Wyckoff Sheet Pile Wall – Nonaqueous Phase Liquid and Plume Migration Barrier Effectiveness Evaluation

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1.0 Introduction

This technical memorandum presents an evaluation of the existing sheet pile containment wall installed at the Wyckoff/Eagle Harbor Superfund Site (the site). The conceptual site model for the site presumes that natural and constructed features, such as aquitard surface topography and the sheet pile wall integrity, influence nonaqueous phase liquid (NAPL) distribution and migration beyond the upland area. The sheet pile wall is also expected to represent a physical barrier to groundwater flow such that there is limited hydraulic communication between the Upper Aquifer and Eagle Harbor. The purpose of this evaluation is to assess the effectiveness of the sheet pile wall to function as a NAPL and dissolved phase plume migration barrier.

The effectiveness of the sheet pile wall was evaluated based on field measurements conducted from January through May 2013, as well as other data analysis. Data collection included measurement of salinity profiles and under pumping and nonpumping conditions in sheet pile wall seams and at monitoring wells located near the sheet pile wall. Additional data analysis included the following types of information:

- Groundwater elevation data
- Groundwater monitoring data (NAPL measurements)
- Sheet pile wall as-built drawings and measurements
- Boring logs and well construction diagrams for wells located near the sheet pile wall

Analysis of these data included evaluating historical gradient reversals in groundwater level data to assess hydraulic containment of the site, assessing patterns in salinity profiles among wells located at various depths in the Upper Aquifer as well as in the Lower Aquifer, estimating tidal efficiency factors to evaluate the potential effect of tidal influences from Eagle Harbor, and estimating flux through the sheet pile wall by evaluating water level response in the seams due to pumping.

Taken together, the various lines of evidence indicate that the sheet pile wall has a relatively moderate to high degree of effectiveness in hydraulically isolating the upland side of the Upper Aquifer from the Eagle Harbor side. Currently, while there is some hydraulic flux though the sheet pile wall via the seams, a comparison of current to historical tidal efficiency factor measurements combined with the understanding of sheet pile wall schematics indicates that the current hydraulic flux through the sheet pile wall is significantly less than during pre-wall conditions.

NAPL observations within the five channels welded to the sheet pile wall seams suggest that NAPL migration through the sheet pile wall seams is possible. As with the hydraulic flux, current NAPL flux through the wall would be significantly less than pre-wall conditions. This is borne out by the observed reduction in NAPL seeps within the intertidal zone, from pre-wall conditions.

2.0 Description of Outer Wall

Construction of the sheet pile wall was completed in February 2001. The sheet pile wall is located around the outer shoreline perimeter of the site. This wall is approximately 1,870 feet long and extends to a depth approximately 20 to 90 feet below grade (CH2M HILL, 2004). It was constructed with the intention to embed (e.g., key) the bottom of the wall into the aquitard layer. A second inner sheet pile wall was also constructed in the interior portion of the site to isolate the steam extraction remediation pilot test area (CH2M HILL, 2004). This second wall has a total length of 536 feet. The focus of this report is the outer sheet pile wall. Construction information for the outer sheet pile wall was obtained from the *Sheet Pile Installation Summary Technical Memorandum* (CH2M HILL, 2007).

The sheet pile wall was constructed of British Steel Z '5'section sheet piling—also referred to as Frodingham #5 sheet pile. Figure 1 displays a schematic of a typical individual pile with interlocking joints, displaying dimensions (all figures are provided at the end of the main text). The sheet pile wall consists of 674 piles, with two interlocking joints per pile. One of the joints was welded prior to installation of each pile. The unwelded interlocking joint has a seam width estimated at approximately 0.6 millimeters (mm). The unwelded seams are not sealed, and therefore, the potential for leakage through the seams may exist (Arcelor, 2006). The entire sheet pile wall has a surface area of approximately 3 acres (130,598 square feet [ft^2]), and the seams represent approximately 0.07 percent (92 ft^2) of that area. Table 1 summarizes the sheet pile wall as-builts segregated into 13 segments (all tables are provided at the end of the main text). Figure 2 shows the location of the sheet pile wall, the sheet pile wall segments, and the production and monitoring wells at the site. During installation of the sheet pile wall, six sheet pile wall seams were encased on the exterior of the wall with a welded channel. Each welded channel measures approximately 5.25 by 4.5 inches and is capped to prevent direct precipitation into the top. The channels were installed for future monitoring of potential seam leakage.

3.0 Field Investigation Activities

3.1 Summary of Activities

The sheet pile wall evaluation began in January 2013 in accordance with the 2013 *Wyckoff Upland NAPL Investigation Quality Assurance Project Plan* and extended through May 2013. Field measurements were conducted at five (1 through 5) of the six existing seams; seam 6 was inaccessible. The following field data were collected from the seams and at selected monitoring wells located near the seams:

- Measurement of groundwater specific conductance (conductivity) while lowering a programmable multimeter instrument through the water column
- Conductivity measurements of purge water during pumping conditions
- Collection of water level transducer data from April 14 through May 24, 2013

Table 2 lists the dates of the field activities at each seam and well.

Vertical conductivity profiles were conducted within the seams and at selected monitoring wells under nonpumping conditions in January and May 2013. During each event, a programmable multi-meter instrument was slowly lowered into the seams and monitoring wells while the instrument recorded data on a one to five second interval. Conductivity profiles were measured for seams 1 through 5, as well as monitoring wells CW02, RPW7, P-3L, CW07, CW06, CW08, and P-4L.

Conductivity measurements during pumping conditions were performed in March, April, and May 2013. A number of challenges were encountered during March and April pumping attempts (see Section 3.1); therefore, data from the May event are the primary dataset analyzed in this memorandum. Seams and wells were pumped on May 14 through 16. The pump suction depth was held constant while pumping with the suction tubing set at a level of a few feet above the bottom of the seam or well. The conductivity of the purge water was recorded as the seams were pumped until they were essentially dewatered while the monitoring wells were pumped until approximately three well casing volumes of water had been removed (lesser volumes were removed from CW06 due to NAPL presence and from RPW7 due to large calculated well volume). It should be noted that due to pumping challenges and slow recovery, the static water level in seam 3 had not yet fully recovered prior to pumping on May 15.

To address a data gap identified following U.S. Environmental Protection Agency's (EPA's) review of this Draft Technical Memorandum, additional investigation activities were conducted to obtain the data needed to assess the wall's physical integrity and to estimate its life expectancy. Field tests conducted on October 30 and 31, 2013, included general observations, measurement of sheet pile thickness and pit depths, and measurement of distance between the top of the wall and the mud line (water side) and fill (soil side). These tests were performed at nine locations distributed around the perimeter of the sheet pile wall (see Figure 2). The thickness of the piling was measured at one or a combination of five vertical spots at each test location. Vertical spot definitions, dimensions, and general description of the piling condition (as found) are summarized in Table 3. These data were used to estimate sheet pile wall corrosion rates, the time to develop pinhole leaks, and the time to structural failure. The memorandum provided in Attachment 1 describes in more detail the field investigation activities and the evaluation of results.

3.2 Difficulties Encountered

Two attempts to obtain conductivity data during pumping conditions were necessitated due to pump malfunctions, as well as variable pump depths within the seams during pumping. During the first measurement attempt, performed in March and April, the pump was not heavy enough to allow it to sink through the water column to the desired height before beginning the pump; therefore, the pump was lowered during pumping. This made the resulting data undecipherable, and the second field effort was employed with a weighted pump. Following completion of the March and April 2013 seam pocket pumping, a decision was made to collect a second round of conductivity profiles on the five seams and selected wells from a fixed pump depth near the bottom depth at each location.

4.0 Sheet Pile Wall Effectiveness—Lines of Evidence Evaluation

The sheet pile wall evaluation examines both the recently collected data described in the previous section, as well as data sourced from hydraulic containment performance monitoring. A number of lines of evidence are evaluated to assess the wall's effectiveness as a hydraulic and NAPL migration barrier. The lines of evidence examined include the following:

- A history of vertical gradient reversals in the ten well pairs used to monitor hydraulic containment effectiveness
- Vertical conductivity profiles in monitoring wells near the sheet pile wall to evaluate potential Eagle Harbor salt water intrusion
- Tidal efficiencies of Upper Aquifer wells calculated from water level monitoring data obtained under nonpumping conditions
- Vertical conductivity profiling inside the seams, groundwater specific conductance measurements of water purged from the seams, and subsequent water level recovery monitoring inside the seams
- The distribution of NAPL as determined by the TarGOST results near the sheet pile wall, relative to the sheet pile wall driven depths and soil type

These lines of evidence focus primarily on migration pathways that might exist through the wall joints or beneath the piles. Pathways through the body of individual piles—associated with potential corrosion or other mechanical failure—are evaluated separately in Section 5.0. Such pathways, if present, are more likely to influence migration of dissolved phase contaminants and, to a lesser extent, light and dense NAPL.

4.1 History of Vertical Gradient Reversals

Performance monitoring of the current hydraulic containment system relies on water level monitoring at ten selected monitoring wells pairs; three are located within the interior portion of the site, with the other seven located just inside the outer sheet pile wall (Figure 2). Historical water level monitoring has indicated that upward vertical gradients have not been continuously maintained in some of the well pairs adjacent to the sheet pile wall. A hypothesis has been suggested that the sheet pile wall is not a perfect low-permeability hydraulic barrier at select locations. This section evaluates recently obtained water level data to identify potentially problematic areas along the sheet pile wall.

In March 2012, Model 705 KPSI™ Level and Pressure Transducers, installed in 22 Upper Aquifer wells and 18 Lower Aquifer wells, were calibrated, subsequently replacing the older Solinst Leveloggers. The water level monitoring data collected following installation of the new transducers are summarized in this section to highlight vertical gradient trends at ten selected monitoring well pairs. Table 4 presents a compilation of the summary tables from the four quarterly water level monitoring reports from March 26, 2012 through March 20, 2013. These reports summarize site water level data that represent the four seasonal observation periods used to evaluate performance of the hydraulic containment remedy. Findings from each of the four quarters are as follows:

- March 26 through June 23, 2012 (on average, 14 percent of annual rainfall occurs during this period)
  - Hydraulic containment was maintained in the ten well pairs as defined by the average lower aquifer to average upper aquifer groundwater elevation ratio of greater than one.
  - Short-term vertical gradient data (short-term change per 15-minute recording) indicate that an upward (e.g., nonnegative) gradient was maintained at all times during the 90-day monitoring period at seven of the ten monitoring well pairs.
  - A series of short-duration downward (e.g., negative) gradient periods occurred at three monitoring well pairs. In two of the three well pairs (CW13/VG-4L and CW08/P-4L), the percent duration of negative gradient period is greater than 10 percent. The average duration of each event is 5.7 hours and 4.2 hours, respectively.
- June 21 to September 24, 2012 (6 percent of average annual rainfall occurs during this period)
  - Hydraulic containment was maintained in the ten well pairs as defined by a Lower Aquifer to Upper Aquifer groundwater elevation ratio greater than one.
  - Short-term vertical gradient data indicate that an upward gradient was sustained at all times during the 90-day monitoring period at two of the monitoring well pairs (VG-2U/VG-2L and VG-5U/VG-5L).
  - A series of short-duration downward gradient periods occurred at eight monitoring well pairs. In one of the eight well pairs (CW08/P-4L), the percent duration of the downward (negative) gradient period was greater than 10 percent. The average duration of the downward gradient period ranged from 1.8 to 4.3 hours.
- September 22 to December 20, 2012 (43 percent of average annual rainfall occurs during this period)
  - Hydraulic containment was maintained in the ten well pairs as defined by a Lower Aquifer to Upper Aquifer groundwater elevation ratio greater than one.
  - Short-term vertical gradient data indicate that an upward gradient was sustained at all times during the 90-day monitoring period at two of the monitoring well pairs (VG-2U/VG-2L and VG-3U/VG-3L).
  - A series of short-duration downward gradient periods occurred in eight monitoring well pairs. In five of the eight well pairs (PO03/99CDMW02A, VG-5U/VG-5L, PO13/VG-1L, CW13/VG-4L, and CW08/P-4L), the percent duration of the downward vertical gradient was greater than 10 percent. At two (CW13/VG-4L and CW08/P-4L) of these five wells, the percent duration was greater than 30 percent, respectively. The average duration of each downward vertical gradient event ranged from 0.8 hours (MW18/02CDMW01) to 18 hours (CW13/VG-4L).
- December 21, 2012 to March 20, 2013 (37 percent of average annual rainfall occurs during this period)
  - Hydraulic containment was maintained, as defined by a Lower Aquifer to Upper Aquifer groundwater elevation ratio greater than one, at nine of the ten well pairs, but not at well pair CW13/VG-4L, where a ratio of 0.99 was calculated.

- Short-term vertical gradient data indicate that an upward gradient was sustained at all times during the 90-day monitoring period at two of the monitoring well pairs (VG-2U/VG-2L and VG-3U/VG-3L).
- A series of short-duration downward gradient periods occurred at eight monitoring well pairs. In five of the eight well pairs (MW14/CW05, VG-5U/VG-5L, PO13/VG-1L, CW13/VG-4L, and CW08/P-4L), the percent duration of the downward vertical gradient period was greater than 10 percent. At two (CW13/VG-4L and CW08/P-4L) of the five wells, the percent duration was greater than 30 percent, respectively. The average duration of each downward vertical gradient ranged from 3.75 hours (MW18/02CDMW01) to 22.25 hours (CW13/VG-4L).

Based on the 2012 to 2013 observation period, there were extended periods (more than 30 percent of the total duration between September 2012 and March 2013) where downward gradients occurred at monitoring well pairs CW13/VG-4L and CW08/P-4L. Well pair CW13/VG-4L is located on the west end of the site near production well PW9 and sheet pile segment 2, while well pair CW08/P-4L is located on the north end of the site next to sheet pile segment 4 (see Figure 2 for well locations). These two well pairs, for all four seasonal observation periods, consistently showed a greater frequency, a greater average duration, and a greater total duration of downward vertical gradients than did the other well pairs.

Downward vertical gradients can be a function of tidal fluctuation, precipitation, and pumping of the hydraulic containment system. The magnitude of tidal influence effects on Upper and Lower Aquifer groundwater elevations might partly depend on the effectiveness of the sheet pile wall. Tidal influences on upland monitoring wells are further evaluated in the following section through estimation of tidal efficiencies. Backup for the data classes is provided electronically in Attachment 2.

4.2 Evaluation of Monitoring Wells near the Sheet Pile Wall

Two data classes are available for analysis in support of evaluating sheet pile wall integrity. These data classes includes vertical conductivity/salinity profiles in select Upper and Lower Aquifer wells and water level elevation data, which are used to estimate tidal efficiency factors for site monitoring wells. Each data class and its associated interpretation are presented separately below.

4.2.1 Groundwater Conductivity/Salinity

Using this first class of data, vertical groundwater conductivity/salinity profiles for three monitoring well clusters may be compared to one another as well as to measurements from Eagle Harbor to evaluate relative hydraulic connection of the wells to Puget Sound using salinity as a qualitative tracer. This approach presumes that, if the sheet pile wall (driven through the Upper Aquifer and keyed into the aquitard) is functioning as a perfect low-permeability hydraulic barrier, then the relative salinity in the monitoring well clusters should be a function of the flow path length from Eagle Harbor. The flow path length includes the horizontal distance from the sheet pile wall to the monitoring well, and the well screen elevation relative to the aquitard as the vertical distance.

If Eagle Harbor is the source of the salinity, its conductivity/salinity influence is expected to decrease with increased distance from the harbor and with increased flow path height above the aquitard. For example, within each well cluster examined, the paired Lower Aquifer well, not isolated from Eagle Harbor by the sheet pile wall, would be expected to have a higher relative salinity measurement than its Upper Aquifer counterpart. The next highest salinity measurements would be expected to occur in deep Upper Aquifer wells screened closest to the aquitard. Shallow Upper Aquifer wells screened near the water table would be expected to have the lowest relative salinity.

Figure 3 displays the conductivity profile for the well cluster RPW7 and CW02 located to the southeast along sheet pile wall segment 10. In this case, RPW7 is screened across the entire Upper Aquifer. Below an elevation of -22 feet MLLW, the percent salinity readings at RPW7 increase above those from CW02 screened in the Lower Aquifer. The elevated salinity observed at the base of RPW7, which is comparable with levels present in the harbor, does not match the expected pattern (i.e., salinity less than 100 percent) for a perfect low-permeability hydraulic barrier. The elevated salinity observed at RPW7 in comparison with the lower salinity at CW02 suggests there is increased hydraulic exchange with Eagle Harbor either through the sheet pile wall or directly beneath it, depending on how the wall is keyed into the aquitard. The salinity profile for Deep Aquifer monitoring well CW02, which was lower than expected based on the observed thinning of the aquitard in its vicinity, suggests this well might lie at the margin of the freshwater-saltwater interface. This interface can be a diffused or sharp boundary that shifts laterally in response to tidal fluctuations. Depending on where the well lies relative to this front, there might be marked differences in salinity between measurement events performed during low and high tide periods.

Figure 4 displays the conductivity profile for the well cluster set CW06, CW07, and P-3L located to the north. The conductivity profile matches the expected pattern for a perfect low-permeability hydraulic barrier. It should be noted that NAPL was observed in at Upper Aquifer well CW06 and Lower Aquifer Well P-3L. Recent TarGOST results also indicate NAPL presence along the top of the aquitard inside the sheet pile wall in this vicinity.

Figure 5 displays the conductivity profile for the well cluster set CW08 and P-4L along Segment 4 of the sheet pile wall to the northwest. In this case there is no Upper Aquifer well screened directly above the aquitard. Below an elevation of -10 MLLW, the percent salinity readings increase and match the readings from well P-4L screened in the Lower Aquifer. If a deeper Upper Aquifer well was present at this location, the CW08 salinity profile suggests that it would have a higher percent salinity than CW08 and most likely be comparable with well P-4L. Consequently, this well cluster's salinity pattern likely does not match the expected pattern for a perfect low-permeability hydraulic barrier. Instead this pattern of higher salinity present in the Upper Aquifer suggests a more direct hydraulic exchange with Eagle Harbor, either through the sheet pile wall beneath it depending on how the wall is keyed into the aquitard or lateral migration around the ends of the wall.

In summary, the conductivity readings by depth, collected in selected Upper Aquifer and Lower Aquifer monitoring wells, indicate greater hydraulic connection to Eagle Harbor; especially near well clusters RPW7/CW02 and CW08/P-4L.

4.2.2 Tidal Efficiencies

Site monitoring well water levels, collected for hydraulic containment performance monitoring, show varying groundwater elevations that mimic tidal fluctuations. For aquifers next to tidal bodies, the magnitude of tidal-induced groundwater elevation fluctuations is greatest closest to the shoreline and dampened inland with increasing distance from the shoreline. Using this phenomenon, the water level data collected for performance monitoring purposes can be utilized to evaluate aquifer system hydraulics. Specifically, the relative amplitudes of the water level elevations in wells versus tidal stage can be used to calculate a tidal efficiency factor for each well. With installation of the sheet pile wall, the tidal efficiency factors for wells inside the wall are expected to decrease because the wall, as a low permeability hydraulic barrier, will dampen the tidal influence inside the wall. Examination of the wall's effects on tidal efficiencies might provide a method for evaluating the wall's effectiveness as a hydraulic and NAPL migration barrier.

Tidal efficiencies were calculated in upland site monitoring wells, at locations adjacent to the wall and at five sheet pile wall seams using the method presented by Erskine (1991). Water levels in the monitoring wells and seams were measured using pressure transducers deployed at the site. Water levels from the Seattle National Oceanic and Atmospheric Association (NOAA) Station 9447130 were used for the tidal stage. The Erskine method calculates the tidal efficiency factor as the ratio of the standard deviation of the two sets of readings. The tidal efficiency factor is a measure of the aquifer's response to tidal changes and can be used to estimate hydraulic properties of the aquifer including transmissivity (Ferris, 1951). For the monitoring wells, tidal efficiencies were calculated for a 24-hour period corresponding to nonpumping conditions (September 16, 2012, 7:48 am to September 17, 2012, 7:48 am). For the seams, tidal efficiencies were calculated for a 24-hour period corresponding to when water levels in the seams had fully recovered from seam pumping performed in May 2013 (May 12, 2013, 11:20 pm to May 13, 2013, 11:20 pm). Based on these calculations, tidal efficiency factors were calculated by well and at sheet pile wall seams to develop another line of evidence on sheet pile wall integrity.

Figure 6 displays the tidal efficiency factors posted on a site map. A scatter plot depicting tidal efficiency factors (Y-axis) versus the distance from the 0 MLLW tidal elevation (X-axis) is also shown. The tidal efficiency calculations are provided on CD in Attachment 2. Tidal efficiencies in the seam channels ranged from less than 1 percent (seam 2) to 6 percent (seam 5). Tidal efficiencies in Upper Aquifer monitor wells ranged from 0.4 percent (CW08) to 54 percent (VG-2U) while Lower Aquifer wells ranged from 24 percent (PZ-03) to 54 percent (P-1L).

Presuming the sheet pile wall acts as an effective hydraulic barrier (note: the joints provide 0.14 percent open area), the Upper Aquifer wells should have similar tidal efficiencies to the seams, while the Lower Aquifer wells are expected to have the greatest tidal efficiencies. In general, the tidal efficiency factor results follow the expected pattern with a few notable exceptions. There are three Upper Aquifer wells within 150 feet of 0 feet MLLW that exhibit tidal efficiencies that are greater than the seams: CW03 at 27 percent, VG-2U at 54 percent, and RPW4 at 25 percent. These results suggest greater hydraulic connection to Eagle Harbor near these three wells.

With respect to well pairs CW13/VG-4L and CW08/P-4L, which showed a greater frequency and duration of downward vertical gradients during the four observation periods as described in Section 4.1, the tidal efficiency factors of the Upper Aquifer wells CW13 and CW08 are 2 percent and 0.4 percent, respectively. The low tidal efficiencies in these Upper Aquifer wells suggest that the sheet pile wall is an effective hydraulic barrier in these areas, and the integrity of the wall is not responsible for the vertical gradient reversals observed at these two well locations.

Historical tidal efficiency factors representing conditions before the sheet pile wall was installed are available for a limited number of site monitoring wells. For Upper Aquifer wells CW13 and MW14, prewall tidal efficiency factors were 54 percent and 21 percent, respectively (CH2M HILL, 1996). The subsequent reduction in tidal efficiency to 2 percent and 7 percent, respectively, indicates a substantial decrease in the hydraulic connection of the Upper Aquifer with Eagle Harbor in these two areas.

4.3 Evaluation of Seam Data

Continuous water level data were measured using pressure transducers installed in the five sheet pile wall seams, while most of the seam investigation activities were conducted. Figure 7 displays the resulting hydrographs for each seam. The hydrographs exhibit the resulting drawdown and recovery from when the seams were pumped, and the arrow indicates when the corresponding seam salinity and conductivity profiles were conducted. This figure is presented because the sequence of the seam investigation activities could influence the data interpretation.

The seam investigation activities resulted in the collection of two data classes—specific conductivity measurements expressed as percent salinity relative to comparative readings from Eagle Harbor and measured water level response to seam pumping. Each data class with resulting interpretations is presented separately below. Backup of the two data classes is provided in Attachment 2.

4.3.1 Specific Conductance as Percent Salinity

The first data class attempts to differentiate the source of water in the seams by measuring its conductivity as a function of depth and by monitoring percent salinity of the water discharged during pumping of the seam. Figure 8 displays the vertical conductivity profiles for the five seams and the timeframe each profile was measured relative to the tidal stage. The seam conductivity profiles are plotted in the five upper charts. In the two lower charts, the times when the profiles were conducted are plotted against tidal stage (tidal fluctuation could affect conductivity profile results). Figures 9A to 9E display conductivity versus time while the seams were being pumped on May 14, 2013. Vertical conductivity profiles for the individual seams are also displayed for comparative purposes. Table 5 summarizes some of the seam data discussed in this analysis.

Relevant interpretations from these figures and supporting data are as follows:

- The vertical conductivity profiles (left-side chart) indicate a transition from freshwater to brackish water in each seam with increasing depth. The transition is indicated by a change in slope in the conductivity profiles. For evaluation purposes, an approximate midpoint elevation of the change in slope was identified for each profile (see Table 5). Midpoint transition elevations ranged from the shallowest depth at -13 feet MLLW (seam 3) to the deepest at -41 feet MLLW (seam 5). The cause of varying depths of the freshwater to saltwater transition is likely a function of upland flux through the sheet pile wall seam channel, versus potential flux through holes in the outer seam box which are expected to be more saline. Regardless, because the seams are capped, thereby precluding the accumulation of precipitation, the presence of the freshwater in each of the seams indicates a hydraulic connection with the upland side of the Upper Aquifer.

- For seams 2, 3 and 5, the conductivity profiles indicate rather significant changes between the January and May measurement events. These changes could be a function of either tidal fluctuations or the first attempt at seam pumping in March and April. Further evaluation of temporal changes in the conductivity profiles would require additional conductivity measurements over multiple depths and tidal cycles. For the purpose of determining sheet pile wall integrity, understanding potential temporal changes in conductivity profiles is likely not necessary.
- Average percent conductivity relative to Eagle Harbor is calculated from the January conductivity profile and presented in Table 5. Values range from 17 percent (seam 4) to 45 percent (seam 2). These values might correlate with the magnitude of potential hydraulic connection through the seam channel relative to the other seams.
- With regards to conductivity versus time during seam pumping, the conductivity values are initially dependent on the pump intake depth. For pump intakes set at shallow depths (due to obstructions encountered at Seams 1 and 2), the conductivity readings are relatively stable with time until the water level is drawn down to the pump's suction intake depth and pumping is ceased. For seams 3, 4, and 5, conductivity readings decrease with time as brackish water at the bottom of the seams is first evacuated followed by the freshwater above.
- NAPL was observed in seam 5 during the initial pumping activities and product odors were observed in seams 1 and 2.

To summarize the analysis of the specific conductance data class, the data results indicate the seams contain a mixture of freshwater and brackish water suggesting a hydraulic connection through the sheet pile wall. Other data relationships—such as the variability in freshwater to saltwater transition depths and potential temporal changes in the conductivity profiles—were identified but deemed less important as an integrity evaluation tool. The presence of NAPL in seam 5 and dissolved phase contamination in seams 1 and 2 suggest that NAPL migration through the sheet pile joints is possible.

4.3.2 Measured Water Level Response to Seam Pumping

The second data class evaluates water level recovery rates following pumping of the seams in an effort to quantify the potential flux across the sheet pile wall. The data collected indicate the fastest recovery rate occurred in seam 2 and the slowest recovery occurred in seam 3. After the pump was shut down, the water level was measured in each seam, and the volumetric flux (milliliters per minute) was calculated by multiplying the change in water level between pressure transducer readings (every 10 minutes) by the total seam area. This results in an estimated flux rate every 10 minutes. The water level in each seam was compared with a concurrent water level measurement from a nearby Upper Aquifer monitoring well to estimate the change in water level across the sheet pile wall. The estimated volumetric flux into the seam was plotted against the change in head across the wall, and a linear interpolation was applied. Figures 10A and 10B present the results for the trend analysis for each of the seams. Using the line equation from the trend analysis, quarterly average water levels for the associated Upper Aquifer wells (see Table 4), and mean sea level, the flux across each of the five seams can be estimated for average conditions.

Table 6 presents the resulting flux estimates for each seam. The estimated flux ranges from -80 milliliters per minute (mL/min) (seam 2) to 0.2 mL/min (seam 1). Because a negative flux indicates flow in from Eagle Harbor to the upland, this analysis suggests that under average conditions the groundwater flux at seams 2 through 5 is from Eagle Harbor to the upland as induced by the hydraulic containment system. As a check on these seam fluxes and to get a sense of the potential magnitude of the flux across the entire sheet pile wall, an order of magnitude estimate of total sheet pile wall flux is calculated by dividing each seam volumetric flux (Q) by individual seam length, resulting in a unit flux (q). These were averaged and multiplied by the total length of all seams across the entire sheet pile to calculate an inward potential flux of -5 gallons per minute.

4.4 TarGOST versus Geology

As the final line of evidence, TarGOST log results are plotted in alignment with the sheet pile wall as fence diagrams (see Figures 11A, 11B, and 11C). Fence diagram alignment locations are shown on Figure 6. Sheet pile wall as-built elevations are used to project driven elevations onto the fence diagrams. Where present and available, geologic, well construction, and NAPL observations are also plotted. Interpolated surfaces are also plotted, including the groundwater levels under nonpumping conditions, the interpolated top of aquitard, and the interpolated TarGOST refusal depths (a potential corollary to the aquitard top). Relevant observations pertaining to sheet pile wall integrity, grouped by the three fence diagrams, are described in the following subsections.

4.4.1 Fence Diagram Ga – Gb (Panel 1 from Southwest to Northeast)

The sheet pile wall was advanced well below the top of the aquitard until the coincident TarGOST boring 2013T-104. After this, the slope of the TarGOST refusal depths steepens relative to the slope of the driven sheet pile depths. At the location coinciding with monitoring well VG-3U, the sheet pile wall driven elevation is approximately 5 feet below the top of the aquitard. This particular well has a tidal efficiency factor of 22 percent, which is relatively high in comparison with other wells screened in the Upper Aquifer. This well is screened at the bottom of the Upper Aquifer. A review of the well screen details and geology description in the neighboring VG-3L boring indicates a 25 foot sequence of clay and silt with an interbedded silty sand layer. The high tidal efficiency factor at VG-3U is likely a function of the relatively shallow driven aquitard depths.

4.4.2 Fence Diagram Gb – Gc (Panel 2 from West to East around the northern point)

The projected sheet pile wall driven depths closely mirror but are slightly deeper than the TarGOST boring refusal depths from VG-3U to just past the TarGOST boring 2013T-106. After this, the TarGOST boring refusal depths rise to well above the sheet pile wall driven depths. At the location coinciding with monitoring well VG-2U, the sheet pile wall driven elevation is approximately 12 feet below the top of the aquitard. This particular well has an elevated tidal efficiency factor of 53 percent. At this location the aquitard thickness is relatively thin compared with other areas of the site. A review of the well screen details and geology description in this boring indicates only a 10-foot-thick silt layer between the bottom of the well screen and the top of the Lower Aquifer. This is the likely reason for the high tidal efficiency factor at VG-2U.

4.4.3 Fence Diagram Gc – Gd (Panel 3 from Northwest to Southeast)

The projected sheet pile wall driven depths mirror, but are deeper than, the TarGOST boring refusal depths from TarGOST boring 2013T-163 to SE-02. At the location coinciding with monitoring well CW03, the sheet pile wall driven elevation is 11 feet into the aquitard. This particular well has an elevated tidal efficiency factor of 27 percent. This well is screened at the bottom of the Upper Aquifer. Also, the aquitard thickness is relatively thin (14 feet) at this location compared with other areas of the site. Furthermore, the aquitard pinches out toward nearby monitoring well SE-02 to the southeast. These are likely reasons for the high tidal efficiency factor at CW03.

5.0 Life Span Evaluation

Based on the investigation data obtained in October 2013, sheet pile wall corrosion rates were estimated at varying wall depths. This information, in turn, was used to estimate the time to develop pinhole leaks and the time to structural failure.

5.1 Corrosion Evaluation Results

Conclusions from the corrosion evaluation are as follows:

1. The atmospheric exposed portion of the wall is experiencing relatively rapid corrosion. The relatively high corrosion rate in this zone is attributed to soil-side corrosion due to salt accumulation in the fill near the surface (very little corrosion was observed on the seaside surfaces in the atmospheric zone).

2. The most significant corrosion is occurring in the “splash” zone. The highest pitting rates were measured in this zone; the most rapid “time-to-penetration” of the wall is expected in this zone.

a. Pit depth measurements indicated pitting is occurring at a rate of 12.5 mils per year. At this pitting rate, the thinner section of the wall (web) would be penetrated approximately 37 years after installation (in the year 2038).

b. However, since only a very small portion of the wall was cleaned for close observation and thickness measurements, the pitting rate in this area could be much higher. As a conservative estimate, a pitting rate as high as 25 mils per year is assumed. At a 25-mil-per-year corrosion rate, the thinnest part of the wall would be penetrated 19 years after installation (in the year 2020).

3. The corrosion rates in the "tidal," "submerged," and "mud" zone are relatively low when compared with the "splash" zone. The time-to-penetration of the wall in these zones will be much longer than that expected for the "splash" zone.

Based on the both the observed and probable pitting rates pin hole leaks are anticipated to develop between 6 and 24 years as measured from late 2013 current conditions. With periodic inspection, these pinhole leaks can be detected and repaired, thereby extending the lifespan of the sheetpile wall.

5.2 Structural Evaluation Results

The minimum expected lifespan of the sheetpile wall in the "splash" zone due to general corrosion rates is approximately 13.5 years, if yearly inspections and repairs are not conducted. Wall failure due to general corrosion rates will likely be in the form of a localized, ductile failure that will be seen as bulging of the wall or splitting or cracking of the sheetpile sections. With periodic inspection, these localized failures can be dealt with on a case-by-case basis and repaired as needed. The sheetpile in the "splash" zone is also vulnerable to the development of small holes due to pitting corrosion that will grow larger if not monitored and repaired. With periodic monitoring and maintenance, the lifespan of the sheetpile wall can be extended to 23 to 29 years.

6.0 Conclusions

This technical memorandum summarizes construction details for the outer sheet pile wall, describes recent field investigation activities performed between January 2013 and May 2013 and presents the results from a multiple lines of evidence data evaluation conducted to assess the sheet pile wall's effectiveness as a NAPL and dissolved phase plume migration barrier. It also presents the supplemental investigation and evaluation of potential life span of the wall.

6.1 General Conclusions

General conclusions from evaluating the multiple lines of evidence of the sheet pile wall effectiveness are as follows:

- The sheet pile wall consists of 674 piles, with two interlocking joints per pile. Each interlocking joint has a seam width estimated at approximately 0.6 mm. The seams are not sealed. The entire sheet pile wall has a surface area of approximately 3 acres (130,598 ft^2), and the seams represent approximately 0.07 percent (92 ft^2) of that total area.

- Evaluation of vertical hydraulic gradients between the Upper and Lower Aquifers over the March 26, 2012, to March 20, 2013, period indicates extended periods of downward vertical gradients at monitoring well pairs CW13/VG-4L and CW08/P-4L. While these downward vertical gradient periods could be a function of tidal fluctuation, precipitation, and/or pumping of the hydraulic containment system, examination of tidal efficiency data suggests that tidal fluctuation plays a minor role in causing short duration downward gradients.

- Groundwater specific conductance profiles for selected monitoring wells located along the sheet pile wall indicate a more direct hydraulic connection to Eagle Harbor at two of the three well clusters evaluated (clusters RPW7/CW02 and CW08/P-4L) than would be expected with the sheet pile wall acting as a hydraulic barrier.

- Comparing historical tidal efficiency factors with current values at Upper Aquifer wells CW13 and MW14 indicates a substantial decrease in the hydraulic connection of the Upper Aquifer with Eagle Harbor (from 54 to 2 percent at CW13, and from 21 to 7 percent at MW14) following installation of the sheet pile wall. This suggests that the sheet pile wall is a considerable, but not complete, hydraulic barrier within the Upper Aquifer between the upland area and Eagle Harbor. Because the pile joints are not sealed, it is expected that some fluid movement through the joints will occur.

- Specific conductance measurements performed on water pumped from the sheet pile wall seams indicates the seams contain freshwater in the upper portion and brackish water in the lower portion. The presence of freshwater in the seam suggests a hydraulic connection with the Upper Aquifer through the pile joints. The presence of NAPL in seam 5 and dissolved phase contaminants in seams 1 and 2 suggests that contaminant migration through the sheet pile wall is possible.
- Water level responses to seam pumping were used to develop correlations between the seam influx and head difference between the seam and a nearby interior monitoring well. Based on these correlations, and averaged hydraulic conditions for the March 26, 2012, through March 20, 2013, period, the estimated flux ranges from -80 mL/min (seam 2) to +0.2 mL/min (seam 1). The averaged groundwater flux for seams 2 through 5 indicates a net inflow from Eagle Harbor to the upland as induced by the hydraulic containment system. An order of magnitude estimate of total sheet pile wall flux was calculated at -5 gallons per minute indicating an inward flux of saltwater across the sheet pile wall toward the upland.
- The final line of evidence consisted of plotting TarGOST log results along the alignment with the sheet pile wall as fence diagrams. Sheet pile wall as-built elevations were used to project driven elevations onto the fence diagrams, and where present, available geologic, well construction, and NAPL observations are also plotted. This line of evidence indicates that the sheet pile wall has been driven to sufficient depths, that it is keyed into the aquitard.

Taken together the various lines of evidence indicate that the sheet pile wall has a relatively moderate to high degree of effectiveness in hydraulically isolating the upland side of the Upper Aquifer from the Eagle Harbor side. Currently, while there is some hydraulic flux though the sheet pile wall via the seams, comparing current to historical tidal efficiency factor measurements, combined with our understanding of sheet pile wall schematics, indicates that the current hydraulic flux through the sheet pile wall is significantly less than during prewall conditions.

NAPL observations within the five channels welded to the sheet pile wall seams suggest that NAPL migration through the sheet pile wall seams is possible. As with the hydraulic flux, current NAPL flux through the wall would be significantly less than pre-wall conditions. This is borne out by the observed reduction in NAPL seeps within the intertidal zone, from when the wall was installed to the present.

6.2 Conclusions from Life-Span Evaluation

Based on the both the observed and probable pitting rates pin hole leaks are anticipated to develop between 6 and 24 years as measured from late 2013 current conditions. The structural evaluation indicates the minimum expected lifespan of the sheetpile wall in the “splash” zone due to general corrosion rates is approximately 13.5 years. Wall failure due to general corrosion rates will likely be in the form of a localized, ductile failure that will be seen as bulging of the wall or splitting or cracking of the sheetpile sections. With periodic inspection, these localized failures can be dealt with on a case-by-case basis and repaired as needed. The sheetpile in the “splash” zone is also vulnerable to the development of small holes due to pitting corrosion that will grow larger if not monitored and repaired. With periodic monitoring and maintenance, the lifespan of the sheetpile wall can be extended to 23 to 29 years.

7.0 References

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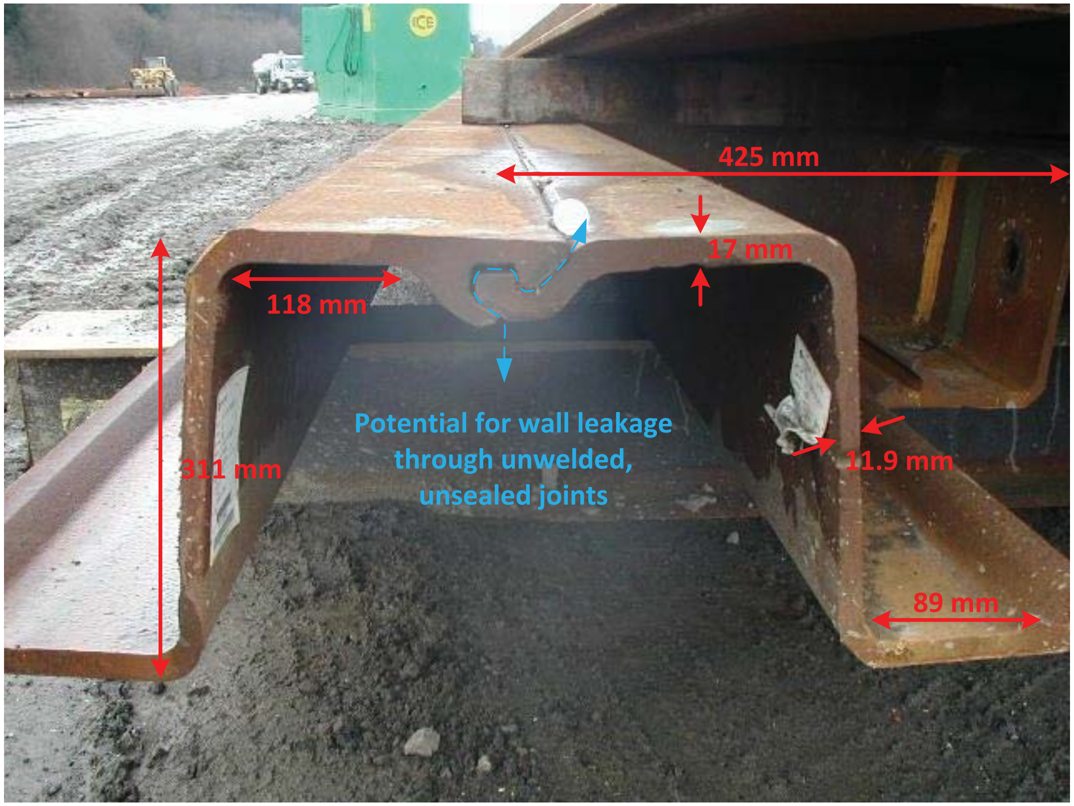
Figures

Dimensions of Typical Pile



Approximate Size of Joint between Piles

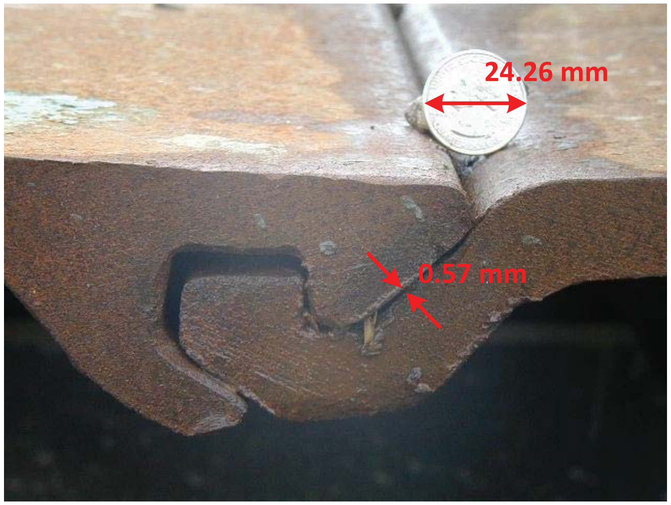


Figure 1

Schematic of Typical Individual Pile with Interlocking Joints

Wyckoff Sheet Pile Wall Investigation

Wyckoff/Eagle Harbor Superfund Site

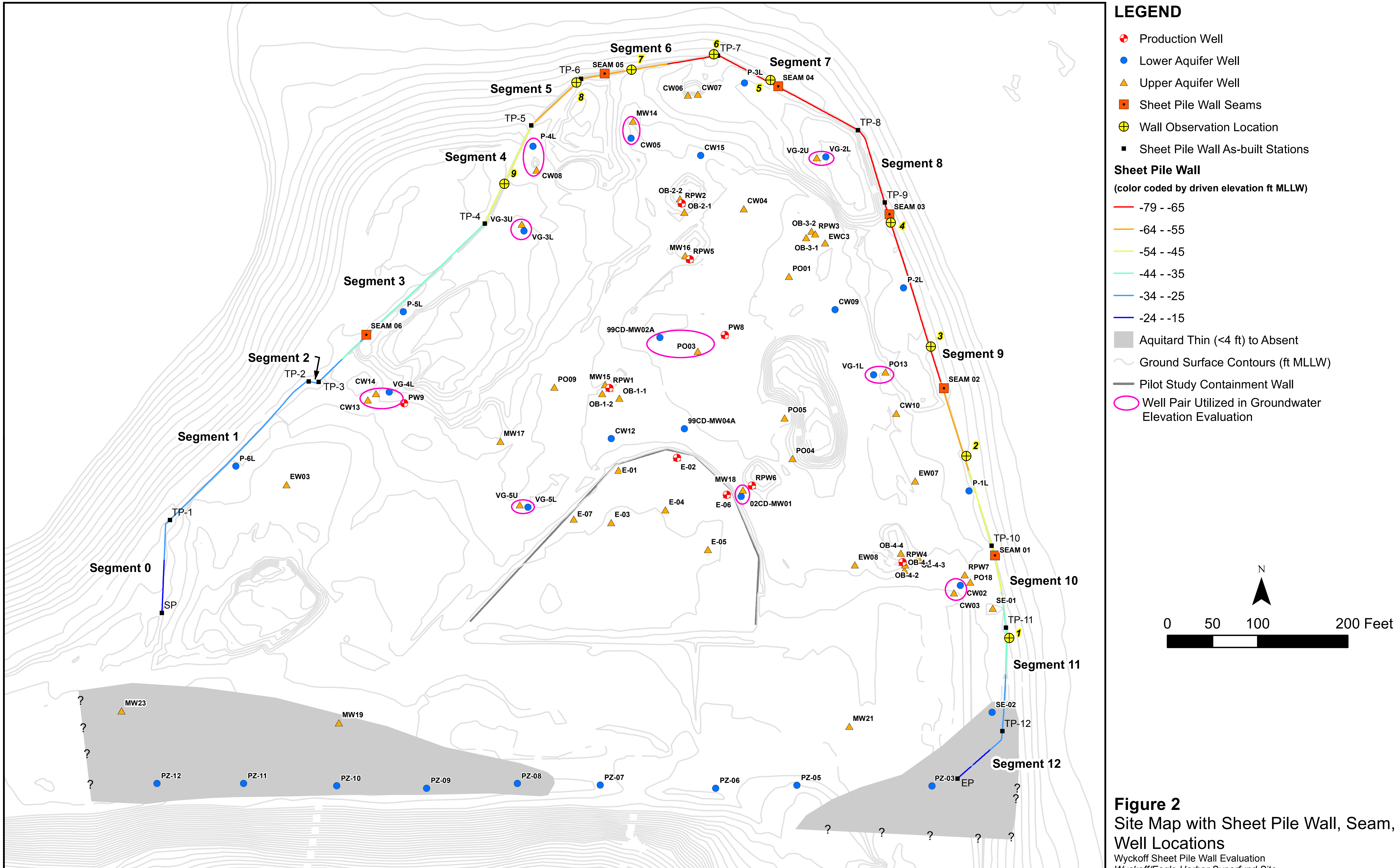


Figure 2

Site Map with Sheet Pile Wall, Seam, and Well Locations

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

C:\USERS\GGEE\DOCUMENTS\GIS\WYCKOFF\MAPFILES\2013\SHEET PILE WALL EVALUATION MEMO\FIGURE2_SITEMAP.MXD GGEE 12/9/2013 7:11:55 AM

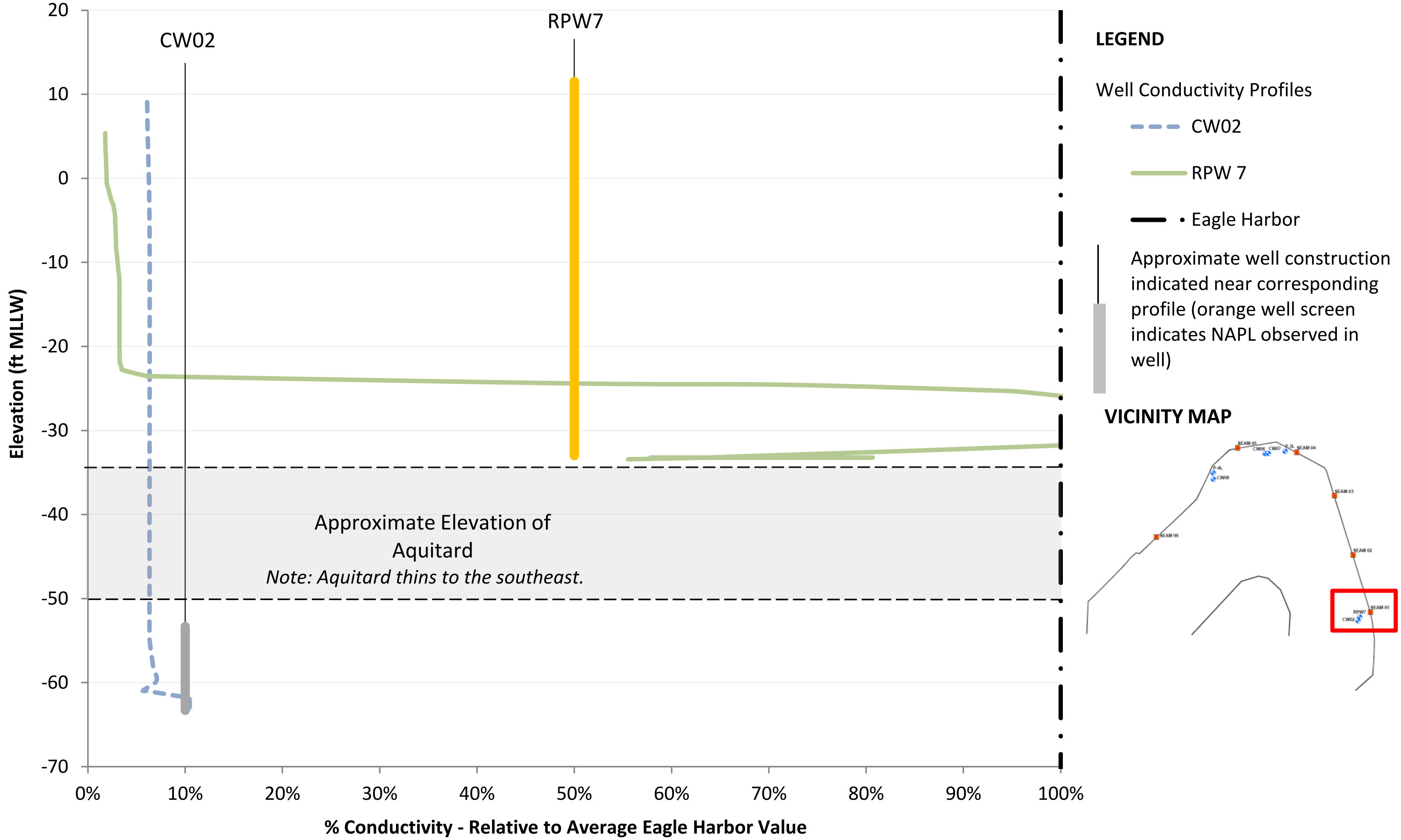


Figure 3

Conductivity Profiles for Wells, May 2013 - Eastern well cluster (CW02 and RPW7)

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

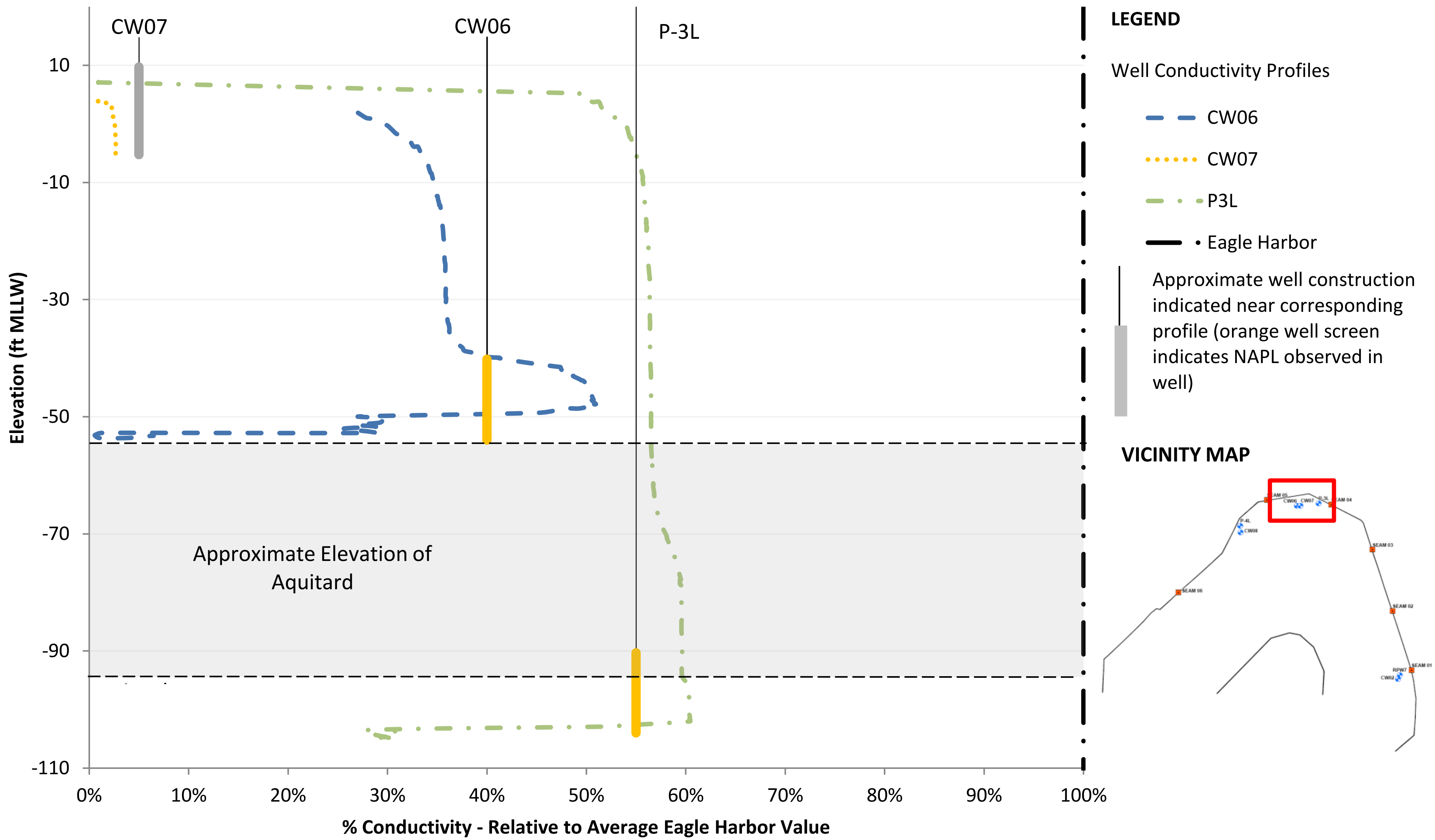


Figure 4

Conductivity Profiles for Wells, May 2013 - Northern well cluster (CW06, CW07, and P-3L)

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

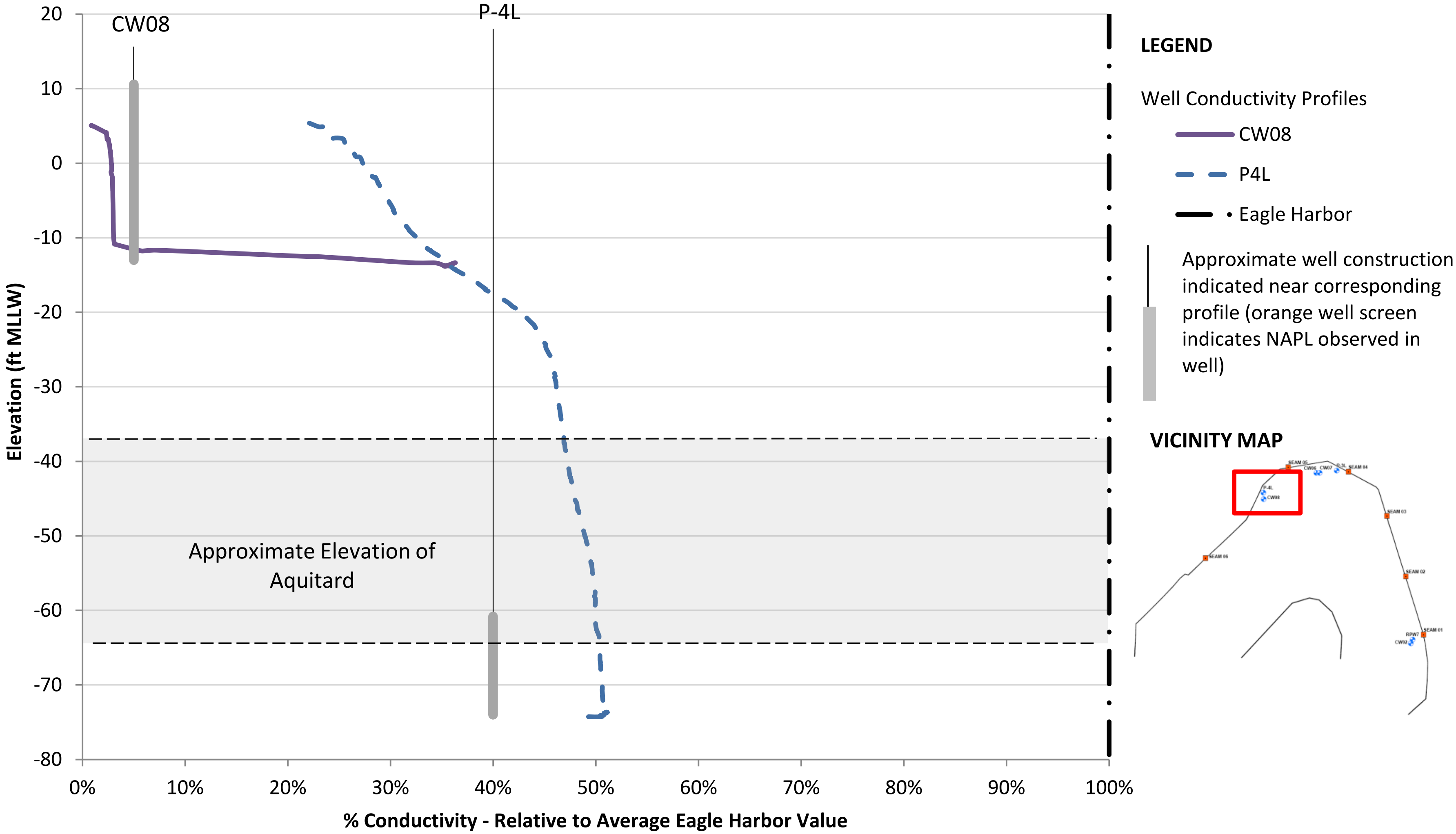
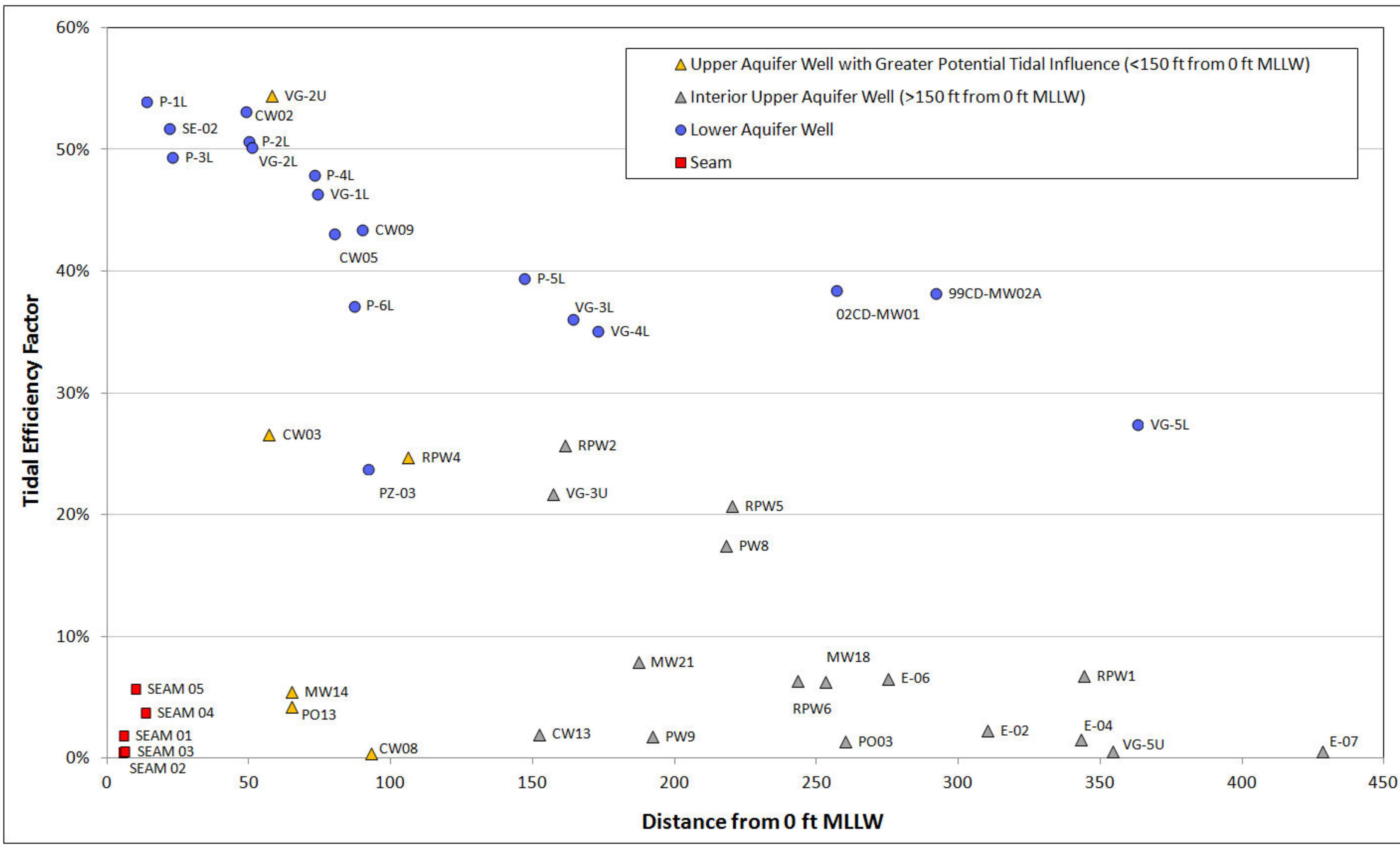


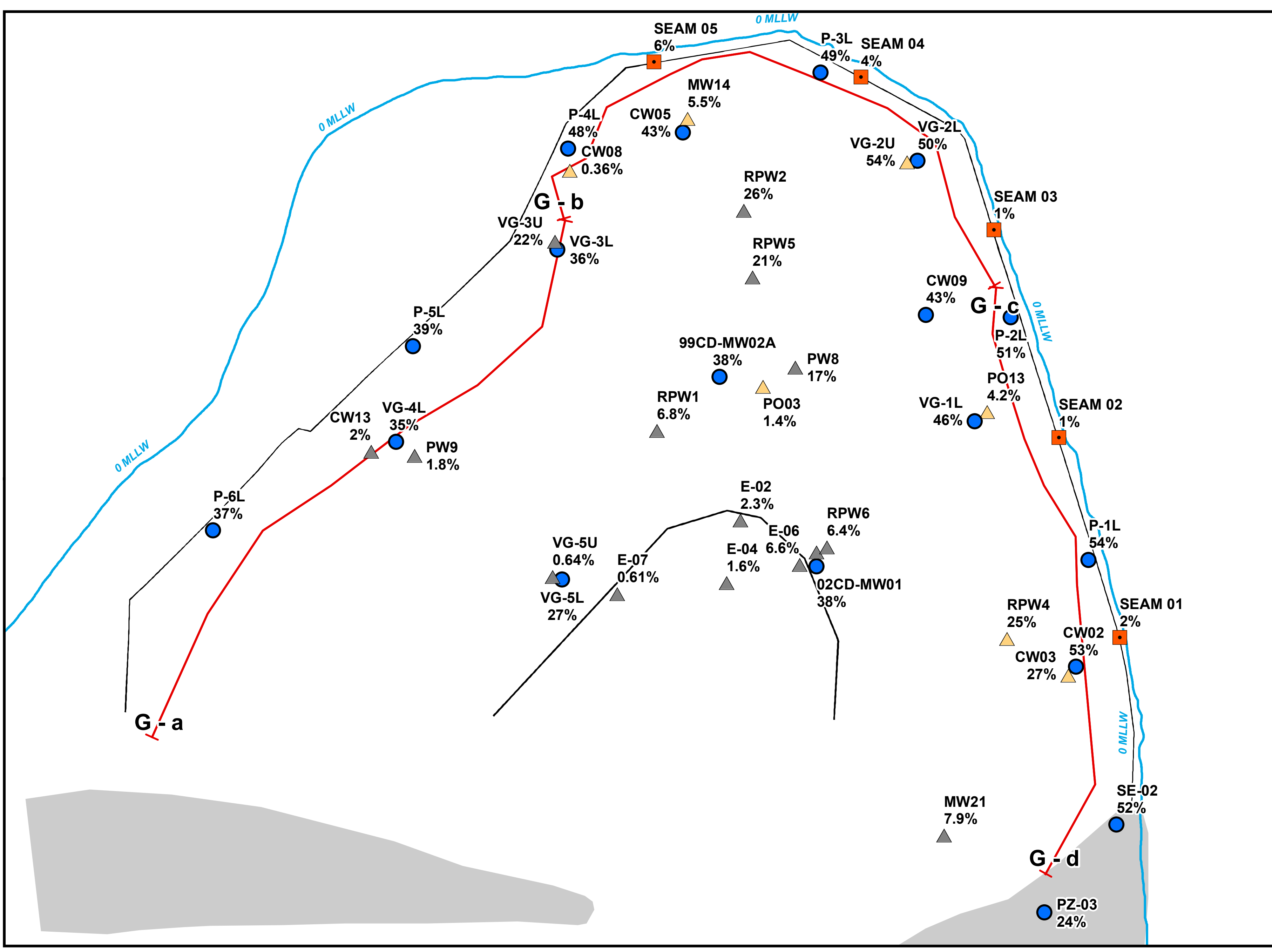
Figure 5

Conductivity Profiles for Wells, May 2013 - Northwestern well cluster (CW08 and P-4L)

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site





LEGEND

Tidal Efficiency Factor at Selected Site Wells and Seams

- Upper Aquifer Well with Greater Potential Tidal Influence
- Interior Upper Aquifer Well (>150 ft from 0 ft MLLW)
- Lower Aquifer Well
- Seam
- Ground Surface Contour (0 ft MLLW)
- Fence Diagram Lines (see Figure 11)
- Aquitard Thin (<4 ft) to Absent

N

0 50 100 200 Feet

Figure 6
Tidal Efficiency Factor for Selected Wells and Seams
Wyckoff Upland Field Evaluation
Wyckoff/Eagle Harbor Superfund Site

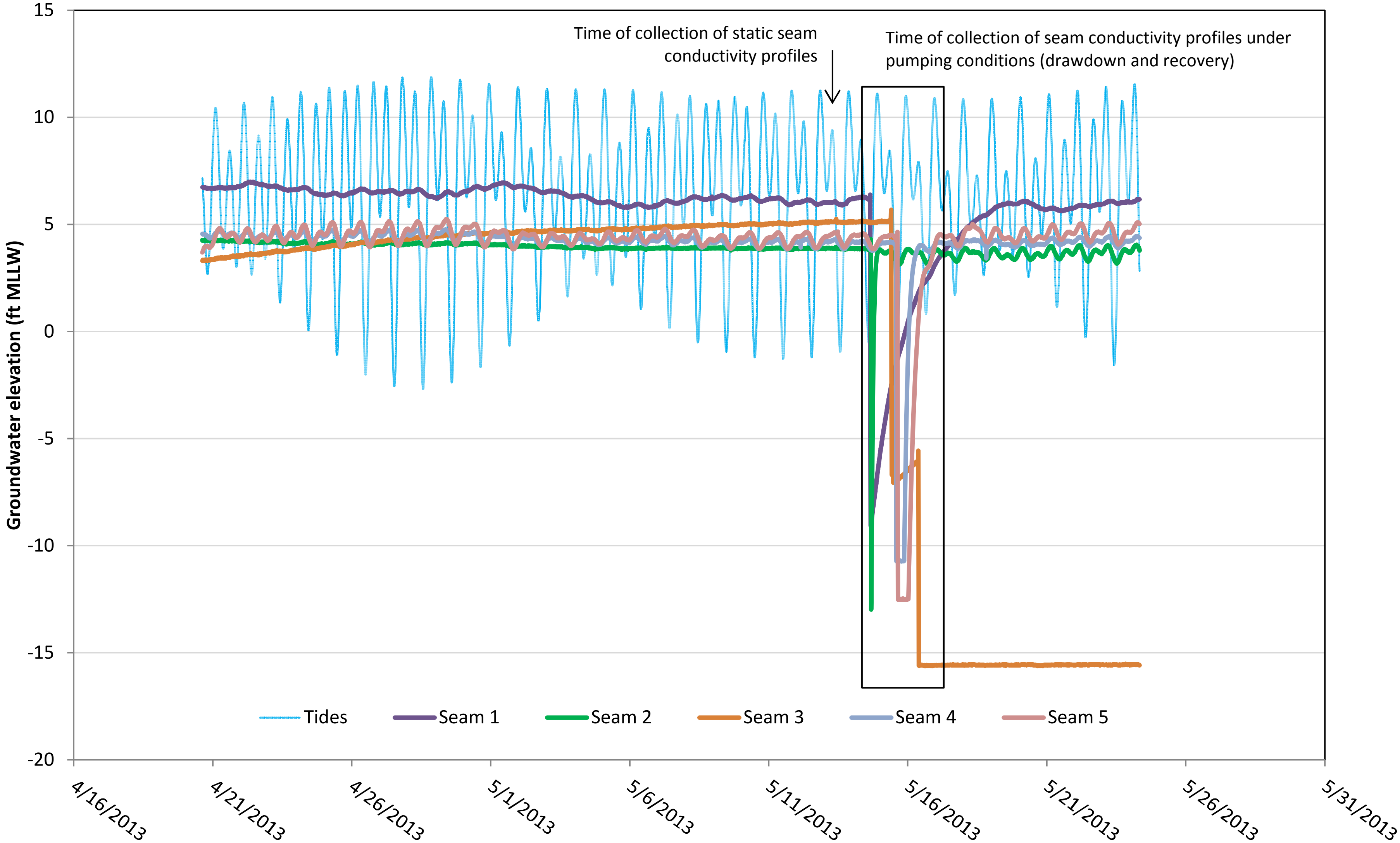


Figure 7
Seam Hydrographs and Tides from April 20 through May 25, 2013
Wyckoff Sheet Pile Wall Evaluation
Wyckoff/Eagle Harbor Superfund Site

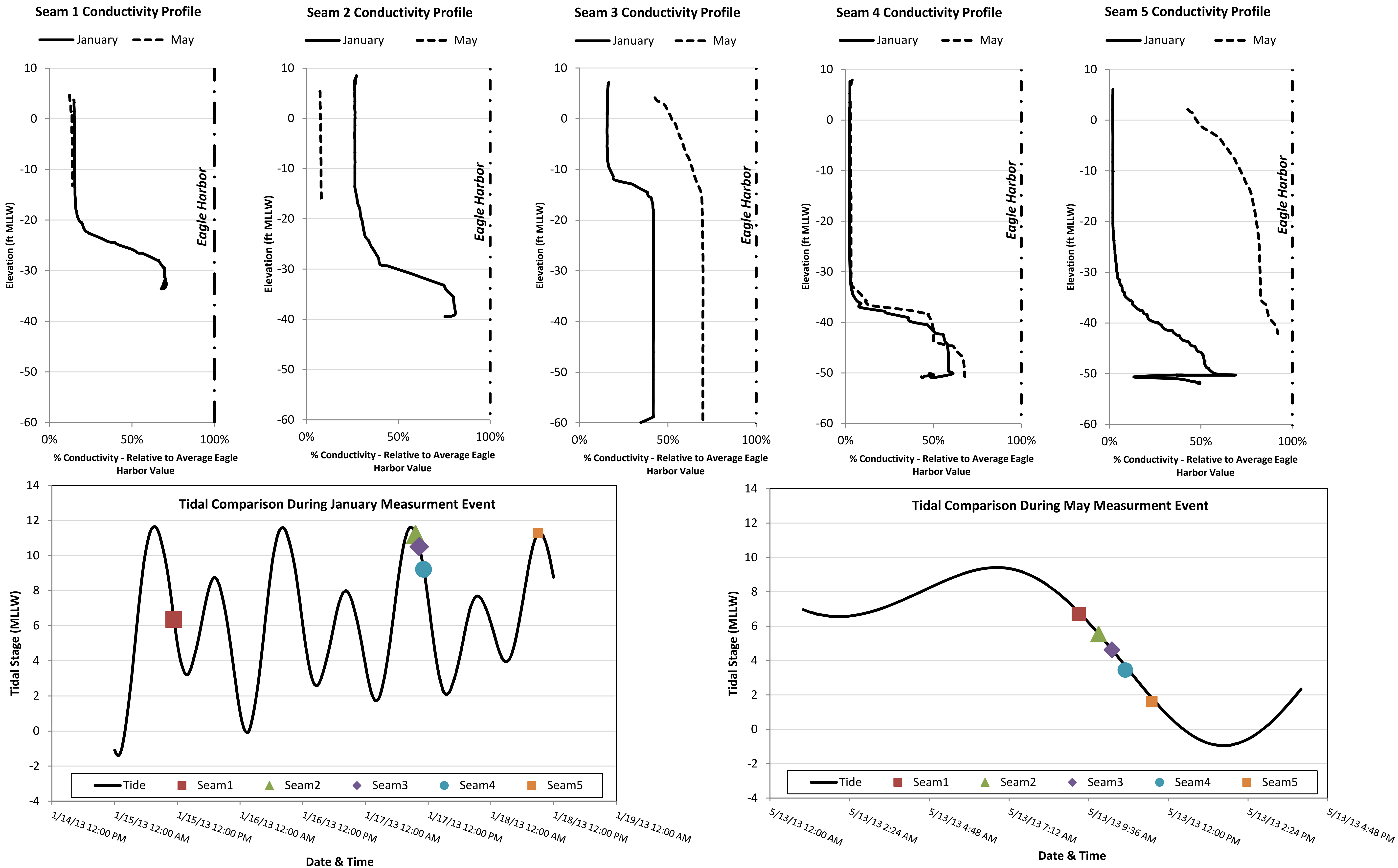
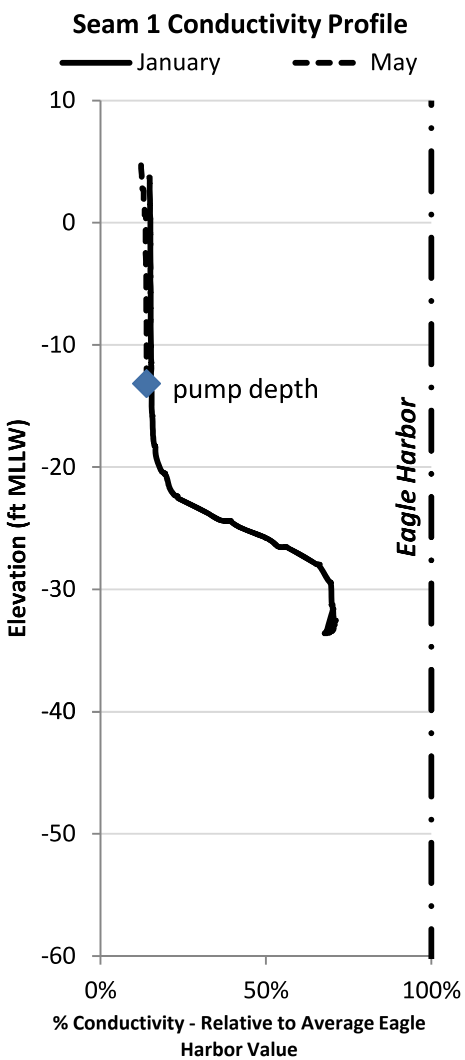


Figure 8

Seam Conductivity Profiles and Comparison with Tide Stages for January and May Measurement Events

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site



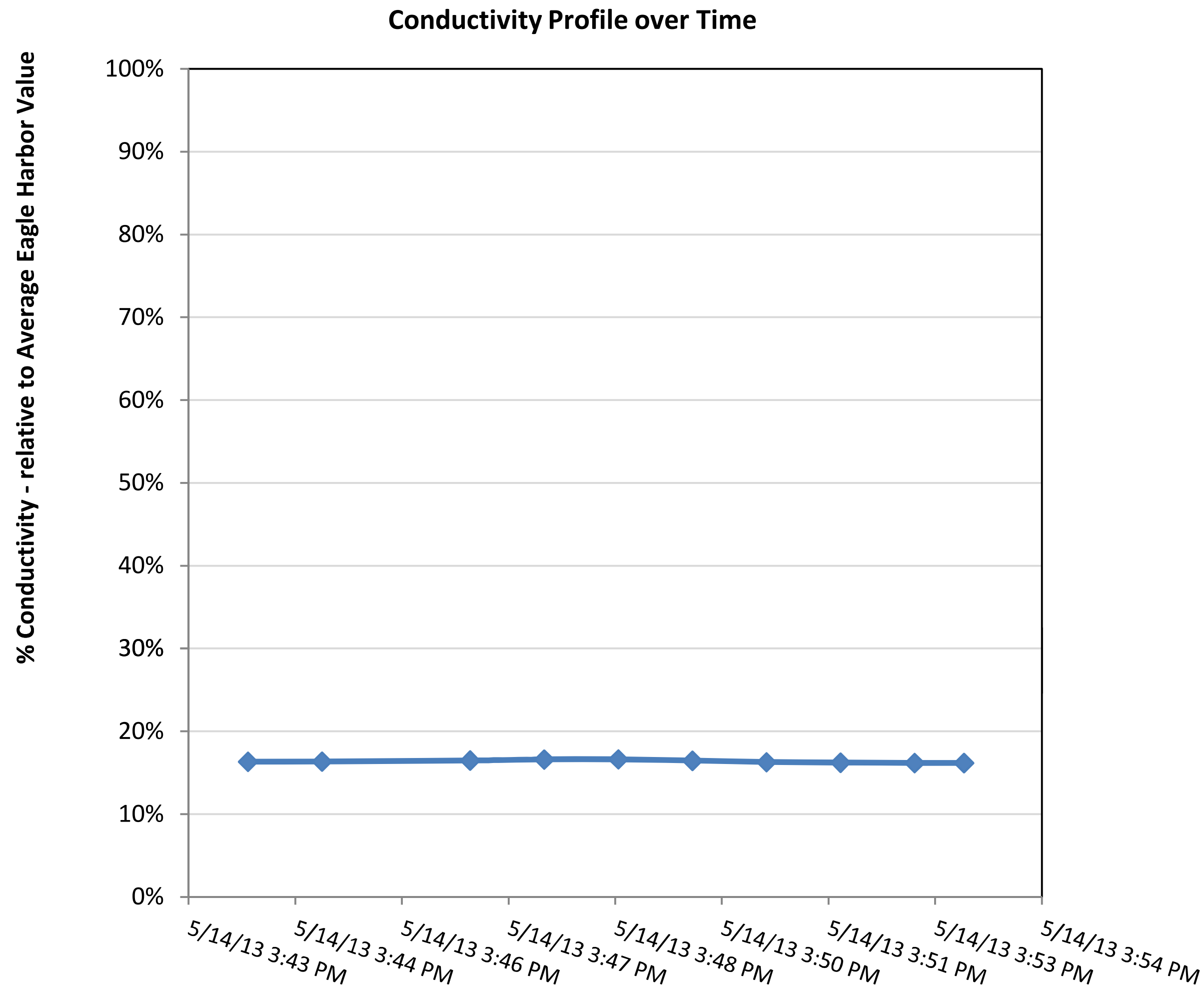
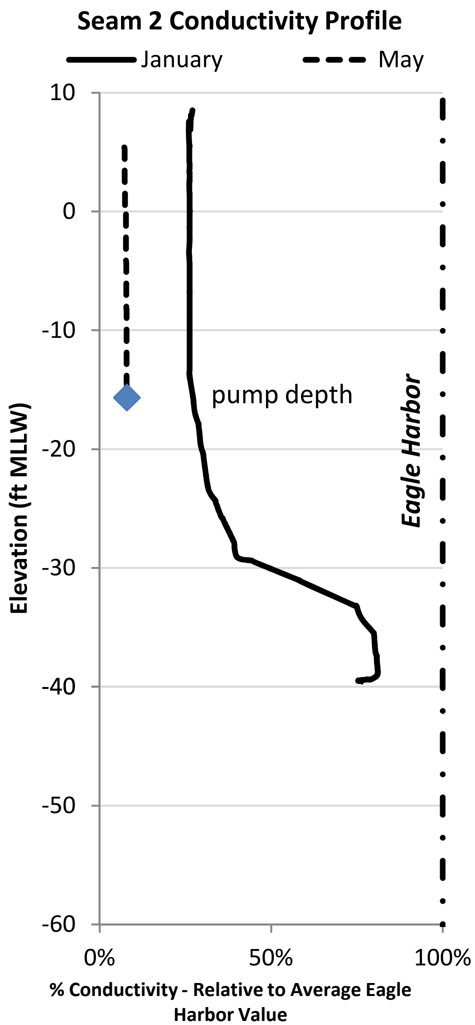


Figure 9A

Conductivity Profiles and Drawdown for Seam Pumping conducted May 2013 - Seam 1

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site



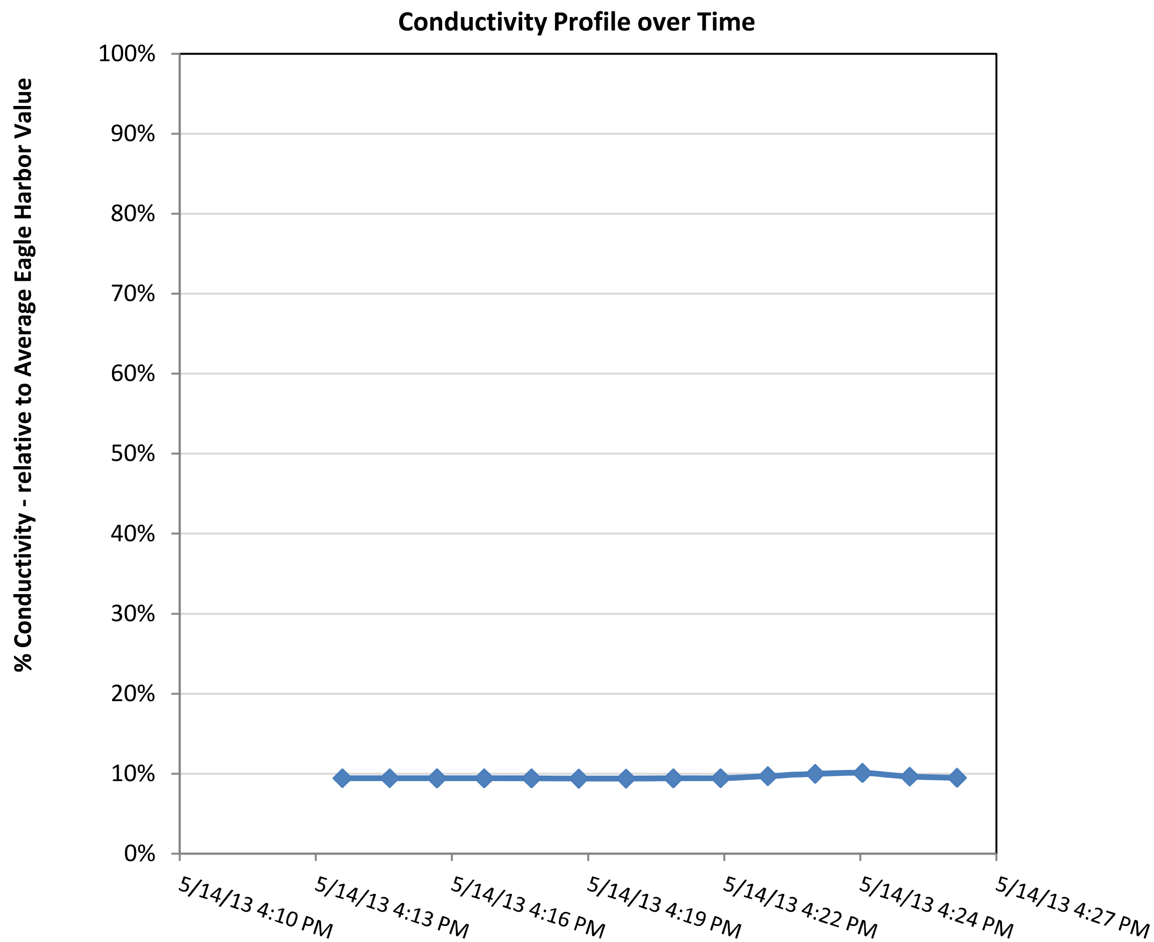
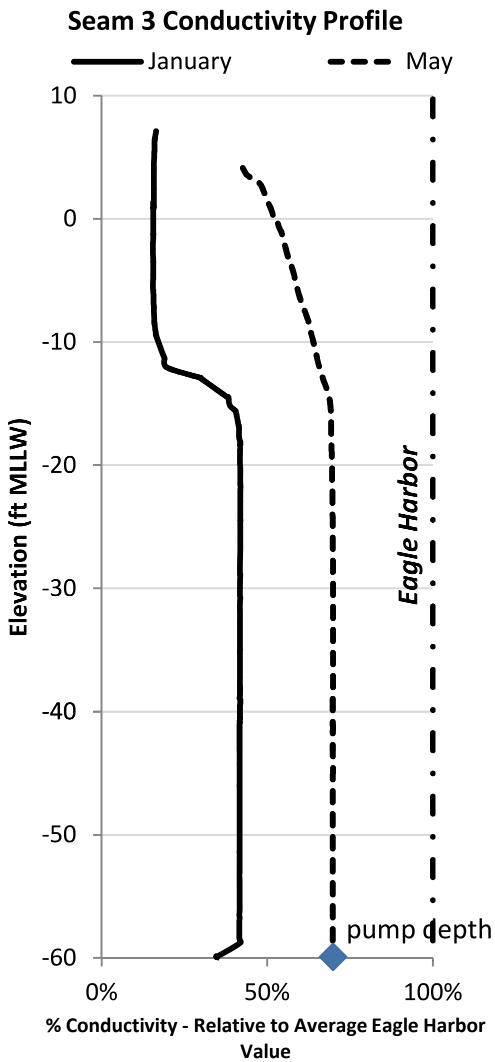


Figure 9B

Conductivity Profiles and Drawdown for Seam Pumping conducted May 2013 - Seam 2

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site



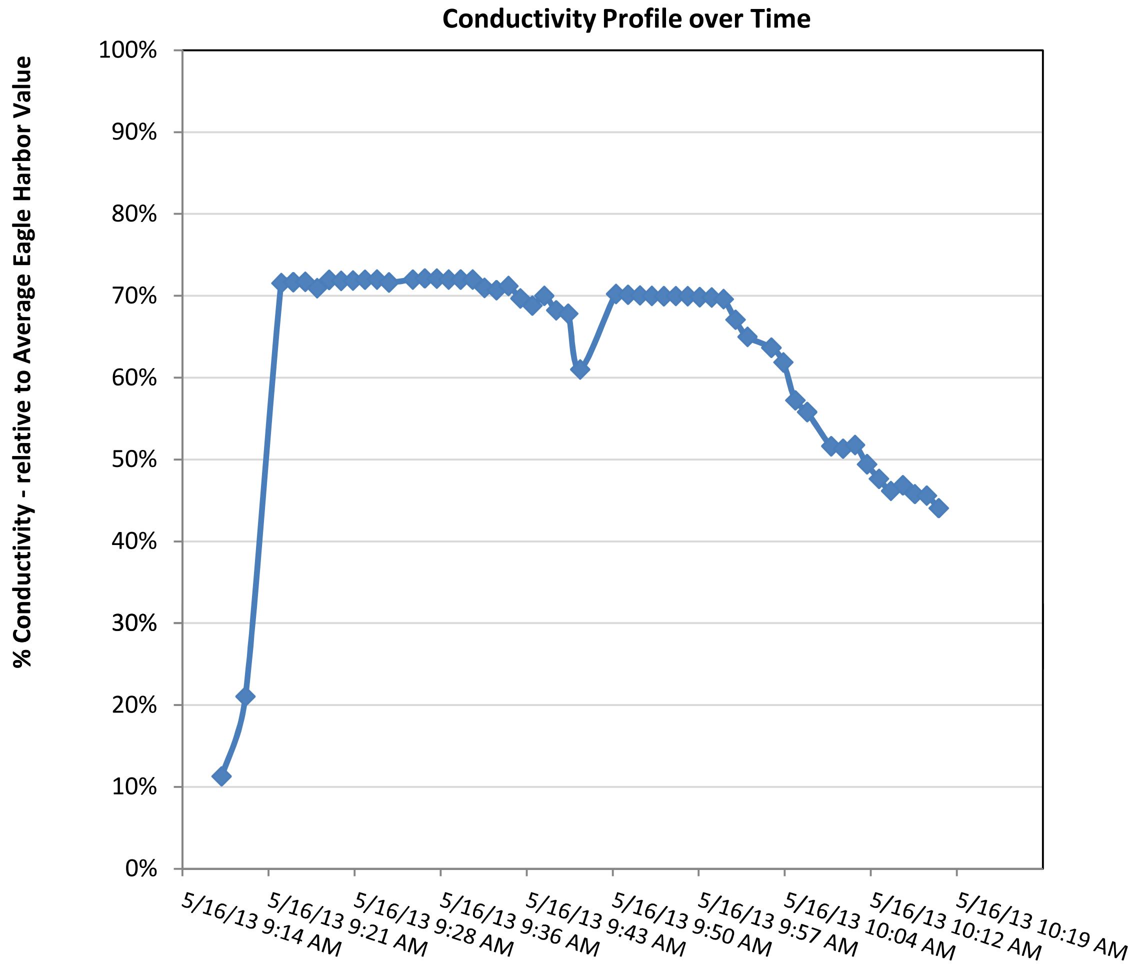
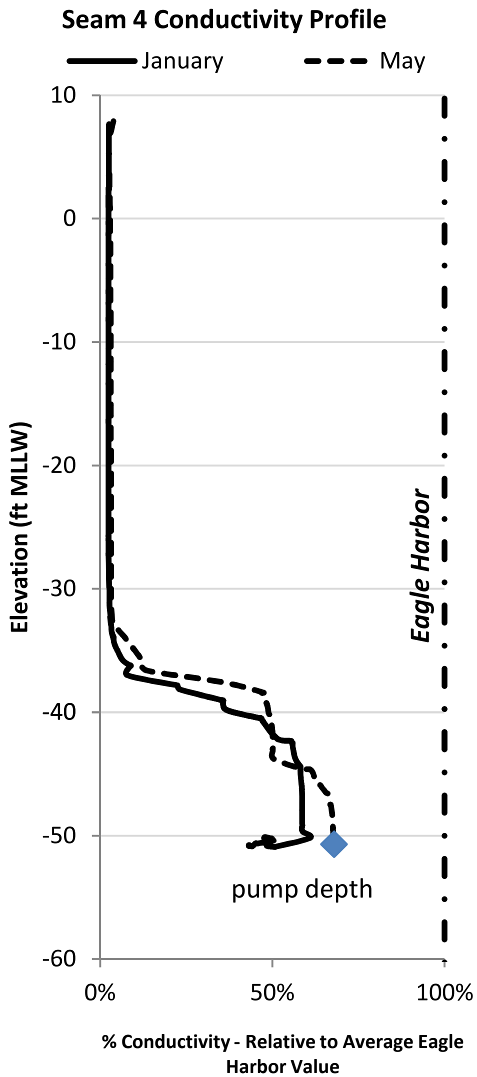


Figure 9C

Conductivity Profiles and Drawdown for Seam Pumping conducted May 2013 - Seam 3

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site



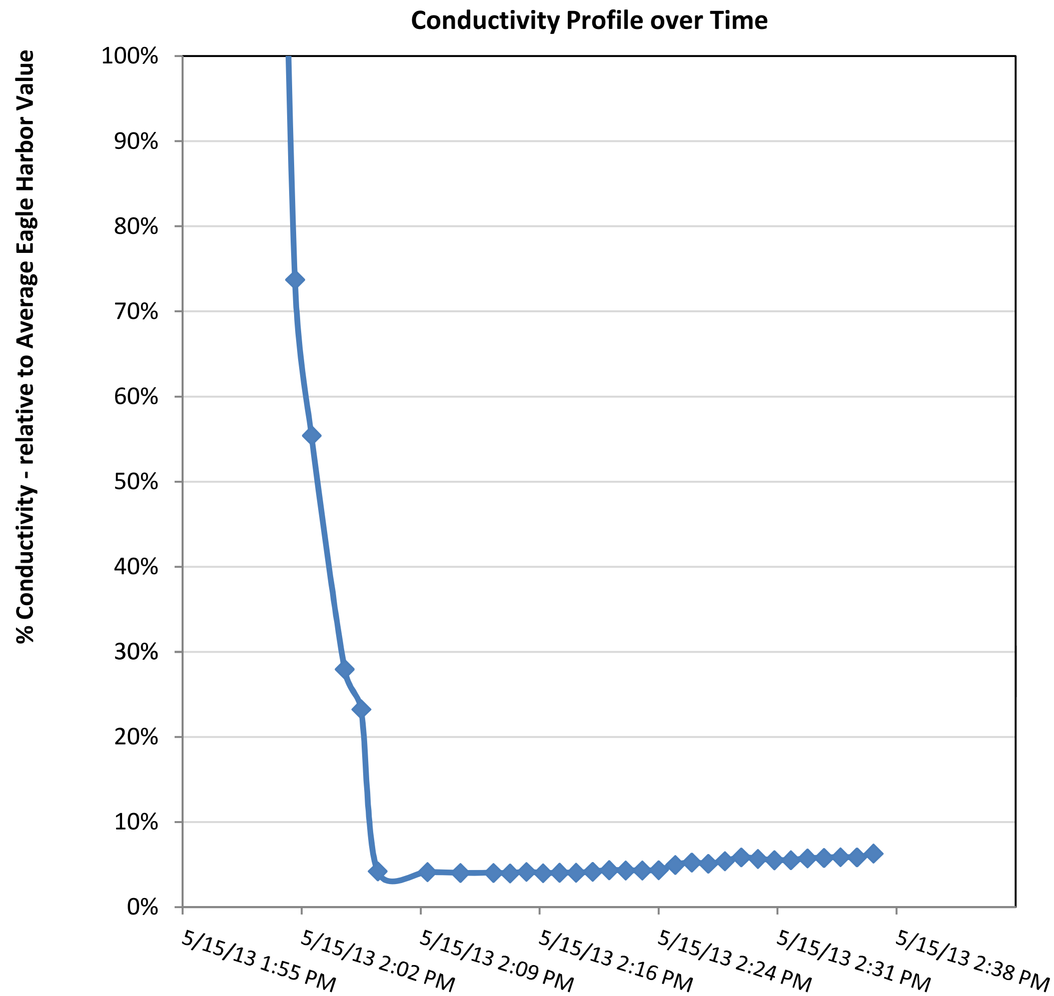


Figure 9D

Conductivity Profiles and Drawdown for Seam Pumping conducted May 2013 - Seam 4

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

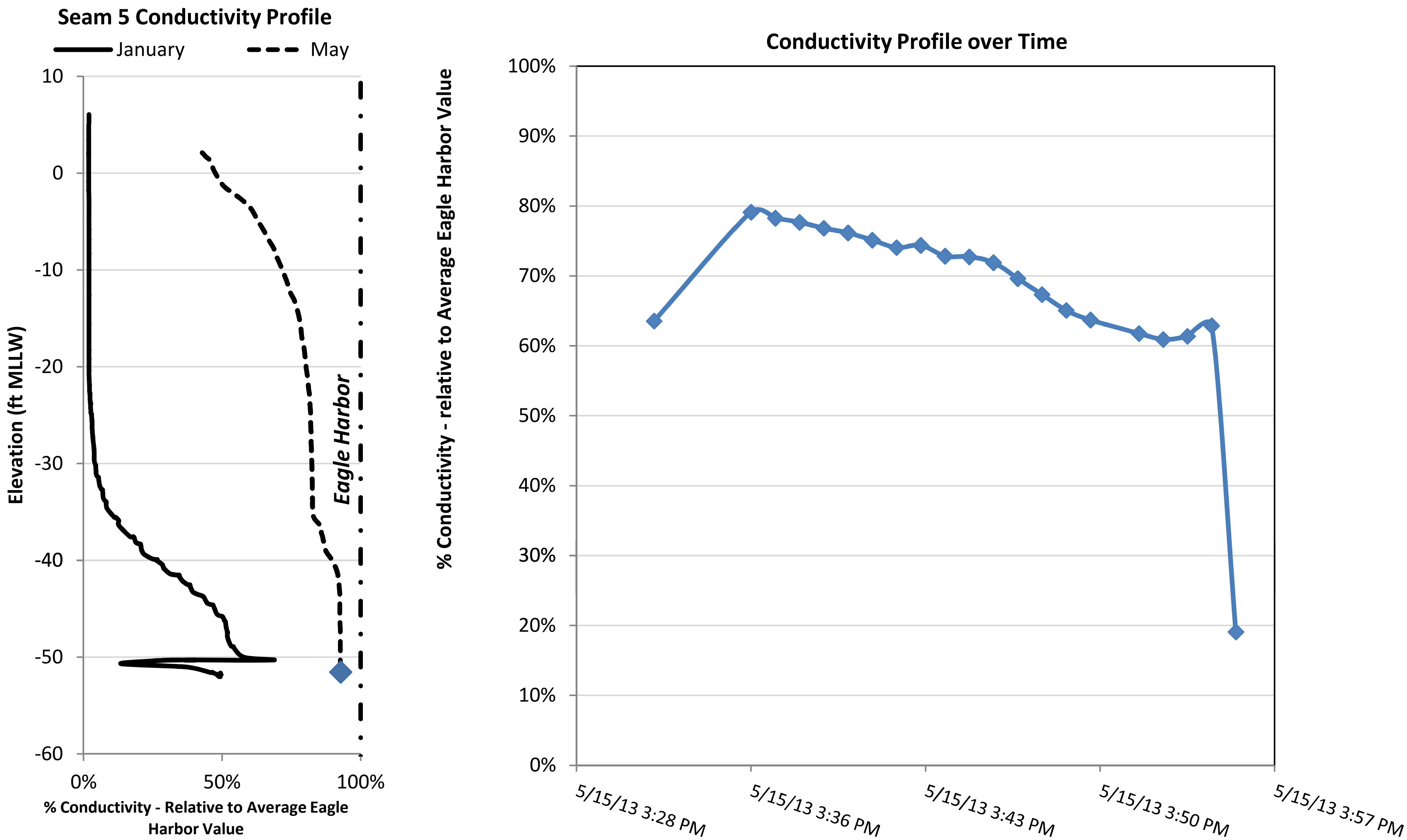


Figure 9E

Conductivity Profiles and Drawdown for Seam Pumping conducted May 2013 - Seam 5

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

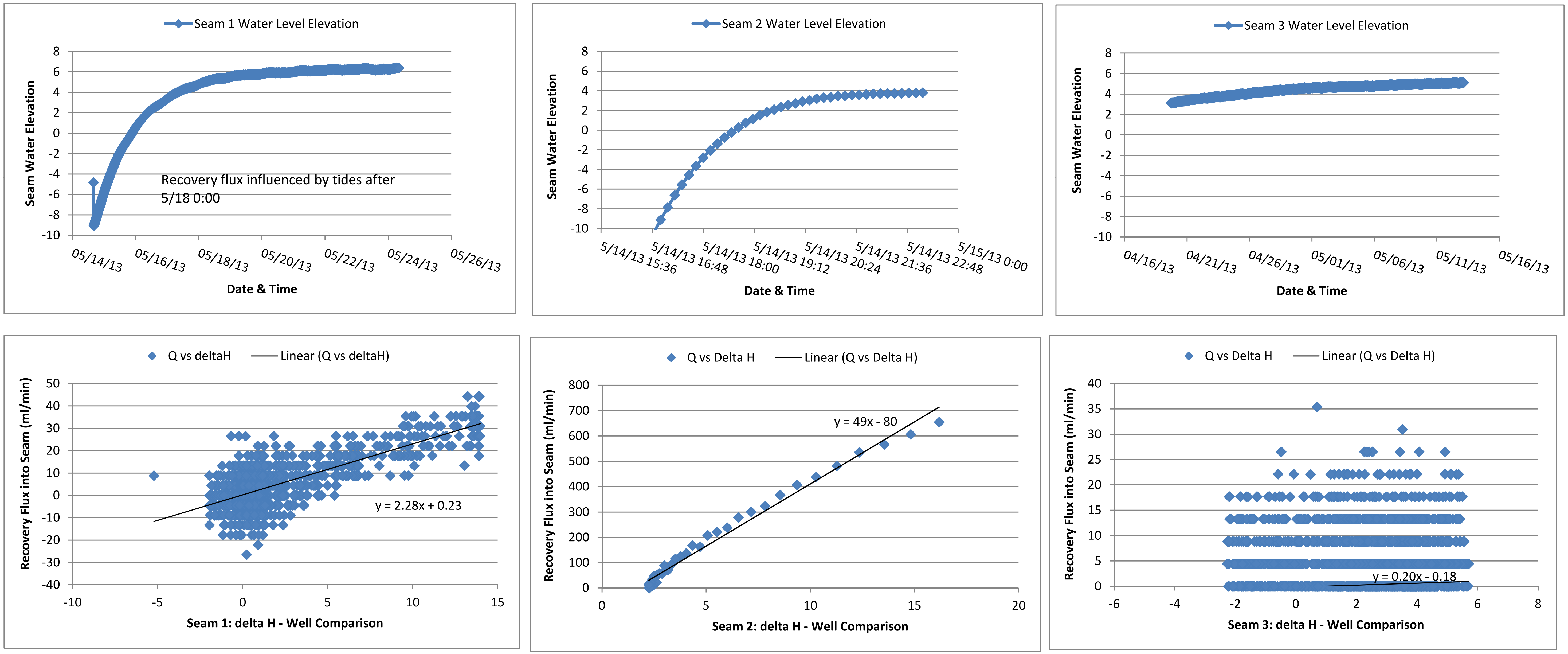
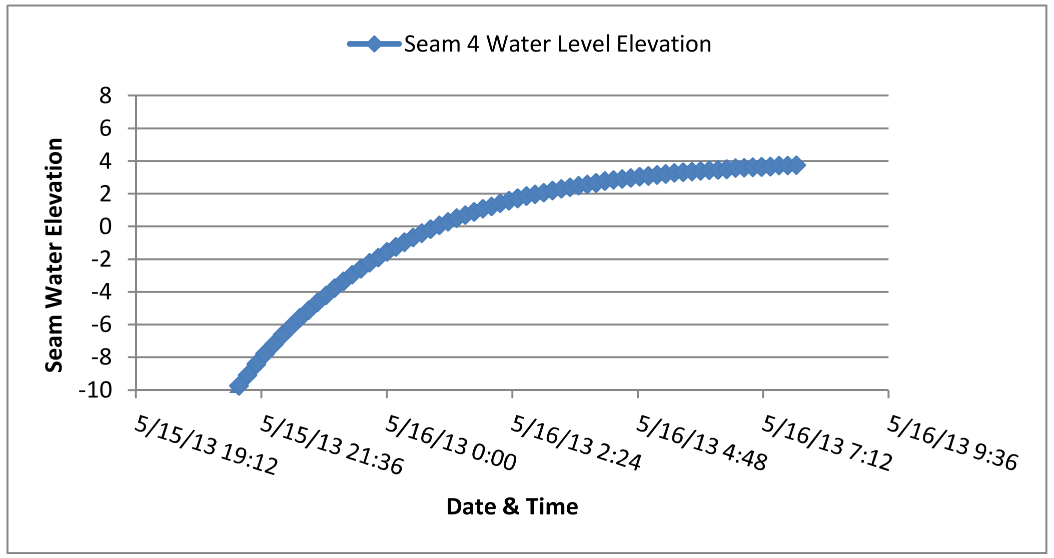
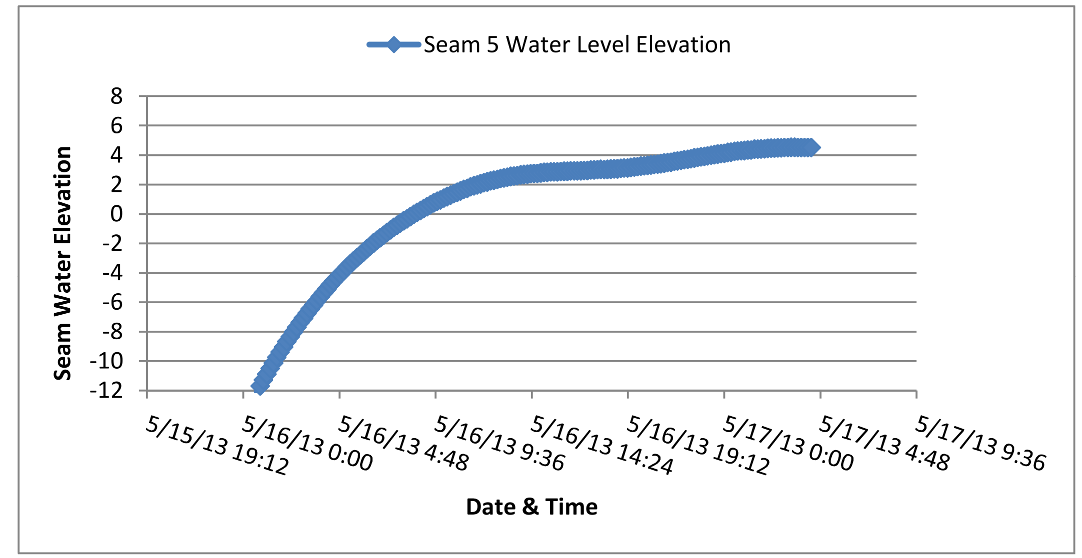
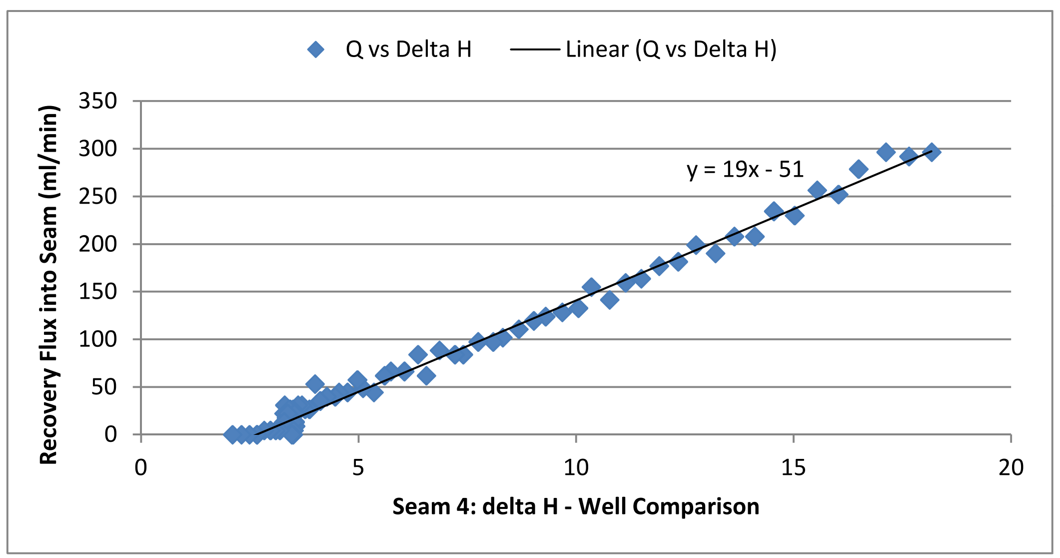


Figure 10A
Seam Recovery Flux Analysis - Seams 1, 2, and 3
Wyckoff Sheet Pile Wall Evaluation
Wyckoff/Eagle Harbor Superfund Site







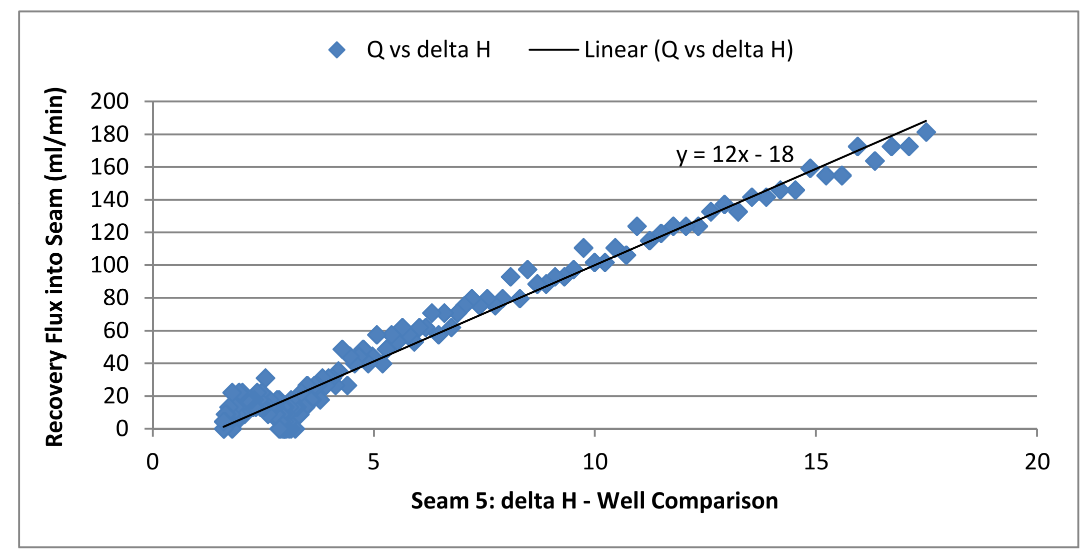


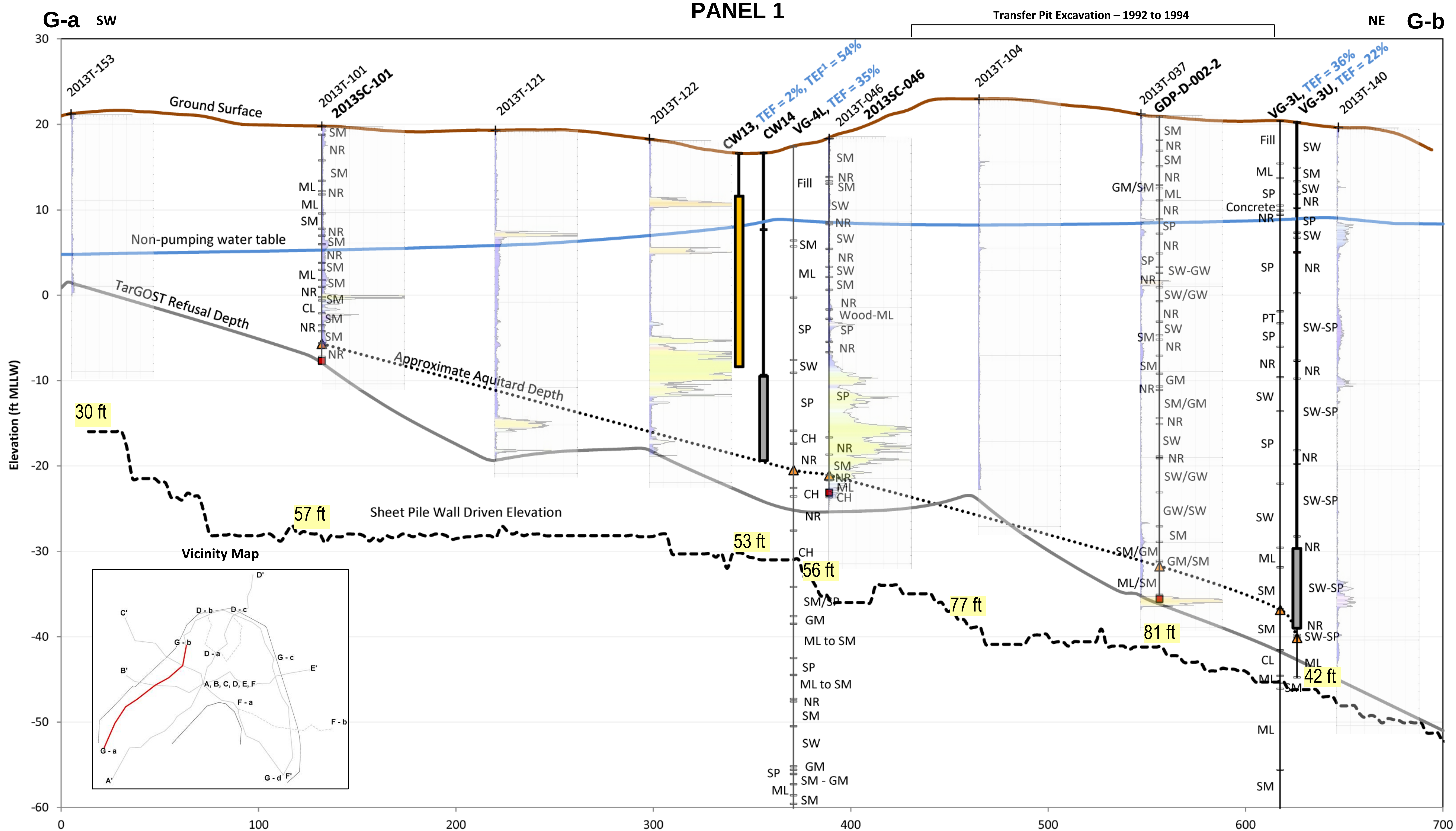
Figure 10B

Seam Recovery Flux Analysis - Seams 4 and 5

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

PANEL 1



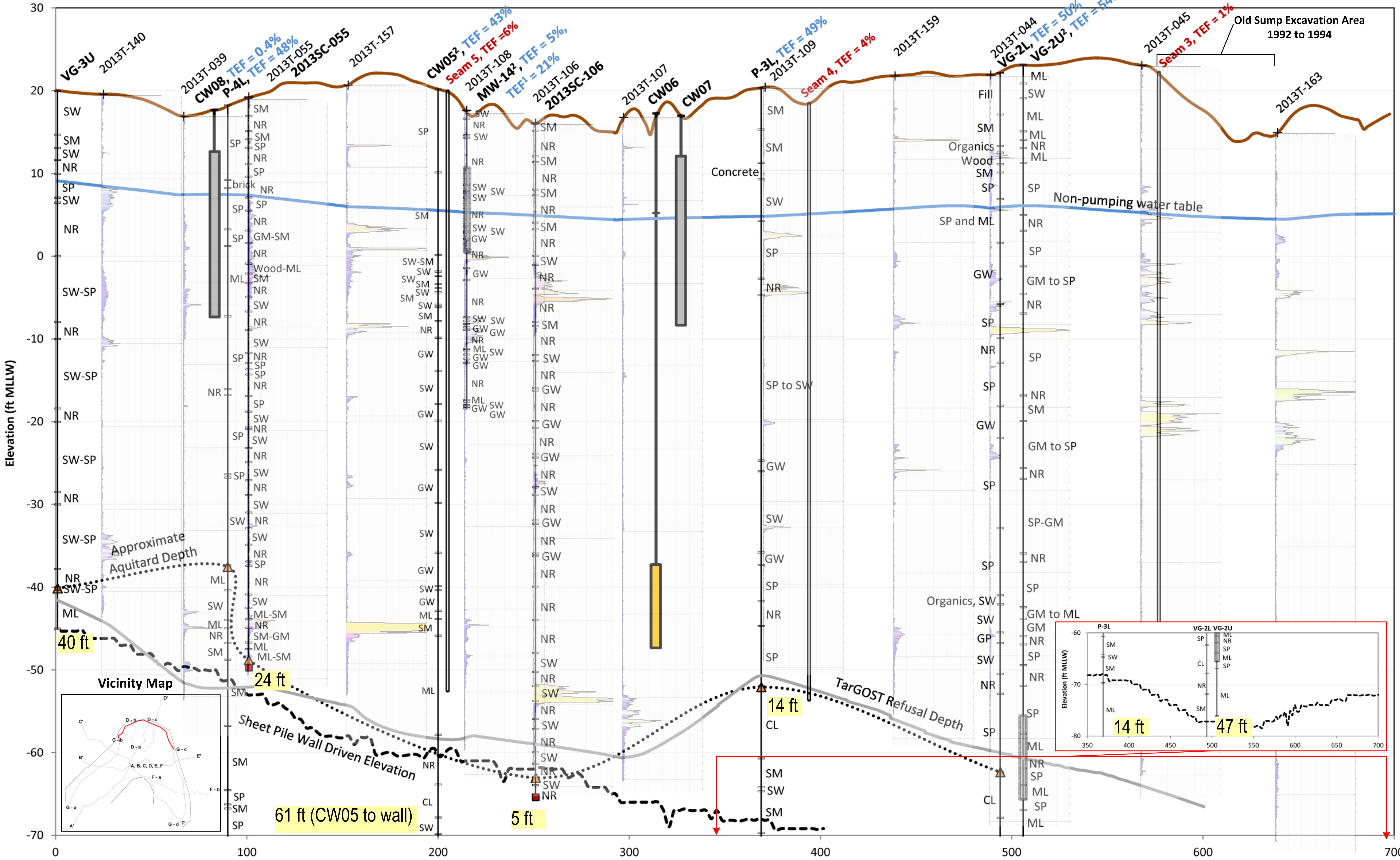
Groundwater Level Non-pumping Conditions (measured September 3, 2012)

Monitoring well screened interval
Orange color-code = NAPL was observed in well during water level monitoring (9/12); Gray color-code = NAPL was not observed in well during water level monitoring (9/12)

Notes:
TEF = Tidal Efficiency Factor
[1]Historical TEF measured prior to sheet pile wall installation.
[2]Projection distance from feature to sheet pile wall.

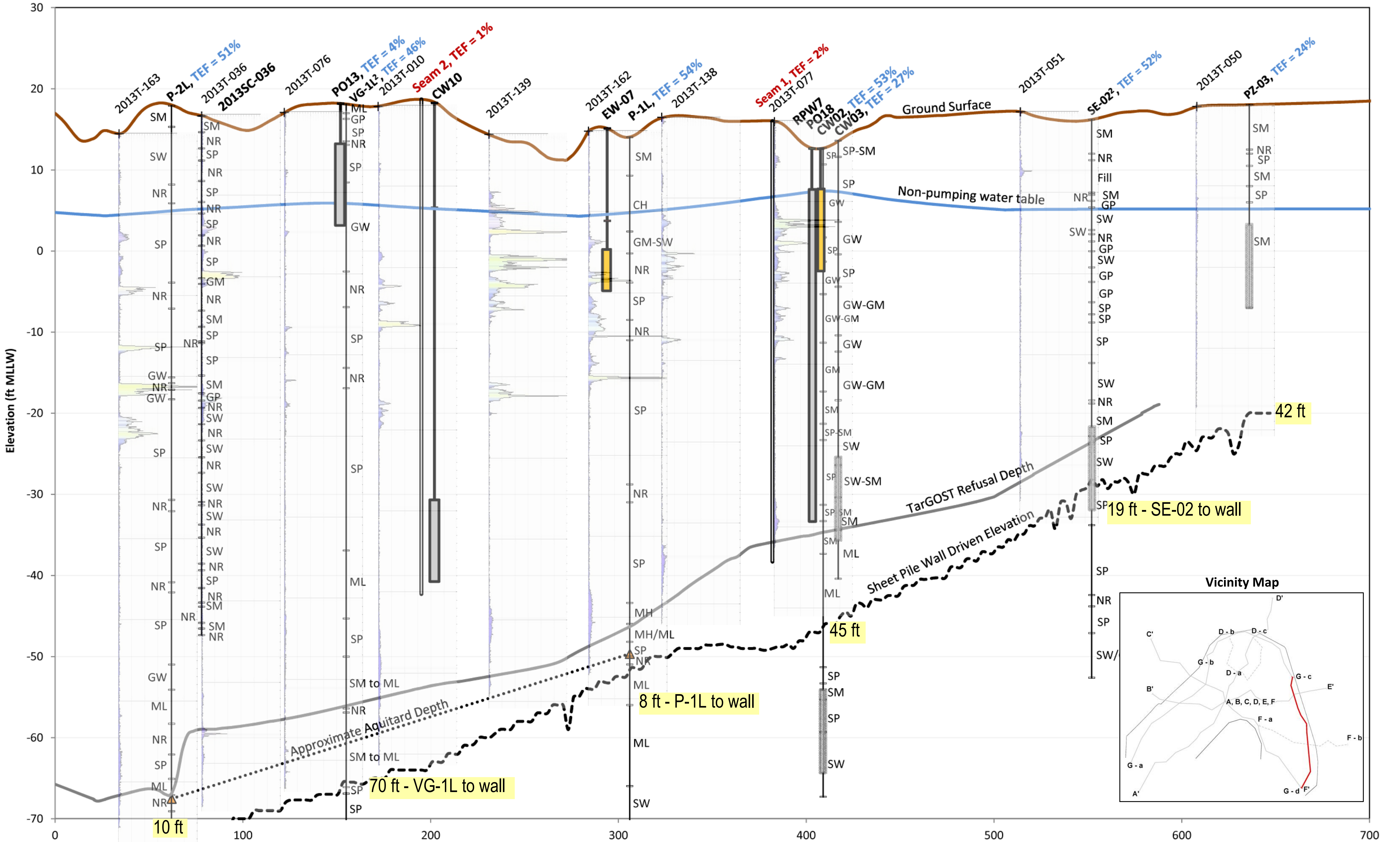
Figure 11 (Panels 1 – 3)
Fence Diagram G-a to G-b to G-c to G-d with TarGOST %RE Response
Wyckoff Sheet Pile Wall Investigation
Wyckoff/Eagle Harbor Superfund Site

PANEL 2



G-b
W
E
G-c
Elevation (ft MLLW)
Old Sump Excavation Area
1992 to 1994
Non-pumping water table
Approximate
Aquitard Depth
Sheet Pile Wall Driven Elevation
TarGOST Refusal Depth
Vicinity Map
40 ft
24 ft
61 ft (CW05 to wall)
5 ft
14 ft
14 ft
47 ft
VG-3U
CW08, TEF = 0.4%
P-4L, TEF = 48%
2013SC-055
CW05², TEF = 43%
Seam 5, TEF = 6%
MW-14², TEF = 5%,
TEF¹ = 21%
2013SC-106
CW06
CW07
P-3L, TEF = 49%
Seam 4, TEF = 4%
VG-2L, TEF = 50%
VG-2U², TEF = 54%
Seam 3, TEF = 1%
Concrete

PANEL 3



G-c
N
S
G-d
Elevation (ft MLLW)
Ground Surface
Non-pumping water table
TarGOST Refusal Depth
Sheet Pile Wall Driven Elevation
Approximate Aquitard Depth
2013T-163
P-2L, TEF = 51%
2013T-036
2013SC-036
2013T-076
PO13, TEF = 4%
VG-1L2, TEF = 46%
2013T-010
Seam 2, TEF = 1%
CW10
2013T-139
2013T-162
EW-07
P-1L, TEF = 54%
2013T-138
Seam 1, TEF = 2%
2013T-077
RPW7
PO18
CW02, TEF = 53%
CW03, TEF = 27%
2013T-051
SE-022, TEF = 52%
2013T-050
PZ-03, TEF = 24%
10 ft
70 ft - VG-1L to wall
8 ft - P-1L to wall
45 ft
19 ft - SE-02 to wall
42 ft
Vicinity Map

Tables

Table 1

Sheet Pile Wall Construction Information

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

Segments	Startpoint	Endpoint	Approximate Section Length (ft)	Minimum As-Built Tip Elev (ft MLLW)	Maximum As-Built Tip Elev (ft MLLW)	Number of Piles
0	TP-1	SP	103.2	-28.8	-16	37
1	TP-1	TP-2	220.3	-30.7	-27	79
2	TP-2	TP-3	11.2	-32	-30.2	4
3	TP-3 and TP-4*		253.8	-44	-30.7	91
4	TP-4	TP-5	119.9	-54.2	-44.5	43
5	TP-5	TP-6	75.3	-60.4	-54	27
6	TP-6	TP-7	153.4	-69	-59.5	55
7	TP-7	TP-8	172.9	-77.4	-67	62
8	TP-8	TP-9	86.5	-78.7	-74	31
9	TP-9	TP-10	398.8	-75.2	-48.5	143
10	TP-10	TP-11	92.0	-49.2	-41.2	33
11	TP-11	TP-12	117.1	-41.2	-28	42
12	TP-12	EP	75.3	-30	-20	27

Notes:

*Piles are not number sequentially in one direction

674 individual piles with 674 interlocking joints

46,831 feet of piles driven

3.0 sheet pile wall surface area in acres

0.07% percent of sheet pile wall surface area as seams

Table 2
Sheet Pile Wall Field Investigation Activities
Wyckoff Sheet Pile Wall Evaluation
Wyckoff/Eagle Harbor Superfund Site

Evaluation Activity	Date	Details
Seam Pocket and Well Specific Conductivity Profiles	Jan 15 2013 to Jan 18, 2013	Seam 1 - Jan 15, 2013 11:17 to 11:29 Seam 2 - Jan 17, 2013 9:34 to 9:44 Seam 3 - Jan 17, 2013 10:14 to 10:21 Seam 4 - Jan 17, 2013 11:05 to 11:12 Seam 5 - Jan 18, 2013 8:55 to 9:05 P4L - Jan 18, 2013 10:08 to 10:16 CW08 - Jan 18, 2013 10:24 to 10:29 CW06 - Jan 18, 2013 10:43 to 10:50 CW07 - Jan 18, 2013 11:01 to 11:04 P3L - Jan 18, 2013 11:12 to 11:34 CW02 - Jan 18, 2013 11:50 to 11:58 RPW7 - Jan 18, 2013 12:08 to 12:14
Seam Pocket Water Level Data Collection	March 27, 2013 to May 24, 2013	Seams 1 and 2 - March 27 - May 24, 2013 Seam 3 - March 28 - May 24, 2013 Seams 4 and 5 - April 4 - May 24, 2013
Seam Pocket Pumping	March 27, 28, and April 19, 2013	Seam 1 - March 27, 2013 13:20 to 14:00 Seam 2 - March 27, 2013 15:05 to 15:45 Seam 3 - March 28, 2013 11:55 to 12:40 Seam 4 - April 19, 2013 11:00 to 11:45 Seam 5 - April 19, 2013 12:30 to 13:21
Seam Pocket Specific Conductivity Profiles	May 13, 2013	Seam 1 - May 13, 2013 9:13 to 9:29 Seam 2 - May 13, 2013 9:49 to 9:56 Seam 3 - May 13, 2013 10:11 to 10:29 Seam 4 - May 13, 2013 10:40 to 10:54 Seam 5 - May 13, 2013 11:27 to 11:43
Well Specific Conductivity Profiles	May 14, 2013	CW02 - May 14, 2013 8:45 to 9:05 RPW7 - May 14, 2013 9:13 to 9:32 P3L - May 14, 2013 9:47 to 10:23 CW07 - May 14, 2013 11:41 to 12:49 CW06 - May 14, 2013 11:50 to 12:17 CW08 - May 14, 2013 12:29 to 12:39 P4L - May 14, 2013 12:40 to 13:12
Seam Pocket and Well Pumping	May 14, 2013 to May 16, 2013	Seam 1 - May 14, 2013 15:44 to 15:53 Seam 2 - May 14, 2013 16:12 to 16:27 Seam 3 - May 16, 2013 9:11 to 10:20 Seam 4 - May 15, 2013 13:49 to 14:37 Seam 5 - May 15, 2013 15:29 to 16:19 RPW7 - May 16, 2013 11:23 to 12:24 CW08 - May 16, 2013 14:00 to 14:47 CW07 - May 16, 2013 15:21 to 15:37 CW06 - May 16, 2013 15:55 to 16:11

Notes:
Two attempts to attain conductivity data during pumping conditions were necessitated due to pump malfunctions as well as variable pump depths within the seams during pumping. During the first measurement attempt, performed in March and April, the pump was not heavy enough to allow it to sink through the water column to the desired height before beginning the pump. Therefore, the pump was lowered during pumping. This made the resulting data undecipherable and the second field effort was employed with a weighted pump. Following completion of the March and April 2013 seam pocket pumping, a decision was made to collect a second round of conductivity profiles on the five seams and selected wells from a fixed pump depth near the bottom depth at each location.

Table 3

Vertical Pile Test Locations

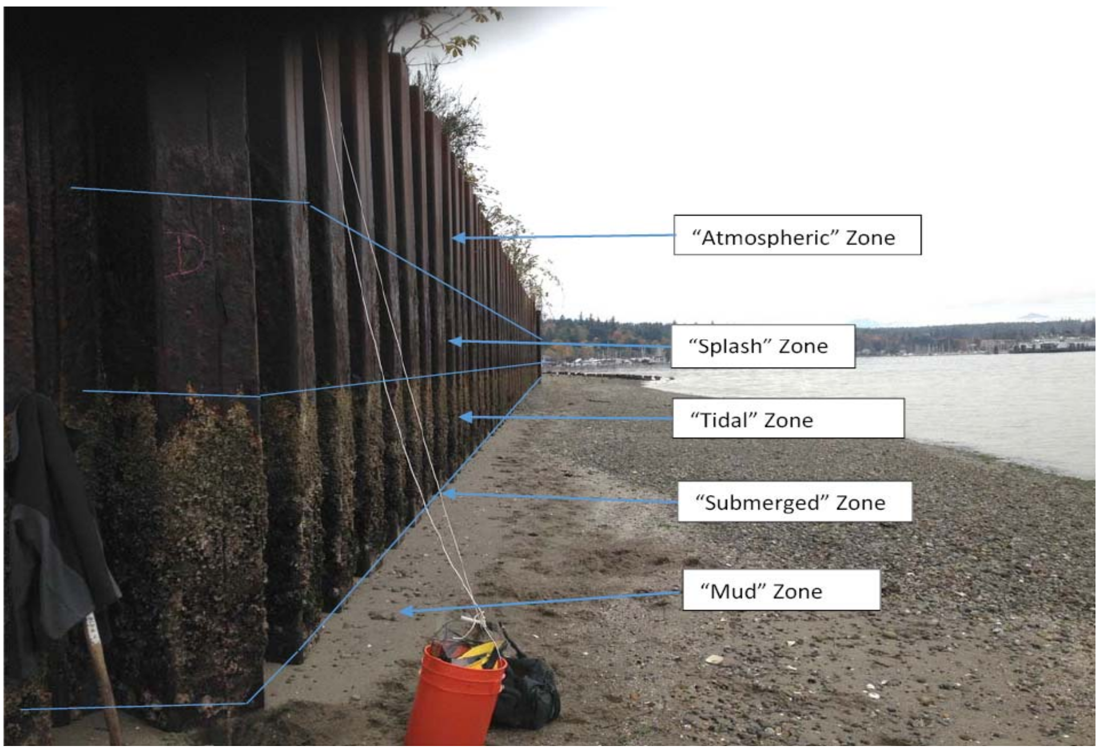
Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

Zone	Typical Distance from Top of Wall to Test Spot (ft)	General Condition, As Found
"Atmospheric"	3	Surface rust
"Splash"	6	Heavy corrosion products (up to 1 inch thick); orange stains on north side
"Tidal"	9.5 - 11.5	Marine growth; tightly adhered corrosion products, moderately thick
"Submerged"	11 - 13.5	No corrosion products or marine growth
"Mud"	12 - 14.5	Thin, tightly adhered corrosion product

Note:

Relative zone location on the wall shown in photograph below.



General condition of the sheet pile wall, Wyckoff (Bainbridge Island), with exposure "zones" shown.
North face.

Table 4

Compilation of Summary of Groundwater Elevation Data by Well Pair

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

March 26 to June 23, 2012 (14 percent of average annual rainfall)

Well Pair	Upper Aquifer Average Groundwater Elevation (ft MLLW)	Lower Aquifer Average Groundwater Elevation (ft MLLW)	Ratio (Avg Lower Aq WL / Avg Upper Aq WL)*	D			results - neg grad analysis			
				Average	Max	Min	Number Neg Grad Events	Average Duration Neg Grad (hr:min:sec)	Total Duration Neg Grad (days)	Percent Duration of 90 day Monitoring Period
MW14/CW05	5.57	9.31	1.67	3.75	6.00	0.43	none			
MW18/02CDMW01	4.48	9.06	2.02	4.58	8.32	0.62	none			
PO03/99CDMW02A	5.08	9.42	1.86	4.34	7.35	0.46	none			
CW03/CW02	5.80	8.77	1.51	2.97	4.91	0.27	none			
VG-2U/VG-2L	6.73	8.49	1.26	1.76	14.81	0.61	none			
VG-3U/VG-3L	5.27	10.28	1.95	5.01	6.70	2.53	none			
VG-5U/VG-5L	7.90	10.97	1.39	3.07	5.64	0.12	none			
PO13/VG-1L	5.67	9.02	1.59	3.35	6.17	-0.38	9	1.75	0.7	0.7%
CW13/VG-4L	9.33	11.35	1.22	2.03	5.55	-2.92	50	5.67	11.8	13.1%
CW08/P-4L	6.86	8.85	1.29	1.99	5.17	-2.46	84	4.24	14.9	16.5%
						Totals	**143**	**12**	**27**	

September 22 to December 20, 2012 (43 percent of average annual rainfall)

Well Pair	Upper Aquifer Average Groundwater Elevation (ft MLLW)	Lower Aquifer Average Groundwater Elevation (ft MLLW)	Ratio (Avg Lower Aq WL / Avg Upper Aq WL)*	D			results - neg grad analysis			
				Average	Max	Min	Number Neg Grad Events	Average Duration Neg Grad (hr:min:sec)	Total Duration Neg Grad (days)	Percent Duration of 90 day Monitoring Period
MW14/CW05	7.43	9.68	1.30	2.26	5.80	-2.97	45	4.59	8.6	9.6%
MW18/02CDMW01	5.50	9.26	1.68	3.76	7.56	-1.30	3	0.83	0.1	0.1%
PO03/99CDMW02A	7.25	9.76	1.35	2.52	6.63	-2.74	37	6.40	9.9	11.0%
CW03/CW02	7.21	9.22	1.28	2.01	4.48	-0.88	32	3.03	4.0	4.5%
VG-2U/VG-2L	7.57	8.72	1.15	1.15	1.99	0.01	none			
VG-3U/VG-3L	6.70	10.36	1.55	3.66	5.76	0.69	none			
VG-5U/VG-5L	9.34	11.08	1.19	1.74	5.02	-2.40	53	6.86	15.15	16.8%
PO13/VG-1L	7.46	9.49	1.27	2.02	5.45	-3.47	70	4.21	12.3	13.7%
CW13/VG-4L	11.04	11.37	1.03	0.33	6.23	-8.33	44	17.99	33.0	36.6%
CW08/P-4L	8.27	9.25	1.12	0.97	5.10	-5.51	102	6.35	27.0	30.0%
						Totals	**386**	**50**	**110**	

June 24 to September 21, 2012 (6 percent of average annual rainfall)

Well Pair	Upper Aquifer Average Groundwater Elevation (ft MLLW)	Lower Aquifer Average Groundwater Elevation (ft MLLW)	Ratio (Avg Lower Aq WL / Avg Upper Aq WL)*	D			results - neg grad analysis			
				Average	Max	Min	Number Neg Grad Events	Average Duration Neg Grad (hours)	Total Duration Neg Grad (days)	Percent Duration of 90 day Operational Period
MW14/CW05	6.57	9.43	1.44	2.86	6.07	-0.67	28	2.0	2.3	2.6%
MW18/02CDMW01	6.54	9.13	1.40	2.59	6.73	-1.10	30	3.0	3.7	4.1%
PO03/99CDMW02A	6.87	9.42	1.37	2.55	5.82	-1.23	37	3.2	4.9	5.4%
CW03/CW02	7.22	8.93	1.24	1.72	10.11	-0.82	46	3.2	6.1	6.7%
VG-2U/VG-2L	7.56	8.36	1.11	0.80	1.91	0.11	none			
VG-3U/VG-3L	7.01	9.69	1.38	2.58	6.23	-0.36	14	2.5	1.5	1.6%
VG-5U/VG-5L	7.98	10.71	1.34	2.72	4.65	0.28	none			
PO13/VG-1L	6.53	9.17	1.40	2.64	5.88	-1.03	52	2.6	5.6	6.2%
CW13/VG-4L	8.40	10.83	1.29	2.43	4.94	-0.46	24	1.8	1.8	2.0%
CW08/P-4L	7.15	8.95	1.25	1.80	5.12	-2.14	94	4.3	17.0	18.9%
						Totals	**325**	**23**	**43**	

December 21, 2012 to March 20, 2013 (37 percent of average annual rainfall)

Well Pair	Upper Aquifer Average Groundwater Elevation (ft MLLW)	Lower Aquifer Average Groundwater Elevation (ft MLLW)	Ratio (Avg Lower Aq WL / Avg Upper Aq WL)*	D			results - neg grad analysis			
				Average	Max	Min	Number Neg Grad Events	Average Duration Neg Grad (hours)	Total Duration Neg Grad (days)	Percent Duration of 90 day Monitoring Period
MW14/CW05	7.46	9.62	1.29	2.16	5.52	-2.68	53	4.88	10.8	12.0%
MW18/02CDMW01	4.89	9.50	1.94	4.61	8.71	-0.70	5	3.75	0.8	0.9%
PO03/99CDMW02A	6.08	9.79	1.61	3.71	7.16	-1.72	20	4.66	3.9	4.3%
CW03/CW02	6.57	9.07	1.38	2.50	4.73	-1.52	20	6.75	3.1	3.4%
VG-2U/VG-2L	7.05	8.73	1.24	1.68	2.48	0.21	none			
VG-3U/VG-3L	5.97	10.53	1.76	4.56	6.70	0.55	none			
VG-5U/VG-5L	9.63	11.42	1.19	1.79	5.01	-2.73	46	10.50	10.86	12.1%
PO13/VG-1L	7.22	9.41	1.30	2.19	6.09	-3.28	56	14.75	11.6	12.9%
CW13/VG-4L	11.82	11.67	0.99	-0.15	3.30	-6.14	99	22.25	29.7	33.0%
CW08/P-4L	9.05	9.18	1.01	0.12	4.10	-5.29	130	19.50	40.6	45.1%
						Totals	**429**	**87**	**111**	

Table 5

Summary of Seam Investigation Results

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

Seam Number	Measured Seam Depth (ft below measurement point)	Average percent conductivity from January profile by depth	Approximate midpoint elevation of freshwater/saltwater transition (ft MLLW)	NAPL Observations
Seam 1	54.3	34%	25	Product smell on transducer (1/15)
Seam 2	61.0	45%	31	Product smell on transducer (1/15)
Seam 3	81.7	30%	13	none
Seam 4	72.0	17%	39	none
Seam 5	72.4	19%	41	Water in seam has product odor and sheen (4/19), several feet of product on tubing from pumping (4/19).

Table 6

Estimated Flux Estimate by Seam for Average Pumping Conditions

Wyckoff Sheet Pile Wall Evaluation

Wyckoff/Eagle Harbor Superfund Site

Summary of Trend Analysis (Figure 10A and 10B)

Seam	slope	intercept	correlation
1	2.28	0.235	0.75
2	49.0	-79.7	0.99
3	0.195	-0.182	0.04
4	19.2	-51.0	0.99
5	11.8	-17.7	0.98

Upper Aquifer Average Quarterly Groundwater Elevation (See Table 3)

Associated Upper Aquifer Well	March 26 to June 23, 2012	June 24 to September 21, 2012	September 22 to December 20, 2012	December 21 to March 20, 2013	Average: March 25, 2012 to March 20, 2013
CW03	5.80	7.22	7.21	6.57	6.70
PO13	5.67	6.53	7.46	7.22	6.72
VG-2U	6.73	7.56	7.57	7.05	7.23
VG-2U	same as above				
MW14	5.57	6.57	7.43	7.46	6.75

Seam Flux Estimates - for an averaged condition

Seam	Average Delta H Across Wall[1] (Average Well Elev. - MSL)	Estimated Seam Q across Wall (ml/min) [2]	Seam Depth (ft)	Estimated unit q across wall (ml/min/ft)
1	-0.020	0.2	54.3	0.003
2	-0.001	-80	60.98	-1.308
3	0.506	-0.1	81.73	-0.001
4		-41	72	-0.573
5	0.033	-17	72.42	-0.239

1) MSL as calculated from NOAA 6 minute historical tide data for Seattle Station 9447130

6.72

2) +Q is outward, -Q is inward

Order of Magintude Estimate of Total Flux through Wall

Total length of Interlock length	Possible Q across wall (ml/min)[3]	Range in Possible Q across wall (gallons/min)	
46830.9	-61,252	-16	Minimum of seam unit q's
	-19,833	-5	Average of seam unit q's
	163	0.043	Maximum of seam unit q's

Attachments

Provided separately on Compact Disk only