 1636 RI\01 Internal Review\Appendix 3F\018684601_Task1636_GW Modeling xSections.dwg TAB:3F-5 (PP) Date Exported: 05/20/19 - 17:37 by cstickel

Notes

1. See Figure 3F-1 for Cross Section Locations.

Hydrostratigraphic Units

- Af - Fill
- Ql - Recent Lacustrine Deposits
- Qvr and Qva - Vashon Recessional and Advance Outwash
- Qpgt - Pre-Fraser Glacial Till

100 0 200

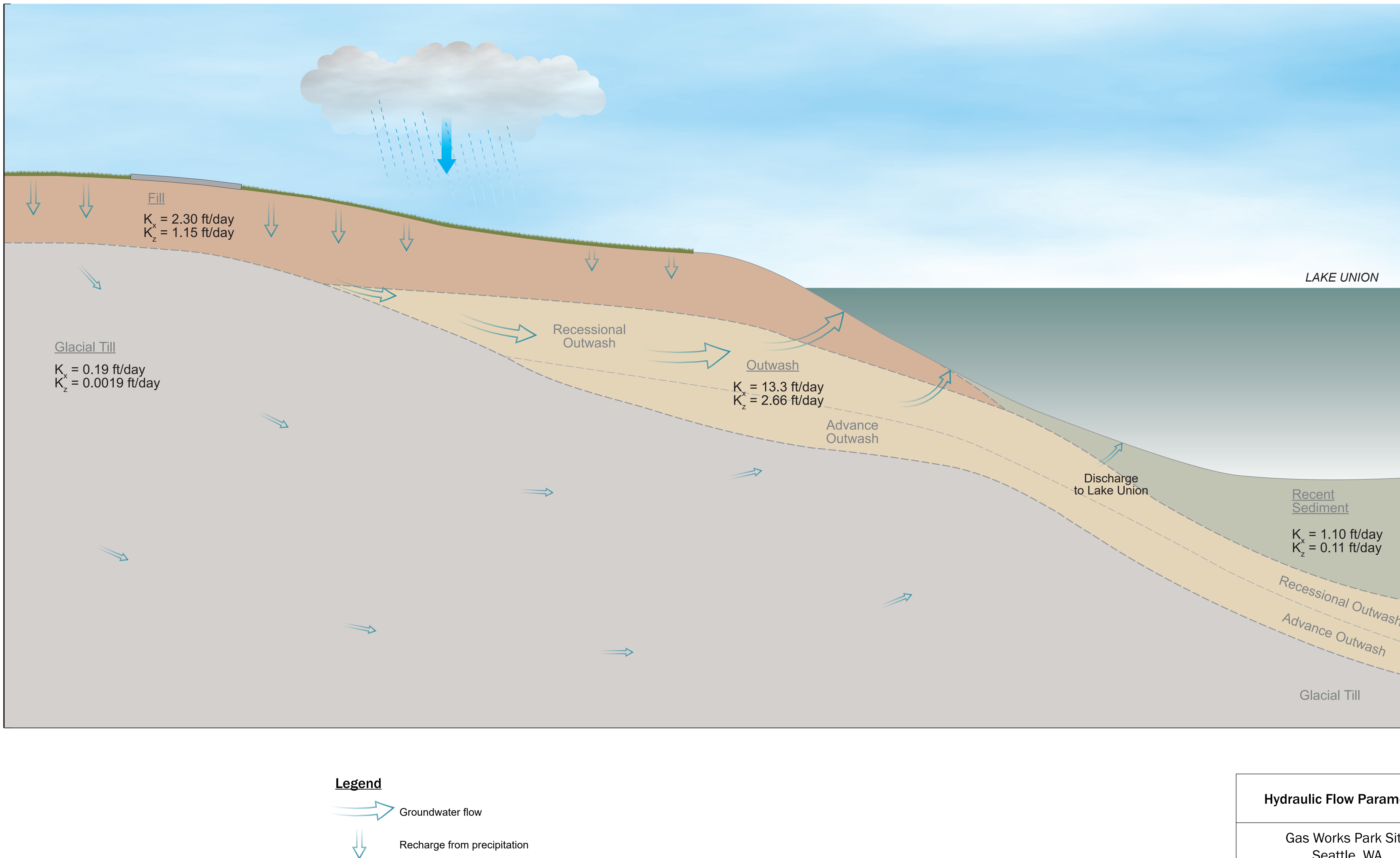
Scale in Feet
Vertical Exaggeration: 4x

Representative MODFLOW Grid Cross-Section P-P'

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-5



Hydraulic Flow Parameters

Gas Works Park Site
Seattle, WA

GeoEngineers

Figure 3F-6

P:\0\0186846\Graphics_Misc\Figure 3F-6 - Hydraulic Flow Parameters.ai Exported 12/10/21 by spride

Legend

Area of Investigation (AOI)

Deep Monitoring Well

Water Table Monitoring Well

MW-40S 21.70 — Monitoring Well Identifier; Groundwater Elevation on April 22, 2013

Notes:
1. Depth to groundwater measured on 4/22/2013.
2. All elevations reported in feet USACE (Locks) datum.
3. MW-09 and MW-9 (Metro) contained LNAPL; reported groundwater elevation has been corrected for NAPL.
4. Basemap 2005 USGS aerial photograph. Does not show current conditions.
5. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

N W E S

0 120 240
Feet

Wells Used in Groundwater Flow Calibration

Gas Works Park Site
Seattle, Washington

GEOENGINEERS

Figure 3F-7

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\018684601_F3F-7_Upland_Wells_Location_Map.mxd Map Revised: 29 November 2021 maugust

Legend

- Area of Investigation (AOI)
- MW-03 Monitoring Well Identifier
- Slug Test
- Pump Test Observation Well
- Pump Test Extraction Well
- Fill
- Outwash
- Glacial Till

Notes:

1. Slug tests were performed on abandoned monitoring wells MW-5, MW-6, and MW-11.
2. Basemap 2005 USGS aerial photograph. Does not show current conditions.
3. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

DISCLAIMER: This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. The locations of all features are approximate. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

N W E S

0 120 240
Feet

Hydraulic Conductivity Testing Locations

Gas Works Park Site
Seattle, Washington

GEOENGINEERS

Figure 3F-8

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\0186846 01_F3F-8_Slugtesting.mxd Map Revised: 29 November 2021 maugust

Legend

- Area of Investigation (AOI)
- No Flow Boundary
- Constant Head Boundary
- Recharge Boundary
- Lake Boundary

Notes:
1. Basemap 2005 USGS aerial photograph. Does not show current conditions.
2. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

N W E S

0 300 600
Feet

Boundary Conditions

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-9

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\0186846_F3F-9_BoundaryConditions.mxd Map Revised: 12 December 2021 maugust

Legend

Recharge Values (Inches/Year)
Recharge Area

- Grass Cover 15
- Ponding Areas 5
- Parking Lot 9
- Northwest Lawn 9

Notes:

1. Basemap 2005 USGS aerial photograph. Does not show current conditions.
2. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

DISCLAIMER: This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. The locations of all features are approximate. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

N W E S

0 120 240
Feet

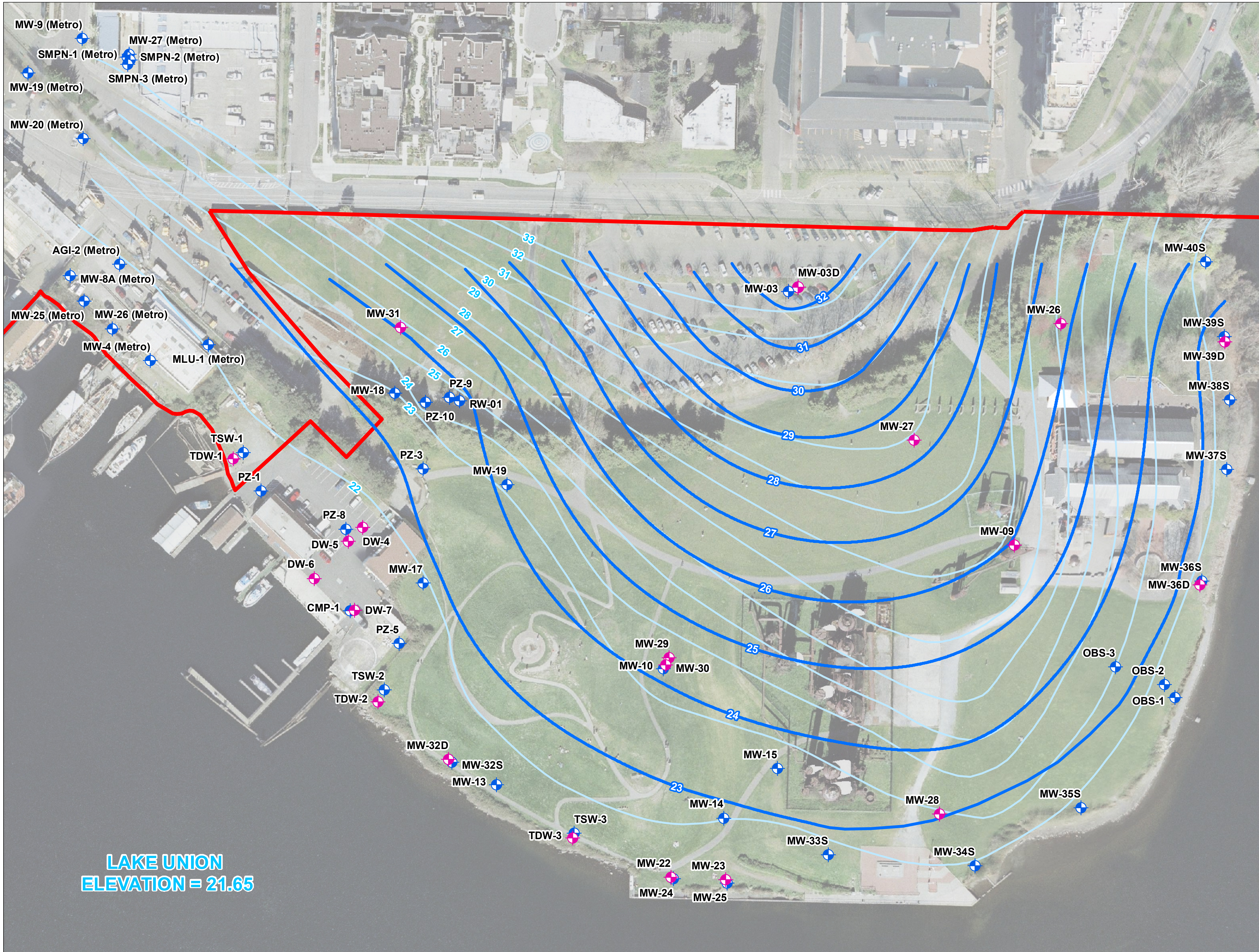
Calibrated Model Recharge Areas

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-10

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\018684601_F3F-10_ModelRechargeAreas.mxd Map Revised: 12 December 2021 maugust



Legend

- Area of Investigation (AOI)
- Monitoring Well (not used for contouring)
- Water Table Monitoring Well
- MW-40S Monitoring Well Identifier
- 21 Groundwater Elevation Contour (measured)
- 21 Groundwater Elevation Contour (modeled)

Notes:

1. Modeled groundwater elevations exported from observation point used wells used in the MODFLOW model.
2. Groundwater elevations on 4/22/2013.
3. All elevations reported in feet USACE (Locks) datum.
4. MW-09 and MW-9 (Metro) contained LNAPL; groundwater elevations were corrected for LNAPL.
5. MW-18, MW-19,MW-20 (Metro), MW-8A (Metro) presumed to be water table wells.
6. Contours developed using Kriging with manual adjustments.
7. Basemap 2005 USGS aerial photograph. Does not show current conditions.
8. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

N W E S

0 120 240
Feet

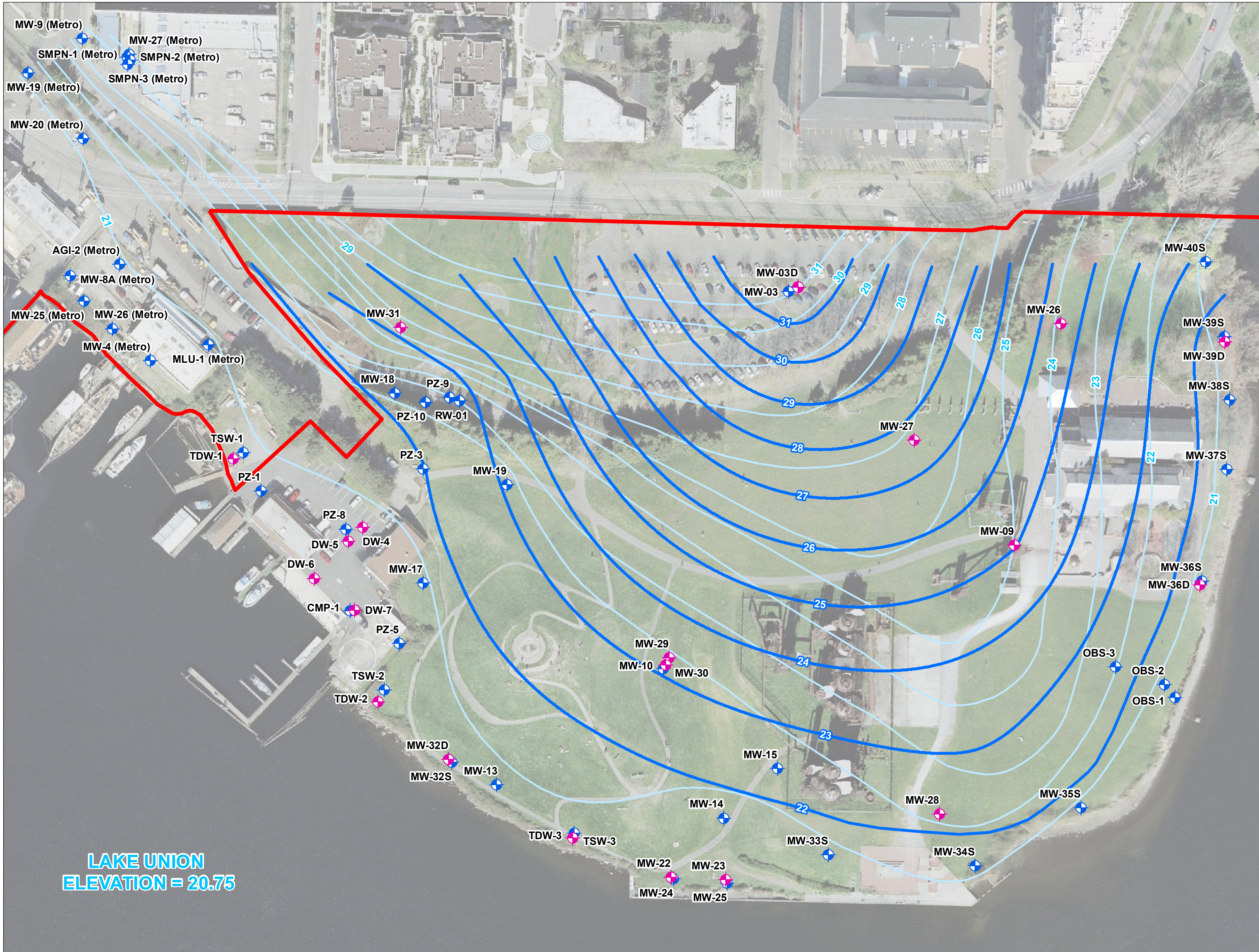
Groundwater Table Contours (April 22, 2013) Measured and Modeled

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-11

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\018684601_F3F-11_GW_Apr2013model.mxd Map Revised: 29 November 2021 maugust



Legend

- Area of Investigation (AOI)
- Monitoring Well (not used for contouring)
- Water Table Monitoring Well
- MW-40S Monitoring Well Identifier
- 21 Groundwater Elevation Contour (measured)
- 21 Groundwater Elevation Contour (modeled)

Notes:

1.Modeled groundwater elevations exported from observation point wells used in the MODFLOW model.
2. Groundwater elevations on 10/14/2013.
3. All elevations reported in feet USACE (Locks) datum.
4. MW-09 and MW-9 (Metro) contained LNAPL; groundwater elevations were corrected for LNAPL.
5. MW-18, MW-19,MW-20 (Metro), MW-8A (Metro) presumed to be water table wells.
6. Contours developed using Kriging with manual adjustments.
7. Basemap 2005 USGS aerial photograph. Does not show current conditions.
8. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

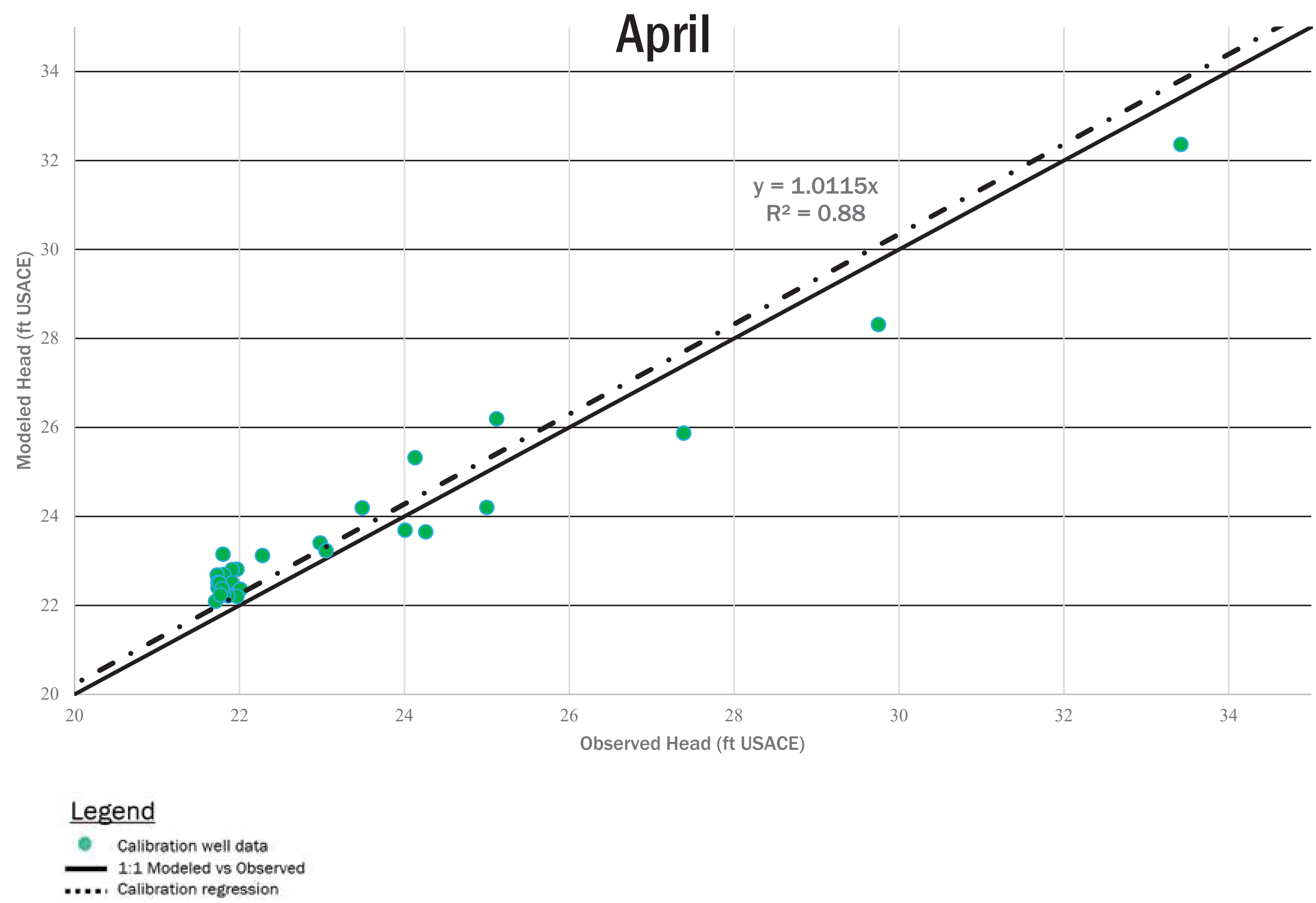
Groundwater Table Contours (October 14, 2013) Measured and Modeled

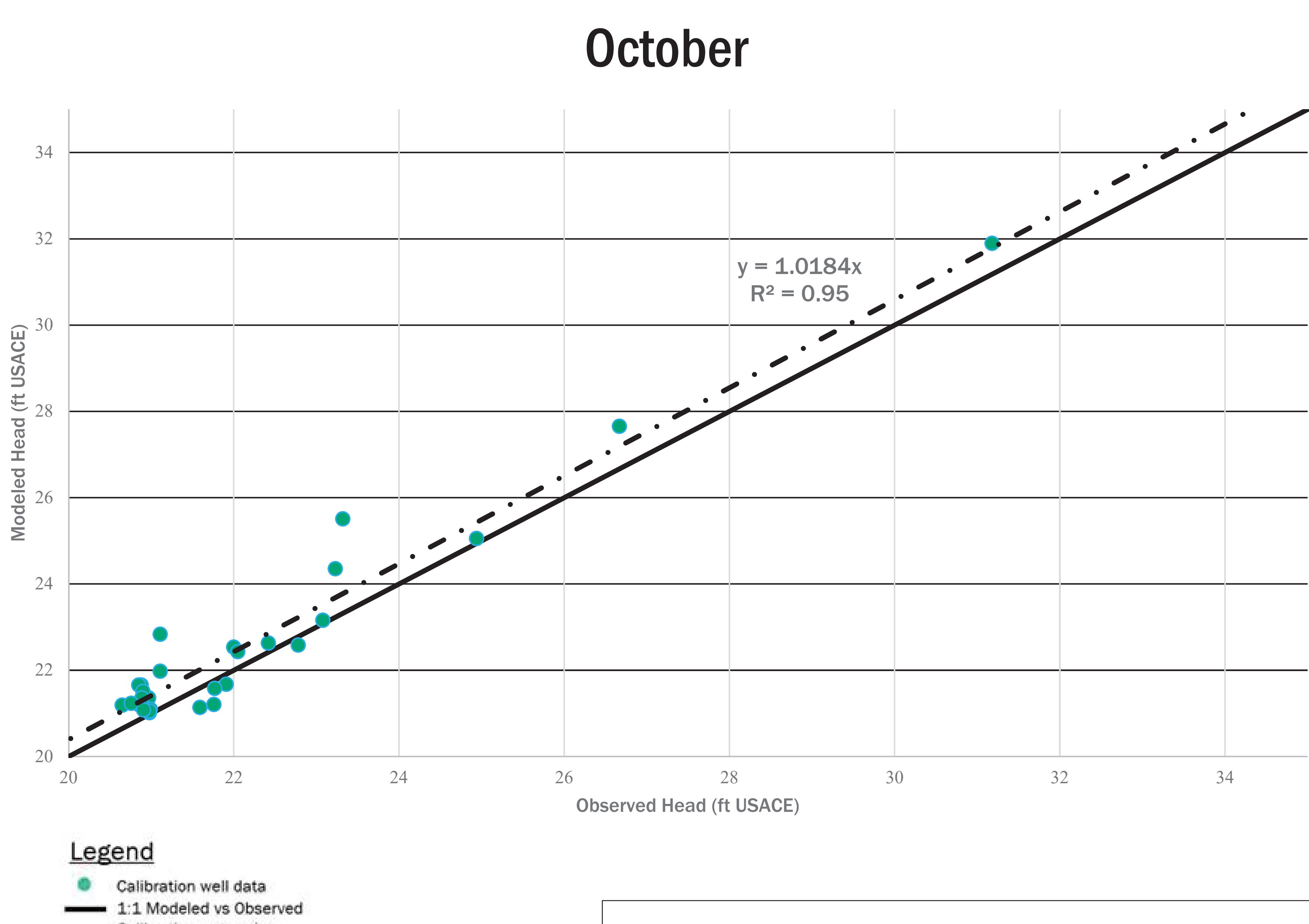
Gas Works Park Site
Seattle, Washington

GEOENGINEERS

Figure 3F-12

Path: P:\0\0186846\GIS\MXD\Phase01\T1635\018684601_F3F-12_GW_Oct2013model.mxd Map Revised: 29 November 2021 maugust



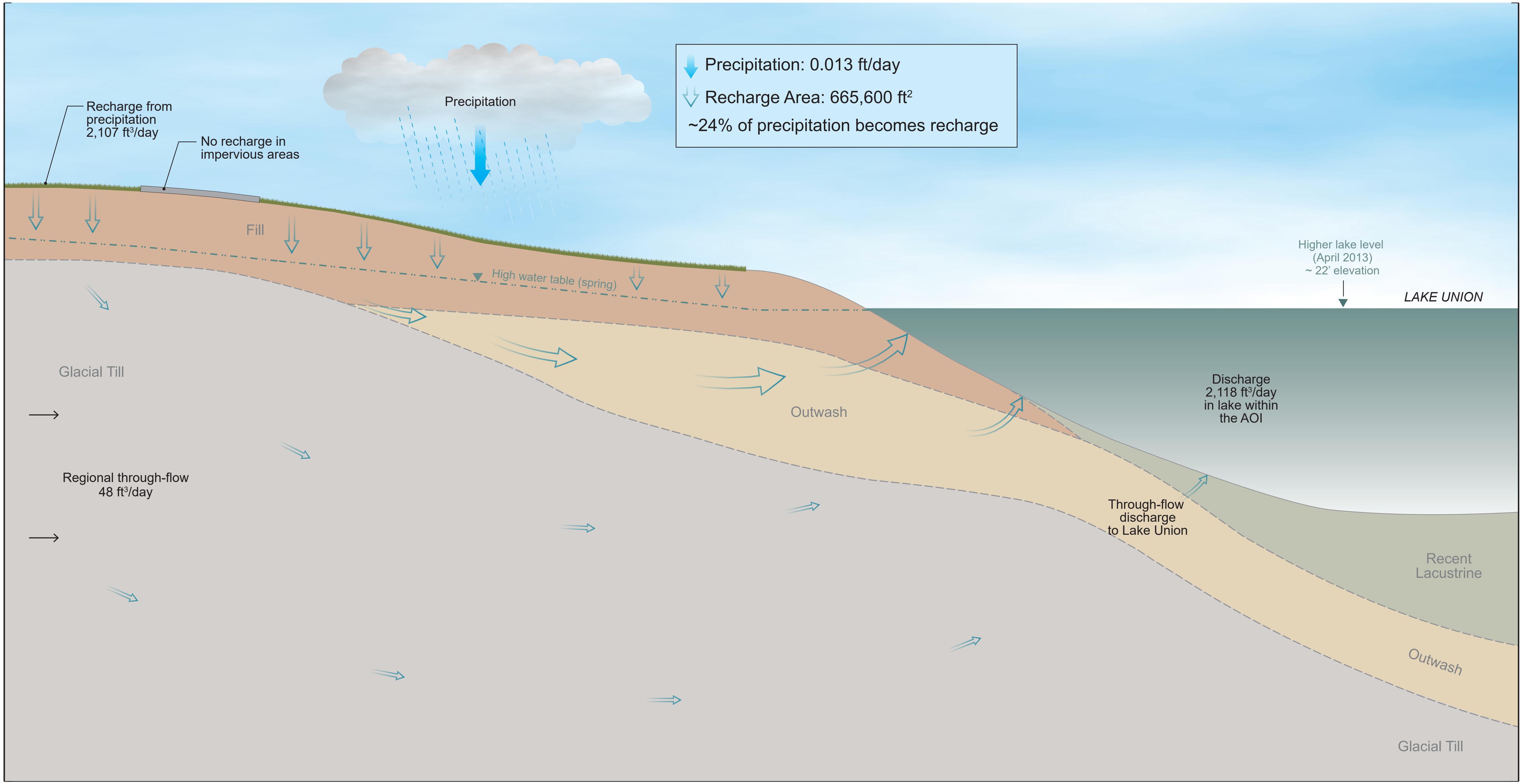


Calibration Statistics

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-13



Notes:

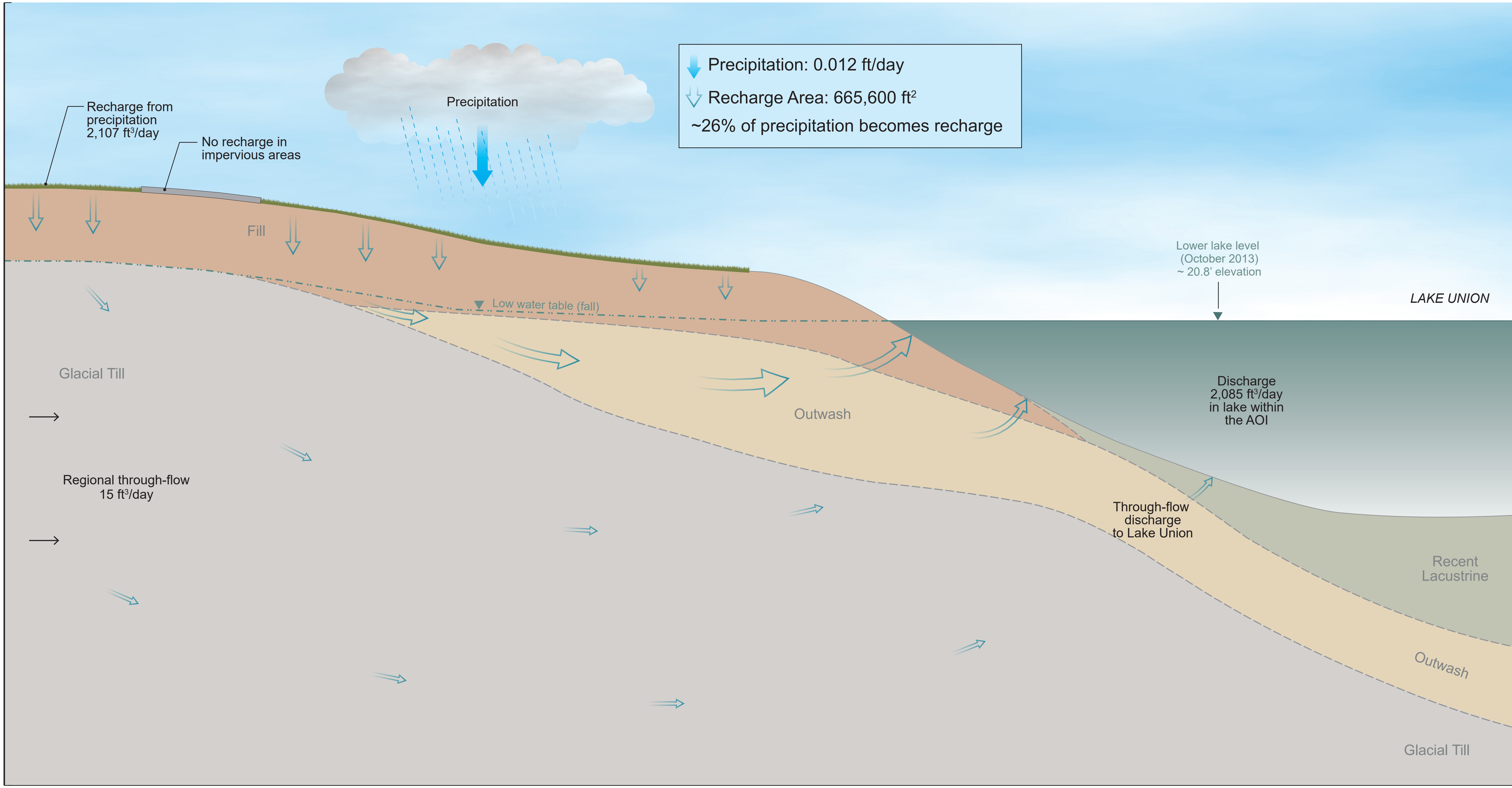
1. An estimated 37 ft³/day flows from the AOI into the larger model domain.

Legend

- Groundwater flow
- Recharge from precipitation
- Regional through-flow

Groundwater Flow Summary - April 2013
Gas Works Park Site Seattle, WA
GeoEngineers — **Figure 3F-14**

P:\0\0186846\Graphics_Misc\Figure 3F-16 - Groundwater Flow Summary April.ai Exported 12/10/21 by spride



Notes:

1. An estimated ~37 ft³/day flows from the sediment within the AOI into the larger model domain.

Legend

- Groundwater flow
- Recharge from precipitation
- Regional through-flow

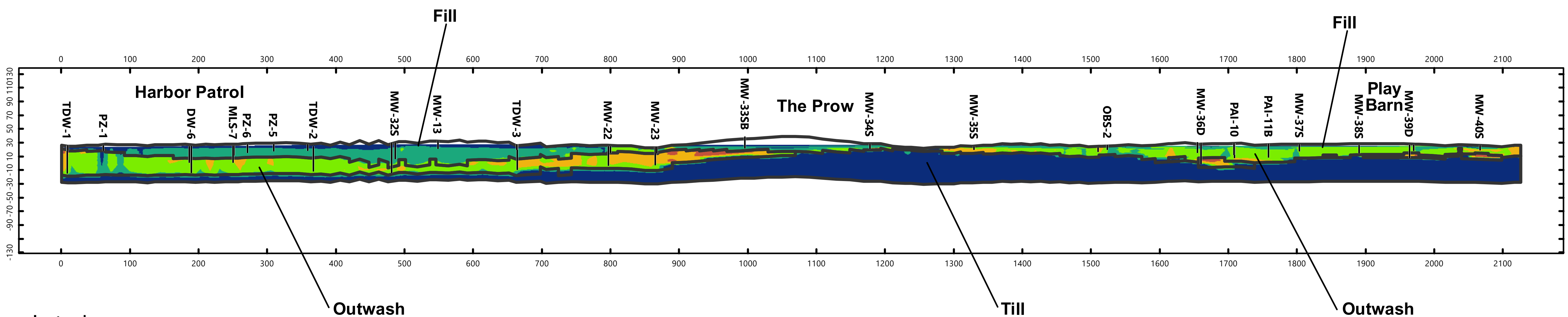
Groundwater Flow Summary - October 2013

Gas Works Park Site
Seattle, WA

GeoEngineers

Figure 3F-15

Groundwater Velocity



Legend

GW Flux (ft/day)

- <0.0001- 0.0049
- 0.005 - 0.0199
- 0.02 - 0.0499
- 0.05 - 0.1
- >0.1

Notes:
1. Data Source: Anchor QEA, LLC, 2018.
2. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

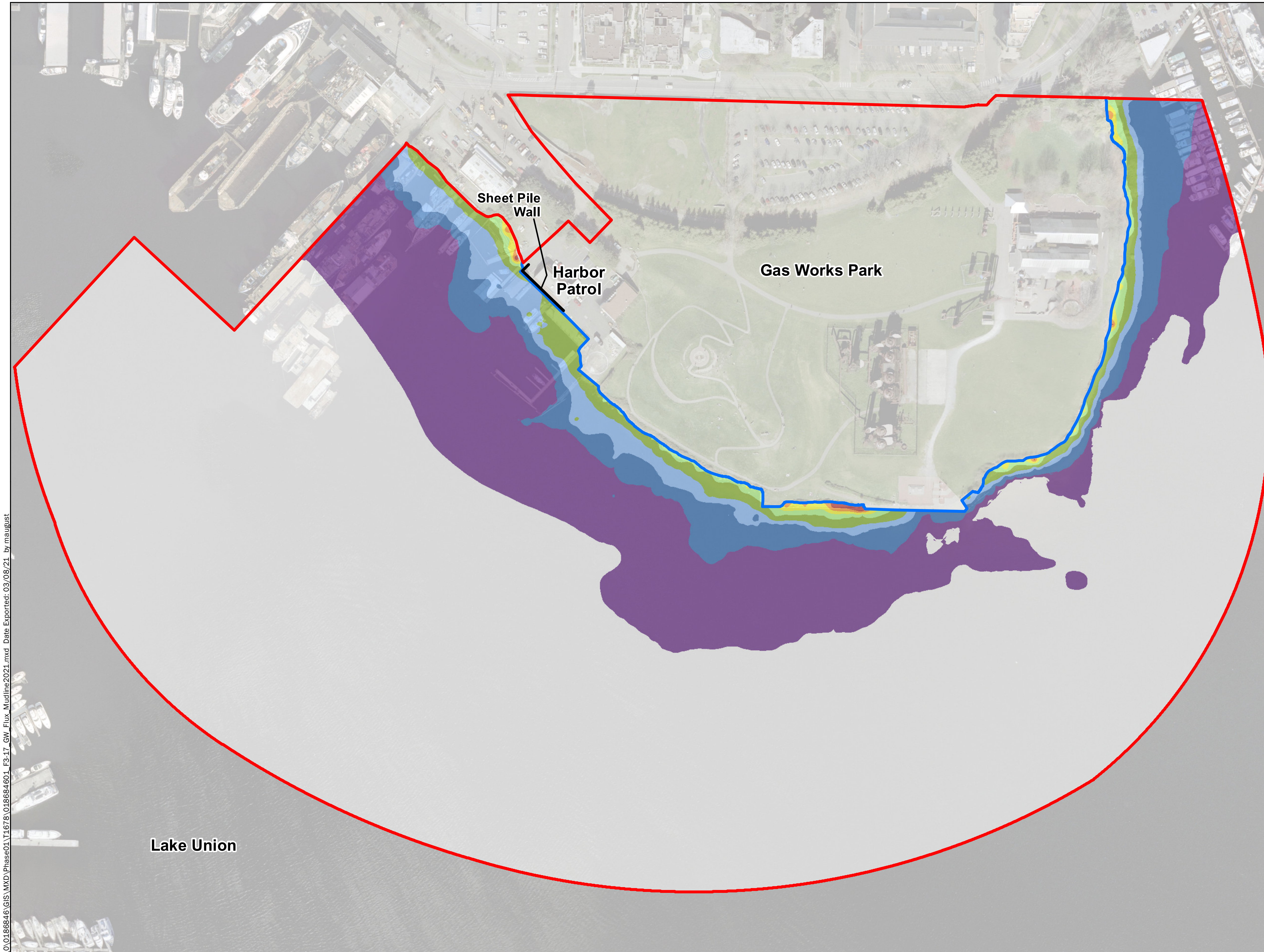
P:\0\0186846\GIS\MXD\Phase01\T1635\018684601_F3F-16_AnchorGWVelocity.mxd Date Exported: 12/12/21 by maugust

Groundwater Velocity

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-16



Legend

- Area of Investigation
- Shoreline (OHWM)

Mudline Discharge (feet/day)	% Total Discharge	% Cumulative Discharge
>0.05	3%	3%
0.05 - 0.04	5%	8%
0.04 - 0.03	9%	17%
0.03 - 0.02	18%	35%
0.02 - 0.01	29%	64%
0.01 - 0.005	17%	81%
0.005 - 0.001	11%	92%
0.001 - 0.0001	6%	98%
<0.0001	2%	100%

Notes:

1. Calculated discharge through the fill and outwash at the shoreline within the AOI is 1,660 cfd. Shoreline fill and outwash groundwater discharges to Lake Union nearshore in the area where mudline discharge is greater than 0.001 ft/day (i.e., Groundwater Discharge Zone).
2. Mudline discharge data from Anchor QEA 2018.
3. Basemap 2005 USGS aerial photograph. Does not show current conditions.
4. Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet.

N
W E
S

200 0 200
Feet

Estimated Groundwater Discharge at Mudline

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3F-17

P:\0\0186846\GIS\MXD\Phase01\T1678\0186846 01_F3-17_GW_Flux_Mudline2021.mxd Date Exported: 03/08/21 by maugust

ATTACHMENT 3F-1
North Lake Union Groundwater Modeling Memorandum

ATTACHMENT 2F-1

North Lake Union Groundwater Modeling Memorandum

North Lake Union Groundwater Modeling Memorandum

Date: March 23, 2006

From: Michael J. Riley

To: Dan Baker

Two 2-dimensional vertical slice models were constructed for transects extending from upland to offshore of Gas Works Park in Seattle, Washington. The first section (A-A') is located at the southern edge of the Park and extends in a southerly direction into North Lake Union. The second section (B-B') is an east-west trending section extending from the eastern edge of the Park into North Lake Union. The locations of the model sections are shown on Figure 1. The sections include geologic units consisting of fill, soft sediment, recessional outwash, till and advanced stratified drift (ASD). Data on the extent and depth and relationship among the geologic units was provided by RETEC. The cross sections are depicted in Figures 2 and 3.

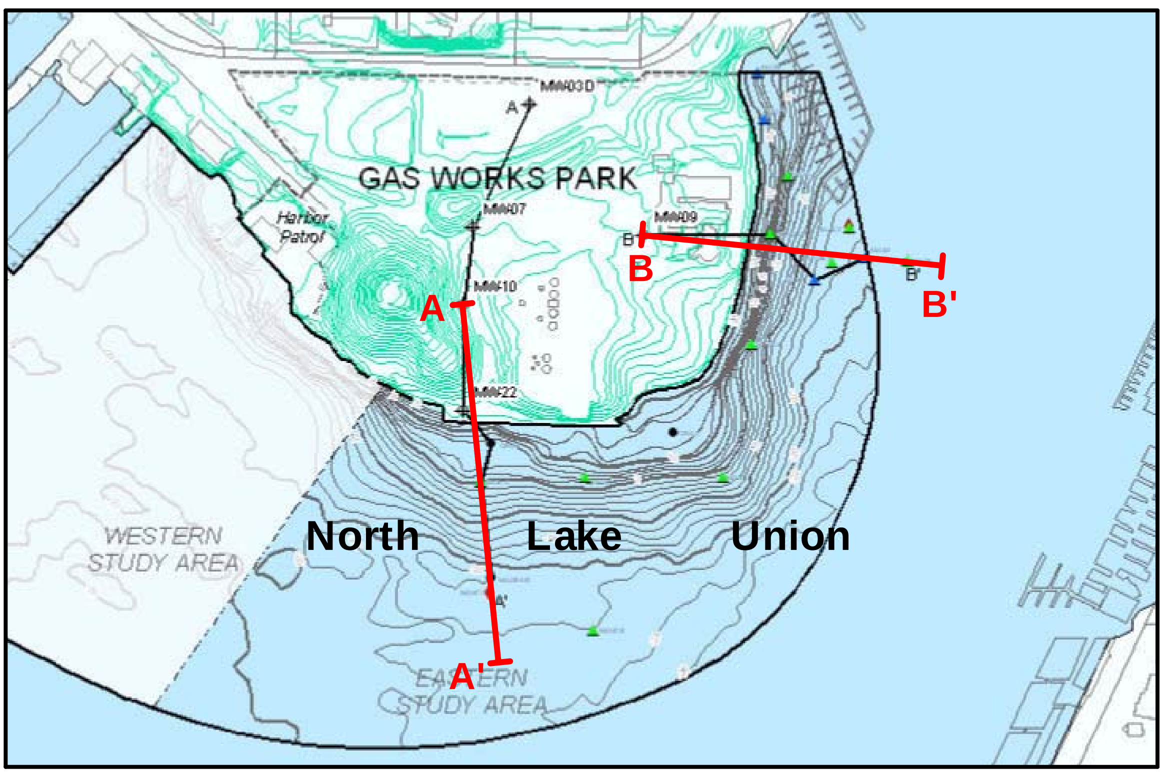


Figure 1. Location and extent of cross section models prepared for this study

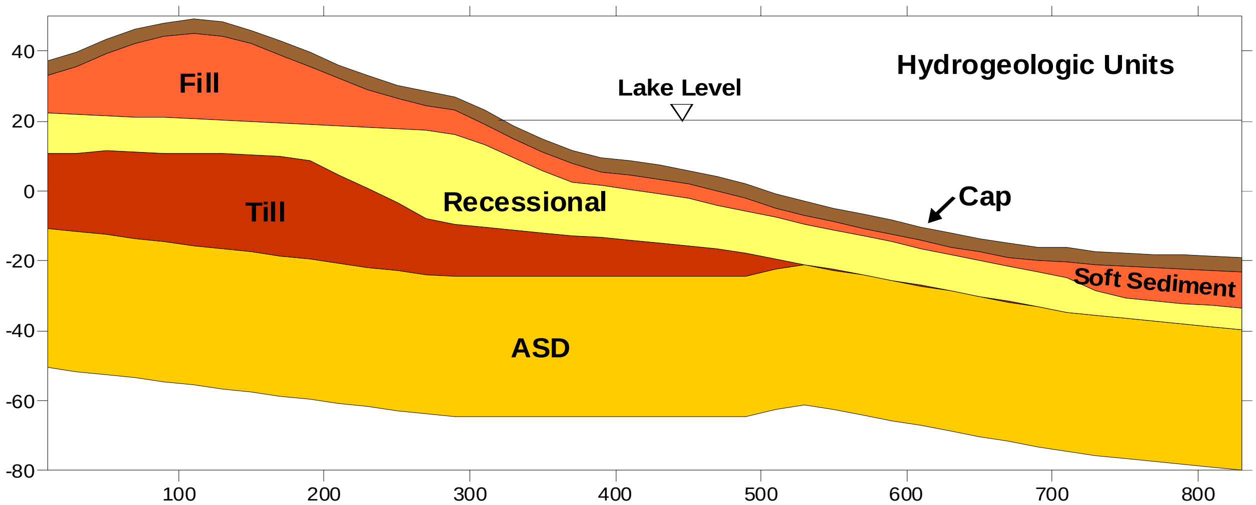


Figure 2. Geologic units of cross section A-A'

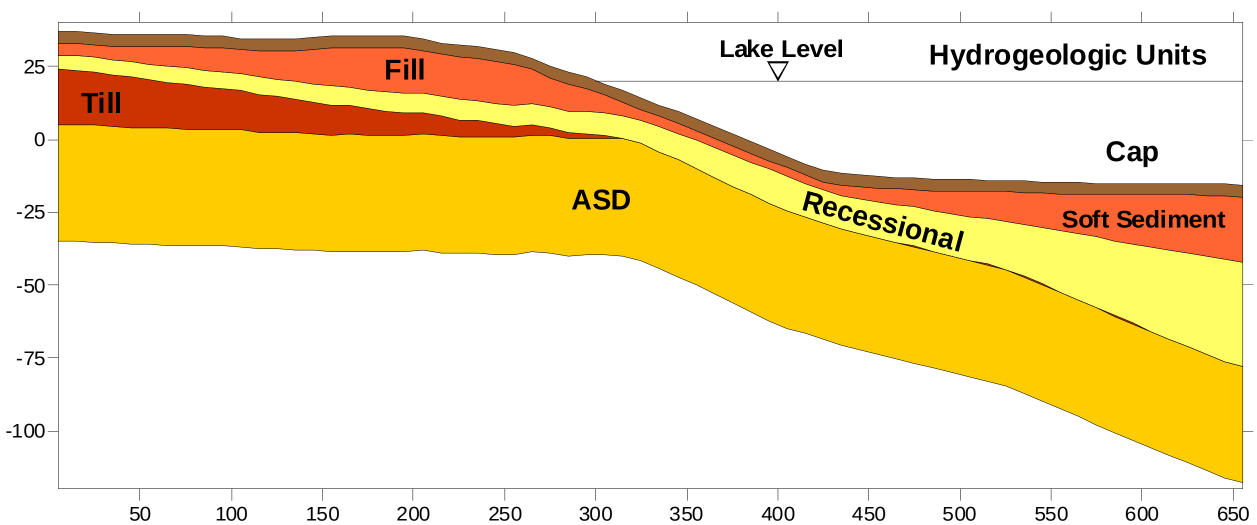


Figure 3. Geologic units of cross section B-B'

The models were used to simulate groundwater flow from upland areas to Lake Union. In addition, the Section B-B' model was used to predict the effectiveness of capping in mitigating chemical impacts to Lake Union from compounds identified in existing sediments. The model was used to simulate the migration of naphthalene and chrysene as representative compounds for light and heavy PAHs in sediment. Naphthalene is the most mobile of the light PAHs in groundwater and has been used as a representative compound for light PAHs in several previous studies (Converse Consultants and Pacific Groundwater Group 1993; Aspect Consulting, 2005). Similarly, chrysene is more mobile in groundwater than most of the other heavy PAHs.

Section B-B' was chosen for the PAH transport simulation as the concentration of PAHs are considerably higher in this section than in Section A-A'. Therefore, a cap design that will mitigate the effect of PAHs in Section B-B' will also be effective for conditions at Section A-A'.

Model Grid and Boundaries

The cross sections were divided into cells consisting of model layers and vertical grid spacing. In both models, the horizontal grid has a uniform spacing: 20 feet in Section A-A' and 10 feet in Section B-B'. The finer grid spacing in the Section B-B' model was used because PAH transport simulations were conducted with this model and the finer grid allowed for a more detailed delineation of source areas.

Model layers follow the geologic units. However, since the fill grades into the soft sediment, these two units fall within the same model layers. The soft sediment/fill units are further subdivided into 4 model layers. The top most soft sediment/fill layer is 4 inches thick and is used in the transport analysis for comparison to surface sediment grab sample data. The recessional outwash unit is divided into 3 model layers and the ASD is divided into two layers. Model layers representing a hypothetical remedial cap are included above native geology layers. For model simulations without the cap, the model cap layers were not used in the simulation. Cross sections of the model layers and grids are shown in Figures 4 and 5. A description of model layers with respect to geologic units is presented in Table 1.

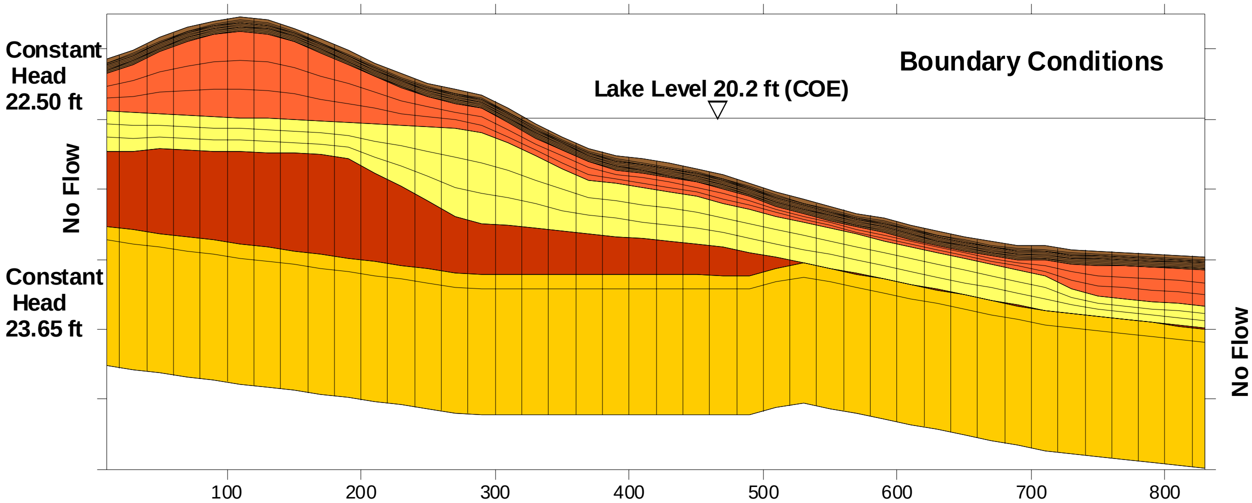


Figure 4. Model grid, layers, and boundary conditions for cross section A-A'

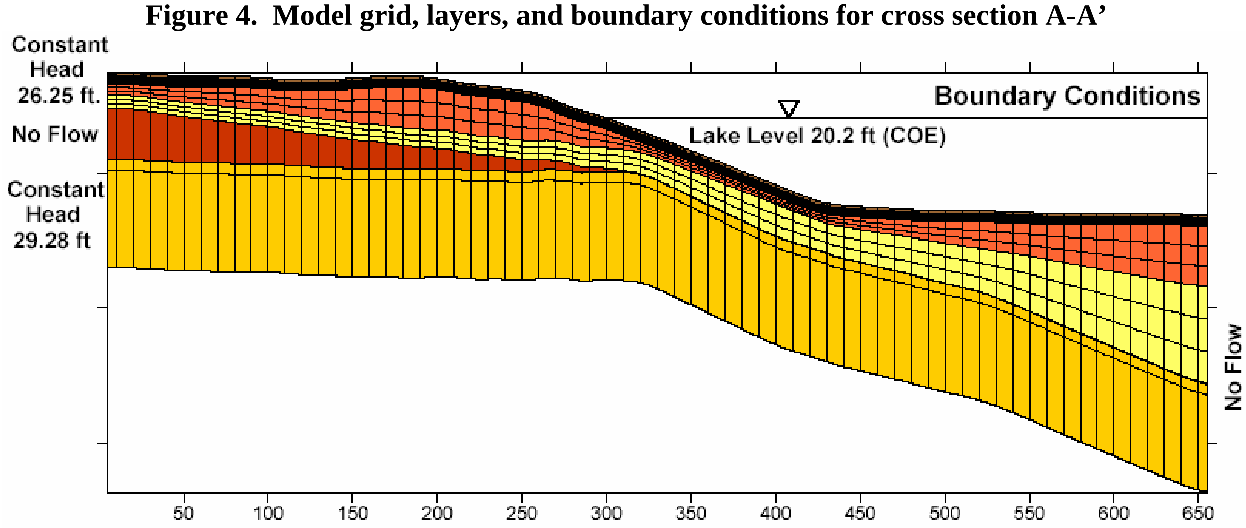


Figure 5. Model grid, layers, and boundary conditions for cross section B-B'

Table 1. Relation between geologic units and model layers

Geologic Unit	Model Layers	Comments
Cap	1-10	Various layers active depending on the thickness of the cap. For the base condition with no cap, all cap layers are specified as constant heads.
Fill	11-14	Transitions to Soft Sediment in offshore area of each model.
Soft Sediment	11-14	
Recessional	15-17	
Till	18	Beyond extent of till in the subsurface, layer 18 becomes 1 foot thick and is assigned the properties of the ASD.
ASD	19-20	

The sections extend to the deepest point in the lake in the offshore direction, which allows use of a no-flow boundary at the outer edge of the section. The upland boundary is based on water level measurements from MW-10 and MW-9 for Section A-A' and Section B-B', respectively. No water level data exists for the ASD, consequently, the ASD upland boundary condition was based on an assumption of an upward vertical gradient from the ASD to the recessional outwash. The water level is based on the assumption that the gradient from the upgradient boundary of the model to the lake is 50 percent greater in the ASD than the gradient in the fill/recessional units above the till.

Material Property Parameters

Material property parameters used in the model are hydraulic conductivity, porosity and bulk density. Porosity and bulk density are used only in the transport analysis described below. Model parameters for the different units are shown in Table 2.

Table 2. Summary of model parameters used in the models

Unit	Horizontal Hydraulic Conductivity (ft/d)	K_v/K_h	Porosity[1]	Bulk Density (kg/L)
Cap	100	0.1	0.44	1.48
Fill	1	0.01	0.30	1.80
Soft Sediment	1	0.1	0.88	0.22
Recessional	5	0.01	0.32	1.80
Till	0.01	0.1	0.21	2.10
ASD	5	0.02	0.28	1.90

1) Since all units consist of uncemented material, effective and total porosity should be approximately equal.

With the exception of the cap and soft sediment units, hydraulic conductivity values are taken from site data and experience with similar units in the Puget Sound area. The hydraulic conductivity for the cap is based on a sand cap design. The hydraulic conductivity of the soft sediment unit was based on the void ratio of the soft sediment. The void ratio is related to the porosity by the following relationship:

$$e = \frac{\phi}{1-\phi}$$

where e is void ratio and ϕ is porosity. The relationship between hydraulic conductivity and void ratio was taken from Lambe and Whitman (1969) for silt based on data with a void ratio in the range of 1.5 to 4.0 (porosity of 0.6 to 0.8). The relationship was extrapolated to a void ratio of 7.5 (porosity of 0.88) based on values used by RETEC for analysis of changing void ratio with compaction of soft sediments by a 2-ft sand cap.

Vertical hydraulic conductivity is computed from the K_v/K_h ratio, which is based on professional judgment and the understanding that more homogenized material has a higher ratio. Consequently, the soft sediment, till and cap are assigned higher values than the other units.

Bulk density for the recessional outwash, till and ASD were taken from data in the Puget Sound region for recessional outwash, till and advance outwash deposits. The ASD was assigned a bulk density based on the bulk density of advance outwash. The bulk density of the soft sediment unit was taken from field measurements and the bulk density of the cap was based on professional experience.

Porosity was computed from the bulk density using the relationship:

$$\phi = 1 - \frac{bulk\ density}{particle\ density}$$

The particle density was taken as 2.65 kg/L, which is a typical value for this parameter.

A list of the model parameters and the basis for the values used in the model are presented in Attachment 1.

To: Dan Baker
Date: March 23, 2006
Page: 7

Groundwater Flow

Both section models were used to simulate groundwater flow from the Gas Works Park upland to Lake Union. Simulating groundwater flow is necessary in the Section B-B' model in order to simulate PAH transport. However, simulating groundwater flow in each section model illustrates the groundwater flow conditions in each area. The results of the groundwater flow simulation are presented in Figures 6 and 7 as flow direction vectors based on a particle tracking analysis using the results from the flow simulations.

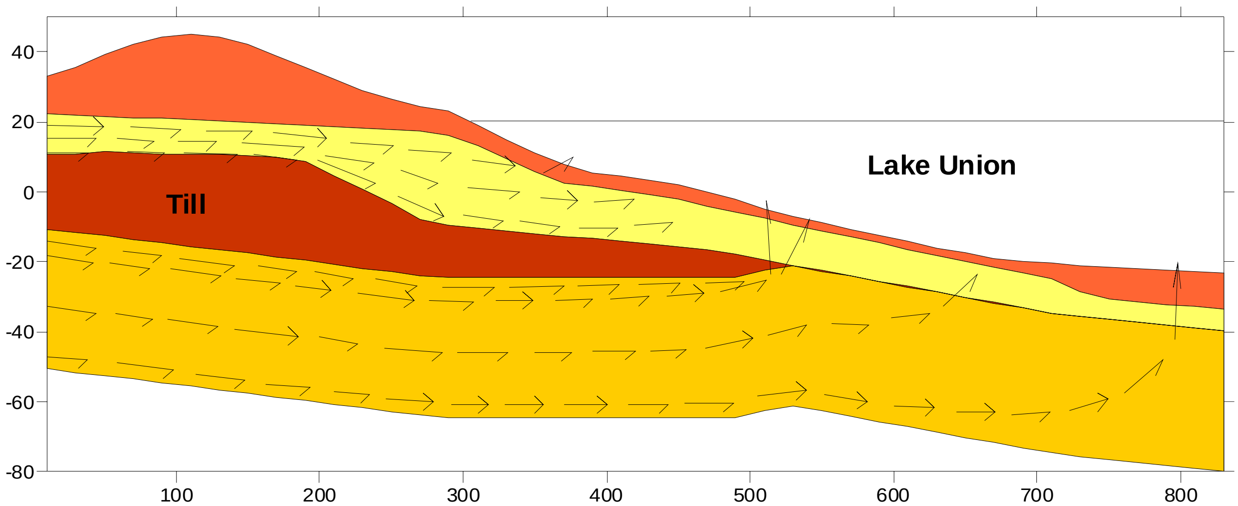


Figure 6. Groundwater flow direction in Section A-A'

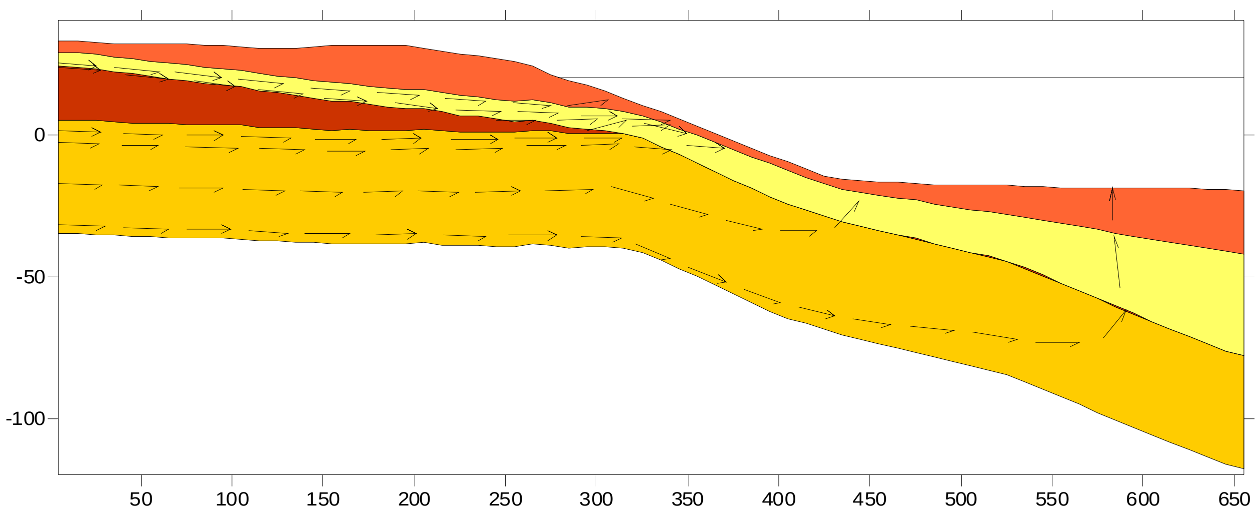


Figure 7. Groundwater flow direction in Section B-B'

Groundwater flow in both sections is quite similar. In both cases, there is little flow in the fill unit as there is very little saturated thickness in the fill at the upgradient model boundary. Flow in the recessional unit is largely horizontal and tends to stay in this unit due to its higher horizontal conductivity as well as the low vertical hydraulic conductivity (low K_v/K_h ratio) in the fill unit. Flow in the ASD is largely horizontal, but becomes vertical after the till unit pinches out. Groundwater flow eventually discharges to Lake Union, but discharge from the recessional unit is farther offshore than would be expected due to the low vertical hydraulic conductivity of the fill unit.

Effect of Capping on Model Parameters

Capping has the potential to compress underlying material. For the fill and recessional outwash the compression is expected to be minimal. However, the soft sediment unit is expected to compress under the weight of a sand cap. To estimate the effect of the sand cap on the soft sediment a compaction analysis was conducted by RETEC.

The compaction analysis indicated that soft sediment in the 0 to 1-ft range would compact to a thickness of 0.4 foot and a void ratio of 2.4 (0.7 porosity). Soft sediment in the 1 to 3-ft range would compact to a thickness of 1.55 feet and a void ratio of 5.6 (0.85 porosity) and soft sediment in the 3 to 6-ft range would compact to 2.44 feet and a void ratio of 5.9 (0.86 porosity). These void ratio values were used to compute a post-capping hydraulic conductivity for the 0 to 1-ft, 1 to 3-ft, and 3 to 6-ft depth intervals. Rather than changing the model layer thickness, the hydraulic conductivity was modified to provide the effective hydraulic conductivity for the reduced thickness of the different depth intervals. The results of this analysis are shown in Table 3.

Table 3. Hydraulic conductivity derived from compaction of soft sediment following capping

Depth range (ft)	Post-capping Hydraulic Conductivity (ft/d)	Effective Hydraulic Conductivity (ft/d)
0-1	5.5e-4	1.4e-3
1-3	6.8e-2	8.7e-2
3-6	1.1e-1	1.3e-1

Post-capping hydraulic conductivity of layers representing soft sediments was adjusted based on the depth of the layer below mudline to account for the compaction. The adjustment for the proportion of a layer in each depth range was made using the harmonic mean (Bouwer, 1978).

Consequently, the hydraulic conductivity of the soft sediment unit varies with both horizontal and vertical location in the post-capping model.

Bulk density also changes due to compaction. However, the compaction causes only a 9% increase in the bulk density in the 0 to 1-ft range with decreasing change with depth. The bulk density is used along with porosity and the sediment-water partitioning coefficient (K_d) in computing the retardation factor for contaminant transport. The change in bulk density and porosity is relatively small and within the certainty with which K_d is known. Therefore, bulk density and porosity were not changed with location and depth in the post-capping model.

Transport Parameters

The primary transport parameters in this analysis are K_d, source concentration/location, and degradation rate. Other transport parameters include soil bulk density and porosity, which are described above. K_d, source concentration/location, and degradation rate are chemical-specific parameters and separate parameter values were developed for naphthalene and chrysene

K_d values were derived from the partitioning analysis conducted at Stanford University. The Stanford results were grouped according to the predominant geologic unit represented in the sample (Table 4). The average K_d value for naphthalene in the fill unit was computed as the average of the NLU55 and NLU68 results. NLU73-Stanford contained anthropogenic carbon and was not considered representative of source area material given its extremely high K_d value. The naphthalene K_d for NLU65 is similar to values for soft sediment samples and was not used for computing the naphthalene K_d of the fill material. The average value for naphthalene in the NLU 55 and NLU68 results is 468, which was rounded to 500 L/kg for this analysis. The average K_d value for the soft sediment unit was computed from all of the soft sediment sample data with the exception of CR10, which contains NAPL and consequently has an unusually high K_d. This produced a soft sediment K_d of 2070. A value of 2000 L/kg was used in the analysis.

Table 4. Sediment/water partitioning coefficients computed from sampling results

Sample ID	Lithology	K_d (L/kg)	
		Naphthalene	Chrysene
NLU55-SS-0010	Fill	135	9.9E+04
NLU65-SS-0010	Fill	2258	4.0E+05
NLU68-SS-0010	Fill	706	1.5E+05
NLU68-US-S1	Fill	528	1.4E+05
NLU68-US-S2	Fill	500	6.1E+04
NLU73-Stanford	Fill	10516	6.3E+06
NLU56-SS-0010	Fill/Soft Sediment borderline	836	5.5E+04
CR10-NAPL	Soft Sediment	5012	7.9E+06
NLU45-DC	Soft Sediment	2755	1.5E+05
NLU47-SS-0010	Soft Sediment	1655	5.6E+05
NLU51-SS-0010	Soft Sediment	2606	2.2E+05
NLU58-SS-0010	Soft Sediment	1798	4.2E+05
NLU62-SS-0010	Soft Sediment	775	4.0E+05
NLU64-SS-0010	Soft Sediment	4225	2.8E+05
NLU72-SS-0010	Soft Sediment	887	3.9E+05
NLU73-SS-0010	Soft Sediment	1859	9.6E+05
NLU73-SS-0010	Recessional Outwash	56	2.6E+04

For chrysene a similar approach was used. The K_d for the fill unit was computed as the average K_d from the NLU55 and NLU68 samples. This gives a chrysene K_d in the fill of 1.1e5 L/kg. The chrysene K_d for soft sediments was computed as the average for all soft sediment samples excluding CR10. This gives a chrysene K_d in soft sediment of 4.2e5 L/kg.

In both the naphthalene and chrysene simulations, the top-most soft sediment layer and the bottom-most cap layers were assumed to be a mixture of the cap and native sediment material. Consequently, the K_d in these layers was taken as the average of the cap K_d and the soft sediment K_d.

Source areas were identified for naphthalene and chrysene by RETEC using a delineation of NAPL-impacted areas and contouring of naphthalene and chrysene sediment concentrations in the model cross section. The highest concentrations generally occur near the interface between the recessional outwash and the overlying fill or soft sediment units. Consequently, the source area was defined as the upper model layer representing the recessional outwash and the lower model layer representing the fill or soft sediment. In addition, in the area from the shoreline to CR-10, the middle model layer representing the fill unit was also identified as a source area to

To: Dan Baker
Date: March 23, 2006
Page: 11

represent the elevated levels of naphthalene and chrysene in shallow core samples at sampling locations NLU55 and CR10.

Source area concentrations were developed by computing the concentration in groundwater from the soil concentration using the K_d values discussed above. For both naphthalene and chrysene, the direct conversion of soil concentration to groundwater concentration resulted in some concentrations above the solubility limit. Consequently, the concentration was limited to the solubility for each compound: 31,900 ug/L for naphthalene and 2.5 ug/L for chrysene. The solubility limit was based on values tabulated in Mackay et al. (2000). For cross-section B-B', the source areas for naphthalene and chrysene are shown in Figures 8 and 9.

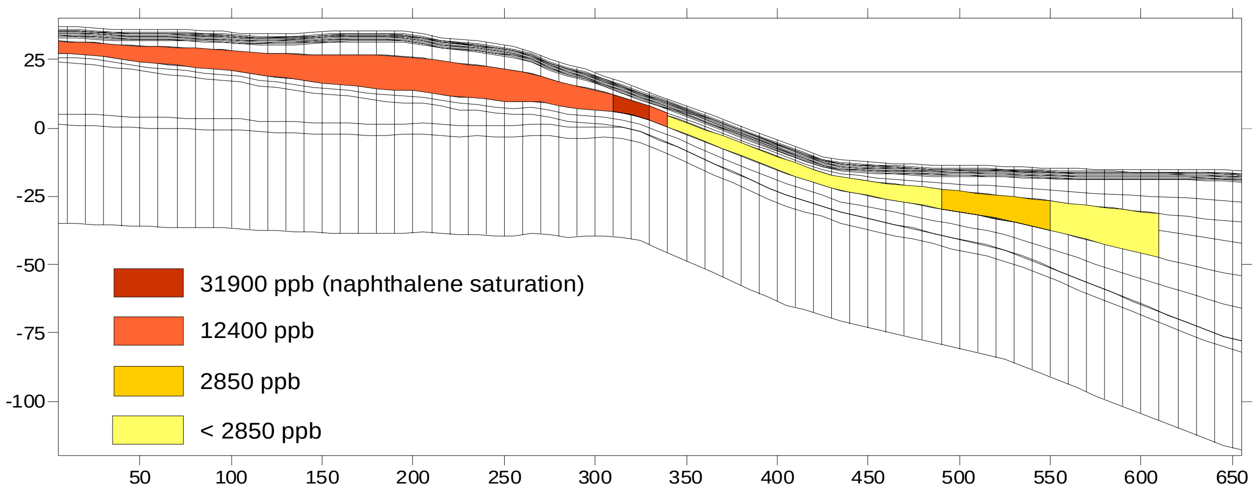


Figure 8. Naphthalene source area concentration in groundwater

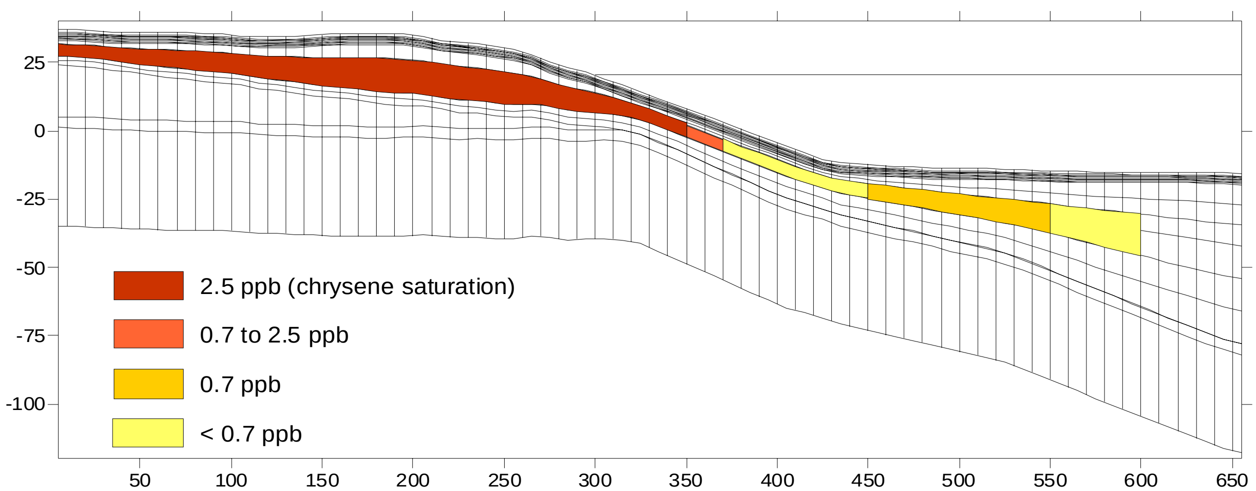


Figure 9. Chrysene source area concentration in groundwater

The source area concentration for naphthalene was applied in the model with no cap present to estimate the ambient concentration in sediments prior to capping. This approach proved to be very conservative as the predicted concentration of naphthalene in surficial sediments was more than ten times higher than the highest concentration detected in surficial sediments (Figure 10).

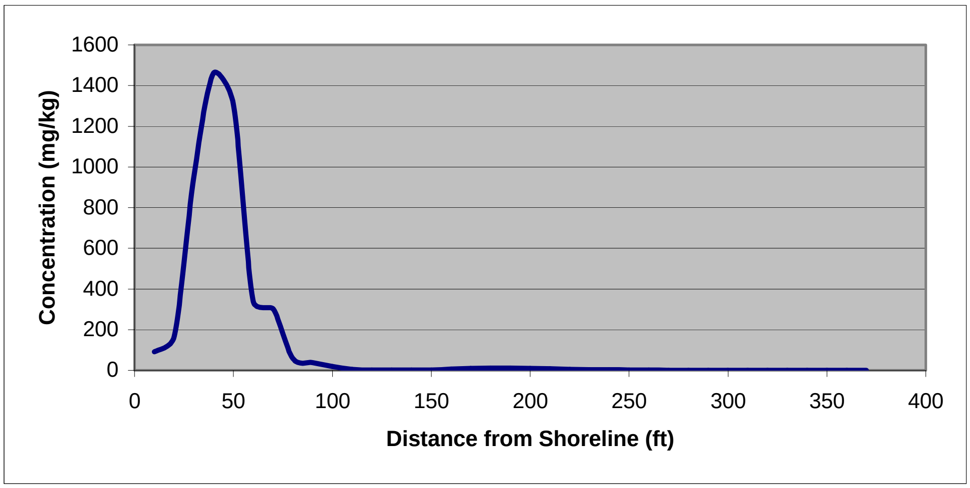


Figure 10. Starting naphthalene concentration in surficial sediments for the sediment cap simulations.

The same approach was used for chrysene. However, due to the slow migration rate of chrysene in groundwater, the predicted concentration was not as high as the concentration detected in surficial sediment. Therefore, a more conservative approach was taken. The source area concentration was applied to just below the mudline (layers 12 to 15). For the surficial sediment layer (layer 11), the maximum concentration in the source area is higher than the maximum chrysene concentration detected in surface sediment samples. Therefore, the maximum detected chrysene concentration in surficial sediment was used as the initial chrysene concentration in the surficial sediment layer in areas with chrysene above 1 mg/kg in the subsurface (Figure 11).

Figure 11. Starting chrysene concentration in surficial sediments for the sediment cap simulations.

The degradation rate for naphthalene was investigated by two methods. The first method used the model to match the concentration profile at NLU52 and NLU55. Both sampling locations are located on Section B-B' and have concentration data at depth and near or at the sediment surface. This is essentially a calibration of the model degradation rate to the data. The model calibration focused on NLU55 data as this location produced a longer half-life than data from NLU52. The half-life from this analysis is approximately 19 years.

The second degradation analysis consisted of a simple one-dimensional advection analysis of the data for NLU55. In this analysis, the degradation rate was derived from the relationship:

$$C = C_0 * e^{(-k*\frac{x}{v})}$$

where:

- C_0 is the concentration at depth,
- C is the concentration at the sediment surface,
- x is the distance between the locations of the two samples,
- v is the retarded groundwater velocity, and
- k is the degradation rate.

The degradation rate computed by this method is 40 years. This method gives a conservatively high estimate of the degradation rate as it does not account for transverse dispersion. The two methods of analysis give a range of degradation rates from 19 to 40 years and represent a reasonable estimate of degradation rate and a reasonable worst-case degradation rate.

The degradation rate for chrysene was computed using the one-dimensional advection analysis described above. The degradation half-life was computed at more than 15,000 years. Given this long timeframe, the cap simulations for chrysene were conducted assuming no degradation.

A summary of the transport parameters used in the model is presented in Table 5.

Table 5. Summary of transport parameters used in the Section B-B' model

	Lithologic Unit	Degradation Half Life (yrs)	Sediment-Water Partitioning Coefficient (L/kg)	Maximum Source Concentration (ug/L)
Naphthalene				
	Cap	19, 40	3.1	0
	Fill	19, 40	500	31900
	Soft Sediment	19, 40	2000	31900
Chrysene				
	Cap	0	287	0
	Fill	0	1.1e5	2.5
	Soft Sediment	0	4.2e5	2.5

Cap Model Results

The model was setup to simulate a 24-inch cap by setting the Lake Union boundary condition in layer 5 and layers 6 through 10 are the cap layers (see Table 1). The same transport model parameters from the analysis without a cap were used in this analysis.

<u>Naphthalene</u>

Naphthalene transport was simulated for a period of 200 years. Simulations were conducted using both the 19-yr and 40-yr half-lives discussed above. In both cases, the maximum concentration at the top of the cap stabilized within 200 years at a naphthalene concentration of 350 ug/L with the 19-yr half-life and 1000 ug/L with the 40-yr half-life (Figure 12). Based on the K_d value used for the cap material, the maximum naphthalene concentration in groundwater corresponds to a concentration of 1.1 and 3.1 mg/kg in sediment for the 19-yr and 40-yr half-life simulations, respectively.

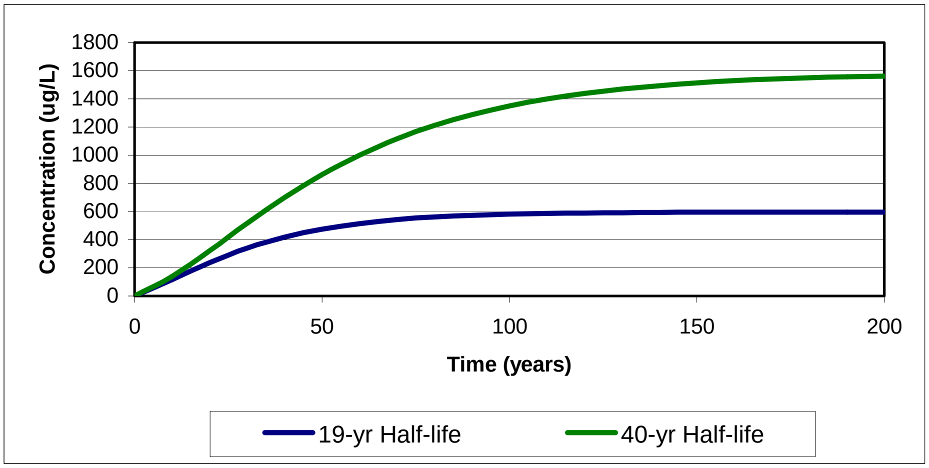


Figure 12. Maximum Naphthalene concentration at top of cap over time

The highest naphthalene concentration occurs over a short segment of the cap directly over the highest concentration material associated with sampling location CR-10 (Figure 13). For most of the cap, the naphthalene concentration is below 10 ug/L.

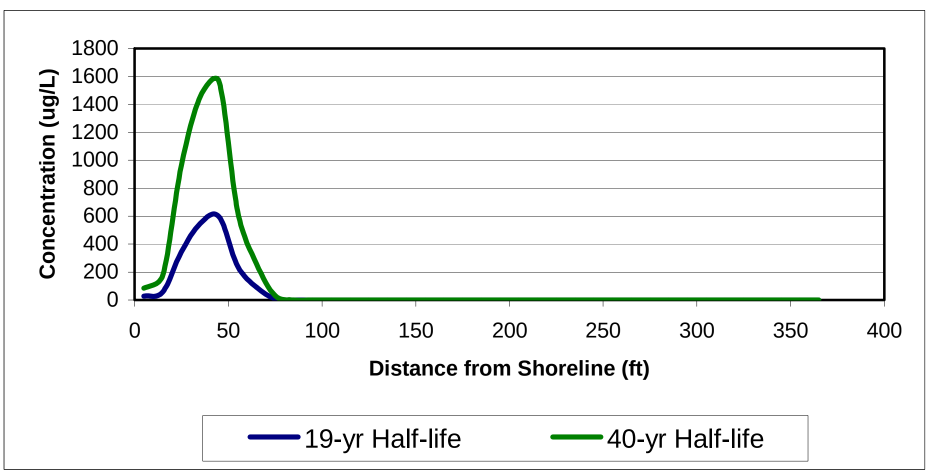


Figure 13. Naphthalene concentration in the top of the cap with distance from the shoreline

Chrysene

Much longer simulation periods were required to show transport of chrysene through the cap than for naphthalene due to the high K_d for chrysene. For chrysene, the simulation period was extended to 10,000 years. The chrysene simulation was conducted without using a degradation half-life as discussed above. The maximum concentration of chrysene at the top of the cap had not stabilized after a 10,000-yr simulation period (Figure 14). However, longer simulation analyses are not warranted given that significant sedimentation can be expected to occur over a 10,000-yr period. Based on the K_d value used for the cap material, the maximum chrysene concentration in groundwater corresponds to a concentration of 0.1 mg/kg in sediment over a period of 10,000 years.

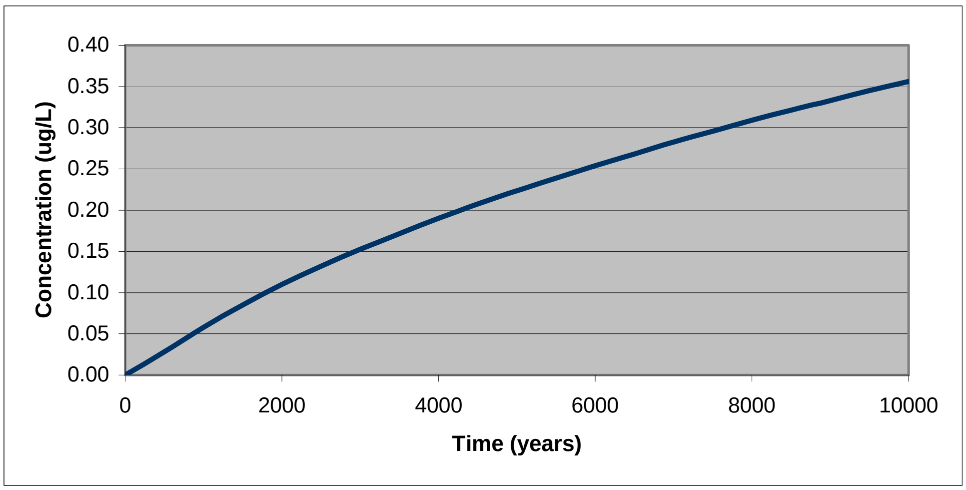


Figure 14. Maximum Chrysene concentration at top of cap over time

Model Sensitivity

Model sensitivity refers to the effect of individual model parameters on model results. Model sensitivity was investigated with respect to the naphthalene degradation rate. Two degradation rates were computed by two different methods giving degradation half-lives of 19 and 40 years. The model is fairly sensitive to naphthalene degradation rate as a doubling of the degradation rate resulted in a 3-fold increase in predicted naphthalene concentration at the top of the sediment cap. However, both degradation rates are conservative as they produced higher concentrations at the mudline in a simulation without a cap than observed in site data.

Summary and Conclusions

Groundwater flow models were constructed for two cross sections starting from Gas Works Park and extending into North Lake Union. Model parameters were developed from site data and regional data for the geologic units identified in the section.

One model was used in a transport analysis to simulate the migration of naphthalene and chrysene through a 2-ft sand cap that may be used as part of a remedy for the offshore area in North Lake Union. The model used conservatively reasonable and reasonably worst-case parameters in the analysis. Among these parameters are:

- Naphthalene degradation rate derived through model calibration of observed naphthalene profiles in sediment as a reasonable estimate of the naphthalene degradation rate;
- Naphthalene degradation rate derived using a one-dimensional advection model and sediment profile data as a reasonable worst-case estimate of the naphthalene degradation rate;
- Chrysene transport analysis conducted assuming no degradation;
- Sediment-water partitioning factors (K_d) derived from laboratory data;
- Source area concentrations set at the solubility limit of both naphthalene and chrysene in some areas of the model.
- Ambient sediment concentrations at the cap sediment interface set greater than or equal to the highest detected concentrations of naphthalene and chrysene in surface sediments.

The results of this analysis indicated that:

- Naphthalene migration through the cap would not reach concentrations at the mudline above the MTCA Method B surface water cleanup level for either of the degradation rates used in the analysis;
- Chrysene migration through the cap would not exceed the Method B surface water cleanup level within approximately 1500 to 2000 years.
- Migration of naphthalene and chrysene results in concentrations in the sediment cap at the mudline that are lower than (i.e. meet) site cleanup goals.

References

Aspect Consulting, LLC. 2005. Seattle-Tacoma International Airport Phase 1 Groundwater Study. Prepared for the Port of Seattle.

Converse Consultants and Pacific Groundwater Group. 1993. Southwest Harbor Cleanup and Redevelopment Project Sediment Dredge Disposal Containment Model Study. Prepared for the Port of Seattle, Washington Department of Ecology and U.S. Army Corps of Engineers.

Bouwer, H. 1978. Groundwater Hydrology. McGraw-Hill Book Company, New York.

Lambe, T.W. and R.V. Whitman. 1969. Soil Mechanics. John Wiley & Sons, New York.

Mackay, D., Wan-Ying Shiu, and Kuo-Ching Ma. 2000. Physical-Chemical Properties and Environmental Fate Handbook. Chapman & Hall/CRCnetBASE.

Attachment L-1

Parameter Development for Groundwater Model Study

101 N. CAPITAL WAY, SUITE 107, OLYMPIA, WASHINGTON 98501
TEL: (360) 709-9540 FAX: (360) 709-0964 E-MAIL: MRILEY@SSPA.COM

North Lake Union: Parameter Development for Ground Water Model

Parameter	Value	Rationale/Source
Effective Porosity		
Cap	0.44	Professional judgement
Fill	0.3	Professional judgement
Sediment	0.9	Computed from field sampling
Recessional Outwash	0.32	Computed from Bulk Density using porosity = (1 - bulk density/particle density), where 2.65 was used for the particle density.
Till	0.21	Computed from Bulk Density using porosity = (1 - bulk density/particle density), where 2.65 was used for the particle density.
ASD	0.28	Computed from Bulk Density using porosity = (1 - bulk density/particle density), where 2.65 was used for the particle density.
Bulk Density (kg/L)		
Cap	1.48	Computed from porosity as Bd = 2.65*(1-porosity), where 2.65 is the average soil grain density.
Fill	1.80	Computed from porosity as Bd = 2.65*(1-porosity), where 2.65 is the average soil grain density.
Sediment	0.22	Site-specific geotechnical data
Recessional Outwash	1.80	Based on data for Q_{vr} in Puget Sound Area
Till	2.10	Based on data for Q_{vt} in Puget Sound Area
ASD	1.90	Based on data for Q_{va} in Puget Sound Area
Kx (ft/day)		
Cap	100	Professional judgement
Fill	1	Professional judgement
Sediment	1	Computed from porosity (Lambe and Whitman, 1969)
Recessional Outwash	5	From site pump test data
Till	0.01	Based on till values used in the Seattle-Tacoma Airport GW model
ASD	5	Assumed to be the same as Recessional Outwash
Kv/Kx		
Cap	0.1	Professional judgement
Fill	0.01	Professional judgement
Sediment	0.1	Professional judgement
Recessional Outwash	0.01	Professional judgement
Till	0.1	Professional judgement
ASD	0.02	Professional judgement
Naphthalene K_d (L/kg)		
Cap	3.1	Based on K_{ow} (Montgomery, 1996) and site-specific foc and doc
Fill	500	From Stanford analysis
Sediment	2,000	From Stanford analysis
Degradation Half-life (years) Naphthalene		
Cap	19	Same rate as for fill and sediment units assumed for cap
Fill	19	From model calibration to sediment naphthalene data
Sediment	19	From model calibration to sediment naphthalene data
Max Source Conc (ug/L) Naphthalene		
Cap	0	
Fill	31,900	Solubility Limit (Mackay et al., 1997)
Sediment	31,900	Solubility Limit (Mackay et al., 1997)
Chrysene K_d (L/kg)		
Cap	287	Based on K_{ow} (Montgomery, 1996) and site-specific foc and doc
Fill	1.1E+05	From Stanford analysis
Sediment	4.2E+05	From Stanford analysis
Degradation Half-life (years) Chrysene		Note: Chrysene simulation conducted without including degradation.
Cap	2.4E+04	Same rate as for fill and sediment units assumed for cap
Fill	2.4E+04	From model calibration to sediment naphthalene data
Sediment	2.4E+04	From model calibration to sediment naphthalene data
Max Source Conc (ug/L) Chrysene		
Cap	0	
Fill	2.5	Solubility Limit (Mackay et al., 1997)
Sediment	2.5	Solubility Limit (Mackay et al., 1997)

Lambe, T.W., and R.V. Whitman, 1969. **Soil Mechanics**, John Wiley & Sons, New York, New York.
Mackay, D., W. Shiu, and K. Ma, 1997. **Physical-Chemical Properties and Environmental Fate Handbook**. CRC Press.
Montgomery, J.H. 1996, **Groundwater Chemicals Desk Reference**. Lewis Publishers.

APPENDIX 3G
Hydrodynamic Data Evaluation

Table of Contents

ATTACHMENTS

APPENDIX 3G
HYDRODYNAMIC DATA EVALUATION

Appendix 3G presents a summary of the hydrodynamic conditions in Lake Union along the shoreline and in the sediment portion of the Area of Investigation (AOI). The purpose of the hydrodynamic field study was to evaluate erosive forces on existing sediment surfaces within the AOI. The RETEC Group, Inc. (RETEC) prepared a summary of hydrodynamic conditions to support a remedial investigation/feasibility study (RI/FS) for the eastern portion of the Gas Works Park Site (GWPS). RETEC's summary was prepared for Puget Sound Energy (PSE) at a time when the City of Seattle and PSE had divided the sediment portion of the AOI into the Western and Eastern Study Areas to allocate remedial investigation/feasibility study work. Their evaluation and conclusions were intended for feasibility study-level analysis and not for use as the basis of design for the in-water cleanup action.

RETEC's summary was submitted to Washington State Department of Ecology (Ecology) in March 2006 as Appendix B of an earlier draft RI/FS report. RETEC updated their work in 2007. This summary of hydrodynamic conditions beginning with "North Lake Union Hydrodynamics" (Page B-1) provides RETEC's updated work. GeoEngineers assembled Attachment 3G-1 from the original text, table, figure, and attachment files provided by AECOM (RETEC's successor) because AECOM did not provide an assembled summary report (they provided the original report and updated component files). GeoEngineers did not modify the individual 2007 RETEC files or technical content of the summary.

The hydrodynamic conditions summary uses the term "North Lake Union Remediation Project." In this case, "North Lake Union" refers to an area generally consistent with the sediment portion of the AOI. RETEC's summary applies to the eastern half of the sediment portion of the AOI where the field study was focused (see current meter locations in RI Figure 3-1).

ATTACHMENT 3G-1
North Lake Union Hydrodyanmics

DRAFT

REVISED (12-06-2007)

Appendix B

North Lake Union Hydrodynamics

North Lake Union Hydrodynamics

1.0 Introduction

Lake Union is a 0.6 square mile (388 acre) lake in the center of the Lake Washington Ship Canal (see Nautical Chart 18447) that extends from Shilshole Bay in Puget Sound to Lake Washington. Knowledge of the motion of water in North Lake Union (NLU) off Gas Works Park (GWP) is important to address such Project issues as:

- Determining design criteria to be used in addressing sediment-water interface interactions during the feasibility phase of the North Lake Union Remediation Project.
- Determining if the lake shoreline requires additional protection as part of the remediation.
- Determining the requirements for a stable cap, should capping be a viable option as part of the remediation.

Some understanding of North Lake Union hydrodynamics is needed to address the above issues and to develop criteria for subsequent feasibility engineering activities. To this end, a series of field investigations and modeling efforts were carried out to assess North Lake Union hydrodynamics.

Forces influencing water movement in the lake are both natural and man-made. The primary natural force is wind. Wind creates shallow surface currents through friction and waves through momentum transfer from the air to the water. The primary man-made forces include water releases through the Hiram M. Chittenden Locks and Dam at the west end of Salmon Bay and vessels transiting the north end of the lake. Water releases cause the water in the ship canal system to flow from Lake Washington to the Sound, thereby setting up a general westward flow of water through Lake Union. Transiting vessels are capable of generating surface wakes (waves) and propeller wash currents further down in the water column.

This appendix summarizes the investigations and modeling efforts to assess the hydrodynamics of North Lake Union as it pertains to addressing issues for the remediation of sediments along the north shore of Lake Union. The appendix topics include winds over Lake Union, wind-generated currents and wind-generated waves influencing the lakes north shoreline, water releases at the dam and locks and the resulting general circulation through North Lake Union, and transiting vessel-generation of wakes and propeller wash and their influence on the north shore of the lake. Knowledge of water motion, whether due to waves or currents, is important in assessing the potential for sediment erosion and transport and for designing shore protection and sediment capping in conjunction with the North Lake Union Remediation.

2.0 Wind

Wind information is necessary to assess wind-generated waves and wind-driven currents in the lake. There are no known wind measurement records for Lake Union. Limited wind measurement records are available from the Washington State Department of Transportation (WSDOT) at the SR 520-Evergreen Point Floating Bridge and from the National Data Buoy

Center (NBDC) Station WPOW1 at West Point. Both sites are considered representative of Lake Union, wind-wise, in that they measure over-water winds and are open to the south, which is the predominate wind direction in the area. The SR 520-Evergreen Point Bridge recording station is approximately 3.6 miles east of Lake Union and provides real-time wind information via a WSDOT website. No attempt has been made to obtain historical records from the WSDOT. The NBDC station is 4.7 miles west of Lake Union and provides both real-time and historical wind data via an NBDC website. The historical wind records for the NBDC station are from 1984 to the present. An example of the NBDC wind data is given in Attachment B-1, which includes wind data for the three months of current meter deployments in 2005. The NBDC has run and made available the statistics on the wind data from 1994 through 2001. Translating the wind data from West Point to Lake Union, the average winds on Lake Union are expected to vary from a high of 11.8 knots (6.1 m/s) in December of any year to a low of 6.9 knots (3.6 m/s) in July or August of any year, blowing typically from the south.

2.1 Wind-Generated Currents

There is a rule-of-thumb that wind-generated currents in an open body of water like Lake Union are 3% of the wind speed and, more or less, in the direction of the wind. The depth of the wind-generated currents is very shallow, generally taken to be on the order of a few inches (deeper with higher wind speeds). Using this rule-of-thumb, average wind-generated currents in the upper few inches of Lake Union are on the order of 0.60 ft/sec (18 cm/s) in the winter and about 0.35 ft/sec (11 cm/s) in the summer.

2.2 Wind-Generated Waves

There are no known wave measurements for North Lake Union upon which to base design criteria for shoreline structures and operations along the north shore of Lake Union. In the absence of wave data, the wave design criteria are obtained from modeling wind-generated waves for the lake. The longest fetch (length and direction) and the highest wind speeds are used in U.S. Army Corps of Engineers (USACE) models to calculate storm wave statistics for North Lake Union. The wave statistics can then be used as design criteria for those analyses and design elements involving wave impacts.

The longest fetch to North Lake Union is 6,358 feet (1,938 m) from due south, as measured from Nautical Chart 18447 (26th Ed., Jan. 25/1997) published by the National Oceanic and Atmospheric Administration – National Ocean Service – Coast Survey. The fastest mile wind speed is 66 miles per hour (mph) from the south recorded in November 1981 as reported in *Seattle, Washington, Seattle-Tacoma Airport Normals, Means, and Extremes* and obtained from website www.wrcc.dri.edu/cgi-bin/clilcd.pl?wa24233. The elevation of the wind instrument is 400 feet above sea level and is over land. The average height of the wind instrument over surface ground level for the period 1981-2001 is 7.1 meters. The USACE (1974) compiled a Wind Velocity Duration Curve (see Attachment B-2) for Lake Washington using a variety of sources, including selected storm records from the SR 520 Bridge. Winds with durations of 30 minutes (1,800 seconds) and 60 minutes (3600 seconds) are selected as being representative of reasonable storm duration winds for wave generation. The associated wind speeds from the USACE curve are 64 mph and 58 mph, respectively. For reference, this is very close to the maximum peak wind speed measured at West Point for the 1994-2001 period discussed above.

The wind speed, wind gage height above surface ground level, and fetch are input into an MSExcel spreadsheet (see Attachment B-3) based on the calculation methods outlined in the Coastal Engineering Manual (USACE, 2002).

The results of the calculations show that a storm wave impinging on the north shoreline of Lake Union has a peak wave period of 1.8 to 1.9 seconds, a significant wave height of 2.0 to 2.4 feet, an H_{10} of 2.5 to 3.1 feet, and a maximum wave height of 3.7 to 4.5 feet, depending on whether the fastest mile wind speed or 30-minute-duration wind speed is used. The calculation of the fetch-limited generation duration (1,841 seconds in Step 13 in Attachment B-3) verifies that the 30-minute-duration wind speed is the closest wind speed to maximum sustainable for wave generation. Therefore, the design wave characteristics for North Lake Union are a wave period of 1.9 seconds, a significant wave height of 2.44 feet, an H_{10} of 3.1 feet, and a maximum wave height of 4.5 feet.

The horizontal and vertical extent of wave action along the lake shoreline is controlled by the USACE manipulation of the water levels in the Lake Washington Ship Canal. The USACE holds the lake level at elevation +22 feet (Corps Datum) in the summer months for recreational reasons and drops the lake level to +20 feet (Corps Datum) in the winter for flood control reasons. This means that the influence of wave action can reach at least as high as about +25 feet (Corps Datum) in the summer due to wave up-rush on the shoreline. Wave influence can be felt as low as about +10 feet (Corps Datum) in the winter, the level where wave orbital motion associated with a 2.44-foot high wave becomes negligible.

3.0 Current Meters

Water flow in the Lake Washington Ship Canal, and by extension, in Lake Union is controlled by water releases from the USACE's Hiram M. Chittenden Locks and Dam. The USACE is mandated by Congress to operate the locks and dam so that water levels in the ship canal are maintained between elevations +20 and +22 feet (Corps Datum). A summary hydrograph is presented in Attachment B-4. By manipulating water levels in the ship canal, the USACE induces flow, as current, throughout the Lake Washington Ship Canal system, including Lake Union. To assess the currents in North Lake Union, current meters were deployed in 2005.

To study the currents in North Lake Union, an acoustic Doppler current profiler (ADCP) and two vector averaging current meters (VACMs) were deployed at the north end of the lake. The purpose of the ADCP current meter data collection and analysis was to determine the vertical distribution of currents in North Lake Union past the Gas Works Park Sediment Site, herein referred to as the Gas Works Sediment Area (GWSA), and to assess whether currents are sufficiently strong to produce erosion forces on the sediments. The purpose of the VACM data collection and analysis was to determine if sediments in North Lake Union are subjected to erosion forces, and more specifically, to determine the maximum current to which the sediment-water interface will be subjected and use it as one of the design criteria for subsequent engineering analysis and design.

3.1 Acoustic Doppler Current Profiler

An ADCP was deployed off Gas Works Park on 21 January 2005. The ADCP mooring consisted of a cinder block anchor, a short cable/line to an acoustic release attached to the bottom of a meter-encapsulating float. The ADCP was deployed in about 41 feet of water and about 340 feet east of Gas Works Park. When deployed, the meter was adjusted so that the ADCP transducer was about 5 feet (1.5 meters) above the mudline. The meter was set to record the 10-minute averaged current speed and direction in 30 1-foot (0.3 meter) bins starting 3.3 feet (1 meter) above the transducer. The meter was retrieved on 18 February 2005 using the acoustic release. Each ADCP data record included:

- the date in year, month, and day;
- time reported on a 24-hour clock in hours, minutes, and seconds relative to Pacific Standard Time (PST);
- pitch of the transducer, in degrees;
- roll of the transducer, in degrees;
- orientation of the third beam of the transducer, in degrees;
- water temperature, in degrees Celsius;
- depth of the transducer, in meters;
- 30 bins of speed, in millimeters per second;
- 30 bins of direction, in tenths of degrees.

All data were measured every second. The data were then averaged over a 10-minute period and recorded. The 10-minute averages for the deployment period of 1/21 to 2/18/2005 yielded 4,003 records of data. The graphical records were assessed for current speed and direction as a function of time and depth in the water column. An example summary and plots of the current speed and direction by depth are given in Table B-1 and Attachment B-5, respectively.

Table B-1. Summary of the ADCP Current Meter Records* Used in the Analysis.

Date	Time (PST)	Avg. Vel. (cm.sec)	Min. Vel. (cm.sec)	Max. Vel. (cm.sec)	Direction (deg from N)	Depths (ft)
1/22/2005	0800	2.7	0.8	5.6	80-240	5-37
1/24/2005	1140	2.4	.6	3.8	000-300	5-37
1/28/2005	0000-2400	2.6	0.2	17.3	000-360	13
1/29/2005	1000	4.0	1.8	7.0	170-310	5-37
2/4/2005	1250	3.5	1.9	6.2	140-310	5-37
2/8/2005	0130	2.0	0	4.9	030-310	5-37

* See associated charts in Attachment B-5.

Analyzing the data contained in Attachment B-5 and summarized in Table B-1, it is evident that the currents at the meter deployment location were slow, averaging less than 4.0 cm/sec generally flowing in a southwesterly direction, and averaging about 181 degrees magnetic from North. The maximum 10-minute average current occurred on Friday, 28 January 2005 at 2140 Pacific Standard Time, at a depth of 13 feet (4 meters) below the lake surface. The maximum current speed spiked at 17 cm/sec in a northerly direction between depths of 12 to 14 feet, whereas the rest of the water column was slow and southwesterly. This is consistent with water draining from the Lake Washington Ship Canal System, of which Lake Union is a part, through the Hiram M. Chittenden Locks and Dam. As water is released by the dam or locks, the water level is lowered at the dam and locks. This creates a water surface gradient in the Lake Washington Ship Canal System that forces water to flow slowly from Lake Washington, through NLU around the point at GWP, and toward the dam and locks.

The spike in current speed and change in direction at 2140 on 28 January 2005 is assumed to be associated with the passage of a large vessel. The propeller wash would most likely be felt at the depth of 12 to 14 feet. If transiting southward, the propeller wash would force a jet of water northward at high speed, estimated to be in excess of 20 meters per sec (200 cm/sec). If the jet lasted only a few tens of seconds, the 10-minute averaging would decrease the average speed to about a tenth of the jet speed. The rest of the water column, above and below the jet, would continue to flow with its general speed and direction as discussed above. As indicated on the daily time-chart (see Attachment B-5) for Bin 22 (depth of 13 feet below lake level), after passage of the vessel, the current returned to its slow southwesterly flow.

3.2 Vector Averaging Current Meters

Two VACMs, InterOcean S4s, were deployed off GWP on 21 January 2005. Each VACM mooring consisted of a cinder block anchor, a short cable/line to an acoustic release. The acoustic release was attached to the bottom of the S4. A short cable/line extended from the top of the S4 to a 14-inch vinyl float. One VACM, designated S4-1, was deployed in about 38 feet of water and about 320 feet south of GWP. The other VACM, designated S4-2, was deployed in about 10 feet of water and about 90 feet south of GWP. Both S4 meters were retrieved on 31 January 2005. The meters were serviced and the data removed. The two S4s were redeployed on 4 February 2005 in essentially the same location and configuration as the first deployment. On 18 February 2005 both meters were again retrieved. The two VACMs were redeployed off Gas Works Park on 5 August 2005. The VACM designated S4-1 was again deployed in about 38 feet of water and about 320 feet south of GWP, essentially the same location as the January/February 2005 deployments. The other VACM, now designated S4-3 because its location changed, was deployed in about 25 feet of water and about 90 feet east of GWP. Both S4 meters were retrieved on 15 August 2005.

The data file for each meter contained between 1.3 and 1.6 million records of current speed and direction as a function of time per deployment. Current speed and direction data from the VACMs were downloaded from the current meters, processed via ACCESS, and tabulated. The data were partitioned as a function of sixteen speed and sixteen direction intervals, or a sixteen by sixteen tabular matrix for each deployment of each meter. The speed and direction intervals are given in Table B-2. The current speed and direction data were reported as both percent and ½-second counts of each total deployment record. The speed versus direction tabulations from the VACMs are presented in Attachment B-6. Simple current speed statistics from each VACM current record, by date and location, are presented in Table B-3.

Table B-2. VACM Current Speed* and Direction Data Intervals.

Interval No.	Speed Interval (cm/sec)	Direction Interval (˚ from North)
1	0-10	348.76-011.25
2	10.1-20	011.26-033.75
3	20.1-30	033.76-056.25
4	30.1-40	056.26-078.75
5	40.1-50	078.76-101.25
6	50.1-60	101.26-123.75
7	60.1-70	123.76-146.25
8	70.1-80	146.26-168.75
9	80.1-90	168.76-191.25
10	90.1-100	191.26-213.75
11	100.1-150	213.76-236.25
12	150.1-200	236.26-258.75
13	200.1-250	258.76-281.25
14	250.1-300	281.26-303.75
15	300.1-350	303.76-326.25
16	350.1-400	326.26-348.75

* Note that the current speed partitions change interval at 100 cm/sec.

Table B-3. Current Speed Statistics for the VACMs Deployed off Gas Works Park in North Lake Union.

Meter (Depth)	Deployment From To	Number of Measurements (1/2-Second Intervals)	Length of Record (Days)	Maximum Speed (cm/sec)	Minimum Speed (cm/sec)	Mean Speed (cm/sec)	Median Speed (cm/sec)	95-Percentile Speed (cm/sec)	99-Percentile Speed (cm/sec)
S4-1 (38 feet)	21 Jan 2005 31 Jan 2005	1,357,635	7.8	160	0	3.5	2.7	8.8	14.8
S4-1 (38 feet)	4 Feb 2005 18 Feb 2005	1,383,110	8.0	188	0	3.7	2.8	9.5	15.5
S4-1 (38 feet)	5 Aug 2005 15 Aug 2005	1,754,881	10.1	326	0	3.7	3.0	9.1	14.4
S4-2 (10 feet)	21 Jan 2005 31 Jan 2005	1,574,520	9.1	333	0	5.5	4.3	13.8	20.3
S4-2 (10 feet)	4 Feb 2005 18 Feb 2005	1,595,292	9.2	350	0	8.9	5.3	22.8	90.7
S4-3 (25 feet)	5 Aug 2005 15 Aug 2005	1,754,881	10.1	397	0	7.0	5.8	16.0	26.0

An analysis of the data summarized in Attachment B-6 for the deeper S4-1 meter indicate that virtually all of the currents (99%) were below 16 cm/sec with dominant directions (>10% each direction) to the east,west-southwest, and west. The mean and median speeds were 4 and 3 cm/sec, respectively. The 95- and 99-percentile speeds were approximately 9 and 15 cm/sec, respectively. Forty-five half-second measurements, over a total recording period of 26 days, were greater than 100 cm/sec. The maximum speed was 326 cm/s with a direction toward the north-northwest.

The data for the meter designated S4-2 in 10 feet of water exhibited a high degree of speed variability between the January and February recordings. In January, mean speed was 6 cm/sec; whereas the February mean speed was 9 cm/sec. Likewise, the 95- and 99-percentile speeds showed an increase from January to February. In January the 95- and 99-percentile speeds were 14 and 20 cm/sec, respectively; but in February the 95- and 99-percentile speeds increased to 23 and 91 cm/sec, respectively. The maximum speeds were closer, being 333 cm/sec toward the north in January and 350 cm/sec toward the northeast in February. Note that over 13,200 half-second measurements, over a total recording period of 18 days, were greater than 100 cm/sec with dominant directions to the east and west.

At the meter location in 25 feet of water designated as S4-3, virtually all of the currents were less than 26 cm/sec and the dominant directions were north-northwest through north-northeast and south. The 95- and 99-percentile speeds were 16 and 26 cm/sec, respectively. Twenty-seven half-second measurements were greater than 100 cm/sec with the maximum speed of 397 cm/s with a direction toward the east-northeast.

The statistics indicate that, generally, the currents were slow but with rare, intermittent speed spikes approaching 300-400 cm/sec. High current speeds were recorded at all three meter locations. However, the frequency of speed spikes (greater than 100 cm/sec) are minimal, representing less than 0.14% of the recorded time. The shallow VACM (S4-2) in February recorded 99% of the speed spikes.

An attempt was made to determine the source of the near-bottom speed spikes. For three hours (1300 – 1600) during the afternoon of Friday, 12 August 2005, boats passing over the meter at the S4-3 location were noted and logged. Vessel characteristics that were recorded included the time of transit, approximate distance offshore, direction of travel, boat type, approximate boat length, and approximate boat speed. The purpose of the observations was to correlate the recorded current speed spikes with vessel characteristics. For example, at 1355 during the period of observation, a current spike of 300 cm/sec to the north was observed on the VACM during which a 50-foot long tour boat traveled south-southwest at about 5 knots approximately 300 feet offshore and a 20-foot boat transited north-northeast about 150 feet offshore. Either vessel could have caused the spike. The determination, in many cases, is whether the spike is due to a larger vessel farther offshore or a smaller vessel close-in. Other examples with speed spikes of 50 cm/sec or greater include:

- 1309 – a 90 cm/sec spike caused by a 70-foot long motoring sailboat making a u-turn about 300 feet offshore,
- 1321 – a 55 cm/sec spike caused by a 100-foot long tourboat heading SSE about 700 feet offshore,

- 1325 – a 60 cm/sec spike of unknown causes,
- 1355 – a 300 cm/sec spike caused by a 20-foot motorboat transiting NNE about 150 feet offshore,
- 1419 – an 80 cm/sec spike caused by a 70-foot long boat transiting NNE about 500 feet offshore,
- 1433 – a 50 cm/sec spike caused by a 50-foot long motorboat heading SSW about 350 feet offshore,
- 1452 – a 50 cm/sec spike caused by a 75-foot long tugboat transiting NNE about 650 feet offshore,
- 1454 – a 50 cm/sec spike caused by a 20-foot long motorboat heading NNE about 100 feet offshore,
- 1458 – a 60 cm/sec spike caused by either a 20-foot long motorboat heading SSW about 75 feet offshore or a 50-foot long motorboat heading SSW about 400 feet offshore,
- 1518 – a 60 cm/sec spike of unknown causes,
- 1545 – a 52 cm/sec spike caused by a 50-foot long motorboat heading SSW about 250 feet offshore.

Out of eleven speed spikes on that afternoon, two cannot be attributed to a known cause. In all other cases, propeller wash is suspected. The dominant speed spike directions appear to be aligned along the navigation channels, which is also the dominant transit directions of vessels. This suggests that the spikes are probably due to vessel traffic-induced wakes or propeller wash.

4.0 Vessel Traffic

Distinguishing between wakes and propeller wash is not possible with the amount of data available at this time. In summary, the dominant high speed current directions are along well demarcated lines: approximately 59º and 239º in shallow water nearshore, and about 89º and 269º in the deeper water offshore. Thus, the dominant high speed current directions appear to be aligned along the navigation channel in proximity. Higher velocities close to the shoreline appear to be topographically induced. The time series for 2/4/2005 at 1026, 2/8/2005 at 1257, and 2/10/2005 at 1208 seem to suggest a bow wave, with an initial sharp spike, followed by propeller wash, with the longer period of rapid fluctuation. All of the other time series, with the rapid fluctuations, indicate propeller wash.

4.1 Vessel-Generated Currents

In the absence of an inventory of vessel movements in NLU, the vessel-generated currents are obtained from modeling vessel-generated waves and propeller wash for the largest assumed vessels to ply the lake. The largest vessels to produce currents in NLU are assumed to be a barge being pulled by a tug and a large motor yacht transiting past GWP at the maximum allowed speed of 7 knots. The assumed dimensions of the vessels are given in Table B-4. It is assumed that the tug and barge combination is manned by prudent mariners and that they transit south of the buoy, or remain 350 feet off GWP in water depths of 40 feet. It is further assumed that the yachtsman in the motor yacht is less prudent and may approach within 100 feet of GWP with a water depth of 20 feet.

There are several vessel-generated propeller wash computational schemes that have been developed over the last thirty years. These include Blaauw and van de Kaa (1978), Verhey (1983), and Hamill (1996). In addition, Maynord (2000) has developed a model that incorporates both wave and propeller wash into one computational scheme. All four computational schemes are used herein to assess the maximum vessel-generated bottom currents that might impinge on the bottom sediments of NLU off GWP. The vessel and navigation parameters discussed above were input into the computational schemes on EXCEL spreadsheets, and the resulting currents noted. For future reference, currents are calculated at bottom depths of 10, 20, 30, and 40 feet.

Table B-4. Summary of Vessel Criteria for Large Vessels Transiting off Gas Works Park.

Vessel	Tug	Barge	Motor Yacht
Length, feet	82	210	70
Beam, feet	22	90	18
Draft, feet	9	10	7
Displacement, tons	94	3,000	60
Speed, knots	7	7	7
Propeller Diameter, feet	3	NA	2.5
Prop Axis Depth, feet	8	NA	6
Engine Power, hp	1,000	NA	200
Bollard Pull, lbf	30,000	NA	5,000
Thrust Coefficient	68.1	NA	2.3
Prop Speed @ 7 kt, rpm	100	NA	200

For examples and results of the modeling calculations for wake/wave and propeller wash velocities, see Attachment B-7. Calculations were done for the following:

- Wake/wave velocities at the bottom of the lake due to passing tug, barge, and yacht;
- Maximum bottom propeller wash velocities due to passing tug and yacht according to Blaauw and van de Kaa (1977);
- Maximum bottom propeller wash velocities due to passing tug and yacht according to Verhey (1984), Hamill (1996, 1999), and Maynord (2000), respectively.

The results of the calculations are summarized on Table B-5. The calculations give a single velocity for vessel condition per distance and depth behind the propeller. An actual current record of wave/wake and propeller wash passage indicates a turbulent fluctuation of current velocities (much like a seismogram after an earthquake). One interpretation of the results is that Hamill's results tend to predict the bottom of the current velocity fluctuations, and Verhey's results tend to represent the peaks of the current velocity fluctuations. Maynord's results indicate higher bottom current velocities than Verhey, but these velocities are questionable because Maynord's computational scheme is really for a tug-barge combination in a constricted, or channelized, river-waterway configuration. This may apply to tug-barge combinations in the channel east of GWP, but would not apply off the south tip of GWP.

The results indicate that expected maximum bottom currents in North Lake Union due to vessels transiting overhead decrease with depth of the bottom. Calculations (excepting Maynord for the reasons cited above) indicate that bottom currents are approximately 1.8 to 5.0 ft/sec (55 – 152 cm/sec) for a yacht transiting in 10 feet of water (tug-barge combination would not transit in 10 feet of water), 0.1 to 5.0 ft/sec (3 – 152 cm/sec) for a tug-barge combination transiting in 20 feet of water, 0 to 2.7 ft/sec (0 – 82 cm/sec) for a tug-barge combination transiting in 30 feet of water, and 0 to 1.9 ft/sec (0 – 58 cm/sec) for a tug-barge combination transiting in 40 feet of water. The tug is more powerful than the yacht and will always exhibit greater bottom current velocities in comparable water depths. In deeper water (greater than about 12 feet), the tug-barge combination, therefore, creates the larger bottom currents.

Actual current meter recordings show that these model calculations tend to underestimate propeller wash (see Section 3.0).

Table B-5. Results of the Vessel-Generated Bottom Currents (ft/sec) at North Lake Union.

Water Depth, ft	10	20	30	40
Maximum bottom wake/wave velocity from:				
Tug	NA	2.3	1.1	0.7
Barge	NA	2.7	1.4	0.8
Yacht	5.0	1.5	0.8	0.5
Maximum bottom propeller wash velocity per Blaauw and van de Kaa from:				
Tug	NA	3.5	1.9	1.3
Yacht	2.7	0.8	0.4	0.3
Maximum bottom propeller wash velocity per Verhey from:				
Tug	NA	5.0	2.7	1.9
Yacht	3.8	1.1	0.6	0.4
Maximum bottom propeller wash velocity per Hamill from:				
Tug	NA	0.1	0	0
Yacht	1.8	0	0	0
Maximum bottom propeller wash velocity per Maynord from:				
Tug	NA	6.5	3.7	2.8
Yacht	6.8	2.1	1.3	0.9

4.2 Vessel-Generated Wakes

There are no known boat-generated wake (vessel-generated waves) measurements for North Lake Union upon which to base design criteria for shoreline structures and operations along the north shore of Lake Union. In the absence of wake data, the wake design criteria are obtained from modeling vessel-generated wakes for the lake for the largest assumed vessel to ply the lake.

The largest vessel to produce wakes in NLU is assumed to be a barge being pulled by a tug. The size of the barge is assumed to be 210 feet long by 90 feet wide with a 10-foot draft. The barge is further assumed to displace about 3,000 tons loaded. The speed limit through the Lake Washington Ship Canal, of which NLU is a part, is 7 knots; so, this is the assumed maximum vessel speed. It is assumed that the barge may approach within 350 feet of Gas Works Park (GWP) with a water depth of 20 feet.

There are at least four vessel-generated wake computational schemes that have been developed over the last thirty years. These include Gates and Herbich (1977), Blaauw et al (1984), PIANC (1987), and Sorensen (1997). All four computational schemes are used herein to assess the maximum wake that might impinge on the GWP shoreline. The vessel and navigation parameters discussed above are input into the computational schemes on EXCEL spreadsheets (see Attachment B-8), and the resulting wake period and maximum height noted.

The results of the calculations show that an assumed maximum wake in North Lake Union has a maximum wake period ranging from 0.2 to 1.9 seconds and a maximum wake height ranging from 0.6 to 1.9 feet, depending on which model one believes. Lacking the means to independently verify the validity of any of the models, let us assume the maximum numbers, a period of 1.9 seconds and a height of 1.9 feet, provide a conservative assessment of the wake criteria. Note that is the maximum wake period and height are similar to, and within the limits of, the wave-generated waves (see Section 2.2).

5.0 Shoaling and Refraction

The only significant fetch in Lake Union occurs due south from GWP and as a result a fully developed storm wave will only impact normal to the south side of the site. As waves travel around the eastern shoreline towards the marina and kayak launch area, wave refraction and shoaling will result. Refraction ultimately determines the distribution of wave energy at the shoreline and, therefore, the erosion potential.

An example of shoaling and refraction is illustrated below (Figure B-1). When waves approach a straight shoreline at an angle, the part of the wave crest closer to shore is in shallower water and moving slower than the part away from the shore in deeper water. The wave crest in deeper water catches up so that the wave crest tends to become parallel to the shore. In doing so, the wave "stretches" and the wave is bent to eventually become an angle parallel with the coastline. Notice the width B of the offshore wave. As this wave passes the headland and enters the cove it "stretches" to a width of B' which is significantly wider than B. As the wave stretches out, energy is dissipated as well, thereby reducing the erosion potential of the wave. This is the phenomenon that occurs at GWP as waves approach from the south.

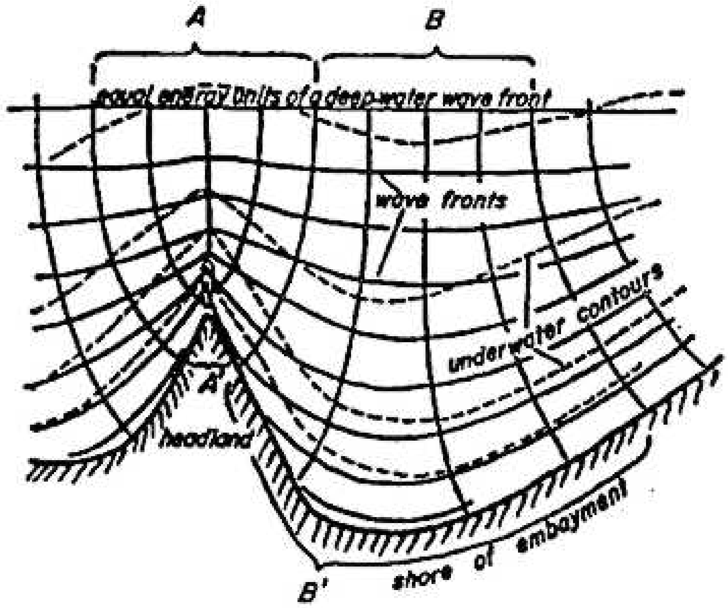


Figure B-1. Wave Refraction

5.1 Refraction Model

To develop incident wave conditions at Gas Works Park, a finite element model was used to propagate the wind generated waves from the southern end of Lake Union toward the shore. The model, CGWAVE, was used to examine detailed shoaling and refraction, and tip diffraction effects. (CGWAVE is a 2D finite element model based on the elliptic mild-slope wave equation[1].) Waves were specified at the model boundaries based on the results of wind-wave calculations provided in Attachment B-3.

A total of 12 arcs perpendicular to the shoreline were identified along the shoreline of GWP to be used for observing wave heights. The arc lines are shown in Attachment B-9 along with the resultant waves.

As expected, the highest waves were encountered in front of the central and western portions of the site due to reflection off the central concrete wall and steep riprapped slope to the west. As the waves progress further along the eastern shore of GWP the wave height slowly diminishes from the peak values in front of the wall to much smaller values in the kayak launch area. Maximum wave height values within 100 ft. of the shore along each arc are presented below in Table B-6.

[1] CGWAVE, SMS Reference Manual, Version 9.0, 2006, Brigham Young University

Table B-6. CGWAVE Results

Arc#	Wave Height (ft)	Distance From Shore for Listed Wave Height (ft.)	Water Depth for Listed Wave Height (ft)
30	4.1	100	34
32	4.4	26	10
34	3.4	7	6
36	4.6	16	7
38	5.4	66	9
40	5.7	98	10
42	3.0	59	5
44	3.3	82	7
46	3.1	46	12
48	3.0	49	8
50	2.5	92	15
52	1.0	76	9

6.0 Shoreline and Sediment Cap

The design criteria for a stable shoreline and sediment cap are based on the velocities at the water-sediment interface in NLU. Sediment stability criteria are assessed by velocity zone: the lake shore zone dominated by waves and wakes; and the lake slope and lake floor zones dominated by propeller wash velocities.

6.1 Shoreline

The lake shore zone lies between lake elevations +15 feet and +25 feet (Corps Datum) and is dominated by wave and wake velocities. The results of the wind-generated wave calculations (see above) show that a storm wave approaching the north shoreline of North Lake Union has a peak wave period of 1.9 seconds, a significant wave height of 2.44 feet. The wake calculations, with a period of 1.9 seconds and maximum wave height of 1.9 feet, are contained within the wind-generated wave envelope.

The wind-generated wave energy will be felt as oscillatory velocities by sediments in a band from the shoreline out to a depth of about 10 feet. The energy of the waves are expended in wave breaking at the shore, with the bottom sediments "feeling" the velocity increase due to wave shoaling and breaking. Velocities associated with the shoaling and breaking of the above waves range from a barely perceptible 0.4 ft/sec (12 cm/s) at a depth of 10 feet (per linear theory), to 1.5 ft/sec (46 cm/s) at a depth of 5 feet, to about 8 ft/sec (244 cm/sec) at the shoreline. The shoreline will move in or out depending on lake level, which is controlled by the U.S. Army Corps of Engineers at the Hiram M. Chittenden Dam & Locks and varies between +20 to +22 feet (Corps Datum).

The shoreline zone is defined as between lake elevations +15 feet and +25 feet based on the wave and wake motion and breaking velocity of at least 1.5 ft/sec. The results of the refraction model (CGWAVE) and a modified shoreline slope varying between 4 and 10 horizontal to 1 vertical were used to size the stable shoreline material (see Attachment B-10 for guidance). The stone size that is stable varies between 4 inches and 17 inches, based on the Hudson equation.

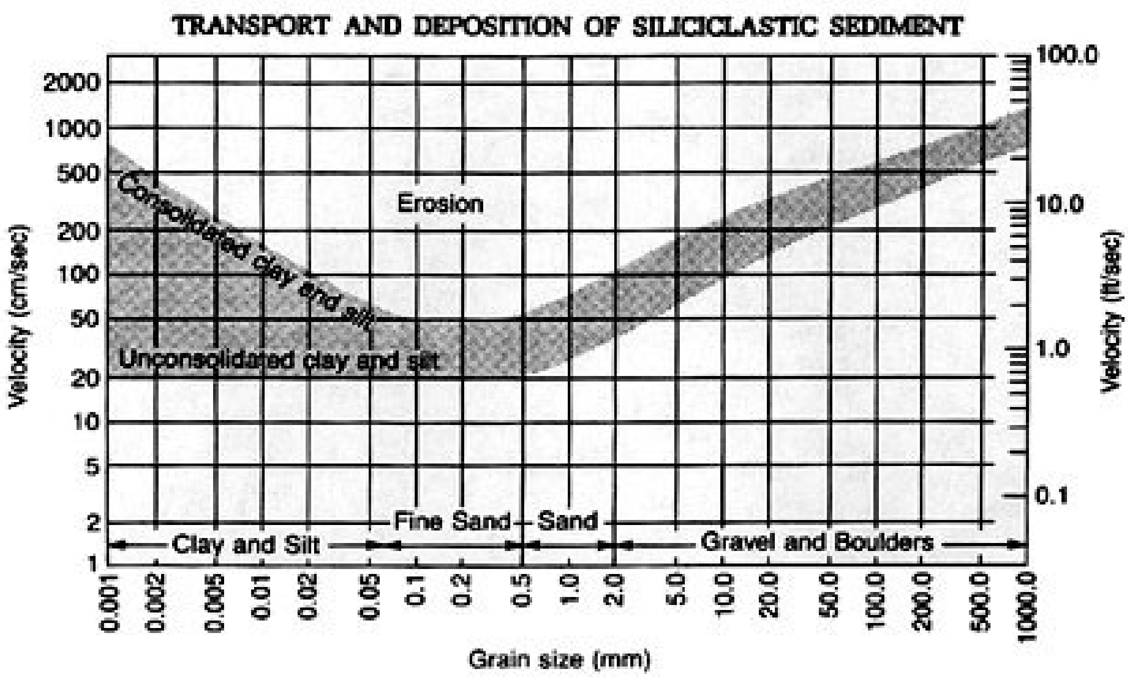
6.2 Lake Slope and Lake Floor

The lake slope and lake floor zones are defined as between +15 feet and -25 feet (Corps Datum) and are dominated by propeller wash. The propeller wash modeling indicates that prop wash velocities in these zones are somewhat depth dependent and can exceed 10 ft/sec (330 cm/s) in short duration.

The main concern is how much credence to place in the short-lived and transient velocity spikes created by propeller wash in sizing stable bottom sediments and cap material. Using the maximum calculated (modeled) or observed velocities would result in very stable bottom material, but the material sizes would be so large as to call into question the judgment factor used. Sizing the capping material on the basis of the 99-percentile speed will mean that capping material will occasionally be resuspended up into the water column by the turbulent propeller wash. However, the general circulation currents in the lake are so low that the eroded material will settle back to the lake bottom within a fairly short radius of where it was eroded. The actual landing distance is controlled, to a large extent, by the spiking horizontal velocity component.

A reasonable method of assessing sediment erosion/movement is to compare the speeds to the Hjulstrom diagram (Figure B-2), which was developed from data collected about 1 meter above the sediment-water interface in the river Fyris. Stable sediment is represented by the intersection of the current speed with the top of the gray line to the right of the dip (and extended down to the left as required by speeds less than 50 cm/sec).

Figure B-2. Erosion-Deposition Relationship for Bed Sediment with Uniform Grain Size (after Hjulstrom, 1935)



The meter location (S4-2) in 10 feet of water (elevation +10 feet Corps Datum) near the shore provides real current velocity data near the upper elevation limit of the lake floor. High current speeds were recorded at the shallow VACM but the duration of the highest speeds was short, on the order of 0.5 to 1 seconds. The maximum current speed in the shallow water was 350 cm/sec (11.5 ft/sec). The 99-percentile speed was 95 cm/sec (3.1 ft/sec) for the shallow meter. The 99-percentile bottom velocity of 91 cm/sec is used to size the cap sediment (see Figure B-2 for guidance) between elevations 0 feet and +15 feet (Corps Datum). The capping sediment should be in the range of 2 mm in size. Additional larger material (20 mm) can be added to the cap to protect against the maximum observed velocity if necessary.

7.0 Summary

The hydrodynamic design criteria and the stable shoreline and cap sediment criteria are summarized below.

7.1 Design Criteria

The hydrodynamic design criteria for NLU are as follows:

- Wave motion with a wave period of up to 1.9 seconds, a significant wave height up to 2.44 feet, an H_{10} of 3.5 feet, and a maximum wave height up to 4.5 feet. Wave influence can be felt from a depth of about 10 feet below still water level to a height of about 6 feet (including runup) above still water level. The latter height (runup) can be modified downward depending on the slope and roughness of the shoreline.

- A 99-percentile velocity up to 91 cm/s (3.0 ft/sec) up to +15 feet.

- Current spikes of up to 2 seconds duration and 350 to 400 cm/s (13 ft/sec) from +15 feet to -15 feet below still water level. This reduces to 300 cm/s (10 ft/sec) from 35 feet below still water level to deeper depths (below -15).

7.2 Shoreline Armor and Capping Material Criteria

Any material placed in North Lake Union off Gas Works Park should be sized as follows to protect against the observed 99-percentile current velocities and model wave action:

- Central and Western Lake Shore Region (+22 to +15 feet) – 18-inch minus material

- Eastern Lake Shore Region (+22 to +15 feet) – 12-inch minus material

- Lake Floor and Lake Slope Region (+15 to -25) – 10 mm minus material

References

Blaauw, H. G. and E. J. van de Kaa. *Erosion of Bottom and Sloping Banks Caused by the Screw Race of Manoeuvering Ships*. Delft Hydraulics Laboratory, Publication Number 202, July 1978.

Blaauw, H.G., F.C.M. van der Knapp, M.T. de Groot and K.W. Pilarczyk. *Design of Bank Protection of Inland Navigation Fairways*. Proceedings of the International Conference on Flexible Armoured Revetments Incorporating Geotextiles, London, England, 29-30 March 1984.

Gates, Edward T., and John B. Herbich. *Mathematical Model to Predict the Behavior of Deep-Draft Vessels in Restricted Waterways*. Report TAMU-SG-77-206, COE Report No. 200, Texas A&M University, College Station, TX, 1977.

Hamill, G. A., H. T. Johnston and D. P. J. Stewart. *Estimating the Velocities in a Ship's Propeller Wash*. PIANC Bulletin No. 89, Pg. 46-54, 1996.

Hamill, G. A., and J. A. McGarvey. *Designing for Propeller Action in Harbours*. ICCE'96, Orlando, FL, Pg. 4451-4463, September 1996.

Hamill, G.A., H. T. Johnston, and D. P. Stewart. *Propeller Wash Scour near Quay Walls*. Journal of Waterway, Port, Coastal, and Ocean Engineering, American Society of Civil Engineers, July/August, 1999.

Hjulstrom, F. *Studies of the morphological activity of rivers as illustrated by the river Fyris*: Bulletin of the Geological Institute of Uppsala, Vol. 25, Pages 221-527, 1935.

Maynord, Stephen T. *Physical Forces near Commercial Tows - Upper Mississippi River - Illinois Waterway System Navigation Study*. Prepared for U.S. Army Engineer Distrct, Rock Island, U.S. Army Engineer Distrct, St. Louis, U.S. Army District, St. Paul, ENV Report 19, March 2000.

Permanent International Association of Navigation Congresses. *Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles for Inland Waterways*. Report of Working Group 4 of the Permanent Technical Committee, Brussels, 1987.

Sorensen, Robert M. *Prediction of Vessel-Generated Waves with Reference to Vessels Common to the Upper Mississippi River System*. Prepared for U.S. Army Engineer Distrct, Rock Island, U.S. Army Engineer Distrct, St. Louis, U.S. Army District, St. Paul, ENV Report 4, December 1997.

U.S. Army Corps of Engineers. *Coastal Engineering Manual (Part II)*. U.S. Army Corps of Engineers, Engineering Manual EM 1110-2-1100, 31 January 2002.

U.S. Army Corps of Engineers. *Shore Protection Manual*. 2 Volumes, Department of the Army, Coastal Engineering Reasearch Center, Waterways Experiment Station, U.S Government Printing Office, Washington, D.C. 1984.

Verhey, H.J. *The Stability of Bottom and Banks Subjected to the Velocities in the Propeller Jet Behind Ships.* Delft Hydraulics Laboratory, Publication Number 303, April 1983.

Attachment B-1

Wind Data

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	1	21	0	0	155	9.2 1	0.1
2005	1	21	1	0	162	6.4	7.7
2005	1	21	2	0	167	8.7	9.2
2005	1	21	3	0	179	10.3 1	1
2005	1	21	4	0	174	7.6	8.8
2005	1	21	5	0	160	6.3	6.8
2005	1	21	6	0	151	6.8	7.4
2005	1	21	7	0	154	5.8	6.1
2005	1	21	8	0	142	4.1	4.5
2005	1	21	9	0	152	5.1	5.7
2005	1	21	10	0	168	5	5.3
2005	1	21	11	0	150	2.9	3
2005	1	21	12	0	155	4	4.1
2005	1	21	13	0	156	3.2	3.3
2005	1	21	14	0	151	1.3	1.8
2005	1	21	15	0	162	1.3	1.5
2005	1	21	16	0	139	0.6	0.8
2005	1	21	17	0	156	2.6	3
2005	1	21	18	0	144	3.3	3.6
2005	1	21	19	0	175	2.7	2.7
2005	1	21	20	0	158	0.8	0.9
2005	1	21	21	0	167	1.6	1.7
2005	1	21	22	0	151	2.2	2.3
2005	1	21	23	0	205	1.8	2
2005	1	22	0	0	176	3.2	3.3
2005	1	22	1	0	147	3.4	3.8
2005	1	22	2	0	185	1	1.2
2005	1	22	3	0	152	3.4	3.6
2005	1	22	4	0	140	3.9	4.2
2005	1	22	5	0	160	3.6	3.9
2005	1	22	6	0	157	5.8	6.3
2005	1	22	7	0	174	7.7	8.1
2005	1	22	8	0	184	6.2	6.7
2005	1	22	9	0	159	7.2	7.5
2005	1	22	10	0	173	6.8	7.1
2005	1	22	11	0	159	6.6	7.1
2005	1	22	12	0	151	6.4	6.8
2005	1	22	13	0	158	6.4	6.9
2005	1	22	14	0	167	5.6	5.8
2005	1	22	15	0	180	7.3	7.7
2005	1	22	16	0	165	6.5	6.8
2005	1	22	17	0	148	5.2	5.5
2005	1	22	18	0	163	4.6	4.9
2005	1	22	19	0	162	4.9	5.2
2005	1	22	20	0	164	4.9	5.4
2005	1	22	21	0	156	5.8	6
2005	1	22	22	0	156	4.4	5.1
2005	1	22	23	0	197	5.5	5.7
2005	1	23	0	0	146	4.4	4.7
2005	1	23	1	0	174	4.7	5.3
2005	1	23	2	0	187	5.3	5.7
2005	1	23	3	0	187	7.7	8.3
2005	1	23	4	0	147	6.1	6.8
2005	1	23	5	0	153	7.8	8.4
2005	1	23	6	0	164	6.6	7.2
2005	1	23	7	0	163	6.2	6.5
2005	1	23	8	0	150	7.1	7.7
2005	1	23	9	0	149	6.5	7.1

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	1	23	10	0	150	5.9	6.3
2005	1	23	11	0	152	6.7	7.1
2005	1	23	12	0	182	5.1	5.6
2005	1	23	13	0	173	4.8	5.7
2005	1	23	14	0	161	5.6	5.9
2005	1	23	15	0	141	3.6	4.1
2005	1	23	16	0	150	7.7	8.4
2005	1	23	17	0	184	4.1	4.5
2005	1	23	18	0	169	4.6	4.9
2005	1	23	19	0	158	6.8	7.5
2005	1	23	20	0	171	7.3	8.2
2005	1	23	21	0	162	7.4	7.6
2005	1	23	22	0	144	4	5.1
2005	1	23	23	0	152	3.4	3.8
2005	1	24	0	0	147	3.1	3.2
2005	1	24	1	0	197	5.3	5.9
2005	1	24	2	0	154	3.2	3.7
2005	1	24	3	0	311	1.5	1.9
2005	1	24	4	0	167	3.1	3.7
2005	1	24	5	0	166	7.1	8.2
2005	1	24	6	0	159	4.3	4.8
2005	1	24	7	0	160	4.9	5.3
2005	1	24	8	0	161	6.2	6.5
2005	1	24	9	0	161	6.4	7.1
2005	1	24	10	0	150	7.9	9.3
2005	1	24	11	0	151	9.2	9.6
2005	1	24	12	0	155	8.3	9.2
2005	1	24	13	0	153	9.6 1	0.8
2005	1	24	14	0	155	7.2	8.3
2005	1	24	15	0	160	7.5	7.8
2005	1	24	16	0	157	6.7	7.7
2005	1	24	17	0	151	5	5.9
2005	1	24	18	0	146	6.1	6.8
2005	1	24	19	0	148	6	6.4
2005	1	24	20	0	156	6.1	6.6
2005	1	24	21	0	162	4.9	5.3
2005	1	24	22	0	162	6	7.2
2005	1	24	23	0	166	5.2	5.4
2005	1	25	0	0	163	6.2	6.5
2005	1	25	1	0	140	3.3	4.1
2005	1	25	2	0	152	2.4	2.8
2005	1	25	3	0	25	2.9	3.4
2005	1	25	4	0	9	2.4	2.6
2005	1	25	5	0	12	2.3	2.6
2005	1	25	6	0	16	1.5	1.8
2005	1	25	7	0	43	2.4	2.6
2005	1	25	8	0	0	0	0
2005	1	25	9	0	37	0.7	0.8
2005	1	25	10	0	0	0	0.1
2005	1	25	11	0	46	1.9	2
2005	1	25	12	0	24	2.3	2.5
2005	1	25	13	0	359	0.4	0.5
2005	1	25	14	0	354	1.2	1.6
2005	1	25	15	0	33	2.3	2.7
2005	1	25	16	0	353	2.2	2.8
2005	1	25	17	0	19	3	3.3
2005	1	25	18	0	2	4	4.5
2005	1	25	19	0	12	4.6	5.1

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	1	25	20	0	355	4	4.4
2005	1	25	21	0	10	5.2	5.6
2005	1	25	22	0	18	6.8	7.2
2005	1	25	23	0	20	5.8	6.2
2005	1	26	0	0	30	4.9	5.3
2005	1	26	1	0	37	3	3.2
2005	1	26	2	0	41	3.5	3.9
2005	1	26	3	0	33	2.3	2.6
2005	1	26	4	0	143	0.6	0.8
2005	1	26	5	0	347	3.2	3.3
2005	1	26	6	0	15	4.7	5.1
2005	1	26	7	0	354	4.3	4.5
2005	1	26	8	0	360	4.8	5.5
2005	1	26	9	0	3	4.2	4.3
2005	1	26	10	0	3	3.6	3.8
2005	1	26	11	0	16	3.7	3.9
2005	1	26	12	0	90	0.4	0.4
2005	1	26	13	0	118	0.1	0.3
2005	1	26	14	0	0	0	0
2005	1	26	15	0	30	0.6	0.9
2005	1	26	16	0	174	3.1	3.9
2005	1	26	17	0	153	2.1	2.6
2005	1	26	18	0	167	3	3.6
2005	1	26	19	0	190	4.9	5.3
2005	1	26	20	0	171	4	4.5
2005	1	26	21	0	158	4.1	4.4
2005	1	26	22	0	167	3.9	4.2
2005	1	26	23	0	175	4.5	4.9
2005	1	27	0	0	176	2.5	3.1
2005	1	27	1	0	150	5.3	5.7
2005	1	27	2	0	162	4.9	5.1
2005	1	27	3	0	157	4.4	5
2005	1	27	4	0	156	5.6	5.8
2005	1	27	5	0	151	5.8	6.2
2005	1	27	6	0	163	5.6	5.9
2005	1	27	7	0	170	4.4	4.6
2005	1	27	8	0	149	5.9	6.2
2005	1	27	9	0	158	5.3	5.6
2005	1	27	10	0	172	5.5	5.9
2005	1	27	11	0	165	5	5.3
2005	1	27	12	0	154	5.2	5.7
2005	1	27	13	0	147	3.5	3.8
2005	1	27	14	0	153	4.5	5.2
2005	1	27	15	0	173	5.3	6.3
2005	1	27	16	0	160	4.8	5.8
2005	1	27	17	0	170	6.1	6.7
2005	1	27	18	0	156	5.2	5.7
2005	1	27	19	0	157	5.2	5.9
2005	1	27	20	0	161	4.2	4.6
2005	1	27	21	0	147	3.8	4.4
2005	1	27	22	0	180	2.4	2.6
2005	1	27	23	0	204	1.3	1.5
2005	1	28	0	0	274	0.9	1
2005	1	28	1	0	16	0.7	0.9
2005	1	28	2	0	2	0.8	1.1
2005	1	28	3	0	44	2.5	2.6
2005	1	28	4	0	20	1.7	1.9
2005	1	28	5	0	341	1.6	1.9

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	1	28	6	0	14	1.9	2.1
2005	1	28	7	0	18	2.2	2.3
2005	1	28	8	0	26	3.8	4.2
2005	1	28	9	0	355	5	5.5
2005	1	28	10	0	4	5.5	5.8
2005	1	28	11	0	11	6.5	7.3
2005	1	28	12	0	7	6	6.8
2005	1	28	13	0	2	5.5	6.1
2005	1	28	14	0	355	5.8	6.1
2005	1	28	15	0	10	7.1	7.7
2005	1	28	16	0	344	5.6	6
2005	1	28	17	0	345	5.2	5.8
2005	1	28	18	0	4	4.9	5.2
2005	1	28	19	0	3	4.7	5.3
2005	1	28	20	0	18	4.9	5.2
2005	1	28	21	0	15	3.7	4
2005	1	28	22	0	18	4.1	4.4
2005	1	28	23	0	5	2.6	3
2005	1	29	0	0	22	4.8	5.3
2005	1	29	1	0	353	2.6	2.9
2005	1	29	2	0	37	4.2	4.3
2005	1	29	3	0	176	6.8	7.4
2005	1	29	4	0	219	8.5 1	0.2
2005	1	29	5	0	231	4.9	5.5
2005	1	29	6	0	146	2.7	3
2005	1	29	7	0	126	0.7	1
2005	1	29	8	0	268	0.8	0.9
2005	1	29	9	0	308	0.4	0.5
2005	1	29	10	0	133	1.5	1.8
2005	1	29	11	0	177	2.3	2.8
2005	1	29	12	0	198	1.8	2.8
2005	1	29	13	0	174	2.4	2.9
2005	1	29	14	0	179	4.9	5.4
2005	1	29	15	0	177	4.5	5
2005	1	29	16	0	187	4.2	4.7
2005	1	29	17	0	166	4.2	4.8
2005	1	29	18	0	163	5.7	6.4
2005	1	29	19	0	168	5.1	5.6
2005	1	29	20	0	173	5.7	6.1
2005	1	29	21	0	151	5.7	5.9
2005	1	29	22	0	154	5.9	6.2
2005	1	29	23	0	166	5.7	6.1
2005	1	30	0	0	157	5.4	5.7
2005	1	30	1	0	166	6.1	6.7
2005	1	30	2	0	162	5.5	6
2005	1	30	3	0	172	7.3	8
2005	1	30	4	0	174	6.9	7.4
2005	1	30	5	0	179	8.3	9
2005	1	30	6	0	181	8.2	9.4
2005	1	30	7	0	167	8.3	9.4
2005	1	30	8	0	163	6.8	7.6
2005	1	30	9	0	155	7.8	8.7
2005	1	30	10	0	165	7.7	8.5
2005	1	30	11	0	166	8.2	9
2005	1	30	12	0	157	5.7	6.5
2005	1	30	13	0	158	6.2	6.8
2005	1	30	14	0	153	5.4	5.7
2005	1	30	15	0	153	5.6	6.1

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	1	30	16	0	154	5.5	5.8
2005	1	30	17	0	157	6.6	7.3
2005	1	30	18	0	154	6.1	6.8
2005	1	30	19	0	158	7	8.2
2005	1	30	20	0	157	8.4	9.4
2005	1	30	21	0	163	7.9	8.3
2005	1	30	22	0	161	7.4	7.9
2005	1	30	23	0	155	5.7	6
2005	1	31	0	0	150	5.5	5.8
2005	1	31	1	0	175	4.7	5
2005	1	31	2	0	161	4.2	4.3
2005	1	31	3	0	160	3.8	4
2005	1	31	4	0	172	5.7	6
2005	1	31	5	0	149	6.5	7.1
2005	1	31	6	0	165	7.9	8.4
2005	1	31	7	0	166	8.6	9.3
2005	1	31	8	0	161	7.9	8.9
2005	1	31	9	0	162	8.1	9
2005	1	31	10	0	159	9.6 1	1.1
2005	1	31	11	0	186	9.4 1	0.7
2005	1	31	12	0	181	11.1 1	2.3
2005	1	31	13	0	167	9.0 1	0.2
2005	1	31	14	0	169	10.2 1	2
2005	1	31	15	0	184	12.5 1	3.5
2005	1	31	16	0	183	11.5 1	3.1
2005	1	31	17	0	192	12.8 1	4.4
2005	1	31	18	0	195	11.6 1	4.3
2005	1	31	19	0	200	7.7	8.7
2005	1	31	20	0	211	7.2	8.2
2005	1	31	21	0	212	5.4	6.4
2005	1	31	22	0	180	4.9	5.8
2005	1	31	23	0	155	6.5	7.1
2005	2	1	0	0	167	6.7	7.4
2005	2	1	1	0	184	5.8	6
2005	2	1	2	0	147	3.7	4
2005	2	1	3	0	193	2.1	2.7
2005	2	1	4	0	173	4.2	4.5
2005	2	1	5	0	189	6.5	6.9
2005	2	1	6	0	182	5	5.5
2005	2	1	7	0	185	5.6	6
2005	2	1	8	0	182	6	6.6
2005	2	1	9	0	149	6.1	6.5
2005	2	1	10	0	140	5.4	6.1
2005	2	1	11	0	159	4.3	4.7
2005	2	1	12	0	153	3.2	3.5
2005	2	1	13	0	190	2.3	2.6
2005	2	1	14	0	173	1.4	1.5
2005	2	1	15	0	156	2	2.3
2005	2	1	16	0	151	1.6	2.1
2005	2	1	17	0	145	2	2.4
2005	2	1	18	0	164	3	3.2
2005	2	1	19	0	159	3.7	3.9
2005	2	1	20	0	154	3.1	3.4
2005	2	1	21	0	157	4.3	4.5
2005	2	1	22	0	166	4.7	4.9
2005	2	1	23	0	193	6.2	6.4
2005	2	2	0	0	180	6.8	7.1
2005	2	2	1	0	162	4.9	5.5

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	2	3	0	187	6.9	7.3
2005	2	2	4	0	165	9.5	9.9
2005	2	2	5	0	157	10.5 1	1.5
2005	2	2	6	0	179	8.1	9.4
2005	2	2	7	0	13	2.1	2.4
2005	2	2	8	0	172	0.8	1.2
2005	2	2	9	0	172	3.7	3.9
2005	2	2	10	0	155	3.7	4
2005	2	2	11	0	154	2.6	3.2
2005	2	2	12	0	145	2.6	3.3
2005	2	2	13	0	167	3.8	4
2005	2	2	14	0	155	1.9	2.1
2005	2	2	15	0	156	2.7	2.9
2005	2	2	16	0	154	5.1	5.3
2005	2	2	17	0	158	5.8	6.2
2005	2	2	18	0	146	5.5	6.3
2005	2	2	19	0	165	4.6	4.9
2005	2	2	20	0	178	3	3.2
2005	2	2	21	0	162	0.7	0.8
2005	2	2	22	0	34	1.1	1.1
2005	2	2	23	0	236	1	1
2005	2	3	0	0	173	1.2	1.3
2005	2	3	1	0	151	3.4	3.6
2005	2	3	2	0	155	2.7	2.8
2005	2	3	3	0	152	3.6	3.7
2005	2	3	4	0	148	3	3.2
2005	2	3	5	0	153	2.9	3.1
2005	2	3	6	0	148	6	6.2
2005	2	3	7	0	146	6.2	6.9
2005	2	3	8	0	151	7.4	7.9
2005	2	3	9	0	150	6.1	6.9
2005	2	3	10	0	147	6.6	7.2
2005	2	3	11	0	169	3.8	4.3
2005	2	3	12	0	169	3.1	3.4
2005	2	3	13	0	144	4.5	5.1
2005	2	3	14	0	164	3.3	3.9
2005	2	3	15	0	177	0.6	0.7
2005	2	3	16	0	150	2.7	3.2
2005	2	3	17	0	135	0.8	1.2
2005	2	3	18	0	174	2.9	3.2
2005	2	3	19	0	164	3.9	4.1
2005	2	3	20	0	179	4.7	4.9
2005	2	3	21	0	163	4.3	4.4
2005	2	3	22	0	160	3.9	4.1
2005	2	3	23	0	194	4.6	5
2005	2	4	0	0	193	2.8	3.2
2005	2	4	1	0	211	1.5	1.6
2005	2	4	2	0	133	4.4	4.6
2005	2	4	3	0	177	3.7	3.9
2005	2	4	4	0	193	2.4	2.6
2005	2	4	5	0	192	3.4	3.8
2005	2	4	6	0	176	5	5.6
2005	2	4	7	0	179	4.6	4.8
2005	2	4	8	0	171	6.4	6.9
2005	2	4	9	0	173	6.5	7
2005	2	4	10	0	162	9.3 1	0.5
2005	2	4	11	0	156	9	9.7
2005	2	4	12	0	152	9.8 1	1.1

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	4	13	0	165	13.2 1	4.3
2005	2	4	14	0	175	12.3 1	3.4
2005	2	4	15	0	190	10.6 1	1.4
2005	2	4	16	0	188	8.8 1	0.9
2005	2	4	17	0	18	10.3 1	1.3
2005	2	4	18	0	45	4.4	4.9
2005	2	4	19	0	68	3.9	4.9
2005	2	4	20	0	117	2.7	4.3
2005	2	4	21	0	213	9.7 1	1.3
2005	2	4	22	0	223	8.5	9.4
2005	2	4	23	0	232	5.1	5.8
2005	2	5	0	0	38	3.7	3.9
2005	2	5	1	0	351	0.1	0.5
2005	2	5	2	0	194	3.5	4.5
2005	2	5	3	0	190	6.1	6.8
2005	2	5	4	0	165	5.9	6.3
2005	2	5	5	0	184	6	6.5
2005	2	5	6	0	181	5.6	6.2
2005	2	5	7	0	189	4.5	5.6
2005	2	5	8	0	184	2.7	3
2005	2	5	9	0	60	2.8	3.8
2005	2	5	10	0	121	2.9	3.8
2005	2	5	11	0	123	2.5	3.1
2005	2	5	12	0	147	6.2	7
2005	2	5	13	0	124	2.9	3.8
2005	2	5	14	0	139	5	6.2
2005	2	5	15	0	152	8	8.5
2005	2	5	16	0	158	7.7	8.6
2005	2	5	17	0	178	6	6.7
2005	2	5	18	0	188	6.1	6.7
2005	2	5	19	0	187	4.7	4.9
2005	2	5	20	0	181	3.3	3.7
2005	2	5	21	0	179	1.3	1.8
2005	2	5	22	0	141	2	2.2
2005	2	5	23	0	0	0	0
2005	2	6	0	0	13	2.3	2.8
2005	2	6	1	0	33	1	1.3
2005	2	6	2	0	316	2.1	3.3
2005	2	6	3	0	296	3.4	3.9
2005	2	6	4	0	184	6.4	6.8
2005	2	6	5	0	185	6.7	8
2005	2	6	6	0	190	6.6	7.4
2005	2	6	7	0	190	7.5	8.6
2005	2	6	8	0	184	10.1 1	1.4
2005	2	6	9	0	156	9.5 1	1
2005	2	6	10	0	147	6.7	7.3
2005	2	6	11	0	145	6.3	6.8
2005	2	6	12	0	144	6.7	7.8
2005	2	6	13	0	132	5.8	7.2
2005	2	6	14	0	139	7.4	9.1
2005	2	6	15	0	148	8.1	9.2
2005	2	6	16	0	142	8.1	9.5
2005	2	6	17	0	126	7.6	9.7
2005	2	6	18	0	130	5.8	7.5
2005	2	6	19	0	160	4.8	6
2005	2	6	20	0	236	1.6	2.2
2005	2	6	21	0	270	3.6	5.7
2005	2	6	22	0	0	0	0

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	6	23	0	108	0.9	1.6
2005	2	7	0	0	133	1.3	2.2
2005	2	7	1	0	64	1.4	2
2005	2	7	2	0	40	2.9	3.4
2005	2	7	3	0	43	2.3	3.2
2005	2	7	4	0	18	4.5	4.9
2005	2	7	5	0	358	5.4	5.8
2005	2	7	6	0	341	7.3	8
2005	2	7	7	0	347	9.4 1	0.3
2005	2	7	8	0	347	8.4	9.4
2005	2	7	9	0	349	6.8	7.7
2005	2	7	10	0	350	6.6	7.4
2005	2	7	11	0	356	7.6	8.8
2005	2	7	12	0	350	8.4	9.2
2005	2	7	13	0	356	8.5	9.3
2005	2	7	14	0	24	6.3	7.1
2005	2	7	15	0	13	5.8	6.5
2005	2	7	16	0	57	3.8	4.5
2005	2	7	17	0	52	3	3.9
2005	2	7	18	0	14	4.8	5.5
2005	2	7	19	0	2	5.1	5.8
2005	2	7	20	0	9	5.3	6.2
2005	2	7	21	0	9	7	7.5
2005	2	7	22	0	13	7.2	7.8
2005	2	7	23	0	7	6.4	7
2005	2	8	0	0	9	5.5	5.9
2005	2	8	1	0	6	5.7	6.2
2005	2	8	2	0	343	4.4	4.8
2005	2	8	3	0	349	5.5	5.8
2005	2	8	4	0	24	4.8	5.4
2005	2	8	5	0	1	5.9	6.2
2005	2	8	6	0	22	4.1	4.5
2005	2	8	7	0	19	5	5.6
2005	2	8	8	0	14	4.8	5.6
2005	2	8	9	0	8	4.5	4.9
2005	2	8	10	0	6	6	6.9
2005	2	8	11	0	56	2.2	2.7
2005	2	8	12	0	45	2.2	2.7
2005	2	8	13	0	49	2.8	3.6
2005	2	8	14	0	34	4	4.6
2005	2	8	15	0	9	4.7	5.9
2005	2	8	16	0	354	5.2	5.7
2005	2	8	17	0	353	4.3	4.8
2005	2	8	18	0	344	5.6	6.1
2005	2	8	19	0	344	5.3	6
2005	2	8	20	0	7	5.2	5.8
2005	2	8	21	0	3	5.5	6
2005	2	8	22	0	356	5.4	5.8
2005	2	8	23	0	358	5.8	6.3
2005	2	9	0	0	6	6.8	7.3
2005	2	9	1	0	2	5.8	6.3
2005	2	9	2	0	350	6	6.4
2005	2	9	3	0	359	6	6.6
2005	2	9	4	0	341	5.4	5.7
2005	2	9	5	0	344	3.9	4.4
2005	2	9	6	0	2	4.2	4.6
2005	2	9	7	0	339	3.9	4.5
2005	2	9	8	0	44	3.2	4

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	9	9	0	337	3.7	4.1
2005	2	9	10	0	331	3.5	3.8
2005	2	9	11	0	46	2.8	3.1
2005	2	9	12	0	347	4	4.6
2005	2	9	13	0	66	3.6	4.8
2005	2	9	14	0	41	1.7	2
2005	2	9	15	0	322	4.2	4.9
2005	2	9	16	0	10	3.7	4.4
2005	2	9	17	0	8	4	4.4
2005	2	9	18	0	46	2.1	2.6
2005	2	9	19	0	357	4.6	5.3
2005	2	9	20	0	352	4.9	5.5
2005	2	9	21	0	10	6.6	7.1
2005	2	9	22	0	7	5.9	6.2
2005	2	9	23	0	10	5	5.6
2005	2	10	0	0	14	5.3	5.7
2005	2	10	1	0	13	4.9	5.3
2005	2	10	2	0	5	6	6.3
2005	2	10	3	0	3	5.1	5.7
2005	2	10	4	0	354	4.7	5.1
2005	2	10	5	0	354	4.5	4.7
2005	2	10	6	0	11	4	4.2
2005	2	10	7	0	335	3.6	3.8
2005	2	10	8	0	39	2.7	3.1
2005	2	10	9	0	51	2	2.3
2005	2	10	10	0	80	0.5	0.8
2005	2	10	11	0	51	1.1	1.2
2005	2	10	12	0	0	0	0.1
2005	2	10	13	0	18	2.5	3.1
2005	2	10	14	0	13	6.3	7.2
2005	2	10	15	0	344	4.5	5.1
2005	2	10	16	0	320	3.8	4.5
2005	2	10	17	0	331	2.8	3.2
2005	2	10	18	0	343	2.9	3.4
2005	2	10	19	0	16	4.7	5.2
2005	2	10	20	0	9	4.5	4.9
2005	2	10	21	0	7	3.6	3.9
2005	2	10	22	0	14	4.2	4.3
2005	2	10	23	0	24	3.2	3.6
2005	2	11	0	0	10	4.6	4.8
2005	2	11	1	0	13	5.3	5.5
2005	2	11	2	0	13	5.9	6.3
2005	2	11	3	0	2	4.5	4.9
2005	2	11	4	0	352	6.1	6.5
2005	2	11	5	0	3	5.8	6.2
2005	2	11	6	0	360	6.5	7.2
2005	2	11	7	0	353	5.2	5.8
2005	2	11	8	0	356	4.7	5.4
2005	2	11	9	0	8	4.5	5.3
2005	2	11	10	0	51	1.8	1.9
2005	2	11	11	0	45	3.2	3.8
2005	2	11	12	0	24	1.8	2.2
2005	2	11	13	0	320	3.2	3.6
2005	2	11	14	0	16	0.1	0.5
2005	2	11	15	0	204	2.3	3.4
2005	2	11	16	0	168	5.1	5.7
2005	2	11	17	0	180	5.6	6.4
2005	2	11	18	0	160	7.4	8.1

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	11	19	0	171	8.1	8.9
2005	2	11	20	0	161	5.4	5.9
2005	2	11	21	0	175	4.1	4.4
2005	2	11	22	0	149	4	4.3
2005	2	11	23	0	149	3.6	3.9
2005	2	12	0	0	150	6.3	6.9
2005	2	12	1	0	159	6	6.5
2005	2	12	2	0	155	5.8	6.3
2005	2	12	3	0	187	6.2	6.6
2005	2	12	4	0	167	7.6	8.2
2005	2	12	5	0	144	6.6	7.3
2005	2	12	6	0	158	8.2	9.3
2005	2	12	7	0	172	9.3 1	0.1
2005	2	12	8	0	169	8.3	9.2
2005	2	12	9	0	167	8.3	9.1
2005	2	12	10	0	163	6.9	8.4
2005	2	12	11	0	150	6.4	7.6
2005	2	12	12	0	150	5.8	6.7
2005	2	12	13	0	147	5.7	6.8
2005	2	12	14	0	174	7.8	8.8
2005	2	12	15	0	174	8.4	9.1
2005	2	12	16	0	180	10.2 1	1.4
2005	2	12	17	0	173	7.8	8.4
2005	2	12	18	0	169	6	6.6
2005	2	12	19	0	155	5.8	6.5
2005	2	12	20	0	179	6.5	7.2
2005	2	12	21	0	217	3.5	3.8
2005	2	12	22	0	17	6.7	7.8
2005	2	12	23	0	42	5.1	5.5
2005	2	13	0	0	65	5	6.3
2005	2	13	1	0	91	2.8	4.4
2005	2	13	2	0	194	4.8	5.6
2005	2	13	3	0	194	4.9	5.8
2005	2	13	4	0	196	7.5	8.3
2005	2	13	5	0	190	7.1	8.4
2005	2	13	6	0	187	7.9	9.4
2005	2	13	7	0	210	5.9	6.8
2005	2	13	8	0	198	6.4	7.3
2005	2	13	9	0	213	5.7	7.2
2005	2	13	10	0	206	4.7	5.6
2005	2	13	11	0	192	2.3	2.6
2005	2	13	12	0	207	4.1	4.5
2005	2	13	13	0	176	3.6	4
2005	2	13	14	0	208	3.6	4.2
2005	2	13	15	0	220	2.6	3.4
2005	2	13	16	0	190	3.9	4.6
2005	2	13	17	0	207	5.7	6.4
2005	2	13	18	0	168	5.6	6
2005	2	13	19	0	179	6.8	7.9
2005	2	13	20	0	185	4.9	5.7
2005	2	13	21	0	181	4.3	4.6
2005	2	13	22	0	166	2.2	2.6
2005	2	13	23	0	274	0.4	0.8
2005	2	14	0	0	7	8.5	9.3
2005	2	14	1	0	9	5.1	5.6
2005	2	14	2	0	27	1.8	2
2005	2	14	3	0	70	3.9	4.7
2005	2	14	4	0	208	4	4.7

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	14	5	0	212	4.4	4.9
2005	2	14	6	0	202	6.9	8.1
2005	2	14	7	0	205	6.7	7.5
2005	2	14	8	0	209	5.9	6.5
2005	2	14	9	0	203	5.8	6.4
2005	2	14	10	0	206	5.9	6.8
2005	2	14	11	0	197	3.9	4.7
2005	2	14	12	0	210	3.2	4.1
2005	2	14	13	0	206	4.3	4.8
2005	2	14	14	0	287	2	2.6
2005	2	14	15	0	182	1.9	2.2
2005	2	14	16	0	181	2.6	2.9
2005	2	14	17	0	208	2.7	3.1
2005	2	14	18	0	37	5.1	5.6
2005	2	14	19	0	13	4.3	4.8
2005	2	14	20	0	25	2.7	3
2005	2	14	21	0	349	4	4.9
2005	2	14	22	0	7	1.5	2
2005	2	14	23	0	328	2.1	2.6
2005	2	15	0	0	329	2.7	3.1
2005	2	15	1	0	344	3.7	4.3
2005	2	15	2	0	338	4	4.4
2005	2	15	3	0	347	4.4	4.8
2005	2	15	4	0	326	3.4	3.8
2005	2	15	5	0	337	4.2	4.8
2005	2	15	6	0	2	4.1	4.6
2005	2	15	7	0	53	3.2	3.8
2005	2	15	8	0	82	2.5	3.4
2005	2	15	9	0	48	3.9	4.9
2005	2	15	10	0	51	2.7	3.3
2005	2	15	11	0	55	1.6	2
2005	2	15	12	0	72	2.6	3.1
2005	2	15	13	0	57	2.6	2.9
2005	2	15	14	0	74	3.9	4.8
2005	2	15	15	0	40	3.6	4.1
2005	2	15	16	0	32	4.1	5
2005	2	15	17	0	14	3.7	4.4
2005	2	15	18	0	12	6.9	7.9
2005	2	15	19	0	359	7.8	9.4
2005	2	15	20	0	2	8.8	9.7
2005	2	15	21	0	13	7.2	8.3
2005	2	15	22	0	355	8.1	9
2005	2	15	23	0	350	9.3 1	0.2
2005	2	16	0	0	349	10.0 1	1
2005	2	16	1	0	354	10.1 1	1.3
2005	2	16	2	0	352	10.3 1	1.3
2005	2	16	3	0	349	9	9.7
2005	2	16	4	0	354	9.5 1	0.6
2005	2	16	5	0	356	8.7 1	0.2
2005	2	16	6	0	34	3.4	4.2
2005	2	16	7	0	351	6	6.5
2005	2	16	8	0	18	5.8	6.4
2005	2	16	9	0	12	7.1	8
2005	2	16	10	0	24	6.8	7.4
2005	2	16	11	0	28	6.2	6.7
2005	2	16	12	0	7	8.8 1	0.1
2005	2	16	13	0	355	8.4	9.4
2005	2	16	14	0	11	6.1	6.9

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	2	16	15	0	21	7.3	8.1
2005	2	16	16	0	7	7.1	7.9
2005	2	16	17	0	31	6.1	7
2005	2	16	18	0	360	8.1	9.1
2005	2	16	19	0	354	7.5	8
2005	2	16	20	0	360	7.4	8
2005	2	16	21	0	359	8.2	8.6
2005	2	16	22	0	1	8	8.7
2005	2	16	23	0	353	6.5	7.2
2005	2	17	0	0	358	7	7.7
2005	2	17	1	0	359	7.1	8.1
2005	2	17	2	0	354	4.9	5.5
2005	2	17	3	0	353	7.1	7.7
2005	2	17	4	0	351	8.3	9.9
2005	2	17	5	0	349	6.8	7.8
2005	2	17	6	0	351	7.2	7.8
2005	2	17	7	0	356	7.3	7.9
2005	2	17	8	0	358	9.1	9.8
2005	2	17	9	0	5	10.2 1	1.2
2005	2	17	10	0	13	8.1	9.2
2005	2	17	11	0	13	7.1	8
2005	2	17	12	0	8	6.7	7.6
2005	2	17	13	0	16	7.9	9.3
2005	2	17	14	0	11	8	8.7
2005	2	17	15	0	5	7.1	8.2
2005	2	17	16	0	360	8	8.8
2005	2	17	17	0	12	7.1	7.7
2005	2	17	18	0	4	7.1	7.9
2005	2	17	19	0	7	7.7	8.4
2005	2	17	20	0	1	7.7	8.3
2005	2	17	21	0	360	8.4	9.2
2005	2	17	22	0	6	9	9.9
2005	2	17	23	0	2	8.1	9
2005	2	18	0	0	1	7.9	8.6
2005	2	18	1	0	2	6.7	7.6
2005	2	18	2	0	354	6.4	6.8
2005	2	18	3	0	355	6.3	6.6
2005	2	18	4	0	356	6.2	6.8
2005	2	18	5	0	4	6.7	7.6
2005	2	18	6	0	360	6.5	7.2
2005	2	18	7	0	3	7	7.7
2005	2	18	8	0	359	6.9	7.5
2005	2	18	9	0	15	7.8	8.3
2005	2	18	10	0	13	7.1	7.7
2005	2	18	11	0	15	5.5	6
2005	2	18	12	0	9	6	6.5
2005	2	18	13	0	2	5.3	5.7
2005	2	18	14	0	5	6.3	6.7
2005	2	18	15	0	3	6.2	6.9
2005	2	18	16	0	13	6.1	6.6
2005	2	18	17	0	6	7.6	8.4
2005	2	18	18	0	3	8.5	9.8
2005	2	18	19	0	3	10.0 1	1.2
2005	2	18	20	0	3	6.1	6.7
2005	2	18	21	0	4	4.8	5.3
2005	2	18	22	0	4	6.1	6.8
2005	2	18	23	0	6	6.1	6.6
2005	8	5	0	0	36	6.3	6.7

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	8	5	1	0	35	6.3	6.9
2005	8	5	2	0	31	6	6.2
2005	8	5	3	0	36	5.9	6.3
2005	8	5	4	0	26	3.3	3.6
2005	8	5	5	0	27	4.4	4.9
2005	8	5	6	0	26	2.4	2.5
2005	8	5	7	0	12	1.2	1.5
2005	8	5	8	0	337	0.8	1.6
2005	8	5	9	0	349	1.4	1.6
2005	8	5	10	0	17	2.6	2.8
2005	8	5	11	0	27	3.8	4.2
2005	8	5	12	0	28	3.3	3.6
2005	8	5	13	0	25	3.3	3.5
2005	8	5	14	0	7	2.2	2.4
2005	8	5	15	0	35	2.4	2.5
2005	8	5	16	0	38	3.7	4
2005	8	5	17	0	41	3.3	3.5
2005	8	5	18	0	38	3.4	3.6
2005	8	5	19	0	31	3.1	3.3
2005	8	5	20	0	31	3.5	3.8
2005	8	5	21	0	36	3.9	4.2
2005	8	5	22	0	36	4.2	4.7
2005	8	5	23	0	38	4.1	4.4
2005	8	6	0	0	38	5.3	5.5
2005	8	6	1	0	25	3.7	4
2005	8	6	2	0	45	2.1	2.5
2005	8	6	3	0	357	4.1	4.4
2005	8	6	4	0	345	4.2	4.6
2005	8	6	5	0	35	2.6	2.8
2005	8	6	6	0	17	3.3	3.6
2005	8	6	7	0	34	1.4	1.4
2005	8	6	8	0	22	2	2.5
2005	8	6	9	0	19	1.3	1.6
2005	8	6	10	0	300	1.3	1.4
2005	8	6	11	0	43	0.7	0.8
2005	8	6	12	0	132	1.1	1.3
2005	8	6	13	0	146	3.1	3.6
2005	8	6	14	0	146	3.8	4.4
2005	8	6	15	0	173	5	5.4
2005	8	6	16	0	186	4.7	5.2
2005	8	6	17	0	167	5.5	5.9
2005	8	6	18	0	164	5.3	5.5
2005	8	6	19	0	159	5.6	6
2005	8	6	20	0	154	5.7	6.2
2005	8	6	21	0	153	4.6	4.9
2005	8	6	22	0	161	3.7	3.8
2005	8	6	23	0	156	2.9	3.2
2005	8	7	0	0	151	3.7	4.1
2005	8	7	1	0	151	3.7	3.9
2005	8	7	2	0	149	3.4	3.9
2005	8	7	3	0	35	2.6	2.9
2005	8	7	4	0	33	4.2	4.6
2005	8	7	5	0	33	3.1	3.5
2005	8	7	6	0	41	3	3.3
2005	8	7	7	0	336	4.6	5.2
2005	8	7	8	0	345	4.7	5.2
2005	8	7	9	0	38	2.8	2.9
2005	8	7	10	0	25	2.2	2.3

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	8	7	11	0	13	2.5	2.8
2005	8	7	12	0	6	1.3	1.4
2005	8	7	13	0	32	2.6	3
2005	8	7	14	0	356	2.9	3.2
2005	8	7	15	0	352	2	2.1
2005	8	7	16	0	10	1	1.1
2005	8	7	17	0	181	4	4.2
2005	8	7	18	0	154	3.1	3.2
2005	8	7	19	0	165	4.7	5.1
2005	8	7	20	0	166	5.7	6.1
2005	8	7	21	0	166	4.8	5.3
2005	8	7	22	0	164	3.5	3.8
2005	8	7	23	0	26	2	2.2
2005	8	8	0	0	34	3.3	3.4
2005	8	8	1	0	27	4.7	5.8
2005	8	8	2	0	40	4.2	4.4
2005	8	8	3	0	27	5.6	5.8
2005	8	8	4	0	36	4.1	4.7
2005	8	8	5	0	5	4.2	5.1
2005	8	8	6	0	360	4.5	5.8
2005	8	8	7	0	33	2.1	2.5
2005	8	8	8	0	12	1.5	2
2005	8	8	9	0	4	4.1	4.6
2005	8	8	10	0	359	4.1	4.5
2005	8	8	11	0	1	3.7	3.9
2005	8	8	12	0	334	1.6	2
2005	8	8	13	0	360	2.8	3.1
2005	8	8	14	0	14	3.9	4.1
2005	8	8	15	0	1	4	4.3
2005	8	8	16	0	1	3	3.1
2005	8	8	17	0	27	3.2	3.5
2005	8	8	18	0	38	1.2	1.3
2005	8	8	19	0	163	2.9	3
2005	8	8	20	0	146	3	3.2
2005	8	8	21	0	25	1.9	2
2005	8	8	22	0	22	2.2	2.2
2005	8	8	23	0	31	2.4	2.8
2005	8	9	0	0	25	2.9	3
2005	8	9	1	0	37	3.4	3.8
2005	8	9	2	0	34	3.9	4.3
2005	8	9	3	0	29	4	4.6
2005	8	9	4	0	25	2.9	3.1
2005	8	9	5	0	36	4.3	4.7
2005	8	9	6	0	36	4.4	4.6
2005	8	9	7	0	44	2	2.3
2005	8	9	8	0	0	0	0
2005	8	9	9	0	149	3.7	3.9
2005	8	9	10	0	152	4.3	4.6
2005	8	9	11	0	173	3.1	3.4
2005	8	9	12	0	190	5.9	6.1
2005	8	9	13	0	179	6.3	7.3
2005	8	9	14	0	188	5.3	5.9
2005	8	9	15	0	185	6.1	6.6
2005	8	9	16	0	166	5.6	5.9
2005	8	9	17	0	178	4.6	4.9
2005	8	9	18	0	168	5	5.3
2005	8	9	19	0	160	4.6	4.9
2005	8	9	20	0	150	4.9	5.2

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	8	9	21	0	157	4.3	4.5
2005	8	9	22	0	160	2.9	3.3
2005	8	9	23	0	165	4	4.7
2005	8	10	0	0	161	4	4.4
2005	8	10	1	0	166	4.4	4.5
2005	8	10	2	0	160	5.4	5.9
2005	8	10	3	0	150	5	5.6
2005	8	10	4	0	147	5.3	5.6
2005	8	10	5	0	156	5.7	6.2
2005	8	10	6	0	166	6.8	7.2
2005	8	10	7	0	161	5.5	5.8
2005	8	10	8	0	169	5.1	6.1
2005	8	10	9	0	177	4.6	4.9
2005	8	10	10	0	191	4.2	4.5
2005	8	10	11	0	185	6.2	6.7
2005	8	10	12	0	193	5.5	5.8
2005	8	10	13	0	191	4.7	5
2005	8	10	14	0	204	3.5	4
2005	8	10	15	0	191	2.6	2.9
2005	8	10	16	0	155	2.6	2.8
2005	8	10	17	0	180	2.6	2.9
2005	8	10	18	0	196	4.2	4.7
2005	8	10	19	0	164	4.7	5.1
2005	8	10	20	0	171	4.8	5.1
2005	8	10	21	0	173	5.8	6.2
2005	8	10	22	0	185	4.6	5.1
2005	8	10	23	0	175	4.1	4.5
2005	8	11	0	0	154	3.7	3.7
2005	8	11	1	0	152	2.4	2.4
2005	8	11	2	0	5	1.3	1.4
2005	8	11	3	0	25	2.2	2.5
2005	8	11	4	0	43	1.9	2
2005	8	11	5	0	42	1.8	1.9
2005	8	11	6	0	25	2.1	2.1
2005	8	11	7	0	35	1.6	1.8
2005	8	11	8	0	141	0.9	1
2005	8	11	9	0	148	2.7	2.9
2005	8	11	10	0	151	2.7	3
2005	8	11	11	0	177	2.2	2.5
2005	8	11	12	0	165	1.4	1.8
2005	8	11	13	0	0	0	0
2005	8	11	14	0	172	0.7	0.7
2005	8	11	15	0	157	2.4	2.4
2005	8	11	16	0	311	1.2	1.3
2005	8	11	17	0	60	0.8	0.8
2005	8	11	18	0	172	0.8	0.8
2005	8	11	19	0	2	1	1.1
2005	8	11	20	0	25	1.6	1.8
2005	8	11	21	0	360	1.8	1.9
2005	8	11	22	0	37	2.1	2.2
2005	8	11	23	0	30	2.1	2.1
2005	8	12	0	0	2	0.7	0.7
2005	8	12	1	0	277	1.1	1.1
2005	8	12	2	0	293	1	1
2005	8	12	3	0	20	1.1	1.1
2005	8	12	4	0	0	0	0
2005	8	12	5	0	326	1	1.1
2005	8	12	6	0	41	4.3	4.6

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	8	12	7	0	17	3.5	3.9
2005	8	12	8	0	31	3.2	3.5
2005	8	12	9	0	3	5	5.6
2005	8	12	10	0	1	5.1	5.6
2005	8	12	11	0	3	5.9	6.2
2005	8	12	12	0	340	4.4	5.2
2005	8	12	13	0	338	4.5	4.7
2005	8	12	14	0	351	4.1	4.6
2005	8	12	15	0	346	3.4	4.1
2005	8	12	16	0	355	4.6	5.3
2005	8	12	17	0	6	3.3	3.6
2005	8	12	18	0	23	2.5	2.8
2005	8	12	19	0	353	2	2.3
2005	8	12	20	0	346	1.5	1.7
2005	8	12	21	0	16	1.5	1.8
2005	8	12	22	0	13	1.2	1.4
2005	8	12	23	0	332	0.7	0.8
2005	8	13	0	0	342	1.1	1.2
2005	8	13	1	0	241	1.6	1.9
2005	8	13	2	0	25	1.1	1.6
2005	8	13	3	0	51	1	1.2
2005	8	13	4	0	309	1.4	1.8
2005	8	13	5	0	359	2.7	2.9
2005	8	13	6	0	30	3.6	3.7
2005	8	13	7	0	44	3.7	4.1
2005	8	13	8	0	20	3	3.1
2005	8	13	9	0	1	1.6	1.8
2005	8	13	10	0	28	3	3.2
2005	8	13	11	0	35	3.1	3.4
2005	8	13	12	0	20	3.7	3.9
2005	8	13	13	0	24	3.6	3.8
2005	8	13	14	0	3	3.6	3.8
2005	8	13	15	0	348	3	3.1
2005	8	13	16	0	12	4.8	5.2
2005	8	13	17	0	26	4.2	4.4
2005	8	13	18	0	27	4.2	4.4
2005	8	13	19	0	34	4	4.4
2005	8	13	20	0	32	3.9	4.3
2005	8	13	21	0	36	4	4.5
2005	8	13	22	0	36	4.7	5.3
2005	8	13	23	0	41	5.5	6.1
2005	8	14	0	0	35	5	5.6
2005	8	14	1	0	40	5.7	6
2005	8	14	2	0	36	5.7	6.4
2005	8	14	3	0	36	5.1	5.6
2005	8	14	4	0	37	4	4.3
2005	8	14	5	0	3	3.3	3.3
2005	8	14	6	0	32	4.7	5
2005	8	14	7	0	32	3.3	3.7
2005	8	14	8	0	39	3.4	3.7
2005	8	14	9	0	46	4	4.3
2005	8	14	10	0	37	4.9	5.3
2005	8	14	11	0	30	3.3	3.5
2005	8	14	12	0	36	2.6	2.9
2005	8	14	13	0	28	2	2.1
2005	8	14	14	0	30	2.1	2.4
2005	8	14	15	0	28	2.7	2.8
2005	8	14	16	0	41	2.6	2.8

B-1 Wind Data - January, February and August 2005

Weather Data

NBDC Station WPCW1, West Point, Seattle, WA

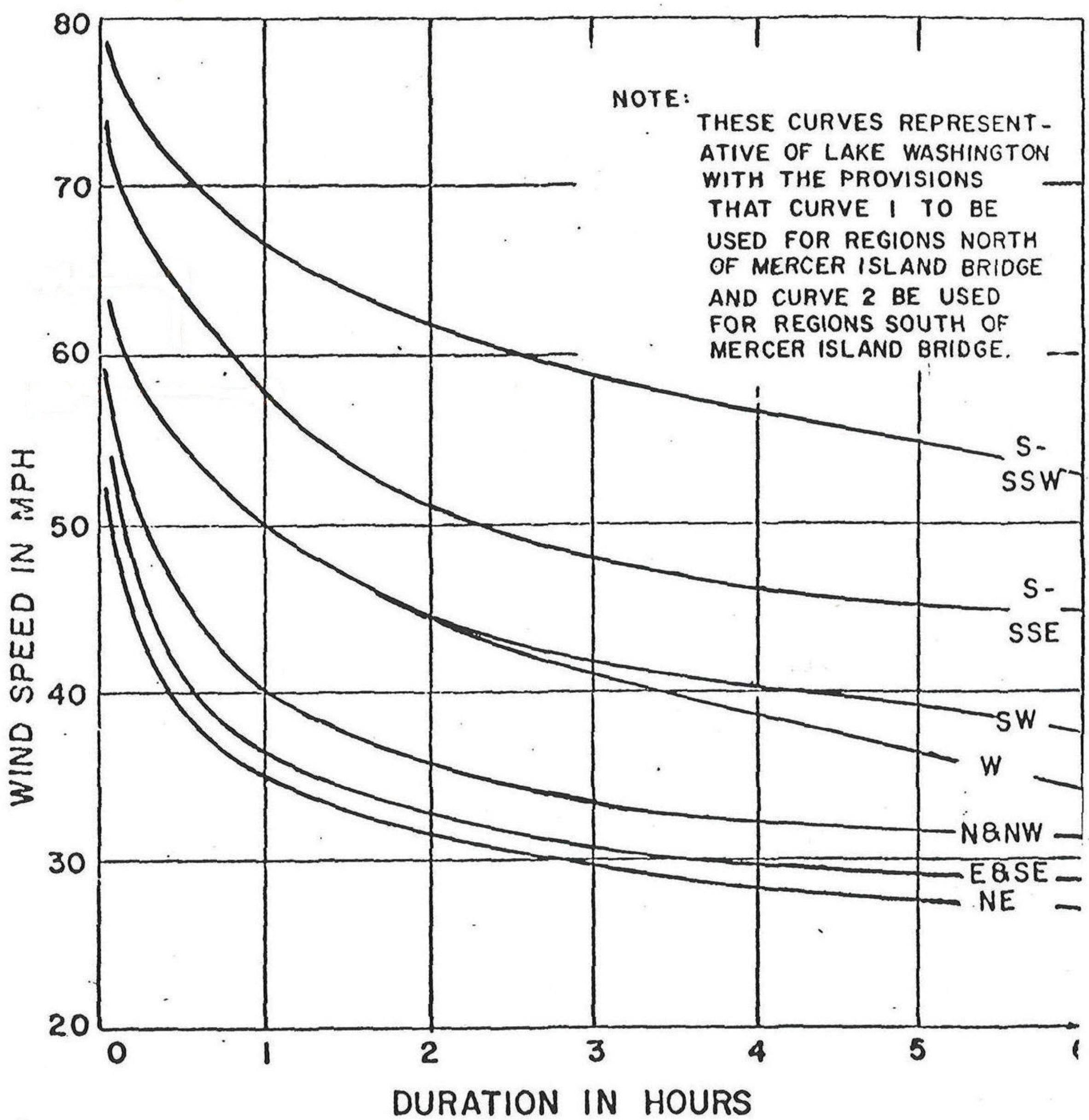
YYYY	MM	DD	hh	mm	WD	WSPD	GST
2005	8	14	17	0	33	2.8	3
2005	8	14	18	0	34	2.4	2.4
2005	8	14	19	0	22	2.4	2.6
2005	8	14	20	0	24	2.8	2.9
2005	8	14	21	0	35	3	3.4
2005	8	14	22	0	32	3.8	4.3
2005	8	14	23	0	31	4.3	5
2005	8	15	0	0	42	4.8	5
2005	8	15	1	0	42	5.2	5.5
2005	8	15	2	0	36	5.6	5.9
2005	8	15	3	0	23	5.5	5.7
2005	8	15	4	0	40	3.9	4.7
2005	8	15	5	0	32	4.2	4.9
2005	8	15	6	0	31	2	2.3
2005	8	15	7	0	45	3	3.2
2005	8	15	8	0	31	3	3.6
2005	8	15	9	0	29	3.6	3.8
2005	8	15	10	0	16	3.1	3.2
2005	8	15	11	0	30	2.7	3
2005	8	15	12	0	31	3.5	3.8
2005	8	15	13	0	39	4.7	5.1
2005	8	15	14	0	5	4.1	4.3
2005	8	15	15	0	13	3.6	3.9
2005	8	15	16	0	20	3.3	3.6
2005	8	15	17	0	17	3.6	4
2005	8	15	18	0	15	2.8	2.9
2005	8	15	19	0	36	2.9	3.2
2005	8	15	20	0	34	2.8	3
2005	8	15	21	0	40	2.7	3
2005	8	15	22	0	35	3	3.3
2005	8	15	23	0	45	5.7	6.2

YYYY	Year
MM	Month
DD	Date
hh	Local Hour
mm	Local Minute
WD	Wind Direction - Clockwise From True North
WSPD	Wind Speed Averaged Over A Two-Minute Period - m/s
GST	Peak 5 Second Gust Speed Measured During Two-Minute Period - m/s

Attachment B-2

Wind Duration Curve

B-2 Wind Duration Curve



THESE CURVES DEVELOPED FROM 24 YEAR RECORD FOR SEA-TAC AIRPORT, 17 YEAR RECORD FOR BOEING FIELD, AND SELECTED STORM RECORDS FROM THE EVERGEEN POINT FLOATING BRIDGE.

LAKE WASHINGTON
WIND VELOCITY
DURATION CURVES

U. S. Army Engr. District, Seattle, Was
Dr.: F.L.S. Transmitted with report
Tr.: R.C.H. dated 7-8-74 19
Ck.: File No.

Attachment B-3

Wind-Generated Waves

B-3 Wind-Generated Waves

Wind-generated Wave Predictions Per the Coastal Engineering Manual (CEM)*

Step		Unit	Symbol			Fastest
	Observed wind speed units	-	-	mph	mph	Mile
1	Observed wind speed	-	U_z	64	58	66
2	Observed wind height	ft	z	33	33	400
3	Observed wind duration	sec	t	1800	3600	55
4	Observation over land (L) or water (W)	-	L,W	W	W	L
5	Fetch length	ft	X	6,358	6,358	6,358
6	Air-sea temperature difference	Deg.C	Δ_T	0	0	0
7	Observed wind speed	ft/sec	U_z	93.9	85.1	77.1
8	Wind speed corrected for height	ft/sec	U_{10}	93.9	85.1	54.0
9	Wind speed corrected for duration	ft/sec	U_{3600}	92.7	85.1	43.0
10	Wind speed corrected for location	ft/sec	U_{water}	92.7	85.1	51.7
11	Wind speed corrected for temp difference	ft/sec	U_c	92.7	85.1	51.7
12	Wind drag coefficient	-	C_D	0.0021	0.0020	0.0017
13	Fetch-limited generation duration	sec	$t_{X,U}$	1,841	1,895	2,237
14	Duration corrected wind speed	ft/sec	U	91.6	84.1	51.3
15	Friction velocity	ft/sec	u	4.201	3.770	2.099
16	Energy-based significant wave height	ft	H_{m0}	2.44	2.19	1.22
17	Energy-based peak wave period	sec	Tp	1.9	1.9	1.5
18	33-Percentile Wave Height	ft	$H_{1/3}$	2.4	2.2	1.2
19	10-Percentile Wave Height	ft	$H_{1/10}$	3.1	2.8	1.5
20	1-Percentile Wave Height	ft	$H_{1/100}$	4.1	3.7	2.0
21	Maximum Wave Height	ft	H_{max}	4.5	4.1	2.3

* *Coastal Engineering Manual (Part II)* . U.S. Army Corps of Engineers, Engineering Manual EM 1110-2-1100, 31 January 2002.

Calculations based on CEM Figure II-2-20:

1-6 Input observed wind speed, observation height, observation duration, observation location, fetch, and air-water temperature difference.

7 U_z [ft/sec] = (6080/3600)[knots] = (5280/3600)[mph] = (3281/3600)[km/hr] = = (5280/3600)[FM]/(1.277+0.296tanh(0.9log0.0125[FM]) = (3.281)[m/s]

8 $U_{10} = U_z(33/z)^{1/7}$

9 $U_{3600} = U_{10}/\{1.277+ 0.296 \tanh[0.9\log(45/t)]\}$ for t<3,600 sec

$= U_{10}/[-0.15 \log(t) + 1.533]$ for t>3,600 sec

10 $U_{water} = 1.2U_{3600}$ if L; otherwise $U_{water} = U_{3600}$

11 $U_c = 0.9U_{water}$ if $T_{air}>T_{water}$

$= U_{water}$ if $T_{air}=T_{water}$

$= 1.1U_{water}$ if $T_{air}<T_{water}$

12 $C_D = 0.001(1.1+0.01067U_{10})$

13 $t_{X,U} = 77.23(0.3048X)^{2/3}/[(0.3048U_c9.81)]^{1/3}$

14 $U = U_c/\{1.277+ 0.296 \tanh[0.9\log(45/t_{X,U})]\}$ for $t_{X,U}$<3,600 sec

$= U_c/[-0.15 \log(t_{X,U}) + 1.533]$ for $t_{X,U}$>3,600 sec

15 $u = (C_DU^2)^{1/2}$

16 $H_{m0} = [(0.3048u)^2/9.81]\{0.0413[9.81(0.3048X)/(0.3048u)^2]^{1/2}\}(1/0.3048)$

17 $T_p = [(0.3048u)/9.81]\{0.651[9.81(0.3048X)/(0.3048u)^2]^{1/3}]$

18 $H_{1/3} = H_{mo}$

19 $H_{1/10} = 1.27\ H_{1/3}$

20 $H_{1/100} = 1.67\ H_{1/3}$

21 $H_{max} = 1.86\ H_{1/3}$

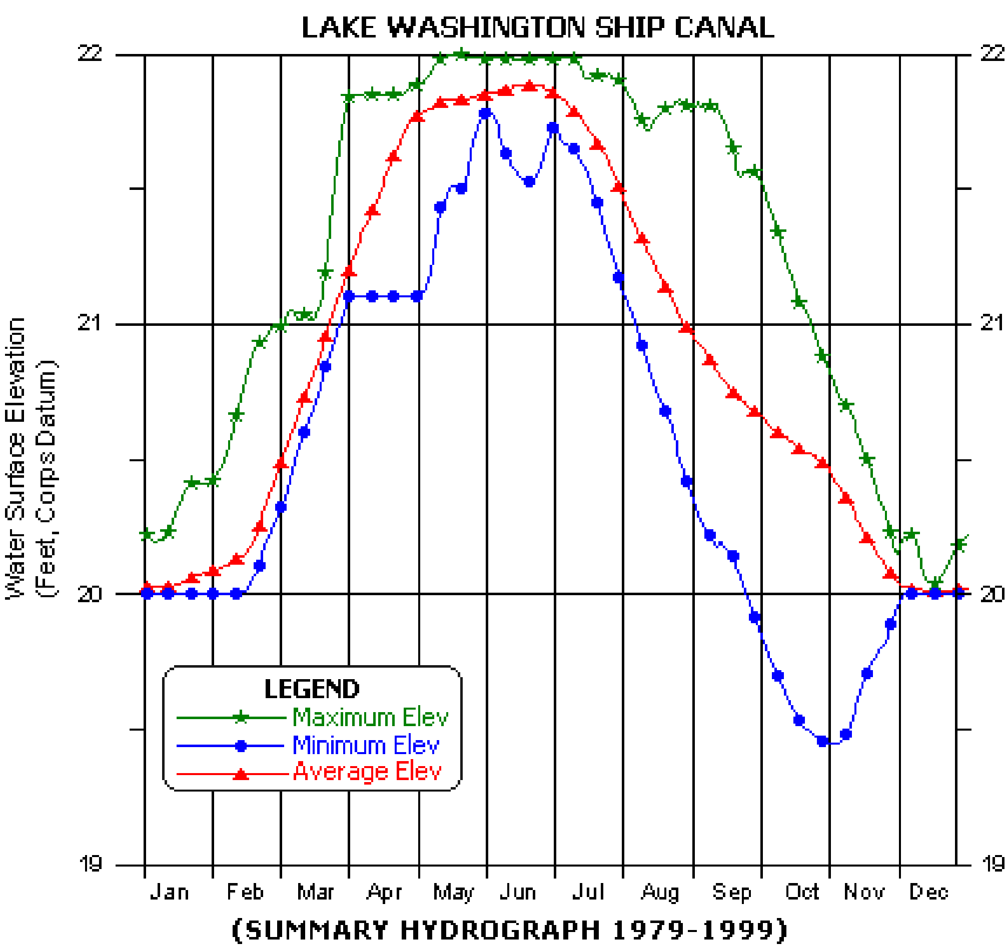
Attachment B-4

Lake Washington Ship Canal
Summary Hydrograph

B-4 Lake Washington Ship Canal Summary Hydrograph

Notes:

1. Summary hydrographs are a family of graphs which show, for each day of the calendar year, the maximum, minimum, and average water surface elevation over the period of record.
2. Lake Washington water surface data were collected at eight am each day.
3. The Lake Washington Ship Canal is operated primarily as a navigation facility connecting Puget Sound and Lakes Union and Washington. Project authorization documents state that under normal operation the Lake Washington Ship Canal should be maintained within a 2-foot range between 20.0 feet and 22.0 feet (Corps of Engineers Datum), respectively. The minimum elevation is maintained during the winter months to allow for annual maintenance on docks, walls, etc., by businesses and lakeside residents, minimize wave and erosion damage during winter storms and provide storage space for high inflow. The storage between 20 and 22 feet is used to augment Lake Washington Ship Canal inflows for use in operating the locks, the saltwater return system, the smolt passage flume, and the fish ladder facility.
4. The locks and spillway dam regulate the elevation of Salmon Bay, Lake Union, Lake Washington and the Lake Washington Ship Canal. The level of Lake Washington was lowered about 8 feet by the construction of the Lake Washington Ship Canal, but it is still the second largest natural lake in the state, with a surface area of 22,138 acres and shoreline of about 91 miles at elevation 22 feet.

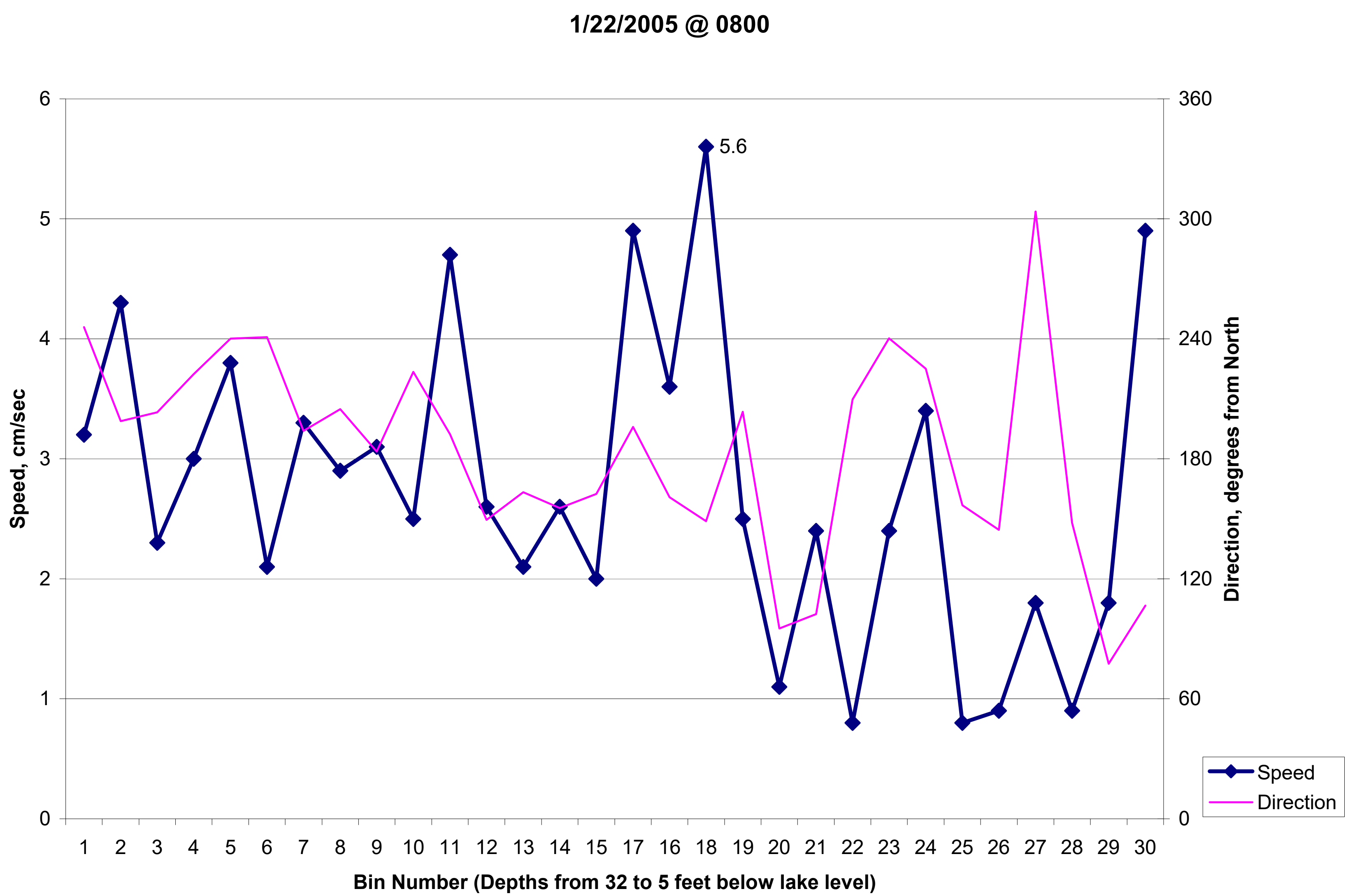


From:http://www.nwd-wc.usace.army.mil/nws/hh/basins/images/lwscsml.gif

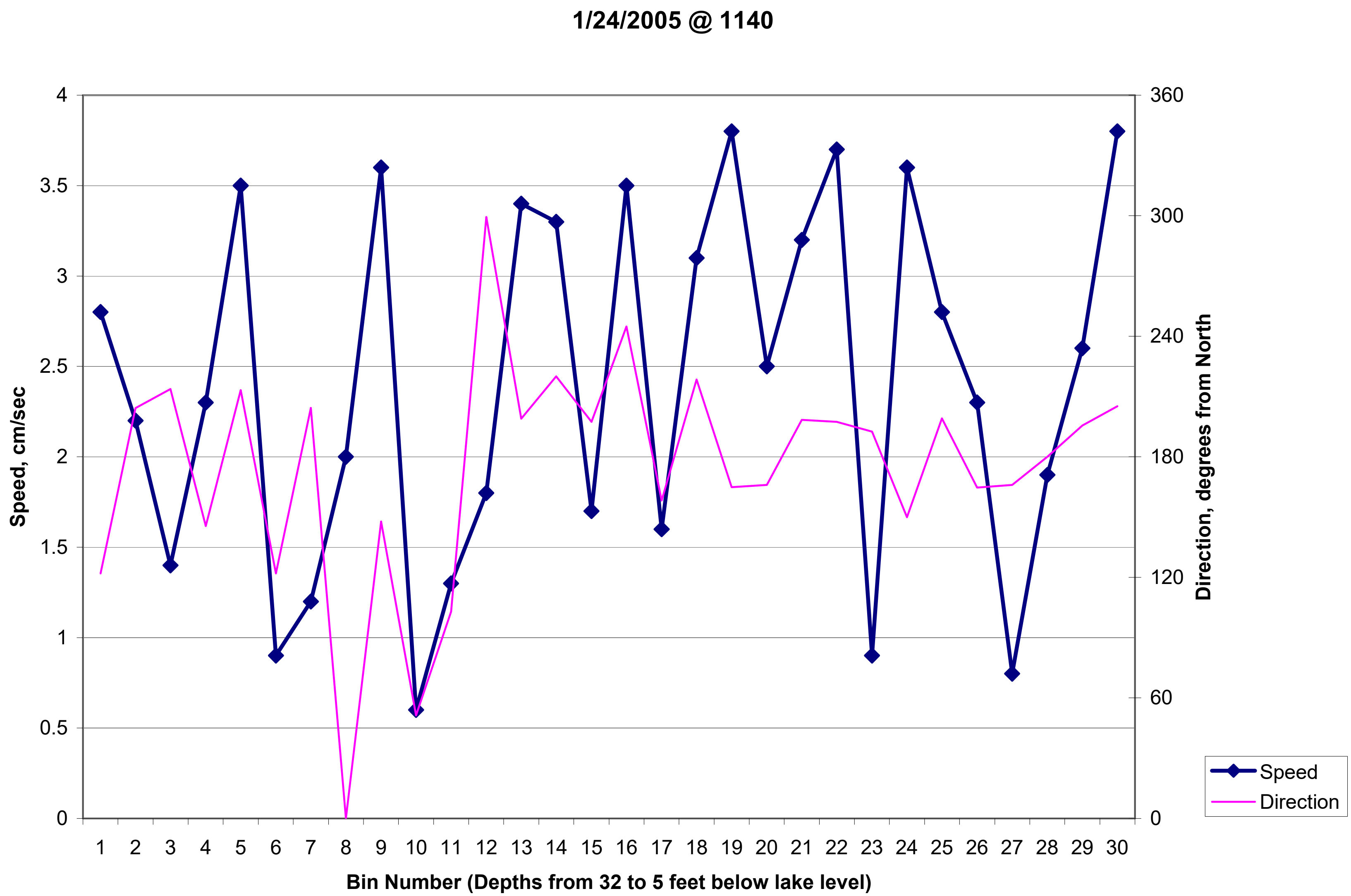
Attachment B-5

ADCP Charts

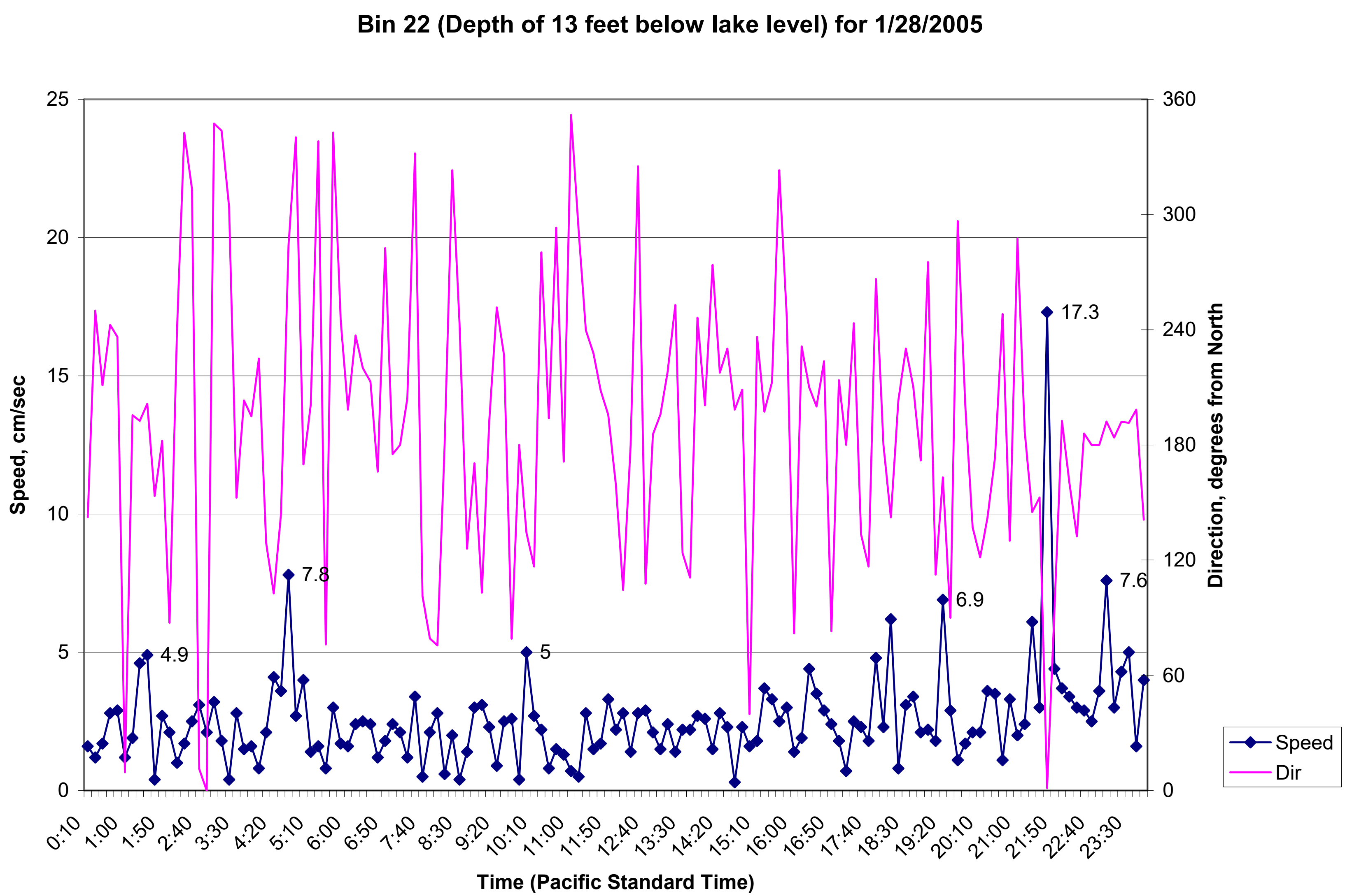
B-5 ADCP Charts



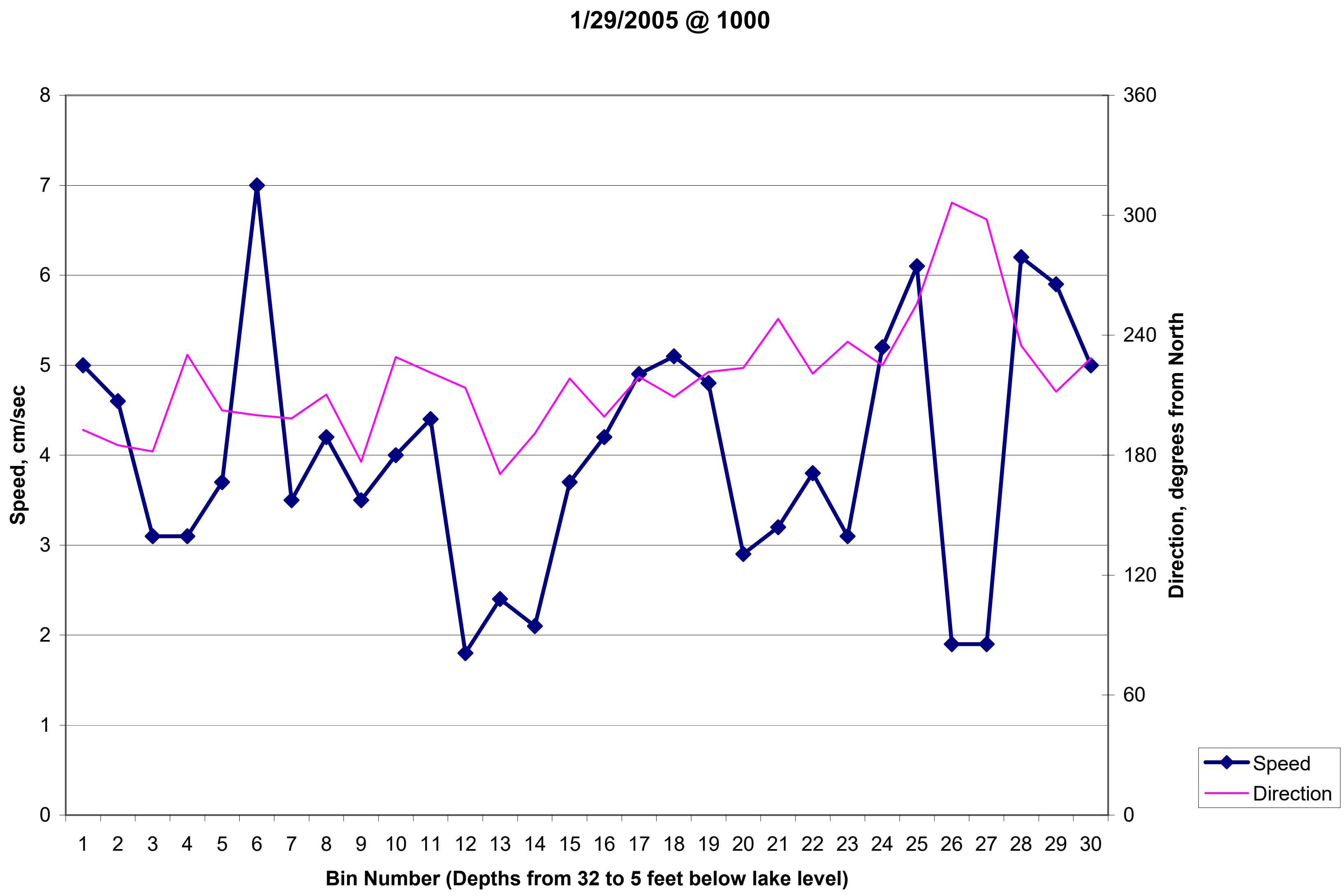
B-5 ADCP Charts



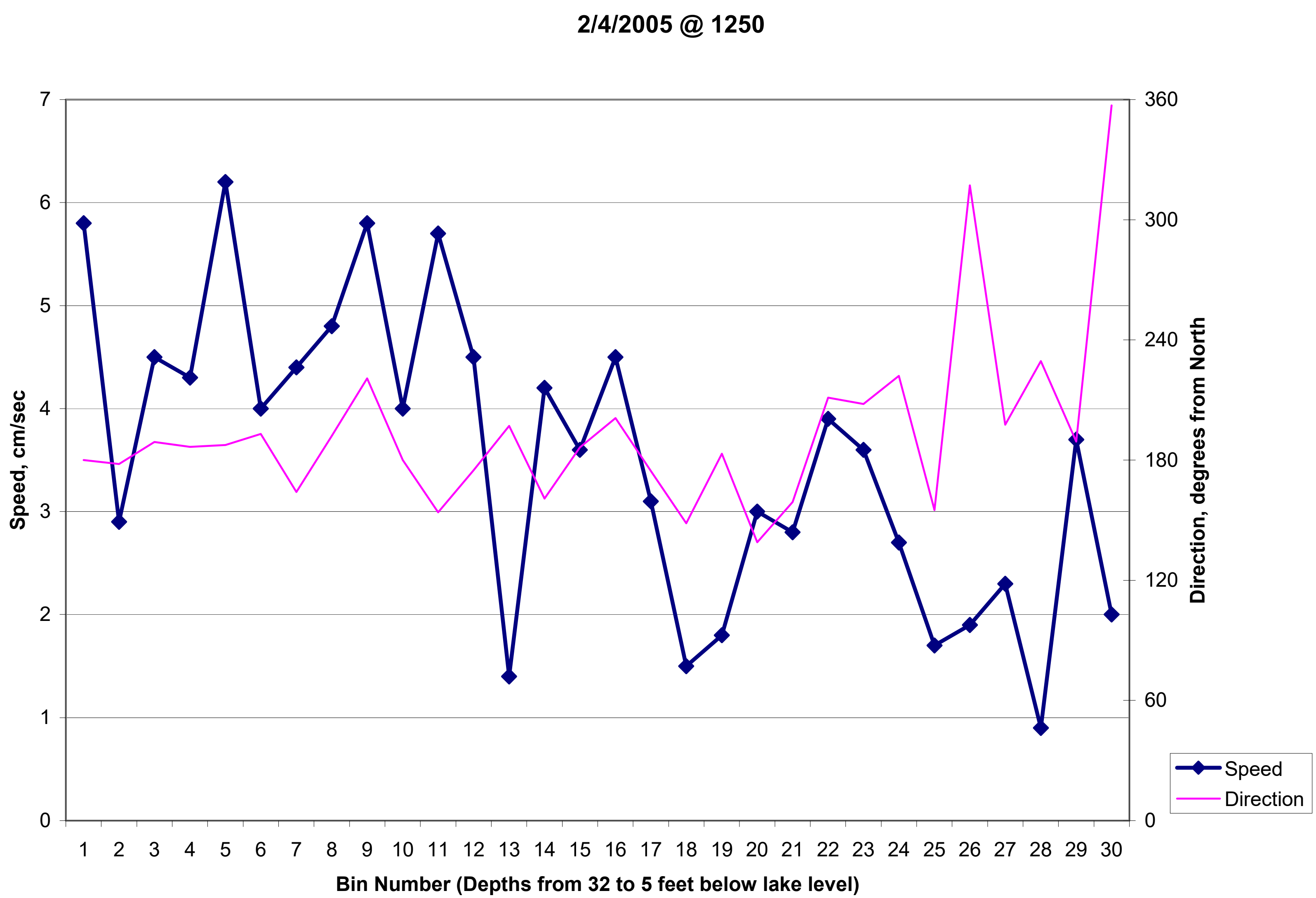
B-5 ADCP Charts

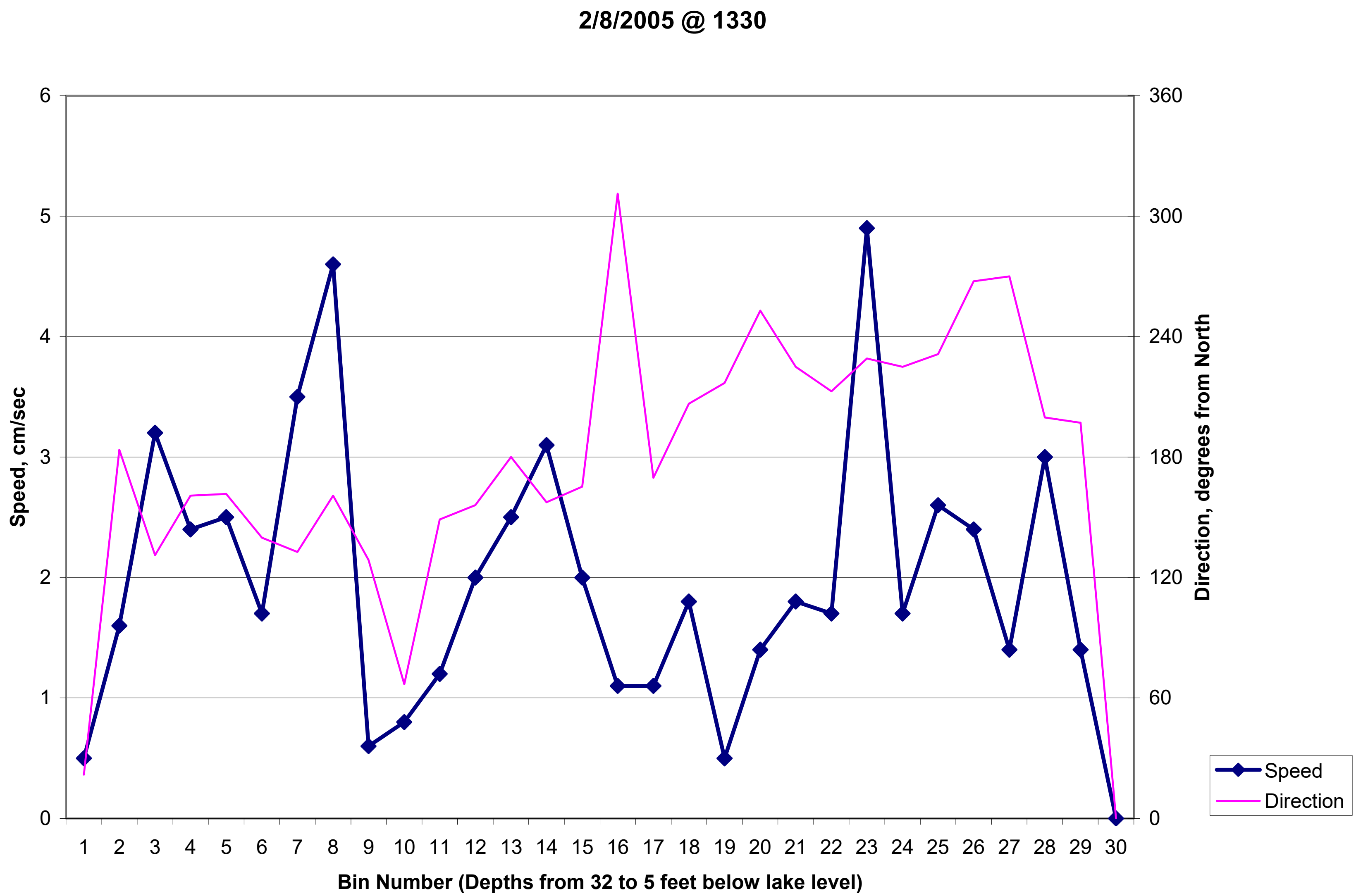


B-5 ADCP Charts



B-5 ADCP Charts




2/8/2005 @ 1330
Speed, cm/sec
Direction, degrees from North
Bin Number (Depths from 32 to 5 feet below lake level)
0
1
2
3
4
5
6
0
60
120
180
240
300
360
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Speed
Direction

Attachment B-6

VACM Tables

VACM S4-1 for 21-31 January 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	58878	45643	82,092	113,656	173,415	61,606	45,263	32,473	77,497	73,175	119,104	145,377	181,766	47,486	31,973	20,973	1,310,377
10.1-20	6	92	2,806	11,627	7,744	37	1	2	10	92	849	13,003	7,557	30	3	1	43,860
20.1-30	0	1	53	1,273	402	0	0	1	1	1	3	1,059	302	0	0	0	3,096
30.1-40	0	1	2	106	20	0	0	0	0	0	3	99	18	0	1	0	250
40.1-50	0	1	0	16	1	1	0	0	0	0	0	9	2	0	0	0	30
50.1-60	0	1	0	1	1	0	0	0	0	0	0	3	1	0	0	0	7
60.1-70	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	3
70.1-80	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2
80.1-90	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3
90.1-100	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2
100.1-150	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4
150.1-200	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
200.1-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
250.1-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300.1-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
350.1-400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	58884	45740	84,953	126,681	181,590	61,644	45,264	32,477	77,508	73,268	119,959	159,553	189,647	47,516	31,977	20,974	1,357,635

VACM S4-1 for 4-18 February 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	45517	27879	78181	120308	155790	82329	64001	29293	56741	48205	133666	177739	177298	66825	42127	17887	1,323,786
10.1-20	49	62	788	15918	5610	145	18	23	42	73	1798	23945	6143	149	24	11	54,798
20.1-30	8	7	12	1601	155	7	1	1	7	9	13	2094	168	10	2	5	4,100
30.1-40	2	1	3	141	8	2	0	1	0	1	6	155	5	4	1	0	330
40.1-50	1	0	0	23	1	0	0	0	1	3	1	21	1	0	0	0	52
50.1-60	0	1	0	0	1	0	0	0	1	1	1	8	0	1	2	0	16
60.1-70	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	4
70.1-80	0	0	1	1	0	0	0	0	0	0	0	1	0	2	0	1	6
80.1-90	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2
90.1-100	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	3
100.1-150	0	0	0	0	1	0	0	0	0	0	2	2	0	3	0	0	8
150.1-200	0	0	0	1	0	0	0	0	0	0	2	1	0	1	0	0	5
200.1-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
250.1-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300.1-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
350.1-400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	45577	27950	78,985	137,996	161,566	82,483	64,021	29,319	56,792	48,292	135,489	203,967	183,615	66,996	42,156	17,906	1,383,110

VACM S4-1 for 5-15 August 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	42661	29990	39,452	121,591	192,937	173,797	154,666	184,577	143,186	115,581	119,412	170,862	93,811	45,087	29,475	32,932	1,690,017
10.1-20	247	80	346	13,367	12,474	1,511	1,382	2,845	520	277	2,609	19,862	3,471	270	487	1,211	60,959
20.1-30	22	3	12	858	389	17	62	428	24	8	20	1,190	157	14	39	278	3,521
30.1-40	1	0	2	57	38	3	7	50	1	1	1	64	11	2	5	22	265
40.1-50	3	3	3	9	2	0	1	6	1	1	1	7	3	0	1	2	43
50.1-60	1	3	1	2	1	0	0	2	0	0	1	3	0	1	0	1	16
60.1-70	1	0	0	1	1	0	0	0	1	0	1	1	1	0	1	2	10
70.1-80	1	1	0	1	1	0	0	0	0	0	0	1	1	0	0	1	7
80.1-90	1	0	0	0	1	0	0	1	0	2	0	0	1	0	0	0	6
90.1-100	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
100.1-150	6	1	0	0	0	2	2	0	0	1	3	0	1	1	1	1	19
150.1-200	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	5
200.1-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
250.1-300	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	4
300.1-350	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	5
350.1-400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**42947**	**30081**	**39,816**	**135,886**	**205,844**	**175,330**	**156,120**	**187,910**	**143,733**	**115,872**	**122,049**	**191,993**	**97,457**	**45,375**	**30,010**	**34,458**	**1,754,881**

VACM S4-2 for 21-31 January 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	36,747	36,513	68,711	130,511	235,184	162,568	65,008	36,997	50,350	56,197	86723	118233	157752	80,242	33179	20,038	1,374,953
10.1-20	200	621	3,437	29,754	73,360	15,580	559	178	247	671	2728	14122	35027	5,996	285	116	182,881
20.1-30	31	61	169	1,275	7,370	700	35	14	20	42	122	451	3918	307	11	8	14,534
30.1-40	14	9	27	95	844	71	10	7	4	12	19	46	508	46	3	5	1,720
40.1-50	9	7	12	28	112	11	2	4	5	6	8	7	57	3	1	2	274
50.1-60	8	3	2	7	16	3	3	0	2	5	4	2	14	0	1	0	70
60.1-70	3	1	0	5	8	1	5	2	1	2	1	2	0	0	1	0	32
70.1-80	3	1	0	1	4	0	1	0	0	0	0	1	1	3	0	1	16
80.1-90	1	1	0	0	2	0	1	0	2	1	0	0	1	1	0	1	11
90.1-100	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	4
100.1-150	0	1	1	0	2	1	2	2	0	0	0	0	0	0	0	0	9
150.1-200	0	0	0	3	1	1	1	0	0	0	0	0	0	0	0	0	6
200.1-250	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	3
250.1-300	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	4
300.1-350	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
350.1-400	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Totals	**37,017**	**37,218**	**72,363**	**161,679**	**316,906**	**178,939**	**65,628**	**37,205**	**50,631**	**56,936**	**89,605**	**132,864**	**197,278**	**86,598**	**33,482**	**20,171**	**1,574,520**

VACM S4-2 for 4-18 February 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	49998	31108	50,265	76,301	188,498	91,494	66,304	49,157	85,337	61,926	87,690	110,608	188,716	60,190	38,738	25,510	1,261,840
10.1-20	1439	2724	4,674	13,993	63,856	13,588	2,753	2,185	5,154	8,324	16,206	34,458	60,351	5,764	640	567	236,676
20.1-30	229	1435	3,247	1,965	10,100	852	54	57	424	1,606	3,438	4,323	10,015	301	18	22	38,086
30.1-40	53	920	3,215	876	1,545	71	1	9	126	1,219	2,874	944	1,564	26	4	5	13,452
40.1-50	14	563	3,017	512	243	9	1	0	41	893	2,773	406	260	1	1	0	8,734
50.1-60	3	313	2,620	268	45	4	1	1	13	606	2,363	214	50	2	0	0	6,503
60.1-70	3	203	2,410	147	9	2	0	1	4	391	2,189	135	9	1	0	0	5,504
70.1-80	1	147	2,070	103	4	1	0	0	3	314	1,854	77	3	0	0	0	4,577
80.1-90	0	90	1,710	58	0	0	0	0	1	190	1,566	39	2	0	1	0	3,657
90.1-100	0	52	1,405	28	2	1	0	0	0	155	1,401	21	1	0	1	0	3,067
100.1-150	0	94	4,019	41	4	1	0	0	1	265	4,020	57	3	0	0	0	8,505
150.1-200	0	15	1,503	7	1	1	0	0	0	35	1,562	7	1	0	0	0	3,132
200.1-250	0	4	564	3	0	0	0	0	0	10	543	1	0	0	0	0	1,125
250.1-300	0	1	191	0	0	0	0	0	0	1	172	1	0	0	0	0	366
300.1-350	0	0	34	2	0	0	0	0	0	0	30	0	1	0	0	0	67
350.1-400	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Totals	51740	37669	80,945	94,304	264,307	106,024	69,114	51,410	91,104	75,935	128,681	151,291	260,976	66,285	39,403	26,104	1,595,292

VACM S4-3 for 5-15 August 2005 by 1/2-Second Counts

Direction (toward)

Current Speed (cm/sec)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Cumulative
0.0-10	221,881	141,867	81,053	59,754	37,049	30,536	35,394	97,192	130,824	84,306	56,892	59,289	48,100	49,772	74,073	193,416	1,401,398
10.1-20	97,410	40,578	13,320	5,800	2,685	1,601	2,235	16,585	43,093	10,420	6,262	6,125	3,294	2,706	8,349	54,037	314,500
20.1-30	7,914	2,064	673	850	701	413	559	1,844	5,178	712	391	661	671	385	666	2,966	26,648
30.1-40	1,074	186	95	205	212	131	356	647	1,141	130	34	149	217	98	405	711	5,791
40.1-50	337	43	25	38	74	41	386	427	446	43	9	46	106	29	337	471	2,858
50.1-60	144	11	1	14	33	2	302	432	232	18	2	13	28	12	318	432	1,994
60.1-70	81	3	2	6	8	0	92	390	157	9	0	5	17	1	100	352	1,223
70.1-80	43	2	0	2	4	3	3	127	49	2	0	1	5	0	6	110	357
80.1-90	15	0	0	0	2	0	1	11	18	1	0	0	1	1	0	14	64
90.1-100	8	0	1	0	0	0	0	3	5	0	0	1	0	0	0	4	22
100.1-150	2	3	0	1	0	0	1	1	2	0	1	2	0	0	0	1	14
150.1-200	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	3	7
200.1-250	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	2
250.1-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300.1-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
350.1-400	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Totals	328,911	184,757	95,170	66,672	40,768	32,727	39,329	117,663	181,146	95,641	63,591	66,292	52,439	53,004	84,254	252,517	1,754,881

Attachment B-7

Vessel-Generated Currents

B-7 Vessel-Generated Currents

Blaauw and van de Kaa (1978)* Propeller Jet Model

Vessel Type	Tug
Propeller Diameter (D), Ft	3
Propeller Rotational Speed (n), rpm	100
Propeller System (Ducted, Non-Ducted):	Non-Ducted
Propeller Thrust Coefficient (K_T)	68.1

Propeller Axial Efflux Velocity (v_o), ft/sec	=	66.0
Initial Slipstream Diameter (D_o), ft	=	2.1
Length of Flow Establishment Zone (x_o), ft	=	5.9

Axial Velocity in Propeller Jet ($v_{x,r}$), ft/sec

Radial Distance from Jet Axis (r),	Jet Axial Distance from Propeller Plane (x), ft													
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**150**	**200**	**250**
0	38.9	19.5	13.0	9.7	7.8	6.5	5.6	4.9	4.3	3.9	3.2	2.6	1.9	1.6
1	33.3	18.7	12.7	9.6	7.7	6.5	5.5	4.9	4.3	3.9	3.2	2.6	1.9	1.6
2	21.0	16.7	12.1	9.4	7.6	6.4	5.5	4.8	4.3	3.9	3.2	2.6	1.9	1.6
3	9.7	13.7	11.1	8.9	7.4	6.2	5.4	4.8	4.2	3.8	3.2	2.6	1.9	1.6
4	3.3	10.5	9.9	8.3	7.0	6.1	5.3	4.7	4.2	3.8	3.2	2.6	1.9	1.5
5	0.8	7.4	8.4	7.6	6.7	5.8	5.1	4.6	4.1	3.7	3.2	2.5	1.9	1.5
6	0.2	4.9	7.0	6.9	6.2	5.6	5.0	4.5	4.0	3.7	3.1	2.5	1.9	1.5
7	0.0	2.9	5.6	6.1	5.7	5.3	4.8	4.3	3.9	3.6	3.1	2.5	1.9	1.5
8	0.0	1.6	4.3	5.2	5.2	4.9	4.5	4.2	3.8	3.5	3.0	2.5	1.9	1.5
10	0.0	0.4	2.3	3.7	4.2	4.2	4.1	3.8	3.6	3.3	2.9	2.4	1.9	1.5
12	0.0	0.1	1.1	2.4	3.2	3.5	3.5	3.4	3.3	3.1	2.8	2.3	1.8	1.5
22	0.0	0.0	0.0	0.1	0.4	0.8	1.2	1.5	1.7	1.8	1.9	1.9	1.6	1.4
32	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	1.1	1.3	1.3	1.2

* Blaauw, H. G. and E. J. van de Kaa. *Erosion of Bottom and Sloping Banks Caused by the Screw Race of Manoeuvering Ships*. Delft Hydraulics Laboratory, Publication Number 202, July 1978.

Symbols match those in the reference article and in the Notes.

B-7 Vessel-Generated Currents

Vessel Type	Yacht
Propeller Diameter (D), Ft	2.5
Propeller Rotational Speed (n), rpm	200
Propeller System (Ducted, Non-Ducted):	Non-Ducted
Propeller Thrust Coefficient (K_T)	2.3

Propeller Axial Efflux Velocity (v_o), ft/sec = 20.2

Initial Slipstream Diameter (D_o), ft = 1.8

Length of Flow Establishment Zone (x_o), ft = 4.9

Axial Velocity in Propeller Jet ($v_{x,r}$), ft/sec

Radial Distance from Jet Axis (r),	Jet Axial Distance from Propeller Plane (x), ft													
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**150**	**200**	**250**
0	9.9	5.0	3.3	2.5	2.0	1.7	1.4	1.2	1.1	1.0	0.8	0.7	0.5	0.4
1	8.5	4.8	3.3	2.5	2.0	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.5	0.4
2	5.4	4.3	3.1	2.4	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.5	0.4
3	2.5	3.5	2.8	2.3	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.5	0.4
4	0.8	2.7	2.5	2.1	1.8	1.5	1.3	1.2	1.1	1.0	0.8	0.7	0.5	0.4
5	0.2	1.9	2.2	2.0	1.7	1.5	1.3	1.2	1.1	1.0	0.8	0.7	0.5	0.4
6	0.0	1.2	1.8	1.8	1.6	1.4	1.3	1.1	1.0	0.9	0.8	0.6	0.5	0.4
8	0.0	0.4	1.1	1.3	1.3	1.3	1.2	1.1	1.0	0.9	0.8	0.6	0.5	0.4
10	0.0	0.1	0.6	0.9	1.1	1.1	1.0	1.0	0.9	0.9	0.7	0.6	0.5	0.4
12	0.0	0.0	0.3	0.6	0.8	0.9	0.9	0.9	0.8	0.8	0.7	0.6	0.5	0.4
14	0.0	0.0	0.1	0.4	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.5	0.4
24	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.3
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3

Verhey (1983)* Propeller Jet Model

Vessel Type	Tug
Propeller Diameter (D_p), ft.	3.0
Propeller Speed (n), rpm	100
Thrust Coefficent (K_T)	68.1
Slipstream Diameter (D_o)**, ft	3
Propeller Axial Efflux Velocity (u_o), ft/sec	66.0

** $D_o = D_p$ for a non-ducted propeller
$= 0.71D_p$ for a ducted propeller
$= 0.85D_p$ for a propeller in a tunnel.

Axial Velocity in Propeller Jet ($u_{x,r}$), ft/sec

Jet Axial Distance from Propeller Plane (x), ft

Radial Distance from Jet Axis (r),	10	20	30	40	50	60	70	80	90	100	120	150	200	250
0	55.1	27.5	18.4	13.8	11.0	9.2	7.9	6.9	6.1	5.5	4.6	3.7	2.8	2.2
1	47.2	26.5	18.0	13.6	10.9	9.1	7.8	6.9	6.1	5.5	4.6	3.7	2.8	2.2
2	29.7	23.6	17.1	13.2	10.7	9.0	7.8	6.8	6.1	5.5	4.6	3.7	2.7	2.2
3	13.7	19.5	15.7	12.6	10.4	8.8	7.6	6.7	6.0	5.4	4.5	3.6	2.7	2.2
4	4.7	14.9	14.0	11.8	10.0	8.6	7.5	6.6	5.9	5.4	4.5	3.6	2.7	2.2
5	1.2	10.5	12.0	10.8	9.4	8.2	7.3	6.5	5.8	5.3	4.5	3.6	2.7	2.2
6	0.2	6.9	9.9	9.7	8.8	7.9	7.0	6.3	5.7	5.2	4.4	3.6	2.7	2.2
7	0.0	4.2	7.9	8.6	8.1	7.4	6.7	6.1	5.6	5.1	4.4	3.5	2.7	2.2
8	0.0	2.3	6.1	7.4	7.4	7.0	6.4	5.9	5.4	5.0	4.3	3.5	2.7	2.2
10	0.0	0.6	3.3	5.2	5.9	6.0	5.7	5.4	5.1	4.7	4.1	3.4	2.6	2.1
12	0.0	0.1	1.6	3.4	4.5	5.0	5.0	4.9	4.7	4.4	3.9	3.3	2.6	2.1
22	0.0	0.0	0.0	0.1	0.6	1.2	1.7	2.1	2.4	2.6	2.7	2.6	2.3	2.0
32	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.1	1.5	1.8	1.9	1.7

* Verhey, H.J. *The Stability of Bottom and Banks Subjected to the Velocities in the Propeller Jet Behind Ships.* Delft Hydraulics Laboratory, Publication Number 303, April 1983.
Symbols match those in the reference article and in the Notes.

B-7 Vessel-Generated Currents

Vessel Type	Yacht
Propeller Diameter (D_p), ft.	2.5
Propeller Speed (n), rpm	200
Thrust Coefficent (K_T)	2.3
Slipstream Diameter (D_o)**, ft	2.5
Propeller Axial Efflux Velocity (u_o), ft/sec	20.2

** D_o = D_p for a non-ducted propeller
= 0.71D_p for a ducted propeller
= 0.85D_p for a propeller in a tunnel.

Axial Velocity in Propeller Jet ($u_{x,r}$), ft/sec

Radial Distance from Jet Axis (r),	Jet Axial Distance from Propeller Plane (x), ft													
	12	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**150**	**200**	**250**
0	11.7	7.0	4.7	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.2	0.9	0.7	0.6
1	10.5	6.8	4.6	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.2	0.9	0.7	0.6
2	7.6	6.0	4.4	3.4	2.7	2.3	2.0	1.7	1.5	1.4	1.2	0.9	0.7	0.6
3	4.5	5.0	4.0	3.2	2.7	2.3	2.0	1.7	1.5	1.4	1.2	0.9	0.7	0.6
4	2.1	3.8	3.6	3.0	2.5	2.2	1.9	1.7	1.5	1.4	1.2	0.9	0.7	0.6
5	0.8	2.7	3.1	2.8	2.4	2.1	1.9	1.7	1.5	1.4	1.1	0.9	0.7	0.6
6	0.2	1.8	2.5	2.5	2.3	2.0	1.8	1.6	1.5	1.3	1.1	0.9	0.7	0.6
8	0.0	0.6	1.6	1.9	1.9	1.8	1.6	1.5	1.4	1.3	1.1	0.9	0.7	0.6
10	0.0	0.1	0.8	1.3	1.5	1.5	1.5	1.4	1.3	1.2	1.1	0.9	0.7	0.5
12	0.0	0.0	0.4	0.9	1.2	1.3	1.3	1.2	1.2	1.1	1.0	0.8	0.7	0.5
14	0.0	0.0	0.2	0.5	0.8	1.0	1.1	1.1	1.1	1.0	0.9	0.8	0.7	0.5
24	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.5
34	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.4

B-7 Vessel-Generated Currents

Hamill et al (1996)* Propeller Jet Model

Vessel Type	Tug
Propeller Diameter (D_p), ft	3.0
Propeller Rotational Speed (n), rpm	100
Propeller Hub Diameter (D_h), ft	0.75
Propeller Thrust Coefficient (C_T)	68.1
Propeller Blade Area Ratio (B)	0.7

Propeller Characteristics Factor (ζ)	=	0.2
Propeller Axial Efflux Velocity (v_o), ft/sec	=	58.6
Length of Flow Establishment Zone (x_o), ft	=	9.0
Radial Position of Maximum Velocity (R_{mo}), ft	=	0.6

Axial Velocity in Propeller Jet ($v_{x,r}$), ft/sec

	Jet Axial Distance from Propeller Plane (x), ft													
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**150**	**200**	**250**
Max Jet Velocity	26.33	20.84	15.35	9.86	4.37	-1.11	-6.60	-12.09	-17.58	-23.07	-34.04	-50.51	-77.95	-105.39
Velocity σ	1.27	2.02	2.77	3.52	4.27	5.02	5.77	6.52	7.27	8.02	9.52	11.77	15.52	19.27
(v_{max}), ft/sec	**26.3**	**20.8**	**15.4**	**9.9**	**4.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Radial Distance from Jet Axis (r), 0	23.3	19.8	15.0	9.7	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	25.2	20.5	15.2	9.8	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	14.7	16.5	13.6	9.1	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	4.6	10.5	10.6	7.9	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.8	5.2	7.3	6.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.1	2.0	4.4	4.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.6	2.3	3.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.1	1.1	1.9	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.4	1.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* Hamill, G. A., H. T. Johnston and D. P. J. Stewart. *Estimating the Velocities in a Ship's Propeller Wash*. PIANC Bulletin No. 89, Pg. 46-54, 1996.
Hamill, G. A., and J. A. McGarvey. *Designing for Propeller Action in Harbours*. ICCE'96, Orlando, FL, Pg. 4451-4463, September 1996.

Symbols match those in the reference article and in the Notes.

B-7 Vessel-Generated Currents

Vessel Type	Yacht
Propeller Diameter (D_p), ft	2.5
Propeller Rotational Speed (n), rpm	200
Propeller Hub Diameter (D_h), ft	0.5
Propeller Thrust Coefficient (C_T)	2.3
Propeller Blade Area Ratio (B)	0.8

Propeller Characteristics Factor (ζ)	=	0.4
Propeller Axial Efflux Velocity (v_o), ft/sec	=	17.9
Length of Flow Establishment Zone (x_o), ft	=	7.5
Radial Position of Maximum Velocity (R_{mo}), ft	=	0.6

Axial Velocity in Propeller Jet ($v_{x,r}$), ft/sec

	Jet Axial Distance from Propeller Plane (x), ft													
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**150**	**200**	**250**
Max Jet Velocity	7.73	5.71	3.69	1.68	-0.34	-2.36	-4.38	-6.39	-8.41	-10.43	-14.46	-20.51	-30.60	-40.68
Velocity σ	1.29	2.04	2.79	3.54	4.29	5.04	5.79	6.54	7.29	8.04	9.54	11.79	15.54	19.29
(v_{max}), ft/sec	**7.7**	**5.7**	**3.7**	**1.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Radial Distance from Jet Axis (r), 0	6.9	5.4	3.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	7.4	5.6	3.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	4.4	4.6	3.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.4	2.9	2.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.2	1.5	1.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.6	1.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.2	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Vessel-Generated Wake Velocity
Maynord (2000)

Vessel Type	Tug	Tug	Tug	Tug	
Vessel Draft, ft (Draft)	9	9	9	9	
Vessel Velocity, ft/sec (V_g), relative to the ground	12	12	12	12	
Ambient Water Velocity, ft/sec (V_a)	0.1	0.1	0.1	0.1	
Water Depth, ft (Depth), under vessel	10	20	30	40	
Bow Wave Bottom Velocity, ft/sec (V_{bow})	7.2	3.0	1.8	1.2	Rapid velocity decrease.
Displacement Bottom Velocity, ft/sec (V_{bd})	7.2	3.1	1.9	1.4	Rapid velocity increase.
Wake Bottom Velocity, ft/sec ($V_{wake,a(max)}$) relative to ambient	7.7	2.2	1.1	0.6	
Wake Bottom Velocity, ft/sec ($V_{wake,g(max)}$) relative to ground	7.8	2.3	1.1	0.7	

[yellow box] = Cell open for input.

Maynord, Stephen T. (2000) *Physical Forces near Commercial Tows - Upper Mississippi River - Illinois Waterway System Navigation Study*. Prepared for U.S. Army Engineer Distrct, Rock Island, U.S. Army Engineer Distrct, St. Louis, U.S. Army District, St. Paul, ENV Report 19, March 2000.

Vessel Type	Barge	Barge	Barge	Barge
Vessel Draft, ft (Draft)	10	10	10	10
Vessel Velocity, ft/sec (V_g), relative to the ground	12	12	12	12
Ambient Water Velocity, ft/sec (V_a)	0.1	0.1	0.1	0.1
Water Depth, ft (Depth), under vessel	10	20	30	40

Bow Wave Bottom Velocity, ft/sec (V_{bow})	8.2	3.4	2.0	1.4	Rapid velocity decrease.
Displacement Bottom Velocity, ft/sec (V_{bd})	8.2	3.5	2.2	1.5	Rapid velocity increase.
Wake Bottom Velocity, ft/sec ($V_{wake,a(max)}$) relative to ambient	9.3	2.6	1.3	0.8	
Wake Bottom Velocity, ft/sec ($V_{wake,g(max)}$) relative to ground	9.4	2.7	1.4	0.8	

Vessel Type	Yacht	Yacht	Yacht	Yacht
Vessel Draft, ft (Draft)	7	7	7	7
Vessel Velocity, ft/sec (V_g), relative to the ground	12	12	12	12
Ambient Water Velocity, ft/sec (V_a)	0.1	0.1	0.1	0.1
Water Depth, ft (Depth), under vessel	10	20	30	40

Bow Wave Bottom Velocity, ft/sec (V_{bow})	5.2	2.1	1.3	0.9	Rapid velocity decrease.
Displacement Bottom Velocity, ft/sec (V_{bd})	5.3	2.3	1.4	1.0	Rapid velocity increase.
Wake Bottom Velocity, ft/sec ($V_{wake,a(max)}$) relative to ambient	4.9	1.4	0.7	0.4	
Wake Bottom Velocity, ft/sec ($V_{wake,g(max)}$) relative to ground	5.0	1.5	0.8	0.5	

Maynord (2000)* Propeller Jet Model

Vessel Type	Yacht	
Propeller Diameter (D_p), ft	2.5	
Propeller Rotational Speed (n), rpm	200	
Thrust per Propeller (T), lbf	5,000	
Propeller Axis Depth (d_p), ft	6.0	
Local Water Depth (h), ft	40	
Propeller Jet Diameter (D_o), ft	1.8	= D_p for ducted propeller; = $0.71D_p$ for open propeller.
Stern Setback from Propeller (S_B), ft	4.0	
Unit Weight of Water (γ), lbf/ft^3	62.5	

Initial Propeller Jet Velocity (V_2), ft/sec	31.9
Vertical Distance from Bottom to Propeller Axis (H_p), ft	34.0

Zone 1 (x/D_p<10 and Central Rudder)

Distance Behind Propeller (x), ft	10	20	30	40	50	60	70	80	90	100	120	150	200	250
Distance Ratio (x/D_p)	4.0	8.0	12.0	16.0	20.0	24.0	28.0	32.0	36.0	40.0	48.0	60.0	80.0	100.0
Open Propeller Jet Maximum Elevation/Propeller Axis (C_J), ft	-1.7	-3.6	-5.4	-7.1	-8.6	-10.0	-11.3	-12.4	-13.3	-14.2	-15.4	-16.2	-14.8	-9.9
Ducted Propeller Jet Maximum Elevation/Propeller Axis (C_J), ft	-1.6	-3.4	-4.9	-6.2	-7.2	-7.9	-8.4	-8.5	-8.5	-8.1	-6.7	-2.5	Surface	Surface
Maximum Propeller Jet Velocity ($V_{x\ max}$), ft/sec	18.6	13.0	10.5	9.0	8.0	7.3	6.7	6.3	5.9	5.6	5.1	4.5	3.9	3.5
Maximum Propeller Jet Velocity at Surface ($V_{x\ surf\ max}$), ft/sec	22.3	15.5	12.6	10.8	9.6	8.7	8.1	7.5	7.1	6.7	6.1	5.4	4.6	4.1
Maximum near Botton Propeller Velocity (Vbot), ft/sec	0.9	0.8	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4

Zone 2 (10<x/D_p<44)

Distance Behind Propeller (x), ft	100	120	150	200	250	300	400	500
Distance Ratio (x/D_p)	40.0	48.0	60.0	80.0	100.0	120.0	160.0	200.0
Maximum Open Propeller Jet Velocity at Surface (V_{surf}), ft/sec	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid
Maximum Ducted Propeller Jet Velocity at Surface (V_{surf}), ft/sec	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid
Maximum near Botton Open Propeller Velocity (Vbot), ft/sec	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid
Maximum near Botton Ducted Propeller Velocity (Vbot), ft/sec	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid	Not Valid

* Maynord, Stephan T. *Physical Forces near Commerical Tows*. U.S. Army Engineer Research and Development Center, Vicksburg, MS, ENV Report 19, March 2000.

Symbols match those in the reference article and in the Notes.

B-7 Vessel-Generated Currents

Notes:

Jets

Blaauw, H. G. and E. J. van de Kaa. *Erosion of Bottom and Sloping Banks Caused by the Screw Race of Manoeuvering Ships*. Delft Hydraulics Laboratory, Publication Number 202, July 1978.

$K_T = T/\rho n^2 D^4 = Tg/\gamma n^2 D^4$ where:

- T = thrust, N or lbf
- ρ = water density, kg/m^3 or lbm/ft^3
- n = propeller rotational speed, rps
- D = propeller diameter, m or ft
- g = gravitational acceleration, m/s^2 or ft/s^2
- γ = water unit weight, N/m^3 or lbf/ft^3

$D_o = D$ for ducted propeller

$D_o = D/(2)^{0.5}$ for non-ducted propeller

$v_o = 0.95nD = 1.60nD(K_T)^{0.5}$ where:

- v_o = axial efflux velocity, m/s or ft/s
- K_T = propeller thrust coefficient

Zone of Flow Establishment

$x < x_o$

$x_o = 2.8D_o$

$v_{max} = v_o$

$v_{x,r} = v_o \exp\{-[r+0.18x-(D_o/2)]^2/[2(0.18x)^2]\}$

Zone of Established Flow

$x > x_o$

$x_o = 2.8D_o$

$v_{max} = v_o\ (D_o/0.36x)$

$v_{x,r} = v_{max} \exp\{-r^2/[2(0.18x)^2]\}$

B-7 Vessel-Generated Currents

Hamill, G. A., H. T. Johnston and D. P. J. Stewart. *Estimating the Velocities in a Ship's Propeller Wash*. PIANC Bulletin No. 89, Pg. 46-54, 1996.

Hamill, G. A., and J. A. McGarvey. *Designing for Propeller Action in Harbours*. ICCE'96, Orlando, FL, Pg. 4451-4463, September 1996.

$v_o = \zeta n D_p (C_T)^{0.5}$

$\zeta = (D_p/D_h)^{-0.403}(C_T)^{-0.179}B^{0.744}$; should be between 1.32 and 1.52, use 1.42.

where:
- D_p = propeller diameter, m or ft
- D_h = propeller hub diameter, m or ft
- B = blade area ratio
- n = propeller rotational speed, rps
- C_T = propeller thrust coefficient
- v_o = axial efflux velocity, m/s or ft/s

Zone of Flow Establishment

$x < x_o$

$x_o = 3D_p$

$v_{max} = v_o[1.017-0.184(x/D_p)]$

$v_{x,r} = v_{max}\exp[-(r-R_{mo})^2/2(\sigma)^2]$

Zone of Established Flow

$x > x_o$

$x_o = 3D_p$

$v_{max} = v_o[0.543-0.0281(x/D_p)]$

$v_{x,r} = v_{max}\exp[-(r-R_{mo})^2/2(\sigma)^2]$

where:
- x = axial distance behind propeller
- r = radial distance from propeller axis
- $R_{mo} = 0.67(D_p/2) - (D_h/2)$
- $\sigma = 0.5R_{mo} + 0.075[x-(D_p/2)]$ at $x > D_p/2$
- $\quad = 0.5R_{mo}$ at $x < D_p/2$

B-7 Vessel-Generated Currents

Verhey, H.J. *The Stability of Bottom and Banks Subjected to the Velocities in the Propeller Jet Behind Ships.* Delft Hydraulics Laboratory, Publication Number 303, April 1983.

$K_T = Tg/\gamma_w n^2 D_p^4$

where: K_T = propeller thrust coefficient
T = thrust or bollard pull per propeller, N or lbf
g = gravitational acceleration, m/s^2 or ft/sec^2
γ_w = unit weight of water, N/m^3 or lbf/ft^3
n = propeller rotational speed, rps
D_p = the propeller diameter, m or ft

$u_o = 1.60 n D_p (K_T)^{0.5}$

where: u_o = axial efflux velocity from the propeller, m/s or ft/sec

Zone of Flow Establishment

$u_{x,r} = u_o \exp[-15.43(r/D_o + 0.18x/D_o - 0.5)^2/(x/D_o)^2]$

where: $u_{x,r}$ = velocity distribution in the zone of flow establishment ($x<x_o=2D_o$), m/s or fps
x = distance behind the propeller plane, m or ft
r = radial distance from the propeller axis, m or ft
D_o = propeller slipstream diameter, m or ft

and

$D_o = D_p$ for a non-ducted propeller
$= 0.71D_p$ for a ducted propeller
$= 0.85D_p$ for a propeller in a tunnel.

Zone of Established Flow

$u_{x,r} = u_{max} \exp[-15.43r^2/x^2]$

where:
$u_{x,r}$ = velocity distribution in the zone of established flow ($x>2D_o$), m/s or fps

$u_{max} = u_o (2.78D_o/x)$.

B-7 Vessel-Generated Currents

Maynord, Stephen J. *Physical Forces near Commercial Tows*. Upper Mississippi River - Illinois Waterway System Navigation Study, U.S. Army Engineer Research and Development Center, ENV Report 19, March 2000.

$V_2 = (1.13/D_o)(T/\rho)^{1/2}$

Ζονε 1 ωηερε ξ/Δπ < 10

$C_J = -\{\tan(12^o)(x\text{-Setback}/2)-[(C_{para}g(x\text{-Setback}/2)^2)/V_2^2\cos(12^o)]\}$

Cpara = 0.12(Dp/Hp)2/3, for open-wheel propellers
= 0.04, for Kort nozzle propellers

$V_{x\ max} = 1.21V_2(x/D_p)^{-0.524}$

$V_{x\ surf\ max} = 1.45V_2(x/D_p)^{-0.524}$

$V_{bot} = 0.34V_{x\ surf\ max}(D_p/H_p)^{0.93}(x/D_p)^{0.24}$

Zone 2

$V_{surf} = 0.66V_2\exp(-0.0178x/D_p)$

$V_{bot} = 0.34V_{surf}(D_p/H_p)^{0.93}(x/D_p)^{0.24}$

where:

V_2 = velocity increase due to propeller
D_o = contracted jet diameter
T = thrust per propeller
ρ = water density
C_J = vertical distance from prop axis to max velocity in jet
Cpara = empirical coefficient
Setback = horizontal distance from prop to stern of vessel
g = gravitational acceleration
x = horizontal distance behind propeller
H_p = vertical distance from bottom to propeller axis
D_p = propeller diameter
$V_{x\ max}$ = maximum propeller jet velocity
$V_{x\ surf\ max}$ = maximum propeller jet velocity at surface
V_{bot} = propeller bottom velocity
V_{surf} = propeller surface velocity

Attachment B-8

Vessel-Generated Wakes

B-8 Vessel-Generated Wakes

Vessel Generated Waves

Gates and Herbich (1977)

Vessel Type	Barge
Vessel Speed, kt (V_s)	7
Vessel Maximum Beam Width, ft (B)	90
Vessel Length, ft (L_v)	300
Water Depth, ft (d)	20
Side Distance to Wave Height of Interest, ft (S)	100
Froude Number (F)	0.47
Coefficient (K_w)	2.73
Hull Entrance Length, ft (L_e)	103.7
Bow Wave Height, ft (H_b)	5.1
Side Distance to Max Wave Height, ft (x)	103.3
Maximum Wave Height, ft (H_m)	2.1
Cusp Angle from Sailing Line, (Θ)	35.21
Wave Celerity, ft/sec (C)	9.7
Wave Length, ft (L)	6
Wave Period, sec (T)	0.6
Cusp Nunber Measured Out from Sailing Line, N	9
Maximum Wave Height at S, ft (H)	2.1

Gates, Edward T., and John B. Herbich (1977) *Mathematical Model to Predict the Behavior of Deep-Draft Vessels in Restricted Waterways*. Report TAMU-SG-77-206, COE Report No. 200, Texas A&M University, College Station, TX

B-8 Vessel-Generated Wakes

Vessel Generated Waves

Blaauw et al (1984)

Vessel Type	Barge
Vessel Speed, kt (V_s)	7
Water Depth, ft (h)	20
Side Distance, ft (S)	100
Interference Peak Coefficient (a)*	0.8
Wave Height, ft (H_i)	1.2
Wave Length, ft (L_i)	18
Wave Period, sec (T)	1.9

*For "a", select from the following: 0.25 for a canal motor boat
0.35 for a tug
0.80 for a barge

Blaauw, H.G., F.C.M. van der Knapp, M.T. de Groot and K.W. Pilarczyk (1984) "Design of Bank Protection of Inland Navigation Fairways." *Proceedings of the International Conference on Flexible Armoured Revetments Incorporating Geotextiles*, London, England, 29-30 March 1984.

B-8 Vessel-Generated Wakes

Vessel Generated Waves

PIANC (1987)

Vessel Type	Barge
Vessel Speed, kt (V_s)	7
Water Depth, ft (h)	20
Side Distance, ft (S)	100
Coefficient (A) *	1.00
Froude Number	0.47
Wave Height, ft (H_i)	0.6
Wave Length, ft (L_i)	18
Wave Period, sec (T)	1.9

* For "A", select from the following:	1.00	for tugs, patrol boats, loaded inland motor barges
	0.50	for empty European barges
	0.35	for empty conventional motor vessels

Permanent International Association of Navigation Congresses (1987) *Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles for Inland Waterways*. Report of Working Group 4 of the Permanent Technical Committee, Brussels

Ship Generated Waves

Sorensen (1997)

Vessel Type	Barge	
Vessel Length, ft (L_v)	300	
Vessel Beam, ft (B)	90	
Vessel Draft, ft (D)	9	
Vessel Speed, kt (V)	7	
Vessel Displacement, tons (W)	3,000	
Distance from Sailing Line, ft (x)	100	
Water Depth, ft (d)	20	
Specific Weight of Water, lb/ft^3 (γ)	63.0	
Froude Number (F)	0.47	Valid from 0.2 to 0.8
Dimensionless Distance from Sailing Line (x*)	2.20	
Dimensionless Depth (d*)	0.44	
Coefficient (a)	-1.29	
Coefficient (b)	1.77	
Coefficient (c)	-0.71	
Coefficient (α)	0.01	
Coefficient (β)	-0.38	
Exponent (δ)	-0.15	
Exponent (n)	-0.44	
Dimensionless Maximum Wave Height (H_m*)	0.01	
Block Coefficient	0.39	
Dimensionless Length	6.6	
Dimensionless Beam	2.0	
Dimensionless Draft	0.2	
Coefficient (A)	1.85	*
Coefficient (B)	0.02	*
Revised Dimensionless Maximum Wave Height (Hm**)	0.01	
Maximum Wave Height, ft (H_m)	0.2	
Cusp Angle from Sailing Line, degrees (Θ)	35.21	
Wave Celerity, ft/sec (C)	9.7	
Celerity Squared (C^2)	93.31	
Wave Length, ft (L)	5.8	**
Celerity Squared check (C^2)	93.38	
Wave Period, sec (T)	0.6	

* Use block coefficient, dimensionless length, dimensionless beam, and dimensionless draft to select values from Table 1 (see Notes).

** Iterate to match "C^2" to "C^2 check".

Sorensen, Robert M. (1997) *Prediction of Vessel-Generated Waves with Reference to Vessels Common to the Upper Mississippi River System*. Prepared for U.S. Army Engineer Distrct, Rock Island, U.S. Army Engineer Distrct, St. Louis, U.S. Army District, St. Paul, ENV Report 4, December 1997.

B-8 Vessel-Generated Wakes

Notes: [yellow box] denotes input

Gates and Herbich (1977)

Parameter	Symbol	Formula
Vessel Type		
Vessel Speed, kt	Vs	
Vessel Maximum Beam Width, ft	B	
Vessel Length, ft	L_v	
Water Depth, ft	d	
Side Distance to Wave Height of Interest, ft	S	
Froude Number	F	$F = (1.689V_s)/(gd)^{0.5}$
Coefficient	K_w	$K_w = -6.760((1.689V_s)/(L_v)^{0.5})+7.346$ for $V_s/L_v^{1/2}<0.919$; $K_w = 1.133$ for $F>0.919$
Hull Entrance Length, ft	L_e	$L_e = 0.416L_v - 0.000235L_v^2$
Bow Wave Height, ft	H_b	$H_b = (K_wB/L_e)((1.689V_s)^2/2g)$
Side Distance to Max Wave Height, ft	x	$x = 1.21(1.689V_s)^2(2N+1.5)/g$; at N = 1, $x = 0.222V_s^2$
Maximum Wave Height, ft	H_m	$H_m = 1.11H_b/(2N+1.5)^{0.33}$, at N = 1, $H_m = 0.731H_b$
Angle Between Sailing Line and Wave Propogation Direction, deg	Θ	$\Theta = 35.27(1-e^{12(F-1)})$ for F<1; $\Theta = \arcsin(1/F)$ for F>1
Wave Celerity, ft/sec	C	$C = (1.689V_s)\cos\Theta$
Wave Length, ft	L	$L = 2C^2/g$
Wave Period, sec	T	$T = 2C/g$
Cusp Nunber Measured Out from Sailing Line	N	$N = \{gS/[2.42(1.689V_s)^2]\}-0.75$
Maximum Wave Height at S, ft	H	$H = 1.11H_b/(2N+1.5)^{0.33}$

Gates, Edward T., and John B. Herbich (1977) *Mathematical Model to Predict the Behavior of Deep-Draft Vessels in Restricted Waterways*. Report TAMU-SG-77-206, COE Report No. 200, Texas A&M University, College Station, TX

B-8 Vessel-Generated Wakes

PIANC (1987)

Vessel Type		
Vessel Speed, kt	Vs	
Water Depth, ft	h	
Side Distance, ft	S	
Coefficient	A	
Froude Number	F	$F = (1.689V_s)/(gd)^{0.5}$
Wave Height, ft	H_i	$H_i = Ah(S/h)^{-0.33}F^4$
Wave Length, ft	L_i	$L_i = 0.67(2\pi/g)(1.689V_s)^2$
Wave Period, sec	T	$T = \{2\pi L_i/[g \tanh(2\pi h/L_i)]\}^{1/2}$

Permanent International Association of Navigation Congresses (1987) *Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles for Inland Waterways*. Report of Working Group 4 of the Permanent Technical Committee, Brussels

Blaauw et al (1984)

Vessel Type		
Vessel Speed, kt	Vs	
Water Depth, ft	h	
Side Distance, ft	S	
Interference Peak Coefficient	a	
Wave Height, ft	H_i	$H_i = ah(S/h)^{-1/3}[(1.689V_s)/(gh)^{1/2}]^{8/3}$
Wave Length, ft	L_i	$L_i = 0.67(2\pi/g)(1.689V_s)^2$
Wave Period, sec	T	$T = \{2\pi L_i/[g \tanh(2\pi h/L_i)]\}^{1/2}$

Blaauw, H.G., F.C.M. van der Knapp, M.T. de Groot and K.W. Pilarczyk (1984) "Design of Bank Protection of Inland Navigation Fairways." *Proceedings of the International Conference on Flexible Armoured Revetments Incorporating Geotextiles*, London, England, 29-30 March 1984.

B-8 Vessel-Generated Wakes

Sorensen & Weggel (1984)

Vessel Type		
Vessel Length, ft	L_v	
Vessel Beam, ft	B	
Vessel Draft, ft	D	
Vessel Speed, kt	V	
Vessel Displacement, tons	W	
Distance from Sailing Line, ft	x	
Water Depth, ft	d	
Specific Weight of Water, lb/ft^3	γ	
Froude Number	F	$F = (1.689V)/(gd)^{0.5}$
Dimensionless Distance from Sailing Line	x*	$x^* = x/(2000W/\gamma)^{0.33}$
Dimensionless Depth	d*	$d^* = d/(2000W/\gamma)^{0.33}$
Coefficient	a	$a = -0.6/F$
Coefficient	b	$b = 0.75F^{-1.125}$
Coefficient	c	$c = 2.653F-1.95$
Coefficient	α	$\log(\alpha)= a+b\,log(d^*)+c\,log^2(d^*)$ or $\alpha = 10^{[a+blog(d^*)+clog2(d^*)]}$
Coefficient	β	$\beta = -0.225F^{-0.699}$ @ $0.2<F<0.55$, $\beta = -0.342$ @ $0.55<F<0.8$
Exponent	δ	$\delta = -0.118F^{-0.356}$ @ $0.2<F<0.55$, $\delta = -0.146$ @ $0.55<F<0.9$
Exponent	n	$n = \beta(d^*)^{\delta}$
Dimensionless Maximum Wave Height	H_m*	$H_m^* = \alpha(x^*)^n$
Block Coefficient		$= W/(\gamma L_v BD)$
Dimensionless Length		$= L_v/(2000W/\gamma)^{1/3}$
Dimensionless Beam		$= B/(2000W/\gamma)^{1/3}$
Dimensionless Draft		$= D/(2000W/\gamma)^{1/3}$
Coefficient	A	*
Coefficient	B	*
Revised Dimensionless Maximum Wave Height	Hm**	$H_m^{**} = AH_m^*-B$
Maximum Wave Height, ft	H_m	$H_m = H_m^{**}(2000W/\gamma)^{1/3}$
Cusp Angle from Sailing Line, degrees	Θ	$\Theta = 35.27(1-e^{12(F-1)})$ for $F<1$; $\Theta = \arcsin(1/F)$ for $F>1$
Wave Celerity, ft/sec	C	$C = (1.689V_s)\cos\Theta$
Celerity squared	C^2	
Wave Length, ft	L	** $C^2 = (gL/2)\tanh^2(2d/L)$
Celerity squared check	C^2	
Wave Period, sec	T	$T = L/C$

B-8 Vessel-Generated Wakes

* Use block coefficient, dimensionless length, dimensionless beam, and dimensionless draft to select values from Table 1 (see below).

** Iterate to match "C^2" to "C^2 check".

Sorensen, Robert M. (1997) *Prediction of Vessel-Generated Waves with Reference to Vessels Common to the Upper Mississippi River System*. Prepared for U.S. Army Engineer Distrct, Rock Island, U.S. Army Engineer Distrct, St. Louis, U.S. Army District, St. Paul, ENV Report 4, December 1997.

Table 1. Coefficients A and B

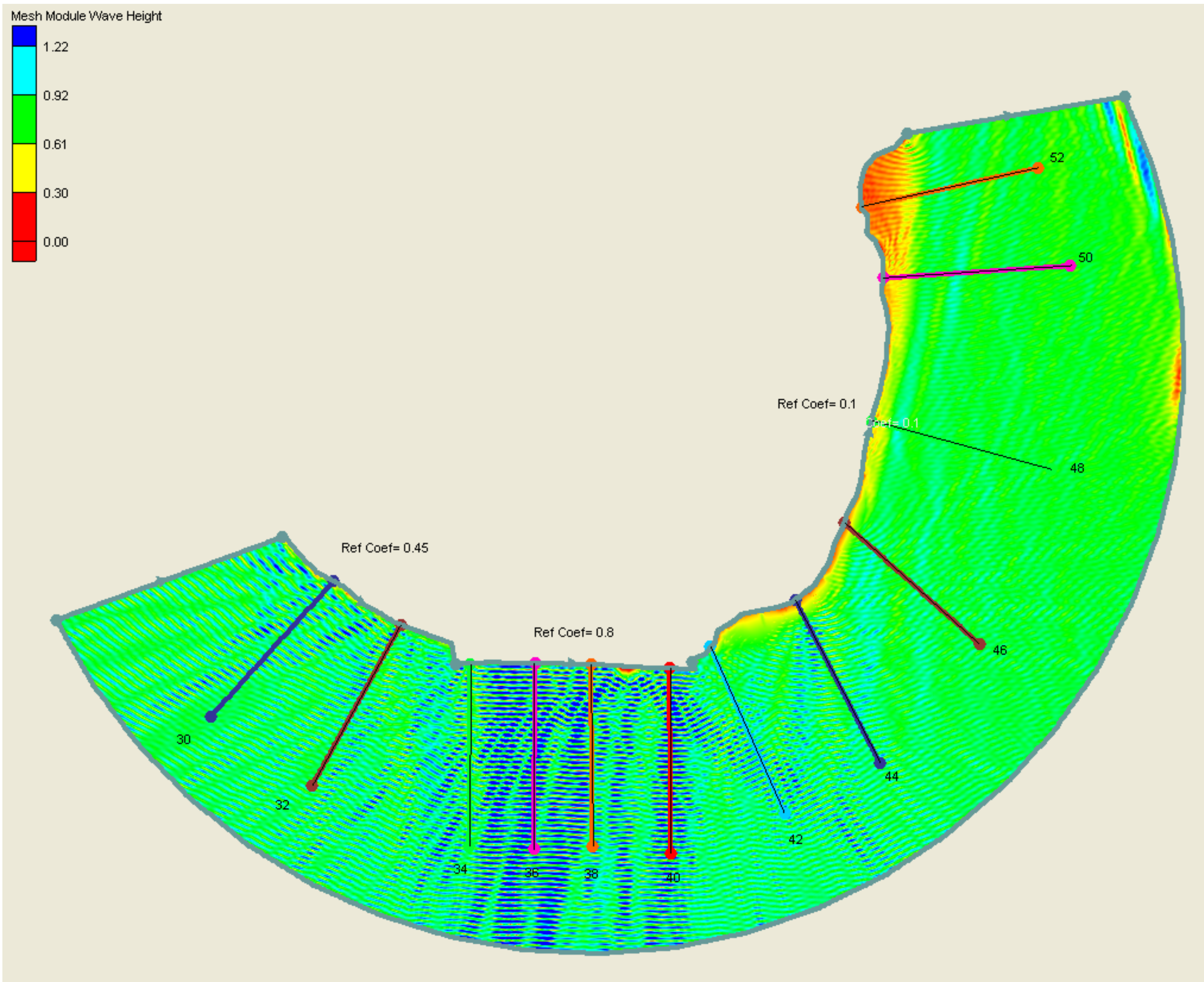
Vessel Type	Block	Dimensionless			A	B
	Coefficient	Length	Beam	Draft		
Cruiser	1.177	5.517	0.679	0.226	3.52	0.078
Barge	0.829	4.798	0.977	0.255	1.85	0.018
Moore Dry Dock Tanker	0.691	5.834	0.764	0.324	2.55	0.036
Auxilary Supply Vessel	0.629	4.922	1.141	0.283	1.89	0.025
Mariner Class Cargo Ship	0.526	6.357	0.831	0.270	0.84	0.008
Ferryboat	0.514	5.343	0.949	0.384	3.19	0.179
Tugboat	0.398	4.736	1.260	0.435	2.52	0.08

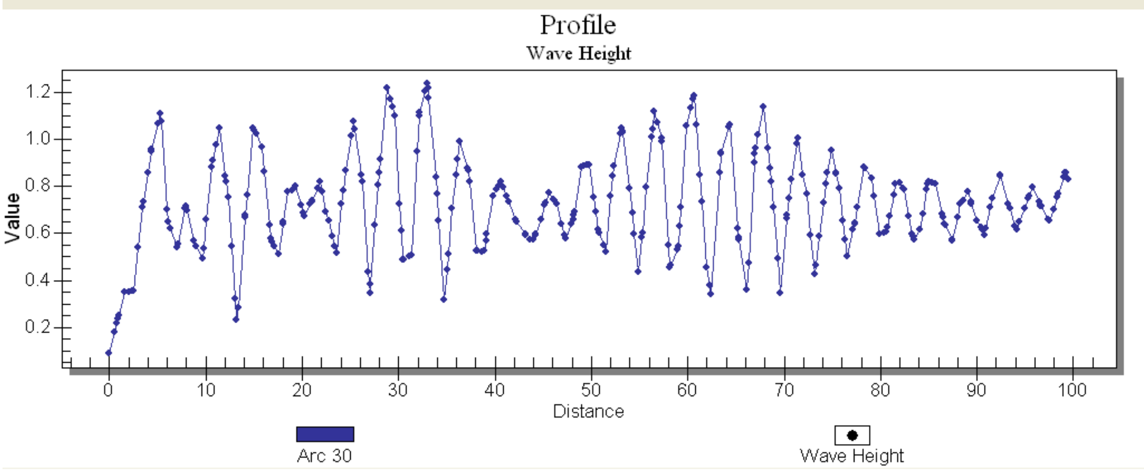
Attachment B-9

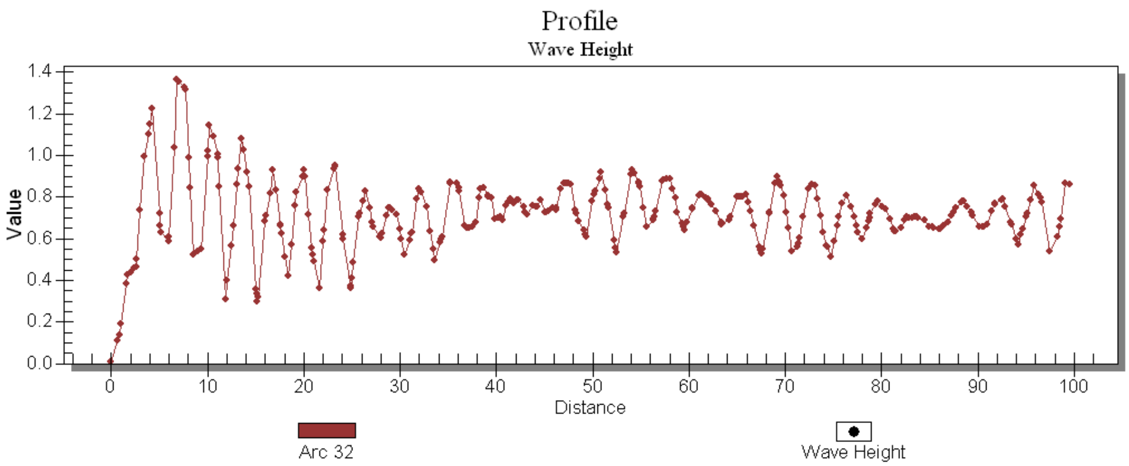
CGWAVE Results

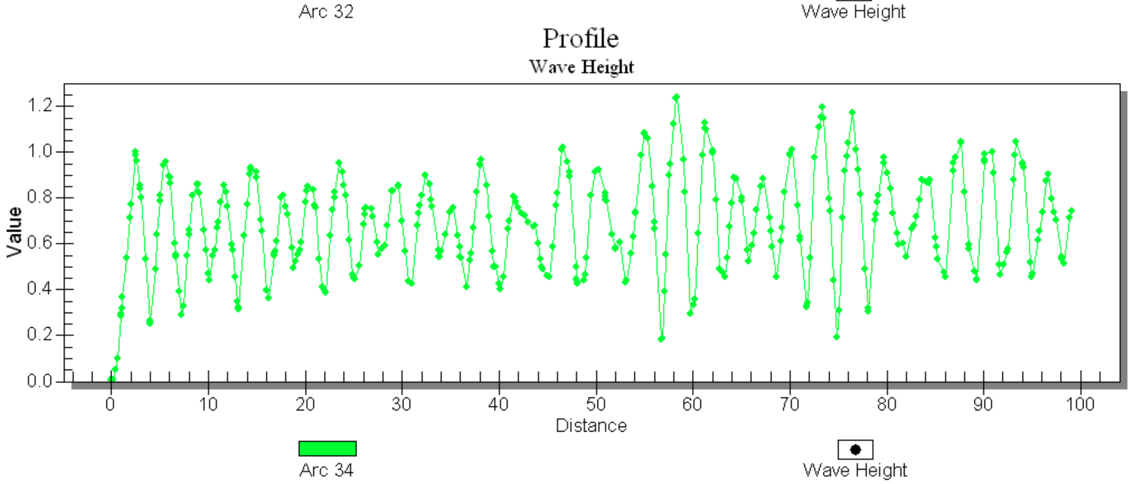
B-9 CGWAVE Results

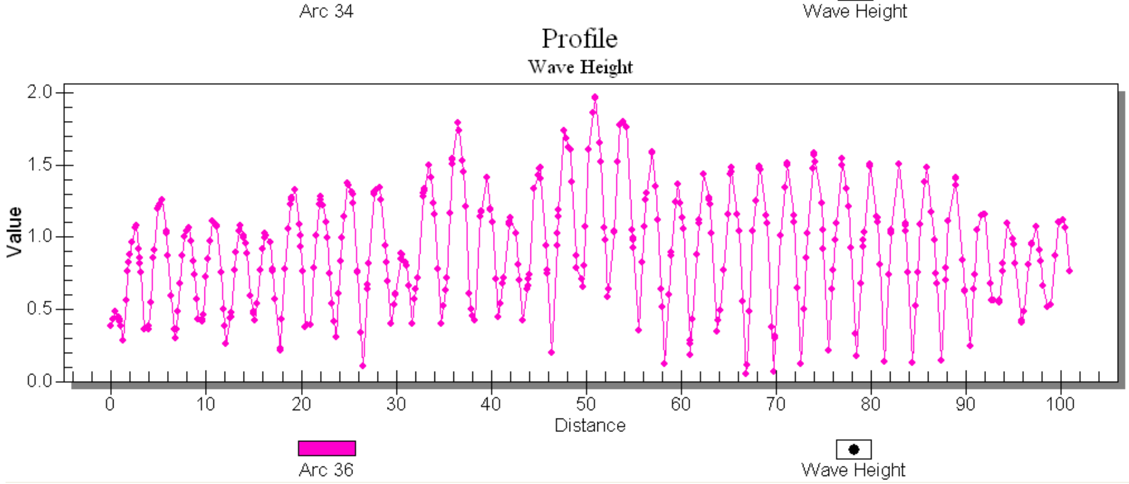
Note: Units Displayed in Meters

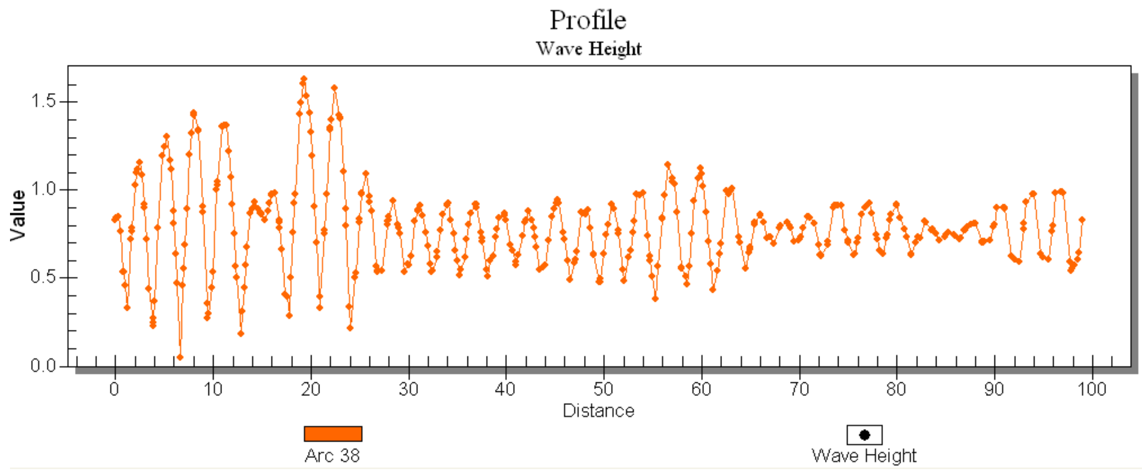


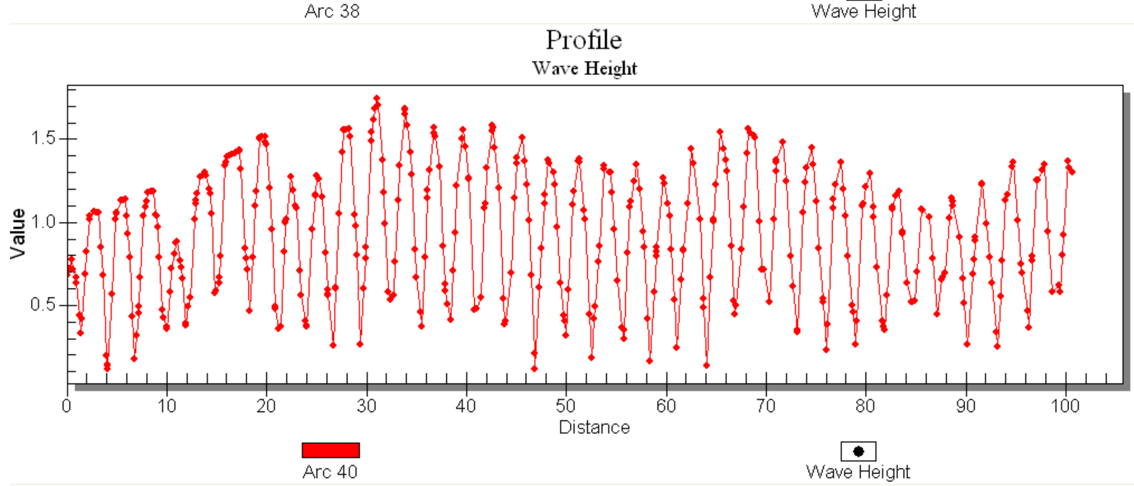


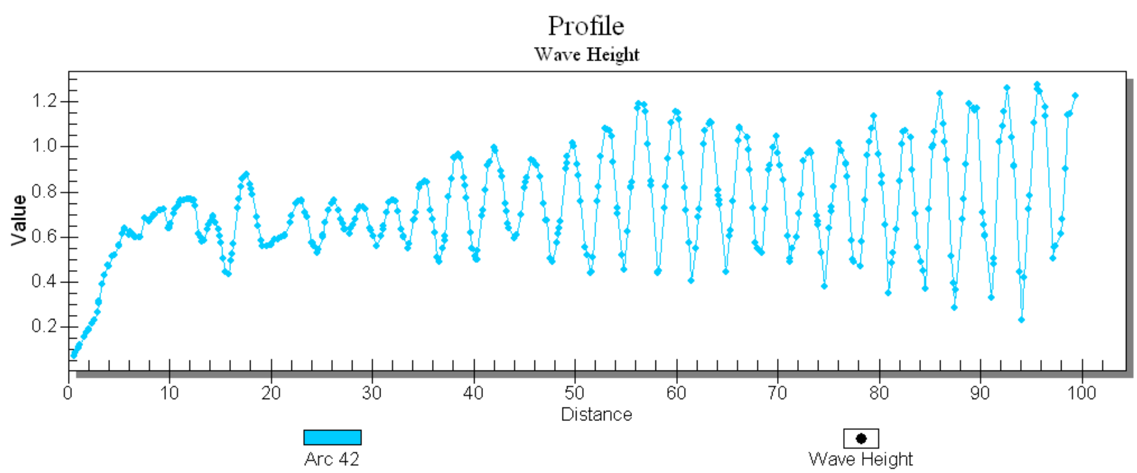

Profile
Wave Height
Value
Distance
Arc 32
Wave Height

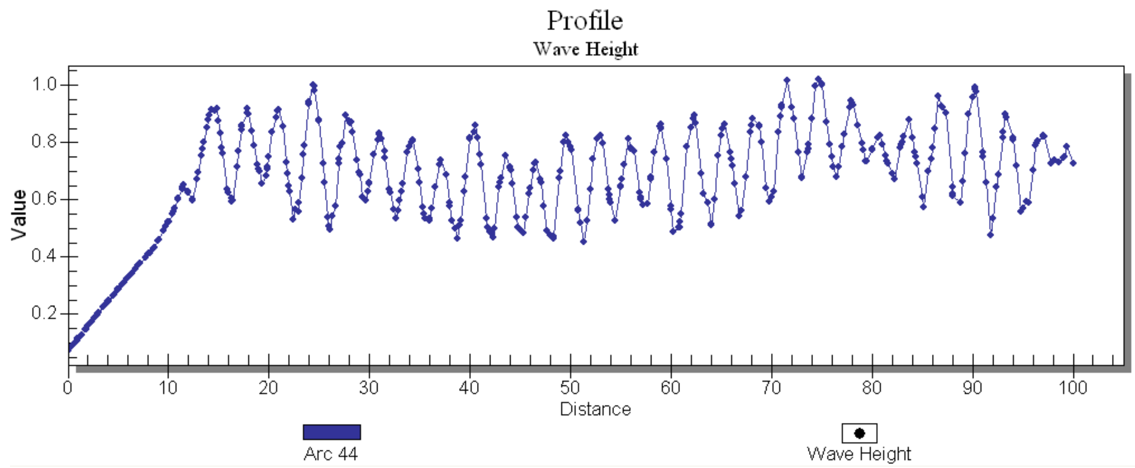

Profile
Wave Height
Value
Distance
Arc 34
Wave Height

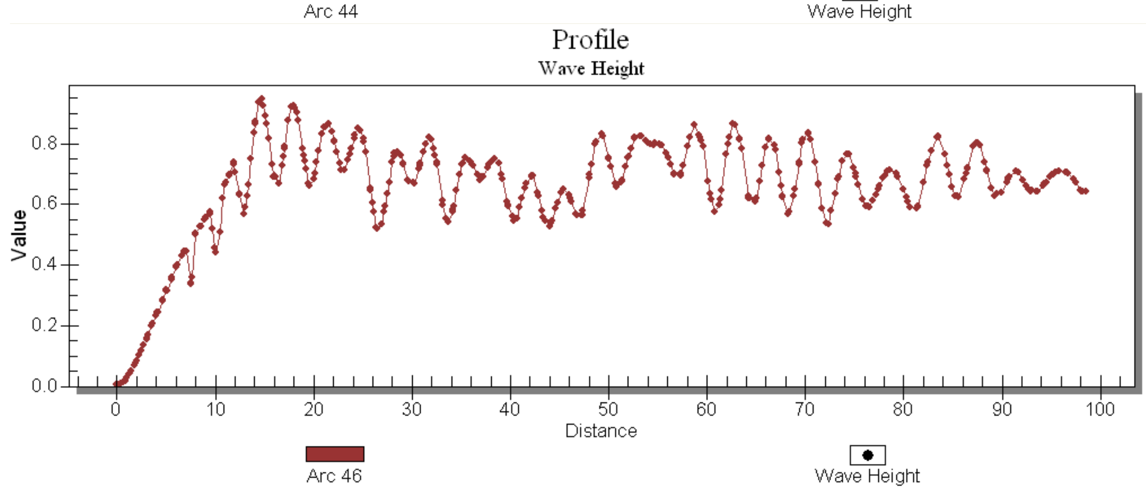

Profile
Wave Height
Value
Distance
Arc 36
Wave Height

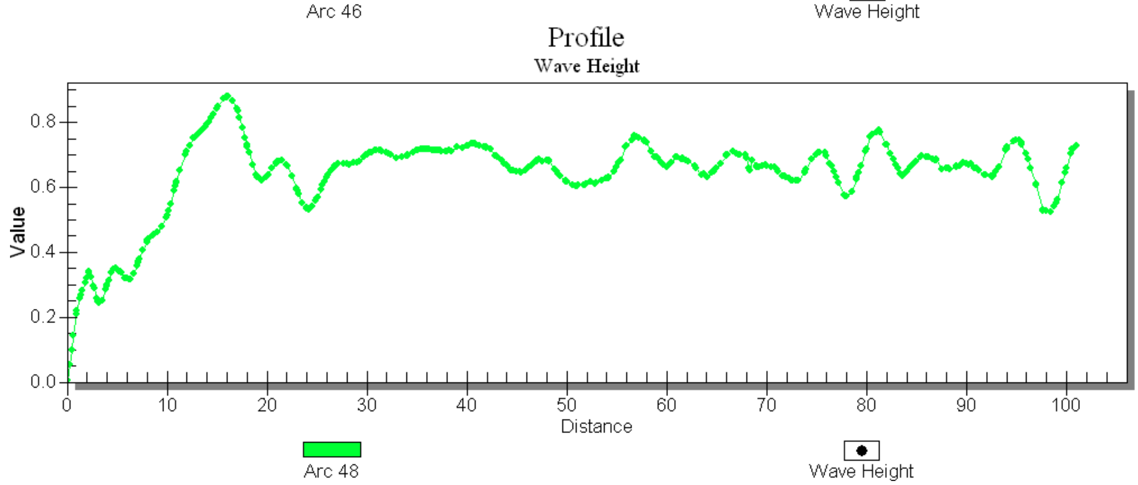

Profile
Wave Height
Value
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 38
Wave Height

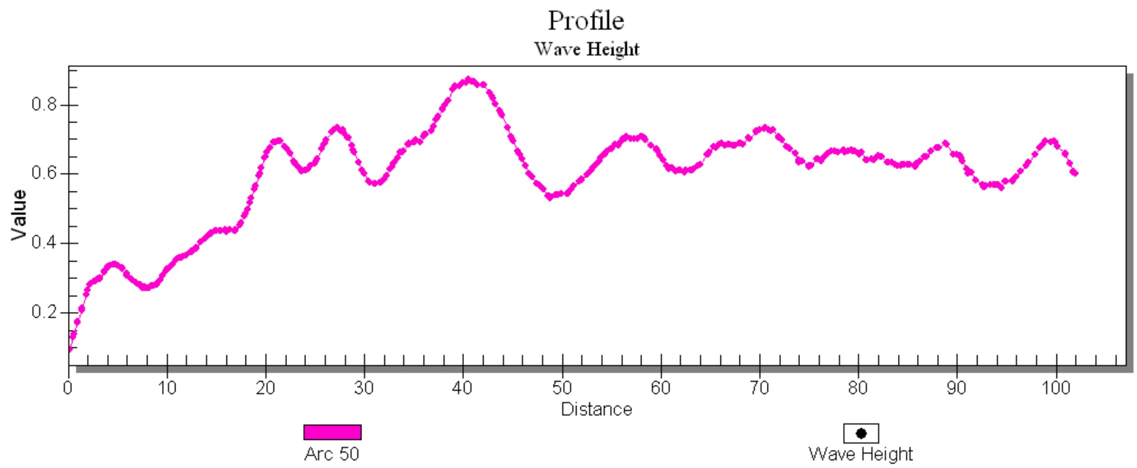

Profile
Wave Height
Value
1.5
1.0
0.5
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 40
Wave Height

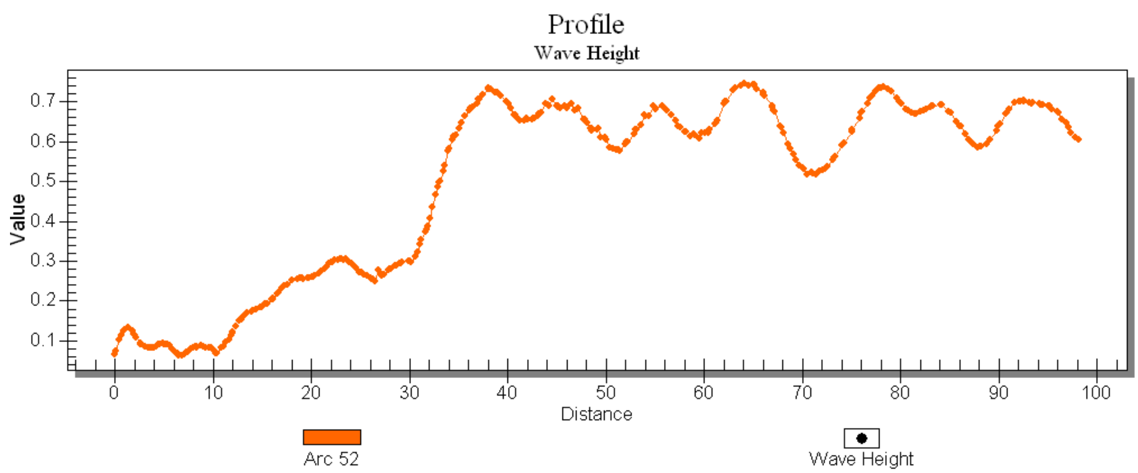

Profile
Wave Height
Value
1.2
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 42
Wave Height


Profile
Wave Height
Value
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 44
Wave Height


Profile
Wave Height
Value
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 46
Wave Height


Profile
Wave Height
Value
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 48
Wave Height


Profile
Wave Height
Value
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 50
Wave Height


Profile
Wave Height
Value
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
90
100
Distance
Arc 52
Wave Height

Attachment B-10

Revetment Design

Revetment Design Per the Coastal Engineering Manual (CEM)*
Rock, Two-Layered Armor, Non-Overtopped

Step	Parameter	Unit	Symbol	Arc 12	Arc 13	Arc 14	Arc 15	Arc 16	Arc 17	Arc 18	Arc 19	Arc 20	Arc 21	Arc 22	Arc 24
1	Significant wave height in front of revetment	ft	H_s	4.1	4.4	3.4	4.6	5.4	5.7	3.0	3.3	3.1	3.0	2.5	1.0
2	Deepwater mean wave period	sec	T_m	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
3	Cotangent of slope angle to 10' depth	-	$\cot\alpha$	2.2	2.6	4.0	3.2	13.1	13.7	14.4	11.4	4.2	3.8	5.4	8.8
4	Weight density of rock or stone	lbf/ft^3	γ_s	165	165	165	165	165	165	165	165	165	165	165	165
5	Weight density of water	lbf/ft^3	γ_w	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
6	Number of waves	-	N_z	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600
7	Stability coefficient	-	K_Δ	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
8	Relative eroded area	-	S	2	2	2	2	2	2	2	2	2	2	2	2
9	Notional permeability	-	P	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
10	Relative density	-	Δ	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
11	Wave steepness	-	s_m	0.22	0.24	0.18	0.25	0.29	0.31	0.16	0.18	0.17	0.16	0.13	0.05
12	Surf-similarity parameter	-	ε_m	1.0	0.8	0.6	0.6	0.1	0.1	0.2	0.2	0.6	0.7	0.5	0.5
13	Critical surf-similarity parameter	-	ε_{mc}	3.7	3.4	2.6	3.0	1.2	1.2	1.2	1.3	2.5	2.7	2.1	1.6
14	Stability number (Hudson)	-	N_s	1.6	1.7	2.0	1.9	3.0	3.0	3.1	2.8	2.0	2.0	2.2	2.6
15	Stability number (van der Meer)	-	N_s	2.6	2.8	3.3	3.2	6.7	7.0	6.1	5.5	3.3	3.1	3.6	3.6
16	Hudson median rock cube length	in	D_{n50}	18	19	12	18	13	14	7	8	11	11	8	3
17	Hudson median rock cube weight	lbf	W_{50}	581	608	182	572	223	251	34	59	137	128	52	2
18	van der Meer median rock cube length	in	D_{n50}	11.6	11.3	7.5	10.5	5.9	6.0	3.6	4.3	6.9	6.9	5.1	2.0
19	van der Meer median rock cube weight	lbf	W_{50}	150	137	40	112	19	20	4	8	31	32	13	1

Step	Parameter	Unit	Symbol	Arc 12	Arc 13	Arc 14	Arc 15	Arc 16	Arc 17	Arc 18	Arc 19	Arc 20	Arc 21	Arc 22	Arc 24
20	**Hudson Armor Layer Gradation:**	lbf	W_{max}	2,326	2,432	729	2,288	892	1,004	135	234	547	512	210	8
		lbf	W_{85}	1,140	1,192	357	1,121	437	492	66	115	268	251	103	4
		lbf	W_{50}	581	608	182	572	223	251	34	59	137	128	52	2
		lbf	W_{15}	233	243	73	229	89	100	14	23	55	51	21	1
		lbf	W_{min}	73	76	23	71	28	31	4	7	17	16	7	0
21	**van der Meer Armor Layer Gradation:**	lbf	W_{max}	601	548	161	448	77	81	17	31	125	128	50	3
		lbf	W_{85}	294	269	79	219	38	40	9	15	61	63	25	2
		lbf	W_{50}	150	137	40	112	19	20	4	8	31	32	13	1
		lbf	W_{15}	60	55	16	45	8	8	2	3	12	13	5	0
		lbf	W_{min}	19	17	5	14	2	3	1	1	4	4	2	0

* *Coastal Engineering Manual (Part VI)*. U.S. Army Corps of Engineers, Engineering Manual EM 1110-2-1100, 31 January 2002.

1-9 Input significant wave height, mean wave period, slope angle, density of rock and water, number of waves, stability coefficient (Table VI-5-22), relative eroded area (Table VI-5-21), and notional permeability (Figure VI-5-11).

10 $\Delta = (\gamma_s/\gamma_w)-1$

11 $s_m = 2\pi H_s/gT_m^2$

12 $\varepsilon_m = \tan\alpha/(s_m)^{1/2}$

13 $\varepsilon_{mc} = [6.2P^{0.31}(\tan\alpha)^{0.5}]^{1/(P+0.5)}$

14 $N_s = H_s/\Delta D_n = (K_D \cot\alpha)^{1/3}$

15 $N_s = H_s/\Delta D_n = 6.2S^{0.2}P^{0.18}N_z^{-0.1}\varepsilon_m^{-0.5}$, if $\varepsilon_m \le \varepsilon_{mc}$

$N_s = H_s/\Delta D_n = 1.0S^{0.2}P^{-0.13}N_z^{-0.1}(\cot\alpha)^{0.5}\varepsilon_m^{P}$, if $\varepsilon_m > \varepsilon_{mc}$

16&18 $D_{n50} = H_s/\Delta N_s$

17&19 $W_{50} = \gamma_s(D_{n50})^3$

20&21 $W_{max} = 4.0W_{50}$

$W_{85} = 1.96W_{50}$

$W_{50} = 1.0W_{50}$

$W_{15} = 0.4W_{50}$

$W_{min} = 0.125W_{50}$

APPENDIX 3H
Soft Sediment Probing

Table of Contents

FIGURES

APPENDIX 3H
SOFT SEDIMENT PROBING

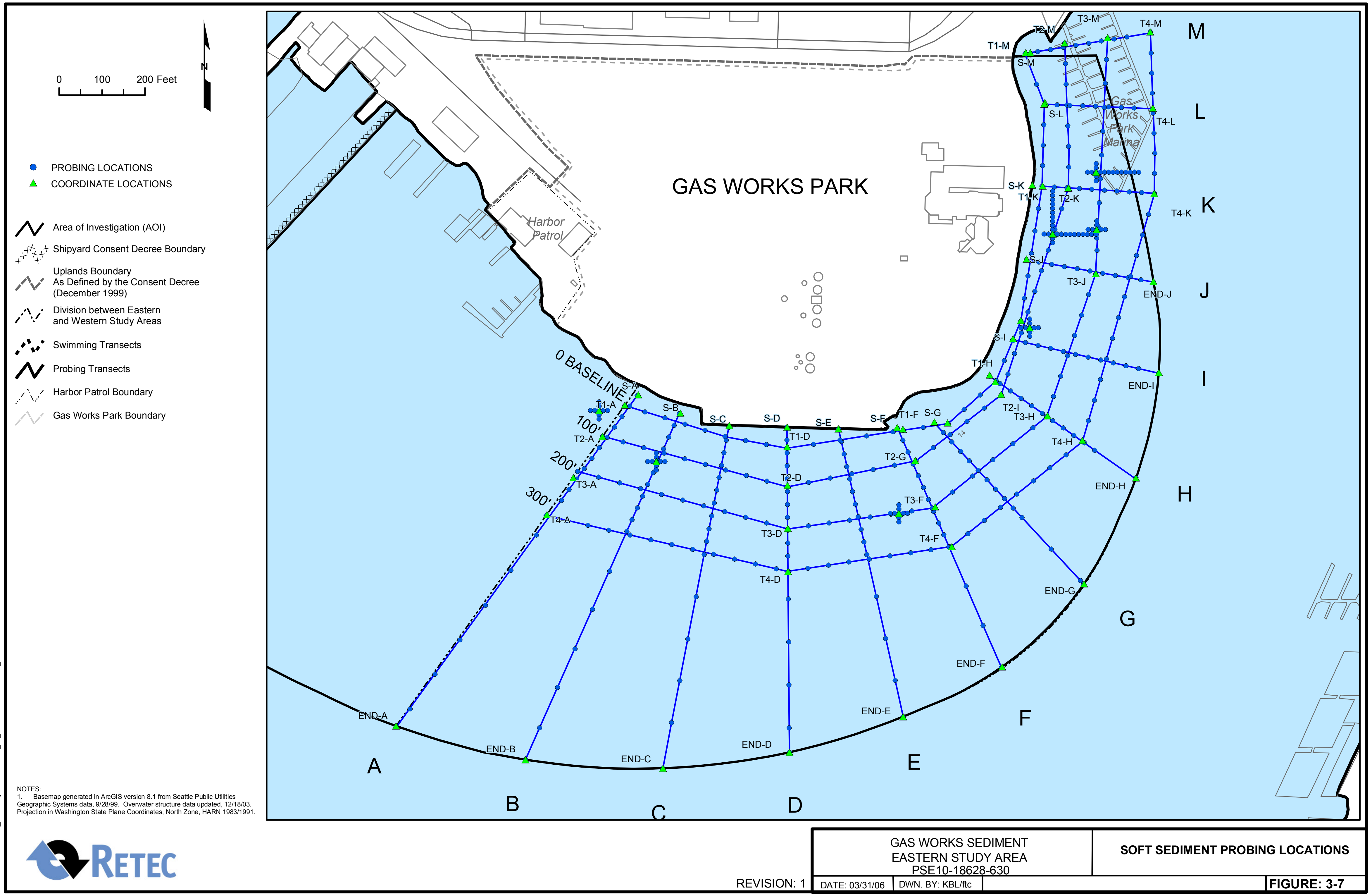
Soft sediment probing was conducted in the eastern half of the sediment portion of the Area of Investigation (AOI) in 2005 to determine the depth of unconsolidated and recent lacustrine sediment and evaluate shallow tar or shallow nonaqueous phase liquid (NAPL) to identify potential tar or NAPL seeps. The initial phase of probing was conducted by divers swimming along transects oriented both perpendicular and parallel to the shore. The eastern lakeshore and lake slope zones of the AOI were the focus of the diver surveys. Thirteen transects were oriented perpendicular to the shoreline out to the AOI boundary and four transects paralleled the shoreline at increasing distances up to 300 feet from the shore (Figure 3H-1).

Depth measurements were made by the diver inserting a measuring rod into unconsolidated sediment at 50-foot intervals along each transect. The rod was capped on one end with a 6-inch plate and uncapped on the other end. The capped end was inserted into the sediment until refusal and the depth was recorded. The rod was reversed and reinserted into the sediment until refusal and the second depth was recorded. If no refusal was encountered, the second measurement was limited to the 12-foot length of the rod. The diver made observations of the material encountered at the point of refusal (e.g., wood or dense glacial deposits).

A search for tar or dense NAPL (DNAPL) seeps and shallow tar or DNAPL was also conducted during diver probing. Two observational methods were used at each point along the transect. First the diver inspected the mudline surface for evidence of tar or DNAPL (staining or pools of DNAPL) to identify potential tar or DNAPL seeps. No evidence of active seeps was observed. The diver also inspected the probe ends for evidence of tar or DNAPL upon retrieval of the rod.

During the second phase of probing, divers probed areas of any tar or DNAPL observed during the initial phase of probing and at previously sampled locations where DNAPL occurred in cores (specifically CR-01, -05, -10, -12, -14, -17; NLU04; and NLU109). Areas of observed tar or DNAPL were probed using 10-foot spacing along two perpendicular transects from the observation point until the extent of shallow tar or DNAPL was determined (Figure 3H-1).

Results of the probing are included in the Figures 3H-2 and 3H-3 in this appendix. Probing results were used to map tar and DNAPL areas.



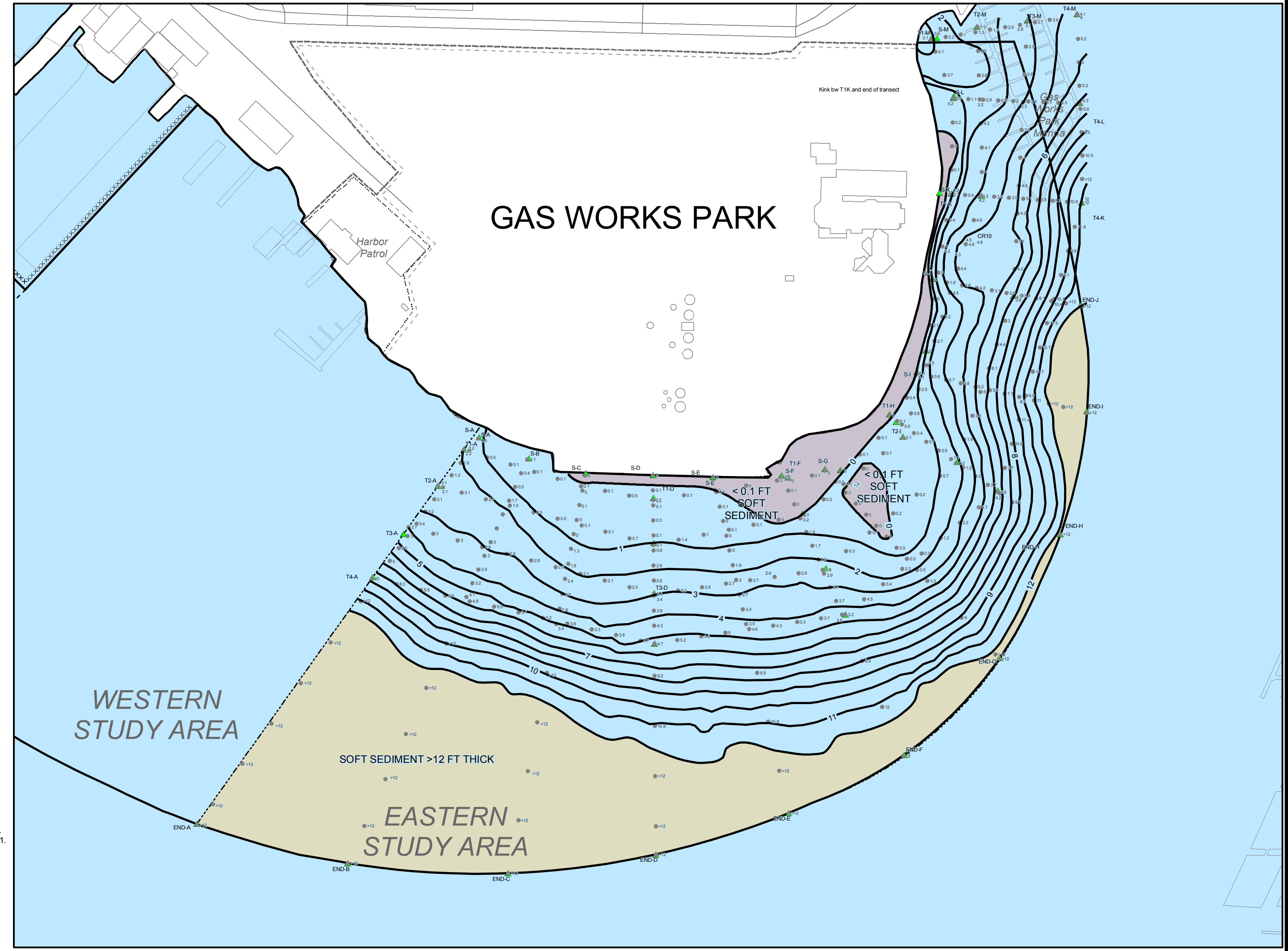
Soft Sediment Probing Locations

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 3H-1

P:\0\0186846\Graphics_Misc\Fig-F-1-Soft-Sediment-Probing-Locations.ai Date Exported: 3/7/2016 by spride



0 100 200 Feet

N

- Probe Locations
- Transect Location Endpoints
- Area of Investigation (AOI)
- Shipyard Consent Decree Boundary
- Uplands Boundary As Defined by the Consent Decree (December 1999)
- Division between Eastern and Western Study Areas
- Harbor Patrol Boundary
- Gas Works Park Boundary
- Soft Sediment Contour 1 Foot Increment Point Penetration Thickness

NOTES:

1. Basemap generated in ArcGIS version 9.0 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.

2. Sediment was probed with a 12-foot long aluminum pole pointed at one end. The diver pushed the pointed end into the sediment until refusal and measured the depth to refusal with a tape.

3. Contour map generated through interpolation and hand alteration using Simple Kriging methods and a Gaussian model (Range = 500, Partial Sill = 3, Nugget = 0.2, LagSize-50, Angular Direction = 232, Maximum Neighbors = 5, Minimum Neighbors = 2, per 4 sector search area).

RETEC

REVISION: 3

GAS WORKS SEDIMENT EASTERN STUDY AREA PSE10-18628-630	SOFT SEDIMENT PROBING MAP PENETRATION WITH POINT
DATE: 03/31/06 DWN. BY: KBL/ftc	FIGURE: 4-8

FILE: T:/LakeUnion_N83/Projects/NLU/ESA_RI_2006/Section4/SOFTSED_PenWPoint_11x17.mxd

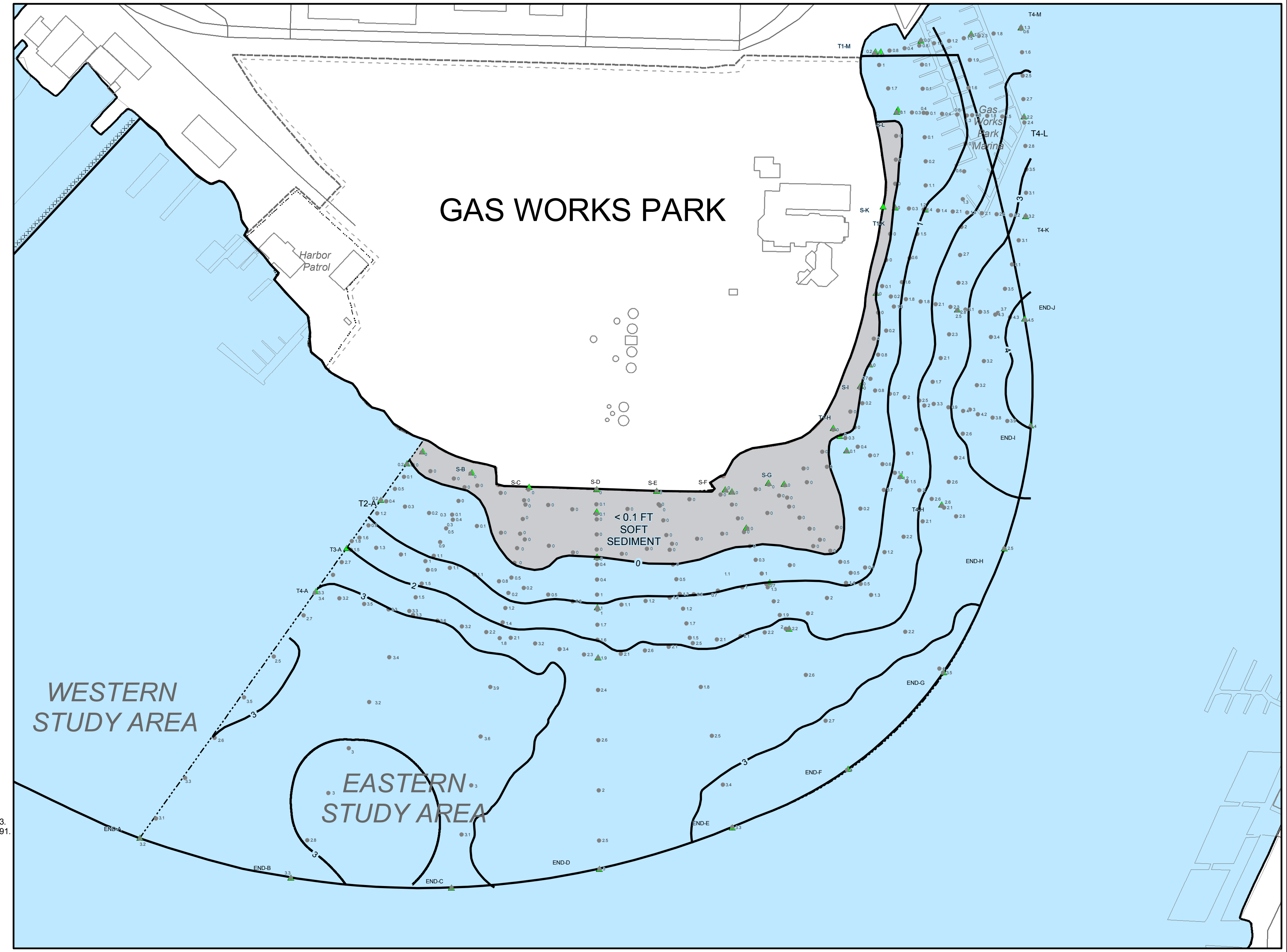
P:\0\0186846\Graphics_Misc\Fig-F-2-Soft-Sediment-Probing-Map-Penetration-With-Point.ai Date Exported: 3/7/2016 by spride

Soft Sediment Probing Map
Penetration with Point

Gas Works Park Site
Seattle, Washington

GEOENGINEERS

Figure 3H-2



- Probe Locations
- Transect Location Endpoints
- Area of Investigation (AOI)
- Shipyard Consent Decree Boundary
- Uplands Boundary As Defined by the Consent Decree (December 1999)
- Division between Eastern and Western Study Areas
- Harbor Patrol Boundary
- Gas Works Park Boundary
- Soft Sediment Contour 1 Foot Increment Disk Penetration Thickness

NOTES:
1. Basemap generated in ArcGIS version 9.0 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.

2. Sediment was probed with a 12-foot long aluminum pole with a 6-inch disk attached at one end. The 6-inch disk is welded on perpendicular to the end of the pole. The diver pushed the disk end into the sediment until refusal and measured the depth to refusal.

3. Contour map generated through interpolation and hand alteration using Simple Kriging methods and a Gaussian model (Range = 500, Partial Sill = 3, Nugget = 0.2, LagSize-50, Angular Direction = 232, Maximum Neighbors = 5, Minimum Neighbors = 2, per 4 sector search area).

FILE: T:/LakeUnion_N83/Projects/NLU/ESA_RI_2006/Section4/SOFTSED_PenWDisk_11x17.mxd

RETEC

REVISION: 3

GAS WORKS SEDIMENT EASTERN STUDY AREA PSE10-18628-630	SOFT SEDIMENT PROBING MAP PENETRATION WITH DISK
DATE: 03/31/06 DWN. BY: KBL/ftc	FIGURE: 4-9

Soft Sediment Probing Map
Penetration with Disk

Gas Works Park Site
Seattle, Washington

GEOENGINEERS **Figure 3H-3**

P:\0\0186846\Graphics_Misc\Fig-F-3-Soft-Sediment-Probing-Map-Penetration-With-Disk.ai Date Exported: 3/7/2016 by spride

APPENDIX 3I
Habitat Evaluation

Table of Contents

ATTACHMENTS

APPENDIX 3I
HABITAT EVALUATION

In support of the habitat evaluation, this appendix includes four attachments. The first three attachments include materials prepared for Puget Sound Energy (PSE) or the City of Seattle (City) at a time when the City and PSE had divided the sediment portion of the Area of Investigation (AOI) into the Western and Eastern Study Areas to allocate remedial investigation/feasibility study work. Although the original evaluations focused on specific areas of the sediment portion of the AOI, they are included here because the findings are applicable to the entire sediment portion of the AOI and will be used to support the development of remedial alternatives.

Attachment 3I-1 includes sediment substrate maps for the Eastern and Western Study Areas prepared by RETEC Group, Inc. (RETEC) and Floyd|Snider, respectively. These maps present substrate types identified during sediment investigations within the sediment portion of the AOI circa 2005. The Eastern Study Area map also shows aquatic vegetation.

Attachment 3I-2 is Grette and Associates' Habitat Preferences of Juvenile Chinook Salmon and Smallmouth Bass in Lake Union technical memorandum (Grette and Associates 2005). The Lake Union habitat memo presented information on the habitat preferences of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and smallmouth bass (*Micropterus dolomieui*) in Lake Union, Washington. The purpose of this memorandum was to present habitat criteria that would be useful in developing design criteria for the sediment remedial alternatives. The memo was prepared for PSE and focused on the Eastern Study Area of the AOI.

Attachment 3I-3 is Geomatrix's Aquatic Habitat in North Lake Union report (Geomatix 2006) which presents information about the nearshore environment of the Gas Works Sediment Western Study Area, what is known about how juvenile Chinook salmon (*Oncorhynchus tshawytscha*) use the nearshore environment of North Lake Union, and the goals of proposed shoreline restoration at Gas Works Park. This report was prepared for City.

Attachment 3I-4 provides meeting notes from the November 15, 2006, Gas Works Sediment Area (i.e., the combined Eastern and Western Study Areas or AOI) habitat objectives meeting. The habitat objectives meeting was a meeting of key stakeholders. The purpose of this meeting was to gain input regarding target species and aquatic habitat objectives to be prioritized for the AOI shoreline area. This input was intended to be used in the development and evaluation of remedial alternatives for AOI sediment (particularly in the nearshore area).

ATTACHMENT 3I-1
RETEC and Floyd|Snider Substrate Maps

0 100 200 Feet

N

Objects
- Large Wood Debris (e.g. piling)
- Boulder
- Wooden Structure
- Log or Beam, Structure

Vegetation Type
- Dense Milfoil, Sparse Elodea
- Sparse Elodea, Milfoil
- Dense Elodea, Some Milfoil
- Sparse Elodea

Substrate
- Concrete Rubble and Boulders
- Cobble
- Gravel
- Sand and Gravel
- Sand
- Sand and Silt
- Organic Silt

- Area of Investigation (AOI)
- Shipyard Consent Decree Boundary
- Uplands Boundary As Defined by the Consent Decree (December 1999)
- Division between Eastern and Western Study Areas
- Harbor Patrol Boundary
- Gas Works Park Boundary

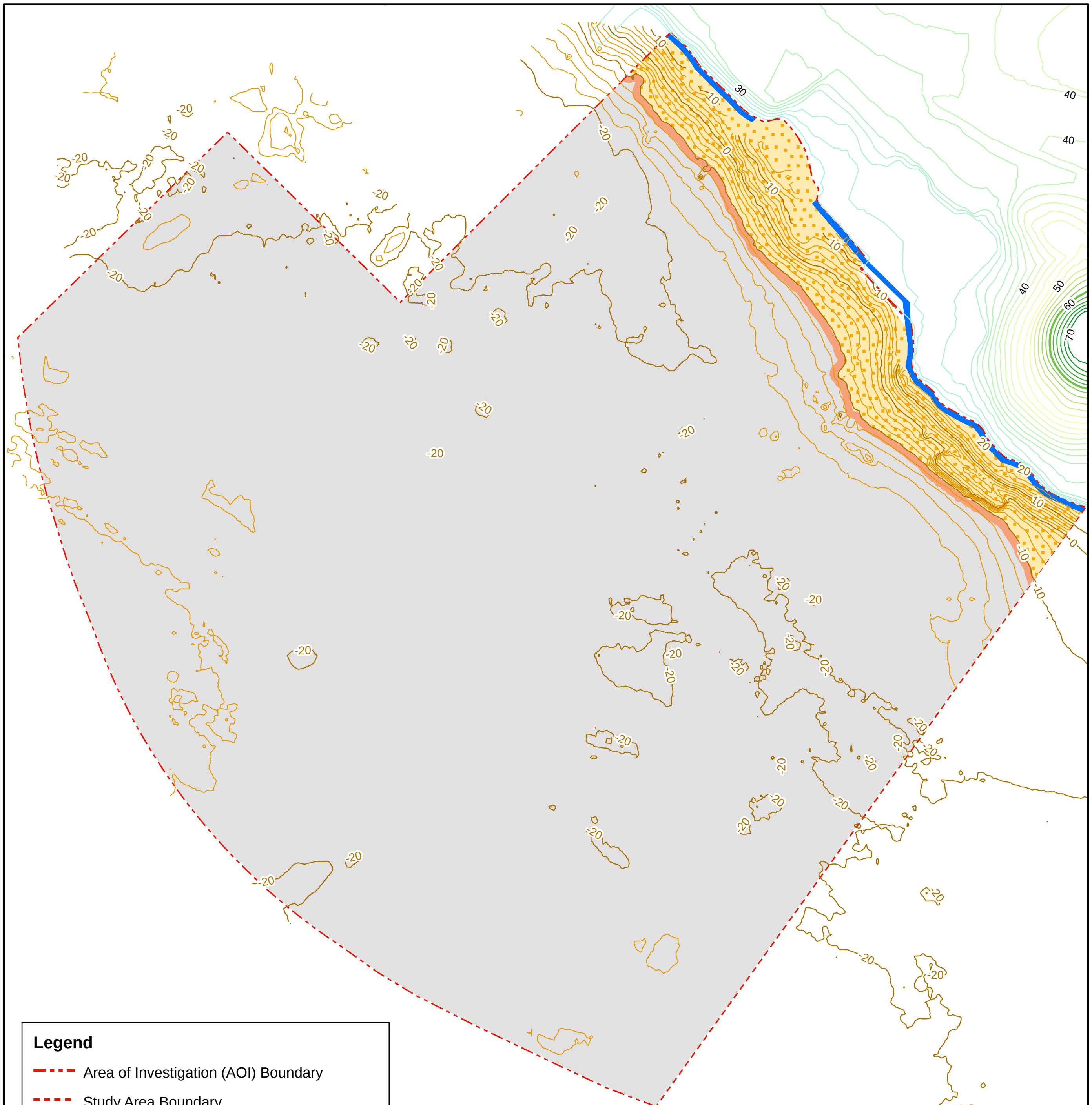
NOTES:
1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.
2. Other miscellaneous debris not shown. See Figure 5-5 from the 2002 Sediment Investigation Report (July 16, 2002) for additional information.

FILE: T:/LakeUnion_N83/Projects/NLU/ESA_RI_2006/Section4/SiteWideSubstrate.mxd

RETEC

REVISION: 5

GAS WORKS SEDIMENT EASTERN STUDY AREA PSE10-18628-630	SUBSTRATE MAP
DATE: 03/31/06 DWN. BY: RLB/ftc	FIGURE: 4-6



Legend

- Area of Investigation (AOI) Boundary
- Study Area Boundary
- -20 Bathymetric Contour in Feet (USACE Datum)
- 15 Topographic Contour in Feet (USACE Datum)

Substrates

- Rip Rap Armor
- Soft Organic Silt with Clay (0 to 50 feet in thickness)
- Medium Dense to Dense Sand with Silt
- Start of Soft Sediment

Note:
Bathymetric data based on multi-beam survey conducted by TetraTech in 2006.

N

0 200 400
Scale in Feet

FLOYD | SNIDER
strategy ▪ science ▪ engineering

Remedial Investigation and Feasibility Study
Gas Works Sediment Western Study Area
City of Seattle

DRAFT

Figure 4.6
Surface Substrate Conditions

F:\projects\COS-GWSA\GIS\RIFS Report\Figure 4.6 (Surface Substrate Conditions Map 8.5 X 11).mxd

ATTACHMENT 3I-2

Grette and Associates Habitat Preferences of Juvenile Chinook Salmon and Smallmouth Bass in Lake Union, Washington Memorandum

TECHNICAL MEMORANDUM

Prepared for: RETEC — Date: November 18, 2005

Prepared by: Glenn Grette; Grette Associates — File No.: 300-007

Re: Lake Union Habitat

INTRODUCTION

This Technical Memorandum presents information on the habitat preferences of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and smallmouth bass (*Micropterus dolomieui*) in Lake Union, Washington. The purpose of this memorandum is to present habitat criteria that are useful for development of design criteria for the sediment remedial alternatives at the Eastern Study Area of the Gas Works Park site on Lake Union,

Chinook salmon are addressed as they are known to make use of shoreline habitat in Lake Washington and Lake Union and they are listed as threatened under the Endangered Species Act. Smallmouth bass are a non-native species that are known to prey on juvenile salmonids including chinook. Based on the predator-prey relationship between these species the primary fish habitat challenge for the site is to ensure no net loss of habitat function for juvenile chinook salmon, while minimizing the potential for improving habitat for predator-size smallmouth bass.

PARAMETERS

Depth

Juvenile chinook salmon inhabit the littoral zone of Lake Washington from January through June before migrating to saltwater. Chinook fry (approximately <60 mm) typically inhabit water 1 m or less deep (Tabor *et al.* 2003) on the southern shoreline of Lake Washington, while smolts (actively migrating juveniles typically >80 mm) use a greater range of depths. Tabor *et al.* (2003) tracked smolts tagged with microacoustic tags for 18 hours in Lake Washington. During that time they used a range of water depths, however areas less than about 4 m (13 ft) deep were used most. At night they used water less than 1.5 m (5 ft) deep. Recent tagging work in the Lake Washington Ship Canal and Lake Union has showed similar use of areas less than 4 m deep by smolts (Julie Hall, personal communication). Use of the Lake Union shoreline by Chinook fry has not been investigated.

Based on the distribution of Chinook fry in Lake Washington (most are present at the southern end of the lake close to the spawning habitat in the Cedar River) (Tabor *et al.* 2003), it is concluded that use of the Lake Union shoreline by Chinook fry is likely much less than for Lake Washington. However, this potential function cannot be completely ignored for Lake Union as it may be related to total spawner abundance in the system (i.e., when spawners are abundant greater use of Lake Washington and Lake Union are likely to occur). Further, shoreline use by Chinook smolts has been demonstrated for Lake Union. Therefore, the information available indicates that shallow shoreline habitat in Lake Union is likely more valuable for Chinook than the open water portions of the lake. Based on the information available water depths shallower than about 10 ft are likely valuable habitat, while a subset of this area (that shallower that 5 ft) is probably even more valuable due to the potential to support fry rearing and its nighttime use by smolts.

Water levels in Lake Union vary through the spring and are lowest in February (approximately 20 ft water surface elevation, Corps datum), and increase to a maximum elevation of approximately 22 ft in late June (USACE 2005). Therefore, water levels are increasing during the period juvenile Chinook may be using the lake. It is proposed that water depth preferences be based on the low water period so they more precisely address the needs of Chinook fry which could be present during the early portion of the spring. Therefore, the above recommendation of 10 ft of water depth would translate to the 10-ft contour (Corps datum) and a 5 ft water depth recommendation would translate to the 15-ft contour (Corps datum).

Smallmouth bass within Lake Washington and the Lake Washington Ship Canal display a seasonal shift in habitat depth preference moving shallow into the littoral zone in May and June as water temperature increases (Fresh unpublished data). Further, larger smallmouth bass (>38 cm) prefer deeper nearshore waters (6-7 m, 20 ft), while smaller bass (<25 cm) preferred shallower depths (1-4 m, <12 ft) (Fresh unpublished data). Smallmouth bass seemed to display a diel shift, moving from 6-7 m water during the day into shallower water at night (Fresh unpublished data). The depth distribution of juvenile Chinook and predator-sized smallmouth bass overlaps during the spring. This overlap is more likely during later spring when Chinook smolts are present rather than during the early spring when Chinook fry are present.

Substrate

Most studies indicate that juvenile chinook prefer sand/gravel substrates, and occasionally exhibit a preference for cobbles (USACE 2001; Tabor, Piaskowski 2001, Tabor 2003), though USACE (2001) found that juvenile salmonids preferred cobble substrates over finer sediment habitat, such as sand and gravel. Tabor has found that fry prefer areas with small substrates, such as small sand and gravel (Tabor in Kurko, 2001). Tabor and Piaskowski (2001) found that juvenile chinook rarely use boulder habitat. Complex habitat (large woody debris, structural diversity) seems to be important sheltering habitat for both fry and smolts (USACE 2001). A study conducted for the USACE on juvenile salmonids in Lake Washington shoreline habitat found that juvenile salmonids (all species) preferred sites with overhanging vegetation to sites with vegetation that did not overhang, or grassy sites (USACE 2001). Tabor found that juvenile salmonids utilize woody debris and overhanging vegetation for refuge (Tabor 2003), and Tabor *et al.* (2003) found that juvenile chinook utilize woody debris as cover, though not in a consistent pattern. They report instances of heavy use of woody debris, and of almost no use. Tabor and Piaskowski found that during the day there is no significant difference between juvenile chinook densities in woody debris/overhanging vegetation habitat and open habitat. At night, significantly more juvenile chinook were in open sites than in sites with woody debris and overhanging vegetation (Tabor, Piaskowski 2001).

Smallmouth bass prefer coarser substrates with more structure. Significant positive correlations were found between smallmouth density and boulder/bedrock substrate and coarse woody debris in Lake Whatcom (Mueller and Rothaus, 2001). Fresh (unpublished data) found a positive correlation between smallmouth bass and cobble substrate. In Lake Whatcom, significant negative correlations were found between smallmouth densities and silt/sand substrates (Mueller, Rothaus, 2001). This is consistent with other studies (Probst *et al* 1984, Todd and Rabeni 1989 in Mueller, Rothaus, 2001). However, Fresh (unpublished data) found that bass preferred sand, mud, and cobble habitat.

Based on the above information, it is recommended that substrates be fine (silt/sand/gravel) to the extent possible. Cobbles and larger rock that form a complex habitat should be minimized as a surface treatment. Due to differing depth preferences between juvenile Chinook and smallmouth bass, cobbles and larger rock in very shallow water (less than 5 ft) may be less of a concern than similar structure at 15-20 ft where larger bass are likely to be present.

Overhanging vegetation is recommended to the extent possible as habitat for juvenile chinook, while woody debris is not recommended due to apparently inconsistent use by juvenile chinook and significant use by smallmouth bass. This recommendation may change with time as new information becomes available.

Slope

Jeanes and Hilgert report that "juvenile salmonids" in the Sammamish River consistently select gently sloped habitat (≤10H : 1V), and that gently sloped habitat seems to be more important to juvenile salmonids than does the presence of large woody debris (USACE 2002).

Based on the above information, it is recommended that gently sloped habitat be created to the extent possible.

Macrophytes

The two dominant submerged macrophyte species observed at the Eastern Study Area of Gas Works Park are elodea (*Elodea canadensis*) and Eurasian watermilfoil (*Myriophyllum spicatum*). These species were only observed to exist between approximately the 3 ft and 10 ft contours (10 ft-18 ft below the early spring water level) and elodea dominates.

Elodea is a native species and favors silty sediments and water rich in nutrients, but will grow in wide range of conditions. Elodea creates good habitat for invertebrates, young fish and amphibians (WSDOE, 2003a).

Eurasian watermilfoil is an aggressive, non-native aquatic weed. It grows very rapidly and forms dense canopies, which shades out native vegetation. Eurasian watermilfoil prefers fine-textured, inorganic sediments, and grows poorly on highly organic sediments (WSDOE, 2003b).

Jeanes and Hilgert report catch rates of juvenile salmonids in the Sammamish River to be lower in Eurasian watermilfoil habitat than other habitats, such as cattail, willow, and nearshore bank habitats (USACE 2002).

It is often speculated that smallmouth bass may benefit from the presence of dense macrophytes, as the increased structure provides opportunities to ambush prey (Bryan and Scarnecchia in Kurko, 2001). However, Mueller, Rothaus (2001) report no significant correlation between smallmouth bass densities and the presence of submerged vegetation in Lake Whatcom.

Based on the above information, it is recommended that elodea establishment be encouraged, while milfoil establishment be discouraged at the project site. This will probably be relatively easy as the current distributions of these species are likely related to energy rather than substrate. If sand is a component of the substrate on the lake bottom at elevations below 10 ft (Corps datum), elodea should be able to colonize portions of the site and milfoil is unlikely to dominate.

REFERENCES

Fresh, K., Rothaus, D., Mueller, K., and C. Waldbillig. Unpublished data. Habitat utilization by predators, with emphasis on smallmouth bass, in the littoral zone of Lake Washington. November 3, 2001.

Hall, Julie. Personal communication with Julie Hall, research biologist, Seattle Public Utilities. October 25, 2005.

Kurko, K. 2001. Seattle's Aquatic Environments: Lake Washington.

Mueller, K. W., and D. P. Rothaus. 2001. Habitat Associations of Introduced Smallmouth Bass and Native Signal Crayfish of Lake Whatcom, Washington During November 1998. April 2001

Tabor, R. A. 2003. Juvenile Chinook Preferred Lakeshore and Ship Canal Habitat: 2002 Results. Presented at 2003 Greater Lake Washington Chinook Workshop. January 24, 2003.

Tabor, R., C. McCoy, S. Camacho, M. Celedonia, S. Vecht, and M. Timko. 2003. Habitat use and movements of juvenile chinook salmon in south Lake Washington, 2003 investigations. Presented at 2003 Greater Lake Washington Chinook Workshop. January 24, 2003.

Tabor, R. A., M. T. Celedonia, F. Mejia, R. M. Piaskowski, D. L. Low, B. Footen, and L. Park. 2004. Predation of Juvenile Chinook Salmon by Predatory Fishes in Three Areas of the Lake Washington Basin. February 2004.

Tabor, R. A. and R. M. Piaskowski. 2001. Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems of the Lake Washington Basin, Annual Report, 2001. U. S. Fish and Wildlife Service. February 2002.

U.S. Army Corps of Engineers (USACE). 2005. Lake Washington Summary Hydrograph. Retrieved from http://www.nmd-wc.usace.army.mil/nws/hh/basins/ lwscsh.html on 6/16/05.

USACE. 2002. Juvenile Salmonid Use of Created Stream Habitats Sammamish River, Washington. Prepared by E.D. Jeanes and P.J. Hilgert, R2 Resource Consultants, Inc. February 2002.

USACE. 2001. Seward Park Rehabilitation Study: Juvenile Salmonid Use of Shoreline Habitats in Seward Park, King County, Washington. Fiscal Year 2000 Planning Assistance to the States Report. Prepared for City of Seattle Parks Department by USACE. January 31, 2001.

Washington State Department of Ecology (WSDOE). 2003a. American Waterweed—A Common Native Plant. Retrieved from http://www.ecy.wa.gov/programs/wq/plants/native/ elodea.html on 6/20/2005. February 24, 2003.

WSDOE. 2003b. Technical information about *Myriophyllum spicatum* (Eurasian Watermilfoil). Retrieved from http://www.ecy.wa.gov/programs/wq/plants/native/elodea.html on 6/20/2005. February 24, 2003.

ATTACHMENT 3I-3
Geomatrix Aquatic Habitat in North Lake Union Report

Gas Works Sediment
Western Study Area
Aquatic Habitat in North Lake Union

1.0 INTRODUCTION

This appendix to the Gas Works Sediment Western Study Area RI/FS presents information about the nearshore environment of the Gas Works Sediment Western Study Area (GWS-WSA), what is known about how juvenile Chinook salmon (*Oncorhynchus tshawytscha*) use the nearshore environment of North Lake Union, and the goals of proposed shoreline restoration at Gas Works Park (GWP). The purpose of this material is to support the RI/FS for the GWS-WSA.

2.0 EXISTING HABITAT CONDITIONS

The shoreline of the GWS-WSA has been extensively modified (see attached figure). The shoreline is comprised of:

- Rip rapped slopes (approximately 375 lineal feet),
- Bulkheads and/or overwater structures (approximately 390 lineal feet), and
- Shallow slopes (approximately 160 lineal feet).

Riparian vegetation along the shoreline (where it exists) consists of a narrow (less than 15 feet wide) band of shrubs. This band of shrubs is dominated by Himalayan blackberry (*Rubus discolor*), scotch broom (*Cytisus scoparius*), and giant horsetail (*Equisetum telmateia*). Himalayan blackberry is considered a noxious weed of concern by King County (King County 2006). Noxious weeds of concern are unregulated weeds that often impact and degrade native habitat. Scotch broom is considered a non-designated noxious weed by King County (King County 2006). King County recommends but does not require control for non-designated noxious weeds. Giant horsetail is a native species that prefers disturbed areas.

The Corps of Engineers regulates the lake water surface elevation of Lake Washington and Lake Union between +22 and +20 ft (MLLW-USACE Locks). Within the GWS-WSA, the slopes along the shoreline between high lake level (+22 ft) and about -12 ft (MLLW-USACE Locks) are fairly steep, averaging about 2.5H:1V. Substrates along the bank and shoreline slope area are generally comprised of rip rap, bulkhead and overwater structures above +15. In the elevation range of +15 feet to -10 feet, shoreline slope area substrate consists of a thin veneer of fill overlying dense sand and gravel glacial deposits. The bank and shoreline slope areas contain significant anthropogenic debris.

Below -10 ft the lake bottom is relatively flat with typical grades from the northern portion of the GWS-WSA to the southern boundary averaging about 100H:1V. The sediment surface of the lake bottom is comprised of recent lake deposits generally consisting of very loose organic clays and silts with wood fragments and anthropogenic material.

Due to the highly modified shoreline, a non-existent or non–functional riparian zone, steep slopes with anthropogenic debris, and the unconsolidated organically enriched lake bottom, the existing habitat in the GWS-WSA likely provides few if any essential functions for fish and other aquatic species.

3.0 FISH SPECIES IN LAKE UNION

The Lake Washington/Lake Union system hosts many fish species, including five salmonid species: Chinook salmon, coho salmon (*O. kisutch*), sockeye/kokanee salmon (*O. nerka*), coastal cutthroat trout (*O. clarki clarki*), and steelhead/rainbow trout (*O. mykiss*). Anadromous forms of each of these species are present, so individuals are present in the lake both as adults during migrations to spawning grounds and as juveniles. Sockeye are known to spawn along some beaches of the Lake Washington while there are unconfirmed reports of Chinook spawning in littoral areas of the lake (Kerwin 2001).

Non-anadromous forms of winter steelhead (rainbow trout), sockeye (kokanee), and cutthroat trout also occur in the Lake Washington system. Resident rainbow trout spend their entire life in Lake Washington. The resident rainbow trout population was sustained with hatchery plants because they rarely successfully reproduce in WRIA 8; however, releases of hatchery rainbow trout have been all but eliminated. Non-anadromous coastal cutthroat trout also occur in Lake Washington and are much more abundant than the anadromous form. Kokanee salmon is the freshwater, resident form of *O. nerka*. Some progeny from the parents of anadromous sockeye may also remain in Lake Washington for all or a portion of their lives (resident/anadromous sockeye) (Kerwin 2001).

Species endemic to the Lake Washington/Lake Union system include the northern pike minnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), sculpins (*Cottus* spp.), and longfin smelt (*Spirinchus thaleichthys*) (Weitkamp et al. 2000; Wydoski and Whitney 1979).

Twenty-four non-native fish species (Table 1) have been identified in Lake Washington. A number of these species are now believed to be no longer present in the system. Some of these species are known to prey on juvenile salmon (e.g., smallmouth bass) while others are potential competitors with juvenile salmonids for food (Kerwin 2001).

Table 1. Non-native Fish Species Introduced into the Lake Washington/Lake Union System (Kerwin 2001)

Common Name	Scientific Name	Status
American shad	*Alosa sapidissima*	uncommon strays
Atlantic salmon	*Salmo salar*	can exceed 1000/yr
Black bullhead	*Ictalurus melas*	extinct
Black crappie	*Pomoxis nigromaculatus*	common
Bluegill	*Lepomis macrocheilus*	common
Brook trout	*Salvelinus fontinalis*	rarely caught
Brown bullhead	*Ictalurus nebulosus*	rare, may be extinct
Brown trout	*Salmo trutta*	no observed reproduction
Channel catfish	*Ictalurus punctatus*	rarely caught
Cherry salmon	*Oncorhynchus masou*	extinct
Common carp	*Cyprinus carpio*	abundant
Fathead minnow	*Pimephales notatus*	unknown
Goldfish	*Carassius auratus*	intermittent
Grass carp	*Ctenopharengodon idella*	triploids only
Lake trout	*Salvelinus namaycush*	extinct
Lake whitefish	*Coregonus clupeaformis*	extinct
Largemouth bass	*Micropterus salmoides*	common
Pumpkinseed sunfish	*Lepomis gibbosus*	abundant
Smallmouth bass	*Micropterus dolomieui*	common
Tench	*Tinca tinca*	abundant
Warmouth	*Lepomis gulosus*	no observed reproduction
Weather loach	*Misgurnus angillicaudatus*	no observed reproduction
White crappie	*Pomoxis annularis*	uncommon
Yellow perch	*Perca flavescens*	abundant

4.0 TARGET SPECIES FOR AQUATIC HABITAT IMPROVEMENTS

In March 1999, the National Marine Fisheries Service listed Chinook salmon as threatened under the Endangered Species Act (ESA). The listing focused the region’s attention on ensuring the survival of salmon, a keystone species of the Pacific Northwest (Weitkamp et al. 2000). In compliance with this and other state and federal laws, the proposed cleanup of sediments offshore of Gas Works Park at the north end of Lake Union addresses improvement of nearshore habitat along the Gas Works Park shoreline. Chinook salmon, being a keystone species, is the target species for habitat improvement. It is expected that the proposed shoreline habitat improvements will also benefit coho, sockeye, and steelhead found in the Lake Washington system, as well as other aquatic species using the nearshore area.

The anadromous salmonids using the Lake Washington system have similar habitat requirements for migration corridors free of barriers; cold, high-quality water; water with a high dissolved oxygen concentration; well aerated gravel for spawning; and complex habitats for rearing. As a keystone species, the Chinook salmon has been selected as the representative species for addressing the habitat requirements of anadromous salmonids in the Lake Washington system. Therefore, the following section presents life history information for this species and summarizes what is known about how Chinook salmon use the area offshore of Gas Works Park.

4.1 Life History of Chinook Salmon In the Lake Washington System

Chinook salmon prefer to spawn and rear in the mainstems of rivers and larger streams (Williams et al. 1975; Healey 1991). Although the incubation period is determined by water temperatures, fry typically hatch in about eight weeks (Wydoski and Whitney 1979; Healey 1991). Most Puget Sound juvenile Chinook migrate to the marine environment during their first year.

Rearing and development to adulthood occurs mainly in estuarine and coastal waters (NMFS 1998). The amount of time juvenile Chinook spend in estuarine areas depends on their size at downstream migration and rate of growth. While living in upper estuaries, juveniles prey mainly on benthic and epibenthic organisms such as amphipods, mysids, and cumaceans. Juveniles typically move into deeper waters when they reach about 65 to 75 mm in fork length. As the juveniles grow and move to deeper waters with higher salinities, their main prey changes to pelagic organisms such as decapod larvae, larval and juvenile fish, drift insects, and euphausiids (Simenstad et al. 1982).

The Lake Washington system provides habitat for ocean-type Chinook salmon. This is an unusual habitat for ocean-type Chinook salmon, as they typically do not rear in large, natural lakes during their migration to and from marine waters (Weitkamp et al. 2000). Adult Chinook returning to the watershed first arrive at the Ballard Locks in mid-June, with the peak time of entry occurring in mid-to-late August. The return is generally complete by early October (Weitkamp et al. 2000).

Most returning Chinook in the Lake Washington system are of hatchery origin and most return to the Issaquah Creek Hatchery or the smaller facility at the University of Washington. The majority of naturally spawning Chinook are destined for the Cedar River (Weitkamp et al. 2000).

In the Cedar River, Chinook fry emerge from the gravel in late winter to early spring. Available data indicate that juvenile Chinook begin migrating downstream by mid-January and continue through at least early July. As juvenile Chinook migrate from Lake Washington, they pass through Lake Union and the Ship Canal.

There are two different life history trajectories of naturally produced juvenile Chinook that enter Lake Washington. The first group consists of Chinook fry that enter the lake from at least mid- January through mid-March. These fish spend little or no time rearing in riverine habitats before entering Lake Washington where they rear for a number of months before migrating to Puget Sound. While rearing in the lake, the most important area used by Chinook fry appears to be the littoral zone. Chinook juveniles are rarely found in limnetic habitats until after early May. Portions of the littoral zone that are most heavily utilized by Chinook fry include areas around creek mouths and areas that are not heavily developed. Studies of microhabitat use of littoral areas found that Chinook fry prefer areas that have small substrates (sand and small gravel) (Kerwin 2001).

The second group of juvenile Chinook that enter Lake Washington are smolts. Smolts enter the lake from mid-May through at least late July and are of a much larger size than fry at the time they enter the lake. These fish rear for a number of months in riverine habitats before entering the lake where they spend much less time than fry rearing. Smolts use the lake primarily as a migratory corridor to exit the watershed (Kerwin 2001).

4.2 Use of the Nearshore Area Near Gas Works Park

Adult Chinook salmon use the Lake Union/Lake Washington Ship Canal system as a migration corridor to upstream spawning grounds. The precise migration routes through Lake Union and the Ship Canal are unknown; however, their residency is expected to be a few days. Water temperatures may influence initial entrance into the Lake Union/Lake Washington Ship Canal system from the Locks as evidenced by the delay observed in adult passage through the Locks during high water temperatures in 1998 (City of Seattle 2003).

Recent studies have been conducted investigating how juvenile Chinook salmon move through the Lake Union/Lake Washington Ship Canal system (Tabor 2006). The US Fish and Wildlife Service (USFWS) conducted acoustic tracking studies in Lake Washington and the Ship Canal from 2003 through 2006 in which Chinook salmon smolts (~100 mm in length) were fitted with acoustic tags and their movements recorded (Tabor 2006). Preliminary, unpublished data (Tabor 2006) for North Lake Union indicate that:

- Chinook salmon smolts behave differently in the Ship Canal than they do in Lake Washington.
- In Lake Washington, Chinook smolts stay close to shore during the day (1-5 m water column depth) and move into deeper water at night (> 10 m water column depth; up to 230 m and more from shore).
- In the Ship Canal (Portage Bay and north Lake Union), Chinook smolts fan out across broad areas and mix across the channel during all times of day and night.
- In Portage Bay, Chinook smolts are most common in water > 8 m deep. They also often appear in water 2-8 m deep and rarely occur in water < 2 m deep.
- In north Lake Union, Chinook smolts are almost exclusively found in water > 10 m deep.
- Four distinct Chinook smolt migrational behaviors have been identified relative to how they use a given area.
- Different sites appear to be used differently by migrating Chinook smolts. Some sites appear to be used mainly as migrational corridors, while other sites are used more for short-term (< 1 day) or long-term (> 1 day) resting and/or rearing.
- Specific sites may be used differently from year-to-year.
- A Lake Washington study site located about 2 km south of Union Bay was used primarily as a migrational corridor.
- Many Chinook smolts appear to spend 1-3 days in the vicinity of Union Bay before moving through the Montlake Cut. A notable minority of smolts migrate directly through Union Bay and the Montlake Cut without spending any time resting or rearing here.
- Portage Bay was used primarily as a short-term (< 1 day) resting/rearing area in 2004, and almost exclusively as a migrational corridor in 2005.

- Coho smolts showed similar movement patterns and habitat use as Chinook smolts in Portage Bay and north Lake Union (2005).

- Chinook smolts migrate quickly between Portage Bay and north Lake Union (1-13 hours).

- North Lake Union was used almost exclusively as a long-term resting/rearing area. Chinook salmon smolts resided in the Lake Union area for 1-7 days before continuing their migration.

- A unique behavior at the North Lake Union site may be an indicator of reluctance to migrate through a specific area.

- Chinook smolts were rarely observed using the same localized areas when resting (i.e., different fish used different localized areas).

- Release location influenced fish behavior. The authors observed markedly different patterns in movement and habitat use between fish released on-site and fish released off-site (> 350 m away).

- Overwater structures: size, width and water depth appear to influence smolt avoidance of overwater structures.

- Overwater structures may cause home ranges of smallmouth bass to decrease, thereby increasing density in the general area.

- There is at least some overlap between Chinook salmon and smallmouth bass habitat. The full extent and implications of this have yet to be explored (need larger sample sizes of bass).

4.3 Chinook Predators and Predator Conditions in Lake Union

This section provides a discussion of predation on Chinook salmon within the Lake Washington/Lake Union system. The majority of the information presented here is summarized from Kerwin's (2001) *Salmon and steelhead habitat limiting factors report for the Cedar-Sammamish Basin (Water Resource Inventory Area 8)*, which discusses predation on all anadromous salmonids in the Lake Washington system.

Predation is a natural process that influences the abundance of anadromous salmon populations wherever they are found and so salmonids have evolved characteristics that minimize predation mortality. Thus, for predation to be a factor of decline, predation mortality must increase over historic conditions due to some change or changes in the ecosystem. Five changes have occurred in Lake Washington that could potentially increase predation mortality.

The Lake Union/Lake Washington system has been modified extensively beginning in the late 19th century. Historically, no surface water connection existed between Lake Washington and Lake Union. A small stream flowed from Lake Union into Salmon Bay, a tidally-influenced embayment of Puget Sound. In the late 1800s a chute was constructed between Lake Washington and Lake Union (City of Seattle 2003). A major alteration of the Lake Washington watershed occurred when the Lake Washington Ship Canal and Hiram M. Chittenden Locks were completed in 1916. The ecological consequences of this alteration were profound: the outlet of Lake Washington was redirected from its south end, at the Black River and the Cedar River diverted to discharge into the Lake; the new outlet at the Locks and Salmon Bay had almost no features of a natural estuary and presented migrating salmonids an abrupt transition from freshwater to saltwater (and saltwater to freshwater); and the level of Lake Washington was dropped about nine feet, which drained wetlands along much of its shoreline and dramatically changed the confluences with its tributaries (City of Seattle 2003; Kerwin 2001).

First, littoral zone habitats have been extensively modified over the last 100 years due to the change in lake level (in 1916); construction of piers, docks, and bulkheads; removal of large woody debris (LWD); and the expansion of Eurasian watermilfoil (*Myriophyllum spicatum*). It is highly probable that the types of changes occurring in the littoral zone of the Lake Washington system have altered the composition, diversity, and abundance of fish communities in the system. However, it is difficult to predict the net effect of changes in littoral zones on fish populations and whether these changes have actually increased predation mortality of juvenile salmonids. While shoreline development and an increased density of macrophytes may result in more habitat for some juvenile salmonids, these changes may also enhance habitat for predators such as smallmouth bass. Preliminary data indicate that Chinook salmon avoid areas with aquatic macrophytes (Corps and SPU 2006), Bass predation could also increase if the habitat provided by piers, docks and bulkheads either provides better spawning habitat and assists bass populations to increase, or it allows predators a better place of ambush their prey.

Fresh et al. (2003) investigated the utilization of the littoral zone of Lake Washington and the Lake Washington Ship Canal by smallmouth bass to determine if anthropogenic habitat features (e.g., docks, rip-rap) affected distribution of this species. Their results indicate that at sites in Lake Washington where smallmouth bass are abundant, the presence of structure had an important influence on the distribution of smallmouth bass as 72 percent of the bass that were observed were within 2 m of some sort of structure; 68 percent of all adult smallmouth bass were observed within 2 m of a dock. The bass did not use dock habitat (defined as within 2 m of a dock) in proportion to its availability. In areas where smallmouth bass are rare or absent, the addition of structure was expected to have little effect on the abundance of smallmouth bass (Fresh et al. 2003). Tabor (2006) noted that overwater structures may cause home ranges of smallmouth bass to decrease, thereby increasing density in an area.

Second, predation mortality of salmonids could increase if there has been a significant increase in the population of one or more predator species. While it is clear that population sizes of non-native predators are larger (there were none historically), it is not clear whether populations of native predators have increased. There is some anecdotal evidence that cutthroat trout are considerably more numerous now than historically. The northern pikeminnow population is believed to have increased 11-38 percent between 1972 and 1997. Further, there is evidence that larger pikeminnow are more numerous than they were historically. Because larger predators consume more prey, this could also increase predation mortality of anadromous juvenile salmonids.

Third, water temperatures in the system have increased since monitoring began in the 1930s. Further, there is also evidence that water temperatures are warming earlier than historically. While this is probably due to the effects of global warming, it may simply be a long-term trend. An increase in water temperature would be expected to increase metabolic rate of predators, which in turn would increase consumption of prey species. These temperature shifts could increase the temporal and spatial overlap between some predators and juvenile salmonids. With increasing spring and summer temperatures above the thermocline, juvenile salmonids could become increasingly concentrated into a narrow depth band along the slope zone or open water along with their predators. Such an increase in water temperatures in the littoral zone could increase overlap between the littoral zone predators (e.g., smallmouth and largemouth bass) and juvenile salmonids. If the littoral zone is warming sooner than it did historically, bass may be present in littoral zones for a longer period and thus capable of eating more juvenile salmon because of an increased overlap between predator and prey or it could force juvenile salmonids into deeper water earlier and at a smaller size.

A fourth factor that could increase predation mortality of anadromous salmonids over historic levels is the introduction of non-native, piscivorous fish, such as smallmouth bass, largemouth bass, rainbow trout, hatchery-produced Chinook and coho salmon, and yellow perch. All of these species are known to prey on juvenile salmon. Impacts of exotic fish predators have not been fully evaluated and are part of ongoing research programs. Tabor et al. (2004) calculated population estimates for smallmouth bass and largemouth bass in the Lake Washington Ship Canal (LWSC), indicating that there were approximately 3,400 smallmouth bass and 2,500 largemouth bass in the LWSC. Estimates were made for fish that were > 130 mm fork length, a length that was expected to include all fish that may consume salmon smolts. A bioenergetics model and a direct meal-turnover model were used to estimate total consumption of smolts. The bioenergetics model predicted smallmouth bass consumed 27,300 salmonids and largemouth bass consumed 8,700. The direct meal-turnover model predicted smallmouth bass consumed 41,100 salmonids and largemouth bass consumed 4,600. The highest consumption occurred in age 2 fish because of their large population size and high growth rates. Incorporating the results of both models, there was little apparent difference in the number of each salmonid species consumed by smallmouth bass. Largemouth bass appeared to consume mostly sockeye salmon and coho salmon and few Chinook salmon.

Footen (2003) investigated the predation on juvenile Chinook salmon by piscivorous fish in Lake Washington and the Ship Canal. His results indicated that smallmouth bass ranging in size from 150 to 250 mm are the primary predators on Chinook smolts migrating through the Ship Canal. Northern pikeminnow were also reported to consume Chinook smolts in this area.

The fifth factor affecting mortality is the availability of alternative prey fishes to buffer the impact of predation on young salmonids. Longfin smelt are a major prey species for cutthroat trout, northern pikeminnow, and rainbow trout. When smelt were abundant, the mortality of sockeye during their lake residence phase was reduced significantly. Mortality of other juvenile salmon species could potentially be buffered in a similar way. Longfin smelt live for two years and their abundance fluctuates cyclically: even year classes (e.g., progeny spawned in 1998 or 2000) are 10 times more abundant than odd-year classes (e.g., progeny from 1999 and 2001 brood years). Longfin smelt play an extremely important ecological role in Lake Washington, but how smelt year class fluctuations affect predator-prey dynamics and the food supply of juvenile salmon are not well understood or fully appreciated, and the current status of the smelt population during odd- and even-year cycles is not known (Kerwin 2001).

5.0 SHORELINE RESTORATION GOALS FOR GAS WORKS PARK – WESTERN STUDY AREA

Improvement of nearshore habitat along the Gas Works Park shoreline is being proposed as part of the proposed sediment cleanup offshore of Gas Works Park, for compliance with state and federal laws governing permitting of in-water work. This section briefly discusses the goals of the proposed shoreline restoration and the short- and long-term benefits of shoreline restoration.

Habitat objectives for the nearshore area of Gas Works Park were developed during a focused meeting with the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Washington State Department of Ecology, the Washington State Department of Fish and Wildlife, the Washington State Department of Natural Resources, the Muckleshoot Indian Tribe, the Seattle Department of Planning and Development, and Seattle Public Utilities (see attached meeting notes). Recognizing that achievement of cleanup requirements under the Washington State Department of Ecology's (Ecology) Model Toxics Control Act (MTCA) is the priority at the site, habitat objectives will be evaluated as possible given remedial requirements, to comply with location-specific ARARs governing permitting of shoreline and in-water work. The stakeholder meeting referenced above developed four primary goals for shoreline restoration at Gas Works Park:

1. Focus on Chinook salmon as target species for habitat improvements, while also addressing other salmonid species such as coho, sockeye and steelhead. To the greatest extent possible pursue habitat features that offer ecological benefits to multiple aquatic species and multiple life history stages of salmonids.

2. Avoid or minimize the creation of nearshore habitat that would facilitate predation on Chinook smolt by piscivorous fish such as smallmouth bass. This could be accomplished by:

    a. Minimizing presence of void spaces or hiding places that are attractive to bass. Remove large debris where possible, reduce size of nearshore rock and provide sand or gravel substrates where possible. When practical, fill void spaces with finer material.

    b. Considering the effects of slopes and slope breaks on bass predation.

    c. Minimizing additional overwater structures that provide cover for bass and affect productivity for prey species.

3. Provide, if possible, a complexity of riparian vegetation to increase terrestrial insect food source (drift) for juvenile salmon using the nearshore area, but not in such a way as to increase large woody debris inputs to the shoreline that may provide predator habitat. Avoid or minimize the use of submerged vegetation.

4. Provide, if possible, natural slope and beach conditions wherever possible while addressing tribal fishing objectives. Design required overwater structures to minimize shading and to deter use by salmon predators. Minimize artificial light impacts to water column.

5.1 Short-Term Benefits of Shoreline Restoration Goals

The proposed shoreline restoration goals are expected to have immediate and short-term benefits to Chinook and other salmon species, as well as other fish species, using the north end of Lake Union. Although preliminary results of the USFWS acoustic tracking study (Tabor 2006) indicate that Chinook salmon smolts in north Lake Union are found almost exclusively in water greater than 10 m deep, these data are based on juveniles that were about 100 mm in length and could be fitted with an acoustic tag (the upper end of the size range of Chinook smolts emigrating for the Lake Washington system). According to Kerwin (2001), while rearing in the Lake Washington, the most important area used by Chinook fry appears to be the littoral zone. Therefore, shoreline restoration may have immediate benefits to small Chinook smolts and fry that may occur in north Lake Union, as well as to larger coho and sockeye salmon smolts and steelhead trout smolts.

5.2 Long-Term Benefits of Shoreline Restoration Goals

The shoreline restoration goals proposed as part of the proposed sediment cleanup offshore of Gas Works Park are consistent with regional and state habitat restoration and improvement goals for greater Puget Sound. In December 2005, Governor Gregoire formed the Puget Sound Partnership with the stated goal to:

"*…ensure that the Puget Sound forever will be a thriving natural system, with clean marine and freshwaters, healthy and abundant native species, natural shorelines and places for public enjoyment, and a vibrant economy that prospers in productive harmony with a healthy Sound.*"

A key component of the Governor's Puget Sound Partnership is salmon recovery, focusing on habitat restoration and recovery. The Puget Sound Partnership envisions a healthy Puget Sound by 2020. In the long term, it is expected that shoreline restoration at Gas Works Park will contribute to the collective benefits of other habitat restoration projects planned in the Lake Washington basin.

The *Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan* (WRIA 8 Steering Committee 2005) proposes actions to prevent further decline of Chinook salmon habitat and to restore habitat within the Lake Washington basin. The Plan recommends implementing these actions and monitoring over the next 10-years. The conservation strategy in the Plan outlines a number of ecosystem objectives:

- Protect and restore habitat Chinook salmon use during all of the life stages that are spent in the WRIA 8 watershed, from egg to fry to smolt to adult;
- Protect and restore the natural processes that create this habitat, such as natural flow regimes and movement of sediments and spawning gravels;
- Maintain a well-dispersed network of high-quality habitat to serve as centers for the population;
- Provide safe connections between those habitat centers to allow for future expansion.

The Plan specifically recommends the restoration of shallow water habitat in maintaining high-quality habitat.

Restoration of aquatic habitat is also consistent with the long-term vision for Lake Union presented in the City of Seattle's *Restore Our Waters Action Plan* (below).

A Long Term Vision for Lake Union
As Described in the Restore Our Waters Action Plan, June 2005

> Overall, the Mayor's aspirations for aquatic environments in the City are that they be: ***Sustainable places that citizens and businesses can utilize, access and have pride in and in which fish and other wildlife can flourish.***
>
> The Mayor's long term vision for Lake Union, Portage Bay, the Ship Canal and the Chittenden Locks is as follows: *This area of the City remains a vital center for Seattle's water-dependent maritime industrial base, and still serves as the home base of the North Pacific fishing fleet. While still used intensively for industry, the water quality of this resource area has greatly improved. The City in collaboration with local*

industries has restored significant areas of shallow water and shoreline habitat for migrating fish and birds, while balancing the needs of industrial businesses in the area. An area habitat plan allows development-required mitigation efforts to effectively contribute to these shore-edge refuge areas and public access points within this major transportation and marine industrial corridor. Sediment contamination and Combined Sewer Overflow (CSO) related water pollution has been adequately addressed, and water quality is sufficient to encourage public recreational uses. A more gradual saltwater/fresh water transition at the western end of the corridor, and cooler summer water temperatures make the waters more hospitable to aquatic life.

6.0 REFERENCES

City of Seattle. 2003. Seattle's urban blueprint for habitat protection and restoration. Seattle, WA: City of Seattle, Salmon Team. Accessed on the web on 11/21/06 at http://www.cityofseattle.net/salmon/blueprintdoc.htm

Corps and SPU (U.S. Army Corps of Engineers and Seattle Public Utilities). 2006. Synthesis of juvenile salmonid research and monitoring: investigations conducted in the western Lake Washington Basin. U.S. Army Corps of Engineers, Seattle District, Seattle, WA and Seattle Public Utilities, Seattle, WA.

Footen, B. 2003. Piscivorous impacts on Chinook (*Oncorhynchus tshawytscha*) in the Salmon Bay Estuary, the Lake Washington Ship Canal and Lake Sammamish. Paper presented at the *2003 Greater Lake Washington Chinook Workshop*, Seattle, WA. Accessed on the web on 11/22/06 at http://www.cityofseattle.net/salmon/workshop.htm

Fresh, K.L., D. Rothhaus, K.W. Mueller, and C. Waldbillig. 2003. Habitat utilization by smallmouth bass in the littoral zones of Lake Washington and Lake Union/Ship Canal. Paper presented at the *2003 Greater Lake Washington Chinook Workshop,* Seattle, WA. Accessed on the web on 11/22/06 at http://www.cityofseattle.net/salmon/workshop.htm

Healey, M.C. 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-393 *in* C. Groot and L. Margolis, editors. *Pacific Salmon Life Histories.* Vancouver, BC: University of British Columbia Press.

Kerwin, J. 2001. Salmon and steelhead habitat limiting factors report for the Cedar-Sammamish Basin (Water Resource Inventory Area 8). Washington Conservation Commission, Olympia, Washington.

King County, 2006, 2006 King County Noxious Weed List. King County Department of Natural Resources and Parks, Water and Land Resources Division, Noxious Weed Control Program, Seattle, WA. http://dnr.metrokc.gov/wlr/lands/weeds/laws.htm

NMFS (National Marine Fisheries Service). 1998. Endangered and threatened species: proposed endangered status for two Chinook salmon ESUs and proposed threatened status for five Chinook salmon ESUs; proposed redefinition, threatened status, and revision of critical habitat for one Chinook salmon ESU; proposed designation of Chinook salmon critical habitat in California, Oregon, Washington, Idaho. Proposed Rule March 9, 1998. *Federal Register* 63(45):11482-11520.

Simenstad, C.A., K.L. Fresh, and E.O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Pages 343-364 *in* V.S. Kennedy, editor. *Estuarine Comparisons.* NY: Academic Press.

Tabor, R. 2006. Unpublished results of U.S. Fish and Wildlife Service acoustic tracking studies in Lake Washington (2003-2005).

Tabor, R., M.T. Celedonia, F. Mejia, R.M. Piaskowski, D. L. Low, B. Footen, and L. Park. 2004. Predation of juvenile Chinook salmon by predatory fishes in three areas of the Lake Washington Basin. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Fisheries Division, Lacey, WA.

Weitkamp, D.E., G.T. Ruggerone, L. Sacha, J. Howell, and B. Bachen. 2000. Factors affecting Chinook populations: background report. City of Seattle, Seattle, WA.

Williams, R.W., R. Laramie, and J.J. Ames. 1975. *A Catalog of Washington Streams and Salmon Use.* Volume 1. Puget Sound. Olympia: Washington Department of Fisheries.

WRIA 8 Steering Committee. 2005. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook salmon conservation plan. Access on the web on December 11, 2006 at:http://dnr.metrokc.gov/Wrias/8/chinook-conservation-plan.htm

Wydoski, R.S., and R.R. Whitney. 1979. *Inland Fishes of Washington.* Seattle: University of Washington Press.


Western Study Area Shoreline Boundary
Rip Rapped Shoreline
Bulkheaded/Overwater Structure Shoreline
Sloped Shoreline

ATTACHMENT 3I-4

GWSA Habitat Objectives Meeting Notes – November 15, 2006

Gas Works Sediment Area
Habitat Objectives Meeting
November 15, 2–4pm, Department of Ecology NWRO

ATTENDEES

Kate Snider	Floyd|Snider	Kate.snider@floydsnider.com
Ann Uhrich	USACE	ann.r.uhrich@usace.army.mil
Jim Muck	US. Fish and Wildlife	Jim.muck@noaa.gov
Peter Adolphson	Ecology	pado461@ecy.wa.gov
Allison Geiselbrecht	Floyd|Snider	Allison.geiselbrecht@floydsnider.com
Cliff Whitmus	Geomatrix	cwhitmus@geomatrix.com
Grant Yang	Ecology	gyan461@ecy.wa.gov
Glenn Grette	Grette Associates	glenng@gretteassociates.com
Dan Berlin	RETEC	dberlin@retec.com
Dan Baker	RETEC	dbaker@retec.com
Maggie Glowacki	Seattle DPD	Margaret.glowacki@seattle.gov
Sarah McKearnan	Seattle Public Utilities	Sarah.mckearnan@seattle.com
Stewart Reinbold	WDFS	reinbsgr@dfw.wa.gov
Joanne Snarski	DNR	Joanne.snarski@dnr.wa.gov
Dan Averill	DNR	Daniel.averill@ndr.wa.gov
Karen Walter	Muckleshoot Indian Tribe Fisheries	Karen.walter@muckleshoot.nsn.us
John Keeling	Ecology	Jkee461@ecy.wa.gov
Maura O'Brien	Ecology	Mobr461@ecy.wa.gov
Pete Rude	Seattle Public Utilities	Pete.rude@seattle.gov

These meeting notes were prepared by Kate Snider.

PURPOSE OF THE MEETING

The Department of Ecology, City of Seattle and Puget Sound Energy are evaluating alternatives for the cleanup of sediments offshore of Gas Works Park at the north end of Lake Union. The purpose of this meeting was to gain input regarding target species and aquatic habitat objectives to be prioritized for the Gas Works shoreline area. This input will be used in the development and evaluation of remedial alternatives.

In later stages of the project, during public comment on the Feasibility Study and during design and permitting of the selected alternative, there will be opportunities for formal review and comment. However, it is extremely valuable for us to receive input from key stakeholders now, before decisions are made on the recommended alternatives to move forward through the process.

Agenda:

2:00 – 2:15 Meeting Purpose and Introductions

2:15 – 2:45 Presentation and Questions – Roger Tabor
USFW 2005-2006 Chinook North Lake Union Usage Data

2:45 – 3:00 Preliminary Gas Works Shoreline Habitat Goals – Kate Snider

3:00 – 3:45 Roundtable Discussion and Input

3:45 – 4:00 Summary – Habitat Objectives for Feasibility Study Evaluations – Kate Snider

Summary - USFW 2003-2006 Chinook North Lake Union Usage Data

Roger Tabor, USFW, has led a team conducting acoustic tracking studies of Chinook smolts in Lake Washington and the Ship Canal.

- Available data indicate that although smolts utilize shallow shoreline areas in Lake Washington for rearing and migration, once they enter the Ship Channel system they begin moving offshore and are generally not present in the shallow shoreline areas.
- The juveniles appear to reside for up to four days in the deeper waters off of Gas Works Park before moving toward the locks.
- Because they are rearing farther offshore in Lake Union, it's not clear that habitat modifications in the shallower nearshore areas along Gas Works and Harbor Patrol will result in greater actual utilization of the shallow nearshore by the juveniles.
- Nevertheless, changes in the substrate and physical character of the nearshore areas should have a net benefit for salmon in North Lake Union.
- There is also a concern about bass predation on smolts in this area. Available data from this site and other sites indicate that bass prefer: overwater structures, rip-rap or other types of substrate that provide cover or prey (e.g., sculpin) hiding places, steeper slopes, and macrophyte edges.
- There is no specific data such as stomach content analyses on the juvenile salmon diet in Lake Union. Lake Washington data suggests they are eating chironomids (midges) and Daphnia (water-fleas). Bass prey include crayfish, sculpin, and salmonids.
- A preliminary document prepared by Roger Tabor Selected Findings of USFWS Acoustic Tracking Studies (2003-2006) in Lake Washington and the Ship Canal is available. Findings from 2006 data collection will be available towards the end of the year.

Habitat Objectives for Feasibility Study Evaluations

Habitat objectives were proposed by the Gas Works Team based on the findings of the 2005-2006 USFW Chinook usage data, and were refined based on input received at the meeting. The objectives presented below will be used in the development and evaluation of remedial action alternatives.

Department of Ecology representatives emphasized that achievement of sediment cleanup requirements under Ecology's Model Toxics Control Act is the first priority at the site. The existing upland cleanup remedial components will also need to be maintained. Habitat objectives will be prioritized as possible given remedial requirements.

1. Focus on Chinook as target species for habitat improvements, while also addressing other salmon species such as Coho, Sockeye and Steelhead. To the greatest extent possible pursue habitat features that offer ecological benefits to multiple aquatic species and multiple life history trajectories of salmon.
2. Avoid or minimize creation of nearshore bass habitat that would facilitate bass predation on Chinook smolt, which primarily utilize the offshore, deeper waters.
    a. Minimize presence of void spaces or hiding places that are attractive to bass. Remove large debris from the sediment surface where possible, provide sand or gravel substrates where possible. When practical, fill void spaces with finer material.
    b. Consider the affect of slopes and slope breaks on bass predation.
    c. Minimize additional overwater structures that provide cover for bass and affect productivity for prey species.
3. Provide a complexity of riparian vegetation as possible to increase insect food source (drift) for salmon, but not in such a way as to increase large woody debris inputs to the shoreline that may provide bass habitat.
    a. Provide riparian shrubs, willows and trees as possible. Establish vegetation as close as possible to the waters edge. Select species that can take seasonal immersion.
    b. Minimize conditions conducive to establishment of submerged vegetation.
    c. Consider interpretive signage to educate park visitors about aquatic species and habitat improvements.
4. Provide natural slope and beach conditions wherever possible while addressing tribal fishing objectives. Design required overwater structures to minimize shading. Minimize artificial light impacts to water column.

Roundtable Discussion

The notes below are a transcription of the flip charts used to document group discussion in the meeting. The points made below were used to develop the revised habitat objectives listed above.

Target Species and Overall Goals

- Breadth of Ecological benefits statement is important. Address species other than Chinook such as Coho, Sockeye, and Steelhead. Address adult migration. Consider effects to DO and temperature.
- Acknowledge that there are multiple development projects occurring in the area.
- It is appropriate to maximize salmon habitat and minimize predator habitat.
- The proposed objectives are consistent with the Chinook draft recovery plan – the recovery plan recommends debris removal and softening of nearshore substrates.
- Look at Coho and Sockeye usage more re: future recovery populations.
- Recognize that implementation of a protective remedy under MTCA for the contaminated sediments is the first priority at the site, and that habitat goals will be implemented where compatible with the MTCA cleanup requirements.

Shoreline Structures and Bathymetry

- Minimizing overwater structures is desirable.
- Natural slope and beach conditions are preferable to bulkhead
- Debris removal is highly desired and a strong benefit to reduce attraction to Bass and minimize Bass habitat.
- Minimize artificial lighting impacts to water column.
- If replace structures consider WDFW guidance for new overwater structures (use of grating, etc).
- Also consider “bioengineered” shoreline- use of logs and vegetation above high water to achieve grade change.
- Agree that large woody debris below water is a concern at this location relative to Bass habitat.
- Small mouth Bass prefer steep slopes and larger substrate and are clear in-shore predator for juvenile Chinook
- Shallowing of bathymetry in nearshore could be a habitat benefit, if associated with placement of beneficial substrates, elimination of steep slopes attractive to Bass, and placement of emergent/riparian vegetation. These changes could make the nearshore more attractive for Chinook utilization.
- Shallowing of bathymetry is potential impact to tribal fishing—consider ability to set nets.
- For the proposed bathymetry, evaluate water depths available at different times of year.

Shoreline Substrates and Vegetation

- Prefer sands and gravel at shoreline (not Bass preference).
- Work to establish beach with good complexity of riparian vegetation – willows, trees, some terrestrial habitat, evergreen trees.
- If sand is placed over riprap, likely to be washed out over time.
- Larger size trees at shoreline are good as they also add to the complexity of riparian vegetation
- Emergent vegetation may be a challenge to establish or maintain given seasonal changes in lake water levels and boat wakes.
- Instead of emergent marsh type vegetation, focus on riparian vegetation that can stand immersion and riparian complexity.
- Minimize conditions that encourage milfoil establishment.
- Submerged vegetation is not an asset or priority at this location.
- Consider integrated management proposal re: noxious species.
- Protect riparian vegetation during establishment.
- Consider interpretive signage regarding habitat improvements.

Appendix 3J
Monitoring Wells Construction Details and Groundwater and NAPL Elevation Tables

Table 3J-1

Well Construction

Gas Works Park Site
Seattle, Washington

Well ID	Screen ID	Installation Date	Status	Installed By	Diameter (inches)	Screen Slot Size (inches)	Well Location		Ground Surface Elevation at Time of Installation	Current Ground Surface Elevation	Current TOC Elevation	Stickup (feet)	Current Total Depth (feet, TOC)[e]	Screen Interval Depth at Time of Installation (feet, bgs)		Screen Interval Elevation		Geologic Unit of Screen Interval[d]
							Northing	Easting						Top	Bottom	Top	Bottom	
Gas Works Park Property																		
MW-1	--	11/1/1986	Abandoned	Tetra Tech	2	0.01	240139.00	1270317.00	84.9	84.5	NA	NA	NA	24.8	34.8	60.1	50.1	NA
MW-2	--	11/1/1986	Abandoned	Tetra Tech	2	0.01	239458.89	1269802.87	38.8	43.0	NA	NA	NA	3.9	13.9	34.9	24.9	NA
MW-03	--	10/31/1986	Existing	Tetra Tech	2	0.01	239453.87	1270268.61	38.7	38.6	38.23	-0.47	9.37	1.6	10.6	37.1	28.1	Qpgt
MW-03D	--	11/1/1986	Existing	Tetra Tech	2	0.01	239459.30	1270280.30	38.9	38.9	38.42	-0.54	57.33	54.6	57.6	-15.7	-18.7	Qpgt
MW-05	--	10/28/1986	Abandoned	Tetra Tech	2	0.01	239238.09	1269873.62	36.0	36.7	NA	NA	NA	8.3	18.3	27.7	17.7	NA
MW-06	--	10/27/1986	Abandoned	Tetra Tech	2	0.01	239338.79	1270433.50	34.0	33.9	NA	NA	NA	1.9	9.9	32.1	24.1	NA
MW-07	--	10/28/1986	Abandoned	Tetra Tech	2	0.01	239173.73	1270144.37	36.1	39.3	NA	NA	NA	7.1	17.1	29.0	19.0	NA
MW-08	--	10/27/1986	Abandoned	Tetra Tech	2	0.01	239210.57	1270332.62	36.7	38.0	NA	NA	NA	9.5	19.5	27.2	17.2	NA
MW-09	--	10/31/1986	Existing	Tetra Tech	2	0.01	239136.41	1270551.13	34.4	34.4	33.97	-0.47	20.49	10.8	20.8	23.6	13.6	Qva
MW-10	--	10/28/1986	Existing	Tetra Tech	2	0.01	238981.71	1270111.92	32.4	33.4 [a]	32.99	-0.49	15.87	5.3	15.3	27.1	17.1	Fill
MW-11	--	10/30/1986	Abandoned	Tetra Tech	2	0.01	238982.48	1270480.37	38.3	37.3	NA	NA	NA	19.9	29.9	18.4	8.4	NA
MW-12	--	10/31/1986	Abandoned	Tetra Tech	2	0.01	238959.79	1270699.25	25.6	28.1	NA	NA	NA	1.3	9.6	24.3	16.0	NA
MW-13	--	10/29/1986	Existing	Tetra Tech	2	0.01	238836.40	1269903.01	32.9	33.1 [a]	32.72	-0.44	17.53	7.3	17.3	25.6	15.6	Fill
MW-14	--	10/29/1986	Existing	Tetra Tech	2	0.01	238794.76	1270187.60	27.2	28.2 [a]	27.53	-0.38	10.25	2.5	9.5	24.7	17.7	Fill
MW-15	--	10/30/1986	Existing	Tetra Tech	2	0.01	238856.87	1270254.85	38.1	38.7 [a]	38.25	-0.46	20.25	9.5	19.5	28.6	18.6	Fill
MW-16	--	10/30/1986	Abandoned	Tetra Tech	2	NA	238807.14	1270616.87	23.4	24.3	NA	NA	NA	2.5	10.5	20.9	12.9	NA
MW-17	--	6/21/1988	Existing	HDR Engineering	2	NA	239089.03	1269811.64	33.1	33.0 [a]	32.66	-0.20	16.94	6.5	16.5	26.6	16.6	Fill
MW-18	--	1989	Existing	HDR Engineering	2	NA	239326.66	1269775.94	38.5	38.5	38.21	-0.31	33.56	NA	NA	NA	NA	NA
MW-19	--	1989	Existing	HDR Engineering	2	NA	239212.12	1269916.33	39.4	NM [b]	39.14	-0.22	29.96	NA	NA	NA	NA	NA
MW-20	--	1989	Abandoned	HDR Engineering	2	NA	239137.59	1270541.87	34.4	34.1	NA	NA	NA	NA	NA	NA	NA	NA
MW-21	--	1989	Abandoned	HDR Engineering	2	NA	238949.04	1270704.12	24.7	27.6	NA	NA	NA	NA	NA	NA	NA	NA
MW-22	--	2/10/1998	Existing	RETEC	2	0.01	238720.78	1270121.67	24.7	25.4 [a]	25.07	-0.44	35.36	24.0	34.0	0.7	-9.3	Qva
MW-23	--	2/11/1998	Existing	RETEC	2	0.01	238717.52	1270189.86	23.8	24.4 [a]	23.92	-0.43	32.15	22.0	32.0	1.8	-8.2	Qpgt
MW-24	--	2/10/1998	Existing	RETEC	2	0.01	238719.09	1270124.82	24.6	25.3 [a]	24.87	-0.49	16.29	5.0	15.0	19.6	9.6	Qvr
MW-25	--	2/11/1998	Existing	RETEC	2	0.01	238713.35	1270191.99	23.7	23.8 [a]	23.39	-0.47	15.71	5.0	15.0	18.7	8.7	Qvr
MW-26	--	9/29/2010	Existing	GeoEngineers	2	0.02	239413.93	1270609.09	32.9	33.6	32.81	-0.51	12.29	9.0	12.6	23.9	20.3	Qpgt
MW-27	--	9/28/2010	Existing	GeoEngineers	2	0.02	239268.09	1270426.02	35.4	35.5	35.26	-0.27	14.27	12.0	15.0	23.4	20.4	Qpgt
MW-28	--	9/29/2010	Existing	GeoEngineers	2	0.02	238800.05	1270457.66	37.6	37.6	37.49	-0.21	27.35	17.0	27.0	20.6	10.6	Qpgt
MW-29	--	9/30/2010	Existing	GeoEngineers	2	0.02	238995.48	1270118.97	31.5	32.8 [a]	32.30	-0.22	24.35	13.0	23.0	18.5	8.5	Qpgt
MW-30	--	9/30/2010	Existing	GeoEngineers	4	0.03	238986.28	1270114.83	31.9	33.3 [a]	32.95	-0.23	23.10	12.0	22.0	19.9	9.9	Qpgt
MW-31	--	10/6/2010	Existing	GeoEngineers	4	0.03	239409.10	1269783.46	41.3	41.4	40.90	-0.45	44.88	35.0	45.5	6.3	-4.2	Qpgt
MW-32S	--	4/12/2013	Existing	GeoEngineers	2	0.01	238864.97	1269847.34	29.8	31.8 [a]	31.12	-0.68	33.40	16.5	31.0	13.3	-1.2	Fill
MW-32D	--	4/12/2013	Existing	GeoEngineers	2	0.02	238868.03	1269843.30	29.9	31.6 [a]	31.35	-0.25	49.10	42.0	47.0	-12.1	-17.1	Qva
MW-33S	--	3/28/2013	Existing	GeoEngineers	2	0.01	238748.97	1270318.67	38.7	39.5 [a]	39.08	-0.42	23.09	13.0	22.0	25.7	16.7	Fill
MW-34S	--	3/27/2013	Existing	GeoEngineers	2	0.01	238734.93	1270501.78	28.4	28.4	28.05	-0.40	9.81	5.0	9.8	23.4	18.6	Fill
MW-35S	--	3/27/2013	Existing	GeoEngineers	2	0.01	238807.89	1270634.86	24.7	24.7	24.15	-0.54	7.01	4.0	6.8	20.7	17.9	Fill
MW-36S	--	3/29/2013	Existing	GeoEngineers	2	0.01	239086.77	1270783.61	30.1	30.1	29.62	-0.51	22.87	8.0	22.8	22.1	7.3	Fill
MW-36D	--	3/28/2013	Existing	GeoEngineers	2	0.02	239091.49	1270785.63	30.0	30.0	29.55	-0.44	33.79	29.3	33.8	0.7	-3.8	Qvr/Qpgt
MW-37S	--	3/26/2013	Existing	GeoEngineers	2	0.01	239231.18	1270816.75	27.1	27.1	26.85	-0.28	14.82	5.1	14.8	22.0	12.3	Fill
MW-38S	--	3/26/2013	Existing	GeoEngineers	2	0.01	239318.10	1270820.88	25.9	25.9	25.42	-0.52	16.84	7.1	16.6	18.8	9.3	Fill
MW-39S	--	3/25/2013	Existing	GeoEngineers	2	0.01	239397.29	1270814.09	26.9	26.9	26.61	-0.28	14.04	3.9	14.1	23.0	12.8	Fill
MW-39D	--	3/25/2013	Existing	GeoEngineers	2	0.02	239391.05	1270814.56	27.0	27.0	26.74	-0.26	22.47	17.0	21.8	10.0	5.2	Qva/Qpgt
MW-40S	--	4/1/2013	Existing	GeoEngineers	2	0.01	239491.03	1270790.39	25.7	25.7	25.18	-0.51	10.92	4.0	10.9	21.7	14.8	Fill
MW-41S	--	3/28/2017	Existing	GeoEngineers	2	0.01	239123.85	1270626.07	32.9 [h]	32.8	32.92	-0.60	11.10	5.5	10.5	27.4	22.4	Fill
MW-41D	--	3/28/2017	Existing	GeoEngineers	2	0.01	239126.07	1270628.03	32.8 [h]	32.8	32.45	-0.31	29.18	18.8	28.8	14.0	4.0	Qvr/Qpgd
MW-42S	--	3/27/2017	Existing	GeoEngineers	2	0.01	239153.02	1270667.56	30.1 [h]	33.2	32.72	-0.43	11.98	8.8	13.8	21.3	16.3	Fill
MW-43S	--	4/12/2017	Existing	GeoEngineers	2	0.01	239087.49	1270677.38	32.6	32.7	32.28	-0.42	13.14	7.8	12.8	24.8	19.8	Fill
MW-44S	--	4/14/2017	Existing	GeoEngineers	2	0.01	239159.31	1270720.72	33.1 [h]	34.1	33.61	-0.52	17.31	7.4	17.4	26.7	16.7	Fill
MW-45S	--	3/31/2017	Existing	GeoEngineers	2	0.01	239142.50	1270725.64	33.7 [h]	34.1	33.75	-0.06	16.79	6.8	16.8	27.2	17.2	Fill
MW-45D	--	3/31/2017	Existing	GeoEngineers	2	0.01	239138.49	1270727.34	32.6 [h]	34.0	33.40	-0.80	30.32	25.6	30.6	8.5	3.5	Qva
MW-46S	--	4/13/2017	Existing	GeoEngineers	2	0.01	239143.44	1270760.23	28.1	28.7	28.10	-0.56	17.62	7.5	17.5	21.2	11.2	Fill
MW-46D	--	4/13/2017	Existing	GeoEngineers	2	0.01	239148.59	1270760.61	28.2	28.7	28.18	-0.47	29.72	24.5	29.5	4.1	-0.9	Qvr

Well ID	Screen ID	Installation Date	Status	Installed By	Diameter (inches)	Screen Slot Size (inches)	Well Location		Ground Surface Elevation at Time of Installation	Current Ground Surface Elevation	Current TOC Elevation	Stickup (feet)	Current Total Depth (feet, TOC)[e]	Screen Interval Depth at Time of Installation (feet, bgs)		Screen Interval Elevation		Geologic Unit of Screen Interval[d]
							Northing	Easting						Top	Bottom	Top	Bottom	
MW-47S	--	4/4/2017	Existing	GeoEngineers	2	0.01	239111.94	1270743.90	33.8 [h]	33.8	33.21	-0.70	19.78	14.8	19.8	18.9	13.9	Fill
MW-48D	--	4/24/2017	Existing	GeoEngineers	2	0.01	239081.86	1270756.15	30.5	30.5	30.05	-0.47	32.78	22.5	32.5	8.0	-2.0	Qvr/Qva
MW-49D	--	4/18/2017	Existing	GeoEngineers	2	0.01	239063.29	1270775.15	30.0	30.0	29.40	-0.60	34.60	24.6	34.6	5.4	-4.6	Qvr/Qva/Qpgd
MW-50D	--	4/17/2017	Existing	GeoEngineers	2	0.01	239117.04	1270793.29	28.8	28.8	28.31	-0.46	34.70	29.6	34.6	-0.8	-5.8	Qvr/Qpgt
MW-51S	--	4/14/2017	Existing	GeoEngineers	2	0.01	239136.65	1270795.79	29.0	29.0	28.62	-0.37	17.15	6.9	16.9	22.1	12.1	Fill
MW-52D	--	4/14/2017	Existing	GeoEngineers	2	0.01	239147.84	1270796.96	29.0	29.0	28.56	-0.45	34.78	29.8	34.8	-0.8	-5.8	Qva
OBS-1	--	7/13/2000	Existing	ThermoRetec	2	0.01	238945.55	1270752.38	23.1	23.1	23.59	0.39	12.89	2.0	11.7	21.1	11.4	Fill
OBS-2	--	7/13/2000	Existing	ThermoRetec	2	0.01	238962.08	1270739.25	22.9	26.5 [f]	26.21	-0.32	15.28	2.0	11.7	20.9	11.2	Qpgt
OBS-3	--	7/13/2000	Existing	ThermoRetec	2	0.01	238984.23	1270677.56	25.4	29.6 [f]	29.39	-0.27	15.96	2.0	11.7	23.4	13.7	Fill
PZ-02	--	12/4/1997	Abandoned	RETEC	1	0.01	239268.75	1269769.75	34.4	35.2	NA	NA	NA	5.0	20.0	29.4	14.4	Fill
PZ-03	--	12/4/1997	Existing	RETEC	1	0.01	239231.84	1269811.44	34.8	34.8	34.52	-0.23	16.10	5.0	20.0	29.8	14.8	Qvr
PZ-09	--	3/30/1998	Existing	RETEC	2	0.01	239321.50	1269844.17	36.8	39.3	38.81	-0.52	24.49	12.5	22.5	24.3	14.3	Qvr
PZ-10	--	3/30/1998	Existing	RETEC	2	0.01	239315.32	1269814.40	37.0	38.8	38.48	-0.27	24.08	12.5	22.5	24.5	14.5	Qvr
RW-01	--	3/30/1998	Existing	RETEC	4	0.01	239316.79	1269857.10	36.9	39.6	39.02	-0.29	24.43	12.5	22.5	24.4	14.4	Qvr
TDW-2	--	9/29/2006	Existing	Floyd|Snider	2	0.02	238940.13	1269754.92	24.7	25.5 [a]	25.11	-0.32	40.61	34.5	39.5	-9.8	-14.8	Qva
TDW-3	--	9/27/2006	Existing	Floyd|Snider	2	0.02	238769.63	1269998.31	26.6	26.6 [a]	26.43 [c]	-0.21	39.25	34.5	39.5	-7.9	-12.9	Qva
TSW-2	--	10/2/2006	Existing	Floyd|Snider	2	0.02	238955.15	1269762.68	27.3	28.4 [a]	28.14	-0.30	13.27	7.0	12.0	20.3	15.3	Fill
TSW-3	--	9/27/2006	Existing	Floyd|Snider	2	0.02	238775.70	1270000.34	27.3	28.3 [a]	27.82	-0.33	12.40	6.0	11.0	21.3	16.3	Fill
Harbor Patrol Property																		
CMP-01	--	7/13/2000	Existing	ThermoRetec	2	0.01	239054.53	1269720.27	25.2	25.2	24.97	NA	21.38	6.5	21.5	18.7	3.7	Fill
DW-04	--	2/6/1998	Existing	RETEC	2	0.01	239158.93	1269735.89	25.9	25.9	25.33	-0.53	36.98	32.0	37.0	-6.1	-11.1	Qpgt
DW-05	--	2/9/1998	Existing	RETEC	2	0.01	239140.99	1269717.99	25.4	25.5	25.12	-0.34	29.35	24.0	29.0	1.4	-3.6	Qva
DW-06	--	2/9/1998	Abandoned	RETEC	2	0.01	239094.76	1269675.28	25.0	25.0	NA	NA	NA	37.0	42.0	-12.0	-17.0	Qva
DW-07	--		Existing	RETEC	2	0.01	239054.93	1269725.88	25.4	25.4	24.99	-0.12	42.29	37.5	42.5	-12.2	-17.2	Qva
PZ-01	--	12/4/1997	Existing	RETEC	1	0.01	239204.23	1269608.57	25.6	25.7	25.09	-0.51	11.50	3.0	13.0	22.6	12.6	Qvr
PZ-04	--	12/5/1997	Abandoned	RETEC	1	0.01	239168.70	1269792.11	33.7	NA	NA	NA	NA	10.0	30.0	23.7	3.7	Qvr/Qva
PZ-05	--	12/5/1997	Existing	RETEC	1	0.01	239013.35	1269781.45	27.7	28.1	27.83	NA	15.10	3.0	18.0	24.7	9.7	Fill
PZ-06	--	12/8/1997	Existing	RETEC	1	0.01	239074.20	1269763.95	27.2	27.7	27.13	NA	13.10	5.0	20.0	22.2	7.2	Fill
PZ-07	--	12/8/1997	Abandoned	RETEC	1	0.01	239073.39	1269709.62	24.53	NA	NA	NA	NA	5.0	20.0	19.5	4.5	Fill
PZ-08	--	12/8/1997	Existing	RETEC	1	0.01	239156.57	1269714.94	25.7	25.7	25.30	-0.36	14.70	5.0	20.0	20.7	5.7	Qvr
TDW-1	--	9/21/2006	Existing	Floyd|Snider	2	0.02	239244.68	1269573.53	24.8	24.9	24.57	-0.30	42.22	37.5	42.5	-12.7	-17.7	Qva
TSW-1	--	9/21/2006	Existing	Floyd|Snider	2	0.02	239252.03	1269586.36	25.6	25.7	25.40	-0.32	9.71 [g]	5.3	10.3	20.4	15.4	Fill
MLS-1	MLS-1-1	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239314.45	1269886.39	36.8	40.2	39.88	-0.37	NM	21.3	22.3	15.5	14.5	Qpgt
MLS-1	MLS-1-2	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239314.45	1269886.39	36.8	40.2	39.88	-0.37	NM	16.8	17.8	20.0	19.0	Qvr
MLS-1	MLS-1-3	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239314.45	1269886.39	36.8	40.2	39.88	-0.37	NM	12.3	13.3	24.5	23.5	Qvr
MLS-2	MLS-2-1	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239231.82	1269817.79	34.2	34.9	34.29	-0.34	NM	23.0	24.0	11.2	10.2	Qva
MLS-2	MLS-2-2	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239231.82	1269817.79	34.2	34.9	34.29	-0.34	NM	18.5	19.5	15.7	14.7	Qva
MLS-2	MLS-2-3	1998	Existing	RETEC	1/4-in tubing in 1-in casing	NA	239231.82	1269817.79	34.2	34.9	34.29	-0.34	NM	14.0	15.0	20.2	19.2	Qvr
MLS-3	MLS-3-1	1998	Abandoned	RETEC	1/4-in tubing in 1-in casing	NA	239192.51	1269778.12	33.6	33.7	NA	NA	NM	26.3	27.3	7.3	6.3	Qva
MLS-3	MLS-3-2	1998	Abandoned	RETEC	1/4-in tubing in 1-in casing	NA	239192.51	1269778.12	33.6	33.7	NA	NA	NM	21.8	22.8	11.8	10.8	Qva
MLS-3	MLS-3-3	1998	Abandoned	RETEC	1/4-in tubing in 1-in casing	NA	239192.51	1269778.12	33.6	33.7	NA	NA	NM	17.3	18.3	16.3	15.3	Qvr
MLS-3	MLS-3-4	1998	Abandoned	RETEC	1/4-in tubing in 1-in casing	NA	239192.51	1269778.12	33.6	33.7	NA	NA	NM	12.8	13.5	20.8	20.1	Qvr
MLS-3	MLS-3-5	1998	Abandoned	RETEC	1/4-in tubing in 1-in casing	NA	239192.51	1269778.12	33.6	33.7	NA	NA	NM	8.3	9.3	25.3	24.3	Fill
MLS-4	MLS-4-1	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239160.91	1269733.44	25.3	25.8	25.30	-0.33	NM	23.0	24.0	2.3	1.3	Qva
MLS-4	MLS-4-2	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239160.91	1269733.44	25.3	25.8	25.30	-0.33	NM	18.5	19.5	6.8	5.8	Qva
MLS-4	MLS-4-3	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239160.91	1269733.44	25.3	25.8	25.30	-0.33	NM	14.0	15.0	11.3	10.3	Qva
MLS-4	MLS-4-4	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239160.91	1269733.44	25.3	25.8	25.30	-0.33	NM	9.5	10.5	15.8	14.8	Qvr
MLS-4	MLS-4-5	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239160.91	1269733.44	25.3	25.8	25.30	-0.33	NM	5.0	6.0	20.3	19.3	Fill
MLS-5	MLS-5-1	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239142.99	1269720.17	25.1	25.4	24.84	-0.23	NM	24.0	25.0	1.1	0.1	Qva
MLS-5	MLS-5-2	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239142.99	1269720.17	25.1	25.4	24.84	-0.23	NM	19.5	20.5	5.6	4.6	Qva
MLS-5	MLS-5-3	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239142.99	1269720.17	25.1	25.4	24.84	-0.23	NM	15.0	16.0	10.1	9.1	Qvr
MLS-5	MLS-5-4	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239142.99	1269720.17	25.1	25.4	24.84	-0.23	NM	10.5	11.5	14.6	13.6	Qvr
MLS-5	MLS-5-5	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239142.99	1269720.17	25.1	25.4	24.84	-0.23	NM	6.0	7.0	19.1	18.1	Fill
MLS-6	MLS-6-1	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239097.37	1269672.36	24.6	25.1	24.76	-0.32	NM	24.0	25.0	0.6	-0.4	Qva
MLS-6	MLS-6-2	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239097.37	1269672.36	24.6	25.1	24.76	-0.32	NM	19.5	20.5	5.1	4.1	Qvr
MLS-6	MLS-6-3	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239097.37	1269672.36	24.6	25.1	24.76	-0.32	NM	15.0	16.0	9.6	8.6	Fill
MLS-6	MLS-6-4	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239097.37	1269672.36	24.6	25.1	24.76	-0.32	NM	10.5	11.5	14.1	13.1	Fill
MLS-6	MLS-6-5	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239097.37	1269672.36	24.6	25.1	24.76	-0.32	NM	6.0	7.0	18.6	17.6	Fill

Well ID	Screen ID	Installation Date	Status	Installed By	Diameter (inches)	Screen Slot Size (inches)	Well Location		Ground Surface Elevation at Time of Installation	Current Ground Surface Elevation	Current TOC Elevation	Stickup (feet)	Current Total Depth (feet, TOC)[e]	Screen Interval Depth at Time of Installation (feet, bgs)		Screen Interval Elevation		Geologic Unit of Screen Interval[d]
							Northing	Easting						Top	Bottom	Top	Bottom	
MLS-7	MLS-7-1	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239057.30	1269723.35	24.9	25.2	24.91	-0.29	NM	24.0	25.0	0.9	-0.1	Qva
MLS-7	MLS-7-2	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239057.30	1269723.35	24.9	25.2	24.91	-0.29	NM	19.5	20.5	5.4	4.4	Qvr
MLS-7	MLS-7-3	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239057.30	1269723.35	24.9	25.2	24.91	-0.29	NM	15.0	16.0	9.9	8.9	Fill
MLS-7	MLS-7-4	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239057.30	1269723.35	24.9	25.2	24.91	-0.29	NM	10.5	11.5	14.4	13.4	Fill
MLS-7	MLS-7-5	1998	Existing	RETEC	1/4-in tubing in 2-in casing	NA	239057.30	1269723.35	24.9	25.2	24.91	-0.29	NM	6.0	7.0	18.9	17.9	Fill
(In/Next to Roads) Near Metro Property																		
MW-09	--	8/13/1993	Existing	Applied Geotechnology, Inc.	NA	NA	239766.62	1269387.59	27.3	NA	39.71	-0.40	NA	11.9	21.9	15.4	5.4	Qva
MW-11	--	8/17/1993	Existing	Applied Geotechnology, Inc.	NA	NA	239704.88	1269430.62	23.9	NA	36.54	-0.40	NA	6.0	15.5	17.9	8.4	NA
MW-13	--	8/18/1993	Abandoned	Applied Geotechnology, Inc.	NA	NA	239756.78	1269680.00	38.2	NA	NA	NA	NA	13.3	22.7	24.9	15.5	Qpgt
MW-14	--	10/11/1993	Existing	Applied Geotechnology, Inc.	NA	NA	239437.60	1269562.11	22.2	NA	34.86	-0.40	NA	9.2	18.6	13.0	3.6	Fill
MW-15	--	10/12/1993	Existing	Applied Geotechnology, Inc.	NA	NA	239503.14	1269498.67	22.1	NA	34.85	-0.40	NA	9.4	18.8	12.7	3.3	Fill
MW-16	--	10/15/1993	Abandoned	Applied Geotechnology, Inc.	NA	NA	239808.83	1269655.61	43.9	NA	NA	NA	NA	9.5	24.1	34.4	19.8	Qpgt
MW-17	--	10/14/1993	Abandoned	Applied Geotechnology, Inc.	NA	NA	NA	NA	24.2	NA	NA	NA	NA	8.7	23	15.5	1.2	Qpgt
MW-19	--	1997	Existing	PEG	NA	NA	239720.96	1269252.54	34.5	34.5	34.12	-0.40	NA	9.0	19.0	25.5	15.5	Fill
MW-20	--	1997	Existing	PEG	NA	NA	239650.93	1269334.42	35.1	35.1	34.74	-0.40	NA	13.0	23.0	22.1	12.1	NA
MW-21	--	1997	Existing	PEG	NA	NA	239539.16	1269546.48	34.9	34.9	34.51	-0.40	NA	5.0	23.0	29.9	11.9	Fill
MW-22	--	1997	Existing	PEG	NA	NA	239628.93	1269404.56	36.2	36.2	35.93	-0.28	NA	5.0	23.0	31.2	13.2	Fill

Notes:

Horizontal Datum: NAD83 WA State Plane North

Vertical Datum: US Army Corps of Engineers

bgs = below ground surface

NA = not available. Unable to verify.

NM = not measured

TOC = top of casing

Qvr: Vashon Recessional Outwash

Qva: Vashon Advance Outwash

Qpgd: Pre-Fraser Diamict

Qpgt: Pre-Fraser Till

[a] Ground surface elevation and well casings modified during Kite Hill maintenance project. See Table 3J-2.

[b] Ground surface elevation was 39.3 ft before Kite Hill construction.

[c] TDW-3 casing was trimmed on 2/1/18, prior TOC elevation was 26.46.

[d] Some screen intervals cross more than one geologic unit. Units listed here are the same as those assigned by Aspect in their groundwater modeling report, with the exception of MW-9, which was formerly interpreted as being screened across Qpgt (Aspect Consulting et al. 2012).

[e] Current total depth measured during field wide gauge event on 11/12/19.

[f] Well casings and ground surface for OBS-2 and OBS-3 were extended during the 2000-2001 cleanup (AS/SVE liner installation).

[g] Total depth of well measurement for TSW-1 is from November 5, 2018. This location was not accessible on November 12, 2019.

[h] Ground surface elevation during well installation was not measured and is considered an estimate.

Table 3J-2

Groundwater Level and NAPL Thickness Measurements in Monitoring Wells

Gas Works Park Site

Seattle, Washington

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
CMP-01	7/25/2001	24.89		3.30						21.59	
CMP-01	10/25/2001	24.89		4.31						20.58	
CMP-01	1/22/2002	24.89		4.31						20.58	
CMP-01	4/26/2002	24.89		3.17						21.72	
CMP-01	7/26/2002	24.89		3.41						21.48	
CMP-01	10/17/2002	24.89		4.46						20.43	
CMP-01	1/13/2003	24.89		4.79						20.10	
CMP-01	4/25/2003	24.89		3.09						21.80	
CMP-01	7/29/2003	24.89		3.80						21.09	
CMP-01	10/31/2003	24.89		4.40						20.49	
CMP-01	1/26/2004	24.89		4.79						20.10	
CMP-01	4/27/2004	24.89		2.88						22.01	
CMP-01	7/20/2004	24.89		3.63						21.26	
CMP-01	10/21/2004	24.89		4.28						20.61	
CMP-01	4/20/2005	24.89		3.03						21.86	
CMP-01	7/21/2005	24.89		3.44						21.45	
CMP-01	1/19/2006	24.89		4.76						20.13	
CMP-01	4/6/2006	24.89		3.42						21.47	
CMP-01	7/11/2006	24.89		3.40						21.49	
CMP-01	10/26/2006	24.89		4.24						20.65	
CMP-01	7/14/2007	24.89		3.43						21.47	
CMP-01	2/28/2008	24.89		4.35						20.54	
CMP-01	1/15/2009	24.89		4.70						20.19	
CMP-01	6/18/2010	24.83		3.01						21.82	
CMP-01	7/1/2010	24.83		2.98						21.85	
CMP-01	9/23/2010	24.83		3.95						20.88	
CMP-01	12/6/2010	24.83		4.79						20.04	
CMP-01	1/25/2011	24.83		4.11						20.72	
CMP-01	3/23/2011	24.83		3.68						21.15	
CMP-01	5/4/2011	24.83		2.95						21.88	
CMP-01	2/27/2013	24.97		4.32		21.70				20.65	
CMP-01	4/16/2013	24.97		3.19						21.78	
CMP-01	4/22/2013	24.97		3.19						21.78	
CMP-01	10/14/2013	24.97		4.04						20.93	
CMP-01	4/14/2016	24.97		3.06		21.40				21.91	
CMP-01*	5/13/2016	24.97	2.23	3.06		21.40	0.83		22.74	22.68	
CMP-01	9/18/2017	24.97	Trace	4.65		21.40	Trace			20.32	
CMP-01	11/5/2018	24.97		4.42		21.40				20.55	
CMP-01	11/12/2019	24.97		4.41		21.38				20.56	
CMP-01	12/10/2020	24.97		4.75		21.44				20.22	
DW-04	2/12/1998	25.01		4.50						20.51	
DW-04	3/31/1998	25.01		4.13						20.88	
DW-04	5/19/1998	25.01		3.95						21.06	
DW-04	7/25/2001	25.01		2.93						22.08	
DW-04	10/25/2001	25.01		3.80				0.27		21.21	
DW-04	1/22/2002	25.01		4.20				3.00		20.81	
DW-04	4/26/2002	25.01		2.91				4.50		22.10	
DW-04	7/26/2002	25.01		2.93				4.00		22.08	
DW-04	10/17/2002	25.01		4.51				0.33		20.50	
DW-04	1/13/2003	25.01		4.64				3.08		20.37	
DW-04	4/25/2003	25.01		3.23				4.42		21.78	
DW-04	7/29/2003	25.01		3.03				5.25		21.98	
DW-04	10/31/2003	25.01		3.65				4.08		21.36	
DW-04	1/26/2004	25.01		4.81				3.75		20.20	
DW-04	4/27/2004	25.01		3.75				4.10		21.26	
DW-04	7/20/2004	25.01		3.66				4.13		21.35	
DW-04	10/21/2004	25.01		4.11				3.79		20.90	
DW-04	4/20/2005	25.01		4.06				3.67		20.95	
DW-04	7/21/2005	25.01		3.00				1.58		22.01	
DW-04	1/19/2006	25.01		19.27						see Note 2	
DW-04	4/6/2006	25.01		18.84				1.80		see Note 2	
DW-04	7/11/2006	25.01		18.31				3.10		see Note 2	
DW-04	10/26/2006	25.01		17.99				3.80		see Note 2	
DW-04	7/14/2007	25.01	Trace	16.65			Trace	0.58		see Note 2	
DW-04	2/1/2008	25.01		--				0.58			
DW-04	2/28/2008	25.01		15.65						see Note 2	
DW-04	1/15/2009	25.01	Trace	14.80			Trace	0.75		see Note 2	
DW-04	2/12/2010	25.01	Trace	13.98			Trace	0.68		see Note 2	
DW-04	6/18/2010	25.33		11.03						see Note 2	
DW-04	7/1/2010	25.33		11.01						see Note 2	
DW-04	9/23/2010	25.33		10.93						see Note 2	
DW-04	12/6/2010	25.33		9.43						see Note 2	
DW-04	1/25/2011	25.33		7.79						see Note 2	
DW-04	3/23/2011	25.33		7.58						see Note 2	
DW-04	5/4/2011	25.33		7.08						see Note 2	
DW-04	2/27/2013	25.33		7.21	33.94	37.00		3.06		see Note 2	-8.62
DW-04	4/15/2013	25.33		7.33	34.62	37.02		2.40		see Note 2	-9.30
DW-04	4/22/2013	25.33		16.31	34.87	37.02		2.15		see Note 2	-9.55
DW-04	4/29/2013	25.33		16.11	34.10	37.02		2.92		see Note 2	-8.78
DW-04	10/14/2013	25.33		16.20	35.13	37.02		1.89		see Note 2	-9.81
DW-04	4/14/2016	25.33		9.31	28.77	36.77		8.00		see Note 2	-3.45
DW-04	9/18/2017	25.33	Trace	7.17	28.45	37.08	Trace	8.63		see Note 2	-3.13
DW-04	11/5/2018	25.33		6.46	32.80	37.08		4.28		see Note 2	-7.48
DW-04	11/12/2019	25.33		--	29.18	36.98		7.80			-3.86
DW-04	12/10/2020	25.33		6.37	28.92	37.12		8.20		see Note 2	-3.60
DW-05	2/12/1998	24.84		4.54						20.30	
DW-05	3/31/1998	24.84		3.75						21.09	
DW-05	5/19/1998	24.84		3.37						21.47	
DW-05	7/25/2001	24.84		3.45						21.39	
DW-05	10/25/2001	24.84		4.37				0.23		20.47	
DW-05	1/22/2002	24.84		4.51				2.17		20.33	
DW-05	7/26/2002	24.84		3.51				3.00		21.33	
DW-05	10/17/2002	24.84		4.07				3.17		20.77	
DW-05	1/13/2003	24.84		4.82				3.83		20.02	
DW-05	4/25/2003	24.84		3.00				3.75		21.84	
DW-05	7/29/2003	24.84		3.78				4.58		21.06	
DW-05	10/31/2003	24.84		4.44				3.79		20.40	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
DW-05	1/26/2004	24.84		4.69				3.94		20.15	
DW-05	4/27/2004	24.84		2.98				3.83		21.86	
DW-05	7/20/2004	24.84		3.58				3.67		21.26	
DW-05	10/21/2004	24.84		4.34				3.33		20.50	
DW-05	4/20/2005	24.84		3.08				3.50		21.76	
DW-05	7/21/2005	24.84		3.61	Trace			Trace		21.23	
DW-05	1/19/2006	24.84		4.49						20.35	
DW-05	4/6/2006	24.84		3.71						21.13	
DW-05	7/11/2006	24.84		3.45				0.40		21.39	
DW-05	10/26/2006	24.84		4.32				0.15		20.52	
DW-05	7/1/2007	24.84		--				0.25		--	
DW-05	7/14/2007	24.84		3.50						21.34	
DW-05	2/1/2008	24.84		--				0.17		--	
DW-05	2/28/2008	24.84		4.40						20.44	
DW-05	1/15/2009	24.84		4.60				1.67		20.24	
DW-05	2/12/2010	24.84		4.44				1.50		20.40	
DW-05	6/18/2010	25.10		3.16						21.94	
DW-05	7/1/2010	25.10		3.13						21.97	
DW-05	9/23/2010	25.10		3.51						21.59	
DW-05	12/6/2010	25.10		4.81						20.29	
DW-05	1/25/2011	25.10		4.12						20.98	
DW-05	3/23/2011	25.10		3.81						21.29	
DW-05	5/4/2011	25.10		3.29						21.81	
DW-05	2/27/2013	25.12		4.31	26.70	29.38		2.68		20.81	-1.58
DW-05	4/15/2013	25.12		3.39	25.89	29.29		3.40		21.73	-0.77
DW-05	4/22/2013	25.12		3.21	28.50	29.38		0.88		21.91	-3.38
DW-05	10/14/2013	25.12		4.15	28.88	29.38		0.50		20.97	-3.76
DW-05*	4/14/2016	25.12	3.35	3.36	28.47	29.27	0.01	0.80	21.77	21.77	-3.35
DW-05	9/18/2017	25.12	Trace	4.75	28.88	29.38	Trace	0.50		20.37	-3.76
DW-05	11/5/2018	25.12		4.55	28.50	29.38		0.88		20.57	-3.38
DW-05*	11/12/2019	25.12	4.5	4.51	28.34	29.35	0.01	1.01	20.62	20.62	-3.22
DW-05	12/10/2020	25.12		4.79	28.50	29.07		0.57		20.33	-3.38
DW-06	2/12/1998	24.29		4.01						20.28	
DW-06	3/31/1998	24.29		3.08						21.21	
DW-06	5/19/1998	24.29		2.78						21.51	
DW-06	7/25/2001	24.29		2.78						21.51	
DW-06	10/25/2001	24.29		3.48						20.81	
DW-06	1/22/2002	24.29		3.65						20.64	
DW-06	7/26/2002	24.29		2.96						21.33	
DW-06	10/17/2002	24.29		3.99						20.30	
DW-06	1/13/2003	24.29		4.05						20.24	
DW-06	4/25/2003	24.29		3.45						20.84	
DW-06	7/29/2003	24.29		3.35						20.94	
DW-06	10/31/2003	24.29		3.35						20.94	
DW-06	1/26/2004	24.29		4.31						19.98	
DW-06	4/27/2004	24.29		2.53						21.76	
DW-06	7/20/2004	24.29		3.28						21.01	
DW-06	10/21/2004	24.29		3.42						20.87	
DW-06	4/20/2005	24.29		3.24						21.05	
DW-06	7/21/2005	24.29		3.35						20.94	
DW-06	1/19/2006	24.29		3.30						20.99	
DW-06	4/6/2006	24.29		3.14						21.15	
DW-06	7/11/2006	24.29		2.99						21.30	
DW-06	10/26/2006	24.29		3.92						20.37	
DW-06	7/14/2007	24.29		3.08						21.22	
DW-06	2/28/2008	24.29		3.70						20.59	
DW-06	1/15/2009	24.29		3.45						20.84	
DW-06	6/18/2010	24.54		3.07						21.47	
DW-06	7/1/2010	24.54		2.94						21.60	
DW-06	9/23/2010	24.54		3.57						20.97	
DW-06	12/6/2010	24.54		3.91						20.63	
DW-06	1/25/2011	24.54		3.74						20.80	
DW-06	3/23/2011	24.54		3.56						20.98	
DW-06	5/4/2011	24.54		3.00						21.54	
DW-06	2/27/2013	24.67		3.86		9.28				20.81	
DW-06	4/16/2013	24.67		3.40						21.27	
DW-06	4/22/2013	24.67		2.83						21.84	
DW-06	10/14/2013	24.67		3.62						21.05	
DW-06	4/14/2016	24.67		3.04		9.28				21.63	
DW-07	2/12/1998	24.71		4.42						20.29	
DW-07	2/18/1998	24.71		4.38						20.33	
DW-07	3/31/1998	24.71		3.47						21.24	
DW-07	5/19/1998	24.71		3.15						21.56	
DW-07	10/4/2006	24.71		4.45						20.26	
DW-07	6/18/2010	25.23		2.99						22.24	
DW-07	7/1/2010	25.23		2.96						22.27	
DW-07	9/23/2010	25.23		3.93						21.30	
DW-07	12/6/2010	25.23		4.73						20.50	
DW-07	1/25/2011	25.23		4.04						21.19	
DW-07	3/23/2011	25.23		3.61						21.62	
DW-07	5/4/2011	25.23		2.93						22.30	
DW-07	2/27/2013	24.99		4.30	40.36	42.50		2.14		20.69	-15.38
DW-07	4/15/2013	24.99		3.15	40.11	42.30		2.19		21.84	-15.13
DW-07	4/22/2013	24.99		3.18	41.96	42.30		0.34		21.81	-16.98
DW-07	10/14/2013	24.99		4.08	41.90	42.30		0.40		20.91	-16.92
DW-07*	4/14/2016	24.99	3.24	3.25	41.46	42.26	0.01	0.80	21.75	21.74	-16.48
DW-07	9/18/2017	24.99	Trace	4.67	41.68	42.30	Trace	0.62		20.32	-16.70
DW-07	11/5/2018	24.99		4.45	41.70	42.30		0.60		20.54	-16.72
DW-07	11/12/2019	24.99		4.45	41.50	42.29		0.79		20.54	-16.52
DW-07	12/10/2020	24.99		4.76	42.10	42.68		0.58		20.23	-17.12
MW-2	12/18/1986	38.49		10.76						27.73	
MW-2	4/1/1987	38.49		9.80						28.69	
MW-2	6/1/1988	38.49		10.21						28.28	
MW-03	12/18/1986	38.46		4.98						33.48	
MW-03	4/1/1987	38.46		4.95						33.51	
MW-03	6/1/1988	38.46		5.45						33.01	
MW-03	5/1/1996	38.46		4.93						33.53	
MW-03	8/26/1997	38.46		6.26						32.20	
MW-03	7/25/2001	38.46		14.07						24.39	
MW-03	1/22/2002	38.46		4.66						33.80	
MW-03	4/26/2002	38.46		4.99						33.47	
MW-03	7/26/2002	38.46		6.61						31.85	
MW-03	10/17/2002	38.46		9.06						29.40	
MW-03	1/13/2003	38.46		4.99						33.47	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-03	4/25/2003	38.46		4.87						33.59	
MW-03	7/29/2003	38.46		7.23						31.23	
MW-03	10/31/2003	38.46		5.67						32.79	
MW-03	1/26/2004	38.46		4.73						33.73	
MW-03	4/27/2004	38.46		5.04						33.42	
MW-03	7/20/2004	38.46		6.61						31.85	
MW-03	10/21/2004	38.46		7.49						30.97	
MW-03	4/20/2005	38.46		5.02						33.44	
MW-03	7/21/2005	38.46		8.08						30.38	
MW-03	4/6/2006	38.46		5.15						33.31	
MW-03	7/11/2006	38.46		6.81						31.65	
MW-03	10/26/2006	38.46		8.35						30.11	
MW-03	7/14/2007	38.46		7.33						31.14	
MW-03	2/28/2008	38.46		4.95						33.51	
MW-03	1/15/2009	38.46		5.10						33.36	
MW-03	2/12/2010	38.46	see Note 1	4.93		9.47	see Note 1			33.53	
MW-03	6/18/2010	38.22		5.16						33.06	
MW-03	7/1/2010	38.22		5.49						32.73	
MW-03	9/23/2010	38.22		7.27						30.95	
MW-03	12/6/2010	38.22		5.25						32.97	
MW-03	1/25/2011	38.22		4.69						33.53	
MW-03	3/23/2011	38.22		4.73						33.49	
MW-03	5/4/2011	38.22		5.06						33.16	
MW-03	2/27/2013	38.23		8.17		9.47				30.06	
MW-03	4/19/2013	38.23		4.84		9.60				33.39	
MW-03	4/22/2013	38.23		4.81		9.47				33.42	
MW-03	10/14/2013	38.23		7.05		9.41				31.18	
MW-03	4/14/2016	38.23		5.19		9.50				33.04	
MW-03	9/18/2017	38.23		8.98		9.39				29.25	
MW-03	11/5/2018	38.23		8.65		9.34				29.58	
MW-03	11/12/2019	38.23		7.68		9.37				30.55	
MW-03	12/10/2020	38.23		5.42		9.39				32.81	
MW-03D	12/18/1986	38.59		15.85						22.74	
MW-03D	4/1/1987	38.59		13.81						24.78	
MW-03D	6/1/1988	38.59		13.79						24.80	
MW-03D	5/1/1996	38.59		13.50						25.09	
MW-03D	8/26/1997	38.59		14.04						24.55	
MW-03D	6/18/2010	38.39		13.38						25.01	
MW-03D	7/1/2010	38.39		13.47						24.92	
MW-03D	9/23/2010	38.39		14.55						23.84	
MW-03D	12/6/2010	38.39		16.43						21.96	
MW-03D	1/25/2011	38.39		15.58						22.81	
MW-03D	3/23/2011	38.39		14.62						23.77	
MW-03D	5/4/2011	38.39		13.98						24.41	
MW-03D	2/27/2013	38.42		13.95		57.45				24.47	
MW-03D	4/19/2013	38.42		14.25						24.17	
MW-03D	4/22/2013	38.42		14.29						24.13	
MW-03D	10/14/2013	38.42		15.19						23.23	
MW-03D	4/14/2016	38.42		14.96		57.42				23.46	
MW-03D	9/18/2017	38.42		15.51		57.85				22.91	
MW-03D	11/5/2018	38.42		15.20		57.39				23.22	
MW-03D	11/12/2019	38.42		14.92		57.33				23.50	
MW-03D	12/20/2020	38.42		15.45		57.34				22.97	
MW-05	12/18/1986	35.55		12.99						22.56	
MW-05	4/1/1987	35.55		12.34						23.21	
MW-05	6/1/1988	35.55		12.23						23.32	
MW-05	5/1/1996	35.55		11.13						24.42	
MW-05	8/26/1997	35.55		13.32				0.20		22.23	
MW-06	12/18/1986	33.56		2.10						31.46	
MW-06	4/1/1987	33.56		1.60						31.96	
MW-06	6/1/1988	33.56		2.43						31.13	
MW-06	5/1/1996	33.56		1.62						31.94	
MW-06	8/26/1997	33.56		2.81						30.75	
MW-07	12/1/1986	35.67		10.13						25.54	
MW-07	4/1/1987	35.67		9.60						26.07	
MW-07	6/1/1988	35.67		10.01						25.66	
MW-07	5/1/1996	35.67		9.27						26.40	
MW-07*	8/26/1997	35.67	11.60	11.61			0.01		24.07	24.07	
MW-07	2/12/1998	35.68		8.53						27.15	
MW-07	3/31/1998	35.68		9.09						26.59	
MW-07	5/19/1998	35.68		10.58						25.10	
MW-08	12/18/1986	36.17		8.05						28.12	
MW-08	4/1/1987	36.17		7.96						28.21	
MW-08	6/1/1988	36.17		7.97						28.20	
MW-08	5/1/1996	36.17		6.52						29.65	
MW-08	8/26/1997	36.17		9.99						26.18	
MW-09	12/1/1986	34.11		8.63						25.48	
MW-09	4/1/1987	34.11		7.74						26.37	
MW-09	6/1/1988	34.11		8.30						25.81	
MW-09	5/1/1996	34.11		6.70						27.41	
MW-09*	8/26/1997	34.11	9.41	11.90			2.49	5.25	24.70	24.50	
MW-09	1/22/2002	33.98		11.05						22.93	
MW-09	4/26/2002	33.98		Dry		20.52				--	
MW-09*	1/13/2003	33.98	7.40	10.10		20.52	2.70		26.58	26.37	
MW-09*	4/25/2003	33.98	7.70	10.92		20.52	3.22		26.28	26.03	
MW-09*	7/29/2003	33.98	8.69	11.65		20.52	2.96		25.29	25.06	
MW-09*	10/31/2003	33.98	7.52	9.13		20.52	1.61		26.46	26.33	
MW-09*	1/26/2004	33.98	7.01	9.91		20.52	2.90		26.97	26.74	
MW-09*	4/27/2004	33.98	8.02	11.05		20.52	3.03		25.96	25.72	
MW-09*	7/20/2004	33.98	9.69	10.99		20.52	1.30		24.29	24.19	
MW-09*	10/21/2004	33.98	8.65	10.03		20.52	1.38		25.33	25.22	
MW-09*	4/20/2005	33.98	7.40	10.40		20.52	3.00		26.58	26.34	
MW-09*	7/21/2005	33.98	7.95	9.09		20.52	1.14		26.03	25.94	
MW-09*	4/6/2006	33.98	8.65	10.50		20.52	1.85		25.33	25.18	
MW-09*	7/11/2006	33.98	10.07	11.57		20.52	1.50		23.91	23.79	
MW-09*	10/26/2006	33.98	10.46	11.76		20.52	1.30		23.52	23.42	
MW-09*	7/14/2007	33.98	9.45	11.03		20.52	1.58		24.53	24.41	
MW-09	2/28/2008	33.98		7.63						26.36	
MW-09	1/15/2009	33.98		7.23						26.76	
MW-09*	2/12/2010	33.98	6.67	8.30		20.52	1.63		27.31	27.18	
MW-09**	6/18/2010	33.88	7.91	10.97			3.06		25.97	25.73	
MW-09**	5/4/2011	33.88		7.42						26.46	
MW-09*	2/27/2013	33.97	8.89	10.50		20.50	1.61		25.08	24.95	
MW-09*	4/15/2013	33.97	6.69	9.83	16.20	20.52	3.14	4.32	27.28	27.03	17.77

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-09*	4/22/2013	33.97	6.43	8.29		20.52	1.86		27.54	27.39	
MW-09*	4/29/2013	33.97	6.52	8.07		20.52	1.55		27.45	27.32	
MW-09*	10/14/2013	33.97	8.95	9.86	18.51	20.52	0.91	2.01	25.02	24.94	15.46
MW-09*	4/14/2016	33.97	7.67	9.09	20.35	20.50	1.42	0.15	26.30	26.18	13.62
MW-09*	9/18/2017	33.97	10.50	11.55	20.45	20.52	1.05	0.07	23.47	23.38	13.52
MW-09*	11/5/2018	33.97	10.68	11.11	19.95	20.52	0.43	0.57	23.29	23.26	14.02
MW-09*	11/12/2019	33.97	9.55	10.32	18.32	20.49	0.77	2.17	24.42	24.36	15.65
MW-09*	12/10/2020	33.97	8.10	10.43		20.50	2.33		25.87	25.68	33.97
MW-10	12/18/1986	32.07		10.18						21.89	
MW-10	4/1/1987	32.07		9.10						22.97	
MW-10	6/1/1988	32.07		9.04						23.03	
MW-10	5/1/1996	31.57		8.47						23.10	
MW-10	8/26/1997	31.57		9.79						21.78	
MW-10	2/12/1998	31.57		9.07						22.50	
MW-10	3/31/1998	31.57		8.83						22.74	
MW-10	5/19/1998	31.57		9.25						22.32	
MW-10	1/22/2002	31.97		9.21						22.76	
MW-10	4/26/2002	31.97		8.91						23.06	
MW-10	7/26/2002	31.97		9.55						22.42	
MW-10	10/17/2002	31.97		10.69						21.28	
MW-10	1/13/2003	31.97		9.42						22.55	
MW-10	4/25/2003	31.97		8.79						23.18	
MW-10	7/29/2003	31.97		8.24						23.73	
MW-10	1/26/2004	31.97		9.48						22.49	
MW-10	4/27/2004	31.97		9.22						22.75	
MW-10	7/20/2004	31.97		9.22						22.75	
MW-10	10/21/2004	31.97		10.14						21.83	
MW-10	4/20/2005	31.97		8.78						23.19	
MW-10	7/21/2005	31.97		9.72						22.25	
MW-10	1/19/2006	31.97		7.51						24.46	
MW-10	4/6/2006	31.97		9.42						22.55	
MW-10	7/11/2006	31.97		9.53						22.44	
MW-10	10/26/2006	31.97		10.68						21.29	
MW-10	7/14/2007	31.97		9.70						22.27	
MW-10	2/28/2008	31.97		9.95						22.02	
MW-10	1/15/2009	31.97		9.25						22.72	
MW-10	6/18/2010	31.93		9.05						22.88	
MW-10	7/1/2010	31.93		9.18						22.75	
MW-10	9/23/2010	31.93		9.84						22.09	
MW-10	12/6/2010	31.93		9.99						21.94	
MW-10	1/25/2011	31.93		8.59						23.34	
MW-10	3/23/2011	31.93		8.10						23.83	
MW-10	5/4/2011	31.93		8.81						23.12	
MW-10	3/1/2013	32.99		9.84		14.91				23.15	
MW-10	4/22/2013	32.99		8.42						24.57	
MW-10	4/23/2013	32.99		8.52						24.47	
MW-10	10/14/2013	32.99		10.10						22.89	
MW-10	4/14/2016	32.99		10.42		23.15				22.57	
MW-10	9/18/2017	32.99		12.18		15.94				20.81	
MW-10	11/5/2018	32.99		12.15		15.90				20.84	
MW-10	11/12/2019	32.99		12.02		15.87				20.97	
MW-10	12/10/2020	32.99		11.93		23.09				21.06	
MW-11	12/18/1986	37.98		12.91						25.07	
MW-11	4/1/1987	37.98		11.90						26.08	
MW-11	6/1/1988	37.98		12.21						25.77	
MW-11	5/1/1996	37.98		10.75						27.23	
MW-11	8/26/1997	37.98		14.71						23.27	
MW-12	12/18/1986	25.13		4.42						20.71	
MW-12	4/1/1987	25.13		3.18						21.95	
MW-12	6/1/1988	25.13		3.04						22.09	
MW-12	5/1/1996	25.13		3.19						21.94	
MW-12	8/26/1997	25.13		3.38						21.75	
MW-13	12/18/1986	32.30		11.81						20.49	
MW-13	4/1/1987	32.30		10.45						21.85	
MW-13	6/1/1988	32.30		10.22						22.08	
MW-13	5/1/1996	32.30		10.37						21.93	
MW-13	8/26/1997	32.30		10.70						21.60	
MW-13	2/12/1998	31.79		11.72						20.07	
MW-13	3/31/1998	31.79		10.62						21.17	
MW-13	5/19/1998	31.79		10.35						21.44	
MW-13	10/4/2006	32.16		11.46						20.70	
MW-13	7/1/2010	32.42		10.18						22.24	
MW-13	9/23/2010	32.42		11.14						21.28	
MW-13	12/6/2010	32.42		11.91						20.51	
MW-13	1/25/2011	32.42		11.31						21.11	
MW-13	3/23/2011	32.42		10.85						21.57	
MW-13	5/4/2011	32.42		10.18						22.24	
MW-13	3/1/2013	32.72		11.49		16.95				21.23	
MW-13	4/22/2013	32.72		10.35						22.37	
MW-13	4/24/2013	32.72		10.37						22.35	
MW-13	10/14/2013	32.72		11.26						21.46	
MW-13	4/14/2016	32.72		11.28		17.58				21.44	
MW-13	9/18/2017	32.72		12.67		17.50				20.05	
MW-13	11/5/2018	32.72		12.45		17.54				20.27	
MW-13	11/12/2019	32.72		12.44		17.53				20.28	
MW-13	12/10/2020	32.72		12.83		17.51				19.89	
MW-14	12/1/1986	26.66		6.32						20.34	
MW-14	4/1/1987	26.66		4.75						21.91	
MW-14	6/1/1988	26.66		4.55						22.11	
MW-14	5/1/1996	26.66		4.71						21.95	
MW-14	8/26/1997	26.66		5.05						21.61	
MW-14	2/12/1998	26.24		5.94						20.30	
MW-14	3/31/1998	26.24		5.01						21.23	
MW-14	5/19/1998	26.24		4.70						21.54	
MW-14	6/18/2010	26.84		4.49						22.35	
MW-14	7/1/2010	26.84		4.52						22.32	
MW-14	9/23/2010	26.84		5.40						21.44	
MW-14	12/6/2010	26.84		6.15						20.69	
MW-14	1/25/2011	26.84		5.33						21.51	
MW-14	3/23/2011	26.84		4.96						21.88	
MW-14	5/4/2011	26.84		4.50						22.34	
MW-14	3/1/2013	27.53		5.46		9.13				22.07	
MW-14	4/22/2013	27.53		4.59						22.94	
MW-14	4/23/2013	27.53		8.00						19.53	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-14	10/14/2013	27.53		5.62						21.91	
MW-14	4/14/2016	27.53		5.94		10.29				21.59	
MW-14	9/18/2017	27.53		7.31		10.25				20.22	
MW-14	11/5/2018	27.53		6.32		10.36				21.21	
MW-14	11/12/2019	27.53		5.56		10.25				21.97	
MW-14	12/10/2020	27.53		5.15		10.23				22.38	
MW-15	12/18/1986	37.52		16.76						20.76	
MW-15	4/1/1987	37.52		15.33						22.19	
MW-15	6/1/1988	37.52		15.16						22.36	
MW-15	5/1/1996	37.52		14.69						22.83	
MW-15	8/26/1997	37.52		16.78						20.74	
MW-15	2/12/1998	37.09		16.14						20.95	
MW-15	3/31/1998	37.09		15.41						21.68	
MW-15	5/19/1998	37.09		15.36						21.73	
MW-15	6/18/2010	37.61		15.06						22.55	
MW-15	7/1/2010	37.61		14.12						23.49	
MW-15	9/23/2010	37.61		16.08						21.53	
MW-15	12/6/2010	37.61		16.62						20.99	
MW-15	1/25/2011	37.61		15.43						22.18	
MW-15	3/23/2011	37.61		14.55						23.06	
MW-15	5/4/2011	37.61		14.96						22.65	
MW-15	3/1/2013	38.25		16.23		19.16				22.02	
MW-15	4/22/2013	38.25		14.90						23.35	
MW-15	4/23/2013	38.25		15.03						23.22	
MW-15	10/14/2013	38.25		16.17						22.08	
MW-15	4/14/2016	38.25		16.43		20.25				21.82	
MW-15	9/18/2017	38.25		18.02		20.26				20.23	
MW-15	11/5/2018	38.25		17.85		20.27				20.40	
MW-15	11/12/2019	38.25		17.81		20.25				20.44	
MW-15	12/10/2020	38.25		17.97		35.33				20.28	
MW-16	12/18/1986	22.90		1.60						21.30	
MW-16	4/1/1987	22.90		0.50						22.40	
MW-16	6/1/1988	22.90		0.36						22.54	
MW-16	5/1/1996	22.90		0.08						22.82	
MW-16	8/26/1997	22.90		1.02						21.88	
MW-17	6/1/1988	33.52		10.86						22.66	
MW-17	5/1/1996	32.57		10.94						21.63	
MW-17	8/26/1997	32.57		11.41						21.16	
MW-17	12/9/1997	32.57		12.69						19.88	
MW-17	12/18/1997	32.57		12.59						19.98	
MW-17	12/23/1997	32.57		12.59						19.98	
MW-17	12/29/1997	32.57		12.62						19.95	
MW-17	1/5/1998	32.57		12.43						20.14	
MW-17	2/12/1998	32.57		12.21						20.36	
MW-17	3/31/1998	32.57		11.32						21.25	
MW-17	5/19/1998	32.57		11.04						21.53	
MW-17	7/25/2001	32.57		11.19						21.38	
MW-17	10/25/2001	32.57		12.18						20.39	
MW-17	1/22/2002	32.57		12.44						20.13	
MW-17	4/26/2002	32.57		10.98						21.59	
MW-17	7/26/2002	32.57		11.28						21.29	
MW-17	10/17/2002	32.57		12.36						20.21	
MW-17	1/13/2003	32.57		12.43						20.14	
MW-17	4/25/2003	32.57		10.94						21.63	
MW-17	7/29/2003	32.57		11.64						20.93	
MW-17	10/31/2003	32.57		12.41						20.16	
MW-17	1/26/2004	32.57		12.45						20.12	
MW-17	4/27/2004	32.57		10.80						21.77	
MW-17	7/20/2004	32.57		11.51						21.06	
MW-17	10/21/2004	32.57		12.15						20.42	
MW-17	4/20/2005	32.57		10.85						21.72	
MW-17	7/21/2005	32.57		11.36						21.21	
MW-17	1/19/2006	32.57		12.00						20.57	
MW-17	4/6/2006	32.57		11.32						21.25	
MW-17	7/11/2006	32.57		11.27						21.30	
MW-17	10/26/2006	32.57		12.16						20.41	
MW-17	7/14/2007	32.57		11.30						21.27	
MW-17	2/28/2008	32.57		12.20						20.37	
MW-17	1/15/2009	32.57		12.35						20.22	
MW-17	6/18/2010	32.87		10.87						22.00	
MW-17	7/1/2010	32.87		10.91						21.96	
MW-17	9/23/2010	32.87		11.87						21.00	
MW-17	12/6/2010	32.87		12.52						20.35	
MW-17	1/25/2011	32.87		11.83						21.04	
MW-17	3/23/2011	32.87		11.31						21.56	
MW-17	5/4/2011	32.87		10.87						22.00	
MW-17	2/27/2013	32.66		12.21		17.22				20.45	
MW-17	4/18/2013	32.66		10.65						22.01	
MW-17	4/22/2013	32.66		10.83						21.83	
MW-17	10/14/2013	32.66		11.78						20.88	
MW-17	4/14/2016	32.66		11.11		16.95				21.55	
MW-17	9/18/2017	32.66		12.45		16.95				20.21	
MW-17	11/5/2018	32.66		12.25		16.95				20.41	
MW-17	11/12/2019	32.66		12.23		16.94				20.43	
MW-17	12/10/2020	32.66		12.00		17.04				20.66	
MW-18	5/1/1996	36.68		13.63						23.05	
MW-18	8/26/1997	36.72		15.25						21.47	
MW-18	12/18/1997	36.72		15.86						20.86	
MW-18	12/23/1997	36.72		15.89						20.83	
MW-18	12/29/1997	36.72		16.02						20.70	
MW-18	1/5/1998	36.72		15.78						20.94	
MW-18	2/12/1998	36.72		15.42						21.30	
MW-18	3/31/1998	36.72		14.76						21.96	
MW-18	5/19/1998	36.72		14.77						21.95	
MW-18	6/18/2010	38.20		16.15						22.05	
MW-18	7/1/2010	38.20		15.95						22.25	
MW-18	9/23/2010	38.20		16.44						21.76	
MW-18	12/6/2010	38.20		16.95						21.25	
MW-18	1/25/2011	38.20		15.96						22.24	
MW-18	3/23/2011	38.20		15.43						22.77	
MW-18	5/4/2011	38.20		15.63						22.57	
MW-18	2/27/2013	38.21		16.41	32.15	33.57		1.42		21.80	6.06
MW-18	4/15/2013	38.21		15.87	33.04	33.59		0.55		22.34	5.17
MW-18	4/22/2013	38.21		15.40	32.51	33.57		1.06		22.81	5.70

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-18	10/14/2013	38.21		16.63	32.25	33.57		1.32		21.58	5.96
MW-18*	4/14/2016	38.21	15.19	15.20	32.35	33.50	0.01	1.15	23.02	23.02	5.86
MW-18	9/18/2017	38.21	Trace	17.43	31.44	33.52	Trace	2.08		20.78	6.77
MW-18*	11/5/2018	38.21	17.33	17.34		33.52	0.01		20.88	20.88	
MW-18*	11/12/2019	38.21	16.7	16.71	30.86	33.56	0.01	2.70	21.51	21.51	7.35
MW-18*	12/10/2020	38.21	17.16	17.17	31.05	33.58	0.01	2.53	21.05	21.04	7.16
MW-19	5/1/1996	36.68		13.63						23.05	
MW-19	8/26/1997	36.68		14.91						21.77	
MW-19	12/9/1997	36.68		15.40						21.28	
MW-19	12/18/1997	36.68		15.18						21.50	
MW-19	12/23/1997	36.68		15.18						21.50	
MW-19	12/29/1997	36.68		15.27						21.41	
MW-19	1/5/1998	36.68		15.16						21.52	
MW-19	2/12/1998	36.68		14.23						22.45	
MW-19	3/31/1998	36.68		14.03						22.65	
MW-19	5/19/1998	36.68		14.39						22.29	
MW-19	7/25/2001	36.68		17.04						19.64	
MW-19	6/18/2010	39.17		16.67						22.50	
MW-19	7/1/2010	39.17		16.69						22.48	
MW-19	9/23/2010	39.17		17.12						22.05	
MW-19	12/6/2010	39.17		17.48						21.69	
MW-19	1/25/2011	39.17		16.18						22.99	
MW-19	3/23/2011	39.17		15.74						23.43	
MW-19	5/4/2011	39.17		16.33						22.84	
MW-19	3/1/2013	39.14		16.43		30.00				22.71	
MW-19	4/18/2013	39.14		16.29						22.85	
MW-19	4/22/2013	39.14		16.06						23.08	
MW-19	10/14/2013	39.14		17.41						21.73	
MW-19	4/14/2016	39.14		16.18		29.98				22.96	
MW-19	9/18/2017	39.14		18.06		29.96				21.08	
MW-19	11/5/2018	39.14		18.09		29.96				21.05	
MW-19	11/12/2019	39.14		17.81		29.96				21.33	
MW-19	12/10/2020	39.14		17.57		29.89				21.57	
MW-20	5/1/1996	34.09		6.97						27.12	
MW-20	8/26/1997	34.09		9.62						24.47	
MW-22	2/12/1998	23.65		3.55						20.10	
MW-22	3/31/1998	23.65		2.52						21.13	
MW-22	5/19/1998	23.65		2.16						21.49	
MW-22	10/4/2006	23.98		3.73						20.25	
MW-22	6/18/2010	24.25		2.00						22.25	
MW-22	7/1/2010	24.25		1.99						22.26	
MW-22	9/23/2010	24.25		2.99						21.26	
MW-22	12/6/2010	24.25		3.82						20.43	
MW-22	1/25/2011	24.25		3.18						21.07	
MW-22	3/23/2011	24.25		2.74						21.51	
MW-22	5/4/2011	24.25		2.00						22.25	
MW-22	3/1/2013	25.07		3.31		34.19				21.76	
MW-22	4/22/2013	25.07		2.21						22.86	
MW-22	4/23/2013	25.07		2.21						22.86	
MW-22	10/14/2013	25.07		3.10						21.97	
MW-22	4/14/2016	25.07		3.56		35.34				21.51	
MW-22	9/18/2017	25.07		4.96		35.61				20.11	
MW-22	11/5/2018	25.07		4.71		35.40				20.36	
MW-22	11/12/2019	25.07		4.74		35.36				20.33	
MW-22	12/10/2020	25.07		5.11		35.33				19.96	
MW-23	2/12/1998	22.76		2.60						20.16	
MW-23	3/31/1998	22.76		1.66						21.10	
MW-23	5/19/1998	22.76		1.26						21.50	
MW-23	7/25/2001	22.76		1.36						21.40	
MW-23	10/25/2001	22.76		2.15						20.61	
MW-23	1/22/2002	22.76		2.91						19.85	
MW-23	4/26/2002	22.76		1.35						21.41	
MW-23	7/26/2002	22.76		1.40						21.36	
MW-23	10/17/2002	22.76		2.51						20.25	
MW-23	1/13/2003	22.76		2.85						19.91	
MW-23	4/25/2003	22.76		1.12						21.64	
MW-23	7/29/2003	22.76		1.72						21.04	
MW-23	10/31/2003	22.76		2.42						20.34	
MW-23	1/26/2004	22.76		2.92						19.84	
MW-23	4/27/2004	22.76		0.98						21.78	
MW-23	7/20/2004	22.76		1.68						21.08	
MW-23	10/21/2004	22.76		2.26						20.50	
MW-23	4/20/2005	22.76		1.03						21.73	
MW-23	7/21/2005	22.76		1.49						21.27	
MW-23	1/19/2006	22.76		2.15						20.61	
MW-23	4/6/2006	22.76		1.50						21.26	
MW-23	7/11/2006	22.76		1.48						21.28	
MW-23	10/26/2006	22.76		2.32						20.44	
MW-23	7/14/2007	22.76		1.48						21.29	
MW-23	2/28/2008	22.76		2.45						20.31	
MW-23	1/15/2009	22.76		2.80						19.96	
MW-23	6/18/2010	23.36		1.09						22.27	
MW-23	7/1/2010	23.36		1.09						22.27	
MW-23	9/23/2010	23.36		2.06						21.30	
MW-23	12/6/2010	23.36		2.88						20.48	
MW-23	1/25/2011	23.36		2.18						21.18	
MW-23	3/23/2011	23.36		1.77						21.59	
MW-23	5/4/2011	23.36		1.07						22.29	
MW-23	3/1/2013	23.92		2.38		31.18				21.54	
MW-23	4/22/2013	23.92		1.27						22.65	
MW-23	4/23/2013	23.92		1.26						22.66	
MW-23	10/14/2013	23.92		2.16						21.76	
MW-23	4/14/2016	23.92		2.46		32.40				21.46	
MW-23	9/18/2017	23.92		3.84		32.14				20.08	
MW-23	11/5/2018	23.92		3.60		32.15				20.32	
MW-23	11/12/2019	23.92		3.63		32.15				20.29	
MW-23	12/10/2020	23.92		3.98		32.25				19.94	
MW-24	2/12/1998	23.59		3.46						20.13	
MW-24	3/31/1998	23.59		2.46						21.13	
MW-24	5/19/1998	23.59		2.08						21.51	
MW-24	10/4/2006	23.90		3.66						20.24	
MW-24	6/18/2010	24.15		1.92						22.23	
MW-24	7/1/2010	24.15		1.91						22.24	
MW-24	9/23/2010	24.15		2.91						21.24	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-24	12/6/2010	24.15		3.74						20.41	
MW-24	1/25/2011	24.15		3.09						21.06	
MW-24	3/23/2011	24.15		2.68						21.47	
MW-24	5/4/2011	24.15		1.94						22.21	
MW-24	3/1/2013	24.87		3.25		15.15				21.62	
MW-24	4/22/2013	24.87		2.13						22.74	
MW-24	4/23/2013	24.87		2.06						22.81	
MW-24	10/14/2013	24.87		3.01						21.86	
MW-24	4/14/2016	24.87		3.42		16.32				21.45	
MW-24	9/18/2017	24.87		4.83		16.30				20.04	
MW-24	11/5/2018	24.87		4.59		16.30				20.28	
MW-24	11/12/2019	24.87		4.61		16.29				20.26	
MW-24	12/10/2020	24.87		4.97		16.29				19.90	
MW-25	2/12/1998	22.64		2.50						20.14	
MW-25	3/31/1998	22.64		1.48						21.16	
MW-25	5/19/1998	22.64		1.14						21.50	
MW-25	7/25/2001	22.64		1.25						21.39	
MW-25	10/25/2001	22.64		2.30						20.34	
MW-25	1/22/2002	22.64		3.86						18.78	
MW-25	4/26/2002	22.64		1.09						21.55	
MW-25	7/26/2002	22.64		1.32						21.32	
MW-25	10/17/2002	22.64		2.42						20.22	
MW-25	1/13/2003	22.64		2.75						19.89	
MW-25	4/25/2003	22.64		1.03						21.61	
MW-25	7/29/2003	22.64		1.80						20.84	
MW-25	10/31/2003	22.64		2.40						20.24	
MW-25	1/26/2004	22.64		2.79						19.85	
MW-25	4/27/2004	22.64		0.82						21.82	
MW-25	7/20/2004	22.64		1.58						21.06	
MW-25	10/21/2004	22.64		2.15						20.49	
MW-25	4/20/2005	22.64		0.97						21.67	
MW-25	7/21/2005	22.64		1.41						21.23	
MW-25	1/19/2006	22.64		2.72						19.92	
MW-25	4/6/2006	22.64		1.42						21.22	
MW-25	7/11/2006	22.64		1.37						21.27	
MW-25	10/26/2006	22.64		2.21						20.43	
MW-25	7/14/2007	22.64		1.38						21.27	
MW-25	2/28/2008	22.64		2.35						20.29	
MW-25	1/15/2009	22.64		2.78						19.87	
MW-25	6/18/2010	23.22		0.95						22.27	
MW-25	7/1/2010	23.22		0.96						22.26	
MW-25	9/23/2010	23.22		1.96						21.26	
MW-25	12/6/2010	23.22		2.79						20.43	
MW-25	1/25/2011	23.22		2.11						21.11	
MW-25	3/23/2011	23.22		1.70						21.52	
MW-25	5/4/2011	23.22		0.98						22.24	
MW-25	3/1/2013	23.39		2.28		15.13				21.11	
MW-25	4/22/2013	23.39		1.20						22.19	
MW-25	4/23/2013	23.39		1.15						22.24	
MW-25	10/14/2013	23.39		2.05						21.34	
MW-25	4/14/2016	23.39		1.90		15.72				21.49	
MW-25	9/18/2017	23.39		3.31		15.72				20.08	
MW-25	11/5/2018	23.39		3.02		15.71				20.37	
MW-25	11/12/2019	23.39		3.37		15.71				20.02	
MW-25	12/10/2020	23.39		3.42		15.71				19.97	
MW-26	12/6/2010	32.43		8.70						23.73	
MW-26	1/25/2011	32.43		7.15						25.28	
MW-26	3/23/2011	32.43		6.60						25.83	
MW-26	5/4/2011	32.43		7.46						24.97	
MW-26	3/17/2013	32.81		7.78						25.03	
MW-26	4/22/2013	32.81		7.69						25.12	
MW-26	4/25/2013	32.81		7.82						24.99	
MW-26	10/14/2013	32.81		9.49						23.32	
MW-26	4/14/2016	32.81		7.97		12.30				24.84	
MW-26	9/18/2017	32.81		9.98		12.29				22.83	
MW-26	11/5/2018	32.81		10.26		12.30				22.55	
MW-26	11/12/2019	32.81		9.84		12.29				22.97	
MW-26	12/10/2020	32.81		9.15		12.29				23.66	
MW-27	12/6/2010	35.15		7.06						28.09	
MW-27	1/25/2011	35.15		5.36						29.79	
MW-27	3/23/2011	35.15		4.84						30.31	
MW-27	5/4/2011	35.15		5.87						29.28	
MW-27	3/1/2013	35.26		6.19		14.29				29.07	
MW-27	4/19/2013	35.26		5.57						29.69	
MW-27	4/22/2013	35.26		5.51						29.75	
MW-27	10/14/2013	35.26		8.59						26.67	
MW-27	4/14/2016	35.26		6.02		14.29				29.24	
MW-27	9/18/2017	35.26		9.76		14.29				25.50	
MW-27	11/5/2018	35.26		10.50		14.29				24.76	
MW-27	11/12/2019	35.26		8.65		14.27				26.61	
MW-27	12/10/2020	35.26		6.69		14.25				28.57	
MW-28	12/6/2010	37.39		15.53						21.86	
MW-28	1/25/2011	37.39		14.83						22.56	
MW-28	3/23/2011	37.39		14.52						22.87	
MW-28	5/4/2011	37.39		14.56						22.83	
MW-28	3/1/2013	37.49		15.38		27.56				22.11	
MW-28	4/22/2013	37.49		14.62		27.61				22.87	
MW-28	4/23/2013	37.49		14.41						23.08	
MW-28	10/14/2013	37.49		15.49						22.00	
MW-28	4/14/2016	37.49		14.78		23.38				22.71	
MW-28	9/18/2017	37.49		16.21		27.60				21.28	
MW-28	11/5/2018	37.49		17.19		27.32				20.30	
MW-28	11/12/2019	37.49		16.02		27.35				21.47	
MW-28	12/10/2020	37.49		15.53		27.36				21.96	
MW-29	12/6/2010	31.31		9.28						22.03	
MW-29	1/25/2011	31.31		7.80						23.51	
MW-29	3/23/2011	31.31		7.33						23.98	
MW-29	5/4/2011	31.31		8.08						23.23	
MW-29	3/1/2013	32.30		8.99		23.15				23.31	
MW-29	4/19/2013	32.30		7.90						24.40	
MW-29	4/22/2013	32.30		7.73						24.57	
MW-29	10/14/2013	32.30		9.43						22.87	
MW-29	4/14/2016	32.30		9.56		24.36				22.74	
MW-29	9/18/2017	32.30		11.43		24.38				20.87	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-29	11/5/2018	32.30		11.47		24.39				20.83	
MW-29	11/12/2019	32.30		11.32		24.35				20.98	
MW-29	12/10/2020	32.30		11.13		25.36				21.17	
MW-30	12/6/2010	31.68		9.78						21.90	
MW-30	1/25/2011	31.68		8.33						23.35	
MW-30	3/23/2011	31.68		7.85						23.83	
MW-30	5/4/2011	31.68		8.54						23.14	
MW-30	3/1/2013	32.95		9.19		21.64				23.76	
MW-30	4/19/2013	32.95		8.40						24.55	
MW-30	4/22/2013	32.95		8.20						24.75	
MW-30	10/14/2013	32.95		9.87						23.08	
MW-30	4/14/2016	32.95		10.38		15.84				22.57	
MW-30	9/18/2017	32.95		12.14		23.12				20.81	
MW-30	11/5/2018	32.95		12.15		23.00				20.80	
MW-30	11/12/2019	32.95		12.02		23.10				20.93	
MW-30	12/10/2020	32.95		11.90		15.84				21.05	
MW-31	12/6/2010	40.88		15.28						25.60	
MW-31	1/25/2011	40.88		14.57						26.31	
MW-31	3/23/2011	40.88		14.38						26.50	
MW-31	5/4/2011	40.88		14.13						26.75	
MW-31	3/1/2013	40.90		14.58		44.95				26.32	
MW-31	4/19/2013	40.90		14.59						26.31	
MW-31	4/22/2013	40.90		15.90						25.00	
MW-31	10/14/2013	40.90		13.77						27.13	
MW-31	4/14/2016	40.90		15.63		46.16				25.27	
MW-31	9/18/2017	40.90		15.48		45.90				25.42	
MW-31	11/5/2018	40.90		15.89		43.85				25.01	
MW-31	11/12/2019	40.90		15.84		44.88				25.06	
MW-31	12/10/2020	40.90		15.78		44.90				25.12	
MW-32S	4/22/2013	31.12		7.68						23.44	
MW-32S	4/23/2013	31.12		7.62						23.50	
MW-32S	10/14/2013	31.12		8.51						22.61	
MW-32S	4/14/2016	31.12		9.68						21.44	
MW-32S	9/18/2017	31.12	see Note 1	11.05		33.57	see Note 1			20.07	
MW-32S	11/5/2018	31.12		10.80		33.57				20.32	
MW-32S	11/12/2019	31.12		10.83		33.40				20.29	
MW-32S	12/10/2020	31.12		11.19		33.37				19.93	
MW-32D	4/22/2013	31.35		7.54						23.81	
MW-32D	4/23/2013	31.35		7.52						23.83	
MW-32D	10/14/2013	31.35		8.40						22.95	
MW-32D	4/14/2016	31.35		9.89		49.12				21.46	
MW-32D	9/18/2017	31.35		11.29		49.10				20.06	
MW-32D	11/5/2018	31.35		11.02		49.15				20.33	
MW-32D	11/12/2019	31.35		11.04		49.10				20.31	
MW-32D	12/10/2020	31.35		11.42		49.12				19.93	
MW-33S	4/19/2013	39.08		16.49						22.59	
MW-33S	4/22/2013	39.08		16.45						22.63	
MW-33S	10/14/2013	39.08		17.31						21.77	
MW-33S	4/14/2016	39.08		16.59		23.13				22.49	
MW-33S	9/18/2017	39.08		18.93		23.09				20.15	
MW-33S	11/5/2018	39.08		18.70		22.96				20.38	
MW-33S	11/12/2019	39.08		18.72		23.09				20.36	
MW-33S	12/10/2020	39.08		19.05		22.10				20.03	
MW-34S	4/22/2013	28.05		6.25						21.80	
MW-34S	4/23/2013	28.05		6.22						21.83	
MW-34S	10/14/2013	28.05		6.94						21.11	
MW-34S	4/14/2016	28.05		6.12		9.81				21.93	
MW-34S	9/18/2017	28.05		7.69		9.80				20.36	
MW-34S	11/5/2018	28.05		7.45		9.81				20.60	
MW-34S	11/12/2019	28.05		7.37		9.81				20.68	
MW-34S	12/10/2020	28.05		6.91		9.81				21.14	
MW-35S	4/22/2013	24.15		2.38						21.77	
MW-35S	4/24/2013	24.15		2.31						21.84	
MW-35S	10/14/2013	24.15		3.24						20.91	
MW-35S	4/14/2016	24.15		2.53		7.02				21.62	
MW-35S	9/18/2017	24.15		3.84		7.02				20.31	
MW-35S	11/5/2018	24.15		3.59		7.01				20.56	
MW-35S	11/12/2019	24.15		3.62		7.01				20.53	
MW-35S	12/10/2020	24.15		3.96		7.03				20.19	
MW-36D	4/22/2013	29.55		7.82						21.73	
MW-36D	4/25/2013	29.55		7.86						21.69	
MW-36D	10/14/2013	29.55		8.70						20.85	
MW-36D	4/14/2016	29.55		8.11						21.44	
MW-36D	9/18/2017	29.55		9.28						20.27	
MW-36D	9/22/2017	29.55		9.21						20.34	
MW-36D	12/14/2017	29.55		9.56						19.99	
MW-36D	2/13/2018	29.55		9.69						19.86	
MW-36D	11/5/2018	29.55		8.98		33.65				20.57	
MW-36D	11/12/2019	29.55		9.02		33.79				20.53	
MW-36D	12/10/2020	29.55		9.42		33.74				20.13	
MW-36S	4/22/2013	29.62		7.88						21.74	
MW-36S	4/25/2013	29.62		7.80						21.82	
MW-36S	10/14/2013	29.62		8.72						20.90	
MW-36S	4/14/2016	29.62		7.97						21.65	
MW-36S	9/18/2017	29.62		9.33						20.29	
MW-36S	9/21/2017	29.62		9.26						20.36	
MW-36S	12/13/2017	29.62		9.46						20.16	
MW-36S	2/14/2018	29.62		9.42						20.20	
MW-36S	11/5/2018	29.62		9.07		22.86				20.55	
MW-36S	11/12/2019	29.62		9.12		22.87				20.50	
MW-36S	12/10/2020	29.62		9.50		22.90				20.12	
MW-37S	4/22/2013	26.85		5.11						21.74	
MW-37S	4/24/2013	26.85		5.05						21.80	
MW-37S	10/14/2013	26.85		5.98						20.87	
MW-37S	4/14/2016	26.85		5.18						21.67	
MW-37S	9/18/2017	26.85		6.56						20.29	
MW-37S	11/5/2018	26.85		6.32		14.82				20.53	
MW-37S	11/12/2019	26.85		6.37		14.82				20.48	
MW-37S	12/10/2020	26.85		6.73		14.83				20.12	
MW-38S	4/22/2013	25.42		3.70						21.72	
MW-38S	4/24/2013	25.42		3.63						21.79	
MW-38S	10/14/2013	25.42		4.55						20.87	
MW-38S	4/14/2016	25.42		3.74						21.68	
MW-38S	9/18/2017	25.42		5.16						20.26	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-38S	11/5/2018	25.42		4.90		16.82				20.52	
MW-38S	11/12/2019	25.42		4.96		16.84				20.46	
MW-38S	12/10/2020	25.42		5.32		16.85				20.10	
MW-39D	4/22/2013	26.74		5.00						21.74	
MW-39D	4/24/2013	26.74		5.09						21.65	
MW-39D	10/14/2013	26.74		5.85						20.89	
MW-39D	4/14/2016	26.74		5.07						21.67	
MW-39D	9/18/2017	26.74		6.49						20.25	
MW-39D	11/5/2018	26.74		6.22		22.50				20.52	
MW-39D	11/12/2019	26.74		6.20		22.47				20.54	
MW-39D	12/10/2020	26.74		6.61		22.46				20.13	
MW-39S	4/22/2013	26.61		4.86						21.75	
MW-39S	4/25/2013	26.61		4.80						21.81	
MW-39S	10/14/2013	26.61		5.74						20.87	
MW-39S	4/14/2016	26.61		4.93						21.68	
MW-39S	9/18/2017	26.61		6.35						20.26	
MW-39S	11/5/2018	26.61		6.10		14.08				20.51	
MW-39S	11/12/2019	26.61		6.16		14.04				20.45	
MW-39S	12/10/2020	26.61		5.00		14.05				21.61	
MW-40S	4/22/2013	25.18		3.48						21.70	
MW-40S	4/25/2013	25.18		3.38						21.80	
MW-40S	10/14/2013	25.18		4.31						20.87	
MW-40S	4/14/2016	25.18		3.54						21.64	
MW-40S	9/18/2017	25.18		4.95						20.23	
MW-40S	11/5/2018	25.18		4.70		10.94				20.48	
MW-40S	11/12/2019	25.18		4.75		10.92				20.43	
MW-40S	12/10/2020	25.18		5.09		10.93				20.09	
MW-41D	9/18/2017	32.44		10.48						21.96	
MW-41D	9/19/2017	32.44		10.53						21.91	
MW-41D	12/11/2017	32.44		9.01						23.43	
MW-41D	2/16/2018	32.44		9.22						23.22	
MW-41D	11/5/2018	32.44		10.30		29.32				22.14	
MW-41D	11/12/2019	32.45		9.56		29.18				22.89	
MW-41D	12/10/2020	32.45		9.16		29.19				23.29	
MW-41S	9/18/2017	32.27		7.94						24.33	
MW-41S	9/21/2017	32.27		7.55						24.72	
MW-41S	12/11/2017	32.27		4.49						27.78	
MW-41S	2/16/2018	32.27		4.47						27.80	
MW-41S	11/5/2018	32.72		5.73		11.10				26.99	
MW-41S	11/12/2019	32.72		5.69		11.10				27.03	
MW-41S	12/10/2020	32.72		5.30		11.10				27.42	
MW-42S	9/18/2017	36.10		12.97						23.13	
MW-42S	9/20/2017	36.10		12.99						23.11	
MW-42S	11/6/2017	36.10		10.92						25.18	
MW-42S	11/9/2017	36.10		10.42						25.68	
MW-42S	11/14/2017	36.10		10.42						25.68	
MW-42S	11/16/2017	36.10		10.32						25.78	
MW-42S	12/8/2017	36.10		10.35						25.75	
MW-42S	2/12/2018	36.10		9.96						26.14	
MW-42S	11/5/2018	32.72		8.70		11.98				24.02	
MW-42S	11/12/2019	32.72		7.58		11.98				25.14	
MW-42S	12/10/2020	32.72		7.10		12.00				25.62	
MW-43S	9/18/2017	32.28		10.92						21.36	
MW-43S	9/21/2017	32.28		10.98						21.30	
MW-43S	11/7/2017	32.28		10.15						22.13	
MW-43S	11/10/2017	32.28		10.31						21.97	
MW-43S	11/14/2017	32.28		10.43						21.85	
MW-43S	11/16/2017	32.28		10.17						22.11	
MW-43S	12/12/2017	32.28		10.25						22.03	
MW-43S	2/19/2018	32.28		10.18						22.10	
MW-43S	11/5/2018	32.28		10.78		13.11				21.50	
MW-43S	11/12/2019	32.28		10.51		13.14				21.77	
MW-43S	12/10/2020	32.28		10.09		13.12				22.19	
MW-44S*	9/18/2017	33.54	13.11	13.45		17.30	0.34		20.43	20.41	
MW-44S*	9/22/2017	33.54	13.05	13.40		17.49	0.35		20.49	20.47	
MW-44S*	11/7/2017	33.54	12.72	12.76		17.49	0.04		20.82	20.82	
MW-44S*	11/10/2017	33.54	12.78	12.80		17.49	0.02		20.76	20.76	
MW-44S*	11/14/2017	33.54	12.78	12.79		17.49	0.01		20.76	20.76	
MW-44S	11/17/2017	33.54	Trace	12.95		17.49	Trace			20.59	
MW-44S*	12/13/2017	33.54	13.05	13.25		17.49	0.20		20.49	20.48	
MW-44S*	2/19/2018	33.54	12.95	13.10			0.15		20.59	20.58	
MW-44S*	11/5/2018	33.26	12.81	13.00		17.30	0.19		20.45	20.44	
MW-44S*	11/12/2019	33.61	12.92	12.93		17.31	0.01		20.69	20.69	
MW-44S*	12/10/2020	33.61	13.14	13.15		17.50	0.01		20.47	20.46	
MW-45S*	9/18/2017	33.99	13.67	13.79		17.23	0.12		20.32	20.31	
MW-45S*	9/25/2017	33.99	13.63	13.77		17.19	0.14		20.36	20.35	
MW-45S*	11/7/2017	33.99	13.41	13.46		17.23	0.05		20.58	20.58	
MW-45S	11/10/2017	33.99		13.46		17.23				20.53	
MW-45S	11/14/2017	33.99		13.51		17.23				20.48	
MW-45S	11/17/2017	33.99		13.60		17.23				20.39	
MW-45S	12/12/2017	33.99	Trace	13.83		17.38	Trace			20.16	
MW-45S	2/19/2018	33.99	Trace	13.70			Trace			20.29	
MW-45S	11/5/2018	33.25		13.02		17.23				20.23	
MW-45S	11/12/2019	33.75		13.12		16.79				20.63	
MW-45S	12/10/2020	33.75	13.43	13.44		16.80	0.01			20.31	
MW-45D	9/18/2017	33.25		12.65						20.60	
MW-45D	9/22/2017	33.25		13.63						19.62	
MW-45D	11/7/2017	33.25		12.25						21.00	
MW-45D	11/10/2017	33.25		12.20						21.05	
MW-45D	11/14/2017	33.25		12.31						20.94	
MW-45D	11/16/2017	33.25		12.34						20.91	
MW-45D	12/12/2017	33.25		12.50						20.75	
MW-45D	2/12/2018	33.25		12.93						20.32	
MW-45D	11/5/2018	33.40		12.45		30.30				20.95	
MW-45D	11/12/2019	33.40		12.46		30.32				20.94	
MW-45D	12/10/2020	33.40		12.83		30.55				20.57	
MW-46D	9/18/2017	28.17		7.25		29.00				20.92	
MW-46D	9/20/2017	28.17		7.47						20.70	
MW-46D	11/10/2017	28.17		7.24						20.93	
MW-46D	11/14/2017	28.17		7.56						20.61	
MW-46D	11/17/2017	28.17		7.64						20.53	
MW-46D	12/7/2017	28.17		7.86						20.31	
MW-46D	2/13/2018	28.17		7.84						20.33	
MW-46D	11/12/2019	28.18		7.61		29.72				20.57	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
MW-46D	12/10/2020	28.18		7.95		29.69				20.23	
MW-46S	9/18/2017	28.09		7.80		17.64				20.29	
MW-46S	9/21/2017	28.09		7.74						20.35	
MW-46S	12/7/2017	28.09		7.91						20.18	
MW-46S	2/13/2018	28.09		7.92						20.17	
MW-46S	11/5/2018	28.09		7.55		17.64				20.54	
MW-46S	11/12/2019	28.10		8.60		17.62				19.50	
MW-46S	12/10/2020	28.10		7.97		17.65				20.13	
MW-47S	9/18/2017	33.05		12.75		19.75				20.30	
MW-47S	9/19/2017	33.05		12.74						20.31	
MW-47S	11/6/2017	33.05		12.50						20.55	
MW-47S	11/9/2017	33.05		12.51						20.54	
MW-47S	11/14/2017	33.05		12.59						20.46	
MW-47S	11/16/2017	33.05		12.65						20.40	
MW-47S	12/8/2017	33.05		12.95						20.10	
MW-47S	2/12/2018	33.05		12.92						20.13	
MW-47S	11/5/2018	33.21		12.58						20.63	
MW-47S	11/12/2019	33.21		12.58		19.78				20.63	
MW-47S	12/10/2020	33.21		12.95		19.80				20.26	
MW-48D*	9/18/2017	30.05	9.68	9.69		32.65	0.01		20.37	20.37	
MW-48D	9/21/2017	30.05		9.66		32.80				20.39	
MW-48D	11/7/2017	30.05		9.34		32.65				20.71	
MW-48D	11/10/2017	30.05		9.41		32.65				20.64	
MW-48D	11/14/2017	30.05		9.50		32.65				20.55	
MW-48D	11/16/2017	30.05		9.53		32.65				20.52	
MW-48D	12/13/2017	30.05		9.80		32.65				20.25	
MW-48D	2/16/2018	30.05		9.92						20.13	
MW-48D	11/5/2018	30.05		9.51		32.65				20.54	
MW-48D	11/12/2019	30.05		9.51		32.78				20.54	
MW-48D	12/10/2020	30.05		9.87		23.66				20.18	
MW-49D	9/18/2017	29.40		9.09		34.69				20.31	
MW-49D	9/20/2017	29.40		9.12						20.28	
MW-49D	12/14/2017	29.40		9.24						20.16	
MW-49D	2/14/2018	29.40		9.02						20.38	
MW-49D	11/5/2018	29.40		8.84		34.64				20.56	
MW-49D	11/12/2019	29.40		8.66		34.60				20.74	
MW-49D	12/10/2020	29.40		9.23		34.65				20.17	
MW-50D	9/18/2017	28.31		8.04		34.73				20.27	
MW-50D	9/20/2017	28.31		8.15						20.16	
MW-50D	12/7/2017	28.31		7.51						20.80	
MW-50D	2/15/2018	28.31		8.12						20.19	
MW-50D	11/5/2018	28.31		7.80		34.74				20.51	
MW-50D	11/12/2019	28.31		9.73		34.7				18.58	
MW-50D	12/10/2020	28.31		8.26		34.55				20.05	
MW-51S	9/18/2017	28.62		8.33		17.15				20.29	
MW-51S	9/21/2017	28.62		9.25						19.37	
MW-51S	12/8/2017	28.62		8.46						20.16	
MW-51S	2/15/2018	28.62		8.49						20.13	
MW-51S	11/5/2018	28.62		8.04		17.15				20.58	
MW-51S	11/12/2019	28.62		8.11		17.15				20.51	
MW-51S	12/10/2020	28.62		8.50		17.15				20.12	
MW-52D	9/18/2017	28.56	Trace	8.35		34.95	Trace			20.21	
MW-52D	9/21/2017	28.56		8.31		34.93				20.25	
MW-52D	12/8/2017	28.56		8.23		34.95				20.33	
MW-52D	2/15/2018	28.56		8.32						20.24	
MW-52D	11/5/2018	28.56		8.03		34.75				20.53	
MW-52D	11/12/2019	28.56		8.02		34.78				20.54	
MW-52D	12/10/2020	28.56	--	8.43	--	34.78				20.13	
OBS-1	7/25/2001	23.31		1.93						21.38	
OBS-1	10/25/2001	23.31		2.95						20.36	
OBS-1	1/22/2002	23.31		3.51						19.80	
OBS-1	4/26/2002	23.31		1.75						21.56	
OBS-1	7/26/2002	23.31		2.10						21.21	
OBS-1	10/17/2002	23.31		3.08						20.23	
OBS-1	1/13/2003	23.31		3.40						19.91	
OBS-1	4/25/2003	23.31		1.75						21.56	
OBS-1	7/29/2003	23.31		2.43						20.88	
OBS-1	10/31/2003	23.31		3.05						20.26	
OBS-1	1/26/2004	23.31		3.41						19.90	
OBS-1	4/27/2004	23.31		1.46						21.85	
OBS-1	7/20/2004	23.31		2.22						21.09	
OBS-1	10/21/2004	23.31		2.90						20.41	
OBS-1	4/20/2005	23.31		1.65						21.66	
OBS-1	7/21/2005	23.31		2.09						21.22	
OBS-1	1/19/2006	23.31		3.51						19.80	
OBS-1	4/6/2006	23.31		2.09						21.22	
OBS-1	7/11/2006	23.31		2.05						21.26	
OBS-1	10/26/2006	23.31		2.88						20.43	
OBS-1	7/14/2007	23.31		2.03						21.29	
OBS-1	2/28/2008	23.31		2.98						20.34	
OBS-1	1/15/2009	23.31		3.43						19.89	
OBS-1	9/23/2010	23.52		2.64						20.88	
OBS-1	12/6/2010	23.52		3.48						20.04	
OBS-1	3/23/2011	23.52		2.39						21.13	
OBS-1	5/4/2011	23.52		1.64						21.88	
OBS-1	2/27/2013	23.59		3.00		12.89				20.59	
OBS-1	4/22/2013	23.59		1.88						21.71	
OBS-1	4/24/2013	23.59		1.83						21.76	
OBS-1	10/14/2013	23.59		2.73						20.86	
OBS-1	4/14/2016	23.59		1.89		12.84				21.70	
OBS-1	9/18/2017	23.59		3.32		12.85				20.27	
OBS-1	11/5/2018	23.59		3.09		12.85				20.50	
OBS-1	11/12/2019	23.59		3.13		12.89				20.46	
OBS-1	12/10/2020	23.59		3.46		12.89				20.13	
OBS-2	7/25/2001	25.95		4.65						21.30	
OBS-2	10/25/2001	25.95		5.58						20.37	
OBS-2	1/22/2002	25.95		6.20						19.75	
OBS-2	4/26/2002	25.95		4.50						21.45	
OBS-2	7/26/2002	25.95		4.71						21.24	
OBS-2	10/17/2002	25.95		5.82						20.13	
OBS-2	1/13/2003	25.95		6.09						19.86	
OBS-2	4/25/2003	25.95		4.46						21.49	
OBS-2	7/29/2003	25.95		5.16						20.79	
OBS-2	10/31/2003	25.95		5.81						20.14	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
OBS-2	1/26/2004	25.95		6.19						19.76	
OBS-2	4/27/2004	25.95		4.19						21.76	
OBS-2	7/20/2004	25.95		4.99						20.96	
OBS-2	10/21/2004	25.95		5.61						20.34	
OBS-2	4/20/2005	25.95		4.44						21.51	
OBS-2	7/21/2005	25.95		4.92						21.03	
OBS-2	1/19/2006	25.95		6.20						19.75	
OBS-2	4/6/2006	25.95		4.92						21.03	
OBS-2	7/11/2006	25.95		4.75						21.20	
OBS-2	10/26/2006	25.95		5.57						20.38	
OBS-2	7/14/2007	25.95		4.75						21.20	
OBS-2	2/28/2008	25.95		5.73						20.23	
OBS-2	1/15/2009	25.95		6.15						19.80	
OBS-2	6/18/2010	26.14		3.62						22.52	
OBS-2	7/1/2010	26.14		4.34						21.80	
OBS-2	9/23/2010	26.14		5.31						20.83	
OBS-2	12/6/2010	26.14		6.17						19.97	
OBS-2	1/25/2011	26.14		5.42						20.72	
OBS-2	3/23/2011	26.14		5.07						21.07	
OBS-2	5/4/2011	26.14		6.37						19.77	
OBS-2	2/27/2013	26.21		5.71		14.65				20.50	
OBS-2	4/22/2013	26.21		4.57		14.67				21.64	
OBS-2	4/24/2013	26.21		4.70						21.51	
OBS-2	10/14/2013	26.21		5.44						20.77	
OBS-2	4/14/2016	26.21		4.63		16.66				21.58	
OBS-2	9/18/2017	26.21		6.02		15.42				20.19	
OBS-2	11/5/2018	26.21		5.78		14.85				20.43	
OBS-2	11/12/2019	26.21		5.80		15.28				20.41	
OBS-2	12/10/2020	26.21		6.16		14.84				20.05	
OBS-3	7/25/2001	29.12		11.98						17.14	
OBS-3	10/25/2001	29.12		10.67						18.45	
OBS-3	1/22/2002	29.12		13.82						15.30	
OBS-3	4/26/2002	29.12		14.80						14.32	
OBS-3	7/26/2002	29.12		9.37						19.75	
OBS-3	10/17/2002	29.12		14.03						15.09	
OBS-3	1/13/2003	29.12		13.75						15.37	
OBS-3	4/25/2003	29.12		11.88						17.24	
OBS-3	7/29/2003	29.12		10.23						18.89	
OBS-3	10/31/2003	29.12		11.40						17.72	
OBS-3	1/26/2004	29.12		12.97						16.15	
OBS-3	4/27/2004	29.12		12.95						16.17	
OBS-3	7/20/2004	29.12		12.61						16.51	
OBS-3	10/21/2004	29.12		12.51						16.61	
OBS-3	4/20/2005	29.12		7.80						21.32	
OBS-3	7/21/2005	29.12		8.01						21.11	
OBS-3	1/19/2006	29.12		8.07						21.05	
OBS-3	4/6/2006	29.12		10.16						18.96	
OBS-3	7/11/2006	29.12		10.92						18.20	
OBS-3	10/26/2006	29.12		8.13						20.99	
OBS-3	7/14/2007	29.12		7.88						21.25	
OBS-3	2/28/2008	29.12		7.70						21.42	
OBS-3	1/15/2009	29.12		7.78						21.35	
OBS-3	2/12/2010	29.12	see Note 1	7.26		15.91	see Note 1			21.86	
OBS-3	6/18/2010	29.33		6.27						23.06	
OBS-3	7/1/2010	29.33		6.20						23.13	
OBS-3	9/23/2010	29.33		7.29						22.04	
OBS-3	12/6/2010	29.33		7.32						22.01	
OBS-3	1/25/2011	29.33		7.21						22.12	
OBS-3	3/23/2011	29.33		6.58						22.75	
OBS-3	5/4/2011	29.33		4.35						24.98	
OBS-3	2/27/2013	29.39		7.17		15.91				22.22	
OBS-3	4/22/2013	29.39		6.34		16.00				23.05	
OBS-3	4/24/2013	29.39		6.10		16.00				23.29	
OBS-3	10/14/2013	29.39		7.34		15.90				22.05	
OBS-3	4/14/2016	29.39		6.03		15.77				23.36	
OBS-3	9/18/2017	29.39		7.77		15.96				21.62	
OBS-3	11/5/2018	29.39		8.31		15.96				21.08	
OBS-3	11/12/2019	29.39		7.54		15.96				21.85	
OBS-3	12/10/2020	29.39		6.98		15.94				22.41	
PZ-01	12/9/1997	24.80		5.00						19.80	
PZ-01	12/18/1997	24.80		4.18						20.62	
PZ-01	12/23/1997	24.80		4.99						19.81	
PZ-01	12/29/1997	24.80		4.99						19.81	
PZ-01	1/5/1998	24.80		4.71						20.09	
PZ-01	2/12/1998	24.80		4.57						20.23	
PZ-01	2/18/1998	24.80		4.58						20.22	
PZ-01	3/31/1998	24.80		3.65						21.15	
PZ-01	5/19/1998	24.80		3.29						21.51	
PZ-01	10/4/2006	24.80		4.55						20.25	
PZ-01	6/18/2010	25.11		3.15						21.96	
PZ-01	7/1/2010	25.11		3.08						22.03	
PZ-01	9/23/2010	25.11		4.06						21.05	
PZ-01	12/6/2010	25.11		4.88						20.23	
PZ-01	1/25/2011	25.11		4.23						20.88	
PZ-01	3/23/2011	25.11		3.83						21.28	
PZ-01	5/4/2011	25.11		3.08						22.03	
PZ-01	2/27/2013	25.09		4.46		9.99				20.63	
PZ-01	4/17/2013	25.09		3.51		10.10				21.58	
PZ-01	4/22/2013	25.09		3.20						21.89	
PZ-01	10/14/2013	25.09		4.17						20.92	
PZ-01	4/14/2016	25.09		3.38		10.08				21.71	
PZ-01	9/18/2017	25.09		4.75		11.55				20.34	
PZ-01	11/5/2018	25.09		4.51		11.52				20.58	
PZ-01	11/12/2019	25.09		4.53		11.50				20.56	
PZ-01	12/10/2020	25.09		4.72		9.03				20.37	
PZ-02	12/9/1997	34.20		14.01						20.19	
PZ-02	12/18/1997	34.20		13.85						20.35	
PZ-02	12/23/1997	34.20		13.90						20.30	
PZ-02	12/29/1997	34.20		13.95						20.25	
PZ-02	1/5/1998	34.20		13.71						20.49	
PZ-02	2/12/1998	34.20		13.46						20.74	
PZ-02	2/18/1998	34.20		13.47						20.73	
PZ-02	3/31/1998	34.20		12.79						21.41	
PZ-02	5/19/1998	34.20		12.66						21.54	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
PZ-03	12/9/1997	34.08		13.74						20.34	
PZ-03	12/18/1997	34.08		13.45						20.63	
PZ-03	12/23/1997	34.08		13.57						20.51	
PZ-03	12/29/1997	34.08		13.63						20.45	
PZ-03	1/5/1998	34.08		13.17						20.91	
PZ-03	2/12/1998	34.08		13.01						21.07	
PZ-03	3/31/1998	34.08		12.46						21.62	
PZ-03	5/19/1998	34.08		12.49						21.59	
PZ-03	7/25/2001	34.08		12.62						21.46	
PZ-03	10/25/2001	34.08		12.96						21.12	
PZ-03	4/26/2002	34.08		12.10						21.98	
PZ-03	7/26/2002	34.08		12.37						21.71	
PZ-03	10/17/2002	34.08		13.61						20.47	
PZ-03	1/13/2003	34.08		12.95						21.13	
PZ-03	4/25/2003	34.08		12.03						22.05	
PZ-03	7/29/2003	34.08		13.07						21.01	
PZ-03	1/26/2004	34.08		13.03						21.05	
PZ-03	4/27/2004	34.08		12.20						21.88	
PZ-03	7/20/2004	34.08		12.78						21.30	
PZ-03	10/21/2004	34.08		13.35						20.73	
PZ-03	4/20/2005	34.08		12.17						21.91	
PZ-03	7/21/2005	34.08		12.86						21.22	
PZ-03	1/19/2006	34.08		12.61						21.47	
PZ-03	4/6/2006	34.08		13.72						20.36	
PZ-03	7/11/2006	34.08		12.70						21.38	
PZ-03	10/26/2006	34.08		13.59	Trace	15.38		Trace		20.49	
PZ-03	7/1/2007	34.08		--		15.38		1.67		--	
PZ-03	7/14/2007	34.08		12.88						21.21	
PZ-03	2/28/2008	34.08	Trace	13.30		15.38	Trace	1.60		20.78	
PZ-03	1/15/2009	34.08	Trace	12.95		15.38	Trace	1.00		21.13	
PZ-03	2/12/2010	34.08	Trace	13.11		15.38	Trace	0.88		20.97	
PZ-03	6/18/2010	34.58		12.22						22.36	
PZ-03	7/1/2010	34.58		12.39						22.19	
PZ-03	9/23/2010	34.58		12.95						21.63	
PZ-03	12/6/2010	34.58		13.23						21.35	
PZ-03	1/25/2011	34.58		12.58						22.00	
PZ-03	3/23/2011	34.58		12.14						22.44	
PZ-03	5/4/2011	34.58		12.22						22.36	
PZ-03	3/1/2013	34.52		12.97		15.38				21.55	
PZ-03	4/15/2013	34.52		12.06	Trace	14.49		Trace		22.46	
PZ-03	4/17/2013	34.52		12.05	Trace	14.49		Trace		22.47	
PZ-03	4/22/2013	34.52		12.24	Trace	14.49		Trace		22.28	
PZ-03	10/14/2013	34.52		13.41	Trace	14.49		Trace		21.11	
PZ-03	4/14/2016	34.52		12.50		16.04				22.02	
PZ-03	9/18/2017	34.52	Trace	13.97	Trace	16.10	Trace	Trace		20.55	
PZ-03*	11/5/2018	34.52	13.85	13.86	14.70	16.10	0.01	1.40	20.67	20.67	19.82
PZ-03*	11/12/2019	34.52	13.81	13.82	14.95	16.10	0.01	1.15	20.70	20.71	19.57
PZ-03	12/10/2020	34.52		13.47	15.87	16.10		0.23		21.05	18.65
PZ-04	12/9/1997	33.55		13.22						20.33	
PZ-04	12/18/1997	33.55		12.33						21.22	
PZ-04	12/23/1997	33.55		13.02						20.53	
PZ-04	12/29/1997	33.55		13.17						20.38	
PZ-04	1/5/1998	33.55		12.43						21.12	
PZ-04	2/12/1998	33.55		10.35						23.20	
PZ-04	2/18/1998	33.55		10.78						22.77	
PZ-04	3/31/1998	33.55		11.59						21.96	
PZ-04	5/19/1998	33.55		11.80						21.75	
PZ-05	12/9/1997	27.53		7.78						19.75	
PZ-05	12/18/1997	27.53		7.76						19.77	
PZ-05	12/23/1997	27.53		7.76						19.77	
PZ-05	12/29/1997	27.53		7.73						19.80	
PZ-05	1/5/1998	27.53		7.51						20.02	
PZ-05	2/12/1998	27.53		7.39						20.14	
PZ-05	3/31/1998	27.53		6.39						21.14	
PZ-05	5/19/1998	27.53		6.05						21.48	
PZ-05	2/27/2013	27.83		7.23		14.65				20.60	
PZ-05	4/17/2013	27.83		6.10						21.73	
PZ-05	4/22/2013	27.83		6.07						21.76	
PZ-05	10/14/2013	27.83		6.94						20.89	
PZ-05	4/14/2016	27.83		6.15		15.14				21.68	
PZ-05	9/18/2017	27.83	Trace	7.53	Trace	15.30	Trace	Trace		20.30	
PZ-05	11/5/2018	27.83		7.20		14.92				20.63	
PZ-05	11/12/2019	27.83		7.23	Trace	15.10		Trace		20.60	
PZ-05	12/10/2020	27.83		7.64	Trace	14.85		Trace		20.19	
PZ-06	12/9/1997	26.80		7.05						19.75	
PZ-06	12/18/1997	26.80		7.01						19.79	
PZ-06	12/23/1997	26.80		7.03						19.77	
PZ-06	12/29/1997	26.80		7.02						19.78	
PZ-06	1/5/1998	26.80		6.75						20.05	
PZ-06	2/12/1998	26.80		6.66						20.14	
PZ-06	2/18/1998	26.80		6.62						20.18	
PZ-06	3/31/1998	26.80		5.65						21.15	
PZ-06	5/19/1998	26.80		5.30						21.50	
PZ-06	2/27/2013	27.13		6.53		13.00				20.60	
PZ-06	10/14/2013	27.13		6.22						20.91	
PZ-06	4/14/2016	27.13		5.44		13.05				21.69	
PZ-06	9/18/2017	27.13		6.85		13.10				20.28	
PZ-06	11/5/2018	27.13		6.61		13.10				20.52	
PZ-06	11/12/2019	27.13		6.62	Trace	13.10		Trace		20.51	
PZ-06	12/10/2020	27.13		6.00		13.05				21.13	
PZ-07	12/9/1997	24.37		4.62						19.75	
PZ-07	12/18/1997	24.37		4.61						19.76	
PZ-07	12/23/1997	24.37		4.63						19.74	
PZ-07	12/29/1997	24.37		4.60						19.77	
PZ-07	1/5/1998	24.37		4.37						20.00	
PZ-07	2/12/1998	24.37		4.23						20.14	
PZ-07	2/18/1998	24.37		4.18						20.19	
PZ-07	3/31/1998	24.37		3.25						21.12	
PZ-07	5/19/1998	24.37		2.91						21.46	
PZ-08	12/9/1997	24.98		5.02						19.96	
PZ-08	12/18/1997	24.98		4.95						20.03	
PZ-08	12/23/1997	24.98		4.97						20.01	
PZ-08	12/29/1997	24.98		4.99						19.99	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
PZ-08	1/5/1998	24.98		4.73						20.25	
PZ-08	2/12/1998	24.98		4.55						20.43	
PZ-08	3/31/1998	24.98		3.68						21.30	
PZ-08	5/19/1998	24.98		3.40						21.58	
PZ-08	7/25/2001	24.98		3.57						21.41	
PZ-08	10/25/2001	24.98		4.50						20.48	
PZ-08	1/22/2002	24.98		4.50						20.48	
PZ-08	4/26/2002	24.98		3.52						21.46	
PZ-08	7/26/2002	24.98		3.62						21.36	
PZ-08	10/17/2002	24.98		4.70						20.28	
PZ-08	1/13/2003	24.98		4.82						20.16	
PZ-08	4/25/2003	24.98		3.31						21.67	
PZ-08	7/29/2003	24.98		4.07						20.91	
PZ-08	10/31/2003	24.98		4.54						20.44	
PZ-08	1/26/2004	24.98		4.83						20.15	
PZ-08	4/27/2004	24.98		3.18						21.80	
PZ-08	7/20/2004	24.98		3.87						21.11	
PZ-08	10/21/2004	24.98		4.51						20.47	
PZ-08	4/20/2005	24.98		3.26						21.72	
PZ-08	7/21/2005	24.98		3.67						21.31	
PZ-08	1/19/2006	24.98		4.53						20.45	
PZ-08	4/6/2006	24.98		3.70						21.28	
PZ-08	7/11/2006	24.98		3.63						21.35	
PZ-08	10/26/2006	24.98		4.49						20.49	
PZ-08	7/14/2007	24.98		3.70						21.28	
PZ-08	2/28/2008	24.98		4.53						20.46	
PZ-08	1/15/2009	24.98		4.68						20.31	
PZ-08	2/12/2010	24.98	see Note 1	4.67		14.85	see Note 1			20.31	
PZ-08	6/18/2010	25.30		3.26						22.04	
PZ-08	7/1/2010	25.30		3.27						22.03	
PZ-08	9/23/2010	25.30		4.16						21.14	
PZ-08	12/6/2010	25.30		4.94						20.36	
PZ-08	1/25/2011	25.30		4.23						21.07	
PZ-08	3/23/2011	25.30		3.75						21.55	
PZ-08	5/4/2011	25.30		3.22						22.08	
PZ-08	2/27/2013	25.30		4.51		14.85				20.79	
PZ-08	4/17/2013	25.30		3.48		14.86				21.82	
PZ-08	4/22/2013	25.30		3.38		14.88				21.92	
PZ-08	10/18/2013	25.30		4.32		14.80				20.98	
PZ-08	4/14/2016	25.30		3.49		14.74				21.81	
PZ-08	9/18/2017	25.30		4.92		14.78				20.38	
PZ-08	11/5/2018	25.30		4.70		14.72				20.60	
PZ-08	11/12/2019	25.30		4.69		14.70				20.61	
PZ-08	12/10/2020	25.30		4.95		14.73				20.35	
PZ-09	5/19/1998	36.34		13.54						see Note 3	
PZ-09	7/25/2001	36.34		13.96						see Note 3	
PZ-09	10/25/2001	36.34		14.90						see Note 3	
PZ-09	1/22/2002	36.34		14.90						see Note 3	
PZ-09	4/26/2002	36.34		13.05						see Note 3	
PZ-09	7/26/2002	36.34		13.99						see Note 3	
PZ-09	10/17/2002	36.34		15.23						see Note 3	
PZ-09	1/13/2003	36.34		14.07						see Note 3	
PZ-09	4/25/2003	36.34		13.17						see Note 3	
PZ-09	7/29/2003	36.34		14.33						see Note 3	
PZ-09	10/31/2003	36.34		14.54						see Note 3	
PZ-09	1/26/2004	36.34		13.65						see Note 3	
PZ-09	4/27/2004	36.34		13.50						see Note 3	
PZ-09	7/20/2004	36.34		14.23						see Note 3	
PZ-09	10/21/2004	36.34		14.85						see Note 3	
PZ-09	4/20/2005	36.34		15.51						see Note 3	
PZ-09	7/21/2005	36.34		16.20						see Note 3	
PZ-09	1/19/2006	36.34		13.28						see Note 3	
PZ-09	4/6/2006	36.34		15.79						see Note 3	
PZ-09	7/11/2006	36.34		15.75						see Note 3	
PZ-09	10/26/2006	36.34		17.00						see Note 3	
PZ-09	7/14/2007	36.34		16.08						see Note 3	
PZ-09	2/28/2008	36.34		16.30						see Note 3	
PZ-09	1/15/2009	36.34		15.75						see Note 3	
PZ-09	2/12/2010	38.80	see Note 1	15.63		24.94	see Note 1			23.17	
PZ-09	6/18/2010	38.80		15.53						23.27	
PZ-09	7/1/2010	38.80		15.56						23.24	
PZ-09	9/23/2010	38.80		16.24						22.56	
PZ-09	12/6/2010	38.80		16.35						22.45	
PZ-09	1/25/2011	38.80		14.51						24.29	
PZ-09	3/23/2011	38.80		13.89						24.91	
PZ-09	5/4/2011	38.80		15.16						23.64	
PZ-09	2/27/2013	38.81		16.10		24.94				22.71	
PZ-09	4/18/2013	38.81		14.54		24.95				24.27	
PZ-09	4/22/2013	38.81		14.55		24.93				24.26	
PZ-09	10/14/2013	38.81		16.03		24.68				22.78	
PZ-09	4/14/2016	38.81		15.25		24.90				23.56	
PZ-09	9/18/2017	38.81		17.10		24.94				21.71	
PZ-09	11/5/2018	38.81		17.29		24.91				21.52	
PZ-09	11/12/2019	38.81		17.39		24.49				21.42	
PZ-10	5/19/1998	38.45		16.18						22.27	
PZ-10	6/18/2010	38.45		15.25						23.20	
PZ-10	7/1/2010	38.45		15.65						22.80	
PZ-10	9/23/2010	38.45		14.83						23.62	
PZ-10	12/6/2010	38.45		15.31						23.14	
PZ-10	1/25/2011	38.45		13.86						24.59	
PZ-10	3/23/2011	38.45		13.39						25.06	
PZ-10	5/4/2011	38.45		15.07						23.38	
PZ-10	2/27/2013	38.48		16.10		24.09				22.38	
PZ-10	4/18/2013	38.48		13.90		24.11				24.58	
PZ-10	4/22/2013	38.48		14.09						24.39	
PZ-10	10/14/2013	38.48		16.20						22.28	
PZ-10	4/14/2016	38.48		15.03		24.35				23.45	
PZ-10	9/18/2017	38.48		16.68		24.38				21.80	
PZ-10	11/5/2018	38.48		12.23		24.10				26.25	
PZ-10	11/12/2019	38.48		17.24		24.08				21.24	
PZ-10	12/10/2020	38.48		15.37		24.06				23.11	
RW-01	5/19/1998	39.26		16.45						22.81	
RW-01	6/18/2010	39.26		15.88						23.38	
RW-01	7/1/2010	39.26		16.01						23.25	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
RW-01	9/23/2010	39.26		16.40						22.86	
RW-01	12/6/2010	39.26		16.43						22.83	
RW-01	1/25/2011	39.26		14.96						24.30	
RW-01	3/23/2011	39.26		14.38						24.88	
RW-01	5/4/2011	39.26		15.58						23.68	
RW-01	2/27/2013	39.02		16.31		24.43				22.71	
RW-01	4/19/2013	39.02		15.04		24.45				23.98	
RW-01	4/22/2013	39.02		15.01						24.01	
RW-01	10/14/2013	39.02		16.60						22.42	
RW-01	4/14/2016	39.02		15.65		24.46				23.37	
RW-01	9/18/2017	39.02		17.23		24.45				21.79	
RW-01	11/5/2018	39.02		17.47		24.48				21.55	
RW-01	11/12/2019	39.02		17.38		24.43				21.64	
RW-01	12/10/2020	39.02		16.54		24.43				22.48	
TSW-1	10/3/2006	25.44		4.92						20.52	
TSW-1	10/4/2006	25.44		4.91						20.53	
TSW-1	11/6/2006	25.44		4.74						20.70	
TSW-1	6/18/2010	25.44		3.42						22.02	
TSW-1	7/1/2010	25.44		3.40						22.04	
TSW-1	9/23/2010	25.44		4.37						21.07	
TSW-1	12/6/2010	25.44		5.17						20.27	
TSW-1	1/25/2011	25.44		4.52						20.92	
TSW-1	3/23/2011	25.44		4.07						21.37	
TSW-1	5/4/2011	25.44		2.50						22.94	
TSW-1	2/27/2013	25.40		4.73		9.75				20.67	
TSW-1	4/17/2013	25.40		3.72						21.68	
TSW-1	4/22/2013	25.40		3.59						21.81	
TSW-1	10/14/2013	25.40		4.49						20.91	
TSW-1	4/14/2016	25.40	see Note 1	3.70		9.74	see Note 1			21.70	
TSW-1	9/18/2017	25.40		5.06		9.71				20.34	
TSW-1	11/5/2018	25.40		4.85		9.71				20.55	
TSW-1	12/10/2020	25.40		5.15		9.73				20.25	
TSW-2	10/3/2006	27.06		6.59						20.47	
TSW-2	10/4/2006	27.06		6.66						20.40	
TSW-2	11/6/2006	27.06		6.55						20.51	
TSW-2	6/18/2010	27.23		5.20						22.03	
TSW-2	7/1/2010	27.23		5.20						22.03	
TSW-2	9/23/2010	27.23		6.19						21.04	
TSW-2	12/6/2010	27.23		7.00						20.23	
TSW-2	1/25/2011	27.23		6.34						20.89	
TSW-2	3/23/2011	27.23		5.93						21.30	
TSW-2	5/4/2011	27.23		5.24						21.99	
TSW-2	3/1/2013	28.14		6.55		12.05				21.59	
TSW-2	4/18/2013	28.14		5.47						22.67	
TSW-2	4/22/2013	28.14		5.42						22.72	
TSW-2	10/14/2013	28.14		6.28						21.86	
TSW-2	4/14/2016	28.14		6.56		13.28				21.58	
TSW-2	9/18/2017	28.14		8.05		13.28				20.09	
TSW-2	11/5/2018	28.14		7.80		13.30				20.34	
TSW-2	11/12/2019	28.14		7.81		13.27				20.33	
TSW-2	12/10/2020	28.14		8.21		13.29				19.93	
TSW-3	10/3/2006	26.99		6.55						20.44	
TSW-3	10/4/2006	26.99		6.58						20.41	
TSW-3	11/6/2006	26.99		6.51						20.48	
TSW-3	6/18/2010	27.38		5.14						22.24	
TSW-3	7/1/2010	27.38		5.12						22.26	
TSW-3	9/23/2010	27.38		6.12						21.26	
TSW-3	12/6/2010	27.38		6.95						20.43	
TSW-3	1/25/2011	27.38		6.29						21.09	
TSW-3	3/23/2011	27.38		5.86						21.52	
TSW-3	5/4/2011	27.38		5.15						22.23	
TSW-3	3/1/2013	27.82		6.45		11.51				21.37	
TSW-3	4/22/2013	27.82		5.35						22.47	
TSW-3	10/14/2013	27.82		6.23						21.59	
TSW-3	4/14/2016	27.82		6.40		12.42				21.42	
TSW-3	9/18/2017	27.82		7.76		12.44				20.06	
TSW-3	11/5/2018	27.82		7.41		12.50				20.41	
TSW-3	11/12/2019	27.82		7.54		12.40				20.28	
TSW-3	12/10/2020	27.82		7.91		39.30				19.91	
TDW-1	10/3/2006	24.60		4.06						20.54	
TDW-1	10/4/2006	24.60		4.08						20.52	
TDW-1	11/6/2006	24.60		3.88						20.72	
TDW-1	6/18/2010	24.60		2.55						22.05	
TDW-1	7/1/2010	24.60		2.53						22.07	
TDW-1	9/23/2010	24.60		3.50						21.10	
TDW-1	12/6/2010	24.60		4.28						20.32	
TDW-1	1/25/2011	24.60		3.71						20.89	
TDW-1	3/23/2011	24.60		3.18						21.42	
TDW-1	5/4/2011	24.60		2.38						22.22	
TDW-1	2/27/2013	24.57		3.85		42.25				20.72	
TDW-1	4/17/2013	24.57		2.82		42.22				21.75	
TDW-1	4/22/2013	24.57		2.71						21.86	
TDW-1	10/14/2013	24.57		3.59						20.98	
TDW-1	4/14/2016	24.57	see Note 1	2.83		42.20	see Note 1			21.74	
TDW-1	9/18/2017	24.57		4.22		42.20				20.35	
TDW-1	11/5/2018	24.57		4.00		42.20				20.57	
TDW-1	11/12/2019	24.57		4.01		42.22				20.56	
TDW-1	12/10/2020	24.57		4.31		42.25				20.26	
TDW-2	10/3/2006	24.50		4.01						20.49	
TDW-2	10/4/2006	24.50		4.06						20.44	
TDW-2	11/6/2006	24.50		3.97						20.53	
TDW-2	6/18/2010	24.52		2.61						21.91	
TDW-2	7/1/2010	24.52		2.62						21.90	
TDW-2	9/23/2010	24.52		3.69						20.83	
TDW-2	12/6/2010	24.52		4.44						20.08	
TDW-2	1/25/2011	24.52		3.71						20.81	
TDW-2	3/23/2011	24.52		3.35						21.17	
TDW-2	5/4/2011	24.52		2.62						21.90	
TDW-2	3/1/2013	25.11		3.93		40.00				21.18	
TDW-2	4/18/2013	25.11		2.87						22.24	
TDW-2	4/22/2013	25.11		2.85						22.26	
TDW-2	10/14/2013	25.11		3.72						21.39	
TDW-2	4/14/2016	25.11		3.63		40.52				21.48	
TDW-2	9/18/2017	25.11		5.02		40.61				20.09	

Well ID	Date Measured	Top of Casing Elevation (ft USACE)	LNAPL Depth (ft TOC)	DTW (ft TOC)	DNAPL Depth (ft TOC)	Total Depth (ft TOC)	LNAPL Thickness (ft)	DNAPL Thickness (ft)	LNAPL Elevation (ft USACOE)	Corrected Groundwater Elevation (ft USACE)	DNAPL Elevation (ft USACOE)
TDW-2	11/6/2018	25.11		4.79		40.61				20.32	
TDW-2	11/12/2019	25.11		4.81		40.61				20.30	
TDW-2	12/10/2020	25.11		5.15		40.67				19.96	
TDW-3	10/3/2006	26.50		6.05						20.45	
TDW-3	10/4/2006	26.50		6.09						20.41	
TDW-3	11/6/2006	26.50		6.03						20.47	
TDW-3	6/18/2010	26.92		4.65						22.27	
TDW-3	7/1/2010	26.92		4.62						22.30	
TDW-3	9/23/2010	26.92		5.63						21.29	
TDW-3	12/6/2010	26.92		6.46						20.46	
TDW-3	1/25/2011	26.92		5.73						21.19	
TDW-3	3/23/2011	26.92		5.36						21.56	
TDW-3	5/4/2011	26.92		4.62						22.30	
TDW-3	3/1/2013	26.62		5.92		39.42				20.70	
TDW-3	4/22/2013	26.46		4.83						21.63	
TDW-3	4/23/2013	26.46		5.32						21.14	
TDW-3	4/24/2013	26.46		4.80						21.66	
TDW-3	10/14/2013	26.46		5.70						20.76	
TDW-3	4/14/2016	26.46		4.92		39.35				21.54	
TDW-3	11/28/2017	26.46		6.38		39.33				20.08	
TDW-3	11/6/2018	26.43		6.00		39.28				20.43	
TDW-3	11/12/2019	26.43		6.02		39.25				20.41	
TDW-3	12/10/2020	26.43		6.41		39.3				20.02	

Notes:

* Well contains LNAPL. Water elevation corrected based on a LNAPL specific gravity of 0.92 (PTS result for MW09-130415-LNAPL).

** Well contains LNAPL. Water elevation corrected based on a LNAPL specific gravity of 0.98

1. Small amount (trace to 0.01 foot) of NAPL detected. Well has no history of NAPL and NAPL was not subsequently detected. Assumed to be an erroneous measurement.

2. Depth to water below lake level. Well damage suspected. Corrected Groundwater Elevation was not calculated.

3. Top of casing elevation is questionable. Corrected Groundwater Elevation was not calculated.

General Notes:

This table presents available data compiled from mulitple sources. Previous investigators did not report all measurements. Orginal field measurements could not be verifed, especially for older data.

In many cases, NAPL thickness but no depth to NAPL measurements were available. In these cases, NAPL depths and elevations are left blank.

Top of Casing Elevations vary over time due to wells being resurveyed (e.g., 2010 and 2013) and well modifications. Well modifications are documented in Table 3J-1 where records are available.

Horizontal Datum: NAD83 WA State Plane North.