Eastwick
Flood Risk Management Feasibility Study

Philadelphia, Pennsylvania

Draft Integrated Feasibility Report & Environmental Assessment

Appendix B

Engineering Support Documentation

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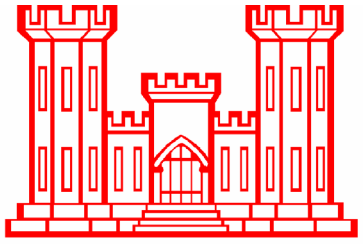
EASTWICK
CAP SECTION 205
FLOOD RISK MANAGEMENT STUDY
CITY OF PHILADELPHIA
PENNSYLVANIA

FEASIBILITY PHASE

PHILADELPHIA, PENNSYLVANIA

DRAFT - AUGUST 2023



U.S. Army Corps of Engineers
Philadelphia District

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Introduction and Background

The US Army Corps of Engineers (USACE) has partnered with the City of Philadelphia (Non-federal Sponsor (NFS)) for the Continuing Authorities Program (CAP) Section 205 Flood Risk Management (FRM) Feasibility Study for the neighborhood of Eastwick.

Eastwick lies east of Darby Creek and southeast of the confluence of the Darby and Cobbs Creek and is subject to frequent and severe flooding. The US Environmental Protection Agency (EPA) manages the Clearview Landfill Site (Lower Darby Creek Area Superfund Site) adjacent to Eastwick Recreation Park and a portion of the Eastwick neighborhood. The landfill footprint is primarily within Darby Township, Delaware County, but partially within the limits of the City of Philadelphia, such that tie-in of any levee feature will likely cross municipal boundaries and require coordination with USEPA. Downstream of 84th Street (Hook Road) bridge, the US Fish and Wildlife Service manages the John Heinz National Wildlife Refuge.

The purpose of this Hydrology and Hydraulics Sub-appendix is to detail current methods, analysis, and results utilized to determine the feasibility of measures to reduce flood risk to the Eastwick neighborhood. This includes analysis of potential levee performance, residual risk remaining even with potential FRM measures, induced flooding resulting from potential measures, and complementary features meant to augment the main FRM measures, and/or mitigate induced flooding.

Previous and ongoing studies of Eastwick flood risk span multiple agencies and stakeholders, from local, state, Federal, academic, and private industry assisting various partners. Hydrologic and hydraulic analyses for the current Section 205 FRM Feasibility Phase builds off previous internal (USACE) and external modeling efforts, to reduce overlap and duplication of work. Where outside USACE data or modeling were utilized, efforts were made to verify data/methods, and modify as necessary, to ensure compliance with current USACE standards and practices.

Drainage Features and Movement of Water through Eastwick and Surroundings

The following description and figures describe the complicated drainage patterns and interaction of features throughout the Eastwick neighborhood and surroundings. These features are mentioned throughout the text in subsequent sections.

The far western edge of Eastwick is drained by the bordering Cobbs Creek and Darby Creek Watersheds, which flow south and west through the John Heinz National Wildlife Refuge and into the Delaware River. The Cobbs Creek watershed drains 21.9 square miles of Philadelphia and Delaware counties above its confluence with Darby Creek. At this point, it merges with Darby Creek, which drains an additional 38 square miles prior to emptying into the John Heinz National Wildlife Refuge.

Upstream of the confluence of Cobbs Creek and Darby Creek, along the southeastern bank of Cobbs Creek, and located between the high elevation points of the Clearview Landfill and S. 78th Street (Figure 1), water overflows the stream bank during periods of heavy rain. The extent of inundation depends on the water surface elevation (WSEL) of Cobbs Creek. The bank elevation of Cobbs Creek between the Clearview Landfill and S. 78th Street is +12 ft NAVD88. Once water surface elevations reach between 12-ft and 16-ft, the floodplain is encroached upon and the flooding of structures in the study area begins. This inundation does not appreciably reduce the peak flow on Cobbs Creek since the water does not leave the Cobbs Creek watershed and the ponded volume is small relative to the size of the watershed. If the WSEL of Cobbs Creek is greater than +16 ft NAVD88, discharge is diverted from the Cobbs Creek watershed and

flows east into the Mingo Creek Drainage Basin, eventually ponding at the low-lying area bounded by Lindbergh Boulevard, Island Avenue and S. 84th Street. Ponding within the low area of Lindbergh Boulevard, Island Avenue and S. 84th Street is augmented by local runoff that exceeds the storm sewer capacity. The surrounding street elevations are approximately +6 ft NAVD88. If the volume reaching this low area is large enough, the structures surrounding this area will also flood as water overflows from the ponding area. During Hurricane Floyd in September 1999, areas to the south of S. 84th Street experienced this high-volume flooding scenario of overflows expanding beyond the ponding area.

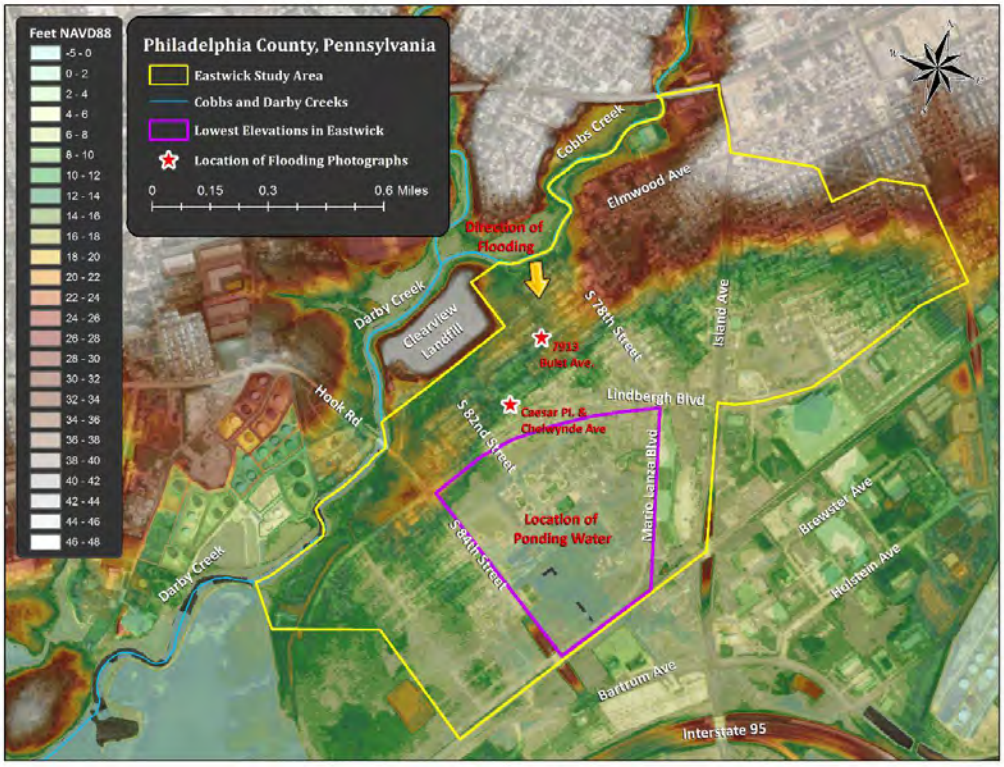

Figure 1: Study Area Inundation Corridor

A more detailed view of the flooding in the lowest areas of the project indicates that a complete understanding of the hydraulic complexities is needed to fully account for the existing and future without project flooding. In addition, these details are important because these flooding issues may be impacted by study alternatives and possibly create induced flooding. Figure 2shows an overview of the project area with selected topographic elevation contours highlighted as indicated in the legend.

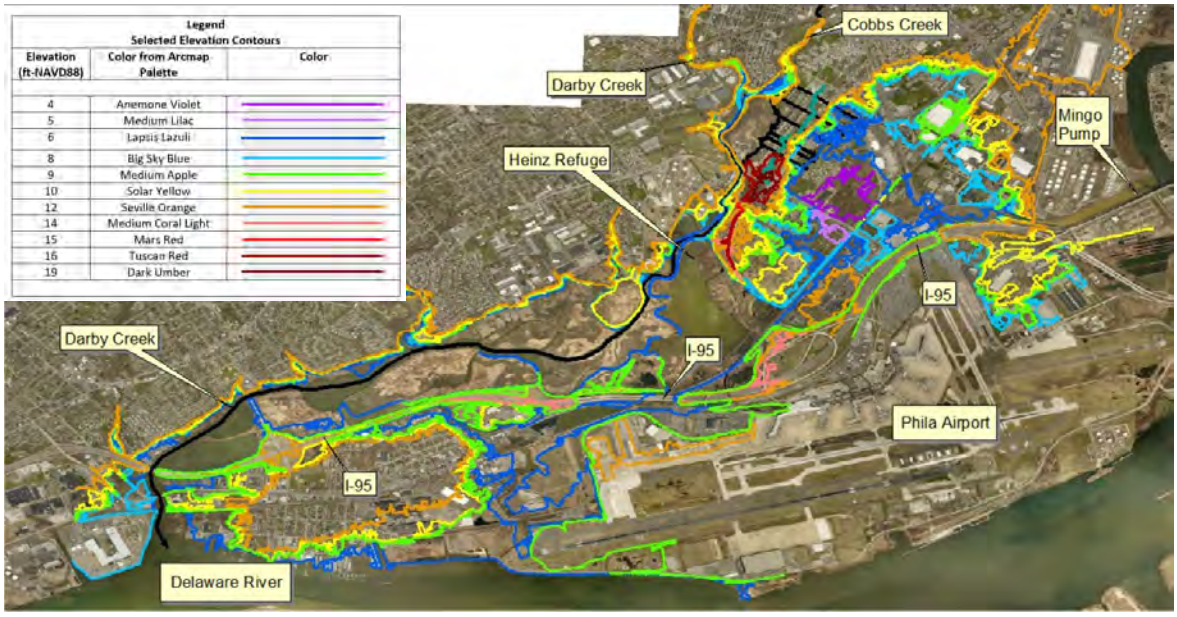

Figure 2: Study Overview with Selected Elevation Contours

During a flooding event, diversion from Cobbs Creek can occur at points A, B and C shown in Figure 3. Water flows along the channel on the back (landward) side of the landfill, diverting off into the streets (black lines with arrows). The ridge divide (Figure 3) is the highest elevation on each street. Once the water gets up to the ridge divide elevation, it can run down the streets to lower areas further from Cobbs Creek. The high elevation of each street at the intersection with the ridge line varies, generally increasing as one moves north from 84th Street. The water flowing on the streets, beyond the ridge divide, collects at the lowest area, ponding first at Point E (Figure 3) at approximately 2ft-NAVD88. As water accumulates, the ponded water spreads outward from Point E into higher and higher contours. Point D is on the entrance road to the landfill and can be overtopped from both directions allowing water out of the low land areas to Cobbs Creek or allowing water from Cobbs Creek to enter the low land areas.

The majority of the low-lying area (Point E) is at elevation 2ft-NAVD88 and is not serviced by storm drains. Points F to G (Figure 4) denote a berm parallel to the Airport Rail Line. The berm elevations are approximately 9 to 10 ft-NAVD88. However, there are gaps in the berm at elevation 5ft-NAVD which allows water to flow onto the Airport Rail Line tracks which are also at elevation 5ft-NAVD88. When the water surface elevation is 6ft-NAVD88 or greater, water will flow towards the Mingo Pump Station. The flow paths shown in Figure 4 are the paths for the initial overflow from the low ponding area. As water in the ponded area rises, other flow paths are engaged. Water also overflows 84th Street discharging into the Heinz Refuge, which is explained below.

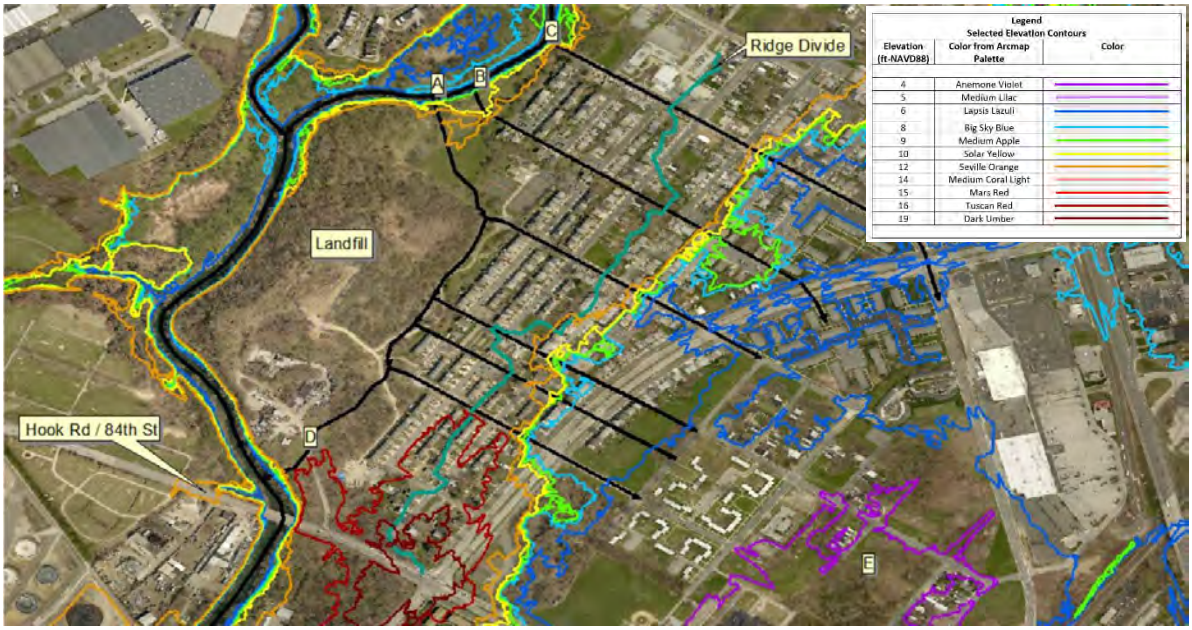

Figure 3: Enlarged View - Landfill Area

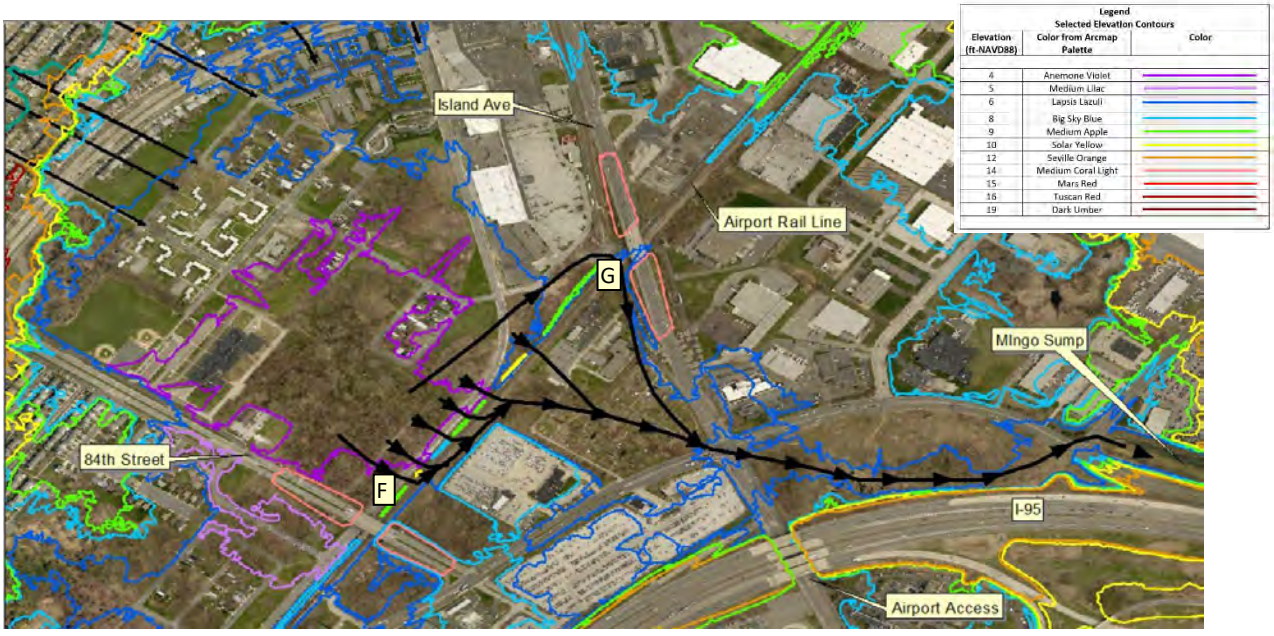

Figure 4: Enlarged View - Lowest Area

Figure 5 shows the elevation contours north of 84th Street. The highest contour shown is elevation 12ft-NAVD88. There are two gaps, Points H and I where outflow can occur at elevations less than 12ft-NAVD88. Point H is an underpass at elevation 10ft-NAVD88. Point I is an underpass at elevation 6ft-NAVD88 and leads to the airport. One can visualize different water surface elevations at the low-lying area (Point E) and the extent of the inundation by matching the assumed water surface elevation to the

color contour. The 1999 Hurricane Floyd water surface elevation at the low-lying area was estimated at 9-10 ft-NAVD88 (green contour).

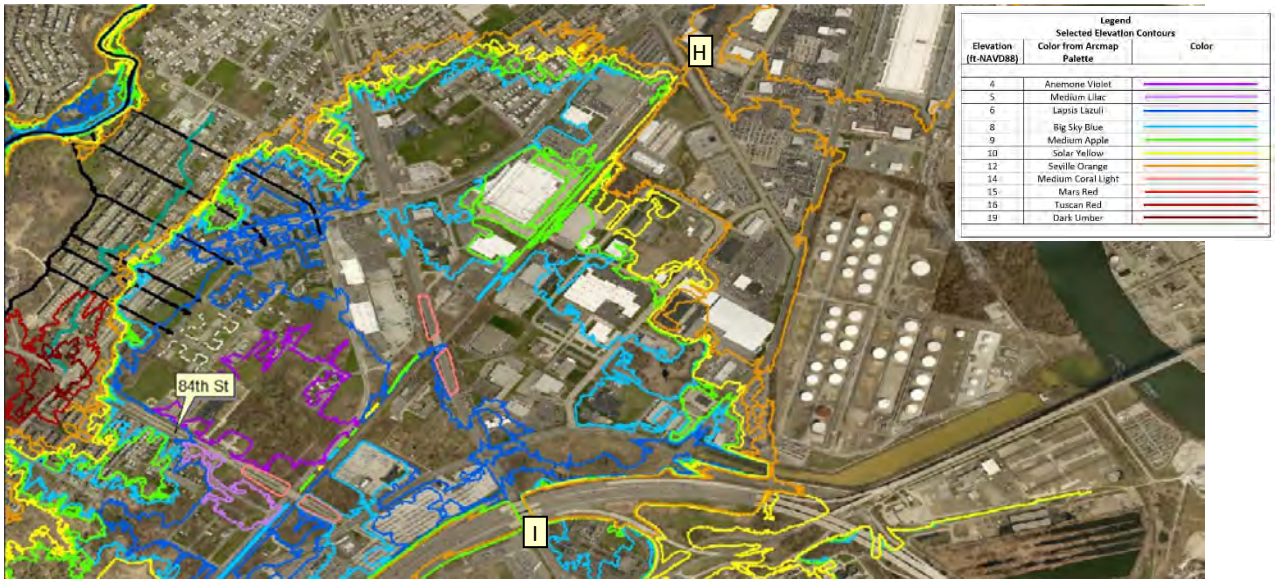

Figure 5: Enlarged View - Mingo Pump Station

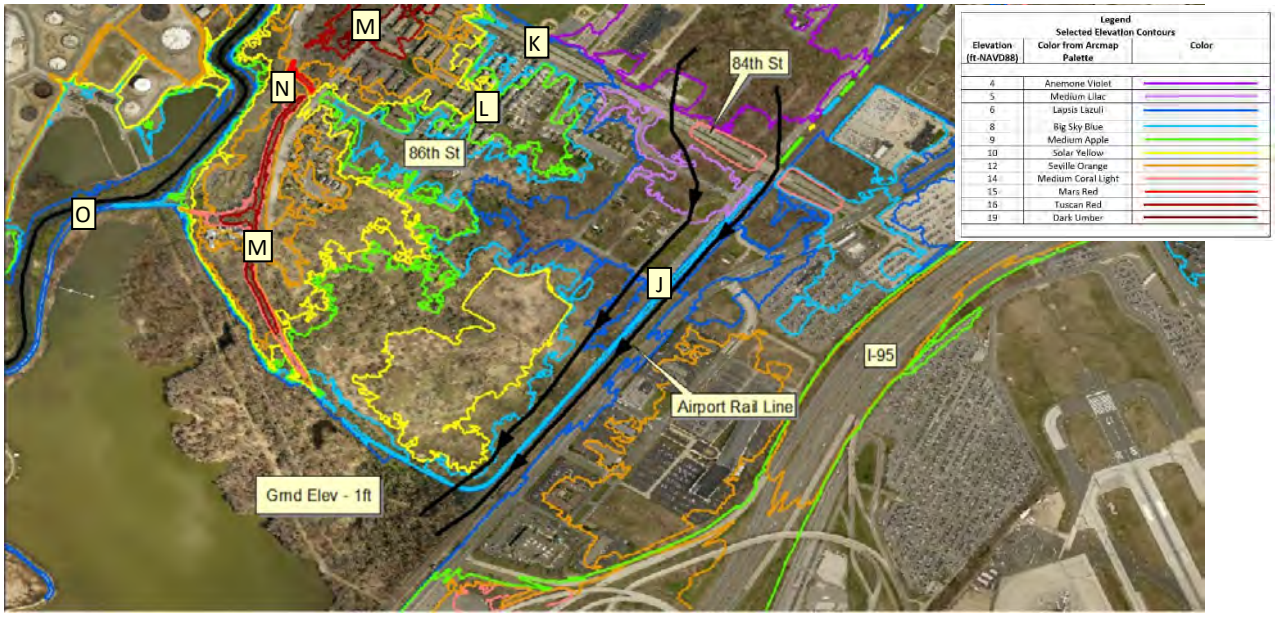

Figure 6: Enlarged View - South of 84th Street

Additionally, water ponded at the low-lying area can overflow 84th Street. The first flow paths are shown as black lines (Figure 6). Water spills out of the ponding area over and under 84th Street at elevation 5ft-NAVD88. Point J is a berm separating the two flow paths which runs the full length of the flow paths shown. The elevation of the berm is approximately 10ft-NAVD88. The Airport Rail Line track elevation is 5ft-NAVD88. The ground elevation of the path on the west side of the berm is elevation 6ft-NAVD88. However, it will not discharge into the Heinz Refugee until the water surface elevation reaches 8ft-

NAVD88 because the ground elevation rises in the downstream direction. However, a water surface elevation at Point J of 6ft-NAVD88 or higher will back up 86th Street.

At higher elevations ponded water spills over 84th Street onto the lateral streets, Point K, but does not flow until a ridge of varying elevations, Point L, is overtopped. Point M shows an existing levee of varying but high elevations that blocks flood water from Darby Creek. However, at the entrance to the Heinz Refuge, Point N, there are two low spots that allow water from Cobbs Creek to spill onto 86th Street.

Point O is a dike with a crest elevation of 6-7ft-NAVD88 that runs for 7700 feet and separates Darby Creek from the open water of the Heinz Refuge. The area behind the dike is approximately 270 acres. It appears to be large but compared to the runoff from the 62 sq. mi. watershed at this location, it is rather small. If the dike is over-topped it only takes 0.57 inches of runoff to fill the protected area to elevation 7ft-NAVD88. This would lead to 2ft of water on the Airport Rail Line tracks that will flow into the low-lying area (Point E in Figure 3).



Figure 7: Enlarged View - Airport

Point P is the discharge location from the lowest area along the Airport Rail Line tracks. Point Q is the downstream end of the 7700 ft long dike. Near Points R and S, I-95 is on a bridge. Points R and S denote a dike which prevents water from flowing under the bridge. The lowest elevation of this dike is Point R, at elevation 11ft-NAVD88. Near Point S, there is a 250-foot-wide gap that allows water to flow to the east side of I-95. Note the large area on the east side of I-95 enclosed by the dark blue line which is elevation 6ft-NAVD88. Point V denotes a dike along the Delaware River. The crest elevation of the dike is 8-9ft-NAVD88. Points T and U are two low spots on I-95 at elevation 10ft-NAVD88. Water from the Heinz Refuge can overflow at these points in the absence of a concrete wall or Jersey barrier.



Figure 8 - Darby-Cobbs Watershed with Eastwick location marked with red star (adapted from Delaware County Planning Department, 2005)

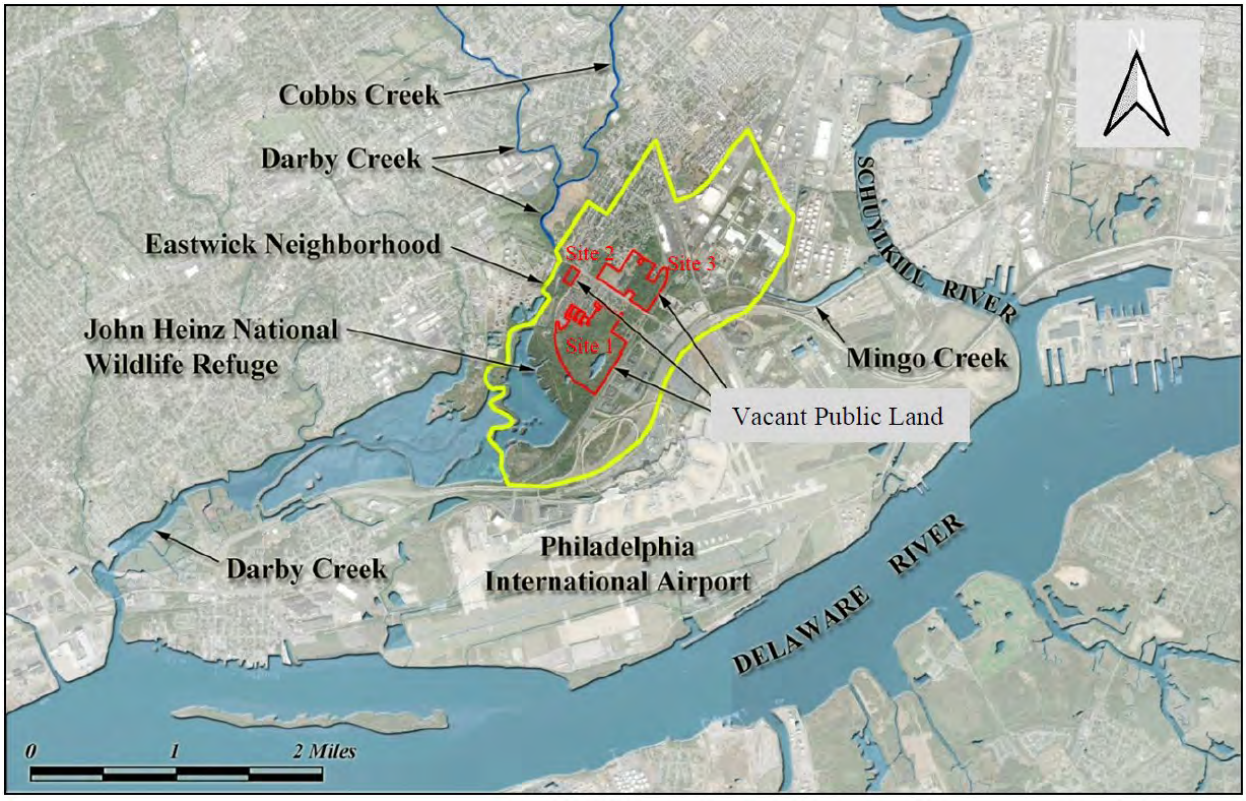

Figure 9 - Eastwick Neighborhood Location (source: AKRF, 2022)

Hydrologic Analysis

For input to the hydraulic modeling described in later sections, it was necessary to compile best estimates for peak flows across the range of natural variability for both Darby and Cobbs Creeks through the reach of interest near the Eastwick neighborhood. Below sections describe methods, considerations, uncertainty, and current recommended flows for use in hydraulic modeling.

Background and Flood History

The Darby-Cobbs watershed is located southwest of the City of Philadelphia (Figure 8). The majority of the watershed is developed with a population of approximately 500,000. The mainstem of Darby Creek flows from northwest to southeast through Chester and Delaware Counties as it travels toward its confluence with Cobbs Creek, near the Eastwick neighborhood. Cobbs Creek, the major tributary of Darby Creek, also flows from northwest to southeast through Delaware County but along the borders with Montgomery and Philadelphia Counties until it turns toward the south to meet Darby Creek, just downstream of Colwyn Borough, adjacent to the Eastwick neighborhood. The combined Darby and Cobbs Creeks then travel from northeast to southwest through a tidal area that includes the John Heinz National Wildlife Refuge, the largest remaining freshwater tidal marsh in Pennsylvania, towards the Delaware River.

The Darby-Cobbs watershed covers approximately 77 square miles. Upstream of the confluence of Darby and Cobbs Creeks, the Darby watershed is about 2 times larger at 39.7 square miles than the Cobbs watershed at 22.3 square miles. The northern area of the Darby watershed, which is further from Philadelphia, is less urbanized than the southern area and the Cobbs watershed, which borders Philadelphia, is very urbanized throughout its area. Up to two thirds of the total watershed surface is impervious. Of the population of approximately 500,000 that live in the Darby-Cobbs watershed, approximately half live in the Cobbs Creek watershed. A stormwater management plan under Act 167 (Delaware County Planning Department, 2005) was developed for the combined Darby-Cobbs basin to help control stormwater runoff from new development on a watershed wide basis.

The Eastwick neighborhood in Southwest Philadelphia is bounded on its west by Cobbs and Darby Creeks and is subject to frequent and severe fluvial flooding from multiple sources, as shown conceptually in Figure 10. Fluvial, or terrestrial, flooding is the result of high flows in creeks and rivers, as opposed to tidal flooding driven by coastal events, and storm surge on the Delaware River. Pluvial flooding, or flooding driven by precipitation and overland stormwater runoff is also an issue in Eastwick, often overwhelming storm sewer network, and the Mingo Creek Pump Station. Given the unknowns and complexity associated with the storm sewer network, and the scale of the issue (much less impact than Cobbs Creek overflow), internally generated runoff was excluded from the current study. Fluvial, or river and creek, flooding is the main focus of the current FRM Feasibility Study.

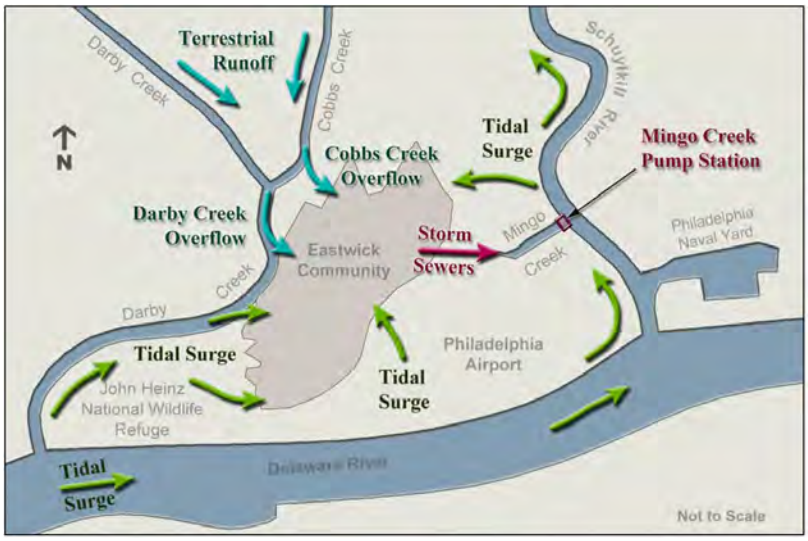

Figure 10 - Conceptual Diagram of Eastwick Flooding Sources (source: AKRF, 2022)

As discussed in previous USACE studies, results from questionnaires provided to residents of Eastwick (2012) by Philadelphia Water Department (PWD) indicated dates of flood-producing fluvial events shown in Table 1.

Table 1 - Significant Events from Resident Questionnaires

Date	Storm Event Name (if named)
September 15, 1999	Hurricane Floyd
August 1, 2004	
September 28, 2004	Tropical Storm Jeanne
August 28, 2006	
June 6, 2009	
August 2, 2009	
August 1, 2010	
August 9, 2010	
August 27, 2011	Hurricane Irene
September 7, 2011	Tropical Storm Lee

Significant storms in the watershed were Hurricane Floyd in 1999, Hurricane Irene in 2011, and Tropical Storm Lee in 2011. Subsequent to the questionnaire, and after previous USACE studies, Hurricane Isaias in 2020 was also a significant event. High water mark data for Isaias was collected in the days following the event by USACE Philadelphia District Staff. Notably, Hurricane Ida in 2021, which caused record or near-record flows on the Schuylkill River and the nearby Perkiomen Creek, did not result in high flow impacts on either Darby or Cobbs Creek.

While Eastwick is also subject to tidal impacts, flood risk management measures specific to coastal flooding are not the focus of the current study. Sea level change is incorporated in the form of updated tidal boundary conditions for future conditions simulations.

The main drivers for flooding in Eastwick are both the mainstem Darby and Cobbs Creeks, however three smaller tributaries enter Darby Creek downstream of the Cobbs Creek confluence, shown in Figure 11, which also contribute to flooding further downstream. Flow contributions from these tributaries are accounted for in the hydrologic boundary conditions, as discussed in later sections.

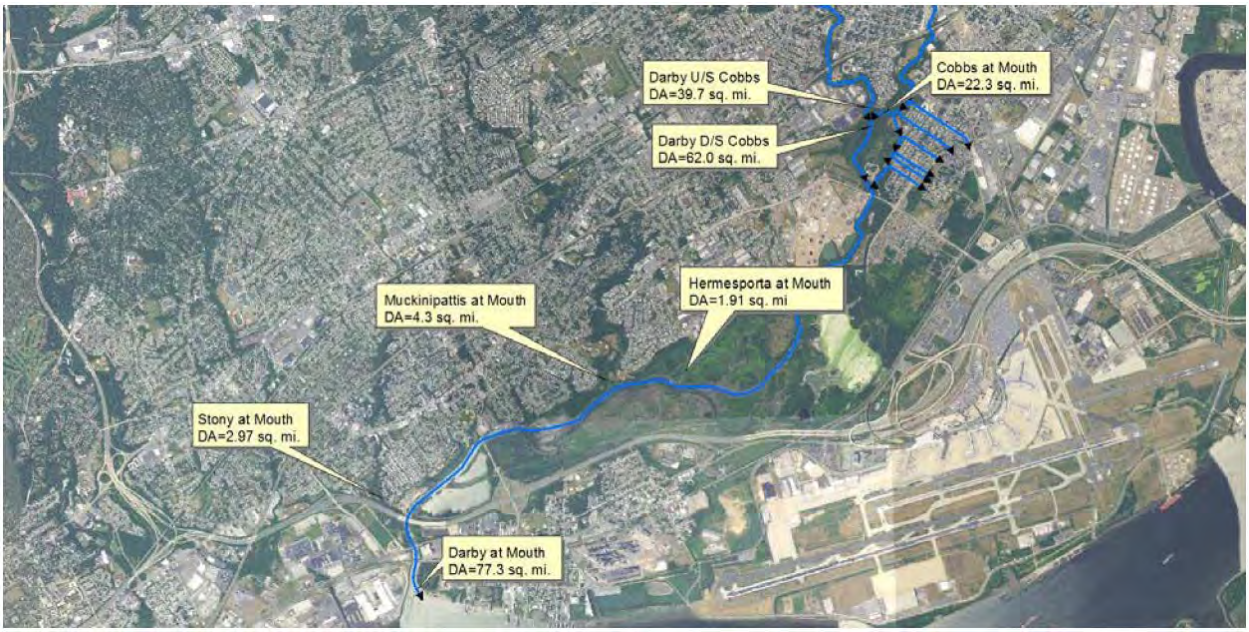

Figure 11 - Mainstem Darby and Cobbs Creeks with Lower Tributaries (USACE, 2016)

Overview of Previous Studies and Current Updates

Previous studies that the current hydrologic analysis builds upon are detailed below, including updates to those previous efforts for this current Feasibility report.

USACE Eastwick Stream Modeling and Technical Evaluation (2014).

USACE Darby and Cobbs Watersheds Hydrologic Study (2016) – This study identified best practices and recommendations for flood frequency estimates using best available data. Updates for the current analysis include additional years of data (2016 through 2022), and revised analysis using Bulletin 17C methods (rather than B17B).

Princeton Hydro (2017) – Flooding estimates for Irene and Lee. Utilized to conceptualize impacts of complementary features, detailed in later sections.

AKRF, Inc. (AKRF) (2022) – Hydraulic model utilized 2014 USACE model, and updated to 2D, calibrated to Isaias. Estimated peak flows for Isaias re-rated. Current study refines estimates of FFA utilized re-rated Isaias, and updates flow change locations, and how they are incorporated. AKRF also completed a detailed tidal-fluvial coincidence analysis. The current study will utilize the AKRF coincidence analysis to guide choice of boundary conditions in coincident flooding assessment, to be completed in later phases.

Fluvial Coincidence

When discussing coincidence between two streams at their confluence, there is consideration of two forms of coincidence - coincidence of magnitude, and coincidence of timing. Both Darby and Cobbs typically have same day for annual peak discharge, approximately 68 percent of the overlapping period of record. Year over year plots showing both Darby and Cobbs typically record annual peak flows in summer months are shown in Figure 12. Additionally, for the years where annual peaks occur on different days, both flows are less than the 2-yr event, indicating no major events in that year. This leads to a reasonable assumption for coincidence of magnitude, that for a given storm event, it is likely that both streams will have similar peaks relative to their drainage areas.

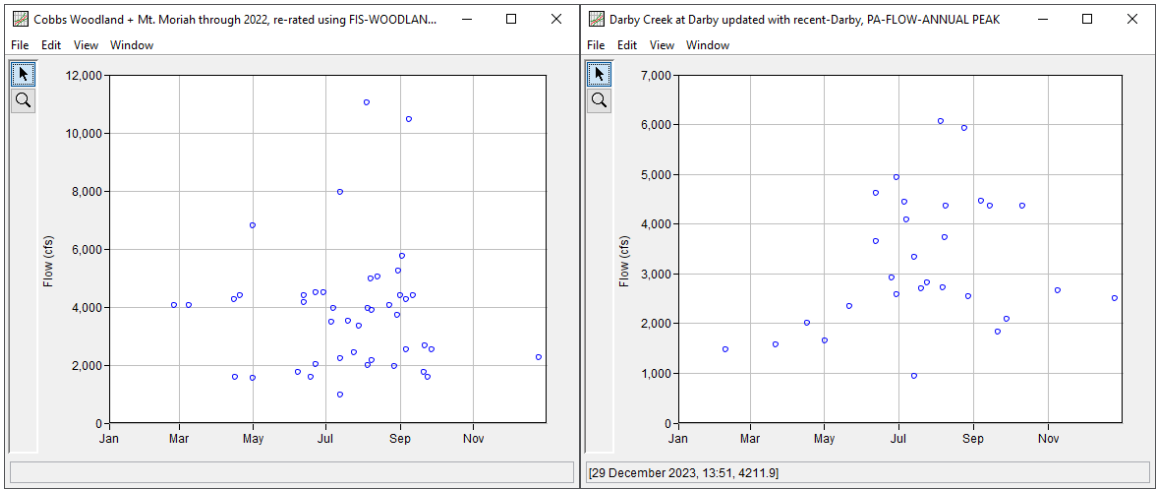

Figure 12 - Year over year Plot for Darby and Cobbs Creeks

Given the large drainage area difference, Darby and Cobbs do not typically peak at the same time – i.e. do not share coincidence of timing. Figure 13 through Figure 17 detail readily available data since October 2018 when both streams have been gaged. Both gages are approximately the same distance from the confluence (Mt. Moriah ~ 2.6 miles, Providence ~2.2 miles) and can be expected to have similar translation moving downstream, i.e. maintain similar timing relationship. Cobbs is shown in each event identified (>3000 cfs) to peak prior to Darby, with the average difference between peaks at approximately 2.5 hrs. Further, the USGS Gage at 84th Street is shown to peak in between, indicating downstream stages are not a result of peak on peak. This is consistent from larger events to smaller event, including Isaias, one of the calibration events.

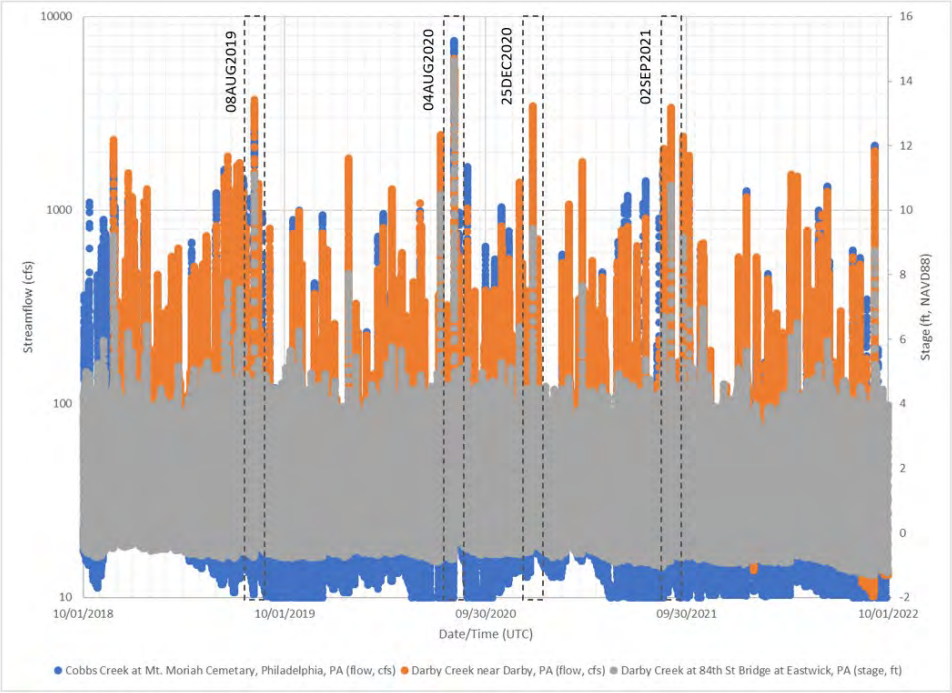

Figure 13 - Gage Data Available on both Darby and Cobbs since 2018 (highlighting peaks examined in subsequent figures)

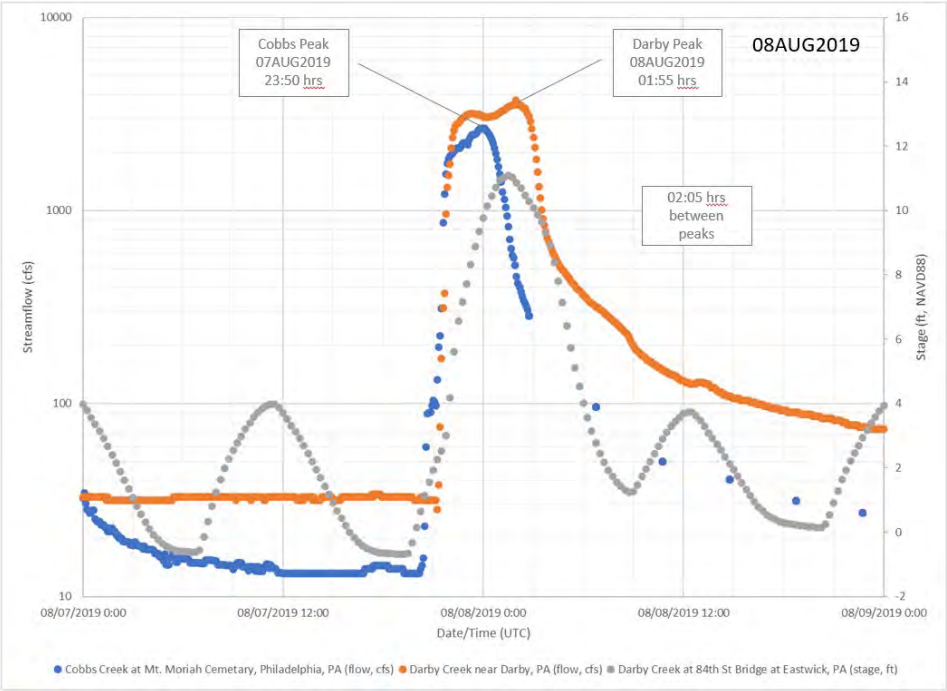

Figure 14 - Hydrograph Timing - AUG 2019 event

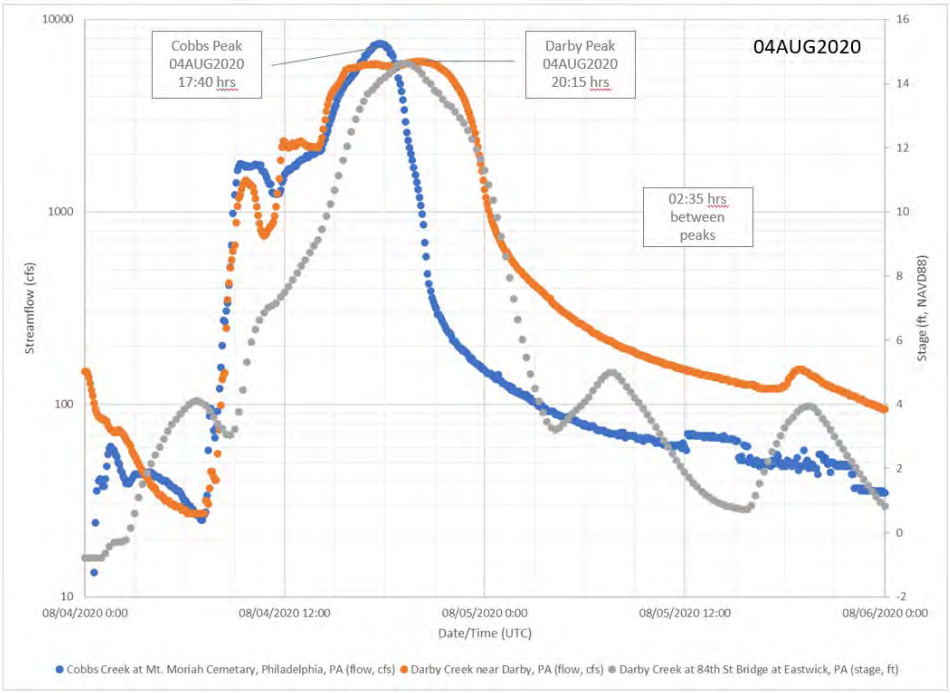

Figure 15 - Hydrograph Timing - AUG 2020 Event (Isaias)

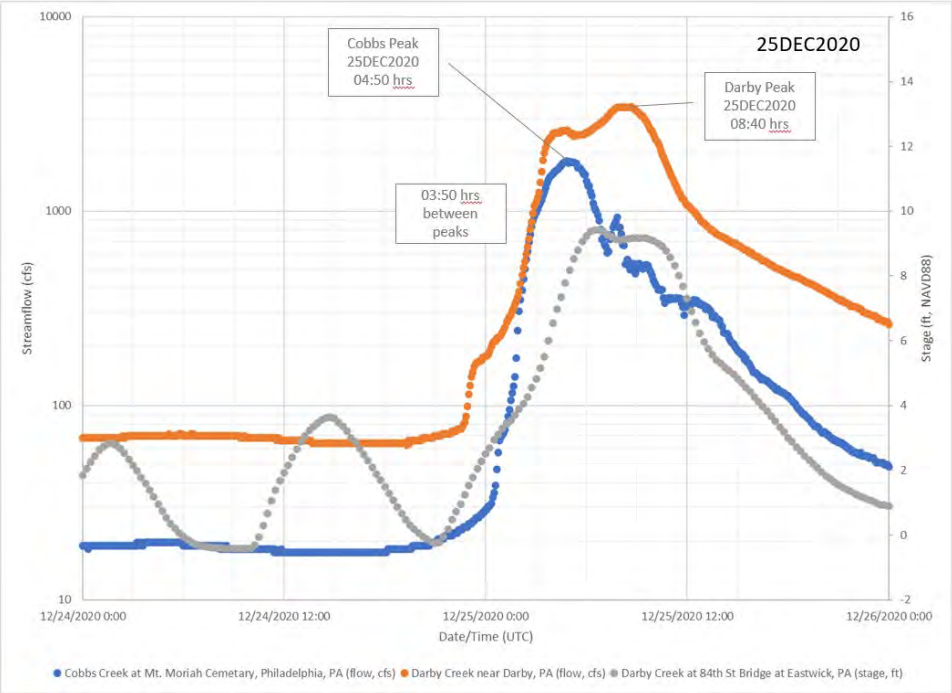

Figure 16 - Hydrograph Timing - DEC 2020 Event

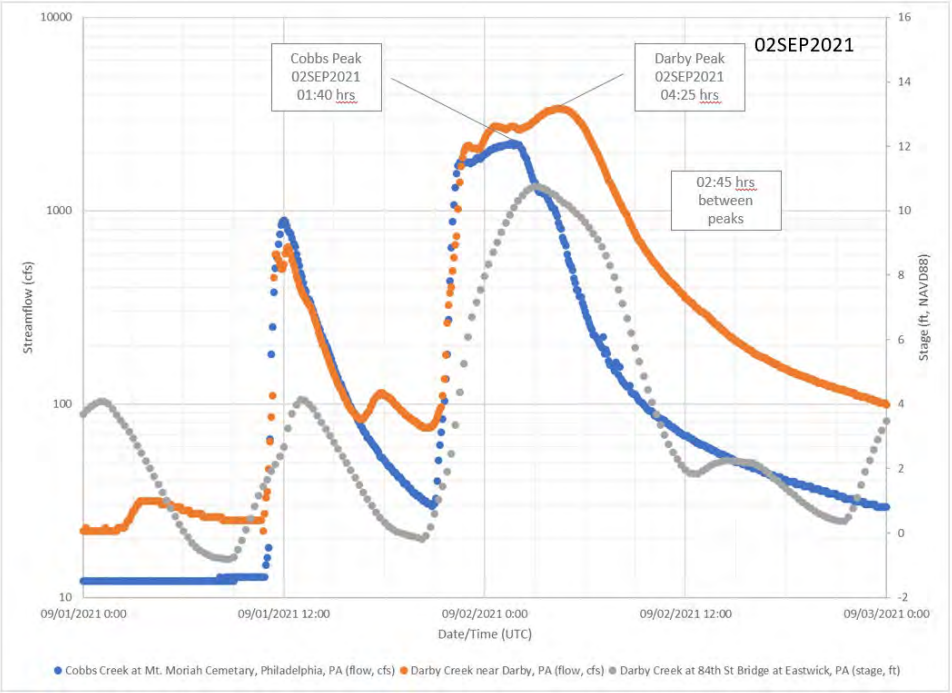

Figure 17 - Hydrograph Timing - SEP 2021 (Ida)

Tidal Coincidence

AKRF (2022) completed a detailed tidal-fluvial coincidence analysis. The current study will utilize the AKRF analysis to guide modeled compound flooding events, to be completed in later phases. Figure 18 shows the AKRF coincident analysis results, generally bounded by the 10% AEP and 1% AEP combined, for both tidal-fluvial, and fluvial-tidal. Tidal gages utilized for their analysis are shown in Figure 19. For the current phase of the USACE feasibility study, downstream tidal boundary conditions are simplified. For all historic calibration events, the highest tide during event is maintained constant, to remove potential effects of timing, where fluvial timing is uncertain, or unknown. This was considered conservative, leading to likely higher modeled WSELs.

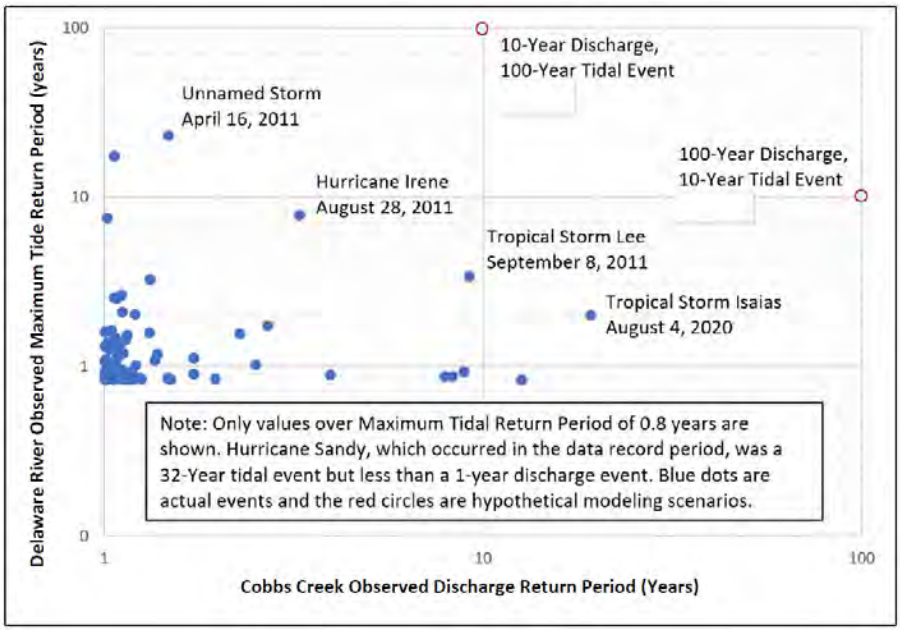

Figure 18 - AKRF Tidal Analysis for Coincidence (source: AKRF, 2022)



Figure 19 - Proximate Tide gages utilized by AKRF (source: AKRF, 2022)

Historic Events

Based on available gage data, resident response surveys, and available HWM data, four (4) events were chosen for calibration and validation. Estimates for each event, at each boundary condition, are described below, and summarized in Table 3 - Boundary Conditions Summary.

- Floyd 1999 – Cobbs estimated peak flow from PWD stage gage, Darby estimated peak from Post Storm USACE report, both hydrograph shapes scaled from Isaias
- Irene/Lee 2011 – Cobbs peak/shape re-rated USGS gage records using combined rating FEMA FIS and USGS; Darby peak estimated using peak factor, Isaias shape
- Isaias 2020 – Cobbs and Darby peak/shape re-rated USGS gage records using combined rating FEMA FIS and USGS

Flood Frequency Peak Flow Estimates

From 2016 Analysis, subsequent years (2016 through 2022) were added to the gage records at Mt. Moriah, re-rated using the combined USGS/FIS rating curve, and transferred to Woodland gage location using the scaling factor. B17C analysis was performed utilizing perception thresholds (USGS, 2013). This process was repeated for the Darby Creek Providence Road gage. Similarly to 2016, Darby peak flow estimates across all eight frequencies were less than Cobbs Creek. Given the drainage area difference, and greater confidence in Cobbs Creek estimates (80+yr effective record length), the current study recommends continued use of peak adjustment factors. This takes estimates at Woodland gage (adjusted from Mt. Moriah), and uses a factor varying across frequencies, to estimate Darby Creek peak discharges. This method is considered conservative in terms of estimating peak flows. Current study results are shown in Table 2 and Figure 23. Summary of the completed updates is bulleted below:

- Updated 2016 estimates, including Isaias, subsequent years
- Both Mt. Moriah (Cobbs) and Providence Road (Darby) gages
- Recommend continued use of peak scaling factors to ensure Darby flow > Cobbs flow
- All frequency hydrographs scaled from Isaias shape on Darby/Cobbs

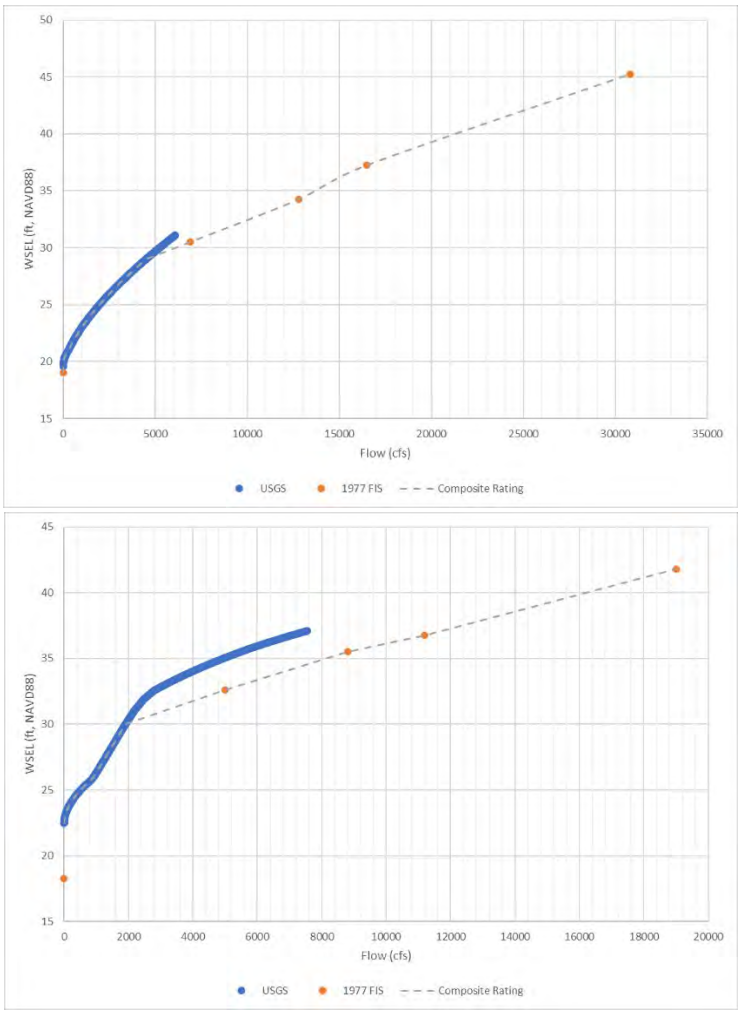

Figure 20 - Rating Curves at Darby Providence Road (above) and Cobbs Mt. Moriah (below) used for re-rating USGS reported flow rates

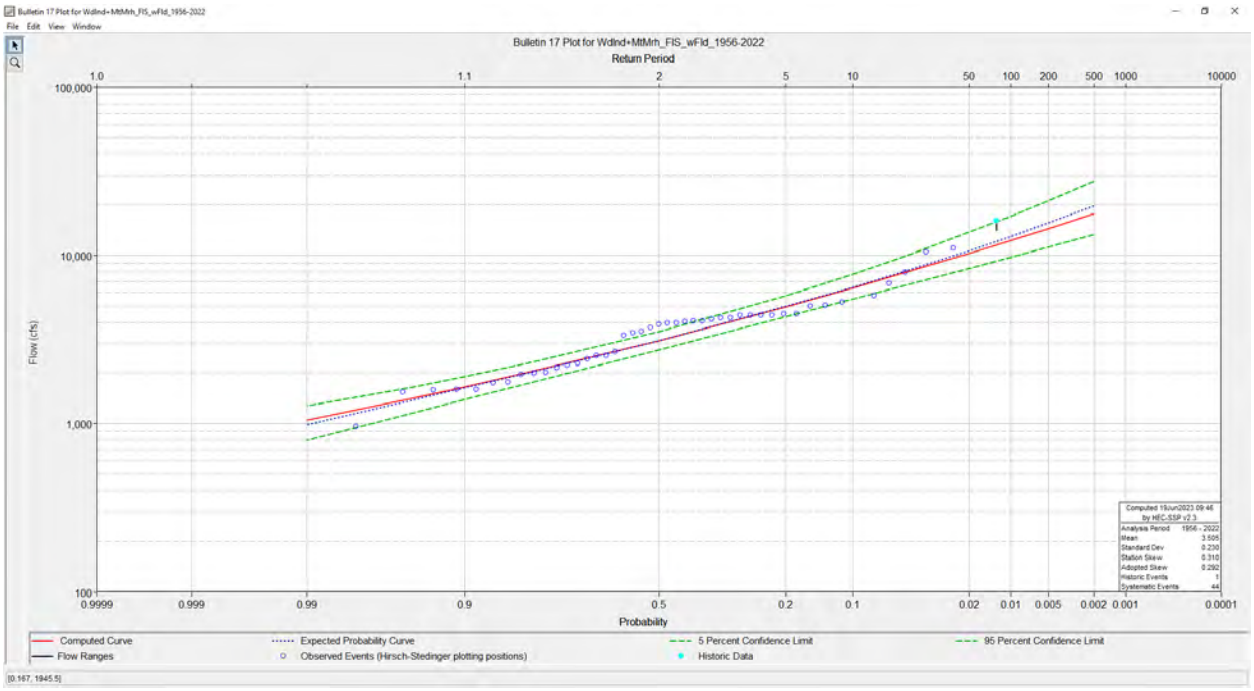

Figure 21 - B17C Output from HEC-SSP for Cobbs Creek Flood Frequency

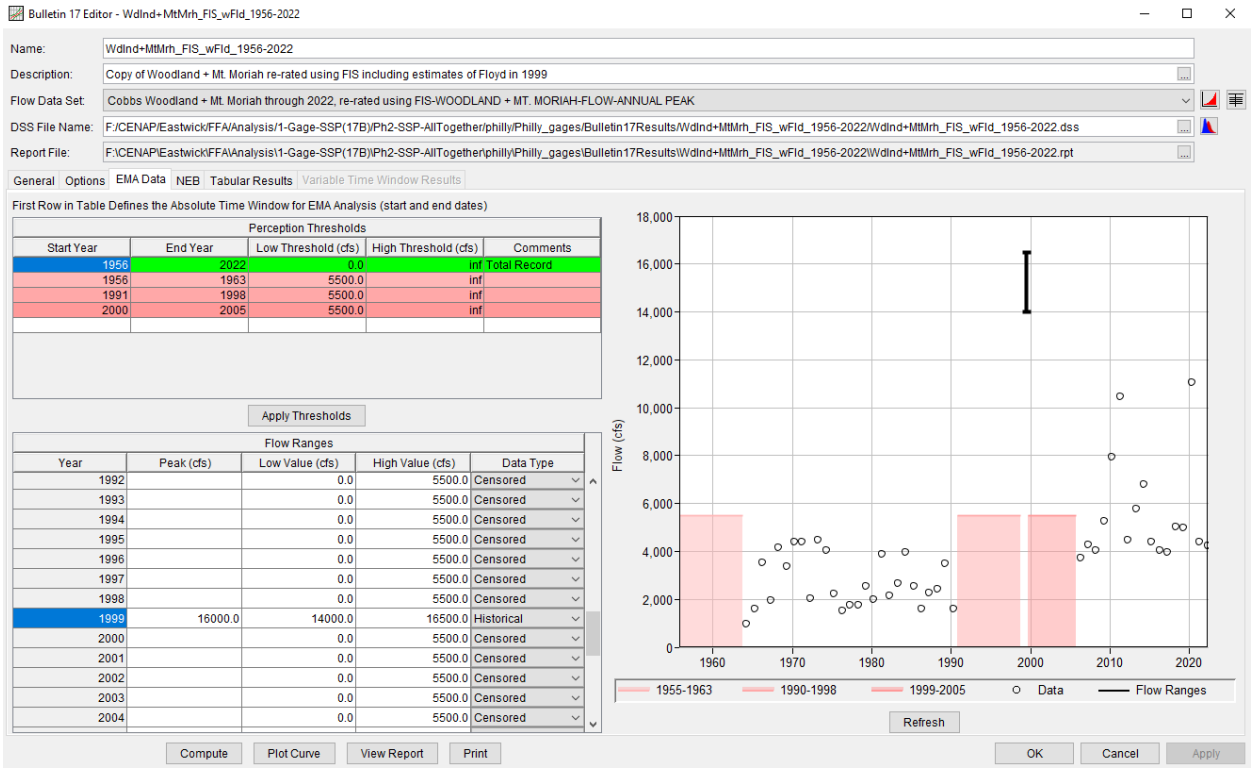

Figure 22 - Example of B17C Perception Thresholds for Cobbs Creek Flood Frequency

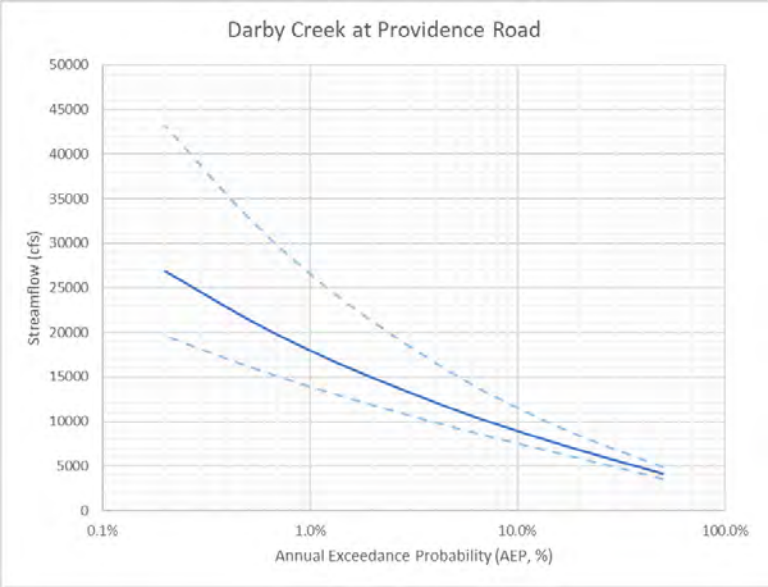



Figure 23 - Flood Frequency Curves for Darby and Cobbs Creeks

Table 2 - Flood Frequency Estimates for Current Study

Event	AEP (%)	Discharge for Cobbs Creek at Woodland Ave (CFS)	Confidence Limits		USACE 2016 Adjustment Factor	Discharge for Darby Creek at Providence Road (CFS)	Confidence Limits		Discharge for Cobbs Creek at Mt. Moriah (CFS)	Confidence Limits	
			5%	95%			5%	95%		5%	95%
2yr	50.0%	3120	3586	2639	1.369	**4271**	4909	3613	**2848**	3273	2409
5yr	20.0%	4984	6094	4262	1.378	**6867**	8398	5873	**4549**	5563	3891
10yr	10.0%	6468	8344	5459	1.384	**8952**	11548	7555	**5905**	7617	4983
20yr	5.0%	8128	10991	6710	1.388	**11281**	15256	9313	**7419**	10033	6125
50yr	2.0%	10667	15221	8499	1.395	**14880**	21233	11856	**9737**	13894	7758
100yr	1.0%	12915	19073	9981	1.394	**18003**	26588	13914	**11789**	17411	9111
200yr	0.5%	15540	23581	11592	1.399	**21741**	32990	16217	**14186**	21526	10582
500yr	0.2%	19714	30715	13945	1.406	**27717**	43185	19607	**17995**	28038	12730

In general, current study estimates for frequency events changed less than +/- a few percent from previous 2016 estimates. Flow estimates are not the same as FEMA FIS discharges, as discussed, because those FIS estimates are based on limited gage data, and were estimated in the original FIS in the 1970s. Current study estimates for frequency discharges are considered best estimates available, and are also considered conservative, consistent with the FRM nature of the study.

Unsteady flow inputs assume NO peak on peak, as supported in above analysis. Modeled hydrographs use Isaias implicit timing to estimate hypothetical frequency events. Future events could vary depending on timing and spatial extent of rainfall. While this is a source of uncertainty, sufficient evidence exists to utilize Isaias hydrograph timing, and as such was utilized throughout the updated hydraulics.

Differences drainage area between Cobbs Creek Mt. Moriah (19.9 sq mi) and Woodland (21.8 sq mi) is small enough that simple ratio for translation of gage data between the gages is sufficient. For reference, from Woodland to Mt. Moriah is a factor of 0.913, and Mt. Moriah to Woodland is 1.095.

Factors for transfer of Cobbs Creek flows to Darby Creek flows are plotted in Figure 24 and Figure 25. There is scatter within gage data comparison (shown as blue dots), but a general power fit with estimates of Floyd included (shown as red dot) approximates the same slope of the adjustment factors (shown as orange dots) utilized in this study. Accounting for uncertainty, this method provides justifiable, conservative peak flow estimates for use in the current phase of analysis. Peak flows for both systems can be reevaluated as additional data or analysis becomes available.

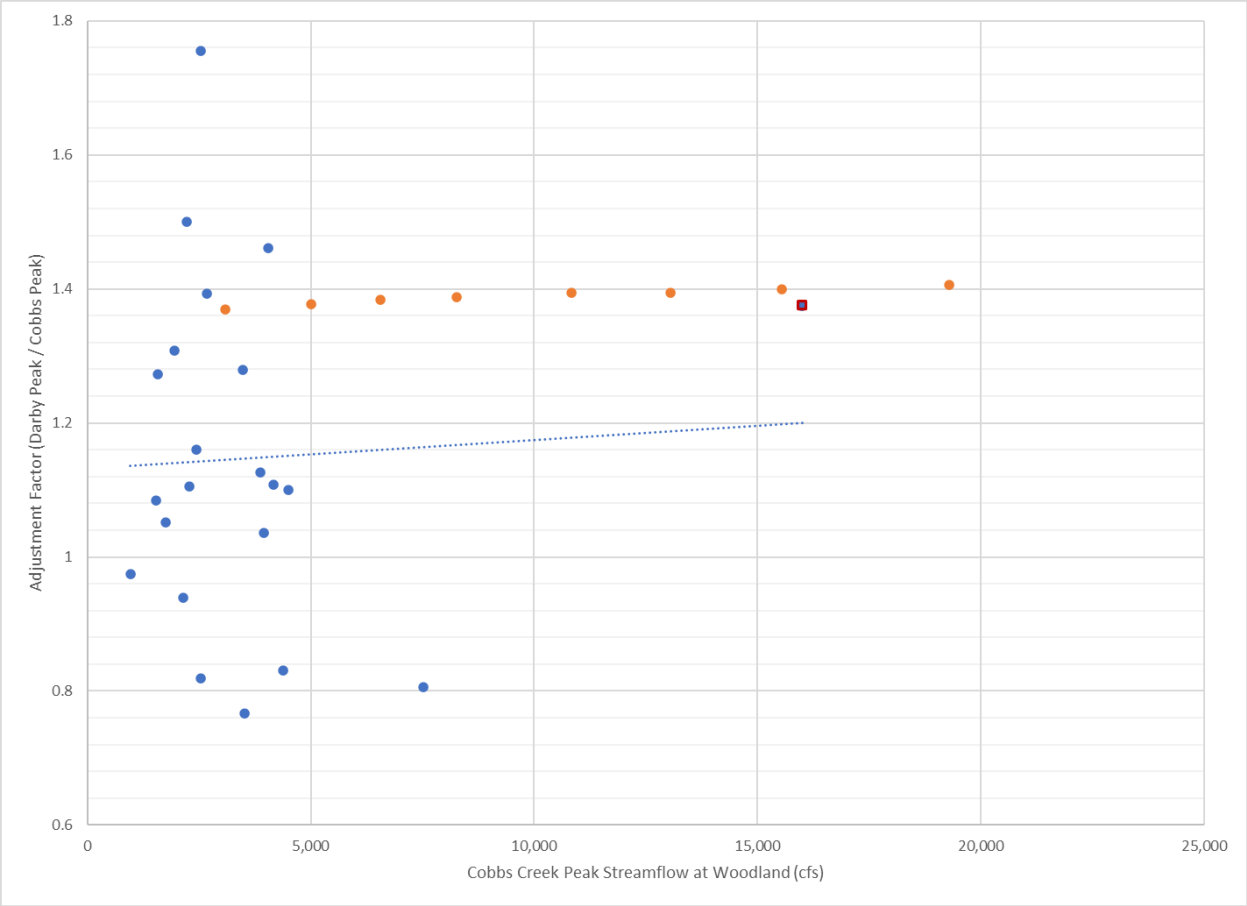

Figure 24 - Flow adjustment factors plotted against flow at Mt. Moriah

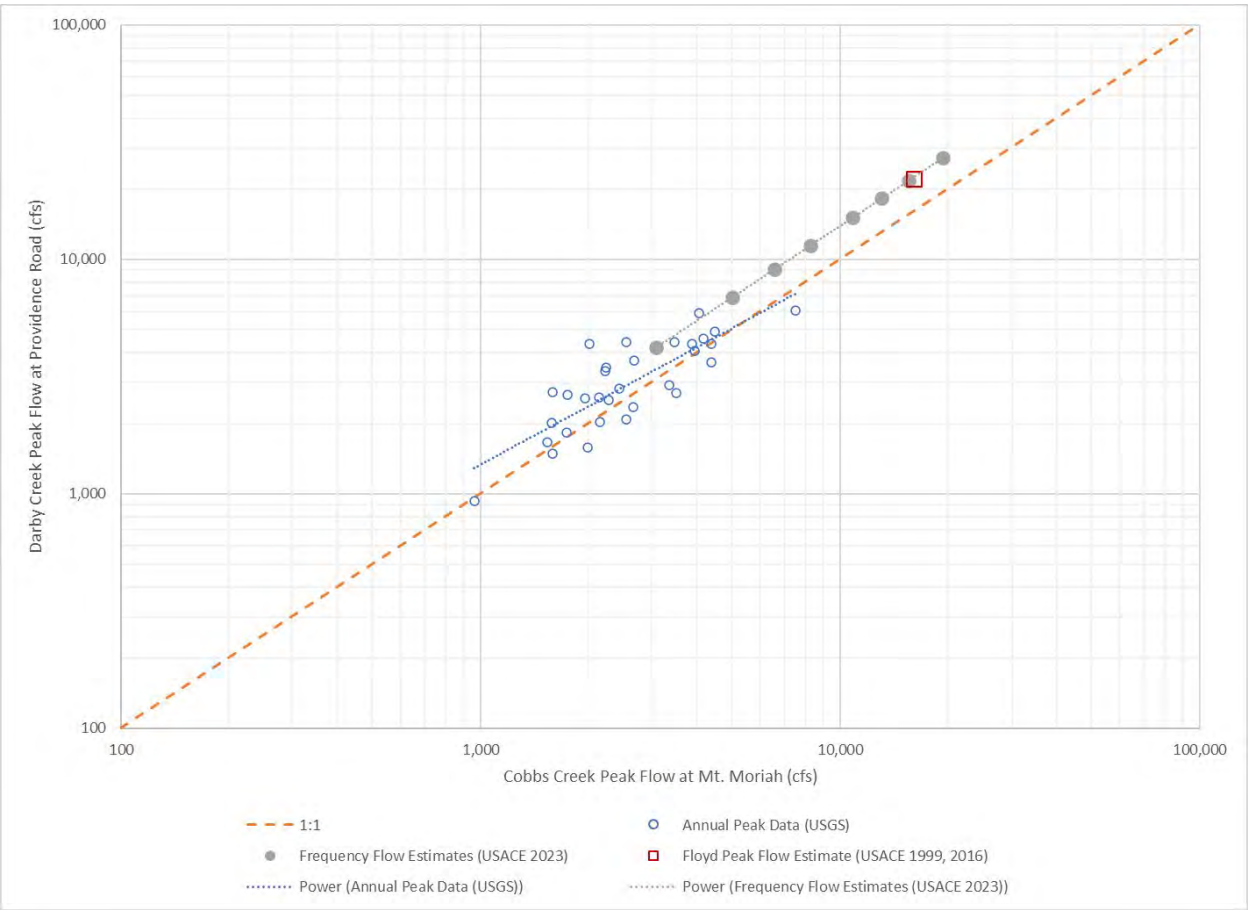

Figure 25 - Relationship of Gage Data and Recommended Flood Frequency Estimates between Darby and Cobbs Creeks

Hydrograph Shape Assumptions

When determining hydrograph shape, there are multiple choices available. Observed hydrograph data, or synthetic hydrograph shapes generated from hydrologic modeling could be used. This study chose to utilize observed hydrograph shapes. The only historic event where both Darby and Cobbs hydrograph shapes are available is Isaias in 2020. These shapes were utilized to scale both missing historic hydrographs, and frequency event hydrographs. Figure 26 through Figure 28 below detail shapes across available events. Cursory runoff volume analysis, Figure 28, shows differences in volumes depending on chosen shape. Isaias and Irene are generally consistent, lending confidence to shape choice. Lee is an outlier, with high peak flow, and less volume because of shorter, more intense rainfall, and wetter antecedent conditions. Available stage hydrograph shape from PWD stage gage during Floyd is not recommended to estimate full flow hydrograph given significant hysteresis associated with this location. Estimated flow hydrograph for Floyd is shown, but was not considered for use in scaling. Balanced hydrograph analysis was not completed but should be considered in future phases to ensure volumetrically consistent inflow hydrographs across all frequency events.

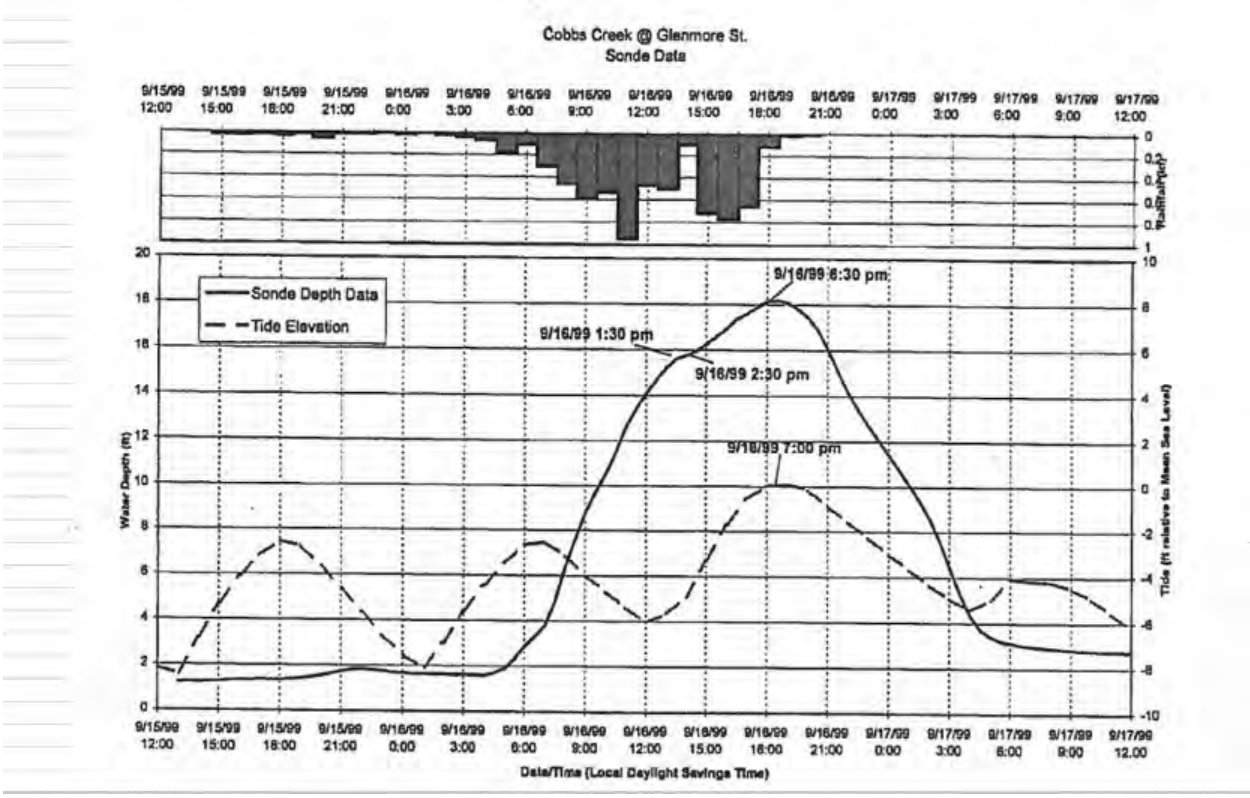

Figure 26 - PWD Stage Gage during Floyd near Glenmore Street Upstream of Eastwick

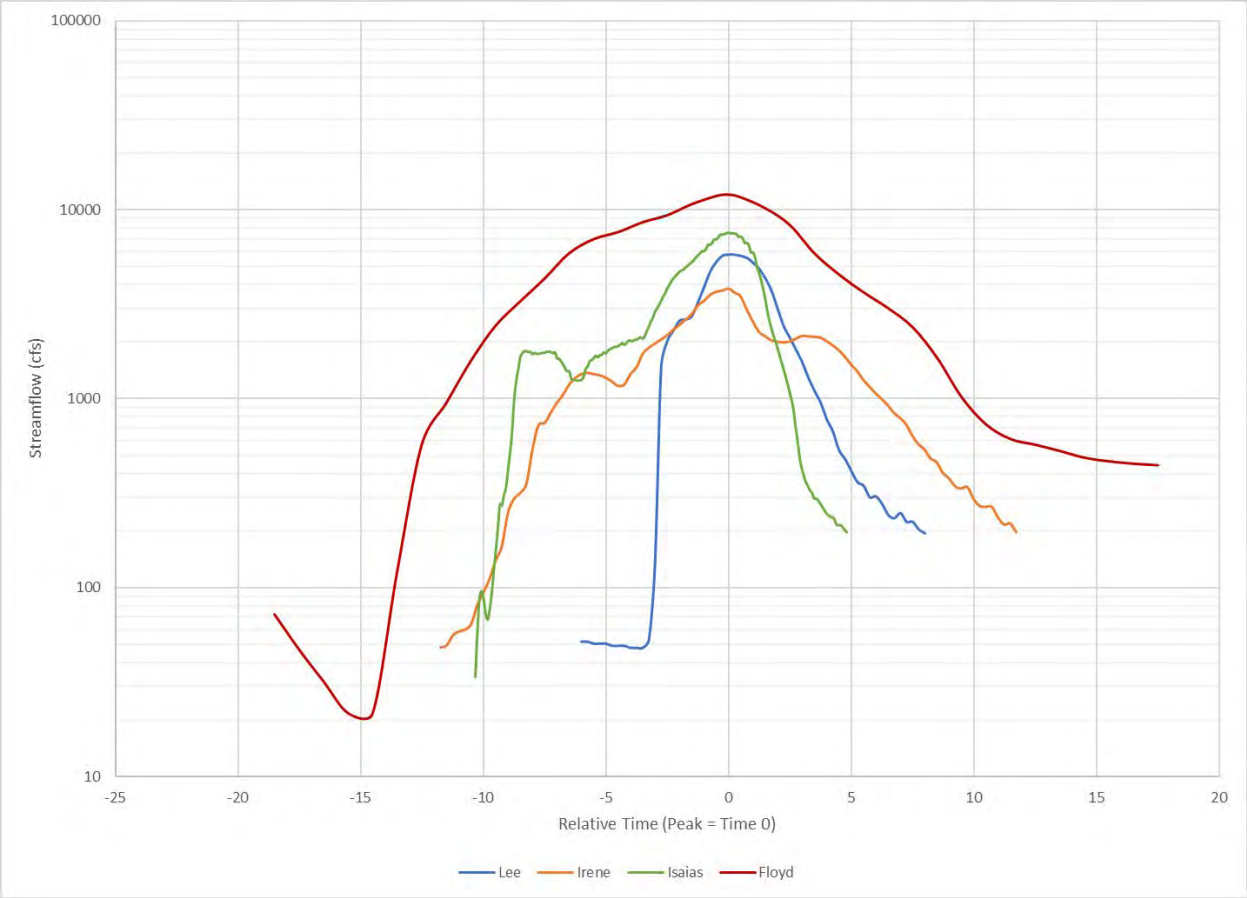

Figure 27 - Comparison of Historic Event Hydrographs on Cobbs Creek (note: hydrograph for Floyd estimated from PWD stage gage, and current study rating curve. Hydrograph not used, as this location is significantly impacted by hysteresis, making translation from stage to flow uncertain)

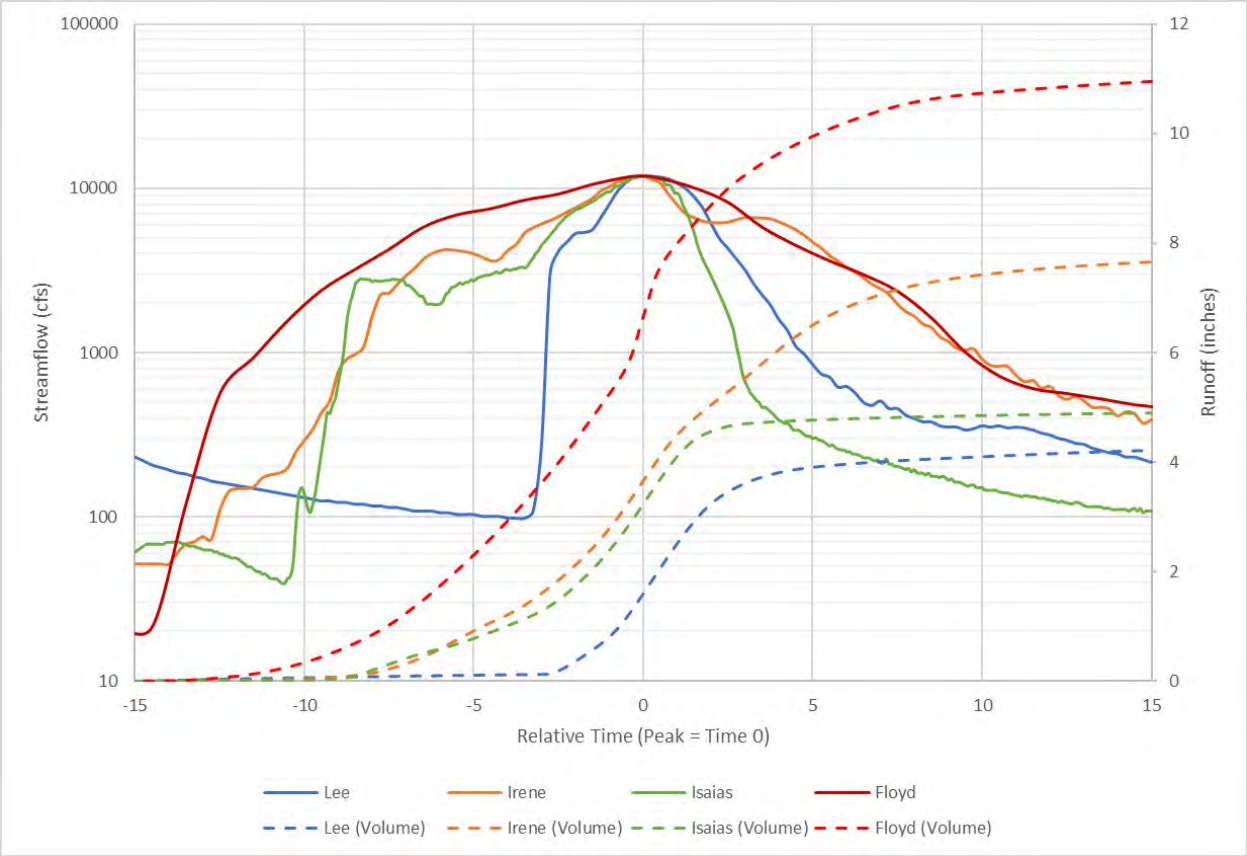

Figure 28 - Volume Comparison of Hydrograph Shapes on Cobbs Creek (note: baseflow separation not performed, so runoff is total volume; Floyd volume likely exaggerated due to effects of hysteresis noted above.)

Downstream Inputs to Peak Flows

With frequency flows updated at the upstream model extents, it is necessary to determine flows further downstream to cover the extent of model domain. For this study, we maintained a similar approach to AKRF, scaling gage hydrographs to intervening drainage areas, shown in Figure 29. This is likely conservative, as most certainly downstream smaller streams (Hermesprota, Muckinpattis, and Stony Creeks) would peak much sooner than main stem Darby Creek, and would not add directly to peak flow.

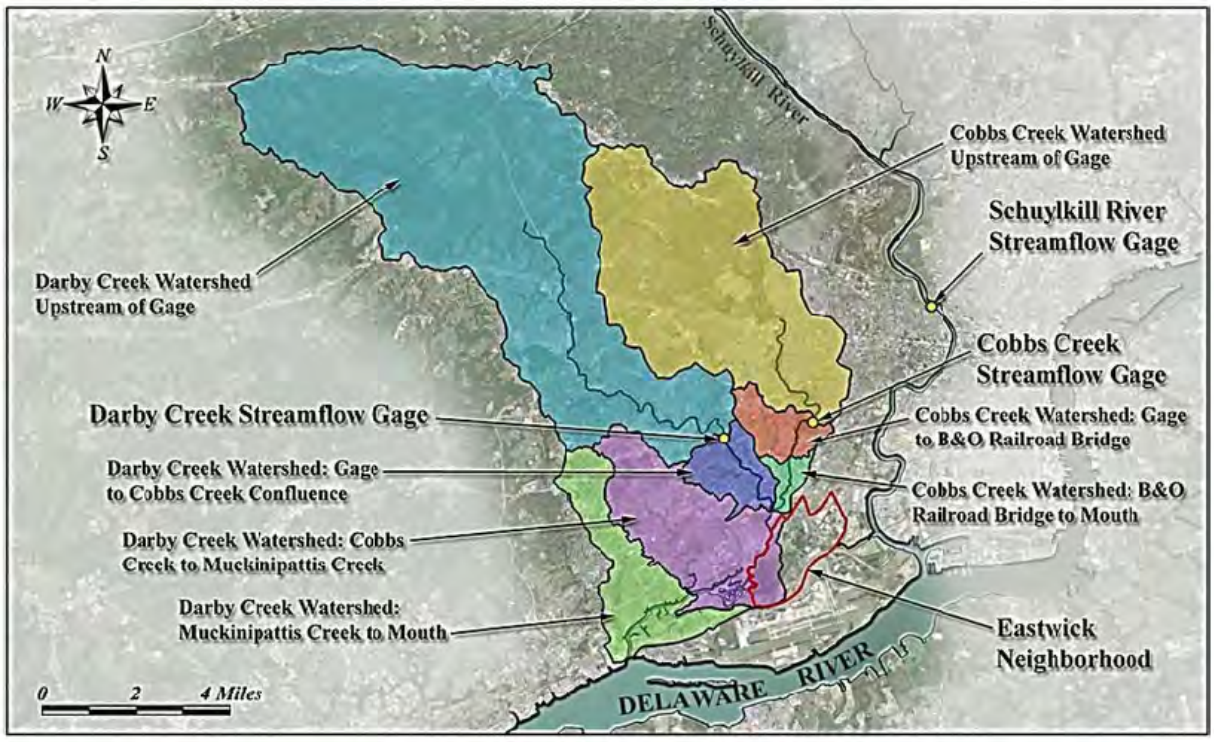

Figure 29 – Watershed Delineations at Flow Change Locations (source: AKRF, 2022)

Table 3 - Boundary Conditions Summary

Stream	Watershed	Drainage Area	DA Factor*	HEC-RAS XS Location	Boundary Type	Factors to adjust from Isaias Event										
						Frequency Events								Historic Events		
						2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	Floyd	Irene	Lee
Cobbs Creek	Upstream of Gage	19.68	-----	13921	Flow Hydrograph	0.2342	0.3810	0.4999	0.6311	0.8287	0.9994	1.1913	1.4818	1.2399	0.5544	0.7834
	Gage to B&O Railroad Bridge	1.88	0.0955	13828 to 4946	Uniform Lateral Inflow	0.0224	0.0364	0.0478	0.0603	0.0792	0.0955	0.1138	0.1416	0.1184	0.0530	0.0748
	B&O Railroad Bridge to Mouth	0.69	0.0351	4741 to 243	Uniform Lateral Inflow	0.0082	0.0134	0.0175	0.0221	0.0291	0.0350	0.0418	0.0520	0.0435	0.0194	0.0275
Darby Creek	Upstream of Gage	37.6	-----	41466	Flow Hydrograph	0.5365	0.8689	1.1383	1.4407	1.9102	2.3203	2.8109	3.6029	2.7295	1.2286	1.7409
	Gage to Cobbs Creek Confluence	2.31	0.0614	41466 to 29209	Uniform Lateral Inflow	0.0330	0.0534	0.0699	0.0885	0.1174	0.1426	0.1727	0.2213	0.1677	0.0755	0.1070
	Cobbs Creek to Muckinipattis Creek	8.52	0.2266	29209 to 11428	Uniform Lateral Inflow	0.1216	0.1969	0.2579	0.3264	0.4328	0.5258	0.6369	0.8164	0.6185	0.2784	0.3945
	Muckinipattis Creek to Mouth	5.64	0.1500	11428 to 694	Uniform Lateral Inflow	0.0805	0.1303	0.1707	0.2161	0.2865	0.3480	0.4216	0.5404	0.4094	0.1843	0.2611

* DA factor refers to fraction of overall drainage area. Adjustment factors are scaling Isaias to frequency or historic events, and include DA factor.

Sea Level Change (SLC) Analysis

USACE SLC Guidance

According to USACE guidance ER 1100-2-8162, future potential relative sea level change (SLC) must be considered in project resiliency assessments. Sea level rise results in a higher starting water surface elevation at Darby Creek's confluence with the Delaware, which is the downstream boundary of the project area. Therefore, a change in the rate of sea level rise impacts the starting water surface elevation for the downstream boundary condition. Given channel elevations, tidal influence extends through the Heinz Refuge and upstream as far as the 84th street bridge and beyond during higher tides.

Relative SLC is a combination of global sea level change effects, and local SLC due to hydrodynamics regional oceanographic circulation patterns, hydrologic cycles, and local or regional vertical land motion. Comparison of the local and regional rate at a particular gage provides an understanding of how much of the local SLC is due to vertical land movement. Three scenarios: "low", "intermediate", and "high" must be considered to estimate the change in the relative local rate of sea level rise. The low rate is equivalent to the global linear trend representing the historic rate of SLC. The intermediate curve is an accelerated rate incorporating the effect of vertical land movement (VLM) as defined by the National Research Council (NRC) modified Curve I. The high curve is an accelerated rate which considers the local rate of VLM as defined by the NRC modified curve III and exceeds the IPCC estimates to accommodate for the potential rapid loss of ice in Antarctica and Greenland. The USACE-defined intermediate rate is equivalent to NOAA's intermediate-low estimate, and the USACE high rate is lower than the NOAA intermediate-high, and high estimates. Using the modified NRC curves, the rate of relative SLC is measured from a starting year of 1992, the midpoint of the current NOAA National Tidal Datum Epoch (1983-2001).

The rate of SLC is then applied to the hydraulic model boundary conditions for both FWOP and FWP analyses.

Data Collection & Uncertainty

The NOAA PORTS® Philadelphia, PA gauge (Station ID: 8548240) was selected for SLC analysis. It is currently located near Washington Avenue and is assumed to provide a good estimate for the tidal effect on the water surface elevation at the Delaware River in the vicinity of Darby Creek. The gauge was installed in 1989 and has a period of record of ~30 full years at this location. The full record extends back to 1900. Given the period of record of ~120 years, the 95% confidence interval in the linear relative sea level trend calculated for a given year is approximately +/- 0.25 mm/yr according to the 2009 NOAA Technical Report NOS CO-OPS 053.

The datums in feet, relative to NAVD88 at the gauge using the present tidal epoch (1983-2001) are provided by NOAA and reproduced Figure 30.

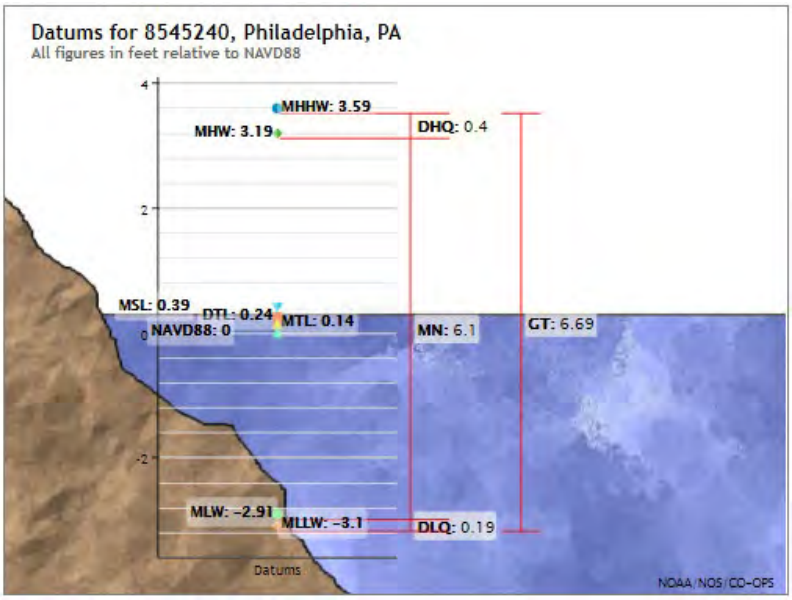

Figure 30 - NOAA Datums for 8545240 Philadelphia, PA

Results

The projected water surface elevation at the Philadelphia gauge was determined using the USACE Sea Level Change Curve Calculator (2021.12) for the entire suite of tidal elevations for the project start year, 2025 and the end of the 50-year period of analysis, 2074. Results were calculated in feet, with reference to the NAVD88 datum. At the gauge, MSL was 0.39 ft above NAVD88 in the year 1992. The SLC rate selected was the NOAA 2006 rate, equal to 0.00915 ft/yr at the Philadelphia gauge. This rate is higher than the regional rate of 0.00906 ft/yr, indicating that the local rate of VLM is higher than the regional average at the Philadelphia gauge. Water surface elevations for the low, intermediate, and high scenarios are presented in Table 4 below.

Table 4 - Sea Level Change Results for 2025 and 2074

	Datum in NAVD88 (Feet)						
Year/SLC Curve	1992	2025 Low	**2025 Int**	2025 High	2074 Low	**2074 Int**	2074 High
Change in MSL from 1992, ft	0.00	0.30	**0.40**	0.71	0.75	**1.35**	3.24
Change in MSL from 2025 Int, ft	N/A	N/A	**N/A**	N/A	0.35	**0.95**	2.84
MHHW, ft	3.59	3.89	**3.99**	4.30	4.34	**4.94**	6.83
MHW, ft	3.19	3.49	**3.59**	3.90	3.94	**4.54**	6.43
MSL, ft	0.39	0.69	**0.79**	1.10	1.14	**1.74**	3.63
NAVD88, ft	0.00	0.30	**0.40**	0.71	0.75	**1.35**	3.24
MLW, ft	-2.91	-2.61	**-2.51**	-2.20	-2.16	**-1.56**	0.33
MLLW, ft	-3.10	-2.80	**-2.70**	-2.39	-2.35	**-1.75**	0.14

Thus, considering future relative SLR results in a 0.40 ft higher water surface at the downstream boundary at the start of the project, and a 1.35 ft higher water surface at the end of the period of analysis. This is a

0.95 ft increase over the period of analysis from 2025 to 2074. The projected SLC curves from 1992-2100 for all USACE and NOAA scenarios is presented in Figure 31. The project start year of 2025 and end year 2074 are within the ovals highlighted and the intermediate rate estimated SLC rise since 1992 for both years is called out.

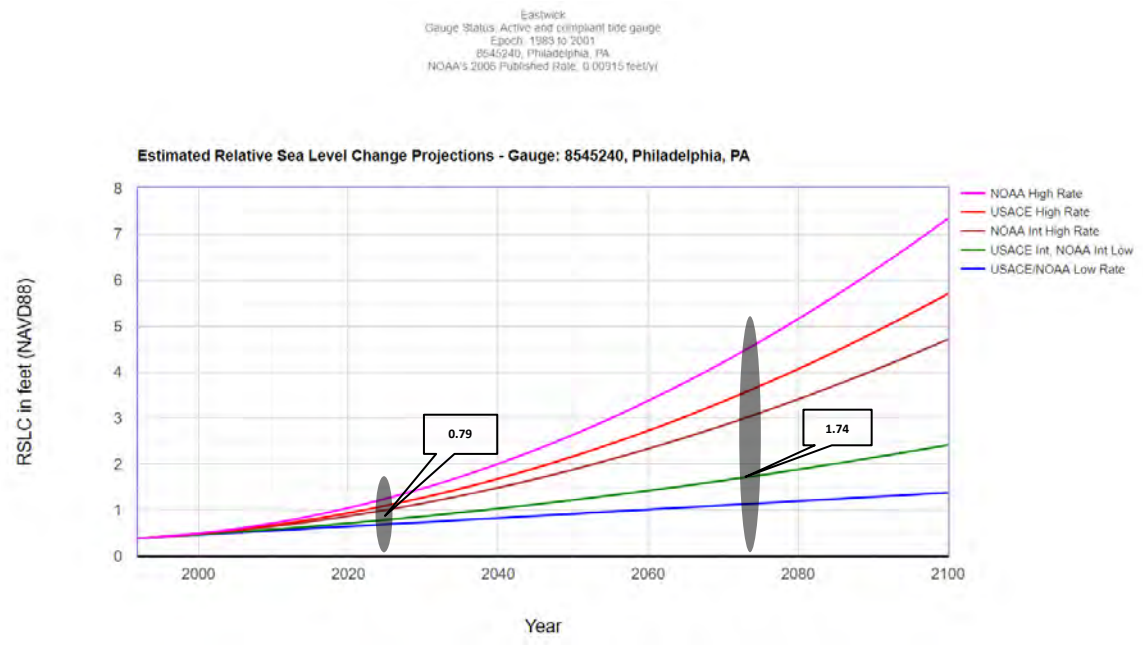

Figure 31 - Projected Sea Level Change Multiple Scenarios

The intermediate scenario will be used for all FWOP and FWP alternatives to determine the alternative's performance and resiliency. The preferred alternative will then be screened to determine its performance under all three USACE SLC scenarios. This is identified in ER 1100-2-8162 as a reasonable approach for a project with low sensitivity to SLC. The SLC factors are added to the current boundary conditions of MHHW, resulting in starting WSEL of 3.99 ft, NAVD88 for Existing Conditions, and 4.94 ft, NAVD88 for all future conditions.

Interior Drainage Analysis

For with project conditions, any potential levee will prevent overland runoff from reaching Cobbs Creek as it does under existing conditions. The majority of the Eastwick neighborhood is connected via surface inlets and subsurface storm sewer network ultimately directed toward the Mingo Creek Pump Station to be pumped into the Schuylkill River (refer to Figure 4 for location). Behind the potential levee, there is approximately 41 acres that drains topographically toward Cobbs Creek, as shown in Figure 32. A detailed interior drainage analysis has not been completed yet but is planned for the next phase. Current level of design and cost estimates include estimated minimum facilities including swales at the toe of the levee, draining toward three (3) 24" diameter pipes through the levee, with backflow prevention, spaced across the length of the levee. Potential measures could include ponding/storage areas, and/or a small pump station. As any interior drainage features are likely to be near or overlapping existing USEPA wetland mitigation areas, coordination with USEPA will continue through the next phase to insure a cohesive design.



Figure 32 - Area draining to TSP Levee

Uncertainty and Path Forward

While current hydrologic analysis efforts are considered sufficient to move forward through TSP and draft report release, there are several outstanding items that were not yet completed for this effort. Detailed below are analyses and considerations to be incorporated in subsequent phases.

- *Comparison/Coordination to other ongoing studies*

Several ongoing studies are completing their work in the remainder of CY2023. As feasible, flows utilized in this study can be compared to other independently generated peak flows (e.g. hydrologic model generating flows from Hurricane Floyd precipitation). This would allow further consensus among all federal partners, and provide weight-of-evidence for the approach.

- *Incorporate other studies compound flooding focus for updated total risk*

Other partners and modeling teams (e.g. Drexel University and Stevens Institute) are more focused on coastal and compound flooding (combined tidal surge AND high fluvial river flows). Coordination with external efforts would be beneficial to inform understanding of total risk.

- *Storm transposition, Stochastic Event Generation*

As noted in the flood history, Hurricane Ida produced record rainfall and flows in near-adjacent watersheds to Darby and Cobbs Creeks. Transposing Ida rainfall to the Darby/Cobbs watershed, in conjunction with a calibrated hydrologic model, would be valuable information to understand potential frequency of more extreme events, particularly with respect to assigning Hurricane Floyd, the largest (but uncertain) historic event modeled, a return frequency. Similarly, again with a calibrated hydrologic model, HEC-WAT, and included Hydrologic Sampler, could be utilized to generate hypothetical combinations of rainfall/runoff and hydraulic parameter uncertainty, to understand total risk more fully.

- *Increased flows with climate change*

Current inland hydrology USACE guidance is qualitative in nature. Investigation of potential increased future precipitation would also help inform risk and uncertainty moving forward.

Hydraulic Analysis

A hydraulic model of the reach of interest near Eastwick was utilized to simulate historic events for calibration, and multiple flood frequency events to determine effectiveness of FRM measures.

Overview of Previous Studies and Current Updates

Previous studies that the hydraulic analysis builds upon are detailed below, including updates to those previous efforts for this current Feasibility report.

USACE (2014) – Study provided preliminary hydraulics, utilized in AKRF and Princeton Hydro modeling (2017, 2022, respectively). Implicitly utilized in current study, as AKRF modeling used as baseline for updated analyses.

Princeton Hydro (2017) – Princeton Hydro study provides flooding estimates for Irene and Lee utilizing 1D/2D combined hydraulics. Their study formed the conceptual basis for AKRF updates to USACE 2014 hydraulics. The current USACE study reviewed the Princeton Hydro results to conceptualize impacts of complementary features, however none of model files from Princeton Hydro were utilized.

AKRF (2022) – AKRF completed their analysis for the current non-federal sponsor, the City of Philadelphia. This current study utilized ARKF modeling files as base for updates and modifications. The AKRF hydraulic model utilized 2014 USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model, and updated to 1D/2D combined hydraulics, with calibration to Isaias high water mark (HWM) data collected by USACE (2020). The current USACE study utilized the AKRF calibrated Isaias modeling as base for hydraulics updates. The AKRF study estimated peak flows for Isaias by re-rating USGS flows, which the current USACE study also uses. The current USACE study refines estimates of FFA utilizing the re-rated Isaias estimates, and updates flow change locations. HEC-RAS geometry for the current USACE study updated topographic data with latest available - 2022 LiDAR from Philadelphia. Current USACE study modified 2D elements to suit level of analysis, refine around points of interest, and accommodate with project conditions (e.g. the TSP levee). Current study calibrated/validated to additional sets of HWM (Floyd, Irene, Lee), and ran frequency events from 50% to 0.2% AEP. AKRF study also completed a detailed tidal-fluvial coincidence analysis. The current USACE study will utilize that analysis to guide choice of boundary conditions in coincident flooding assessment, to be completed in later phases. Current USACE study uses latest HEC-RAS capability to allow varying n-values along cell face, allowing larger cell sizes, but maintaining resolution of n-value delineations.

Additionally, prior to updates to the hydraulic model to combined 1D/2D, screening level hydraulic analysis was performed to assist with plan formulation. Screening level H&H analysis is contained in the main report text, and is not repeated within this Appendix.

Model Setup and Assumptions

The USACE hydraulic model HEC-RAS was utilized for this analysis, given the software's capability for combined 1D/2D hydraulics. HEC-RAS version 6.3.1 was utilized throughout the study. The current hydraulic analysis builds on previous 2014 USACE and 2022 AKRF HEC-RAS modeling.

The model domain is shown in Figure 33 and Figure 34, and described in Table 5 below.

Topography for the 2D portion of the model has been updated using most recent 2022 LiDAR data available from the City of Philadelphia, however bathymetric data (in channel) still relies on limited 2014 USACE and 2013 USEPA (USACE 2014, AKRF 2022) channel information, and for areas upstream of Eastwick, relies on FEMA FIS profiles and data dating to 1977. The modeling domain includes all bridges and culverts identified in the effective FEMA model. Cross-sections were laid out perpendicular to anticipated flow paths across the range of flow events modeled, accounting for changes in conveyance, roughness (n-values), floodplain obstructions, and instream structures observed in the field, and through review of aerial photography. Manning's n-values varied from 0.011 for asphalt, 0.028 to 0.035 for varying substrate in-channel conditions, 0.06 to 0.14 for varying density of forested conditions, with higher values utilized (up to 0.2-0.4) to account for sheet flow characteristics, and increased roughness and flow impedance from fencing and parked cars surrounding dense residential areas in the urban setting. Buildings in the 2D domain were assigned an n-value of 100 to prevent conveyance, but allow water surfaces to intersect structural inventory, facilitating economic calculations. N-values were varied as appropriate throughout the HEC-RAS modeling domain, depicted in Figure 33 below. Refer to USACE (2014) and AKRF (2022) for additional discussion regarding n-value discussion and original model layout, as necessary.

All hydraulic model runs were completed using unsteady state conditions (flow varying with time), varying inflows, and boundary conditions as appropriate with each run.

Frequency flow simulations completed using constant downstream tidal boundary, set to Mean Higher High Water (MHHW) for both present (2025) and future (2075) conditions to account for sea level change. Given a hypothetical event could coincide with any given point in the tidal cycle, this assumption removes the uncertainty of timing, resulting in conservative estimates for WSEL during hypothetical frequency events.

All hypothetical frequency flow events were scaled from observed hydrographs during Isaias (2020). This inherently accounts for observed timing between Darby and Cobbs Creeks, justified in above sections. Boundary conditions are summarized below for all events.

With Project conditions incorporated the TSP levee by altering the base topographic DEM in the vicinity of the levee. Top of levee and anticipated side slopes were burned into the topographic DEM available tools in HEC-RAS RAS Mapper, shown in Figure 36. Breaklines were added to ensure grid cell faces captured the top of levee alignment. The main levee elevation of the managed overtopping section (23.7 ft, NAVD88) was utilized to understand when events would begin overtopping of the proposed design. As the levee height will be optimized in later phases, including design of the overtopping section, and incorporating required risk and uncertainty assessments, this was considered sufficient at the current level of analysis, but will be updated as the levee design progresses moving forward.

Current assumptions for ineffective flow areas throughout the model domain are that they remain permanent, even when overtopped. This is considered conservative for bridge overtopping, leading to higher predicted WSELs. This was considered acceptable practice as the current model runs do not account for debris build up at bridges during events, so conservatism with current modeling methods accounts for some uncertainty. In other areas this is also considered generally conservative, but more appropriate for the majority of ineffective flow areas throughout the USFWS Refuge Marsh reaches where even when overtopped, flow is still generally confined and non-conveying below the top of berms/levees.

There is still considerable uncertainty through the downstream reaches of Darby Creek through the Heinz refuge, given lack of any HWM or gage data through this reach. Requests to project partners have not returned additional HWM data to date, however if additional data becomes available, calibration of historic events should be revisited and verified, particularly in areas outside of Eastwick.

Table 5 - HEC-RAS Model Domain Summary

Methods	River	Stream Length (mi)	# of XS	#of Bridges	# of Lateral Structures
1D	Darby Creek	7.8	131	9	3
	Cobbs Creek	2.6	73	7	1
	Schuylkill River	7.7	31	-----	1
	Delaware River	19.4	45	-----	1
	Area	Area covered (ac)	# of Cells	Average Cell Spacing (ft)	# of Breaklines
2D	Eastwick	1911	11266	86	18

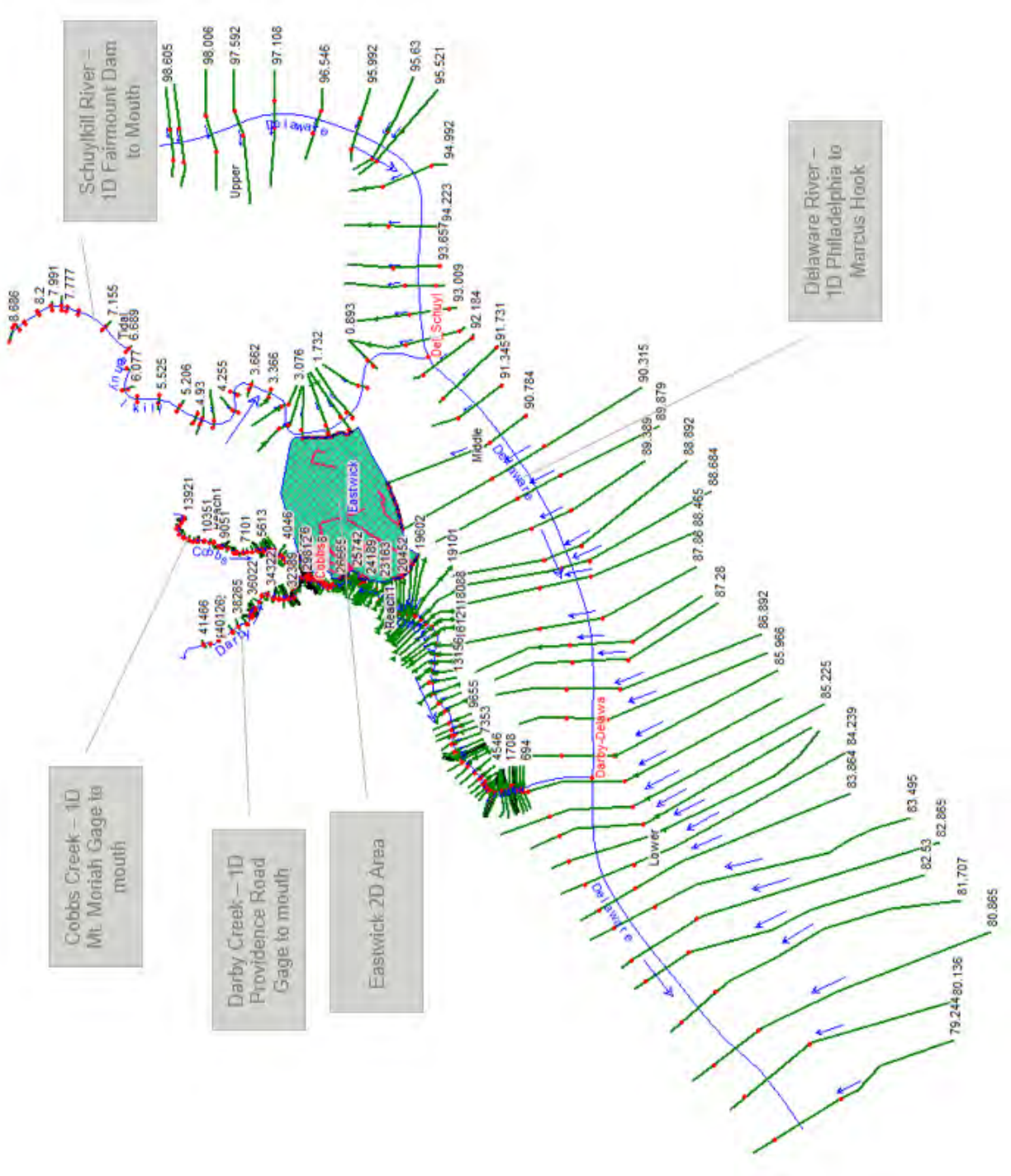

Figure 33 – HEC-RAS Model Domain

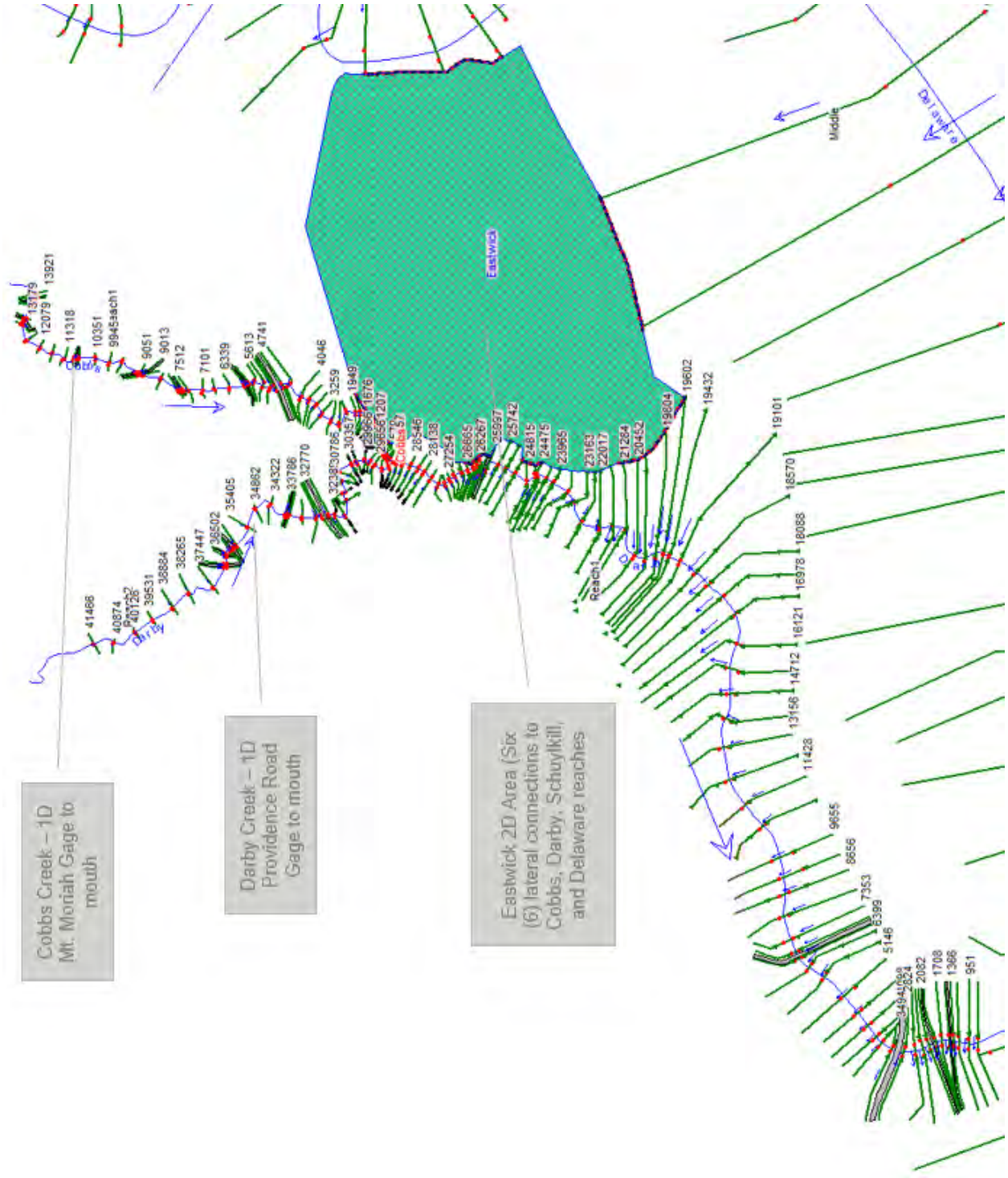

Figure 34 - HEC-RAS Model Domain – Zoom Eastwick Vicinity

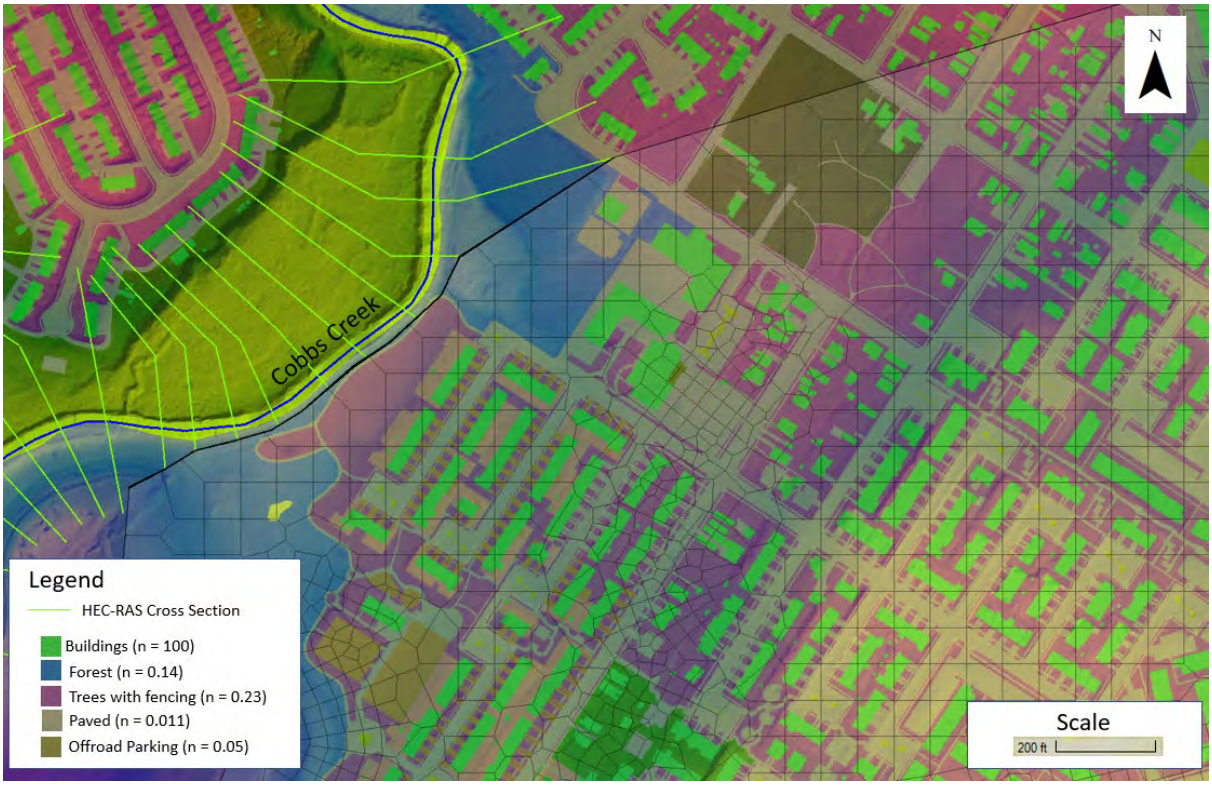

Figure 35 - Example of N-value delineations throughout Eastwick 2D area

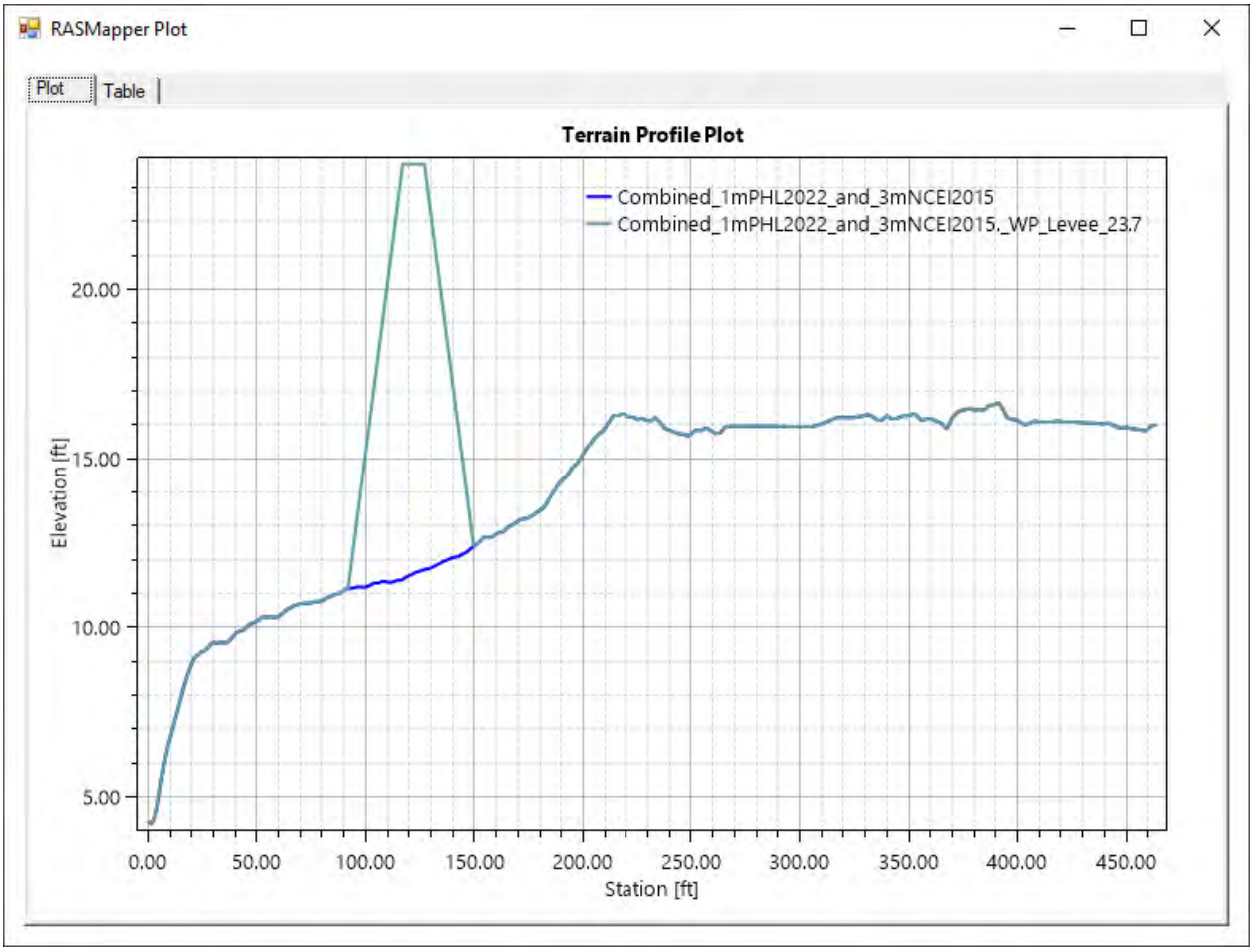

Figure 36 - Plot showing TSP Levee modified DEM

Calibration and Validation

As discussed above, four (4) historic events were assessed for calibration (Isaias) and validation (Floyd, Irene, and Lee). Table 6 through Table 9 detail comparisons of high water mark (HWM) data to model results. Figure 37 through Figure 42 show estimated floodplain limits and distribution of available HWM data during the historic events, and graphical comparison of these data. While Floyd offers the most available HWM data, there is significant uncertainty associated with location of reported depths, given HWM data was associated with just an address, not a specific geographic location. Effort was made to estimate ground elevation near addresses reported, however variation in topography leads to uncertainty. Similar residence reported HWM for Irene and Lee have similar uncertainty. It is suspected that the larger differences between modeled and observed HWM are due to uncertainty associated with assumed location of observation, and subsequent estimates of ground elevation, rather than model error.

Overall performance of the model across four (4) events is deemed acceptable and lends confidence to subsequent stage-frequency relationships determined for all flow frequency events across both FWOP and FWP conditions. Calibration outside of the Eastwick area is uncertain as there were no available HWM data in those areas. Further, given uncertainty discussed in previous sections with observed and

estimated flows, in combination with uncertainty associated with HWM data (considered +/- 1-2 ft, some reported as ranges, e.g. 9-12 ft), it is recommended that calibration be revisited as flow estimates are refined in future phases, and/or if additional more robust calibration data is collected or provided.

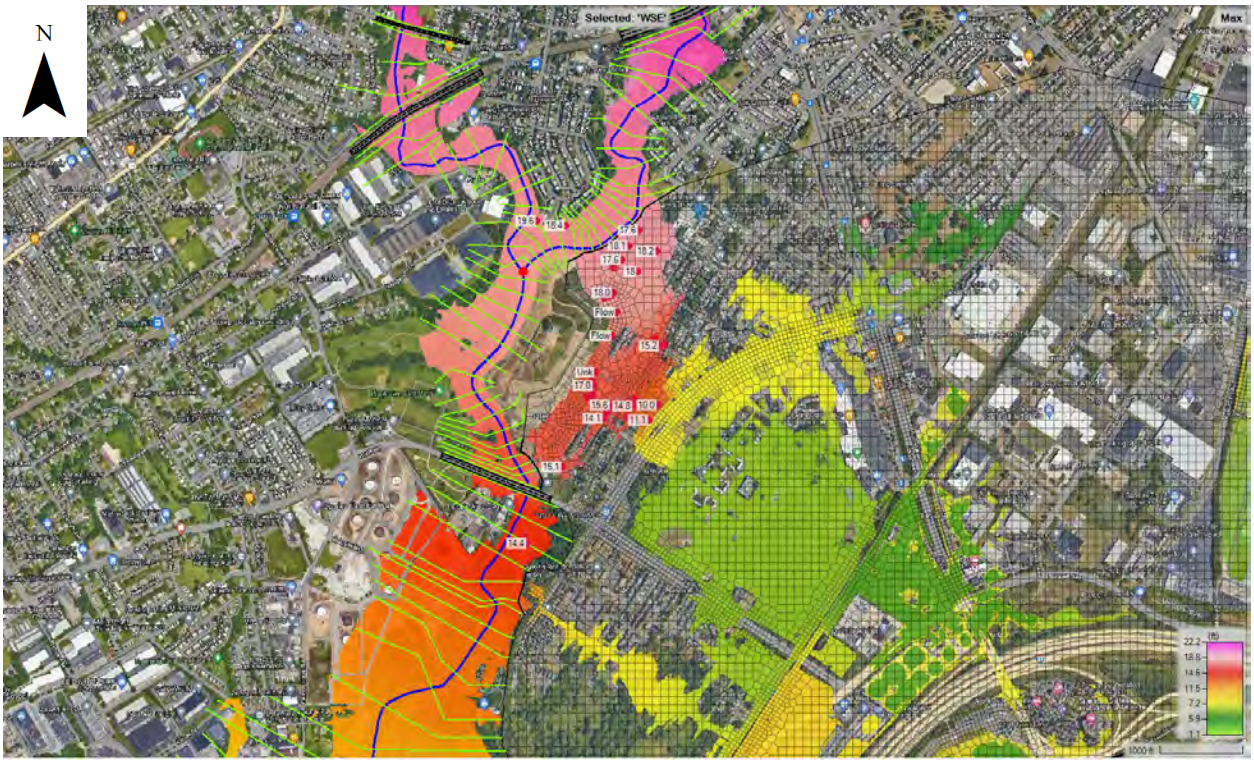

Figure 37 - HWM Data Available for Isaias (2020) shown as red dots with modeled WSEL in color gradient

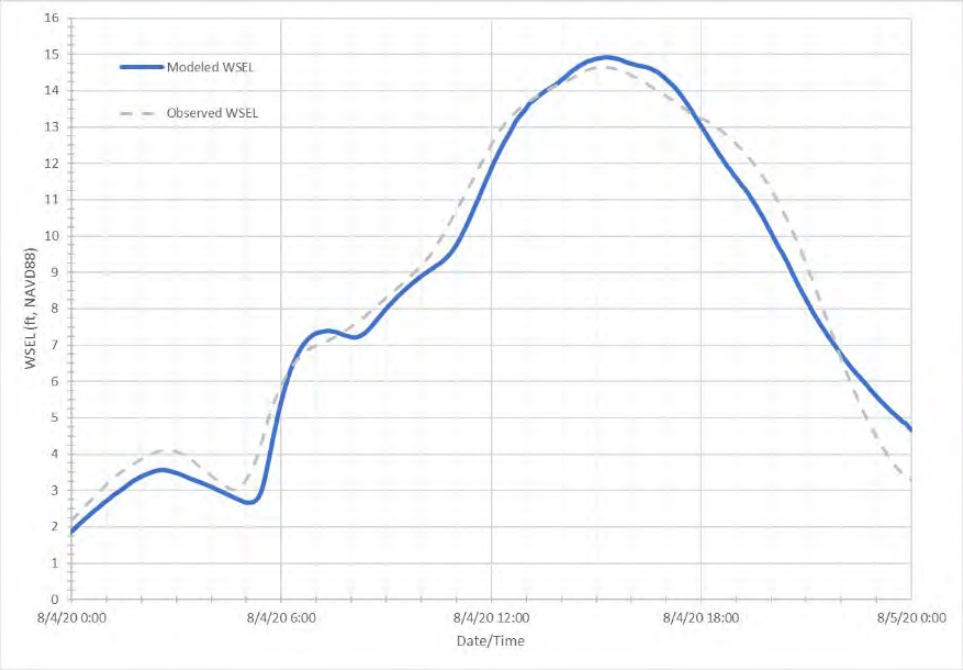

Figure 38 - Isaias Calibration at 84th USGS Gage

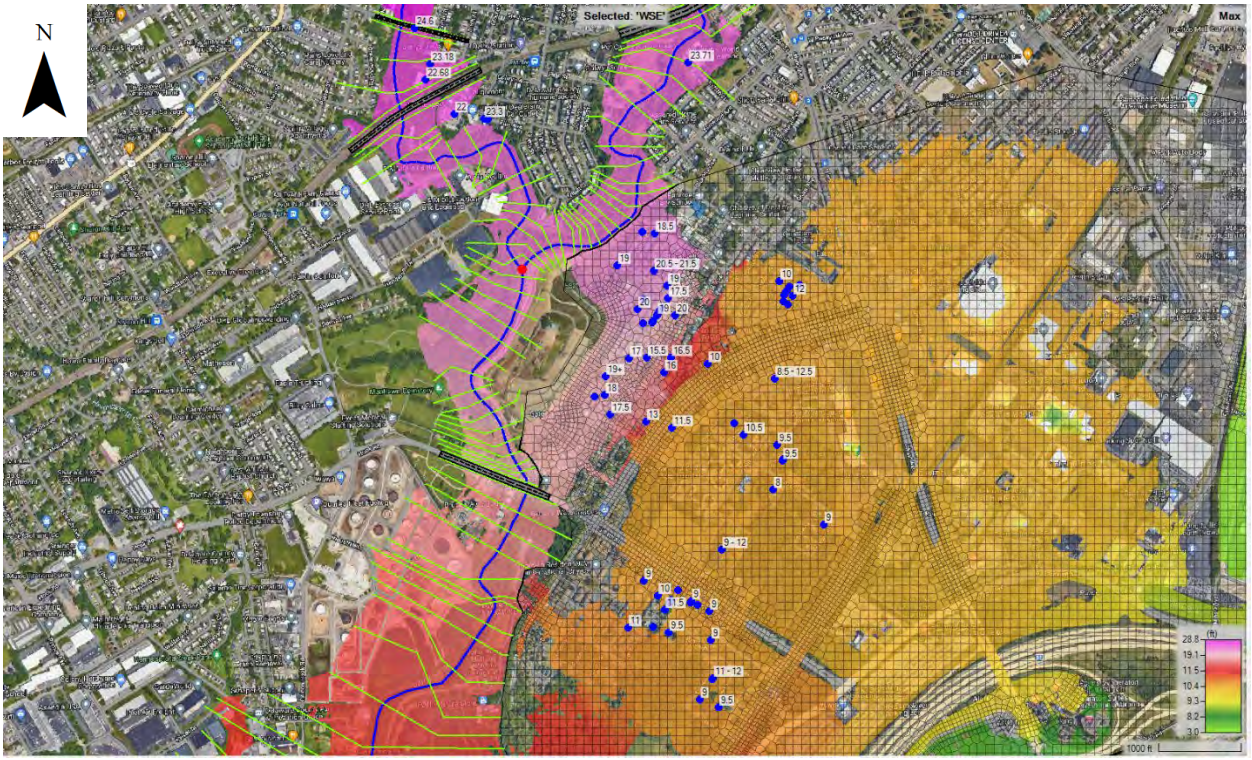

Figure 39 - HWM Data Available for Floyd (1999) shown as blue dots with modeled WSEL in color gradient

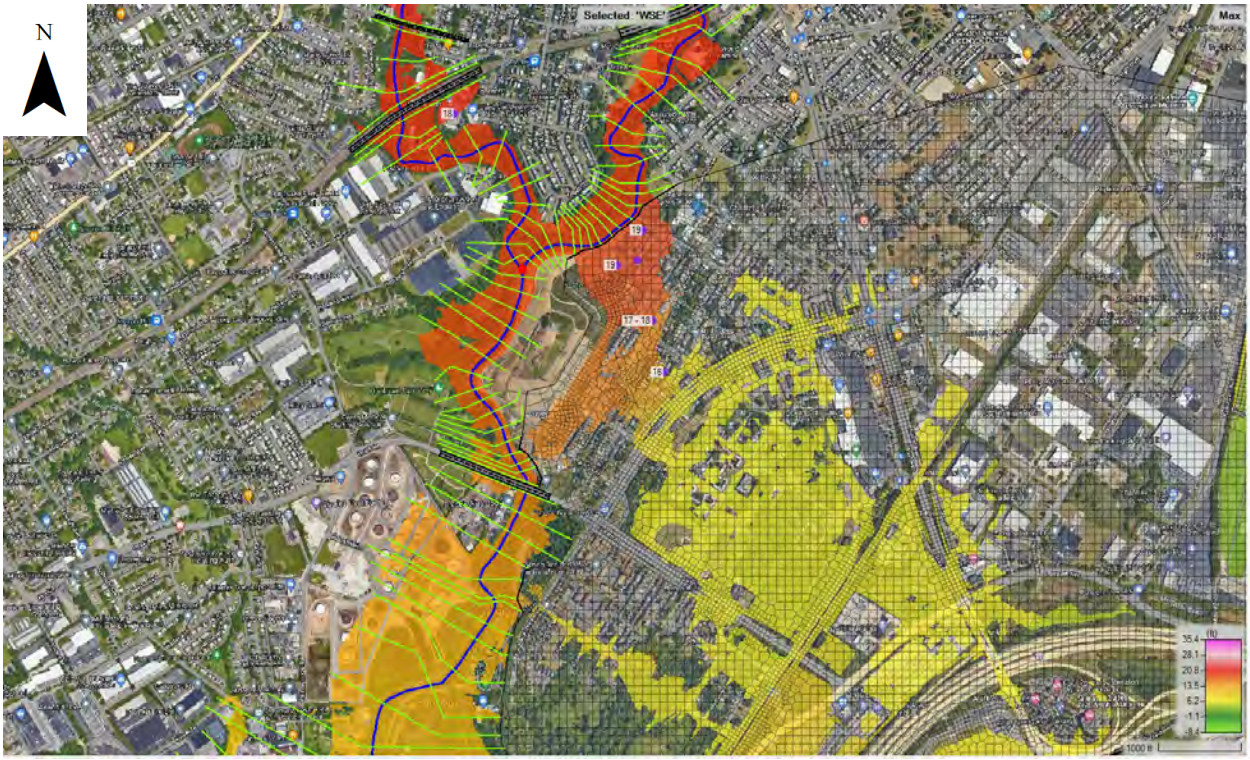

Figure 40 - HWM Data Available for Irene (2011) shown as purple dots with modeled WSEL in color gradient

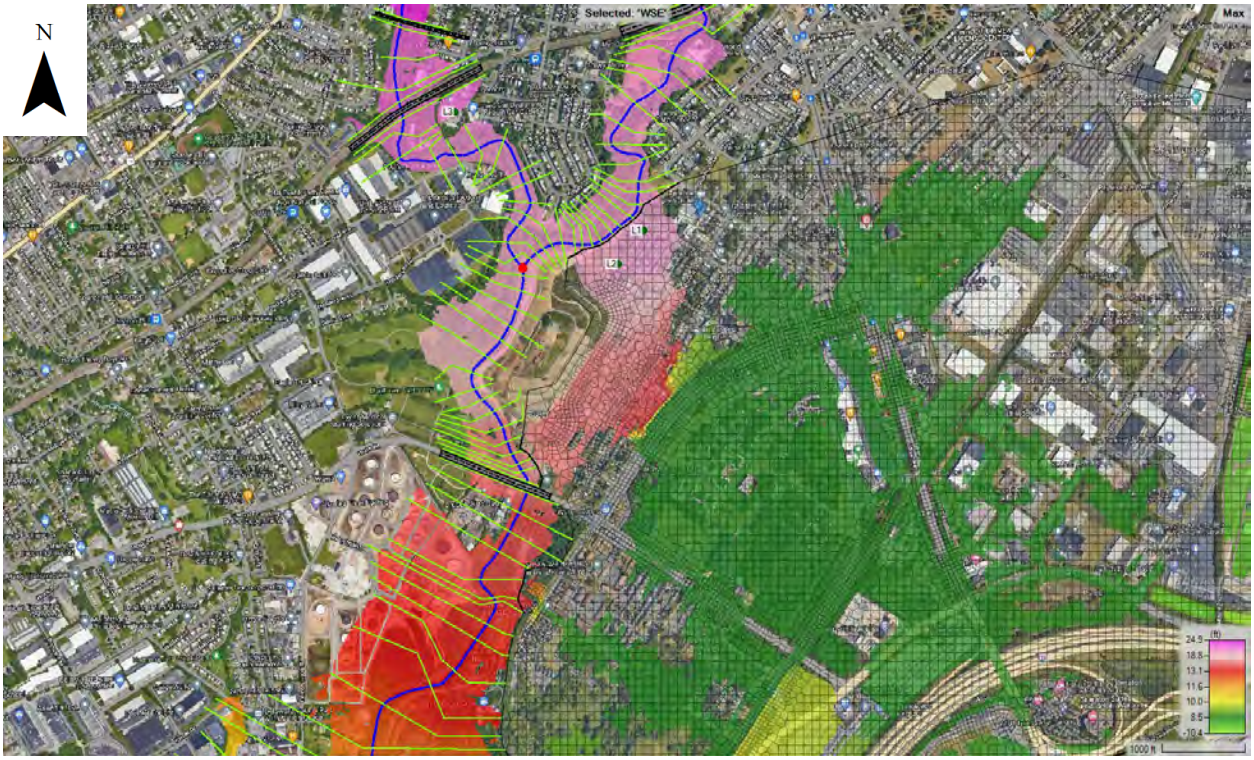

Figure 41 - HWM Data Available for Lee (2011) shown as green dots with modeled WSEL in color gradient

Table 6 - Isaias Calibration Comparison

Name	Est_HWM_El	Short_Desc	HWM_Label	Avg HWM (ft, NAVD88)	Modeled WSEL (ft, NAVD88)	Difference (ft)
0469 - 21"	0	Unk	IS01			
0470 - 43.5"	0	Unk	IS02			
0445 - Flow Pattern	0	Flow	IS03			
0448 - Flow Pattern	0	Flow	IS04			
0450 - Flow Pattern	0	Flow	IS05			
0458 - Flow Pattern	0	Flow	IS06			
0459 - Flow Pattern	0	Flow	IS07			
0460 - Flow Pattern	0	Flow	IS08			
0465 - Flow Pattern	0	Flow	IS09			
0466 - Evidence of Flow	0	Flow	IS10			
0467 - Evidence of Flow	0	Flow	IS11			
0506 - 45.5"	19.6	19.6	IS12	19.6	19.05	-0.55
0464 - 39"	18.8	18.8	IS13	18.8	18.82	0.02
0503 - 43"	18.4	18.4	IS14	18.4	19.06	0.66
0476 - 15.5"	18.2	18.2	IS15	18.2	19.17	0.97
0453 - 22"	18.1	18.1	IS16	18.1	19.19	1.09
0455 - 44"	18.1	18.1	IS17	18.1	19.08	0.98
0456 - 39"	18	18	IS18	18	18.65	0.65
0475 - 31"	18	18	IS19	18	19.16	1.16
0452 - 26-30"	17.6	17.6	IS20	17.6	19.3	1.7
0454 - 28"	17.6	17.6	IS21	17.6	19.13	1.53
0471 - 60"	17	17	IS22	17	15.66	-1.34
0440 - 28.5"	16.4	16.4	IS23	16.4	15.64	-0.76
0473 - 56.5"	16.3	16.3	IS24	16.3	15.66	-0.64
0441 - 31"	16.1	16.1	IS25	16.1	15.64	-0.46
0474 - 19.5"	16.1	16.1	IS26	16.1	15.67	-0.43
0472 - 60"	16	16	IS27	16	15.65	-0.35
0443 - 32"	15.7	15.7	IS28	15.7	15.64	-0.06
0479 - Highest Water Mark	15.7	15.7	IS29	15.7	15.77	0.07
0442 - 37"	15.6	15.6	IS30	15.6	15.64	0.04
0480 - 31"	15.3	15.3	IS31	15.3	15.78	0.48
0478 - Highest Water Mark	15.2	15.2	IS32	15.2	15.77	0.57
0444 - 30.5"	14.8	14.8	IS33	14.8	14.52	-0.28
0496 - 17.5"	14.4	14.4	IS34	14.4	14.74	0.34
0439 - 13"	14.1	14.1	IS35	14.1	15.64	1.54
0451 - 11"	14.1	14.1	IS36	14.1	14.05	-0.05
0497 - 31.5"	13.7	13.7	IS37	13.7	14.66	0.96
0447 - 33"	11.1	11.1	IS38	11.1	13.09	1.99
0446 - 41"	10	10	IS39	10	13.89	3.89

Table 7 - Irene Validation Comparison

HWM_Label	Address	HWM_Desc	Gnd_El_ftNAVD88	Est_HWM_El_ftNAVD88	Avg HWM (ft, NAVD88)	Modeled (ft, NAVD88)	Difference (ft)
IR1	7807 SATURN PL	4-6ft deep in street	15	19 - 21	19.00	18.23	-0.77
IR2	7805 SATURN PL	4ft deep in street	15	19	19.00	18.24	-0.76
IR3	7842 SATURN PL	Up to window of cars	16	19.5	19.50	18.21	-1.29
IR4	7866 SATURN PL	5ft deep sloping driveway	14	19	19.00	18.18	-0.82
IR5	7933 BUIST AVE	4-5 ft deep on street	13	17 - 18	17.00	16.33	-0.67
IR6	8024 CHELWYNDE AVE	4ft deep on street	12	16	16.00	11.50	-4.5
IR7	522 ELLIS AVE	8ft	10	18	18.00	19.22	1.22

Table 8 - Lee Validation Comparison

HWM_Label	Address	HWM_Desc	Gnd_El_ftNAVD88	Est_HWM_El_ftNAVD88	Avg HWM (ft, NAVD88)	Modeled (ft, NAVD88)	Difference (ft)
L1	7807 SATURN PL	2 -4 ft deep on street	15	17 - 19	19.00	20.09	1.09
L2	7866 SATURN PL	5ft deep sloping driveway	14	19	19.00	19.90	0.9
L3	522 ELLIS AVE	3ft	10	13	13.00	21.35	8.35

Table 9 - Floyd Validation Comparison

HWM_Label	Address	HWM_Desc	Gnd_El_ftNAVD88	Est_HWM_El_ftNAVD88	Avg HWM (ft, NAVD88)	Modeled WSEL (ft, NAVD88)	Difference (ft)
F01	7807 SATURN PL	6-8ft deep in street	15	21 – 23	23.00	23.08	0.08
F02	2502 S 78TH ST	Up to car window	15	18.5	18.50	23.00	4.5
F03	7842 VENUS PL	4-5ft deep In street	16.5	20.5 – 21.5	21.50	22.81	1.31
F04	7848 MERCURY PL	Covered Car tires	17.5	19	19.00	20.95	1.95
F05	7866 SATURN PL	5ft at sloping driveway	14	19	19.00	22.83	3.83
F06	7915 MARS PL	Above car windows	16	20	20.00	21.33	1.33
F07	7901 MARS PL	Above car windows	16	20	20.00	21.60	1.6
F08	7942 MARS PL	Up to windows of cars	16	19.5	19.50	20.15	0.65
F09	7935 BUIST AVE	6ft deep in street	13	19	19.00	19.84	0.84
F10	7933 BUIST AVE	4-5ft deep in street	13	17 – 18	18.00	19.48	1.48
F11	7925 BUIST AVE	5ft deep in street	14	19	19.00	19.09	0.09
F12	7923 BUIST AVE	4ft deep in street	14	18	18.00	18.84	0.84
F13	7921 BUIST AVE	5ft covered cars	15	20	20.00	18.62	-1.38
F14	7919 BUIST AVE	Covered car tires	15	16.5	16.50	18.60	2.1
F15	7917 BUIST AVE	3ft or more in garage	15	18+	18.50	18.71	0.21
F16	7903 BUIST AVE	Covered car tires	16	17.5	17.50	20.69	3.19
F17	7912 BUIST AVE	6ft deep instreet	14	20	20.00	18.51	-1.49
F18	7921 LINDBERGH BLVD	4ft deep sloping driveway	6	10	10.00	10.86	0.86
F19	8029 BUIST AVE	6ft deep sloping driveway	11	17	17.00	18.32	1.32
F20	8020 BUIST AVE	Car completely submerged	11	15.5	15.50	18.06	2.56
F21	8024 CHELWYNDE AVE	4ft deep in street	12	16	16.00	15.05	-0.95
F22	2622 S 80TH ST	Up to windows of cars	13	16.5	16.50	15.34	-1.16
F23	8046 MARS PL	Over 4ft deep on street	15	19+	19.00	18.39	-0.61
F24	8118 ANGELO PL	4ft deep in street	11	15	15.00	18.13	3.13
F25	8119 BUIST AVE	5ft deep in street	13	18	18.00	18.11	0.11
F26	8118 BUIST AVE	Up to car windows	14	17.5	17.50	17.98	0.48
F27	8123 LINDBERGH BLVD	Approx 6ft deep on street	7	13	13.00	14.98	1.98
F28	429 7TH ST	NA	NA	23.18	23.18	25.49	2.31
F29	433 7TH ST	NA	NA	22.68	22.68	25.71	3.03
F30	716 PINE ST	NA	NA	24.6	24.60	26.76	2.16
F31	443 ELLIS AVE	NA	NA	23.2	23.20	23.53	0.33
F32	447 ELLIS AVE	NA	NA	23.3	23.30	23.54	0.24
F33	522 ELLIS AVE	NA	NA	22	22.00	24.57	2.57
F34	2739 S 78TH ST	1 ft	5.5	6.5	6.50	10.45	3.95
F35	2745 S 78TH ST	5 ft - Covered cars	5.5	10.5	10.50	10.45	-0.05
F36	7705 JASON PL	Up to the window of cars	7	10.5	10.50	10.45	-0.05
F37	7713 OLYMPUS PL	Up to windows of cars	6.5	10	10.00	10.45	0.45
F38	7718 OLYMPUS PL	3 ft	6.5	9.5	9.50	10.45	0.95
F39	7719 JASON PL	6ft	6	12	12.00	10.45	-1.55
F40	7722 OLYMPUS PL	4 ft	6	10	10.00	10.45	0.45
F41	7724 OLYMPUS PL	4 ft	6	10	10.00	10.45	0.45
F42	7728 OLYMPUS PL	Up to car tires	5.5	7	7.00	10.45	3.45
F43	8400 GIBBS PL	Top of cars	8	13	13.00	10.45	-2.55
F44	8400 SUFFOLK PL	Top of cars	4	9	9.00	10.49	1.49
F45	8402 BRUNSWICK PL	Up to the window of cars	6.5	9	9.00	10.49	1.49
F46	8403 SUFFOLK PL	5+ft	3.5	8.5+	9.00	10.49	1.49
F47	8404 BRUNSWICK PL	6 ft	6.5	12.5	12.50	10.50	-2
F48	8410 GIBBS PL	Hoods of cars	9	11.5	11.50	10.49	-1.01
F49	8411 LYONS PL	up to the window of cars	6.5	9	9.00	10.50	1.5
F50	8412 GIBBS PL	Tops of cars	9	13	13.00	10.49	-2.51
F51	8415 GIBBS PL	above the street curb	9	10	10.00	10.49	0.49
F52	8418 GIBBS PL	covered car tires	10	11.5	11.50	10.50	-1
F53	8428 BRUNSWICK PL	1 foot, above street curb	9.5	11	11.00	10.53	-0.47
F54	8428 GIBBS PL	3-5ft	11	14 – 16	15.00	10.64	-4.36
F55	8439 SUFFOLK PL	up to car doors	6	9	9.00	10.50	1.5
F56	8510 LUTHER PL	6 to 7 ft	5	11 – 12	11.00	10.53	-0.47
F57	8512 LUTHER PL	6 to 7 ft	5	11 – 12	11.00	10.53	-0.47
F58	8514 LYONS PL	3 feet	8	11	11.00	10.64	-0.36
F59	8536 HARLEY PL	2 ft	7.5	9.5	9.50	10.57	1.07
F60	8540 LUTHER PL	5 ft	4	9	9.00	10.57	1.57
F61	7800 LINDBERGH BLV	3-7 ft of water	5.5	8.5 – 12.5	10.50	10.48	-0.02
F62	8023 MADISON AVE	5 ft	5.5	10.5	10.50	10.48	-0.02
F63	8024 BRUNSWICK AVE	5 ft	4.5	9.5	9.50	10.47	0.97
F64	8025 BRUNSWICK AVE	5 ft	4.5	9.5	9.50	10.47	0.97
F65	8026 BRUNSWICK AVE	5 ft	4.5	9.5	9.50	10.48	0.977
F66	8026 MADISON AVE	5 ft	5.5	10.5	10.50	10.48	-0.02
F67	8111 SUFFOLK AVE	5 ft	3	8	8.00	10.47	2.47
F68	8113 HARLEY AVE	5 ft	4	9	9.00	10.45	1.45
F69	8114 LINDBERGH BLV	6 ft	5.5	11.5	11.50	10.53	-0.97
F70	PWD Stage Gage	DS of RR bridge, 18.19 ft depth	5.52	23.71	23.71	23.85	0.14
F71	Pepper School	9-12 ft	0	10.5	10.50	10.48	-0.02

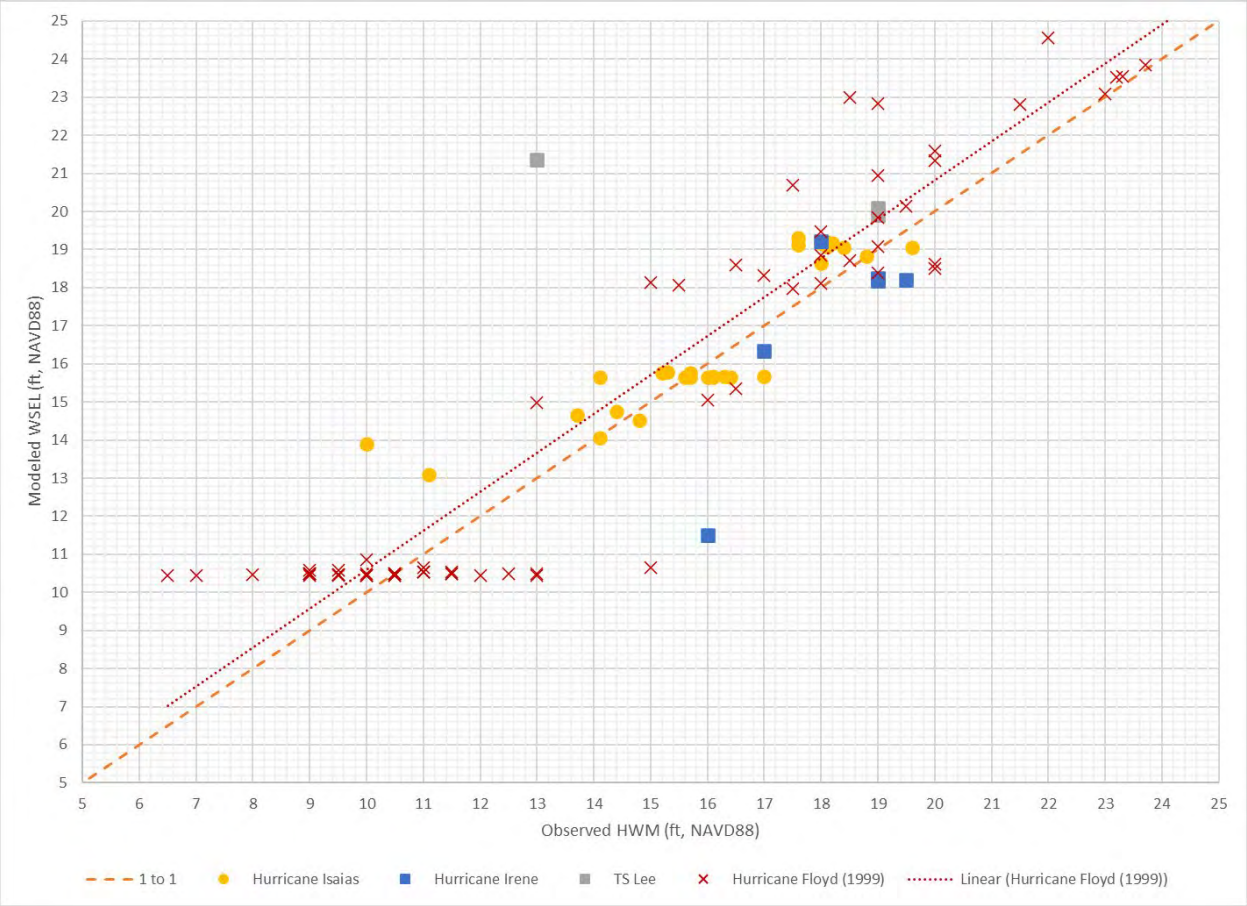

Figure 42 - Comparison of Calibrated WSEL to Observed HWM data for all Historic Events

The hydraulic model performs acceptably well across historic calibration/validation events, particularly considering uncertainty with both flows, and residence reported HWM data, and as such was deemed sufficient for use with frequency flows to determine stage frequency relationships.

Existing Conditions Results

Existing Conditions (year 2025) were computed for all frequency events. Existing conditions was utilized for baseline comparison to With Project (year 2025) conditions. Depth grids were exported for the entire model domain (both 1D and 2D areas) for import into Economic calculations in HEC-FDA, described within the Economics Appendix.

Alternatives Assessment and Recommended TSP

Alternatives assessment was completed with the full 1D model, prior to updating the hydraulic modeling to combined 1D/2D. Results indicated levee plan was most feasible. Screening level H&H analysis is contained in the main report text, and is not repeated within this Appendix.

Recommended TSP is a Levee within Eastwick Park. The top of levee elevation is set to 24.7 ft NAVD88, with managed overtopping section set slightly lower at 23.7 ft NAVD88. Top of levee height currently reduces risk up to 1% AEP flood event, and begins overtopping at larger events. Levee height will be optimized in later phases. Figure 43 through Figure 45 show the TSP levee cross-sections and alignment.

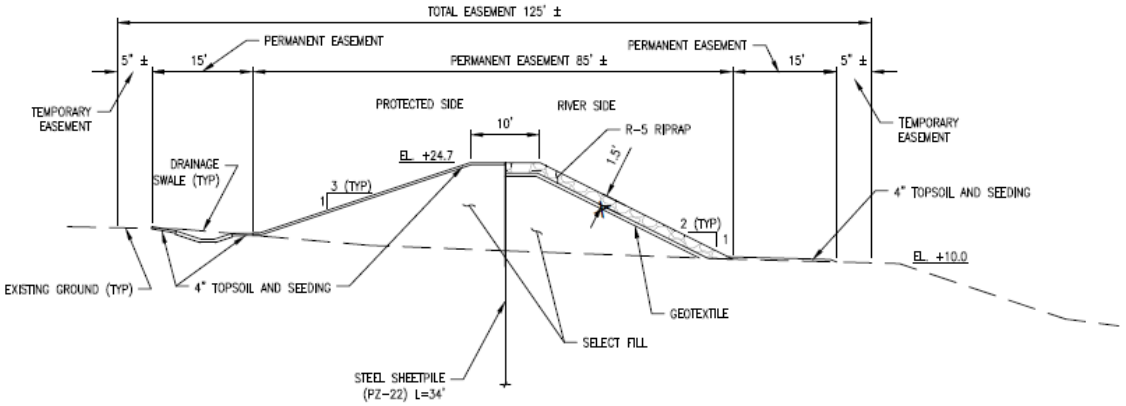

Figure 43 - TSP Levee Typical Section

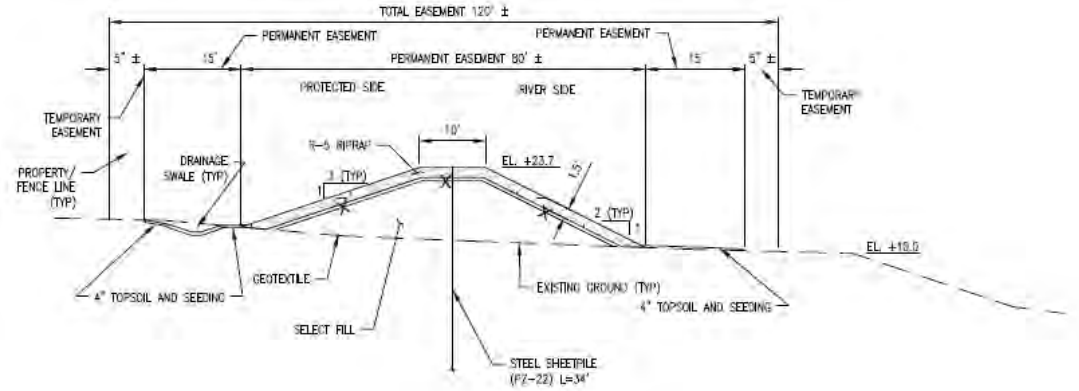

Figure 44 - TSP Levee Typical Section at Managed Overtopping Area



Figure 45 - TSP Levee Alignment

With Project (WP) Results

With-project conditions (year 2025) were computed for all frequency events for the TSP base levee plan. Existing conditions was utilized for baseline comparison to With Project (year 2025) conditions. Depth grids were exported for the entire model domain (both 1D and 2D areas) for import into Economic calculations in HEC-FDA, described within the Economics Appendix.

Future Without Project (FWOP) Results

Future without project conditions (year 2075) were computed for all frequency events, including estimated SLC for downstream boundary conditions. FWOP conditions were utilized for baseline comparison to Future With Project (year 2075) conditions. Depth grids were exported for the entire model domain (both 1D and 2D areas) for import into Economic calculations in HEC-FDA, described within the Economics Appendix. HEC-RAS Profiles for all frequency events, and floodplain limits for the 1% AEP are detailed in Attachment 1.

Future With Project (FWP) Results

Future with project conditions (year 2075) for the base levee plan were computed for all frequency events, including estimated SLC for downstream boundary conditions. FWOP results were utilized for baseline comparison to FWP conditions. Depth grids were exported for the entire model domain (both 1D and 2D areas) for import into Economic calculations in HEC-FDA, described within the Economics Appendix. HEC-RAS Profiles for all frequency events, and floodplain limits for the 1% AEP are detailed in Attachment 1. Stage-frequency relationships at the TSP levee location are shown in Table 10.

Table 10 - Stage-Frequency Relationships at TSP Levee Location

Event	Scenario							
	Existing Conditions		FWOP Conditions		WP Conditions		FWP Conditions	
	Q Total	W.S. Elev	Q Total	W.S. Elev	Q Total	W.S. Elev	Q Total	W.S. Elev
	(cfs)	(ft)	(cfs)	(ft)	(cfs)	(ft)	(cfs)	(ft)
50pctAEP	2931.5	13.0	2911.7	13.0	2934.5	13.0	2907.0	13.0
20pctAEP	4448.2	15.3	4394.4	15.8	4525.5	15.4	4509.6	15.9
10pctAEP	5548.9	17.5	5569.5	17.6	5867.5	17.7	5877.2	17.7
5pctAEP	7060.3	19.0	7065.4	19.0	7180.4	19.3	7458.0	19.3
2pctAEP	9316.3	20.7	9316.6	20.7	9316.7	21.4	9725.6	21.4
1pctAEP	11825.3	21.9	11832.4	21.9	11837.5	23.0	11825.7	23.0
0.5pctAEP	13454.4	23.1	12953.7	23.1	13867.3	24.2	12285.2	24.0
0.2pctAEP	15228.2	24.8	15135.0	24.8	15829.5	25.7	15739.5	25.5
		indicates overtopping of current TSP levee height						

Induced Flooding Assessment

For the With Project conditions levee plan, both downstream and upstream impacts were evaluated. Placement of a levee along Cobbs Creek is efficient in eliminating modeled flows through the Eastwick neighborhood. This has the effect of pushing more flow downstream, because that flow is no longer leaving Cobbs Creek. More flow downstream leads to minor WSEL increases. Additionally, placement of a levee cuts off a portion of the adjacent floodplain, where floodwaters cannot spread out. This constriction leads to minor WSEL increases upstream. Generally, WSEL increases dissipate with distance from the potential levee. Moving downstream from Cobbs Creek into Darby Creek, and through Hook Road bridge, flows spread out through the larger, wider floodplain, and attenuate slightly, leading to WSEL increases that decrease moving downstream toward the Delaware River. Similarly, largest upstream WSEL increases are generally limited to reaches on both Darby and Cobbs between the confluence and the upstream B&O railroad bridges. These bridges both have limited capacity to pass large floods, leading to backup at the upstream faces of each. The upstream WSEL increases dissipate to generally less than 0.5 feet upstream of the railroad. Figure 46 and Figure 47 detail anticipated WSEL differences across frequency flows, both upstream and downstream, on both Darby and Cobbs Creek. As shown on the figures, the maximum impact of the levee is seen during the 1% AEP event. Events larger than the 1% AEP event begin to overtop the current top of levee elevation, and as such there is less effect to both upstream and downstream induced WSELs. The structural inventory within these areas is described in more detail within the Economics Appendix. Investigation is ongoing for several areas, and will be completed in future phases, in conjunction with complementary measures (discussed in later sections).

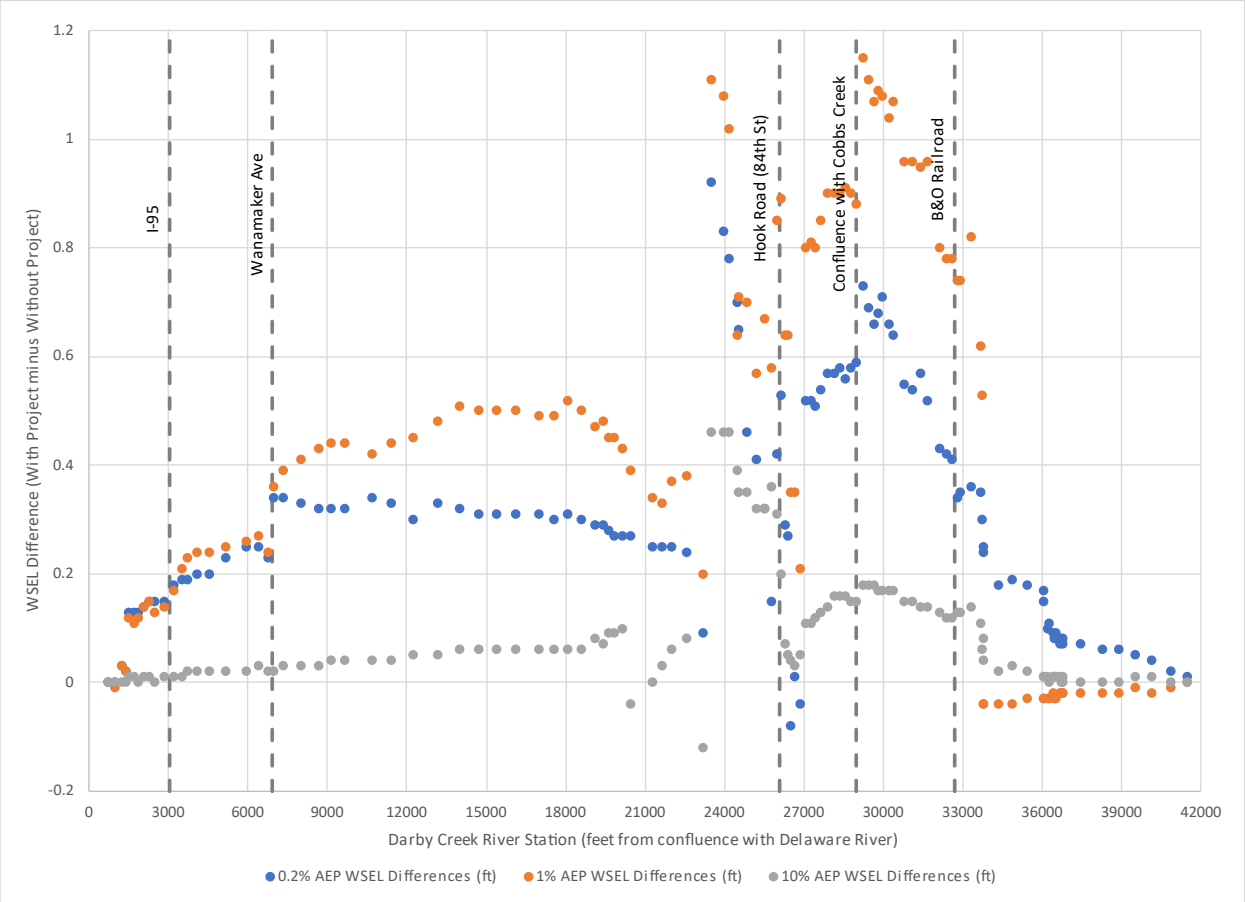

Figure 46 - WSEL Differences - Darby Creek FWOP and FWP

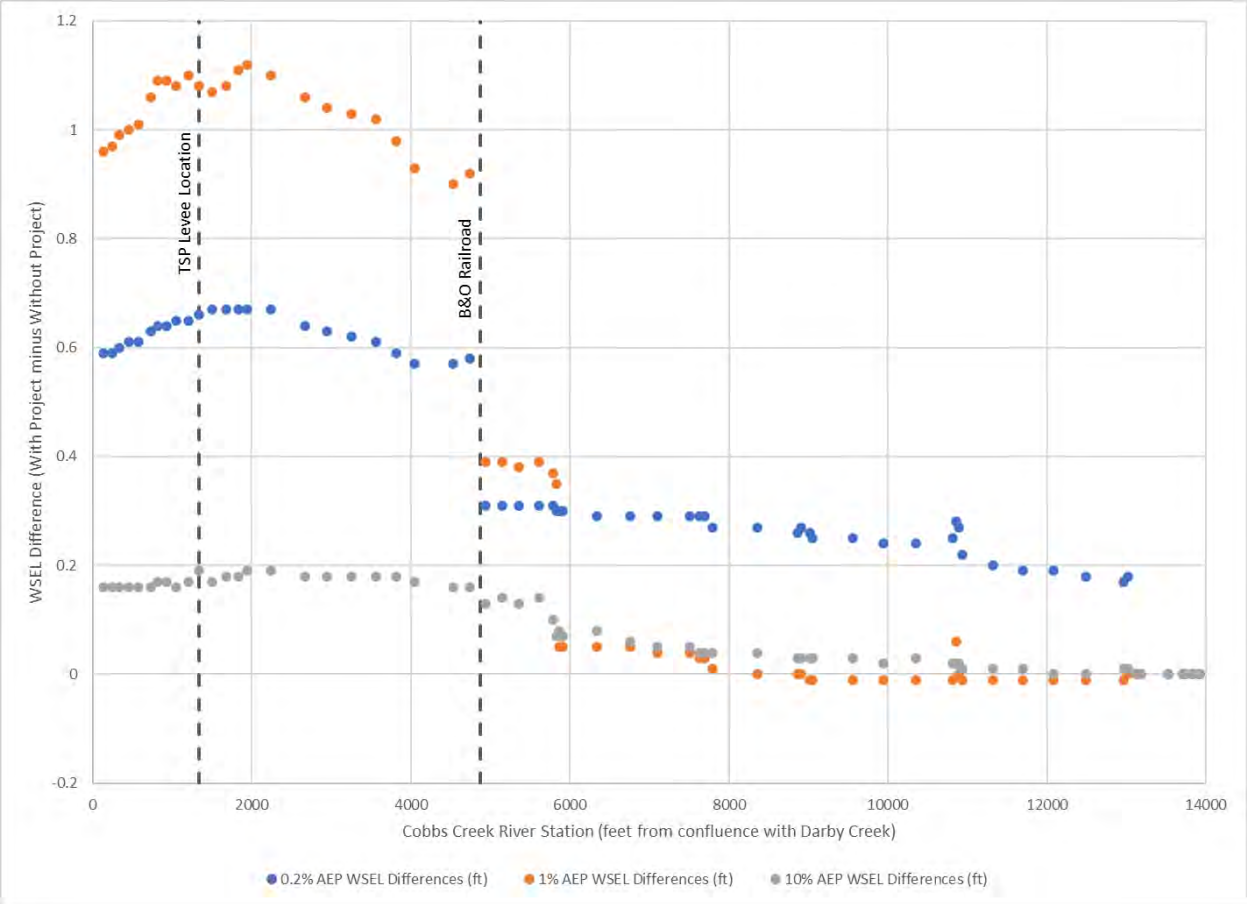

Figure 47 - WSEL Differences – Cobbs Creek FWOP and FWP

Complementary Measures Assessment

To potentially mitigate induced flooding, several complementary measures were preliminarily assessed to determine potential associated WSEL reduction benefits. These included lowering banks/floodplain upstream and downstream of Hook Road, increasing natural high ground elevations at multiple locations, and realignment of high ground near the southeast corner of Eastwick to prevent interaction with Darby Creek and the Heinz Refuge. Generally, no complementary measures were sufficient to fully offset induced flooding, however some measures were effective in reducing residual flooding within Eastwick during the largest events. Figure 48 through Figure 52 depict the locations of modeled complementary measures. These complementary features were only preliminarily modeled, not fully designed. Complementary measures analysis is ongoing, and additional measures, particularly with involvement from USFWS and USEPA (other Federal Agency partners) will be further assessed in later phases, including structure specific potential measures (e.g. local FRM measures, non-structural solutions, etc.). Following is a list of measures that were preliminarily modeled, and will be further assessed in conjunction with additional measures moving forward:

- Floodplain benching right bank above Hook Rd
- Floodplain benching left bank below Hook Rd
- Small berm area at DS end of Landfill
- Small berm area at 86th St.
- Slight modifications (earthwork only) at Hook Rd. Bridge
- Marsh backflow/SEPTA overflow prevention
- Re-alignment of Berm separating Marsh and Eastwick

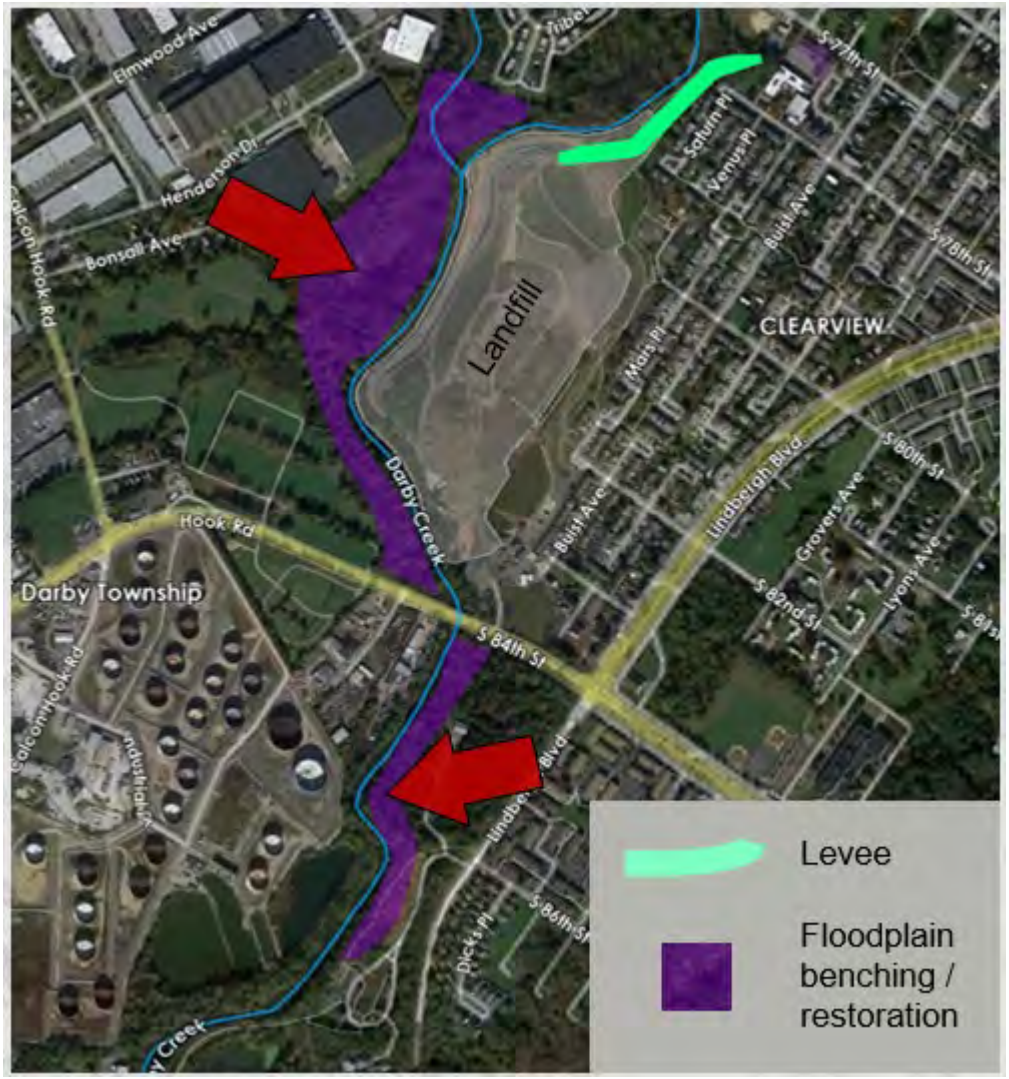

Figure 48 - Alternatives for Complementary Measures Near Hook Road

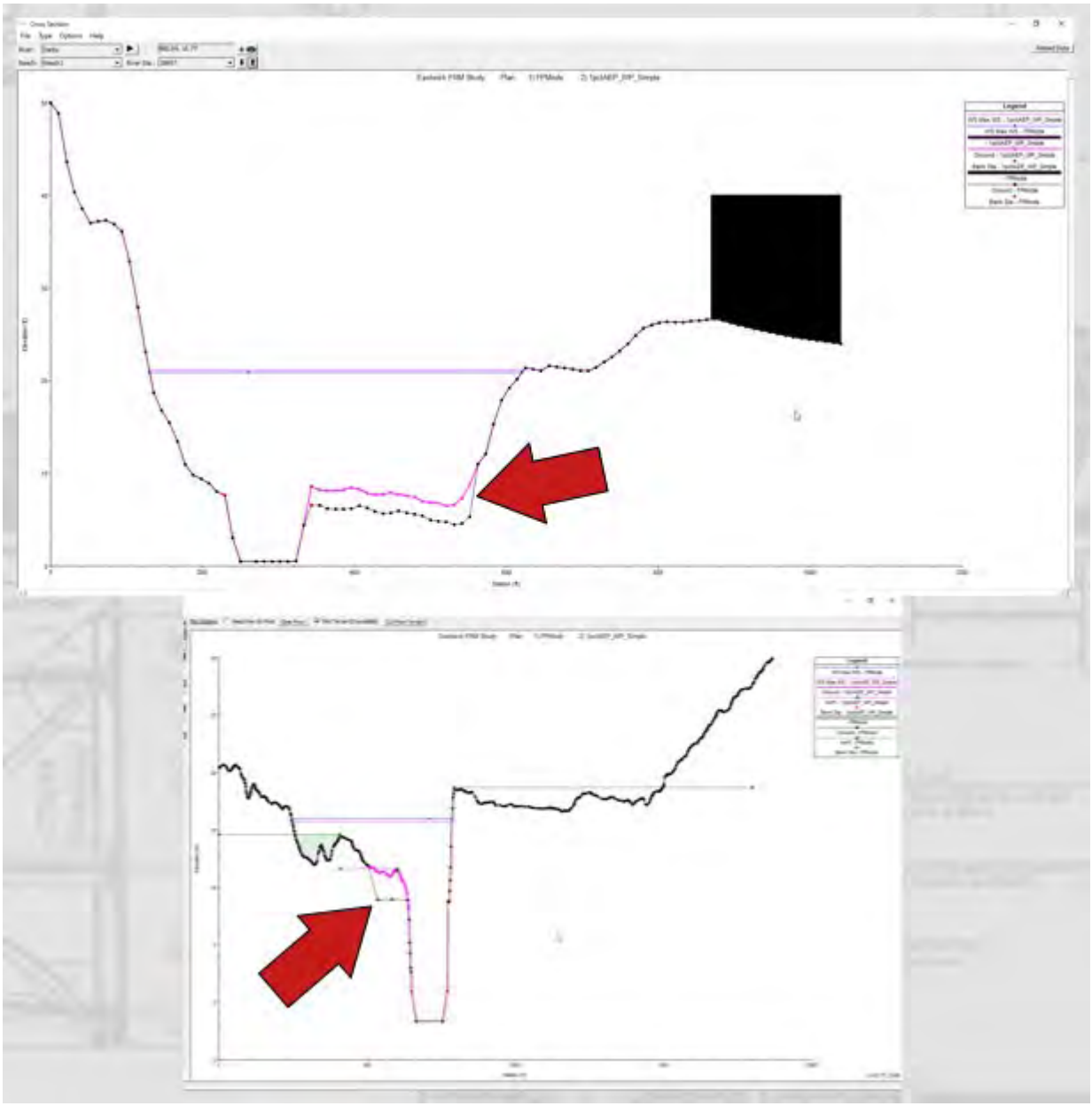

Figure 49 - Example of Floodplain Benching both Upstream and Downstream of Hook Road

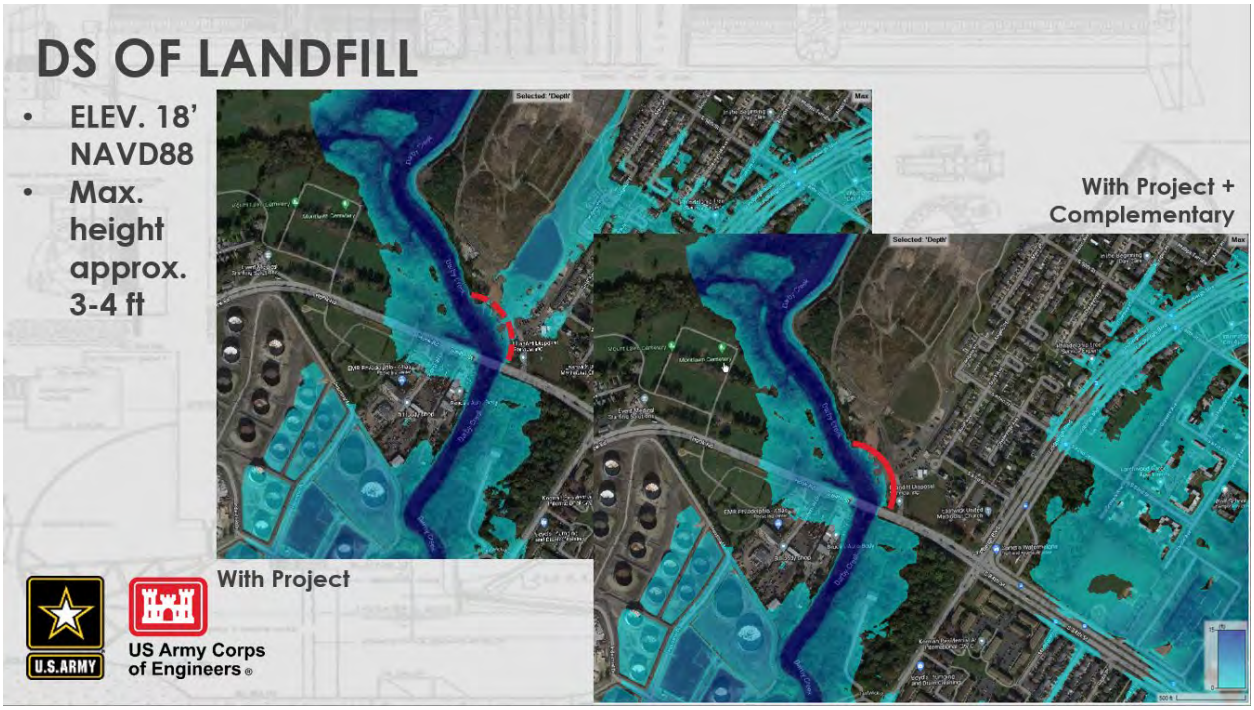

Figure 50 - DS End of Landfill Increased Berm Height to Prevent Backwater



Figure 51 - Increased berm height near USFWS Entrance (86th street)

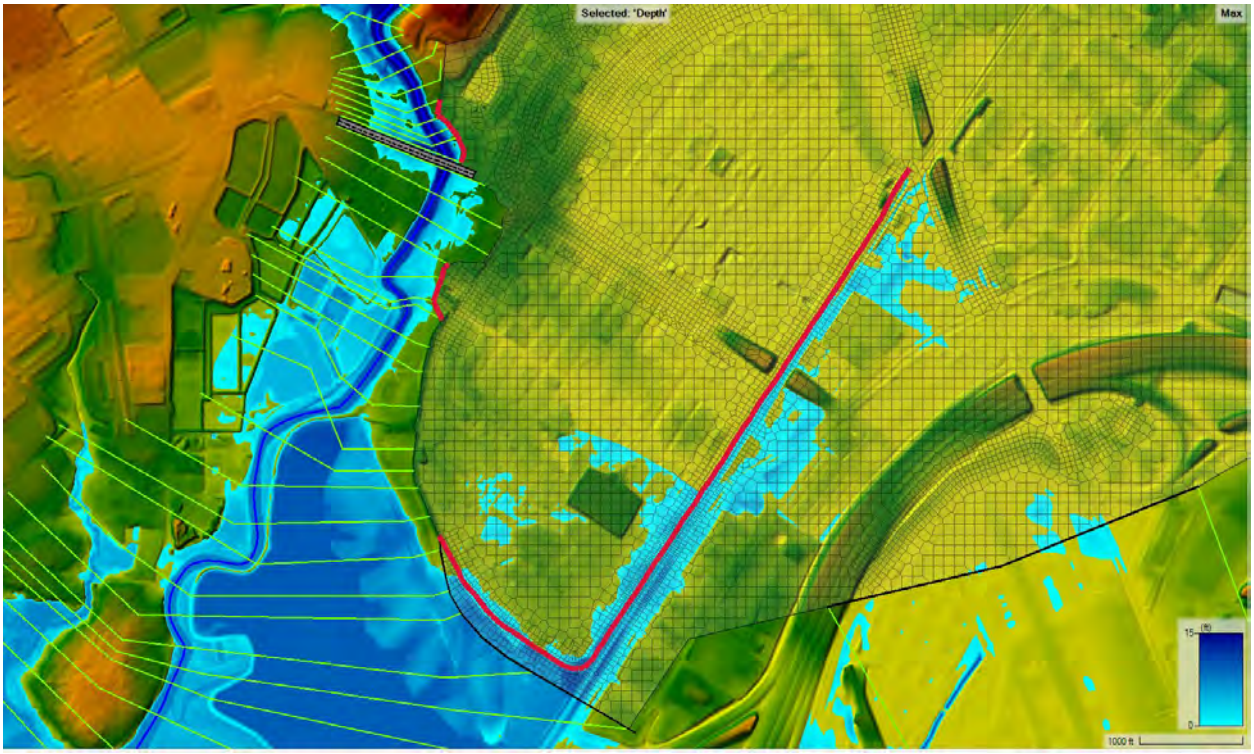

Figure 52 - Combined Landfill, 86th Street Cutoff, and Raised SEPTA Levee (all shown in red) to reduce residual flooding in Eastwick

Levee Overtopping Assessment and Superiority (Preliminary)

To inform the preliminary layout of levee overtopping, cursory calculations were completed, but must be refined in later phases. Current USACE guidance (ECB 2019-8) requires a managed overtopping section for levee design. In general levee systems should have features to accommodate capacity exceedance. The concept is that, where feasible and practical, the system should be designed and constructed to take into account that capacity exceedance. Should capacity exceedance result in overtopping or breaching of the levee system, the breaching will occur in a predictable location, allowing orderly floodplain evacuation and minimize reconstruction requirements (time and cost) after an exceedance or breach. Levee superiority is the concept of designing one levee reach at an elevation different than another adjacent reach so that one overtops before the other in a predictable fashion (USACE 2019). Figure 53 through Figure 55 describe current level of analysis.

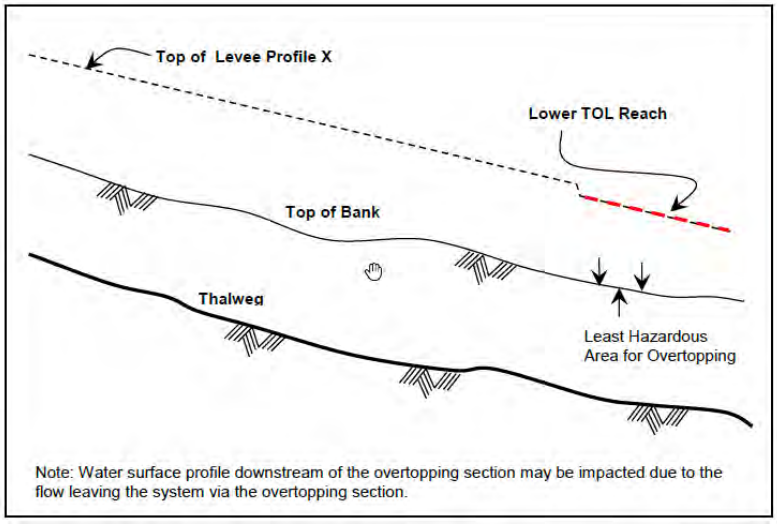

Figure 53 - Figure from ECB 2019-8 Showing Definitions of Top of Levee (TOL) and Managed Overtopping Section

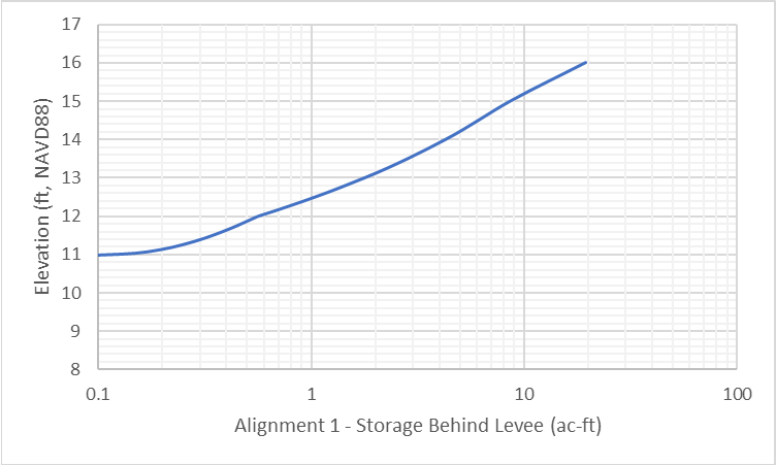

Figure 54 - Available Storage Behind Levee (Alignment #1)

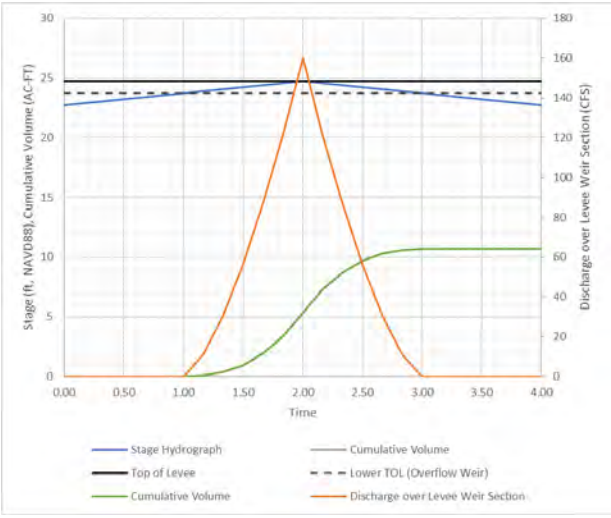

Figure 55 - Initial estimates of overtopping (80 ft overtopping section) during simplified 0.2% AEP event stage hydrograph

Uncertainty and Path Forward

While current hydraulic analysis efforts are considered sufficient to move forward through TSP and draft report release, there are several outstanding items that were not yet completed, or are ongoing, for this effort. Detailed below are analyses and considerations to be incorporated in subsequent phases.

- *Induced Flooding/Complementary Measures*

Induced flooding and complementary features analysis are ongoing and will continue to be developed in later phases.

- *Risk/uncertainty, optimization/update economics*

Levee height and alignment will be optimized in subsequent phases to maximize benefits. This will include risk and uncertainty analysis to determine statistical efficiency of the levee across the range of events (e.g. 90 percent assurance of protection for the 1 percent AEP).

- *Debris Blockage Sensitivity*

A sensitivity analysis should be completed between the Cobbs Creek water surface elevation at the playground diversion point and debris blockage at Hook Road, as this bridge is a major driver of upstream flood elevations. The maintenance history of Hook Road should be researched to document the frequency and magnitude of debris at Hook Road.

- *FWP increased flows from climate change*

As described in the hydrology section, if future conditions flows are deemed to increase, those flows should be modeled hydraulically to determine impacts to levee height, overtopping, etc.

- *Levee overtopping/superiority*

Preliminary assessment of levee overtopping was considered in the initial design of the TSP Levee, however this analysis will be completed in later phases, and part of the optimization of the levee height and alignment.

- *Additional gage installation recommendations*

Recommend installation of water level gages where lacking HWM data to reduce uncertainty. Locations within Eastwick, and downstream through the Heinz Refuge would be a priority, and collaboration with other modeling teams and partners would be beneficial to this and any future efforts.

- *Storage in USFWS impoundment*

Initial coordination with USFWS managers of the Heinz Refuge, indicate there are plans to adjust operation of several dikes and water control structures. Opening up storage areas prior to overtopping has the potential to lower water surface elevations and decrease flows. Additional coordination with USFWS on this and additional complementary features will continue through subsequent phases.

- *Sedimentation assessment*

Sedimentation, or deposition, near potential levee could reduce effectiveness by raising WSEL, or lead to potential maintenance requirements. Sedimentation potential in the Eastwick area has not been assessed, but will be progressed in later phases.

- *Additional Topographic/Bathymetric Survey*

As discussed, topographic data is readily available in 2022 LiDAR from the City of Philadelphia. However, all in channel (bathymetric) data dates to 2014, 2013, 2002, or in some cases from original 1977 FEMA FIS studies – a minimum of 10 years out of date. This also applies to bridge geometries throughout the domain. It is recommended full survey of in channel and cross-sections be updated either before finalizing Feasibility report, or prior to Preconstruction Engineering and Design phase, should the feasibility study move forward. All hydraulics should be updated based on the above, and these additional data will also inform the above listed sedimentation assessment.

- *Groundwater Assessment*

Steel sheetpile within the levee cross-section may influence groundwater flow paths in the area. Given proximity to the Clearview Landfill, any changes to groundwater flow paths will be important to understand to inform fate and transport potential of any known contamination. This will be further assessed in later phases, coordinating with USEPA.

Conclusions

The current level of analysis updated flow estimates, modeled hydraulics for updated flows, calibrated/validated to four (4) historic events, provided basis for updated economic calculations, estimated potential induced flooding impacts for the TSP Levee Plan, and investigated potential complementary features. Updates to previous analyses support the TSP of a levee, but need further refinement with respect to induced flooding and complementary features for a complete plan. While sufficient to move forward with TSP and draft feasibility report, these updates are insufficient to answer all issues explicitly. Additional analysis is identified in previous sections moving forward to reduce uncertainty, and finalize feasibility level analyses.

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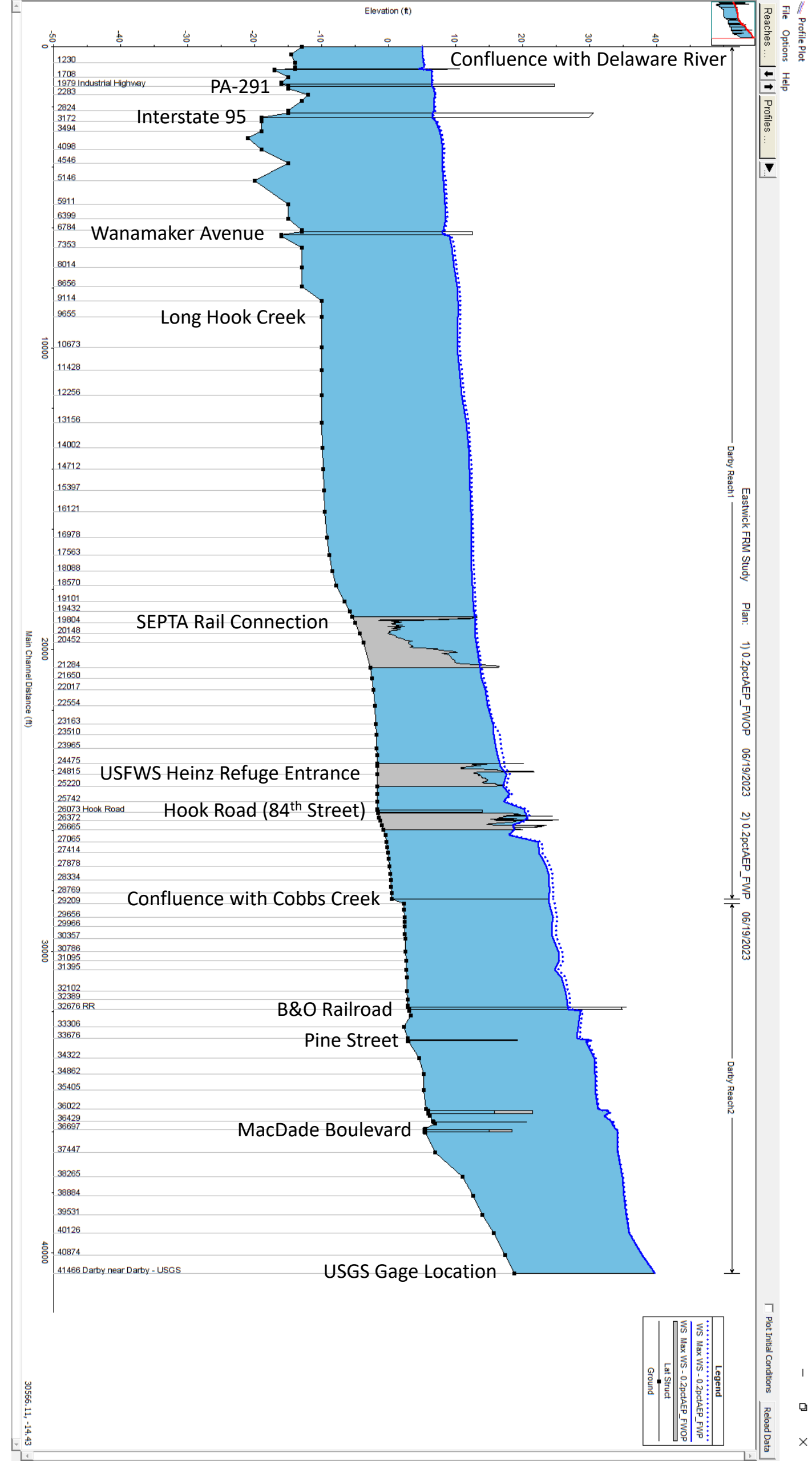
England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2019, Guidelines for determining flood flow frequency — Bulletin 17C (ver. 1.1, May 2019): U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p., https://doi.org/10.3133/tm4B5.

Attachment # 1

Selected HEC-RAS Profiles and Inundation Maps

Darby Creek Profiles – FWOP and FWP

- 0.2 percent AEP through 50 percent AEP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-20
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40
Confluence with Delaware River
PA-291
Interstate 95
Wanamaker Avenue
Long Hook Creek
SEPTA Rail Connection
USFWS Heinz Refuge Entrance
Hook Road (84th Street)
Confluence with Cobbs Creek
B&O Railroad
Pine Street
MacDade Boulevard
USGS Gage Location
1230
1708
1979 Industrial Highway
2283
2824
3172
3494
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4546
5146
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7353
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8656
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41466 Darby near Darby - USGS
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Main Channel Distance (ft)
Darby Reach1
Darby Reach2
Eastwick FRM Study
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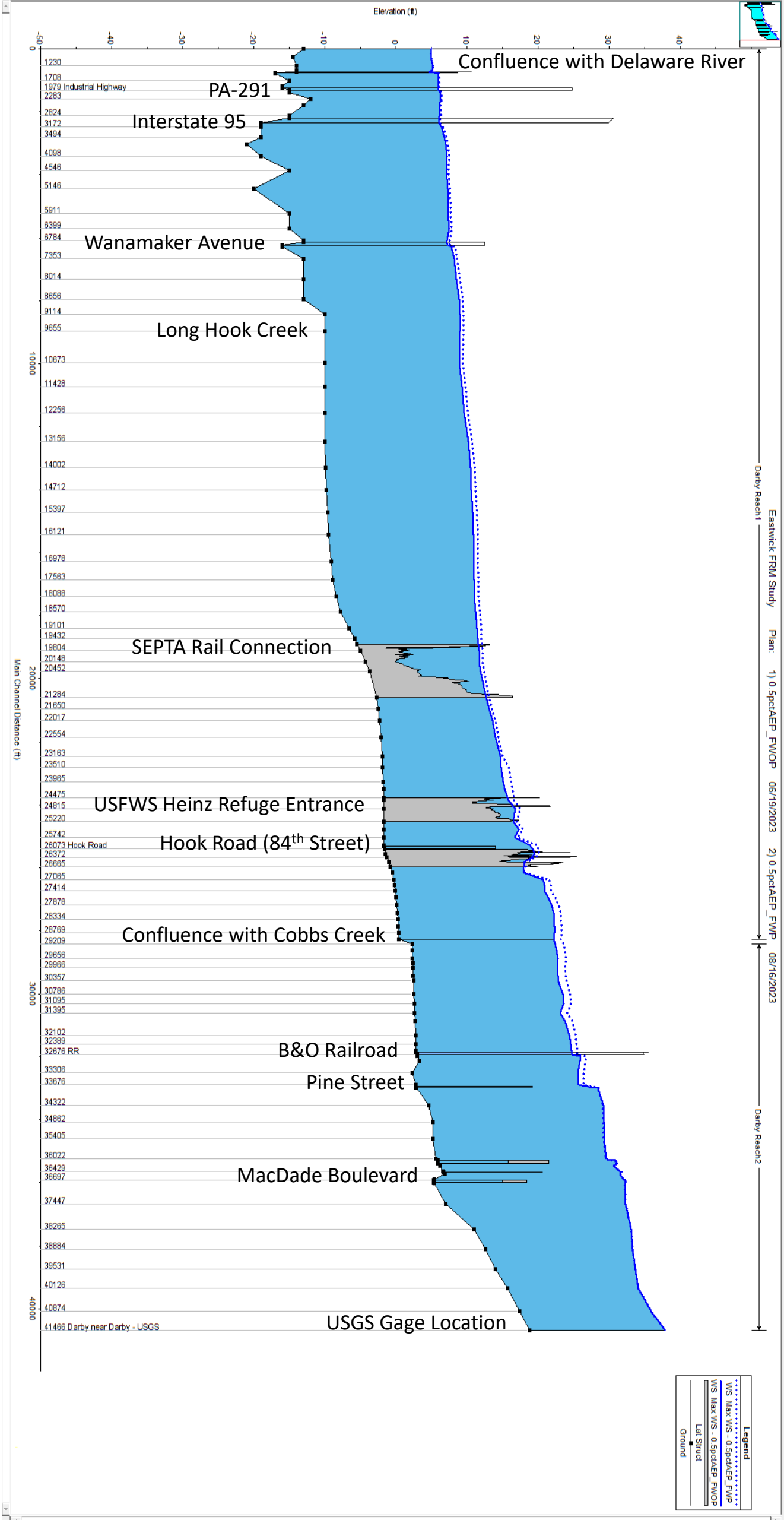
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Confluence with Cobbs Creek
B&O Railroad
Pine Street
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USGS Gage Location
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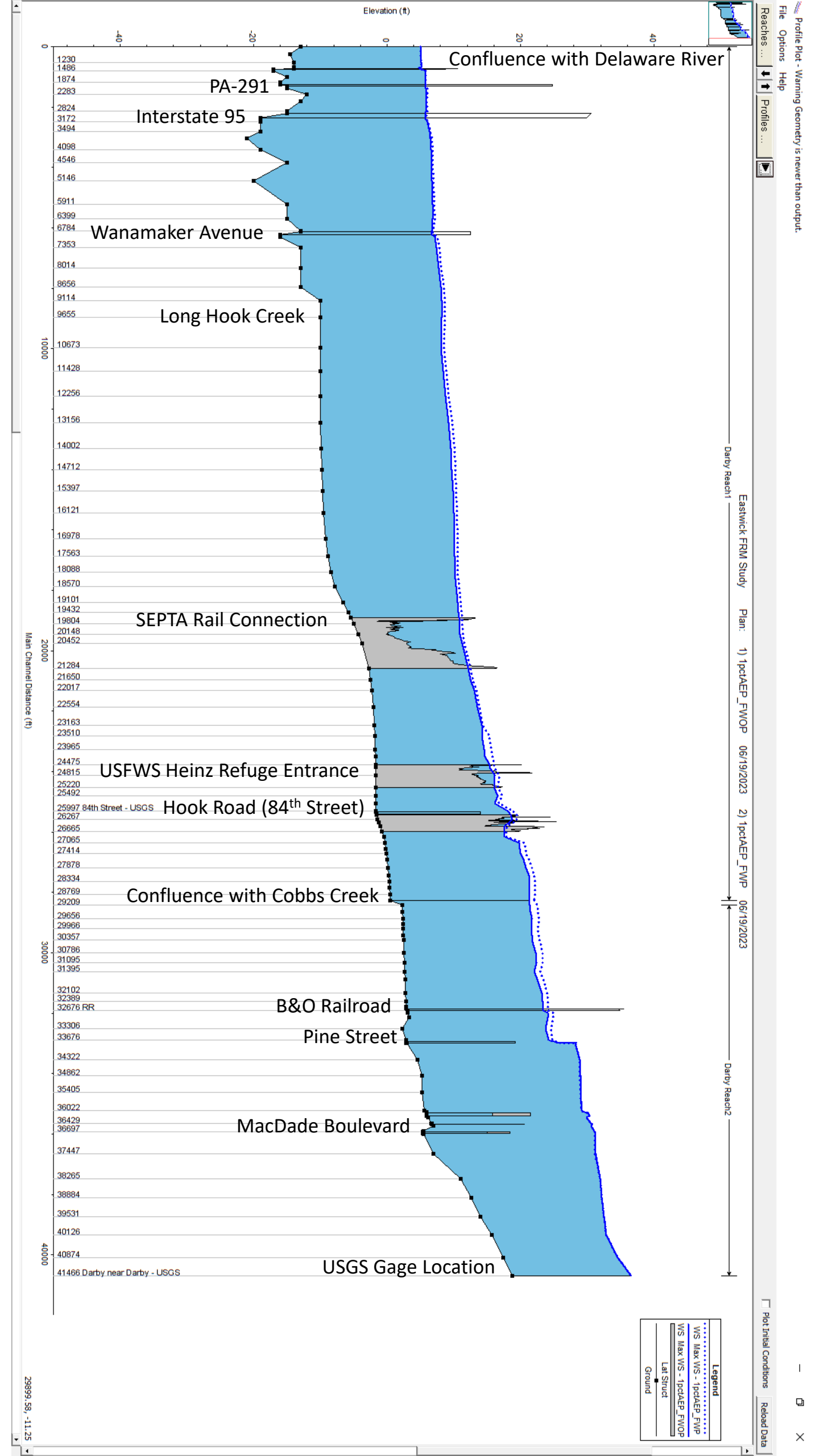
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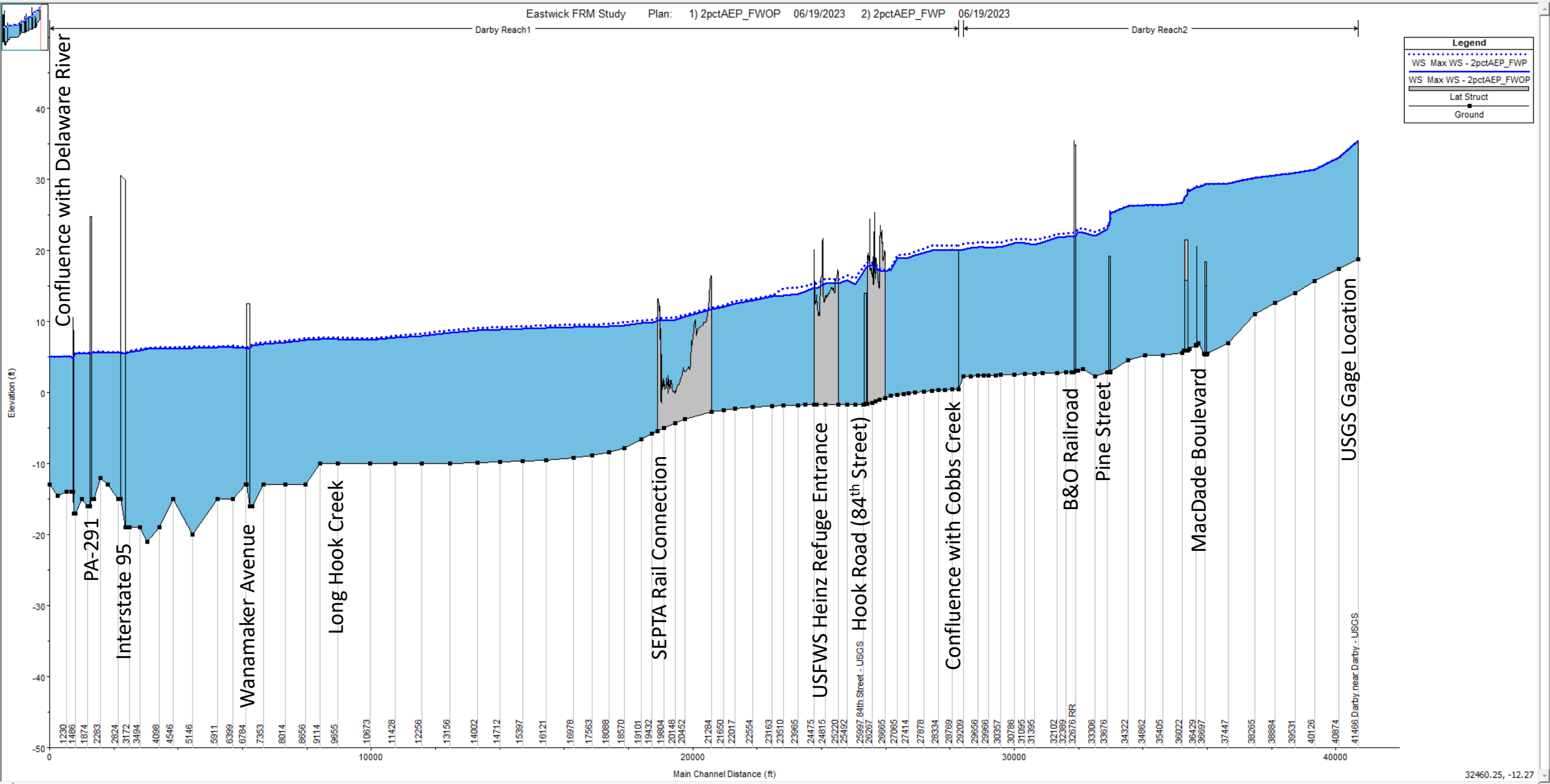

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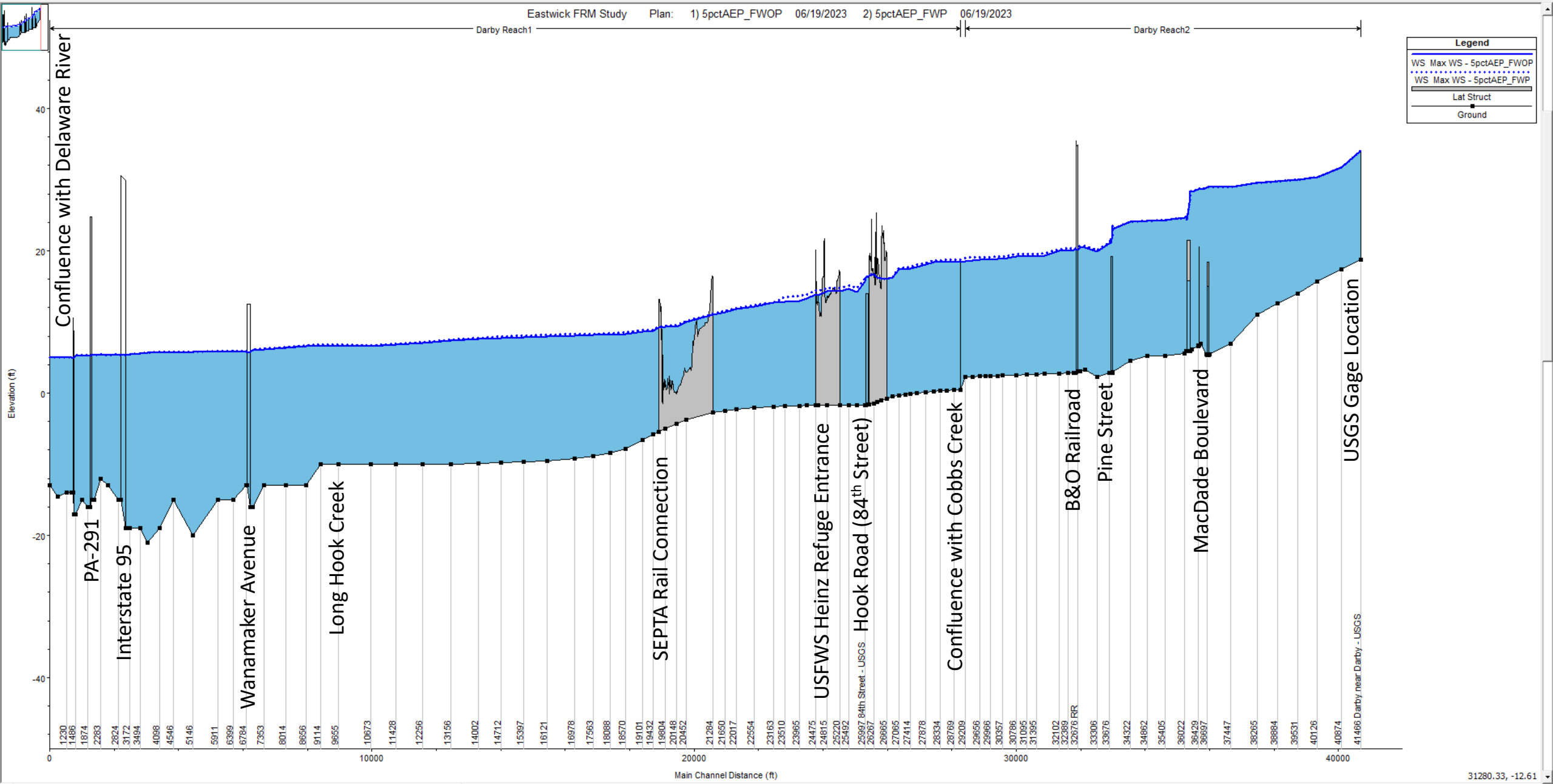

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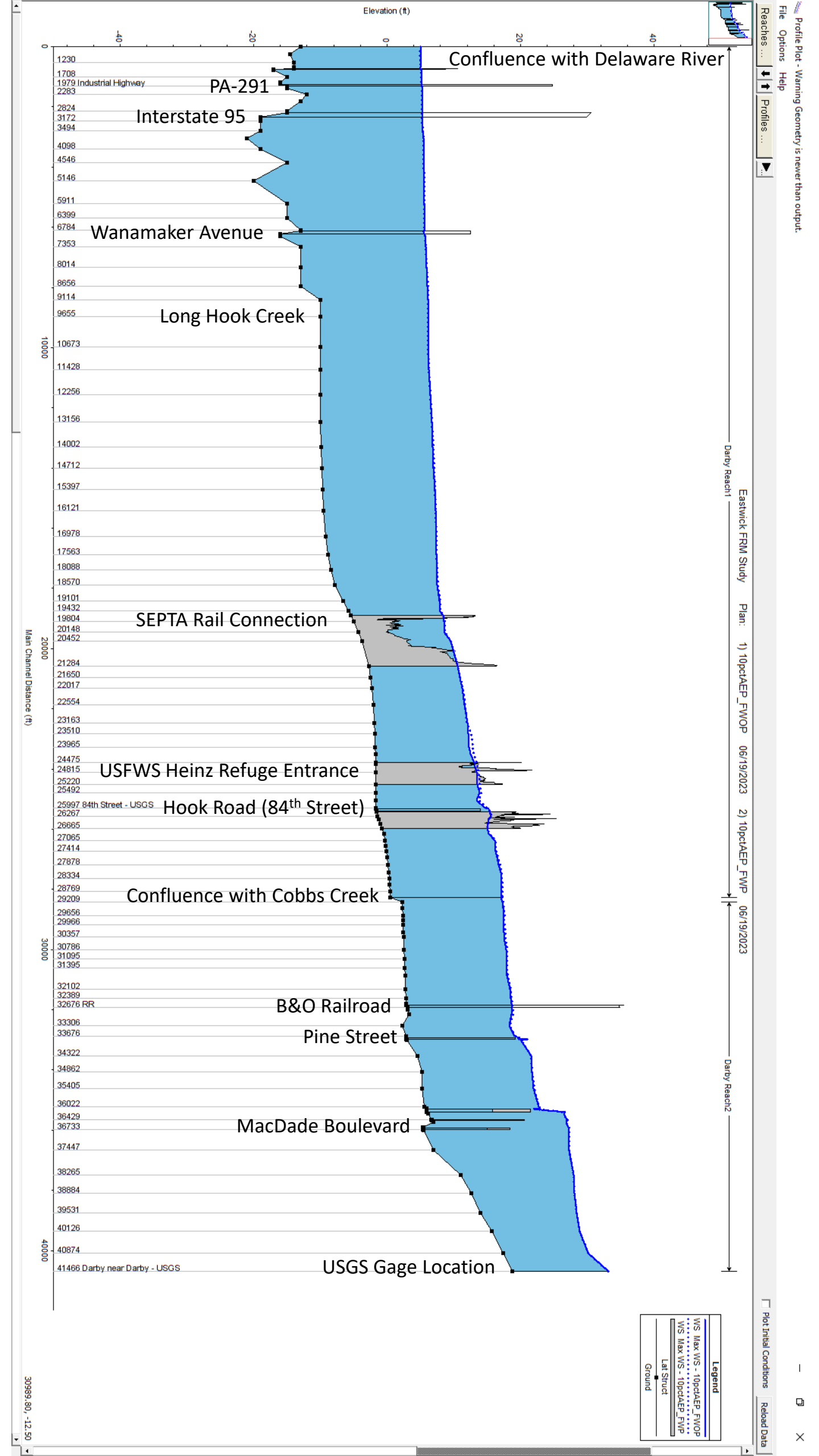
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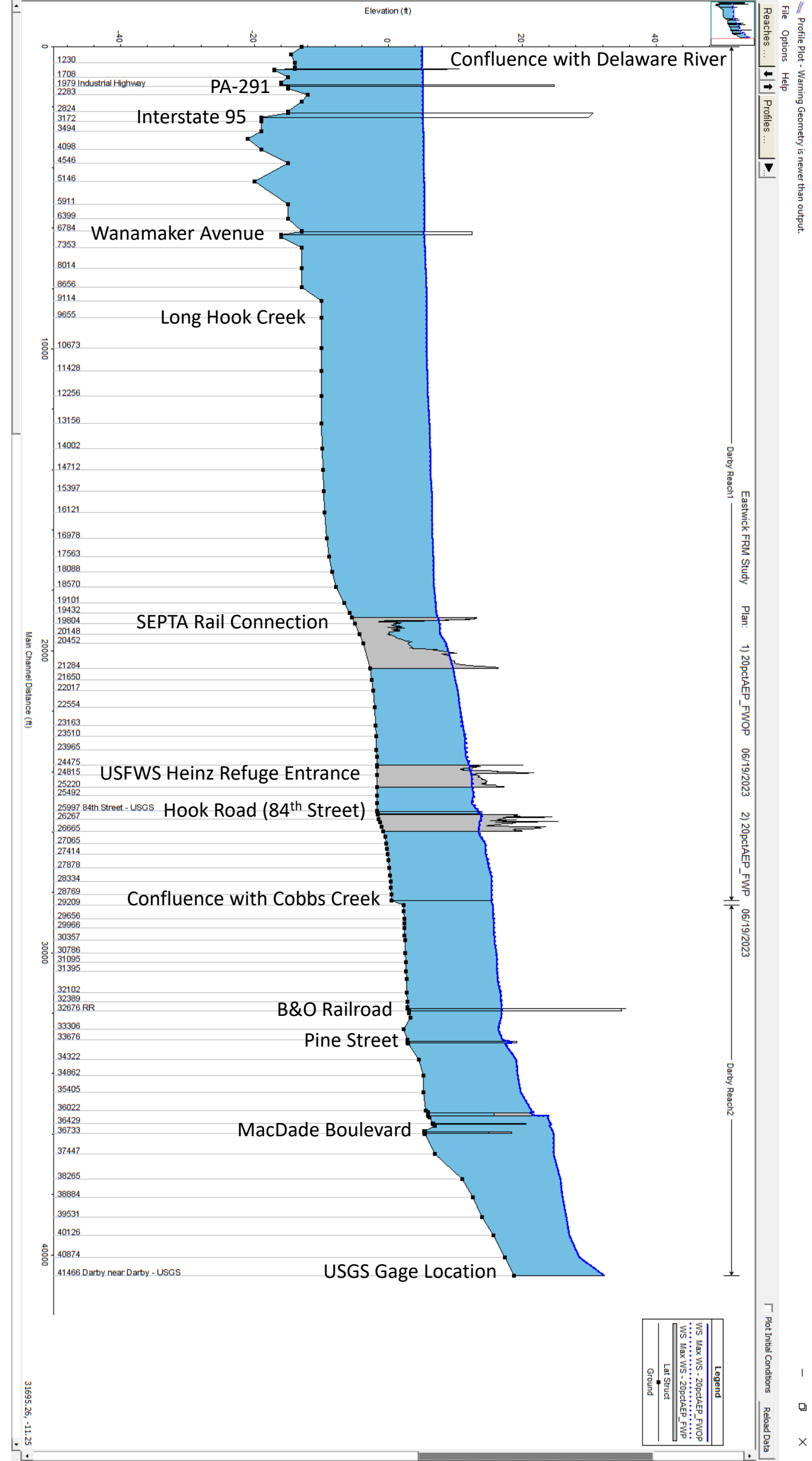
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Main Channel Distance (ft)
Darby Reach1
Darby Reach2
Eastwick FRM Study
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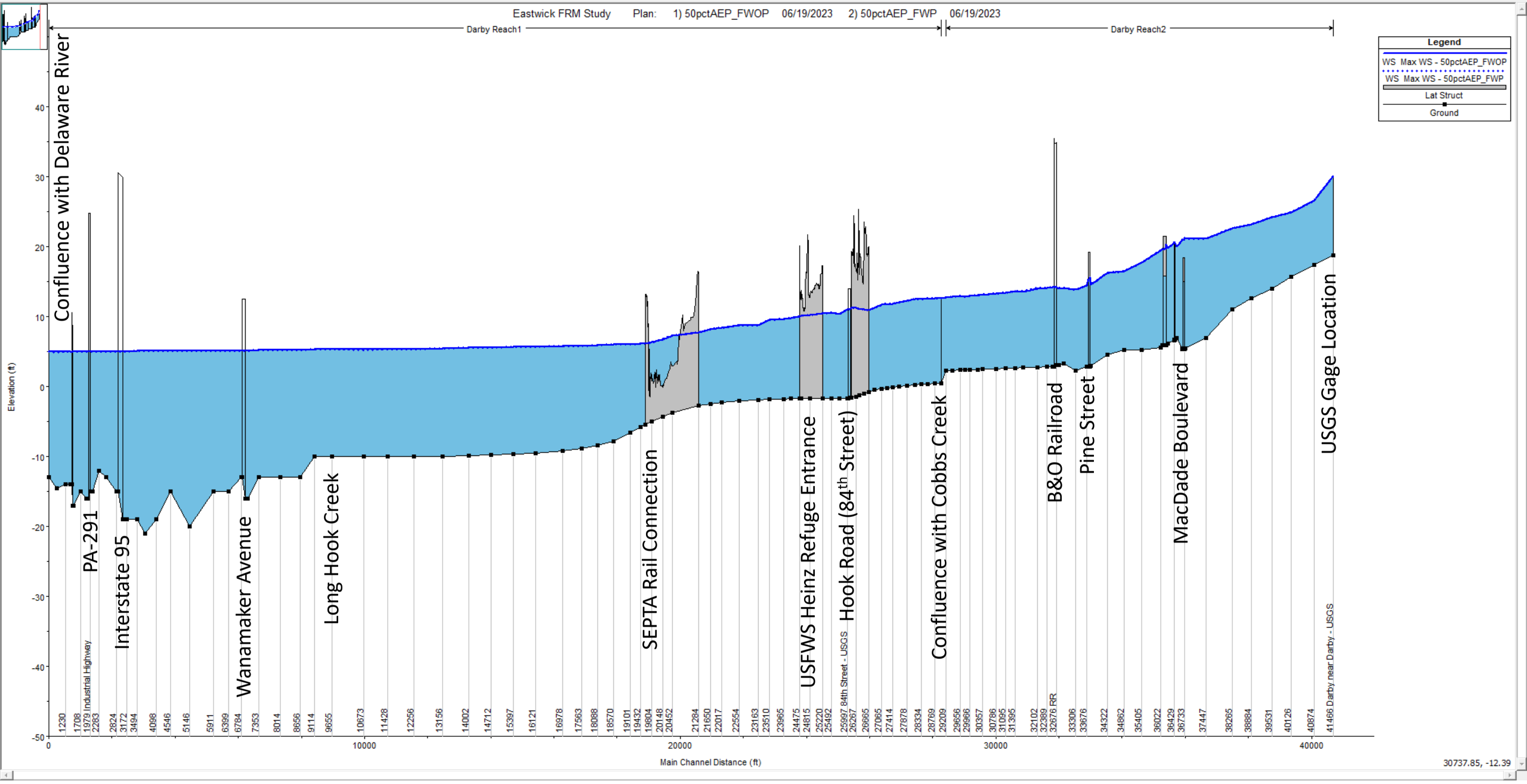

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Cobbs Creek Profiles – FWOP and FWP

- 0.2 percent AEP through 50 percent AEP

Profile Plot

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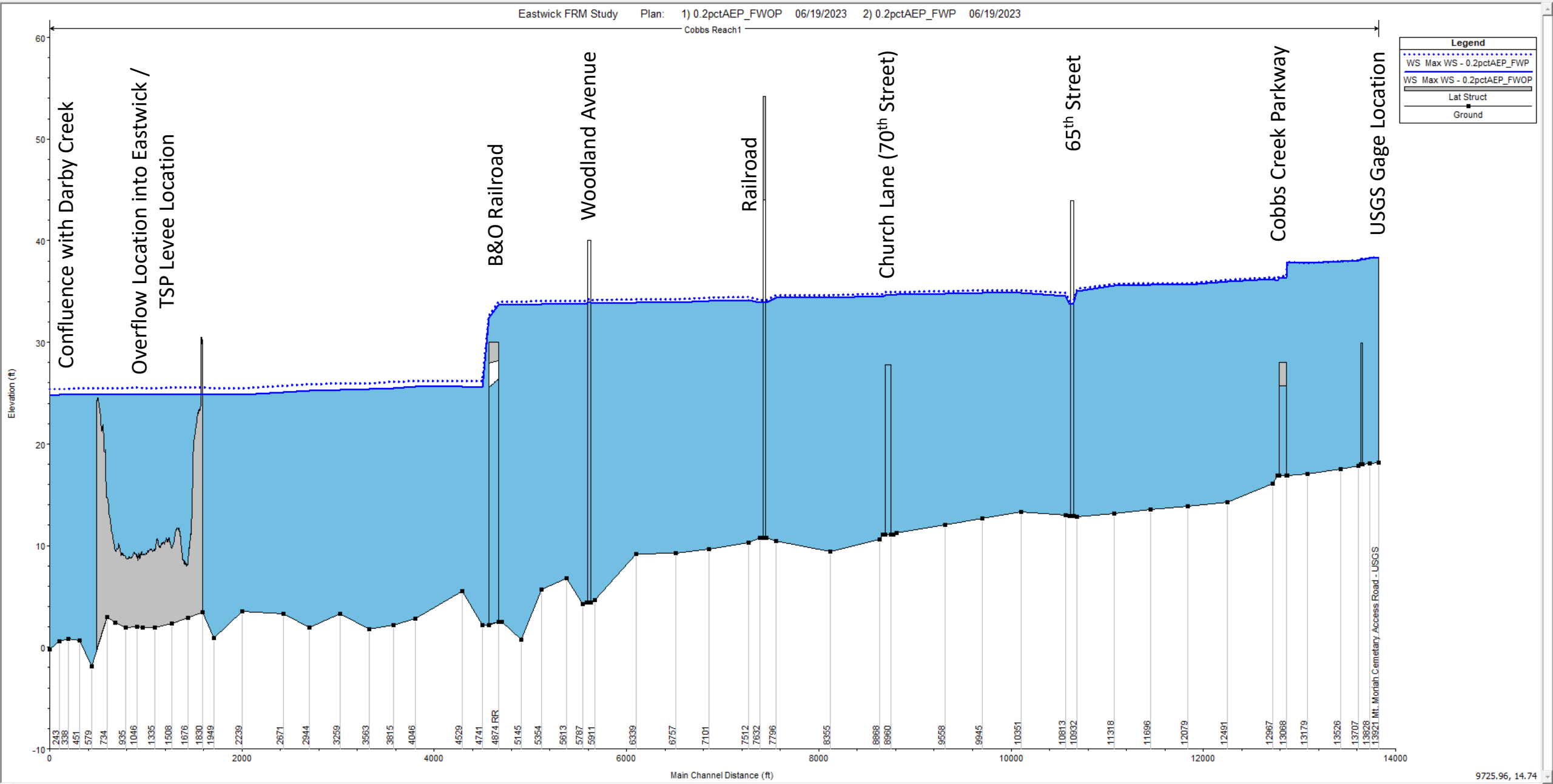

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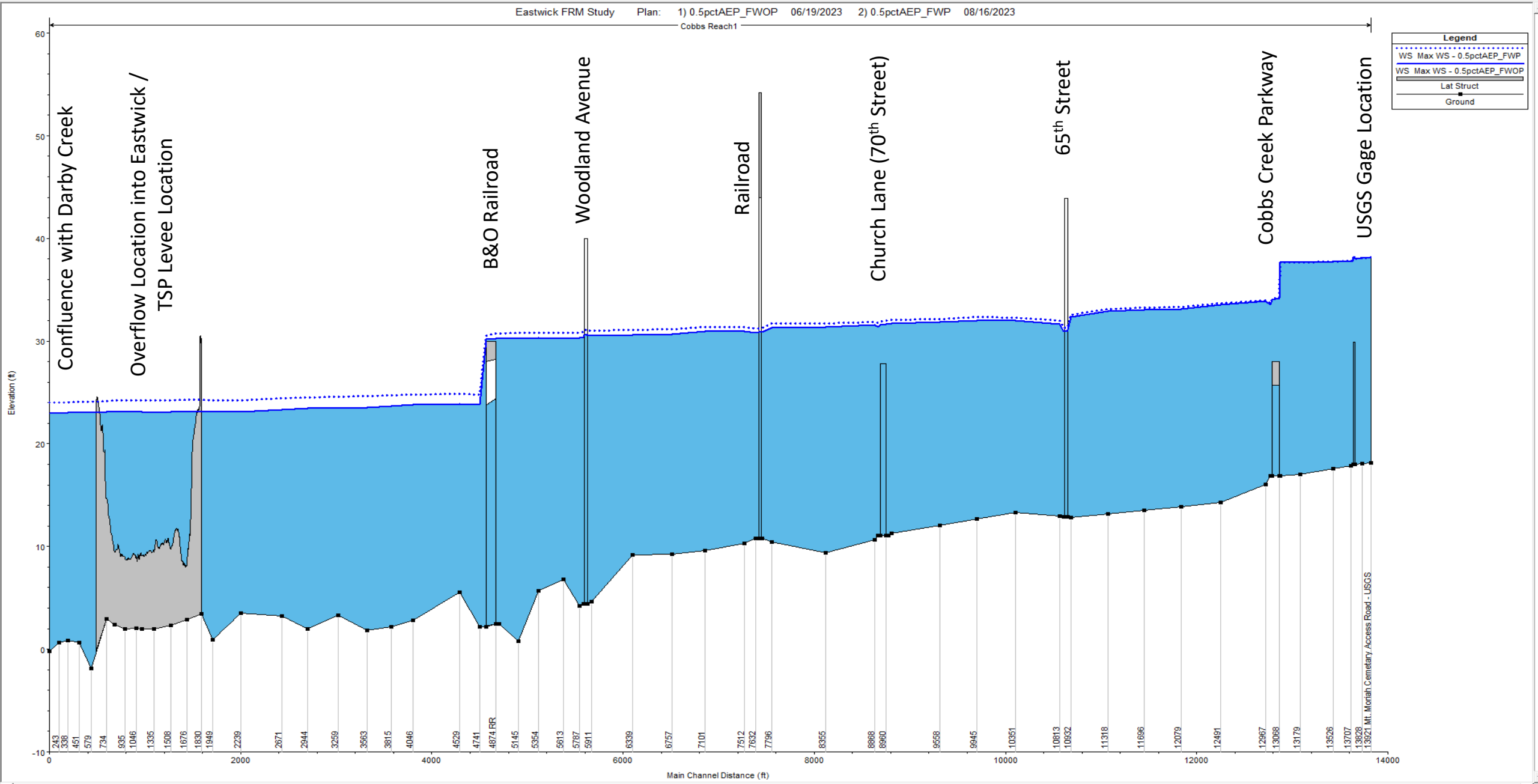

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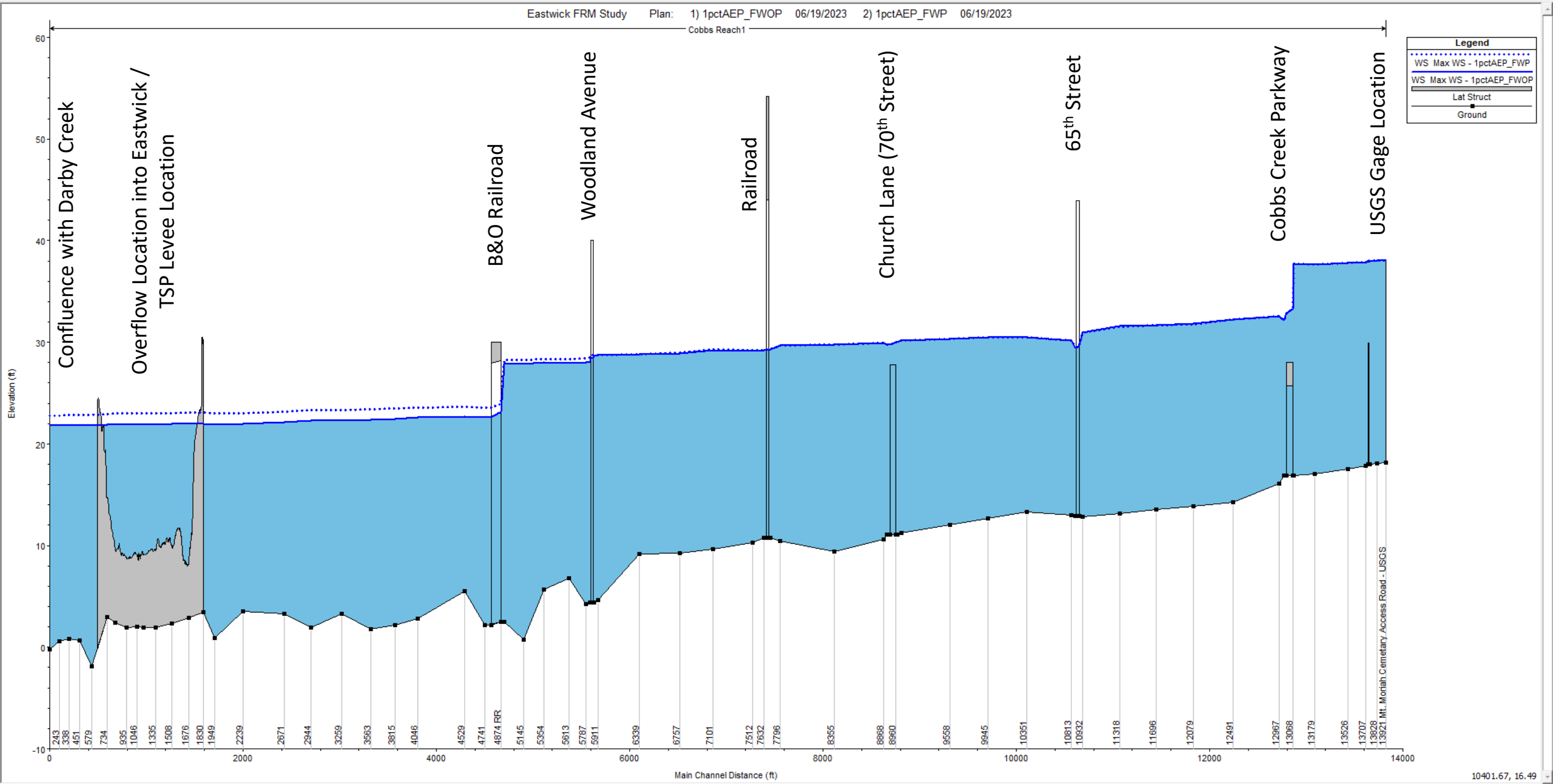

10401.67, 16.49

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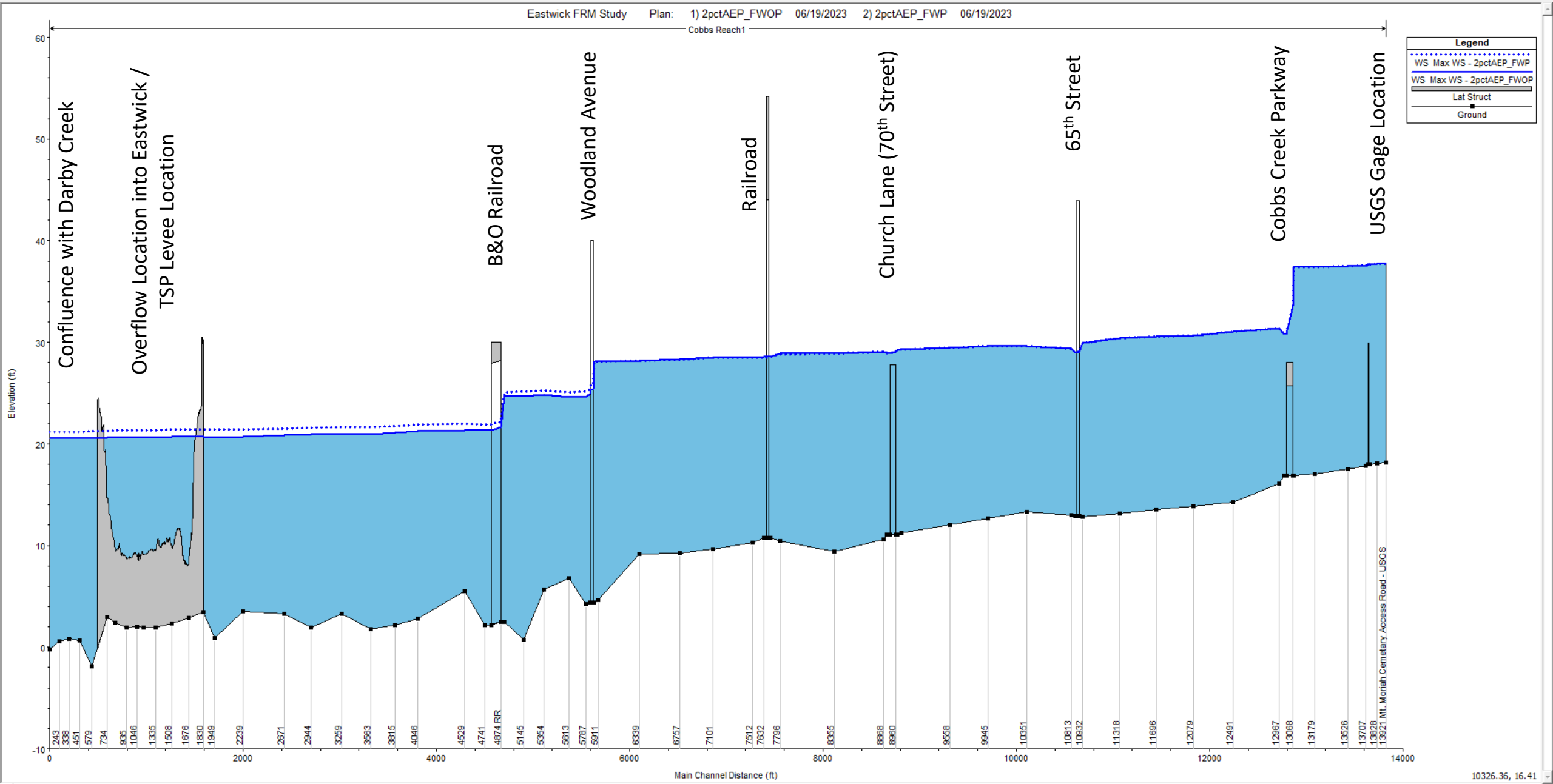

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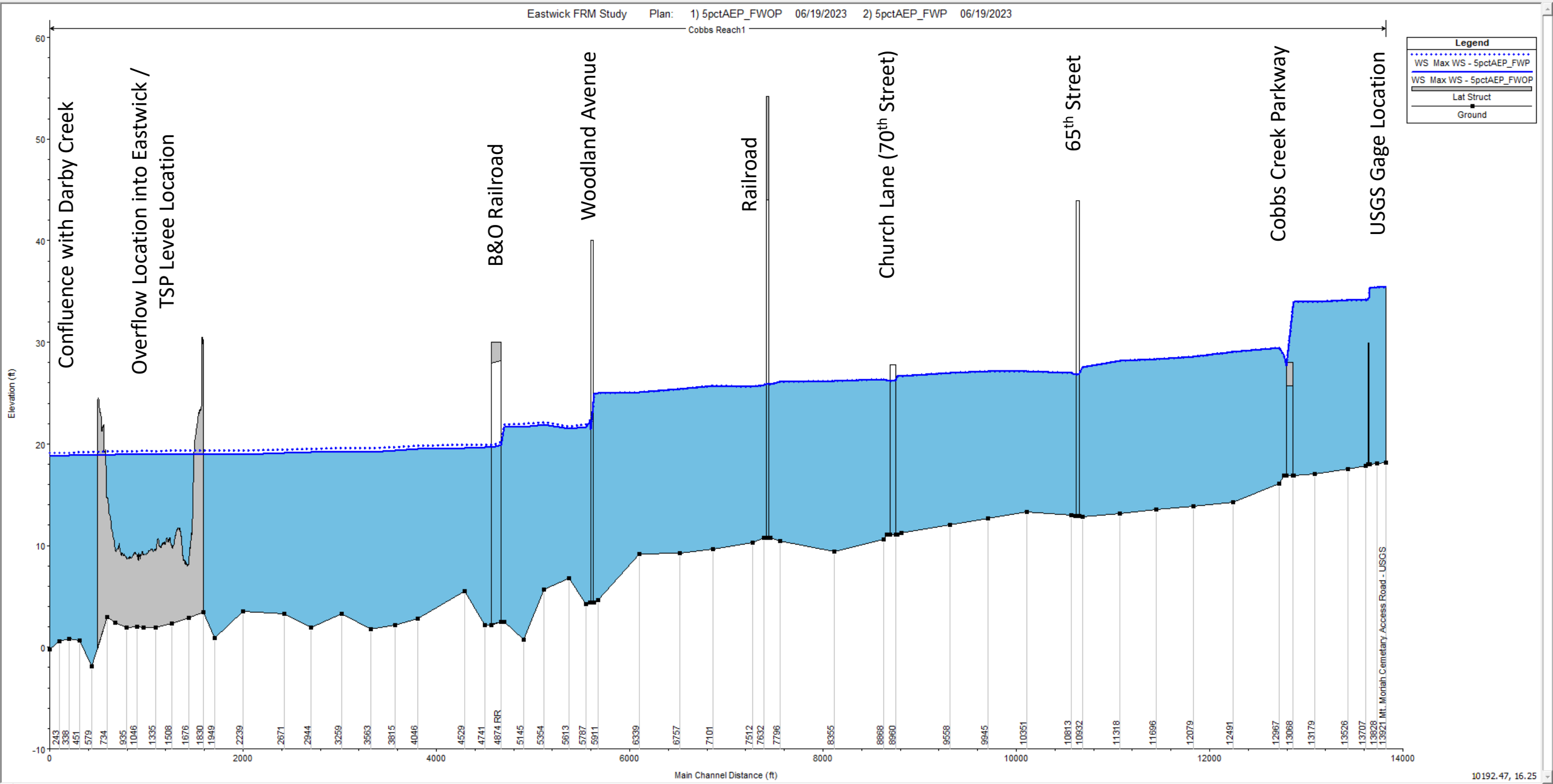

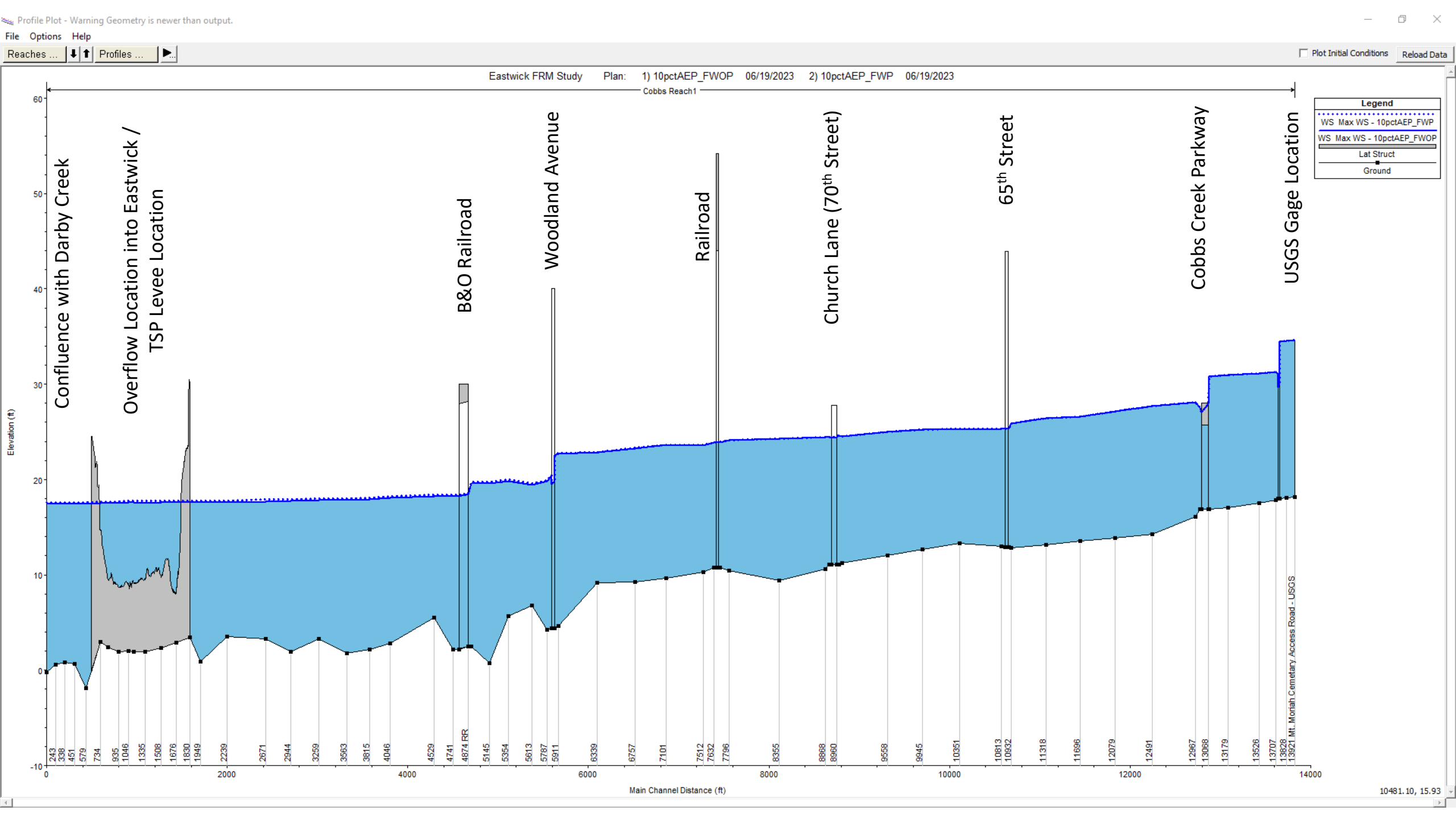
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Eastwick FRM Study Plan: 1) 10pctAEP_FWOP 06/19/2023 2) 10pctAEP_FWP 06/19/2023
Cobbs Reach1
Legend
WS Max WS - 10pctAEP_FWP
WS Max WS - 10pctAEP_FWOP
Lat Struct
Ground
Confluence with Darby Creek
Overflow Location into Eastwick / TSP Levee Location
B&O Railroad
Woodland Avenue
Railroad
Church Lane (70th Street)
65th Street
Cobbs Creek Parkway
USGS Gage Location
Elevation (ft)
Main Channel Distance (ft)
10481.10, 15.93

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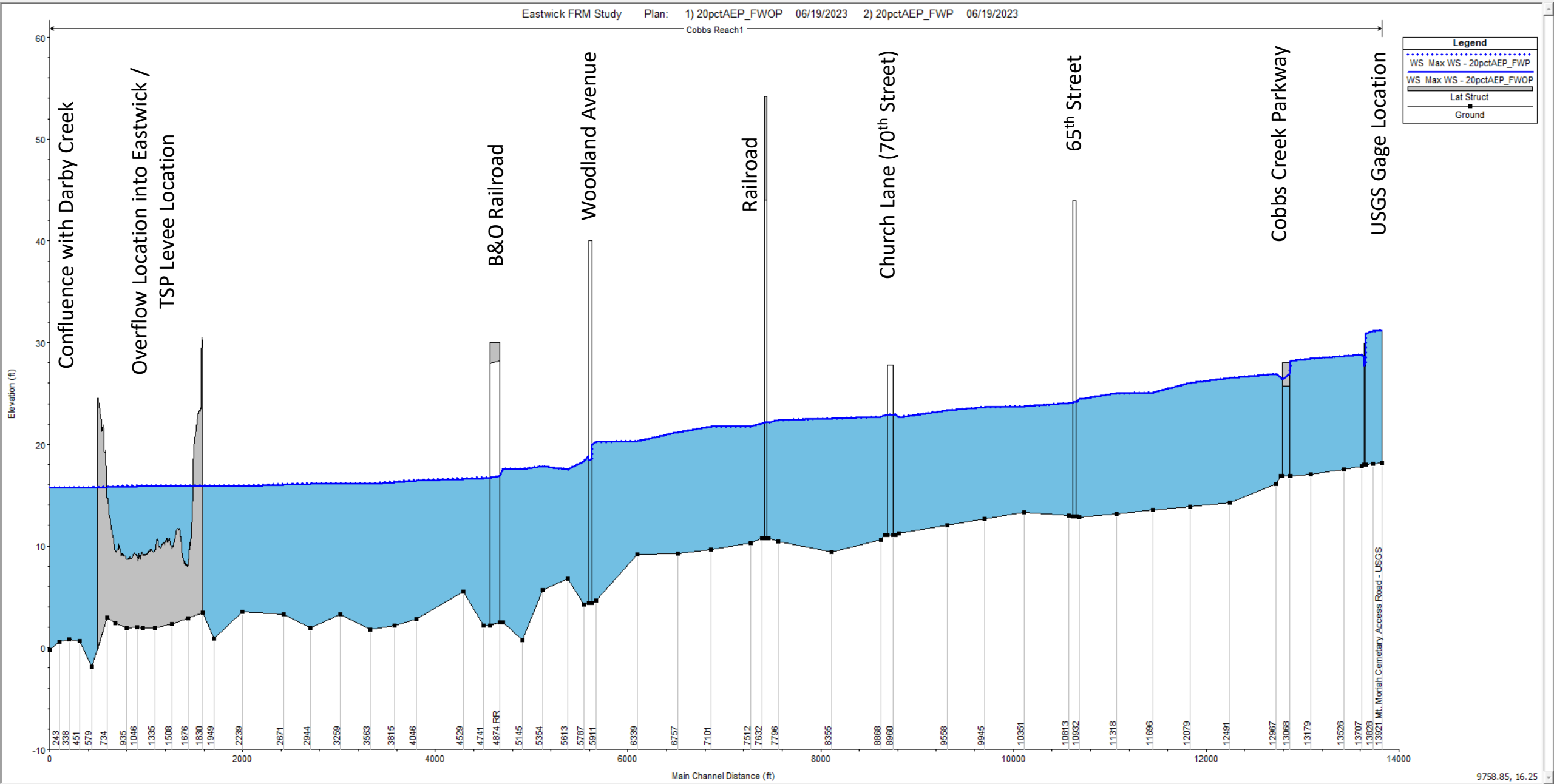

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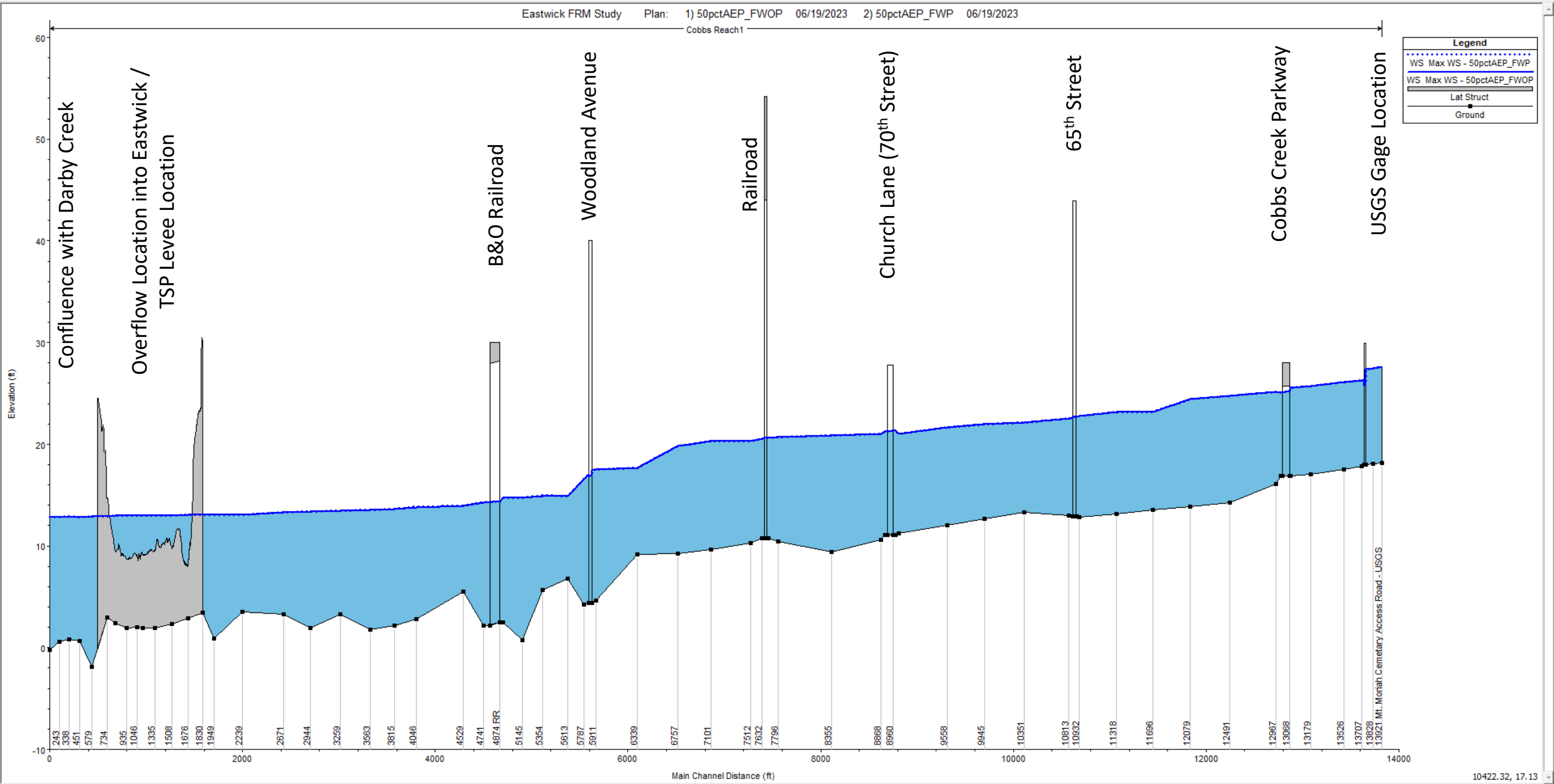
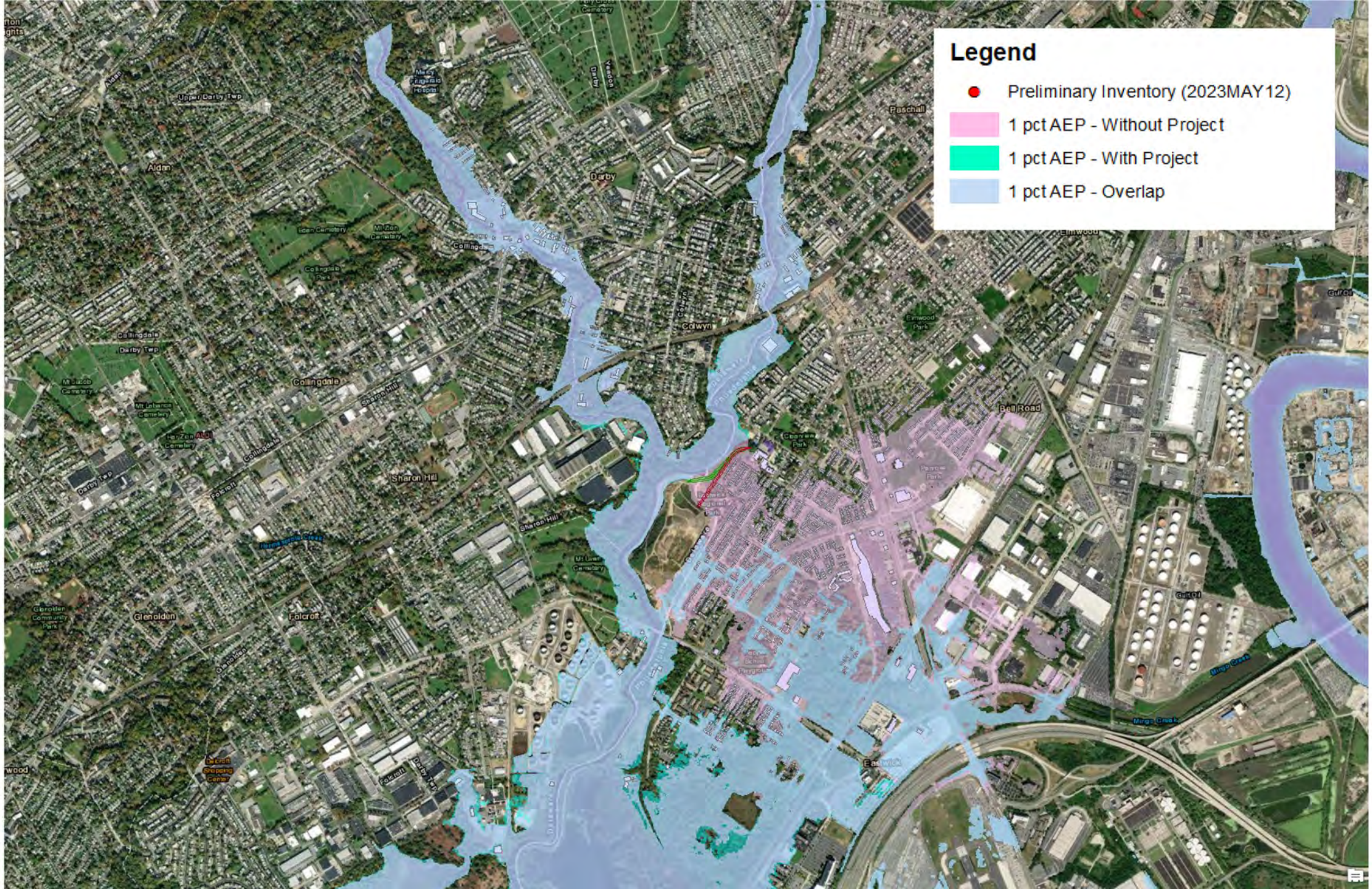
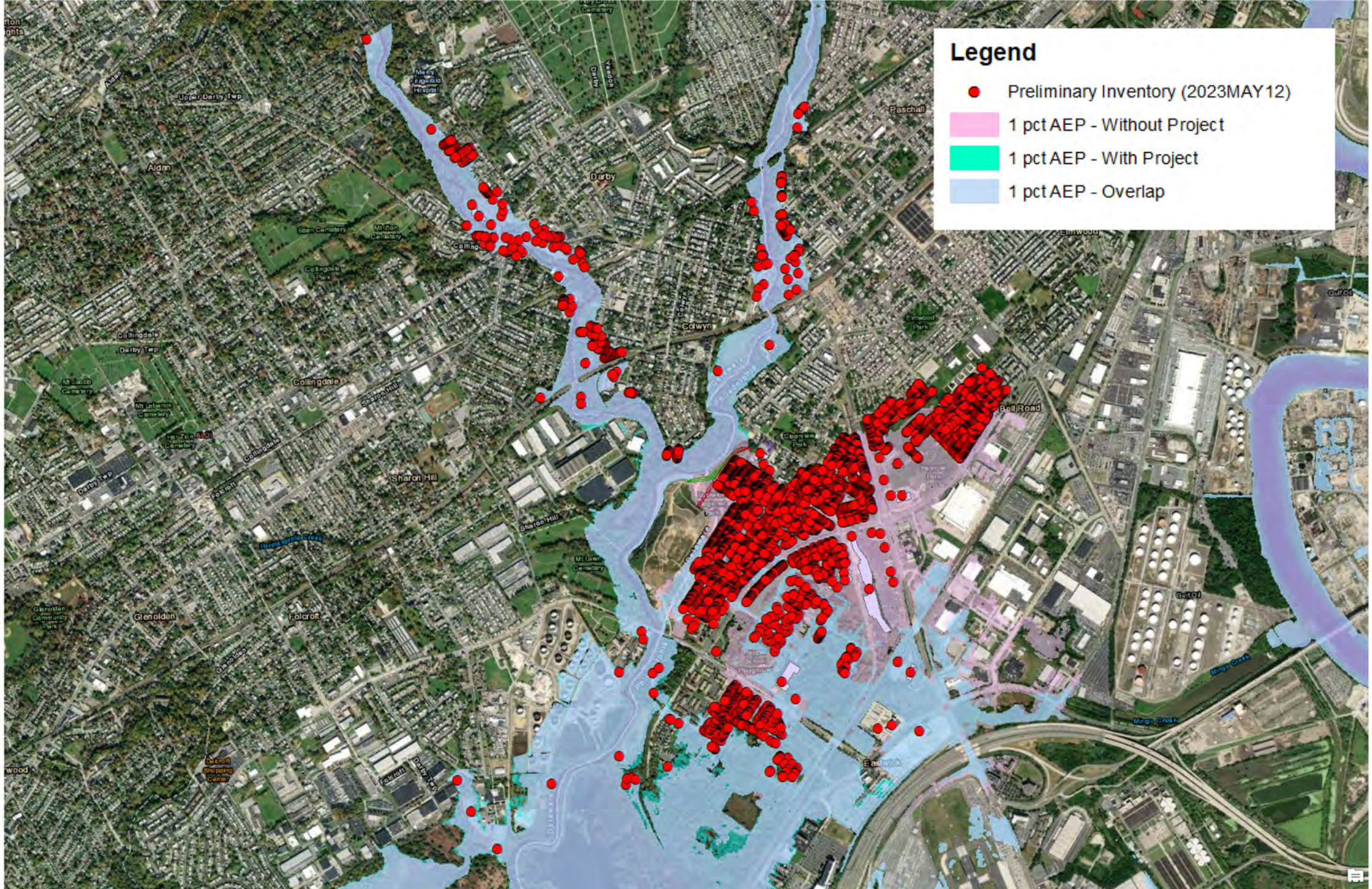


10422.32, 17.13

Inundation Maps – FWOP and FWP

- 1 percent AEP


Legend
Preliminary Inventory (2023MAY12)
1 pct AEP - Without Project
1 pct AEP - With Project
1 pct AEP - Overlap
Darby
Paschall
Colwyn
Collingdale
Sharon Hill
Glenolden
Folcroft
Bell Road
Eastwick
Upper Darby Twp
Darby Twp
Mt Jacob Cemetery
Mt Lebanon Cemetery
Mt Lawn Cemetery
Mingo Creek
Gulf Oil


Legend
Preliminary Inventory (2023MAY12)
1 pct AEP - Without Project
1 pct AEP - With Project
1 pct AEP - Overlap
Aldan
Upper Darby Twp
Darby
Paschall
Collingdale
Darby Twp
Colwyn
Sharon Hill
Folcroft
Glenolden
Bell Road
Eastwick
Mingo Creek

Attachment # 2

Climate Change Assessment

Climate Assessment Report (no nonstationarities detected)

ECB 2018-14 Analysis of Potential Climate Vulnerability

This is an evaluation of potential climate vulnerabilities facing the Eastwick neighborhood in Southwest Philadelphia, PA. Eastwick lies east of Darby Creek and southeast of the confluence of the Darby and Cobbs Creek and is subject to frequent and severe flooding. Eastwick is being studied by the U.S. Army Corps of Engineers (USACE), Philadelphia District, and the City of Philadelphia. This analysis is being carried out in support of a Feasibility Study (Section 205) for flood risk management (FRM) measures in and around Eastwick. This assessment was performed to highlight existing and future challenges facing the project's ability to mitigate flood risk in response due to past and future climatic changes, in accordance with the guidance in Engineering Construction Bulletin (ECB) 2018-14, last revised 19 AUG 2022. Background information on the project can be found in the main report, and background information on climate-affected risks to projects and assessments thereof can be found in the ECB.

Literature Review

Eastwick, PA, including Cobbs Creek and Darby Creek, is located in Water Resource Region (i.e., HUC-2 watershed) number 02, the Delaware Mid-Atlantic Region. A January 2015 report conducted by the USACE Institute for Water Resources (USACE 2015) summarizes the available climate change literature for this region, covering both observed and projected changes. These include:

Temperature.

Described by the USACE Institute for Water Resources (USACE 2015), there has been an apparent warming in the region over the past century, particularly early in the century and then again in the past 30 to 40 years. There have also been noted increasing trends in the number of extreme heat days and decreasing trends in the number of extreme cold days. Many studies have focused on southern New York State, all of which demonstrate significant warming trends in that region. Temperatures will rise between 2 and 4 degrees Celsius (3.6 to 7.2 degrees Fahrenheit), with substantially more warming in summer than in winter, resulting in more extreme heat days. Strong consensus exists in the literature that projected temperatures in the study region show a sharp increasing trend through the next century.

Temperatures in Pennsylvania have risen almost 2 degrees Fahrenheit since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century (Runkle et al., 2022). For densely populated urban areas, such as Philadelphia where Eastwick is located, extreme heat is a particular concern, as high temperatures and high humidity can cause dangerous heat index values. Extreme heat is a particular concern for Eastwick and other urban areas, where the urban heat island effect raises summer temperatures. This warming has occurred mostly in the winter and spring months, while summer and fall months have not warmed as much. Since record keeping began in 1895, the highest annual average temperature for the state was 51.8 degrees Fahrenheit, set in 1998 and tied again in 2012. (Runkle et al., 2022). While heat waves are projected to become more intense, cold waves are projected to become less intense.

Brown et al. (2010) used a large period data set (1893 – 2005) to investigate for trends in climate extremes in the northeast. This study area for the Mid-Atlantic Region portion included New York and Pennsylvania. The early part of the record exhibits largely increasing, and statistically

significant, trends in the number of summer high heat days, while the latter part of the record exhibits primarily decreasing trends, or no trend at all, for this same metric. The number of cold spells, however, appears to largely be on the decline for this portion of the Mid-Atlantic Region, particularly for the most recent record. Differences between the first half and the second half of the 20th century are also apparent in the apparent in the work presented by Warrach et al. (2006). These authors quantified a statistically significant ($p < 0.05$) trend in average annual temperature for a station in southern New York over the entire 20th century (at a rate of 0.01 degrees Celsius [0.018 degrees Fahrenheit] per year). However, the rate of increase during the first half of the century was much higher than that during the latter half of the century.

Precipitation.

Precipitation parameters considered in analyzing trends include total annual precipitation, intensity, frequency, event duration and soil moisture. Reasonable consensus exists in the literature that total annual precipitation, as well as the intensity and frequency of extreme storm events, will increase in the future for the Mid-Atlantic Region. Significant uncertainty exists, however, with respect to the extent of these increases.

An upward trend in precipitation over the past century in the study region, in terms of both annual totals and occurrence and magnitude of storm events, has been identified by multiple authors with a high level of consensus. The study by Najjar et al. (2009) quantified an ensemble mean increase in annual precipitation for three major Mid-Atlantic watersheds: the Chesapeake Bay, the Delaware Bay, and the Hudson River Estuary. Mid and end of century projections show an average 2 – 5% increase in annual precipitation for the study region, compared to historical baseline (1971 – 2000). However, the uncertainty in these projections is reflected in the relatively high standard deviations (3 – 12%) associated with these values. In line with projections for the rest of the country, projections of future changes in precipitation in the Mid-Atlantic Region are variable and generally lacking in consensus among studies or across models.

Pennsylvania has experienced a large increase in extreme precipitation events. Future increases in winter and spring precipitation expand the risk of springtime flooding along rivers and streams. (Runkle et al., 2022). Pennsylvania experiences abundant precipitation. Statewide annual precipitation has ranged from a low of 28.9 inches in 1930 to a high of 64.0 inches in 2018. In Pennsylvania, the number of extreme precipitation events has increased. These heavy rains can cause devastating flooding, and particularly damaging floods when they combine with spring snowmelt.

The study by the Philadelphia Water Department (Maimone, et al., 2019) developed a practical approach to creating a future hourly time series using delta change factors that are based on season and storm size for a GCM ensemble average of daily precipitation output from 1995–2015 and 2080–2100. This study estimated approximate 10% increase to 24 hour duration 100-yr ARI average precipitation intensity.

Streamflow.

The USACE 2015 report cited four studies that examined trends and nonstationarity in streamflow data over the past century. None of the studies found significant trends, in either direction, in streamflow for gages in the Mid-Atlantic region. No significant trends in historical streamflow, in either direction, have

been identified in the literature for the Mid-Atlantic Region. This is also supported by recent analyses by the Delaware Basin River Commission (DRBC, 2019) .

The period of record analyzed in these studies varied but most data fell within the period of 1950-2015, with one study using data starting in 1934. While additional uncertainty is introduced by the use of hydrologic models, there is moderate consensus that flows, particularly peak flows, will increase in the region through the 21st century as a result of increased precipitation. Low flows, however, are generally projected to decrease in the future. For snowpack dominated watersheds in the region, studies predict decreased snowpack and earlier snowmelt.

Summary.

Within the literature reviewed, the results indicate mild upward trending in both temperature and precipitation in the Mid-Atlantic Region (HUC 02) over the past 50 to 100 years as the region has gotten warmer and wetter. No such trends have been identified for streamflow, suggesting that the two climate trends may be offsetting. The 2015 USACE *Civil Works Technical Report CWTS-2015-13* provides a visual summary of the trends in observed and projected hydrometeorological variables as shown in Figure 1.

Strong consensus exists in the literature that projected temperatures in the study region show a sharp increasing trend through the next century. Reasonable consensus exists in the literature that total annual precipitation, as well as the intensity and frequency of extreme storm events, will increase in the future for the Mid-Atlantic Region. Significant uncertainty exists, however, with respect to the extent of these increases. While additional uncertainty is introduced by the use of hydrologic models, there is moderate consensus that flows, particularly peak flows, will increase in the region through the 21st century as a result of increased precipitation. Low flows, however, are generally projected to decrease in the future. For snowpack dominated watersheds in the region, studies predict decreased snowpack and earlier snowmelt (USACE 2015).

In addition to primary variables, peer-reviewed literature addressing climate change within the geographic region or inclusive of Water Resources Region 02 (fully or partially) revealed additional, secondary, climatic variables that have been studied such as the spring index (SI), drought indices, and soil moisture.

There is strong consensus in the literature that air temperatures will increase in the study region, and throughout the country, over the next century. The studies reviewed here generally agree on an increase in mean annual air temperature of approximately 2 to 5 degrees Celsius by the latter half of the 21st century for the Mid-Atlantic region. The largest increases are projected for the summer months. Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long-term future compared to the recent past.

Projections of precipitation and hydrology in the study region are less certain than those associated with air temperature. However, most of the studies reviewed here project increases in precipitation and streamflow through the 21st century. Extreme high events (storms and floods), in particular, are projected to increase in the future. Low flows, however, have been projected to decrease in the future because of the projected temperature (and ET) increases. The trends and literary consensus of observed and projected primary variables noted above are summarized for reference and comparison in Figure 1.

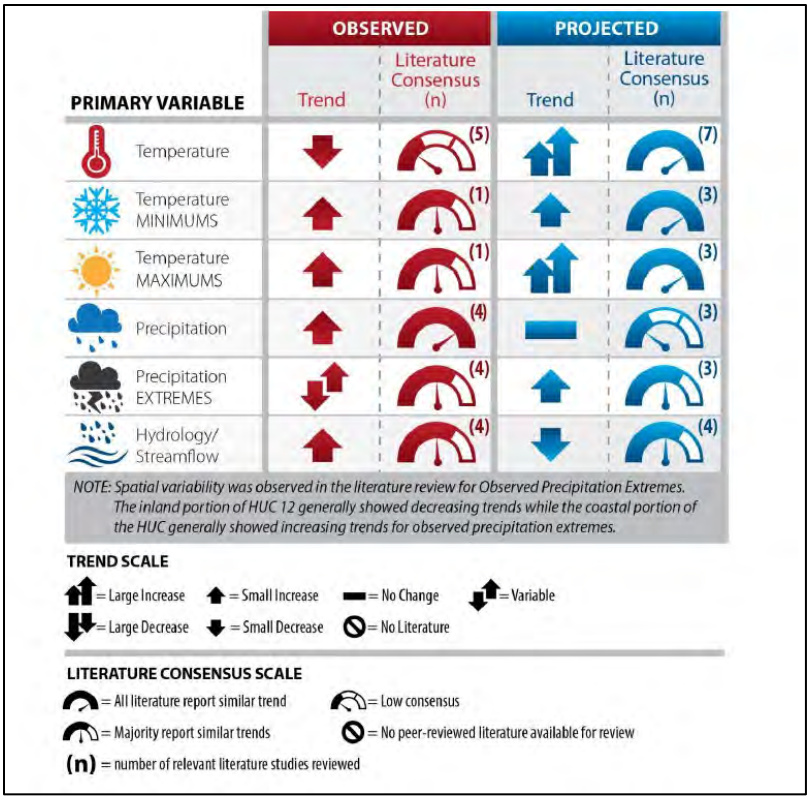


Figure 1. Summary matrix of observed and projected climate trends (USACE 2015)

Nonstationarity Detection

The assumption that discharge datasets are stationary (their statistical characteristics are unchanging) in time underlies traditional flow frequency analysis. Statistical tests can be used to test this assumption using techniques outlined in Engineering Technical Letter (ETL) 1100-2-3. The Nonstationarity Detection (NSD) tool is a web-based tool to perform these tests on datasets of annual peak streamflow at U.S. Geological Survey (USGS) stream gages. The primary objective of this study is to evaluate flood control operations, so the focus of this investigation is the high flow regime that is best represented by annual instantaneous peak flows.

The Nonstationarity Detection Tool (NDT), which was developed to support USACE Engineering Technical Letter (ETCL) 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges* (2017), was used to assess the stationarity assumption of Darby Creek and Cobbs Creek. The NDT enables the user to test the assumption of stationarity, the assumption that the statistical characteristics of hydrologic time series data are constant through time, is valid for a given hydrologic time series dataset. This assumption provides the basis for the use of statistical methods in water resources planning and design in which future conditions reply primarily on the observed record.

USGS Gage 01475548 Cobbs Creek at Mt. Moriah Cemetery

For this project, the NSD tool was applied using annual peak streamflow data from USGS gage 01475548, Cobbs Creek at Mt. Moriah Cemetery in Philadelphia, PA. The gage captures 19.9 square

miles of drainage area. This is the closest gage upstream of the project. Annual peak data has been collected since 2006. The NSD tool applies analysis to the period of record from 2006 to 2020.

As shown in Figure 2, no strong nonstationarities were detected in this record. Without consensus or robustness from other tests, there is insufficient evidence to reject the null hypothesis of statistical stationarity at this site. Additionally, no monotonic trends are detected in the peak streamflow dataset between 2006 and 2020 using the Mann-Kendall (p-value = 0.11>0.05) and Spearman Rank Order (p-value = 0.10>0.05) tests applied using a 0.05 level of significance.

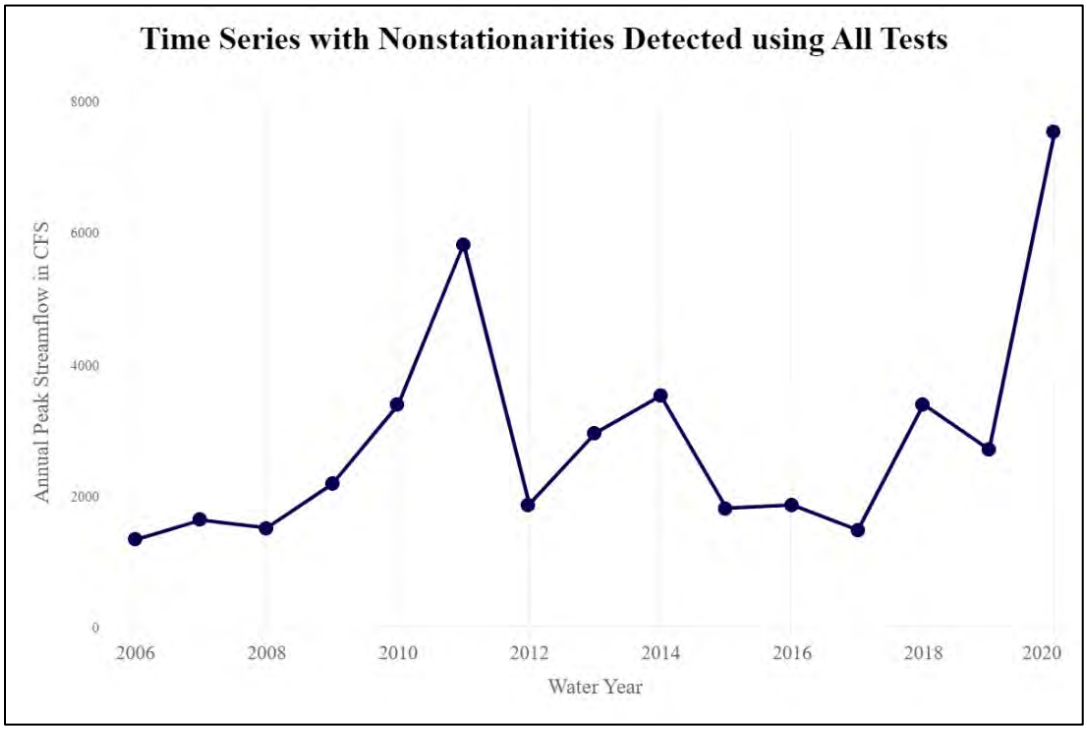
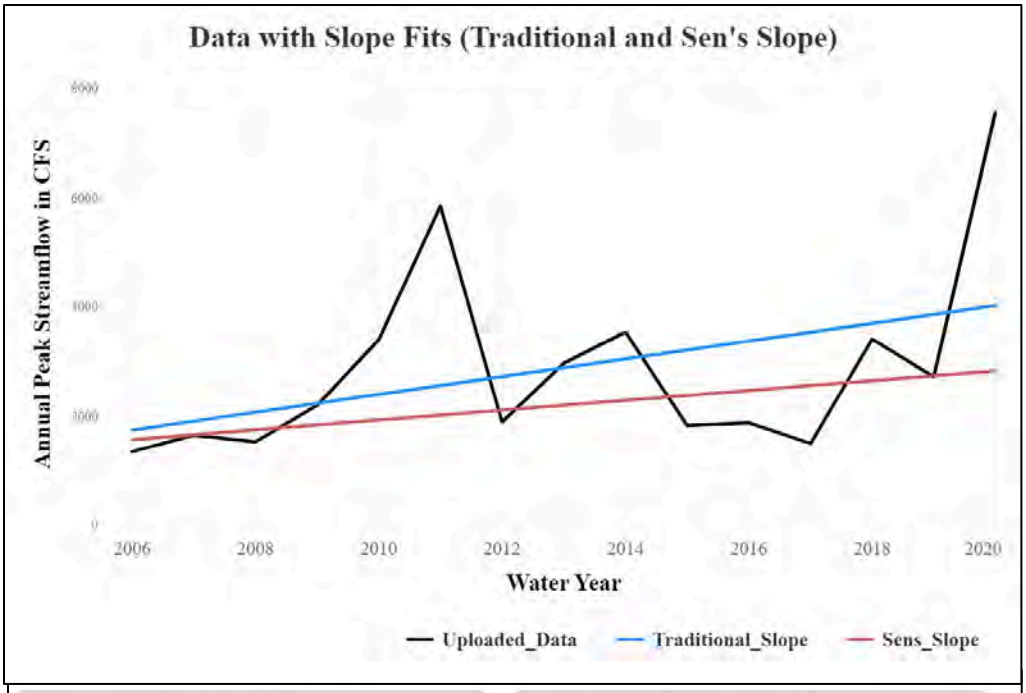


Figure 2. Output of the Nonstationarity Detection Tool for USGS Gage 01475548



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	163	-325067
Sen's Slope	Positive	90	-179020

Trend Hypothesis Test

Test	P-Value
t-Test	0.12316
Mann-Kendall	0.11329
Spearman Rank-Order	0.10449

- A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.

Figure 3. Output of the Nonstationarity Detection Tool for USGS Gage 01475548, Monotonic Trend Analysis

USGS Gage 01475530 Cobbs Creek at U.S. Highway No. 1 at Philadelphia, PA

For this project, the NSD tool was applied using annual peak streamflow data from USGS gage 01475530, Cobbs Creek at U.S. Highway No. 1, in Philadelphia, PA. The gage captures 4.78 square miles of drainage area. Annual peak data has been collected since 1985. The NSD tool applies analysis to the period of record from 1985 to 1981 and from 2005 to 2021. There is a period of record missing from 1982 to 2004. By analyzing a non-continuous period, the timing of the changepoints is affected by missing WY values, as indicated below in Figure 4.

As shown in Figure 4, no strong nonstationarities were detected in this record of USGS gage 01475530. Without consensus or robustness from other tests, there is insufficient evidence to reject the null hypothesis of statistical stationarity at this site. Additionally, no monotonic trends are detected in the peak streamflow dataset between 1985 to 1981 and from 2005 to 2021 using the Mann-Kendall (p-value = 0.13>0.05) and Spearman Rank Order (p-value = 0.15>0.05) tests applied using a 0.05 level of significance.

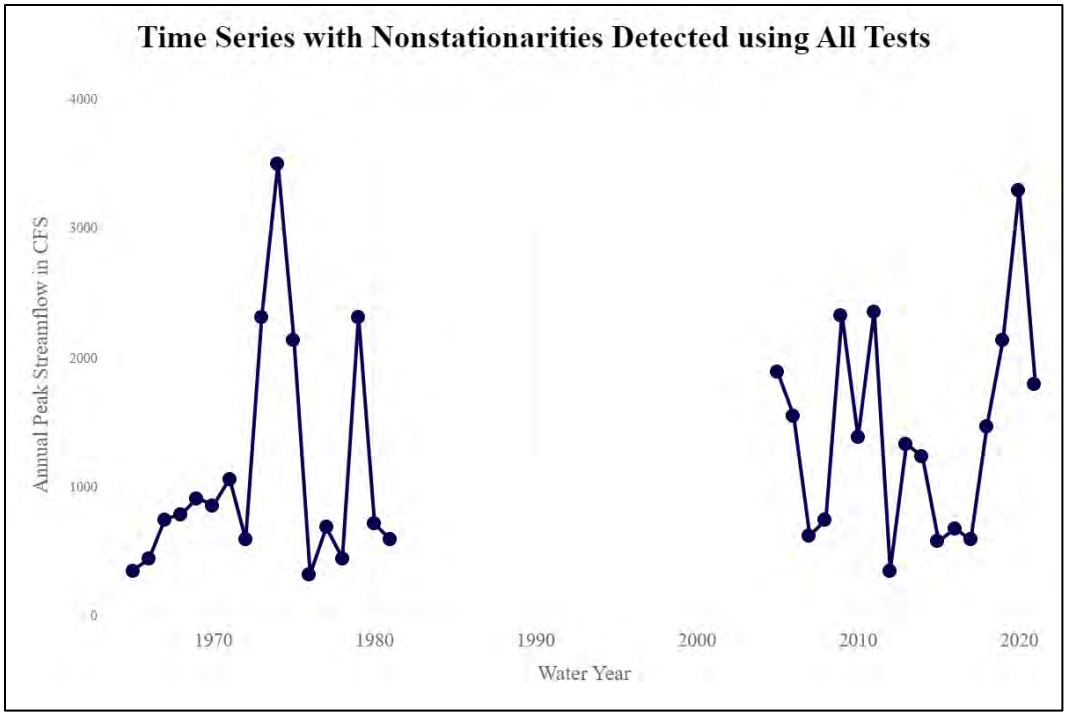
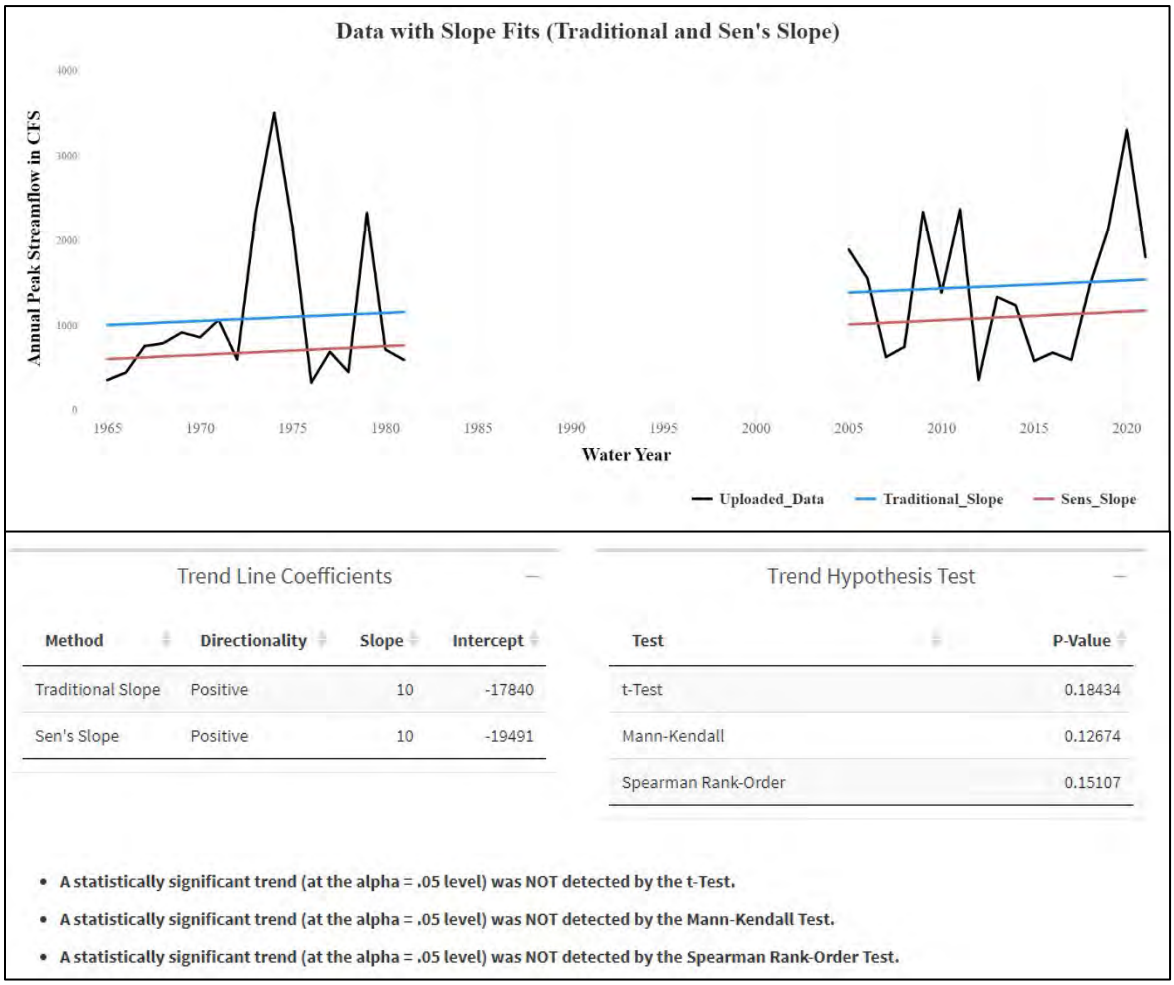


Figure 4. Output of the Nonstationarity Detection Tool for USGS Gage 01475530



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	10	-17840
Sen's Slope	Positive	10	-19491

Trend Hypothesis Test

Test	P-Value
t-Test	0.18434
Mann-Kendall	0.12674
Spearman Rank-Order	0.15107

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Figure 5. Output of the Nonstationarity Detection Tool for USGS Gage 01475530, Monotonic Trend Analysis

USGS Gage 01475510 Darby Creek near Darby, PA

For this project, the NSD tool was applied using annual peak streamflow data from USGS gage 01475510, Darby Creek near Darby, PA. The gage captures 37.4 square miles of drainage area. Annual peak data has been collected since 1964. The NSD tool applies analysis to the period of record from 1964 to 1990 and from 2019 to 2020. There is a period of record missing from 1991 to 2018. By analyzing a non-continuous period, the timing of the changepoints is affected by missing WY values, as indicated below in Figure 6.

As shown in Figure 6, no strong nonstationarities were detected in this record of USGS gage 01475510. Without consensus or robustness from other tests, there is insufficient evidence to reject the null hypothesis of statistical stationarity at this site. Additionally, no monotonic trends are detected in the peak streamflow dataset between 1964 to 1990 and from 2019 to 2020 using the Mann-Kendall (p-value = 0.43>0.05) and Spearman Rank Order (p-value = 0.52>0.05) tests applied using a 0.05 level of significance.

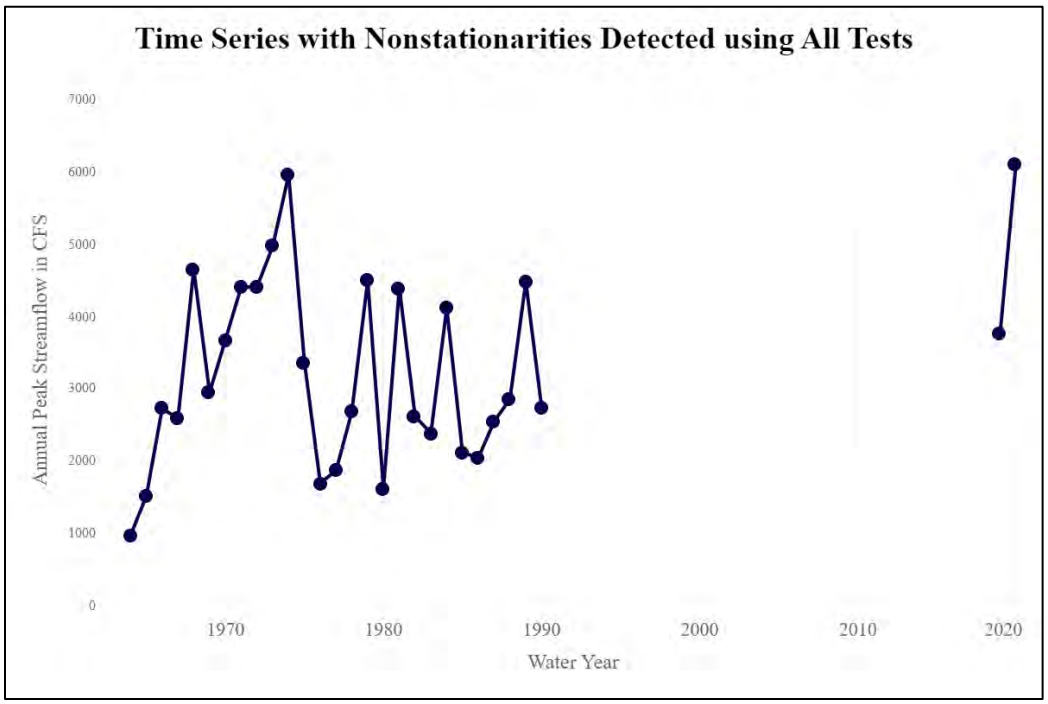
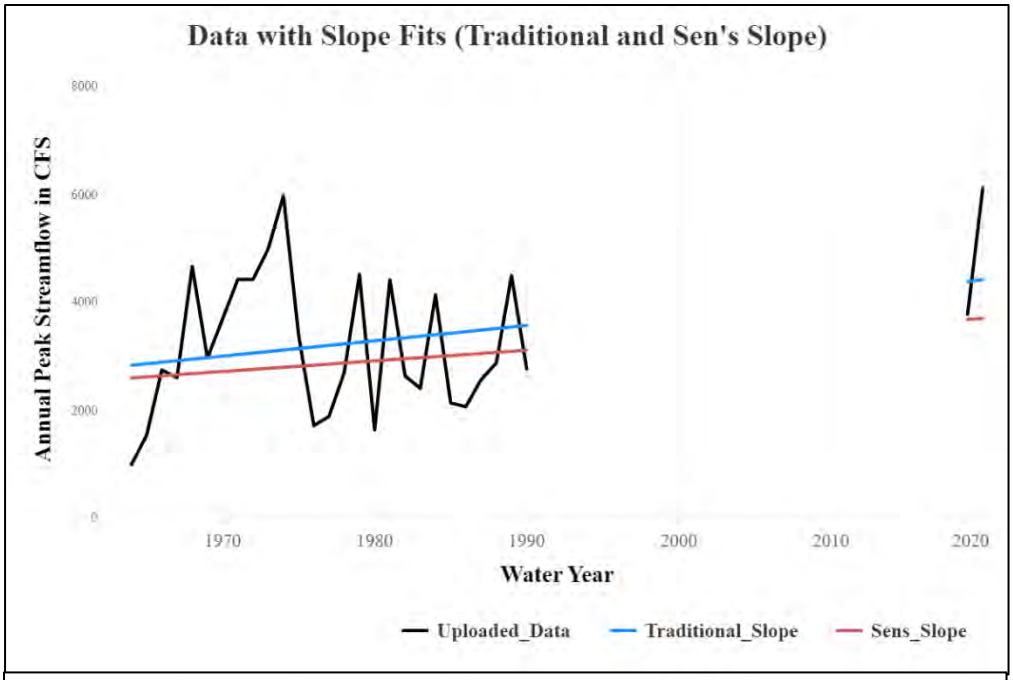


Figure 6. Output of the Nonstationarity Detection Tool for USGS Gage 01475510



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	28	-52914
Sen's Slope	Positive	20	-36180

Trend Hypothesis Test

Test	P-Value
t-Test	0.13474
Mann-Kendall	0.43071
Spearman Rank-Order	0.51859

- A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.

Figure 7. Output of the Nonstationarity Detection Tool for USGS Gage 01475510, Monotonic Trend Analysis

Climate Hydrology Assessment Tool

The USACE Climate Hydrology Assessment Tool (CHAT) can be used to assess projected, future changes to streamflow in the watershed. Projections are at the spatial scale of a HUC-4 watershed, with flows generated using a Variable Infiltration Capacity (VIC) model from temperature and precipitation data statistically downscaled from GCMs using the Bias Corrected, Spatially Disaggregated (BCSD) method. The VIC model is setup to simulate unregulated basin conditions. Cobbs and Darby Creeks in Eastwick, PA are in HUC 0204 (Delaware-Mid Atlantic Coastal Headwaters).

For Cobbs Creek, Figure 8 shows the range of output presented in the CHAT using 93 combinations of GCMs and representative concentration pathways (RCP) of greenhouse gas emissions applied to the generate climate-changed hydrology using the VIC model. The range of data is indicative of the uncertainty associated with projected, climate-changed hydrology.

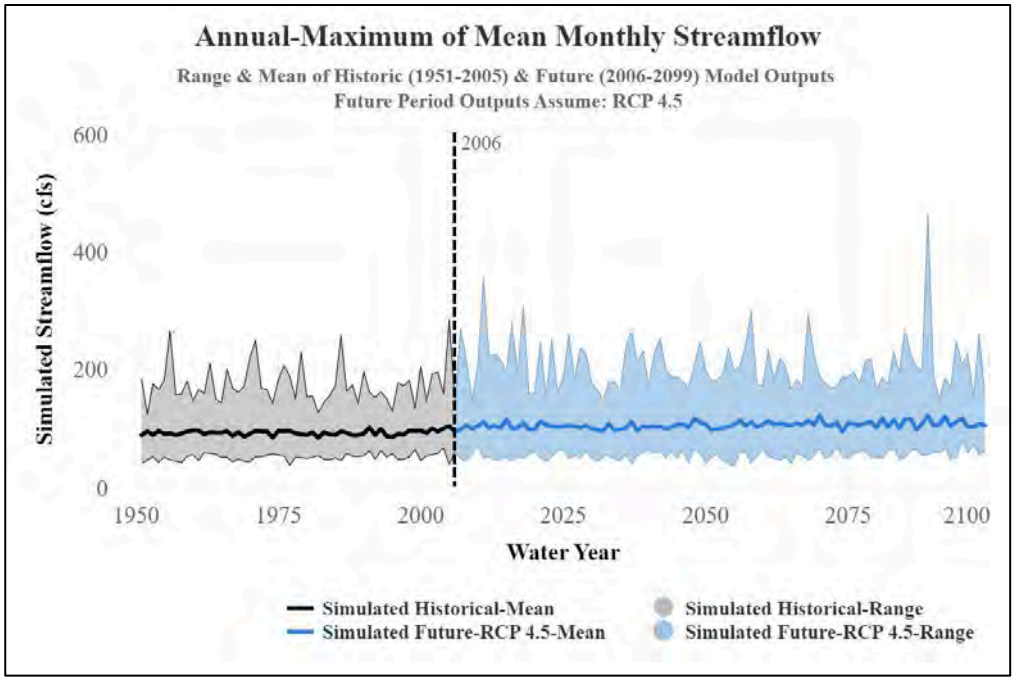


Figure 8. Range of 93 Climate-Changed Hydrology Model Output for Cobbs Creek stream segment of the Lower Delaware Watershed (HUC 0204)

For the Cobbs Creek stream segment of the Lower Delaware Watershed of the Delaware-Mid Atlantic Coastal Headwaters (HUC 0204), there is no statistically significant linear trend for the mean of projected annual maximum monthly streamflow between 2000 and 2099 (p-value = 0.09>0.05; dashed blue line shown in Figure 9). Therefore, neither the projected hydrology data nor the observed peak flow data investigated on the mainstem of the Lower Delaware Watershed at Cobbs Creek of Eastwick, PA have linear trends.

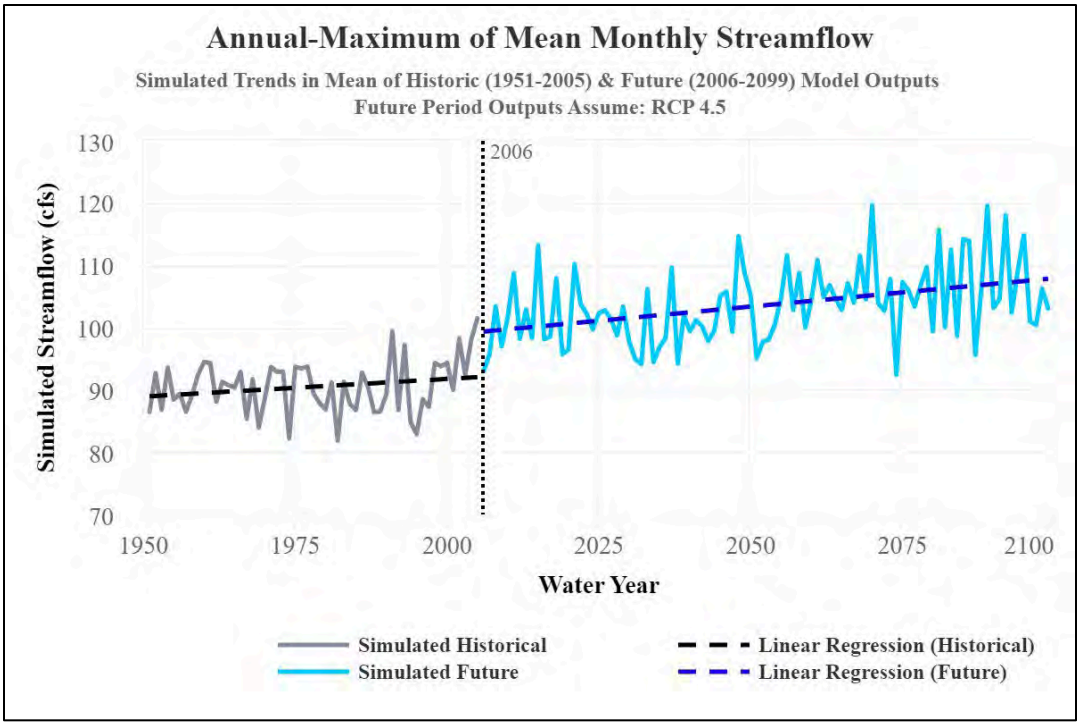


Figure 9. Projected mean annual maximum monthly flows for the Cobbs Creek stream segment of the Lower Delaware Watershed (HUC 0204)

For Darby Creek, Figure 10 shows the range of output presented in the CHAT using 93 combinations of GCMs and representative concentration pathways (RCP) of greenhouse gas emissions applied to the generate climate-changed hydrology using the VIC model. The range of data is indicative of the uncertainty associated with projected, climate-changed hydrology.

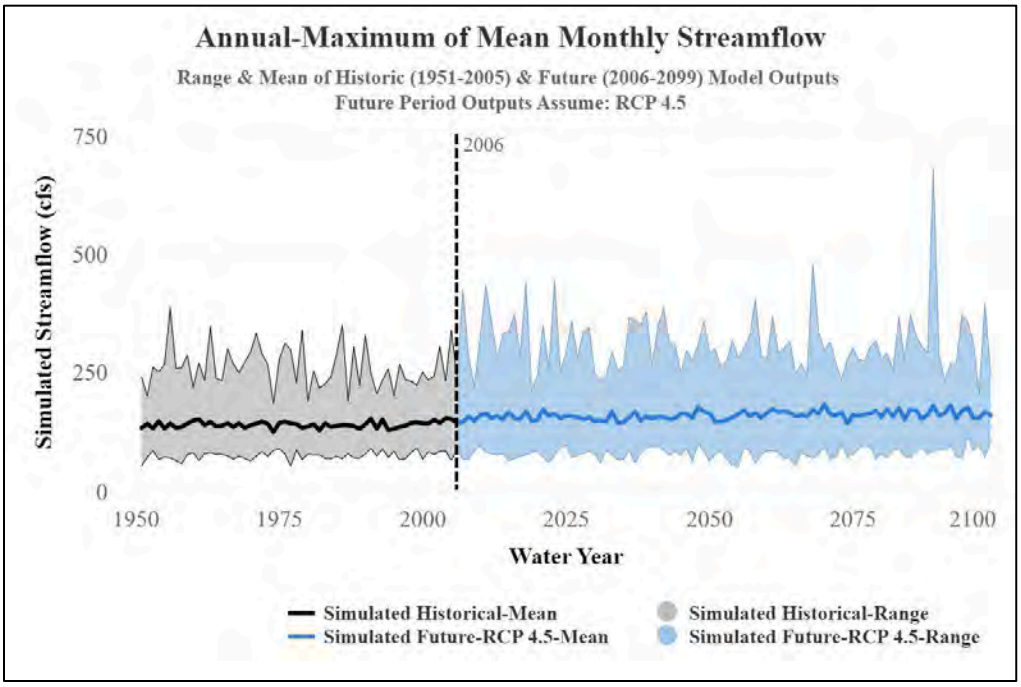


Figure 10. Range of 93 Climate-Changed Hydrology Model Output for Darby Creek stream segment of the Lower Delaware Watershed (HUC 0204)

For the Darby Creek stream segment of the Lower Delaware Watershed of the Delaware-Mid Atlantic Coastal Headwaters (HUC 0204), there is no statistically significant linear trend for the mean of projected annual maximum monthly streamflow between 2000 and 2099 (p-value = 0.07>0.05; dashed blue line shown in Figure 11). Therefore, neither the projected hydrology data nor the observed peak flow data investigated on the mainstem of the Lower Delaware Watershed at Darby Creek of Eastwick, PA have linear trends.

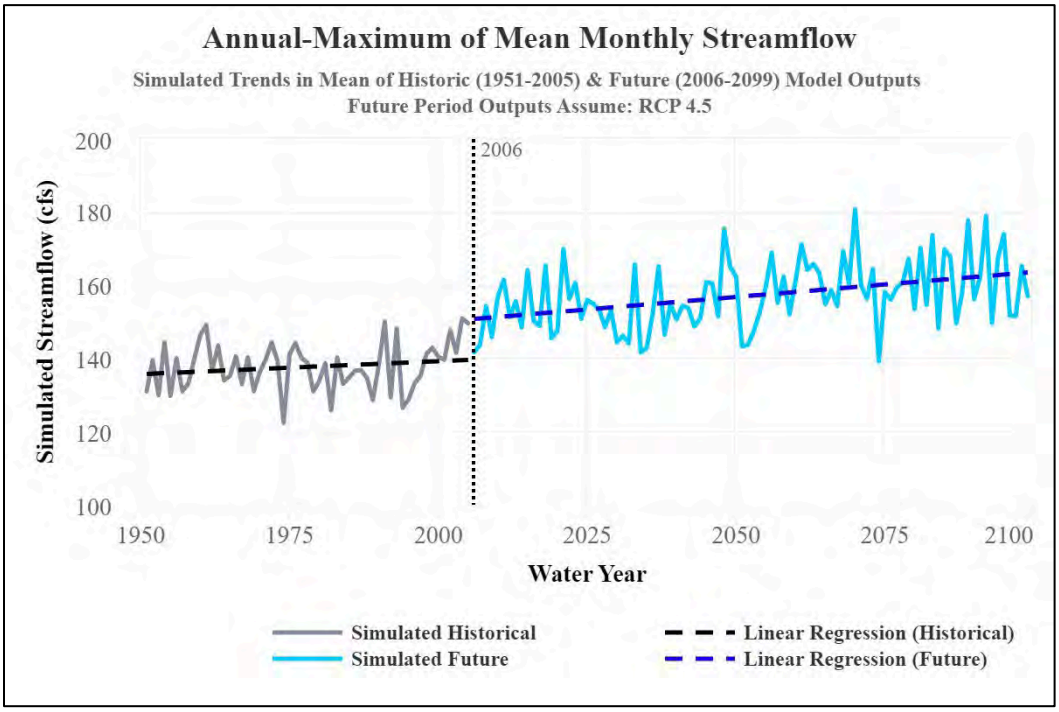


Figure 11. Projected mean annual maximum monthly flows for the Darby Creek stream segment of the Lower Delaware Watershed (HUC 0204)

Vulnerability Assessment

The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening-level, comparative assessment of the vulnerability of a given business line and HUC-4 watershed to the impacts of climate change, relative to the other HUC-4 watersheds within the continental United States (CONUS). It uses the Coupled Model Intercomparison Project (CMIP5) GCM-BCSD-VIC dataset (2014) to define projected hydrometeorological inputs, combined with other data types, to define a series of indicator variables to define a vulnerability score.

Vulnerabilities are represented by a weighted-order, weighted-average (WOWA) score generated for two subsets of simulations (wet—top 50% of cumulative runoff projections; and dry—bottom 50% cumulative runoff projections). Data are available for three epochs. The epochs include the current time period ("Base") and two 30-year, future epochs (centered on 2050 and 2085). The Base epoch is not based on projections and so it is not split into different scenarios. For this application, the tool was applied using its default, National Standards Settings. In the context of the VA Tool, there is some uncertainty in all of the inputs to the vulnerability assessments. Some of this uncertainty is already accounted for in that the tool presents separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result.

As shown in Figure 4, the Delaware River (HUC 0402) watershed is considered relatively vulnerable to climate change impacts for the flood risk reduction business line, being among the 20% most vulnerable watersheds for this business line in the CONUS (202 HUC04s). This is true for the dry scenarios and both the 2050 and 2085 epochs. Indicators used to compute the Flood Risk Reduction WOWA score include: the acres of urban area within the 500-year floodplain, the coefficient of variation in cumulative annual flow, runoff elasticity (ratio of streamflow runoff change to precipitation change), and two indicators of

flood magnification (indicator of how much high flows are projected to change over time), one of which includes contributions from upstream watersheds and the other focused only on the change in flood frequency within the watershed of interest. For the wet scenarios, the dominant indicator for the 2050 epoch is Urban Area, contributing 46% to the Delaware River watershed's vulnerability score. This indicator refers to the acres of urban area within the 500-year floodplain. For the 2085 epoch of the wet scenario, the dominant indicator is Flood Magnification, contributing 46% of the score. For the dry scenarios, the dominant indicator is Urban Area for both the 2050 and 2085 epochs, contributing 48% of the score for both.

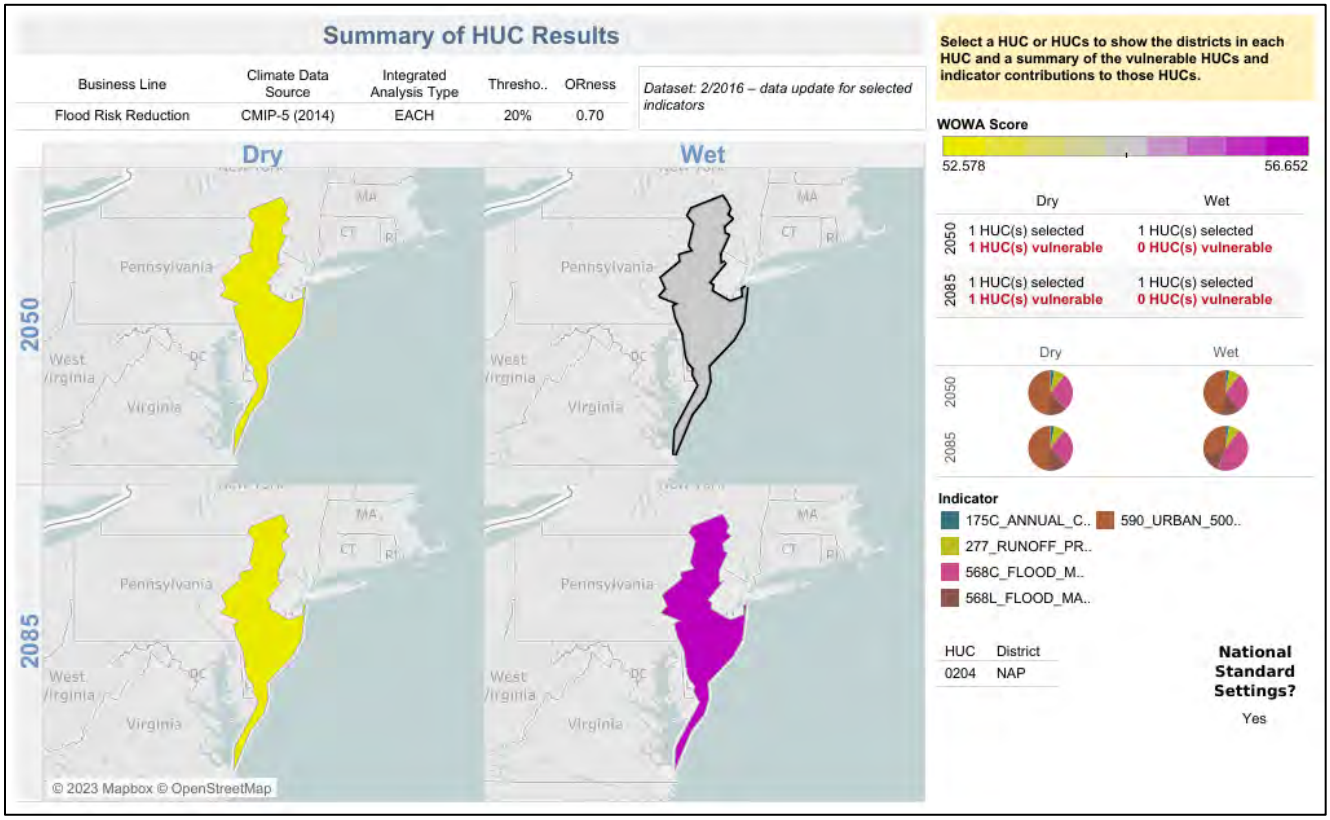


Figure 12. Output of the VA tool indicates that the Delaware River watershed is among the 20% most vulnerable CONUS watersheds for the Flood Risk Reduction business line

Conclusion

Recent climate science literature is equivocal on observed trends in mean and extreme temperatures in this region but provides reasonable consensus that projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves, can be expected in the long-term future compared to the recent past. Increases in precipitation have been both observed and projected for this region, though increased drought severity is also projected. As a result, projections of future streamflows are mixed and depend on the climate model and its assumptions. Observed trends in streamflow vary by season, but some evidence exists of increasing flows on average.

No strong nonstationarities or monotonic trends were detected at the closest gage upstream of the project for Cobbs Creek or for Darby Creek. Projections of runoff in the pre-2000 period show no significant trend, while projections post-2000 show a decreasing trend in the annual maximum monthly average runoff. This watershed is relatively vulnerable in the flood risk management business line

compared to other CONUS watersheds, primarily due to the high population residing in the 500-year floodplain.

As indicated in Table 1, climate change has the potential to result in increased hazard to any constructed FRM measures at Eastwick. However, the residual risk due to climate change to the project is classified as low in both cases. The risk to the a potential levee is low because the analysis presented here gives little evidence for increases in peak streamflows near term.

In the literature reviewed, a warmer and wetter climate is expected in the future. Air temperatures are expected to increase in the study region over the next century. . The studies reviewed here generally agree on an increase in mean annual air temperature of approximately 2 to 5 degrees Celsius by the latter half of the 21st century for the Mid-Atlantic region. The literature also predicts projected increases in extreme temperature events, such as more intense summer heat waves. Projections of precipitation and hydrology in the study region are less certain than those associated with air temperature. However, the majority of the studies reviewed here project increases in precipitation and streamflow through the 21st century. Extreme high events (storms and floods) are projected to increase in the future. Low flows, however, have been projected to decrease in the future because of the projected temperature (and ET) increases.

However, the literature did not contain much consistency on how the hydrology within the project area could change. Analysis of projected annual maximum monthly streamflow data produces results consistent with the literature review findings (i.e., no statistically significant trends). The USACE VA Tool indicates that Flood Risk Reduction in the Delaware River (HUC 0402) watershed is more vulnerable to the impacts of climate change relative to other watersheds in the CONUS. This vulnerability is based on increasing flood flows (i.e., the monthly flow exceeded 10% of the time) and not the peak flows that drive FRM measures.

Table 1. Residual Risk Due to Climate Change to Eastwick

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Levee	Higher river discharges	Flood frequency increase	More frequent overtopping of leveee	Low; no significant trend in observations or consensus among projections

Although the risks to this project are identified as low, potential adaptation actions for climate-affected hydrology still exist. Potential adaptation actions to address project vulnerabilities include increasing height and level of protection of the levee, utilizing a floodwall at the crest. To be effective, this concept would first be extensively analyzed, designed, and coordinated across the system and its stakeholders to ensure effective risk management at downstream and upstream induced flooding locations, ensuring the project would not introduce unintended negative consequences.

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CIVIL DOCUMENTATION
SUB-APPENDIX II

EASTWICK
CAP SECTION 205
FLOOD RISK MANAGEMENT STUDY
CITY OF PHILADELPHIA
PENNSYLVANIA

FEASIBILITY PHASE

PHILADELPHIA, PENNSYLVANIA

DRAFT - AUGUST 2023



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1 INTRODUCTION

1.1 BACKGROUND

Over the last several decades the neighborhood of Eastwick in Philadelphia, PA has experienced significant flooding events. This Civil Technical appendix describes structural and non-structural alternatives considered to develop a feasible Tentatively Selected Plan (TSP), to significantly reduce flood risk in Eastwick.

1.2 GENERAL SITE DESCRIPTION

The area available for the construction of structural alternatives is, Eastwick Park, located at the end of Saturn Pl. and S 78th St. Eastwick park is relatively flat with private residences to the east and southeast of the park, the capped Clearview Landfill to the southwest of the park, forested land and the Cibotti Park athletic fields to the northeast. The park is bounded to the west and northwest by the bank of Cobbs Creek. The park is mostly open green space with some larger trees near the creek bank. The park contains a nearly 1.5 acre constructed wetland near the base of the capped landfill. The site area is shown in Figure 1.2.1, Figure 1.2.2, and Figure 1.2.3. While the City of Philadelphia is the project sponsor, part of the area available for the construction of this project, primarily the Clearview Landfill, is in Darby Township in Delaware County.



Figure 1.2.1: Project Site



Figure 1.2.2: Aerial View From North



Figure 1.2.3: Aerial View From the South

1.3 LOWER DARBY CREEK AREA (LDCA) SUPERFUND SITE

1.3.1 EPA CLEANUP EFFORT

Approximately two-thirds of the project area are within either the footprint of the former Clearview Landfill, or within the limits of soil contamination from refuse. The Environmental Protection Agency (EPA) is in the process of a superfund cleanup of the landfill. The area of contamination within the park has been addressed by removing the refuse from the park and placing approximately three to four feet of clean fill and grading. This effort also involved the construction of a wetland and the planting of trees.

1.3.2 SITE IMPACTS

The presence of the landfill and cleanup effort have two primary impacts on the project. The first is that the levee footprint will likely overlap the constructed wetland and portions of this wetland would need to be remediated elsewhere. The second impact is that because there is contaminated soil below depths of 3-4 feet throughout most of the park, the selected alternative needs to utilize construction methods that minimize the total depth of excavation.

1.4 EXISTING UTILITIES

Currently, two known utilities pas through or into the park area from the neighborhood and/or the other side of Cobb Creek. The first are overhead electric transmission lines, with a single pole in the park, visible in Figure 1.2.2. The other utilities are the underground power supply lines for the various light poles throughout the park. Some of these light poles will likely be relocated or removed as part of any structural solution.

2 ALTERNATIVES

2.1 OVERVIEW

The Alternatives section of this technical appendix serves the primary purpose of explaining different structural and nonstructural alternatives that were considered as part of the Eastwick CAP 205 Study. These are the alternatives that did not become the tentatively selected plan (TSP).

2.2 NON-STRUCTURAL ALTERNATIVES

The first alternative considered is a non-structural approach. This would involve the dry or wet floodproofing of commercial and public structures, and the elevation of individual residences. Home raising was removed as a possible alternative early in the study process for two main reasons. The first is that the number of homes that would need to be raised would far exceed the number of home raisings that could be accomplished within the funding constraints of CAP 205. The second reason is that the predominant house type present in Eastwick, are townhomes that are connected to one another. Townhomes like this cannot be raised as individual homes as would normally be the case and instead would be raised as a whole block of homes. It was determined to be infeasible to raise homes in this manner without damaging them.

2.3 CONCRETE FLOODWALL

A concrete cantilever floodwall (T-wall) solution was considered That would follow a similar alignment to the Levee alternative running north to south across Eastwick Park. The line of protection extends from high ground at elevation 24.7 NAVD88 near Cibotti Park to the north and ties into the Clearview Landfill at the same elevation to the south. A section view of this floodwall is included below as Figure 2.3.1.

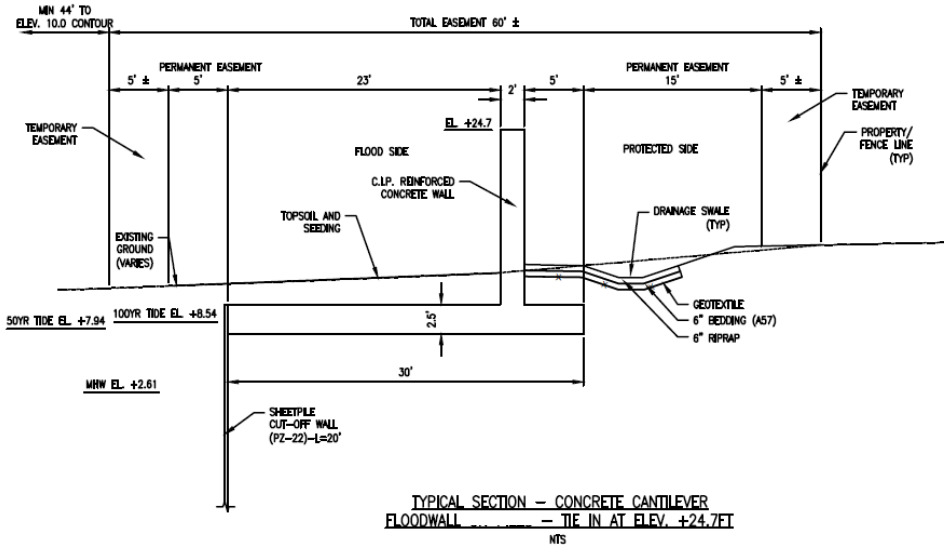


Figure 2.3.1: CONCRETE T-WALL TYPICAL SECTION

This alternative was removed from further consideration because the 2.5'-3.5' of excavation required to install the footings for the floodwall, would likely result in the exposure of contaminated soil in the park and refuse on the landfill.

3 TENTATIVELY SELECTED PLAN (TSP)

3.1 OVERVIEW

This section explains the general layout and characteristics of the TSP. The TSP consists of an earthen levee embankment with a sheet pile wall from the level crest to bedrock. The alignment of the levee passes through Eastwick Park connecting the high ground near Cibotti Park to the northeast of the park and the Clearview Landfill to the southwest. A levee with sheet pile seepage protection was the selected alternative because this is the solution that maximizes benefits to the community, while minimizing excavation. Minimizing excavation also minimizes the risk of exposing contaminated soil.

3.2 SECTION

The TSP levee typical sections are shown below as Figure 3.2.1, Figure 3.2.2, and as Exhibit D. The levee section has a crest width of 10 ft. and slopes of 3H:1V on the interior side and 2H:1V on the exterior. The exterior levee slope is armored with 18" of R-5 Riprap, underlain with geotextile fabric. The interior slope for most of the levee alignment is covered with topsoil and grass. In the designed overtopping section, the interior slope is also armored with 18" of R-5 Riprap. Throughout the entire length of the levee alignment there is a sheet-pile wall driven to bedrock that is aligned parallel to the levee along the centerline of the levee crest.

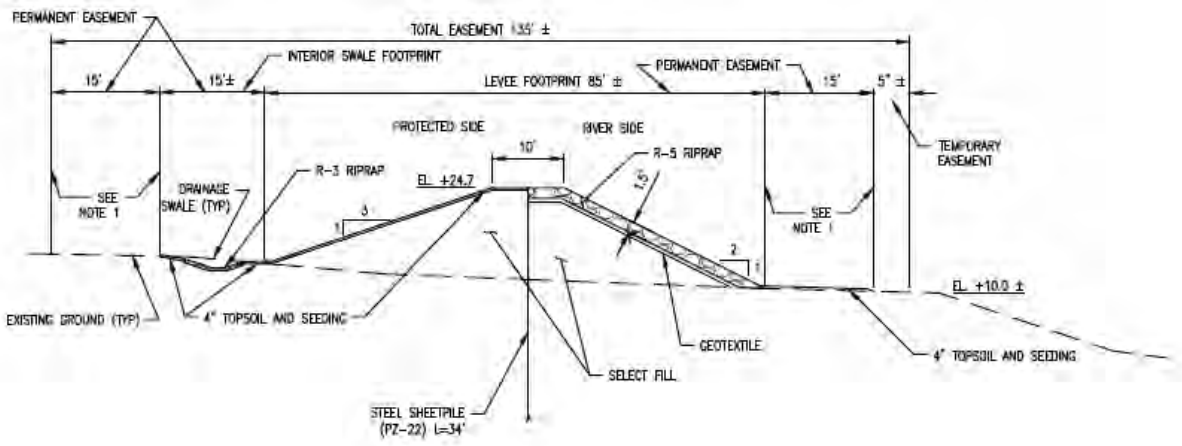


Figure 3.2.1: TSP LEVEE TYPICAL SECTION

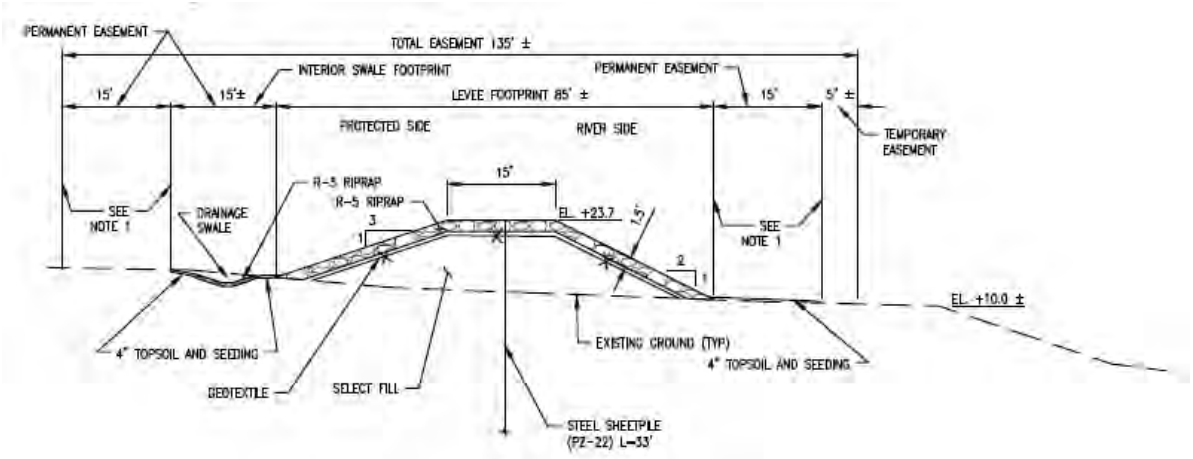


Figure 3.2.2: TSP TYPICAL CROSS SECTION DESIGNED OVERTOPPING AREA

The screening version of this section included riprap and 2H:1V slope on both sides of the levee. The levee slope used for the proposed TSP were selected for the following reasons. A 2H:1V slope, used on the flood side of the levee, is the steepest allowable slope for a levee embankment per the requirements of EM 1110-2-1913,, and results in the narrowest section, and the least amount of fill needed to construct the levee. Riprap is provided to reduce the risk to the levee embankment from burrowing animals, provide slope stability protection, and erosion protection from the flow of Cobbs Creek. 3H:1V is the steepest that can be mowed with conventional mowing equipment. Specialized equipment is available that can mow slopes as steep as 2.5H:1V, but equipment like that is expensive.

The slope on the inside of the levee was adjusted to 3:1 for two reasons: pedestrian access and ease of maintenance. Additionally, it is generally understood that a grass covered levee embankment is more aesthetically pleasing, for people to see from their homes or enjoy in the park. A shallower sloped levee has the potential to be a more well integrated part of the park landscape. For operation and maintenance purposes a 3:1 slope is advantageous as it may be possible for the same mowing equipment that is used to mow the park to be used to mow the levee.

As additional geotechnical analysis is performed, changes to the TSP levee section slopes, such as a more gradual slope on the creek side of the levee for enhanced stability, and additional erosion and slope stability measures are possible.

3.3 LAYOUT

Two feasible levee alignments were considered for this study, for the purpose establishing a boundary condition of where a feasible levee can be constructed. In other words, as the project moves into PED the area bounded by the two alignments represents the likely location of the levee that would be constructed.

The TSP alignment, shown in Figure 3.3.1 in section 3.3, represents a sinuous alignment replicating the curvature of the river. This levee is the shortest in length which has the benefit of minimizing the amount of sheet pile for construction. The TSP alignment. also leaves the largest amount of remaining space inside the levee for ponding of interior drainage. The TSP alignment has the greatest impacts on the constructed wetland.

The alternate alignment, shown on Exhibits A and C, takes a straighter route with one fewer curve and ties into the Clearview Landfill southeast of the TSP alignment location. This alignment is approximately 150’ longer in length, but because this alignment is farther from the creek where the existing ground elevation is higher, the levee height is shorter resulting in less fill required for construction than the TSP alignment. The alternative levee footprint minimizes impacts on the constructed wetland.

The TSP alignment was selected in part because it allows for the greatest amount of interior ponding. Additionally, this alignment was selected because the levee passing through constructed wetland versus nearly missing it, results in a more conservative cost estimate when it comes to environmental mitigation requirements. As interior drainage analysis is advanced, if the amount of interior ponding area required is relatively small, the alignment will likely be closer to the Alternative alignment, reducing the environmental impacts of the levee.



Figure 3.3.1: TSP Levee Alignment

3.4 INTERIOR DRAINAGE

As stated earlier the interior drainage analysis for this project is not far enough along to state what kind of features will be necessary beyond the minimum interior drainage elements included in the TSP plan at this time. The minimum interior drainage facilities consist of a swale running along the inside toe of the levee to collect and carry interior rainfall to three culverts through the levee. These culverts are roughly evenly spaced along the alignment at natural low spots in the park. The culverts are currently 24” Reinforced Concrete Pipe (RCP) with flared headwalls at both ends. The downstream ends will feature a backflow prevention system, such as a flap gate, or a duckbill. As interior drainage analysis progresses additional information including the size of needed interior ponding areas, and whether a pump station is necessary will be added. The existing street drainage system flows away from the project area in the park.

3.5 INTEGRATION INTO EASTWICK PARK

There are some additional ancillary features of the TSP levee that will enhance its integration into a park environment. One of these features is a crossover. In some form, whether through a ramp integrated into the levee embankment through overbuild that runs parallel to the levee, or a wooden structure that runs perpendicular to the levee, a crossover to allow access for the public and the maintenance of the levee will be necessary. The crossover would serve the purpose of allowing the park area on the outside of the levee to be accessible, thus allowing it to remain functionally a park. This feature has not yet been designed as part of this study.

3.6 REAL ESTATE CONSIDERATIONS

At this stage in the study a 15’ not-vegetated permanent easement from both the outside toe, and inside top of slope of the interior swale of the levee is needed for inspection and maintenance. An additional 5’ of temporary easement for construction is needed on both sides of the levee. This is best illustrated in the levee typical sections in Figure 3.2.1 in section 3.2.

4 DESIGN GUIDANCE

Below is a list of United States Army Corps of Engineering Design Guidance referenced in the development of the Eastwick CAP 205 Tentatively Selected Plan (TSP):

1.USACE. Engineer Manual (EM) 1110-2-1913 Design and Construction of Levees

2. USACE. Engineer Manual (EM) 1110-2-2902 Conduits, Pipes, and Culverts associated with dams and levee systems

3. USACE. Engineer Manual (EM) 1110-2-2100 Stability Analysis of Concrete Structures

4. USACE. Engineer Manual (EM) 1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures.

5. USACE. Engineer Manual (EM) 1110-2-2504 Design of Sheet Pile Walls.

8. USACE. Engineer Regulation (ER) 1100-2-8162 Incorporating Sea Level Change in Civil Works Programs.

9. USACE. Engineer Engineering Technical Letter (ETL) 1110-2-58 Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, And Appurtenant Structures.

10. USACE. Engineer Engineering Technical Letter (ETL) 1110-2-2105 Design of Hydraulic Steel Structures.

11. USACE. Executive Order (EO) 11988 Flood Risk Management.

5 EXHIBITS

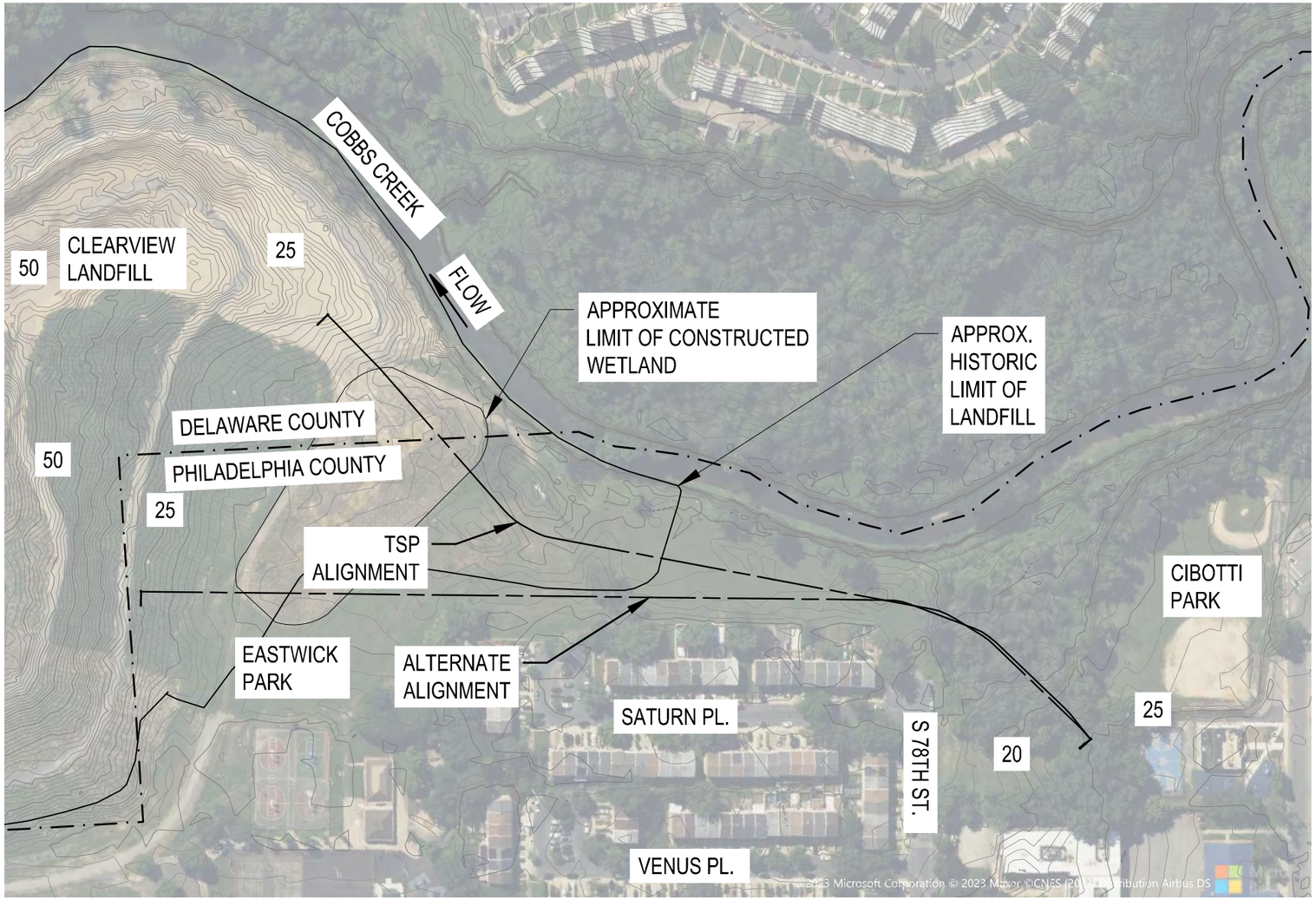
A. DRAWING – TSP LEVEE ALIGNMENT

B. DRAWING – TSP LEVEE FOOTPRINT

C. DRAWING – ALTERNATIVE LEVEE ALIGNMENT

D. DRAWING – LEVEE TYPICAL SECTIONS

E. TABLES – LEVEE QUANTITIES



PLAN NORTH

1

GENERAL PLAN - LEVEE ALIGNMENTS

200’ 100’ 0 200’

SCALE IN FEET

NOTES:

1. 1-FT FPMS CONTOURS SHOWN, REFERENCED TO NAVD88
2. EXISTING GROUND SURFACE GENERATED FROM THESE CONTOURS

US Army Corps of Engineers
PHILADELPHIA DISTRICT

ISSUE/SUBMITTAL DATE:
JUNE 2023

DES BY: C. BOMBA
DWN BY: C. BOMBA
CKD BY: -
REVIEWED BY: -

U.S. ARMY CORPS OF ENGINEERS
PHILADELPHIA DISTRICT

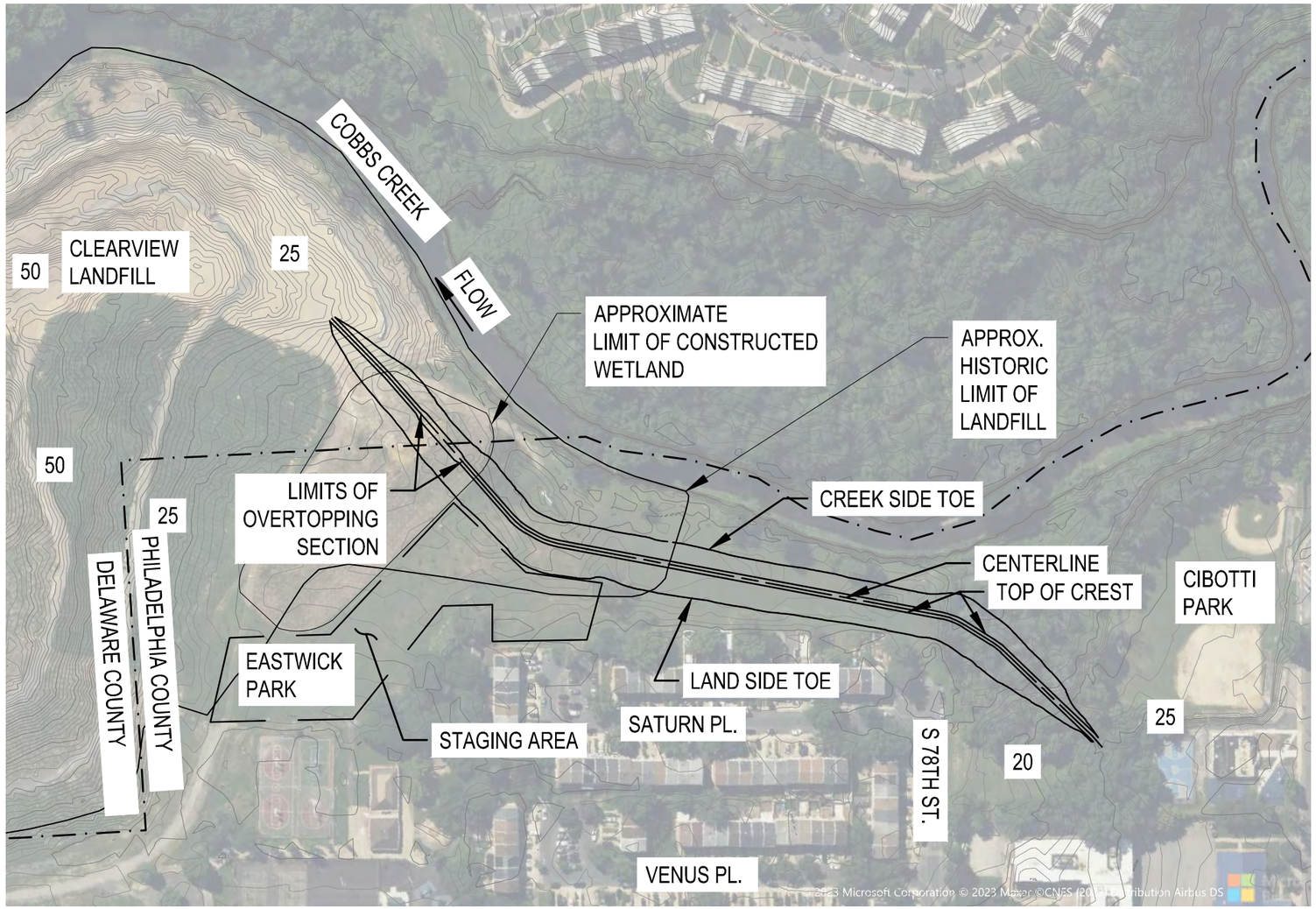
EASTWICK 451948 CAP 205
PLANNING STUDY

PHILADELPHIA, PENNSYLVANIA

GENERAL PLAN
LEVEE ALIGNMENTS

SHEET NUMBER

EXHIBIT A



PLAN NORTH

1

GENERAL PLAN - TSP LEVEE FOOTPRINT

200' 100' 0 200'

SCALE IN FEET

NOTES:

1. 1-FT FPMS CONTOURS SHOWN, REFERENCED TO NAVD88
2. EXISTING GROUND SURFACE GENERATED FROM THESE CONTOURS

US Army Corps of Engineers
PHILADELPHIA DISTRICT

ISSUE/SUBMITTAL DATE: JUNE 2023

DES BY: C. BOMBA
DWN BY: C. BOMBA
CKD BY: -
REVIEWED BY: -

U.S. ARMY CORPS OF ENGINEERS
PHILADELPHIA DISTRICT

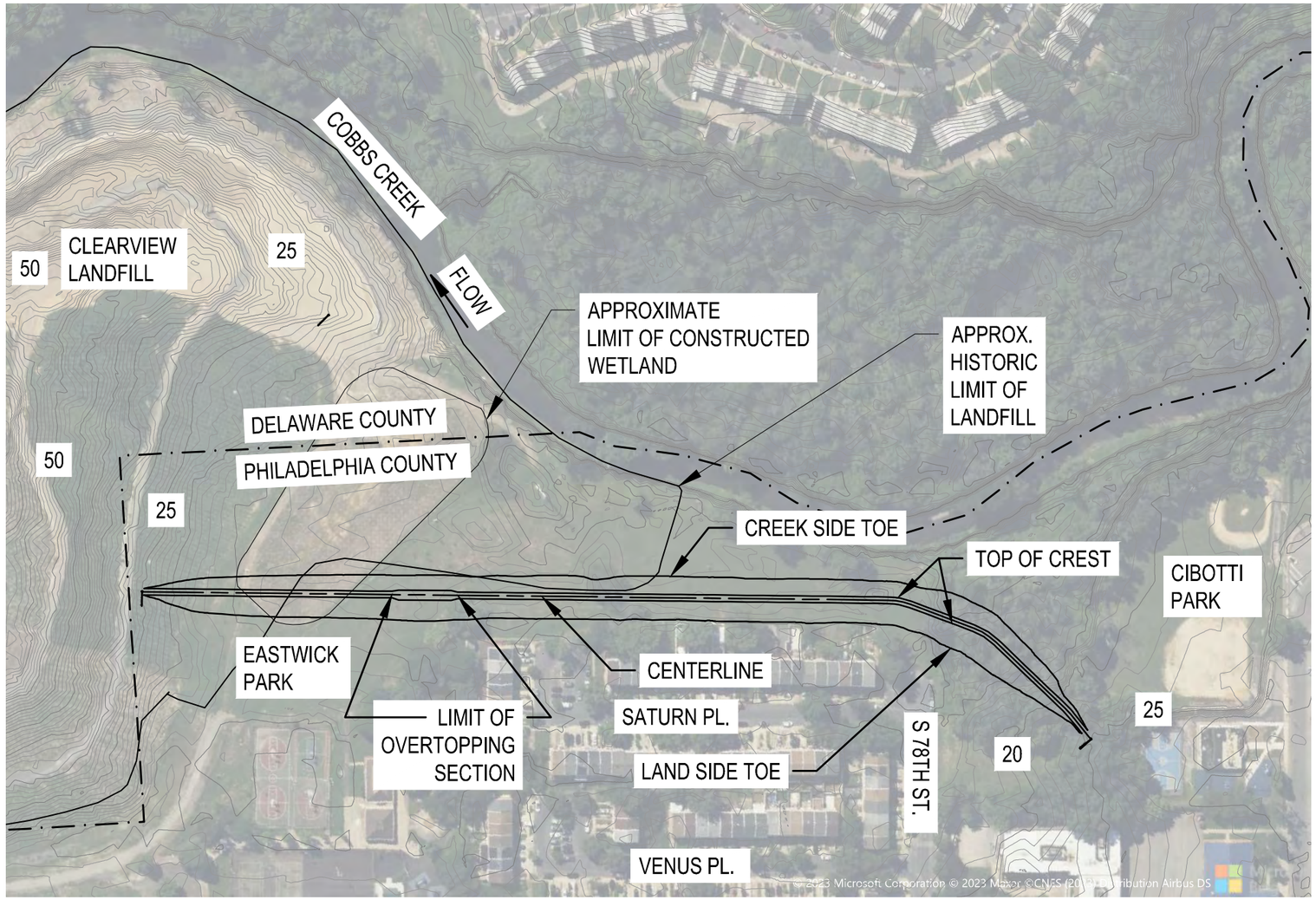
EASTWICK 451948 CAP 205
PLANNING STUDY

PHILADELPHIA, PENNSYLVANIA

GENERAL PLAN
TSP LEVEE FOOTPRINT

SHEET NUMBER

EXHIBIT B



PLAN NORTH

1

GENERAL PLAN - ALTERNATIVE LEVEE FOOTPRINT

200' 100' 0 200'

SCALE IN FEET

NOTES:

1. 1-FT FPMS CONTOURS SHOWN, REFERENCED TO NAVD88
2. EXISTING GROUND SURFACE GENERATED FROM THESE CONTOURS

US Army Corps of Engineers
PHILADELPHIA DISTRICT

ISSUE/SUBMITTAL DATE: JUNE 2023

DES BY: C. BOMBA
DWN BY: C. BOMBA
CKD BY: -
REVIEWED BY: -

U.S. ARMY CORPS OF ENGINEERS
PHILADELPHIA DISTRICT

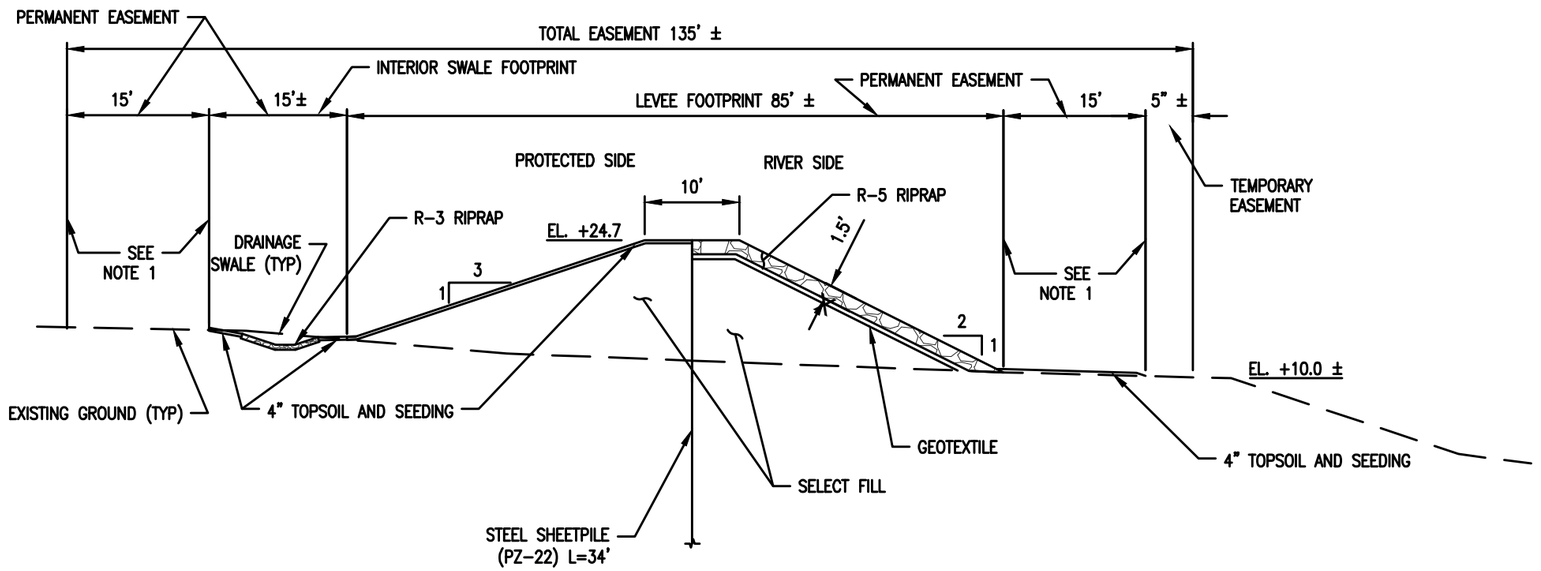
EASTWICK 451948 CAP 205
PLANNING STUDY

PHILADELPHIA, PENNSYLVANIA

GENERAL PLAN
ALTERNATIVE LEVEE FOOTPRINT

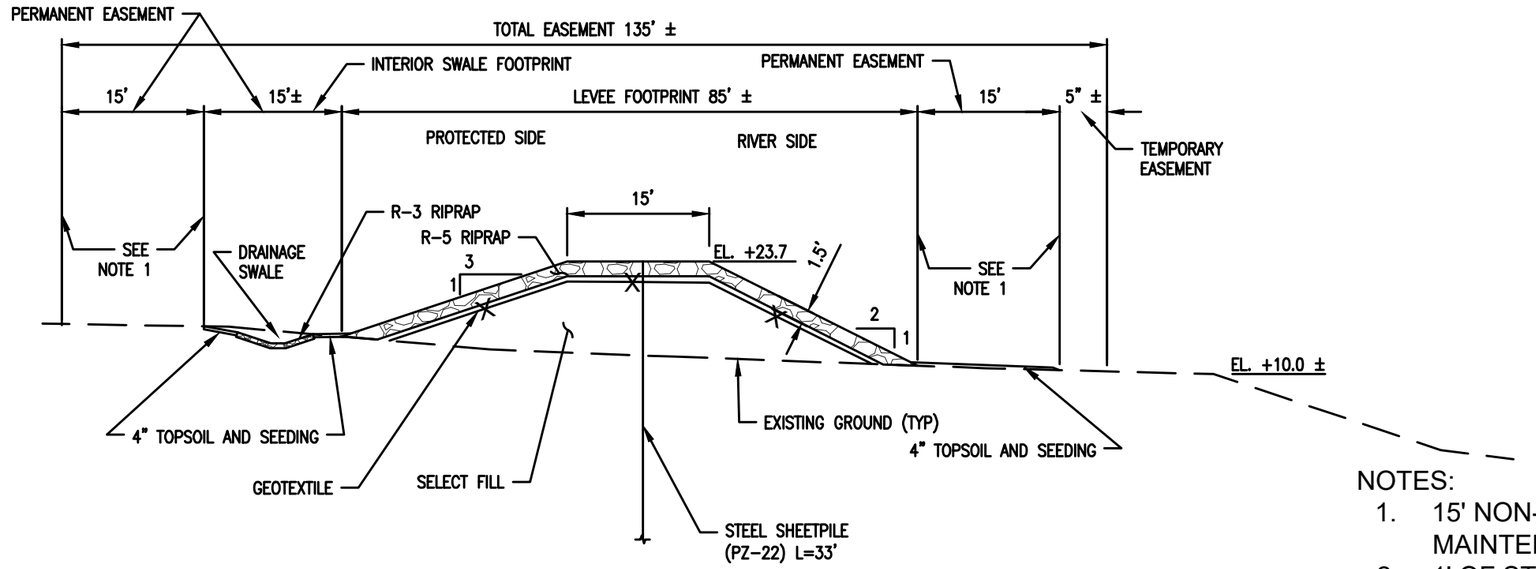
SHEET NUMBER

EXHIBIT C



1 TYPICAL SECTION - LEVEE

NTS



NOTES:

1. 15' NON-VEGETATED/ MAINTENANCE ZONE
2. 1' OF STRIPPING BELOW LEVEE FOOTPRINT NOT SHOWN FOR CLARITY

2 TYPICAL SECTION - LEVEE OVERTOPPING SECTION

NTS

US Army Corps of Engineers
PHILADELPHIA DISTRICT

ISSUE/SUBMITTAL DATE: JUNE 2023

DWN BY: C. BOMBA | DES BY: C. BOMBA | CKD BY: - | REVIEWED BY: -

U.S. ARMY CORPS OF ENGINEERS
PHILADELPHIA DISTRICT

EASTWICK 451948 CAP 205
PLANNING STUDY

PHILADELPHIA, PENNSYLVANIA

TYPICAL SECTION
LEVEE TYPICAL SECTIONS

SHEET NUMBER

EXHIBIT D

EXHIBIT E

LEVEE QUANTITIES

Prepared by: CTB
Date: 14-JUN-23

TSP Levee - 24.7'				
Item	**QTY**	**UNIT**	**QTY/LF**	**COMMENTS**
Sheetpile (PZ-22)	47148	SF	33.9	Calculated from Typical Sections
4" top soil and seeding	1136	CY	0.8	Calculated from Typical Sections
R5-RIPRAP	2602	CY	1.9	From CAD
R5-RIPRAP	3873	TN	2.8	Estimated from Volume
GEOTEXTILE Under R5-RIPRAP	46840	SF	33.7	From CAD
Select Fill	24668	CY	17.8	Calculated
R3-RIPRAP Ditch Lining	217	CY	0.2	Calculated from Typical Sections
R3-RIPRAP Ditch Lining	322	TN	0.2	Estimated from Volume
GEOTEXTILE Under R3-RIPRAP	11488	SF	8.3	Calculated from Typical Sections
Cut	5457	CY	3.9	Calculated from Typical Sections
24" Precast RCP Culvert Pile Supported	168.0	LF	N/A	2 Culverts
24" Precast RCP Culvert Cut and Cover	98.7	LF	N/A	1 Culvert
24" Concrete Headwall With Flap Gate	3	EA	N/A	
24" Concrete Headwall Without Flap Gate	3	EA	N/A	

Prepared by: CTB
Date: 14-JUN-23

ALTERNATIVE Levee - 24.7'				
Item	**QTY**	**UNIT**	**QTY/LF**	**COMMENTS**
Sheetpile (PZ-22)	51623	SF	33.9	Calculated from Typical Sections
4" top soil and seeding	1159	CY	0.8	Calculated from Typical Sections
R5-RIPRAP	2748	CY	1.8	From CAD
R5-RIPRAP	4091	TN	2.7	Estimated from Volume
GEOTEXTILE Under R5-RIPRAP	49470	SF	32.5	From CAD
Select Fill	23104	CY	15.2	Calculated
R3-RIPRAP Ditch Lining	237	CY	0.2	Calculated from Typical Sections
R3-RIPRAP Ditch Lining	353	TN	0.2	Estimated from Volume
GEOTEXTILE Under R3-RIPRAP	12576	SF	8.3	Calculated from Typical Sections
Cut	5674	CY	3.7	Calculated from Typical Sections
24" Precast RCP Culvert Pile Supported	168.0	LF	N/A	2 Culverts
24" Precast RCP Culvert Cut and Cover	98.7	LF	N/A	1 Culvert
24" Concrete Headwall With Flap Gate	3	EA	N/A	
24" Concrete Headwall Without Flap Gate	3	EA	N/A	

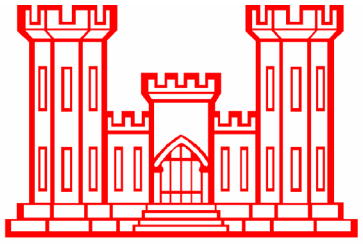
GGEOTECHNICAL DOCUMENTATION
SUB-APPENDIX III

EASTWICK
CAP SECTION 205
FLOOD RISK MANAGEMENT STUDY
CITY OF PHILADELPHIA
PENNSYLVANIA

FEASIBILITY PHASE

PHILADELPHIA, PENNSYLVANIA

DRAFT - AUGUST 2023



U.S. Army Corps of Engineers
Philadelphia District

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Introduction

The following presents a preliminary geotechnical evaluation performed to determine the feasibility of constructing various flood risk reduction features proposed for the Eastwick Flood Risk Management Project. The flood risk reduction proposed for this project includes a levee with a sheet pile cut off wall. The levee will have a 10-foot-wide crest, with a crest elevation of +24.7 feet NAVD88. The upstream side of the levee face will be at a 2.5-1 slope with riprap armoring, whereas the downstream face will be at a 3-1 slope without riprap armoring. The sheet pile will be driven through the center of the levee crest to bedrock. The project area is shown in Figure 1.



Figure 1 - Project Area

Local Geology

The Eastwick Section of Philadelphia is situated near the boundary between the Atlantic Coastal Plain Province and the Piedmont Province, according to the Geological Map of Pennsylvania, published by the Pennsylvania Geological Survey in 1989. The southeastern half of Eastwick is generally within the Atlantic Coastal Plain Province and the northwestern half is generally within the Piedmont Province. The Piedmont is characterized by strongly folded and faulted metamorphic rock and the residual soils derived from the in-situ decomposition of the parent bedrock. The mapping indicates that the surficial fill is underlain by the Trenton Gravel Formation at the project site; however, recent marsh deposits and alluvial sediments are also present in some areas above the Trenton Gravel. The Trenton Gravel consists of gray to pale-reddish-brown, very gravelly sand and interbedded cross-bedded sand and clay/silt layers. The Trenton Gravel is underlain by the residual soils and rock of the Wissahickon Formation. The residual soils of this formation typically consist of micaceous sand and silt, with subordinate percentages of clay. Differential weathering in the Wissahickon is common, and as a result, the rock surface is characterized by irregular profiles. The Wissahickon typically weathers into saprolite of variable thickness, underlain by weathered and then relatively sound bedrock. The most prevalent rock type of the Wissahickon Formation is oligoclase mica schist.



Figure 2 - Pennsylvania Geological Survey Map

Geotechnical Exploration

A geotechnical investigation was not performed explicitly in support of this feasibility study. However, previous geotechnical subsurface explorations were performed in this area and used as a

basis for choosing design properties. These explorations are summarized in the following sections.

Historical Subsurface Investigations

USACE Subsurface Exploration

The USACE-NAP retained Duffield Associates to perform Standard Penetration Test (SPT) borings along the Philadelphia side of the Darby Creek and Cobbs Creek between South 78th Street and South 84th Street, in the Eastwick Neighborhood, Philadelphia, Pennsylvania.

Three SPT borings to collect disturbed "split-spoon" samples (ASTM D 1586) and undisturbed "Shelby Tube" samples (ASTM D 1587) were performed by CGC Geoservices LLC, as a subcontractor to Duffield Associates, utilizing an ATV-mounted Deitrich D-50 drill rig. The test borings were performed between August 26 and 29, 2013.

Beneath surficial fill deposits, Duffield Associates' field program, geologic map review, review of topographic data, and experience from past studies in Philadelphia County, Pennsylvania, supports that the shallow geologic framework beneath the area being considered for flood risk management can be characterized by the following materials, in order of increasing age and/or depth below ground surface:

- Holocene Marsh/Estuarine Deposits;
- Quaternary Alluvium;
- Quaternary Trenton Gravel; and
- Weathered Bedrock.

These four map units have been discussed below.

1. **Holocene Marsh/Estuarine Deposits.** Beneath fill materials and within an elevation range of a few feet above to several feet below present day sea-level (referenced to the North American Vertical Datum of 1988), exist apparent estuarine/marsh deposits that are consistent with published descriptions of alluvial silts and clays, deposited by the Holocene marine incursion into the ancestral Delaware River Estuary and its tributaries. These deposits can be described as grayish brown to greenish gray silts and clays with a trace of fine quartz sand. Commonly, these deposits were finely-laminated as a result of tidal influence, bioturbated, and contained trace to little organic material (e.g., leaf mats). Lithologic variability included lenses of fine gray micaceous sand and peat layers, representing apparent changes in the depositional environment and water depth (e.g., fringing marsh to intertidal).

2. **Quaternary Alluvium.** Beneath modern marsh and estuarine environments, geologic mapping data available from the Pennsylvania Geological Survey (PGS) indicates that stream alluvium deposits may be present. These sediments were laid down by ancient streams/rivers that once occupied lower topography proximal to and under the modern

Delaware estuary, prior to the latest incursion of sea-level (generally prior to the last 20,000 years). Mapping data describes this alluvium as predominantly quartz sand and silt, with common intercalated deposits and lenses of gravel, peat, and less commonly silt/clay. The alluvium observed was heterogeneous and varied from coarse gravel/rock fragments to coarse, poorly-sorted, angular/sub-angular quartz sand, and floodplain silts/clays with organic material. In general, the alluvium coarsened with depth nearer the lower contact with weathered basement rock.

3. **Quaternary Trenton Gravel.** According to the 1980 Bedrock Geologic Map of Pennsylvania, the Quaternary Trenton Gravel should be present near the Eastwick neighborhood in a pattern that fringes the Delaware River, representing the bulk of the Coastal Plain deposits that thin and "pinch out" up against the Piedmont Province in this area. In general, published maps place the Trenton Gravel below a maximum elevation of approximately 60 feet in the Philadelphia area, where it forms a terrace and is found to be at its thickest. Published information describes the Trenton Gravel as a gray to pale reddish brown, gravelly to very gravelly sand that has been identified to be interbedded with sand and clay/silt in places. Where mapped to be present, the apparent Trenton Gravel as reddish gray, gray to varicolored, poorly-sorted, micaceous fine to medium sand with little to some gravel, some to little clay/silt, and very gravelly lenses. Most of the gravel was noted to be comprised of some combination of regional Piedmont metamorphic and Valley and Ridge sedimentary rocks, including red sandstone/mudstone, quartzite, and schist.

4. **Weathered Bedrock.** The 1980 Bedrock Geologic Map of Pennsylvania indicates that the Wissahickon Formation is present in the vicinity of the Eastwick neighborhood. Further and Bosbyshell (2008) has mapped the Fairmount Member of the Wissahickon Formation to be present. In general, bedrock within this formation is metamorphic and composed of fine to coarse-grained, psammitic schist with a strong foliation. The weathered rock was observed to consist of variably-weathered mica schist with a strong foliation. Generally, top of weathered rock was encountered at elevations ranging from approximately -11 to -23 feet (NAVD 88), beneath alluvial deposits.

These borings can be found in Attachment.

USEPA Subsurface Exploration

Two geotechnical field investigations were conducted to identify the types and extents of soils and waste at and below the elevation of the EPA's proposed crib walls and mechanically stabilized earth (MSE) walls, intended to support the landfill cap, and to obtain the engineering properties of the soils for use in performing the engineering design for the retaining structures and their foundations, as described below:

- Field Investigation 1 (February 8 and 9, 2017): A Tetra Tech field engineer obtained multiple grab samples in gallon bags along the alignment for the crib walls and MSE walls.
- Field Investigation 2 (March 6 to 10, 2017): Twenty-five geotechnical borings were drilled to depths on the order of 25 feet along the alignment for the crib walls and MSE

walls. Samples were collected in split spoon samples, from the auger cuttings, and in relatively undisturbed Shelby tube samplers.

CRIB WALL LOCATIONS

Exploratory borings were drilled within the footprints of the log crib walls. The laboratory testing indicates the retained soil (soil behind the wall) profile will consist of silty sand to sandy silt, and sandy elastic silt with varying percentages of waste/debris. The foundation soils (soil below the base of the wall) generally consist of sandy silt to elastic silt. The borings generally indicate subsurface water elevations corresponding with the adjacent stream elevation.

MSE WALL LOCATIONS

Exploratory borings were drilled in the vicinity of the MSE walls. The laboratory testing on samples of soil obtained from the borings indicates silty sand with varying amounts of gravel. The percent of gravel indicated in the laboratory test results may have been restricted due to the size of the sampler used to obtain the samples. A hand excavated grab sample was obtained from the MSE wall vicinity and indicates a significantly higher percentage of gravel is present (37% vs 11 to 16% in the sampler samples). The exploratory boring logs also indicate portions of the subsurface consist of predominately municipal solid waste materials.

These borings can be found in Attachment 1.

Subsurface Conditions

Although the USEPA investigation subsurface conditions were considered, they were only used to determine the risk of encountering HTRW and compressible strata where the levee ties into the existing landfill. The soil conditions identified in the USACE exploration were used as the basis for evaluating the feasibility of a levee. The borings indicate that surficial soils, fill and recent river alluvium overlie glacial deposits that are underlain by bedrock. These deposits are broken down into four stratigraphic units as follows:

a) Historical Fill: fill material consisting of medium to very firm silt extending to elevations of approximately -1 foot NAVD 88.

b) Silty Clay, Clayey Silt: The historical fill soils were underlain by interlayered soft silts and clays extending to elevations of approximately -4 feet NAVD 88.

c) Sands and Gravels: Beneath the silty clay/clayey silt strata a mixture of loose to dense sands and gravels were encountered, depending on location, to elevations of approximately -7 feet NAVD 88.

d) Weathered Bedrock: The overburden soils are underlain by weathered bedrock white and greyish in color was encountered below elevation -7 feet NAVD 88.

Groundwater, likely perched, depths ranging from 7 to 10 feet below the ground surface,

corresponding to elevation +5 to +2 feet NAVD 88.

Geotechnical Analyses

For the geotechnical analyses, two soil profiles were developed based on the differing site conditions associated with borings BH – 1 and BH – 2. The following table summarizes the two profiles and their stratification:

Table 1 - Soil Profile for BH-1

Strata	Elevation (NAVD)	Minimum Uncorrected N-Value (blows/foot)	Maximum Uncorrected N-Value (blows/foot)
Historic FILL (Silty Sand)	>11.2	9	9
Silt	11.2 - 6.7	7	9
Silty Sand/Gravel	6.7 - -4.3	6	49
Weathered Bedrock	<-4.3	50+	50+

Table 2 - Soil Profile for BH-2

Strata	Elevation (NAVD)	Minimum Uncorrected N-Value (blows/foot)	Maximum Uncorrected N-Value (blows/foot)
Historic FILL (Silty Sand)	> -0.8	9	23
Silt	-0.8 - -4.3	2	2
Silty Sand/Gravel	-4.3 - -7.2	31	32
Weathered Bedrock	<-7.2	50+	50+

Seepage Analysis

Due to concerns over hazardous material within the landfill soils, the levee was designed to minimize excavation. As such, a design decision was made to forgo the standard compacted clay core with a key that is typically used in levees as a hydraulic barrier. Instead, a sheet pile will be driven through the center of the levee crest until it reaches weathered bedrock. This effectively cuts off any through or under seepage that will typically occur. Therefore, a seepage analysis was not performed.

However, in support of the rapid drawdown slope stability analysis, GeoStudio's SEEP/W was used. SEEP/W is a finite element program that can identify phreatic levels, exit gradients, and pore-water pressures in both steady state and transient cases. The following table summarizes the hydraulic conductivities input into the program.

Table 3 - Hydraulic Conductivity Constants

Geostudio Material Name	Subsurface Strata	Hydraulic Conductivity		Anisotropy	GeoStudio Color
		feet/sec	cm/sec	kv/kh	
Levee Fill Material	-	3.28 x 10-6	1 x 10-4	1	
Native Fill (SM undrained)	Historic FILL (Silty Sand)	3.28 x 10-5	1 x 10-3	1	
Native Fill (SM drained)	Historic FILL (Silty Sand)	3.28 x 10-5	1 x 10-3	1	
Silt (undrained)	Silt	3.28 x 10-8	1 x 10-6	1	
Silt (drained)	Silt	3.28 x 10-8	1 x 10-6	1	
Silty Sand/Gravel	Silty Sand/Gravel	3.28 x 10-5	1 x 10-3	1	
Weathered Siltstone	Weathered Bedrock	NFB*	NFB*	1	
Rip Rap	-	3.28 x 10-1	1 x 101	1	

*NFB – No Flow Boundary

Slope Stability

The following soil parameters were used for analyzing the slope stability:

Table 4 - Slope Stability Soil Parameters

Soil Area	Subsurface Strata	Unit Weight pcf	Cohesion Psf	Friction Angle degrees	GeoStudio Color
Levee Fill Material	-	125	0	34	
Native Fill (SM undrained)	Historic FILL (Silty Sand)	100	1000	0	
Native Fill (SM drained)	Historic FILL (Silty Sand)	100	0	28	
Silt (undrained)	Silt	110	250	0	
Silt (drained)	Silt	110	0	28	
Silty Sand/Gravel	Silty Sand/Gravel	115	0	32	
Weathered Siltstone	Weathered Bedrock	NA	NA	NA	
Rip Rap	-	120	0	38	

The circular failure surface was analyzed using GeoStudio SLOPE/W for three different cases; End-of-Construction, rapid drawdown, and steady-state conditions. SLOPE/W performs a two-dimensional limit equilibrium stability analysis. The analyses were run using Spencer's Method for this project. Pore pressure conditions for each SLOPE/W analysis were derived using the GeoStudio SEEP/W program. For the End-of-Construction case, the levee was assumed to not be hydraulically loaded and thus pore pressure only existed due to groundwater conditions. For the steady-state condition, it was assumed the levee would be loaded to its maximum height, for sufficient time such that fully saturated conditions are met. Consequently, the water elevation on the riverside for this analysis was also assumed to be top of levee height. For the rapid drawdown

case, a transient analysis was performed with a full water level drop instantaneously taking place, and analyses at 10 intervals over 1 day, with the intervals spaced exponentially.

The following table summarizes the factors of safety for the analyzed soil profiles, which correlate to borings one and two, respectively:

Table 5 -Factor of Safety Summary

Load Condition	Factor of safety	
	BH – 1	**BH – 2**
Case I – End- of-Construction (total stress)	1.9	2.1
Case II - Rapid Drawdown	1.5	1.6
Case III - Long-Term (effective stress)	2.1	2.1

Bearing Capacity and Settlement

Bearing capacity and settlement calculations were not performed for the proposed levee geometry as the encountered subsurface conditions are not anticipated to impact the feasibility of implementing the proposed project. However, should settlement be determined to cause significant impact to the levee's efficacy during the design phase, it's constructed height may be higher than the intended level of protection to compensate for any expected settlement.

Conclusions

The information provided in this report is for conceptual purposes only and details and assumptions provided are subject to change. Further evaluation/analysis and information (including, but not limited to, additional borings, field tests, laboratory tests, surveys) will be required in future phases in order to refine designs, layout and cost estimates.

Attachments:

Subsurface Investigations
GeoStudio Figures
GeoStudio Reports

Subsurface Investigation Reports

USACE Subsurface Exploration

DUFFIELD ASSOCIATES

PRELIMINARY GEOTECHNIAL SUBSURFACE EXPLORATION EASTWICK NEIGHBORHOOD PHILADELPHIA, PENNSYLVANIA

USACE Contract No. W912BU-11-D-0005
Task Order 0011

December 2013
(Revised January 2014)

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EXECUTIVE SUMMARY

The following report summarizes Duffield Associates, Inc.'s (Duffield Associates') evaluation of subsurface conditions along the proposed alignment for a conceptual flood risk reduction project along the Darby Creek and Cobbs Creek between South 78th Street and South 84th Street, in the Eastwick Neighborhood of Philadelphia, Pennsylvania. The results of the subsurface explorations are to be utilized by the U.S. Army Corps of Engineers (USACE) in the evaluation of flood risk reduction alternatives. These services were performed in general accordance with the Scope of Work for Contract No. W912BU-11-D-0005 and Task Order No. 0011, dated August 2, 2013.

As part of this evaluation, three Standard Penetration Test (SPT) borings were performed to collect disturbed "split-spoon" samples and undisturbed "Shelby Tube" samples spaced along the proposed project alignment, as identified by the USACE. Laboratory testing on selected samples included the performance of index testing, consolidation testing, and triaxial "Q" (unconsolidated - undrained, UU) and "R-bar" (consolidated - undrained, CU) compression strength testing.

Test boring locations were established by our representatives and USACE utilizing a handheld GPS and existing site features as a reference. "As-performed" surveying of the test boring locations (including Northings, Eastings, and elevations) were performed by Transition Engineering & Surveying.

The subsurface conditions observed at each of the proposed flood risk reduction sites were generally consistent in stratigraphy, but variable in thickness and textural consistency of the shallow deposits. Beneath surficial fill deposits (where present), Duffield Associates' field program, geologic map review, review of topographic data, and experience from past studies in the area supports that shallow subsurface deposits beneath the area being considered for a flood risk reduction project can be characterized by the following stratigraphic framework, in order of increasing age and depth below ground surface:

- Holocene Marsh and Estuarine Deposits;
- The Quaternary Alluvium;
- The Quaternary Trenton Gravel Formation; and
- Weathered Bedrock.

These four map units have been discussed herein. The Quaternary Alluvium stratum soils generally consisted of loose to medium dense sand soils. The underlying geologic formations were observed to consist primarily of coarse-grained dense soil.

This report includes a summary of the field and laboratory testing programs. Logs summarizing the conditions observed during performance of the SPT borings are also included. A Metadata file describing the geospatial data acquired as part of this Task Order has also been included.

I. INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Philadelphia District retained Duffield Associates (Duffield Associates) to perform Standard Penetration Test (SPT) borings along the Philadelphia side of the Darby Creek and Cobbs Creek between South 78th Street and South 84th Street, in the Eastwick Neighborhood of Philadelphia, Pennsylvania. It is understood that this data, along with the results of laboratory testing performed on selected samples, is to be utilized by USACE to evaluate potential design alternatives for flood risk reductions along the Delaware River. These services were performed in general accordance with the Scope of Work for USACE Contract No. W912BU-11-D-0005 and Task Order No. 0011, dated August 2, 2013.

The following report summarizes Duffield Associates' evaluation of subsurface conditions along the Darby Creek and Cobbs Creek. Two areas along the creeks have been identified by USACE as zones where flood waters in the creek have the potential to permit flooding of the adjacent Eastwick neighborhood. One area is to the north of the former Clearview Landfill along Cobbs Creek and one area is in the southern portion of the former Clearview Landfill along Darby Creek. The general site areas are indicated on the enclosed Location Sketch in Appendix A.

Prior to the start of this project, USACE provided Duffield Associates with a Scope of Work, including:

- Reference standards and scope for subsurface exploration, including SPT boring numbering, proposed locations, and depths;
- Reference standards and scope for geotechnical laboratory testing;
- Reference information for survey control of the test borings; and
- Metadata requirements.

In addition, representatives of Duffield Associates visited the site with representatives of USACE on June 12, 2013, to review the proposed test boring locations and existing site conditions.

This information was utilized as the basis for performance of the items required for this Task Order.

II. FIELD EXPLORATION PROGRAM

Prior to performing our field program, a site-specific Accident Prevention Plan (APP) and Site Investigation Work Plan addressing issues related to performing a subsurface investigation at the Eastwick site was submitted in August 2013, and approved by USACE following a set of revisions based on comments provided by USACE. In addition, due to the proximity of the test boring locations to the former landfill, a Waste Handling and Management Plan addressing issues related to the potential for encountering environmentally-impacted soils at the site was submitted and approved by USACE.

As required by the Scope of Work, the field exploration program included the performance of three SPT borings. Prior to the performance of the test borings, the locations were determined by USACE and Duffield Associates' representatives utilizing site features as a reference.

The general locations of the SPT borings are indicated on the Test Boring Location Sketch, which is included in Appendix B of this report and discussed in the following sections.

A. STANDARD PENETRATION TEST BORINGS

Three SPT borings to collect disturbed "split-spoon" samples (ASTM D 1586) and undisturbed "Shelby Tube" samples (ASTM D 1587) were performed by CGC Geoservices, LLC, as a subcontractor to Duffield Associates, utilizing an ATV-mounted Deitrich D-50 drill rig. The test borings were performed between August 26 and 29, 2013. Test borings were sampled as follows:

- Test boring BH-1, in the Cobbs Creek location, was continuously sampled to a depth of 36 feet below the existing ground surface as specified. However, spoon refusal encountered in the very dense weathered rock soils resulted in a few non-continuous samples (i.e., spoon refusal prevented 2 feet of penetration for some samples performed at 2-foot intervals).
- Test boring BH-2, in the Cobbs Creek location, was continuously sampled to a depth of 26 feet below the existing ground surface, where refusal to the penetration to the drilling augers and sampling equipment was encountered.
- Test boring BH-3, in the Darby Creek location, encountered apparent environmentally-impacted soils at a depth of 4 feet below the existing ground surface. During sampling, the organic gases and vapors detected by the Photoionization Detector (PID) at the sampling equipment were observed to be 2,850 deflections units, which exceeded the limits indicated in the approved APP. The test boring was terminated, offset, and restarted. It is noted that average defection units observed in the work zone following the termination of the test boring did not exceed the 5 deflection unit limit indicated in the approved APP.

Refusal to the penetration to the drilling augers was encountered within the miscellaneous fill materials at the site three times at depths ranging from 3 to 18 feet. The fifth attempt of the test boring, designated Test boring BH-3D, was continuously sampled from a depth of 16 feet to a depth of 36 feet below the existing ground surface.

To collect the "disturbed" samples, a 2-inch diameter split-spoon was driven 24 inches utilizing a "cat head" and 140-pound safety hammer dropped from a height of 30 inches, as specified for SPT sampling. The "undisturbed" samples were collected in 3-inch-diameter, 30-inch-long seamless brass Shelby Tubes, utilizing an Ostenberg sampler.

The scope of services specified that nine undisturbed samples were to be collected, however, the soils encountered consisted of predominantly sand soils. The subsurface conditions and the undisturbed sample collection were discussed with USACE's field representative during the performance of the test borings. A total of four "undisturbed" Shelby Tube samples were collected from the SPT borings.

Duffield Associates' geologist was present during the performance of the drilling, and logged the conditions observed in the SPT borings. Logs describing the soil and groundwater conditions encountered in the test borings are included in Appendix D. Upon completion of test borings, each borehole was grouted with portland cement-bentonite slurry to the ground surface.

B. LOCATION SURVEYING

Upon the completion of the field investigation program, the "as-performed" locations and elevations for the SPT borings were determined by Transition Engineering and Surveying, Inc., as a subconsultant to Duffield Associates. As required for the project, horizontal controls were established within Pennsylvania South Plane Coordinates (NAD 1983) and vertical control was referenced to the North American Vertical Datum (NAVD 1988).

A copy of the survey report is included in Appendix C. In addition, the "as-performed" survey coordinates and ground surface elevation of each boring are included on the test boring logs included in Appendix D, and a summary of the "as-performed" test boring locations are included in Appendix E.

III. SUBSURFACE CONDITIONS

A. FILL MATERIALS AND LANDFILL WASTE

The Clearview Landfill site is reportedly a former landfill that was utilized to dispose of municipal solid waste (MSW) material and industrial waste between the 1950s and 1970s (EPA, 2011). As a result, the shallow site conditional and the higher elevation zone between the two evaluations sites are reported to consist of debris laded fill material, which may include zones of trash and variable industrial debris. Sampling and evaluation previously performed for the EPA has identified numerous environmentally impacted soils in, surrounding, and underlying the landfill zones. The purpose of the test borings performed for this evaluation was to collect information to evaluate the geotechnical properties of the areas adjacent to the main portion of the landfill; however, the EPA has directed the installation of more than 20 monitoring wells as part of the site environmental assessments (EPA, 2012).

The shallow fill material observed in the test borings at the two sites was highly variable. At the Cobbs Creek site, a relatively thin layer of fill material was observed in test boring BH-1 (approximately 2 feet at the surface), and the fill material was observed to consist primarily of fine-grained soil with trace amounts of brick, coal, and stone. However, it should be noted this boring was performed outside of the footprint of the landfill, as indicated in the EPA reports. The fill materials observed in test boring BH-2, at the Cobbs Creek site, were also generally fine-grained soil with trace amounts of coal, glass, stone, and possible slag. Test boring BH-2 is also located outside of the reported extents of the landfill, but is located along what was formerly identified as an access roadway to the landfill in available historical aerial photographs.

The Darby Creek site is located within a portion of the reported footprint of the landfill; however, the relative elevation of the ground is an indication that less waste was placed in this portion of the site (ground surface elevations on the order of 15 feet in this area versus elevation in excess of 70 feet in the main portion of the landfill). The samples collected in the fill stratum at the test boring BH-3 location were observed to consist primarily of debris (including municipal waste, plastic, concrete, and Styrofoam, etc.). Based on our field observations during drilling operations and the drilling refusal encountered, it is probable that much larger pieces of debris, specifically large pieces of wood and other debris, are present within the fill stratum.

B. REGIONAL GEOLOGY AND STRATIGRAPHIC CONDITIONS

Beneath surficial fill deposits, Duffield Associates' field program, geologic map review, review of topographic data, and experience from past studies in Philadelphia County, Pennsylvania, supports that the shallow geologic framework beneath the area being considered for flood risk reductions can be characterized by the following materials, in order of increasing age and/or depth below ground surface:

- Holocene Marsh/Estuarine Deposits;
- Quaternary Alluvium;
- Quaternary Trenton Gravel; and
- Weathered Bedrock.

These four map units have been discussed below.

1. **Holocene Marsh/Estuarine Deposits.** Beneath fill materials and within an elevation range of a few feet above to several feet below present day sea-level (referenced to the North American Vertical Datum of 1988), Duffield Associates' field staff identified apparent estuarine/marsh deposits that are consistent with published descriptions of alluvial silts and clays, deposited by the Holocene marine incursion into the ancestral Delaware River Estuary and its tributaries. These deposits can be described as grayish brown to greenish gray silts and clays with a trace of fine quartz sand. Commonly, these deposits were finely-laminated as a result of tidal influence, bioturbated, and contained trace to little organic material (e.g., leaf mats). Lithologic variability noted in the published descriptions included lenses of fine gray micaceous sand and peat layers, representing apparent changes in the depositional environment and water depth (e.g., fringing marsh to intertidal).

   Based on the test borings performed as a part of this exploration, the estuarine deposits were noted to range in thickness from thin to absent at upstream locations that may have approximated the head of tide prior to land filling activities (test borings BH-1 and BH-2) to approximately 14 feet thick down gradient of the confluence of Cobbs and Darby Creeks (test boring BH-3D).

2. **Quaternary Alluvium.** Beneath modern marsh and estuarine environments, geologic mapping data available from the Pennsylvania Geological Survey (PGS) indicates that stream alluvium deposits may be present. These sediments were laid down by ancient streams/rivers that once occupied lower topography proximal to and under the modern Delaware estuary, prior to the latest incursion of sea-level (generally prior to the last 20,000 years). Mapping data describes this alluvium as predominantly quartz sand and silt, with common intercalated deposits and lenses of gravel, peat, and less commonly silt/clay.

Based on the field program performed as a part of this exploration, apparent alluvium was identified at test boring locations BH-1, BH-2, and BH-3D. The alluvium observed was heterogeneous and varied from coarse gravel/rock fragments to coarse, poorly-sorted, angular/sub-angular quartz sand, and floodplain silts/clays with organic material. In general, the alluvium coarsened with depth nearer the lower contact with weathered basement rock.

3. **Quaternary Trenton Gravel.** According to the 1980 Bedrock Geologic Map of Pennsylvania (Duffield Associates used the digital GIS version published in 2001), the Quaternary Trenton Gravel should be present near the Eastwick neighborhood in a pattern that fringes the Delaware River, representing the bulk of the Coastal Plain deposits that thin and "pinch out" up against the Piedmont Province in this area. In general, published maps place the Trenton Gravel below a maximum elevation of approximately 60 feet in the Philadelphia area, where it forms a terrace and is found to be at its thickest. Published information describes the Trenton Gravel as a gray to pale reddish brown, gravelly to very gravelly sand that has been identified to be interbedded with sand and clay/silt in places.

   Where mapped to be present, Duffield Associates observed the apparent Trenton Gravel as reddish gray, gray to varicolored, poorly-sorted, micaceous fine to medium sand with little to some gravel, some to little clay/silt, and very gravelly lenses. Most of the gravel was noted to be comprised of some combination of regional Piedmont metamorphic and Valley and Ridge sedimentary rock, including red sandstone/mudstone, quartzite, and schist.

   It should be noted that at test boring BH-2, apparent alluvial soil accumulation was observed underlying and overlying the fill soils associated with the Clearview landfill activates (fill material which included apparent slag, brick, coal, glass, and concrete). This is an indication that the accumulation of alluvium within the Cobbs Creek floodplain has continued in this area, following the disturbance that occurred during the landfill operations.

4. **Weathered Bedrock.** The 1980 Bedrock Geologic Map of Pennsylvania (see Appendix B) indicates that the Wissahickon Formation is present in the vicinity of the Eastwick neighborhood. Further, Bosbyshell (2008) has mapped the Fairmount Member of the Wissahickon Formation to be present. In general, bedrock within this formation is metamorphic and composed of fine to coarse-grained, psammitic schist with a strong foliation.

   Duffield Associates identified weathered bedrock in all three test locations. The weathered rock was observed to consist of variably-weathered mica schist with a strong foliation. Generally, top of weathered rock was encountered at elevations ranging from approximately -11 to -23 feet (NAVD 88). At all test boring locations, the weathered zone above competent bedrock was observed to be relatively thin (approximately less than 5 feet total thickness).

C. GROUNDWATER

As indicated on the test boring logs, apparent groundwater was observed in the test borings at the upper creek location (test borings BH-1 and BH-2) at depths ranging from approximately 7.0 to 7.4 feet below the existing ground surface during drilling, corresponding to an approximate elevation of 3.8 to 5.3 feet (NAVD). Apparent groundwater was observed in the test boring at the down creek location at depths ranging from approximately 6.5 to 7.0 feet below the existing ground surface during drilling, corresponding to an approximate elevation of 8.3 to 8.5 feet within the miscellaneous fill materials at the surface.

The U.S. Environmental Protection Agency (EPA) has performed active monitoring of the Clearview Landfill site as part of the environmental cleanup. The monitoring activities have included groundwater monitoring to the south of the upper creek location and in the area of the down creek zone. These groundwater observations have been summarized in a Supplemental Groundwater Investigation report dated July 2012. The report indicates that the "static" groundwater level in the wells in the vicinity of the upper creek location were approximately at elevation 5 feet and the groundwater level in the wells in the vicinity of the down creek location were approximately at elevation 9.6 feet (Mean Seal Level Datum). The conversion between NAVD (the current datum) and Mean Seal Level Datum (the EPA datum) could result in a change in elevation of up to 2 feet, which generally corresponds to the groundwater data collected during the current test boring program.

IV. LABORATORY TESTING

Samples obtained from the SPT borings were returned to Duffield Associates' Wilmington, Delaware office for further review and laboratory testing. After review of the field borings logs, selected samples were identified for specific laboratory testing. On September 12, 2013, preliminary test boring logs were forwarded to the USACE for review and approval. During extraction of the samples from the Shelby Tubes, interbedded zone of coarse-grained fill materials prevented the testing of the full amount of the soil recovered in the field, because the soil recovered in the Shelby Tube consisted of a combination of the fine grained soils which were tested and zones of gravel and sand that were not suitable for triaxial or consolidation testing. As a result, modifications to the approved testing program were required. A copy of the final Schedule of Laboratory Testing is included in Appendix F.

Table 1: Summary of Geotechnical Laboratory Testing

Test	ASTM Designation	Number of Samples
Sieve Analysis w/o Hydrometer	D 422	15
Atterberg Limits	D 4318	15
Natural Water Content	D 2216	15
Triaxial "Q" Test (Unconsolidated Undrained)	D 2850	3
Triaxial "R" Test (Consolidated Undrained)	D 4767	2
Consolidation Test	D 2435	3

The laboratory testing results are summarized in Appendix G. Actual laboratory testing results, including data forms for the laboratory testing performed, are included in Appendix H.

V. LABORATORY STRENGTH TESTING PROGRAM

A. CONSOLIDATION AND TRIAXIAL COMPRESSION TESTS

To evaluate soil strength, testing was performed on three undisturbed samples from the Eastwick site. One undisturbed sample was tested from the Cobbs Creek location and two samples were tested from the Darby Creek location.

1. **Consolidation Tests.** Three consolidation tests were performed on undisturbed samples utilizing the loading increments specified by USACE. The sample collected from the Cobbs Creek location exhibited results indicating a slightly disturbed sample (a well-defined previous consolidation pressure was not apparent, but is estimated). This is likely due to the close proximity of disturbed soils to the sample and the shallow depth that the sample was collected.

   The samples collected from the Darby Creek location indicated previous consolidation pressures ranging from 2,800 to 2,930 pounds per square foot (psf) from samples obtained from elevations ranging from approximately -4 to -14 feet, with the previous consolidation pressure increasing with depth. Based on the previous consolidation pressures, the approximate depth of sample and an average effective soil unit weight of 60 pcf, the soil has an over consolidation ratio on the order of 1.3 to 1.6. The compression index of these soils was observed to range from 0.79 to 1.05.

   Individual testing results are included in Appendix H.

2. **Triaxial "Q" Tests.** Three triaxial "Q" compression (unconsoildated undrained, UU traixial) tests were performed on undisturbed samples. USACE specified that the tests be performed at three confining stresses: 1,000 psf, 2,000 psf, and 4,000 psf. Due to the quality of the undisturbed samples collected at the Cobbs Creek location from test boring BH-2, and the upper portion of the fine-grained deposit at the Darby Creek location from test boring BH-3D, one "UU" trixial compression test was ran at a confining stress of 2,000 psf for the sample in BH-2 and two "UU" trixial compression tests were ran at confining stresses of 2,000 psf and 4,000 psf for the sample in BH-3D.

   The cohesive strength of the soils from the triaxial "Q" tests at the Cobbs Creek location was observed to be 490 psf at an elevation of approximately 0 feet, and ranged from 430 to 990 psf from elevations ranging from approximately -4 to -14 feet at the Darby Creek Location. Individual testing results are included in Appendix H.

3. **Triaxial "R-Bar" Tests.** Two triaxial "R-bar" compression (consolidated, undrained, CU traixial) tests, with pore pressure measurements, were performed on undisturbed samples collected in test boring BH-3 at the Darby Creek location. As requested by USACE, the tests were performed at three confining stresses: 1,000 psf, 2,000 psf, and 4,000 psf.

   Consolidated-undrained cohesive strengths ranged from 600 to 1,000 psf, with corresponding friction angles ranging from 10.0° to 20.0° were obtained. Based on the undrained cohesion, friction angle values, the approximate depth of sample, and an average effective soil unit weight of 60 pcf, the undrained shear strength of the soils ranged from approximately 1,300 to 1,390 psf from elevations approximately ranging from -4 to -14 feet. The strength of the soils was observed to increase with depths; however, the increased strength is likely attributable to the higher granular proportion of the deeper sample and may not be indicative of a trend of an increase in undrained shear strength with depth.

   Estimated consolidated drained results were derived utilizing Mohr's circle plots with the pore pressure measurement at the observed maximum deviator stress subtracted. The resulting effective stress envelopes indicated drained cohesive strengths of 0 psf, and drained friction angles ranging from approximately 44.3^{o} to 56.3^{o}. Based on the estimated drained cohesion, drained friction angle values, and approximate depth of sample, the drained shear strength of the soils ranged from approximately 2,130 to 2,550 psf from elevations approximately ranging from -4 to -14 feet.

It is noted that an effective friction of 44.3 and 56.3° are considered extremely high for the soils tested. This is based on an idealized case where it is likely that a high degree of soil improvement has occurred in a controlled manner, and these effective stress values are based on the strength values following loading of the test specimens to a strain in excess of 10 percent. It is our opinion that these levels of soil improvement loading would be difficult to replicate in the variable field conditions. Accordingly, these high values are not recommended for use in evaluation of the shear strengths of the subsurface conditions.

Individual testing results are included in Appendix H.

B. INDEX TESTING

Index testing; including the performance of 15 Atterberg Limits, sieve analyses (without hydrometer), and natural water contents; was conducted on disturbed split-spoon samples and undisturbed Shelby Tube samples. Results of the index testing are summarized in Appendix G. The results of the sieve analysis and specific gravity testing are included on the individual grain size distribution reports for the samples tested included in Appendix H. The results of the Atterberg Limits are also provided in Appendix H.

VI. METADATA

As required by the Scope of Work, a digital Metadata file was generated for the "geospatial" data acquired as part of this Task Order. Geospatial data is defined as information that identifies the geographic location and characteristic of natural or constructed features and boundaries of the earth. For the purposes of this project, the geospatial data includes the following:

- SPT boring location data (i.e., Northing and Easting coordinates);
- Ground surface elevation; and
- Soil stratigraphy based on visual and geotechnical laboratory testing.

Information related to the geospatial data, as part of the field program for the Eastwick project, was entered into a Federal Geographic Data Committee (FGDC) compliant Metadata file. A text version of the Metadata file is included in Appendix I. The actual Digital Metadata file is included on the Compact Disk accompanying this report.

VII. CONCLUSIONS AND RECOMMENDATIONS

Based on the data obtained as part of this evaluation, the following conclusions and recommendations are presented.

1. It is understood that the flood risk reduction project is generally indented to mitigate the risk of a flooding event along the Darby and Cobbs Creeks, which have reportedly affected the Eastwick neighborhood in the past. The two sections have been identified as low lying zones located between two higher elevations zones where flood waters may enter the neighborhood. These low lying areas are generally traversed by the higher landfill zone, which is created land reportedly consisting of Municipal Solid Waste (MSW) and debris-laded fill. The low lying area to the north of the landfill is along the Cobbs Creek (area of test borings BH-1 and BH-2). The low lying area in the southern portion of the landfill zone is along the Darby Creek (area of test boring BH-3).

2. The presence of the municipal solid waste (trash) materials in the areas being considered will significantly affect the design of a flood risk reduction program. The available subsurface information indicates that the trash layers observed are likely to be significant and highly variable, both along the length of the alignment and in extent. In our test borings, the waste materials were observed to consist of large debris, and have been reported by EPA contracted drillers to include waste materials on the order of several feet in size, which was consistent with the conditions observed at the refusal locations of test boring BH-3.

   The potential variability and extent of this material should be considered in the preparation of cross sections for a stability analysis. If it proposed to construct a levee or protection berm though this area, it may be required to install a cut-off trench along the length of the alignment extending below the fill materials and into the underlying estuarine deposits due to the high variability of fill materials.

   In addition, it is likely that the two ends of a potential levee or protection berm (where the berm intersects the higher existing topography) would be in an area where MSW material or debris laded material is present.

   Due to the high potential variability of water flow through MSW materials, the design should consider the potential for seepage or piping through the MSW material which could occur around the structure of a levee system (i.e. flow around the ends or below the base).

3. The natural groundwater elevation in the vicinity of the site should approximately correspond to the water surface elevation in the Creeks, and has been reported to generally slope down to the east. In addition, large zones of perched groundwater should be anticipated within the municipal solid waste zones.

4. It is understood that the information included in this report will be utilized to develop concept scale designs for flood risk reduction improvements along this portion of the lower Darby Creek watershed. Due to the difficulty in sampling the shallow debris fill layer observed (refusal, and limited SPT recovery), it is recommended that the design phase evaluation consider in-situ sampling techniques combined with physical sampling and testing, which could be utilized to further develop the subsurface profile of the debris and shallow MSW material along the length of the risk reduction project.

   Specifically, due to the high variability observed in the MSW material, it is unlikely that SPT sampling and the laboratory testing of disturbed and undisturbed samples would be sufficient to characterize the fill materials along the entire project alignment. Since the design of the levee system is dependent on the geotechnical characteristics of the MSW materials, a combination of geophysical and in situ testing should be considered for the design phase evaluation. The in situ testing could include evaluation of the flow characteristics of the waste stratum would be more appropriately characterized utilizing large scale in situ permeability testing though large diameter borehole or test pits opposed to the collection of undisturbed samples and laboratory permeability testing which does not appear practical for the MSW material.

This report has been prepared according to generally accepted soil engineering standards, and is based on the conditions encountered by the individual test borings performed for this evaluation. Duffield Associates has presented field boring logs and laboratory testing in accordance with a scope of services prepared by USACE. Interpretation of this data should consider the requested scope of services and the conditions encountered at the site as a whole. In the event that changes in the presentation of this data are proposed, this report will not be considered valid unless the changes have been reviewed and the recommendations of this report modified and re-approved in writing by Duffield Associates, Inc.

[WORD\8919GM.0114-EASTWICK.RPTREV]

VIII. REFERENCES

1. Bosbyshell, H.A., 2008. Bedrock Geologic Map of a Portion of the Philadelphia Quadrangle, Montgomery and Philadelphia Counties, Pennsylvania, Pennsylvania Bureau of Topographic and Geologic Survey Open File Bedrock Map No. 08-05.0: Scale 1:24,000.

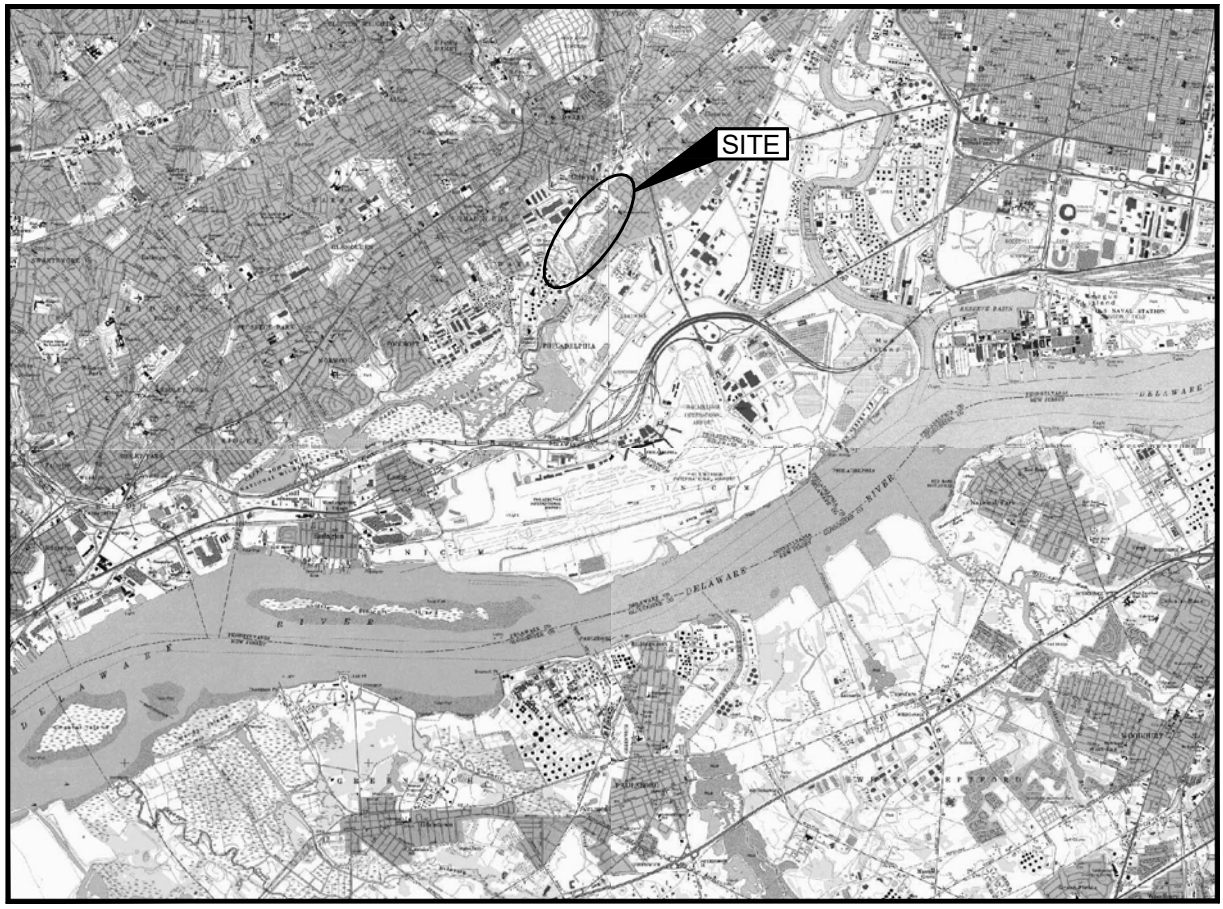
2. Miles, C.E. and Whitfield, T.G., 2001. Bedrock Geology of Pennsylvania, Pennsylvania Geological Survey, 4th Series: Scale 1:250,000 (Digital Map Data).

3. U.S. Environmental Protection Agency, 2012. 2011 Supplemental Groundwater Investigation for Lower Darby Creek Area Site, Clearview Landfill Operable Unit 1, Philadelphia and Delaware Counties, Pennsylvania.

4. U.S. Environmental Protection Agency, 2011. Remedial Investigation and Feasibility Study, Lower Darby Creek Area Site, Operable Unit 1 – Clearview Landfill, Delaware and Philadelphia Counties, Pennsylvania, Phase 1 Archaeological Survey Report.

APPENDIX A

SITE LOCATION SKETCH

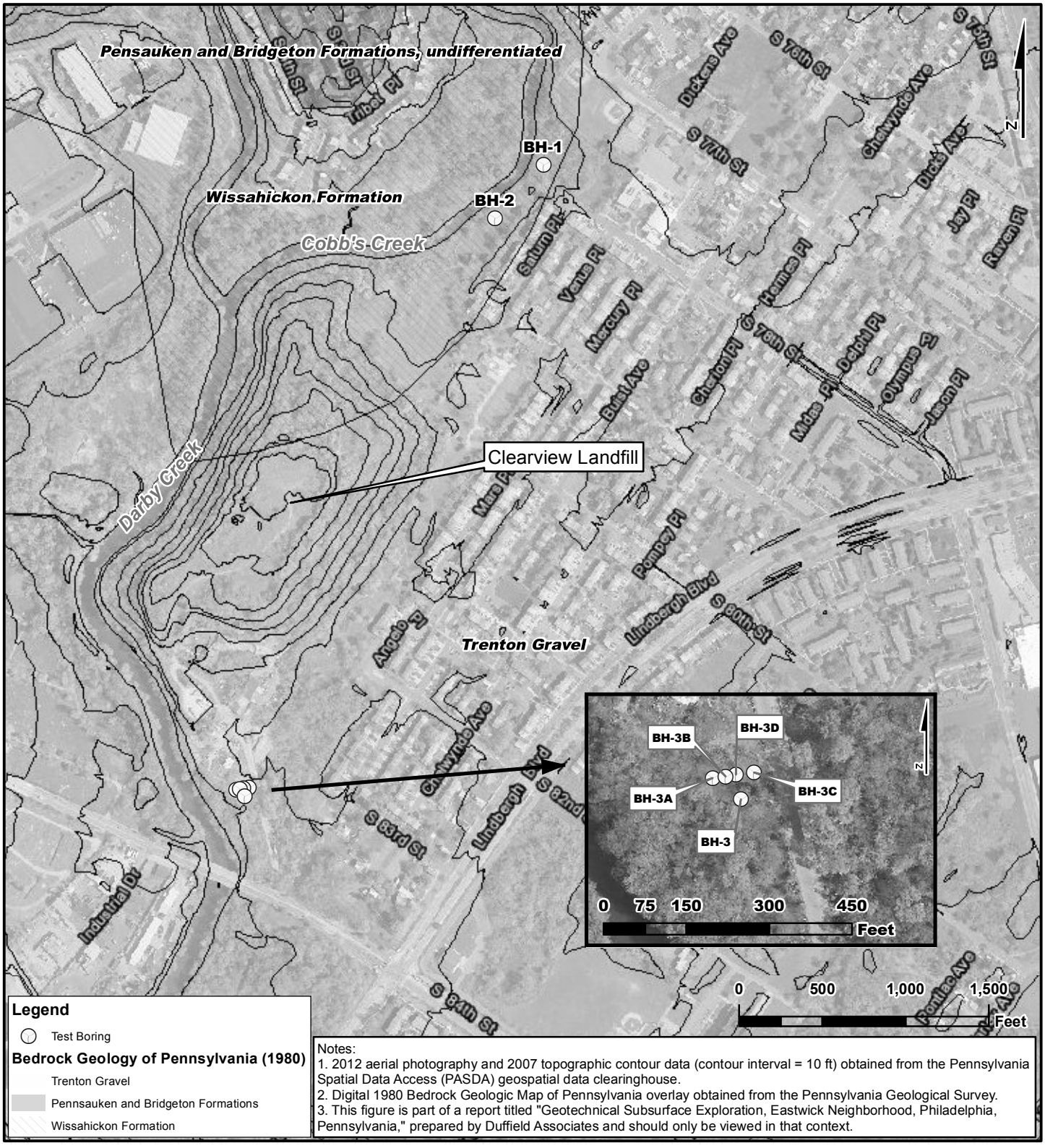


NOTE:
THIS LOCATION SKETCH IS ADAPTED FROM THE U.S.G.S. TOPOGRAPHIC MAP, 7.5 MINUTE SERIES, FOR PHILADELPHIA, LANSDOWNE, BRIDGEPORT AND WOODBURY, DELAWARE-NEW JERSEY-PENNSYLVANIA 1993.

DATE: 21 OCTOBER 2013	SITE LOCATION SKETCH	**DESIGNED BY:** BJD	DUFFIELD ASSOCIATES
SCALE: N.T.S.	**SUBSURFACE EXPLORATION AT EASTWICK NEIGHBORHOOD**	**DRAWN BY:** BJD	5400 LIMESTONE ROAD WILMINGTON, DE 19808-1232 TEL. (302)239-6634 FAX (302)239-8485
PROJECT NO. 8919.GM		**CHECKED BY:**	OFFICES IN DELAWRE, MARYLAND PENNSYLVANIA AND NEW JERSEY
SHEET: FIGURE 1	**PHILADELPHIA ~ PENNSYLVANIA**	**FILE:** A-8919GM-01	E-MAIL: DUFFIELD@DUFFNET.COM

APPENDIX B

TEST BORING LOCATION SKETCH



Notes:
1. 2012 aerial photography and 2007 topographic contour data (contour interval = 10 ft) obtained from the Pennsylvania Spatial Data Access (PASDA) geospatial data clearinghouse.
2. Digital 1980 Bedrock Geologic Map of Pennsylvania overlay obtained from the Pennsylvania Geological Survey.
3. This figure is part of a report titled "Geotechnical Subsurface Exploration, Eastwick Neighborhood, Philadelphia, Pennsylvania," prepared by Duffield Associates and should only be viewed in that context.

Date: 10/2013	TEST BORING LOCATION SKETCH	DESIGNED BY: ADK	DUFFIELD ASSOCIATES Soil, Water & the Environment
SCALE: AS SHOWN	**GEOTECHNICAL SUBSURFACE EXPLORATION - EASTWICK NEIGHBORHOOD**	DRAWN BY: ADK	5400 LIMESTONE ROAD WILMINGTON, DE 19808-1232 TEL. (302)239-6634 FAX (302)239-8485
PROJECT NO. 8919.GM	U.S. ARMY CORPS OF ENGINEERS (USACE) - PHILADELPHIA DISTRICT	CHECKED BY: BJD	OFFICES IN PENNSYLVANIA, SOUTHERN DELAWARE, MARYLAND AND NEW JERSEY
SHEET: APPENDIX B	PHILADELPHIA~PENNSYLVANIA	FILE: 8919GM_APPENDIXB.mxd	EMAIL: DUFFIELD@DUFFNET.COM

APPENDIX C

SURVEYOR'S REPORT

TRANSITION
ENGINEERING
SURVEYING

116 Middessa Drive
Middletown, DE 19709
Phone: (302) 983-7008
eFax: 1 (413) 215-4517

October 29, 2013

Brian Devine, P.E.
Duffield Associates, Inc.
5400 Limestone Road
Wilmington, DE 19808

RE: Geotechnical Subsurface Exploration
Eastwick Southwest Philadelphia – Pennsylvania – Test Boring Survey

Two of the locations are off of the intersection of 78th Street and Saturn Place, Philadelphia (7800 Saturn Place) in Eastwick Southwest Philadelphia

The third location is off of South 84th Street west of Lindbergh Boulevard in Eastwick Southwest Philadelphia

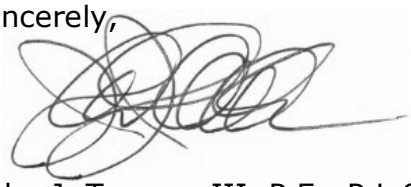
Dear Brian:

The Table below is a list of the elevations associated with the location of Geotechnical Borings located at the above referenced site on September 19, 2013. Horizontal Datum is referenced to the Pennsylvania State Plane Coordinate System, North American Datum of 1983 (NAD 83). Vertical Datum is referenced by using RTK GPS collection on the Leica SmartNet North American Portal Virtual Reference System Network (Geoid Model: GEOID12A) to North American Vertical Datum of 1988 (NAD 88). Instrumentation used was Carlson All-in-One Surveyor+GPS dual frequency RTK GNSS receiver and field controller with Carlson SurvCE v2.5 data collection field data collection software, and Leica TCRP 1203 R300 Robotic Total Station System with RH1200 Radio Handle, Allegro Data Collector and Carlson SurvCE v1.67 "field to finish" data collection software. Positional accuracy is guaranteed compliant with the standards of RTK (Kinematic) GPS surveying. For L1+L2 –H:3mm+0.5ppm(x baseline length); V:15mm+1.0ppm(x baseline length). Survey observations and resultant data exceeds a positional accuracy of 0.10' horizontal and 0.10' vertical for both RTK and convention methods of data collection.

Boring No. / Control Point No.	Northing	Easting	Ground Elevation	Point No.
BH-1	219169.42	2669901.34	12.67	101
BH-2	218877.93	2669501.99	10.84	102
BH-3D	216223.10	2668487.44	15.28	103
BH-3	216181.72	2668505.83	15.23	104
BH-3B	216225.78	2668466.93	14.64	105
BH-3A	216222.24	2668499.13	15.56	106

Thank you for having Transition Engineering Surveying LLC provide you with the surveying services for this project.

Sincerely,



John J. Traynor III, P.E., P.L.S.
Pennsylvania Professional Land Surveyor Registration Number SU037565R
Transition Engineering Surveying LLC

APPENDIX D

SPT TEST BORING LOGS (3)

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-1

Geotechnical Subsurface Investigation - Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 27, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 27, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 12.67 feet +/- NAVD 88
Weather	: Sunny, 70s	Northing	: 219,169 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,669,901 +/- PASSPFT NAD83

Sample Condition: ⊠ Remolded
Water Levels: ▼ During Drilling

Depth in feet	Surf. Elev. 12.67 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0										
	11.2		ML	APPARENT FILL [grayish brown to brownish yellow silt/clay, little fine to very fine sand (slightly micaceous) (trace brick/coal/stones) (trace organic material) (damp to moist)]		1	3-4-5-3	1.4		
						2	2-3-4-5	1.5	Apparent top of alluvium deposits.	
	8.7		ML	Yellowish brown SILT, little very fine to fine sand (micaceous) (faintly mottled light yellowish brown; root mottles) (moist)		3	3-4-5-12	1.6		
5	6.7		SM	Brownish yellow and yellowish brown SILT some very fine SAND, trace to little clay (highly micaceous) (sand content increases with depth) (quartzite gravel in drive shoe) (moist)		4	5-7-8-8	1.4	Apparent rust ring/seasonal high water table at 7.4' +/- b.e.g.s..	▼
						5	5-9-7-5	1.4		
10	2.7		SM	Reddish yellow medium to fine SAND, little coarse sand, little silt/clay, trace to little fine gravel (common lenses of very coarse to coarse sand and granular sand with a trace clay/silt) (strong brown color @ 7.4' +/-) (moist to wet)		6	1-2-4-7	1.1		
	0.2					7A	31-32-43	1.2	Driller used drilling fluid to wash out heave in augers.	
			SM	SAME (strong brown to dark brown color) (mostly coarse sand, little very coarse sand, trace to little pebbles) (gravels are mixed sub-rounded and angular) (few thin lenses silt/clay) (saturated)		7B 8A 8B	14-28-21-50	1.3		
15	-4.3			Reddish yellow fine to very coarse SAND, trace to no silt (few rip-up clay/silt clasts) (trace granular sand) (micaceous) (moderately poorly-sorted) (saturated)		9	10-30-50/0.2'	1.4	Driller switched to mud rotary drilling at 15.5' +/- b.e.g.s..	
				SAME (saturated)		10	45-50/0.2'	0.5	Hard drilling	
20				Varicolored coarse GRAVEL/ROCK FRAGMENTS, some to and coarse to fine sand, little silt (micaceous) (rock fragments are highly weathered mica schist) (wet)		11	50/0.3'	0.0		
				SAME (wet)						
				SAME (highly weathered mica schist cobble) (wet)						
				SAME (moist to damp) (*change to apparent weathered rock in drive shoe)		12	50/0.3'	0.4		
				APPARENT HIGHLY WEATHERED ROCK [white and greenish gray mica schist (strong foliation) (moist to damp)]		13	50/0.3'	0.3		
25				NO RECOVERY						
				SAME (damp to dry)		14	50/0.3'	0.4		
				SAME (garnetiferous) (damp to dry)						
				SAME (less weathered than above; moderately to slightly weathered mica schist) (damp to dry)		15	50/0.0'	0.0	Very hard drilling; roller bit bouncing.	
				SPOON REFUSAL						
30				NO RECOVERY		16	50/0.1'	0.0		
				NO RECOVERY		17	50/0.1'	0.0		
				NO RECOVERY		18	50/0.1'	0.0		
35	-23.4			NO RECOVERY		19	50/0.1'	0.0		

NOTES:
1. Test boring terminated at 36.1 feet +/- below existing ground surface (b.e.g.s.).
2. Saturation encountered at approximately 8 feet b.e.g.s..
3. Borehole backfilled with bentonite-amended portland cement and holeplug through drilling rods upon completion.
4. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
5. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
6. Test boring location and ground surface elevation per Transition Engineering and Surveying, Inc. data.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-2

Geotechnical Subsurface Investigation - Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 26, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 26, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 10.84 feet +/- NAVD 88
Weather	: Sunny, 70s	Northing	: 218,878 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,669,502 +/- PASSPFT NAD83

Sample Condition: Remolded; Undisturbed
Water Levels: ▼ During Drilling

Depth in feet	Surf. Elev. 10.84 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0	10.3		SM	TOPSOIL AND ROOT MATERIAL Pale brown and light yellowish brown very fine to fine SAND, some pebbles to fine gravel, trace to little coarse gravel (quartz), trace to little silt (few rip-up mud clasts) (micaceous) (dry to damp)		S-1A S-1B	2-5-10-20	1.0	Apparent top of alluvium deposits.	
	8.8		ML	Reddish yellow and pink SILT, trace very fine to fine sand (micaceous) (few stringers - thin lenses of fine sand, some to little silt, little to trace fine gravel) (few lenses of dark gray CLAY/SILT) (damp)		S-2	5-11-12-11	1.5		
	6.8			APPARANT FILL [black and white clay/silt, trace to little fine to coarse sand, trace fine gravel/stones (trace glass, slag) (damp)]		S-3A S-3B	5-5-14-10	1.4		
5	5.9			SAME (mostly stone, coal fragments, slag, and glass) (damp)		S-4	6-9-5-5	1.2		▼
				SAME (mostly black to very dark gray coal fragments, cinders, concrete interlayered with clay/silt) (sand content increases with depth) (trace organic material/peat in drive shoe) (wet)		S-5	1-4-5-1	1.6	8.0 - 10.0 feet: Shelby tube attempted and failed to push	
10	0.8		ML	SAME (coarse gravel, brick fragments, concrete) (wet)		ST-1	300 psi	1.8	Apparent top of relic alluvium deposits.	
				SHELBY TUBE ST-1: 10.0' - 12.0' - SHELBY TUBE SAMPLE		S-6	1-1-1-1	1.2		
15	-4.3		GP-GM	Brownish gray SILT, trace fine to very fine sand (slightly micaceous) (trace to little organic material) (few micaceous sand stringers) (wet)		S-7A S-7B	WOH-2-24-46	1.6	Rig rocking at 15.0± feet.	
	-7.2			Light gray to grayish brown CLAY/SILT, some fine sand (14-14.1' dark brown soil horizon with roots) (micaceous) (faintly mottled) (wet)		S-8	32-22-10-9	0.7		
				Yellowish brown coarse GRAVEL, some fine to coarse sand, little silt (mostly varicolored weathered rock fragments) (saturated to wet)		S-9	6-12-19-28	1.4		
20				SAME (very coarse quartzite gravel in drive shoe) (saturated to wet)		S-10	18-33-50/0.4	1.2		
				APPARENT COMPLETELY WEATHERED ROCK [varicolored mica schist (garnetiferous) (strong foliation) (wet)]		S-11	16-50/0.3	0.3	23.0 - 24.0 feet: hard drilling, auger refusal at 26.0± feet	
25	-15.2			SAME (completely to highly weathered) (wet)		S-12	50/0.4	0.3		
				SAME (finer-grained than above; apparent gneiss) (damp)						
				SAME (highly to moderately weathered mica schist) (damp)						
30										
35										

NOTES:
1. Test boring terminated at 26 feet +/- below existing ground surface (b.e.g.s.).
2. Saturation encountered at approximately 7 feet b.e.g.s..
3. Borehole backfilled with bentonite-amended portland cement and holeplug through drilling rods upon completion.
4. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
5. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
6. Test boring location and ground surface elevation per Transition Engineering and Surveying, Inc. data.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-3

Geotechnical Subsurface Investigation -
Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 28, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 28, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 15.23 feet +/- NAVD 88
Weather	: Cloudy, Showers	Northing	: 216,182 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,668,506 +/- PASSPFT NAD83

Sample Condition: ⊠ Remolded

Water Levels

Depth in feet	Surf. Elev. 15.23 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0				APPARENT FILL [yellowish brown fine to coarse sand, little fine gravel/rock fragments (moist)]		S-1A	3-8-16-22	1.5		
2				APPARENT FILL [dark brown and black stones/rock fragments/coal fragments (trace organic material) (dry to damp)]		S-1B				
				SAME (mostly asphalt) (saturated; apparent free product encountered)		S-2	14-6-10-4	0.5	Apparent free product encountered; oil saturation. Borehole abandoned.	
4	11.2									
6										
8										
10										
12										
14										
16										
18										
20										

NOTES:
1. Test boring terminated at 4 feet +/- below existing ground surface (b.e.g.s.).
2. Oil saturation encountered in sample S-2. Borehole abandoned in accordance with Health and Safelty Plan.
3. Borehole backfilled with auger cuttings upon completion.
4. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
5. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
6. Test boring location and ground surface elevation per Transition Engineering and Surveying, Inc. data.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-3A

Geotechnical Subsurface Investigation - Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 28, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 28, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 15.56 feet +/- NAVD 88
Weather	: Cloudy, Showers	Northing	: 216,222 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,668,499 +/- PASSPFT NAD83

Sample Condition: Remolded; Undisturbed
Water Levels: ▼ During Drilling

Depth in feet	Surf. Elev. 15.56 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0				APPARENT FILL [yellowish brown fine to coarse sand, little fine gravel/rock fragments (moist)]		S-1A	2-5-10-4	1.4		
	14.9			APPARENT FILL [black and white debris/trash/brick fragments/plastic (slight hydrogen sulfide odor) (damp)]		S-1B				
2				SAME (mostly wood/apparent asbestos/concrete/styrofoam) (little clay/silt) (damp)		S-2	8-9-32-31	1.2		
4				SAME (concrete and variegated fill/brick fragments) (wet)		S-3	20-6-5-11	0.7		
6				SAME (saturated)		S-4	7-10-4-9	0.2		▼
8				SAME (color change to dark gray and black) (mostly fine to medium black sand, sticky) (saturated)		S-5	4-10-11-5	0.4	9.5 - 10.0± feet: driller reports easy drilling	
10				SHELBY TUBE SAMPLE (poor recovery)				1.4	10.0 - 12.0 feet: Shelby tube attempted and failed to push	
12				APPARENT FILL [black concrete debris/brick/wood (saturated)]		S-6	4-6	0.6		
				SAME (slight creosote odor) (saturated)		S-7	9-11-5-6	0.4		
14				NO RECOVERY (spoon bouncing on apparent wood/timber)		S-8	8-50/0.0	0.0	14.5 - 16.0± feet: Augered without plug through wood, used mud rotary to clear wood chips from augers	
16	-0.4									
			CL	Gray to brownish gray CLAY/SILT, trace very fine to fine sand (little organic material; few leaf mats) (wet to saturated)		S-9	5-2-2-2	1.5	Apparent top of floodplain/marsh deposit. Lost auger plug; abandoned borehole.	
18	-2.4									
20										

NOTES:
1. Test boring terminated at 18 feet +/- below existing ground surface (b.e.g.s.). Boring performed at location originally staked in fill area.
2. Saturation encountered at approximately 6.5 feet b.e.g.s.
3. Borehole backfilled with bentonite-amended portland cement and holeplug through drilling rods upon completion.
4. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
5. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
6. Test boring location and ground surface elevation per Transition Engineering.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-3B

Geotechnical Subsurface Investigation -
Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 29, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 29, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 14.64 feet +/- NAVD 88
Weather	: Cloudy, Showers	Northing	: 216,226 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,668,467 +/- PASSPFT NAD83

Sample Condition: Auger Cuttings; Remolded
Water Levels: ▼ During Drilling

Depth in feet	Surf. Elev. 14.64 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0										
2										
4										
6				APPARENT FILL [brick fragments/concrete/rocks/debris, some fine to coarse sand and clay/silt (damp to wet)]						▼
8										
10										
	3.6									
12										
14				APPARENT FILL [wood/timbers and concrete debris]						
16										
	-1.9									
				NO RECOVERY (heave in spoon consisted of brick, stones, glass, coal, and sand)		S-1	50/0.0	0.0	Driller used mud rotary to bring up cuttings and clear augers. 16.0-16.5± feet: Spoon, roller bit, and auger refusal.	
18										
20										

NOTES:
1. Test boring terminated at 16.0 feet +/- below existing ground surface (b.e.g.s.) due to refusal.
2. Borehole backfilled with bentonite-amended portland cement and holeplug through drilling rods upon completion.
3. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
4. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
5. Test boring location and ground surface elevation per Transition Engineering and Surveying, Inc. data.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
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TEST BORING BH-3C

Geotechnical Subsurface Investigation -
Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 29, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 29, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 15 feet +/- NAVD 88
Weather	: Cloudy, Showers	Northing	: 216,255 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,668,440 +/- PASSPFT NAD83

Sample Condition: Auger Cuttings

Water Levels

Depth in feet	Surf. Elev. 15 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0				APPARENT FILL [yellowish brown fine to coarse sand, little fine gravel/rock fragments (moist)]						
2	13.0			APPARENT FILL [dark brown and black stones/rock fragments/coal fragments (trace organic material) (dry to damp)]						
	11.5			APPARENT FILL [concrete]					3.5± feet: Lost drill bit bolts; borehole abandoned.	
4										
6										
8										
10										
12										
14										
16										
18										
20										

NOTES:
1. Test boring terminated at 3.5 feet +/- below existing ground surface (b.e.g.s.) due to refusal.
2. Borehole backfilled with auger cuttings upon completion.
3. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
4. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
5. Test boring location estimated in the field using site features. Test boring ground surface elevation estimated using 2007, 2 foot contours for the City of Philadelphia.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

DUFFIELD ASSOCIATES
Consultants in the Geosciences

TEST BORING BH-3D

Geotechnical Subsurface Investigation - Eastwick Neighborhood
Philadelphia, Pennsylvania
Project No. 8919.GM
USACE Contract No. W912BU-11-D-0005, T.O. 0011

Date Started	: August 29, 2013	Drilling Equipment	: ATV-Mounted Diedrich D-50
Date Completed	: August 29, 2013	Drilling Methods	: 3.75" H.S.A.
Logged by	: ADK	Surface Elevation	: 15.28 feet +/- NAVD 88
Weather	: Sunny, 80s	Northing	: 216,223 +/- PASSPFT NAD83
Driller/Agency	: J. Feldmann/CGC Geoservices	Easting	: 2,668,487 +/- PASSPFT NAD83

Sample Condition: Auger Cuttings; Remolded; Undisturbed
Water Levels: ▼ During Drilling

Depth in feet	Surf. Elev. 15.28 ft	GRAPHIC	USCS	DESCRIPTION	SAMPLES	Sample Number	Blows per 6 inches or Fluid Pressure	Recovery (ft)	Remarks	WATER LEVEL
0				APPARENT FILL [yellowish brown fine to coarse sand, little fine gravel/rock fragments (moist)]						
	13.8			APPARENT FILL [dark brown and black stones/rock fragments/coal fragments (trace organic material) (dry to damp)]						
5										▼
10				SAME (less debris than above; some wood) (saturated)						
15										
	-1.2			Grayish brown SILT, trace very fine to fine sand (trace to little organic material/leaf mats) (micaceous) (saturated to wet)		S-1	2-1-2	0.3	Driller switched to mud rotary drilling. Apparent top of relic marsh deposit.	
20				SHELBY TUBE ST-1: 19.5' - 21.5' - SHELBY TUBE SAMPLE		ST-1	250 psi	1.9		
			MH	SAME (light brownish gray to light gray color) (common very thin mats of organic material) (little organic material/roots) (wet to saturated)		S-2	1-1-2-2	1.5		
25				SHELBY TUBE ST-2: 23.5' - 25.5' - SHELBY TUBE SAMPLE (full push, however sample not recovered)		ST-2	300 psi	0.3		
				SAME (greenish gray color) (some to and organic material; peaty) (wet)		S-3	3-3-3-3	0.8		
	-12.2			SHELBY TUBE ST-3: 27.5' - 29.5' - SHELBY TUBE SAMPLE		ST-3	280 psi	1.9		
30			SM	SAME (vesicular; apparent gas breakout) (saturated)		S-4A	2-1-2-3	1.6		
	-15.2			Gray fine to medium SAND, and to some CLAY/SILT, little fine to pea gravel (few thin lenses of highly micaceous fine sand) (very coarse rounded sandstone gravel stuck in drive shoe) (micaceous)(wet)		S-4B S-5	13-13-9-10	1.2	Apparent top of alluvium/Trenton Gravel.	
	-18.7		SM	SAME (some to little clay/silt) (coarser than above; some weathered rock fragments and fine to medium, rounded-sub rounded quartz gravel) (wet)						
35	-18.8			APPARENT HIGHLY TO MODERATELY WEATHERED ROCK [white and greenish gray mica schist (strong foliation) (wet)]		S-6	50/0.1	0.1		

NOTES:
1. Test boring terminated at 36.0 feet +/- below existing ground surface (b.e.g.s.).
2. Saturation encountered at approximately 7 feet b.e.g.s..
3. Borehole backfilled with bentonite-amended portland cement and holeplug through drilling rods upon completion.
4. Soil descriptions performed in general accordance with ASTM D 2488, the Practice for Description and Identification of Soils (Visual-Manual Procedure).
5. Standard, split-barrel sampling performed in general accordance with the Method for Penetrative Test and Split-Barrel Sampling (ASTM D 1586). Driller utilized 140 pound safety hammer for sampling.
6. Test boring location and ground surface elevation per Transition Engineering and Surveying, Inc. data.

TBLOGUSAC 8919GM_EASTWICK_TBLOGS.GPJ DUFFIELD.GDT 12/13/13

APPENDIX E

“AS-PERFORMED” LOCATION DATA

AS-PERFORMED BORING LOCATIONS

SUBSURFACE EVALUATION AT

EASTWICK, PHILADELPHIA, PENNSYLVANIA

USACE Contract No. W912BU-11-D0005, Task Order 0011

SPT Boring Designation	Northing	Easting	Elevation (Feet)
BH-1	219169.4	2669901	12.67
BH-2	218877.9	2669502	10.84
BH-3	216181.7	2668506	15.23
BH-3A	216222.2	2668499	15.56
BH-3B	216225.8	2268467	14.64
BH-3D	216223.1	2268487	15.28

NOTE: Horizontal Datum – Pennsylvania North State Plane Coordinates (NAD 83).
Vertical Datum – NAVD 1988.

APPENDIX F

"AS-PERFORMED"
SCHEDULE OF LABORATORY TESTING

SCHEDULE OF LABORATORY TESTING

SUBSURFACE EVALUATION AT

EASTWICK, PHILADELPHIA, PENNSYLVANIA

USACE Contract No. W912BU-11-D0005, Task Order 0011

Test Boring	Sample Number	Sample Depth (ft.)	Testing
BH-1	S-2	2 – 4	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-1	S-3	4 – 6	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-1	S-5	8 – 10	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-1	S-8A	13.5 – 14.5	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-1	S-10	17.5– 19.5	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-1	S-14	25.5 – 27.5	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-2	S-2	2 – 4	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-2	T-1	10 – 12	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits, Tube Density, Consolidations, Trixial “Q” Test.
BH-2	S-7A	14 – 15	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-2	S-8	16 – 18	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-2	S-10	20 – 22	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-3A	S-9	16 – 18	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.
BH-3D	T-1	19.5 – 21.5	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits, Tube Density, Consolidations, Trixial “Q” Test, Triaxial “R” test.
BH-3D	T-2	27.5 – 29.5	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits, Tube Density, Consolidations, Trixial “Q” Test, Triaxial “R” test.
BH-3D	S-5	30 – 32	MC, Pass #200 Sieve, Sieve w/out hydrometer, Atterberg Limits.

APPENDIX G

SUMMARY OF LABORATORY TESTING RESULTS

SUMMARY OF LABORATORY TESTING RESULTS

SUBSURFACE EVALUATION AT EASWICK NEIGHBORHOOD
PHILADELPHIA, PENNSYLVANIA

USACE Contract No. W912BU-11-D0005, Task Order 0011

Test Boring Number	Sample #	Sample Depth (feet)	Visual Description [1]	Natural Moisture Content [2] (ASTM D 2216) %	Less Than No. 200 Sieve (ASTM D 1140) %	USCS Classification (ASTM D 2487)	Atterberg Limits (ASTM D 4318)		Triaxial Compression "Q" Test (ASTM D2850)	Triaxial Compression "R" Test (ASTM D4767)		Consolidation Test (ASTM D 2435)		
							Liquid Limit	Plasticity Index	Total c = (ksf) ϕ = °	Total c = (ksf) ϕ = °	Effective c' = (ksf) ϕ' = °	P_c (ksf)	C_c	C_r
BH-1	S-2	2 – 4	SILT, little fine sand, trace medium sand	21.3	80.0	ML	31	6	- - -	- - -	- - -	- - -	- - -	- - -
	S-3	4 – 6	SILT, some fine sand, trace medium sand	23.8	69.2	ML	25	1	- - -	- - -	- - -	- - -	- - -	- - -
	S-5	8 – 10	Medium to fine SAND, little silt, trace coarse sand, trace gravel.	21.5	17.9	SM		NP	- - -	- - -	- - -	- - -	- - -	- - -
	S-8A	13.5 – 14.5	Medium to fine SAND, little silt, little coarse sand, little gravel.	15.7	13.5	SM		NP	- - -	- - -	- - -	- - -	- - -	- - -
	S-10	17.5 – 19.5	Medium to fine SAND, little silt, trace coarse sand, trace gravel.	16.1	11.0	SM		NP	- - -	- - -	- - -	- - -	- - -	- - -
	S-14	25.5 – 27.5	Medium to fine SAND, little silt, trace coarse sand.	16.6	15.9	SM		NP	- - -	- - -	- - -	- - -	- - -	- - -
BH-2	S-2	2 – 4	SILT, little fine sand, trace medium sand.	21.0	76.7	ML	23	2	- - -	- - -	- - -	- - -	- - -	- - -
	T-1	10 – 12	SILT, trace fine sand	42.7	91.1	ML	49	18	Q c = 0.49	- - -	- - -	1.01	0.28	0.04
	S-7A	14 – 15	CLAY/SILT, some fine sand, trace medium sand.	25.0	69.3	CL-ML	25	5	- - -	- - -	- - -	- - -	- - -	- - -
	S-8	16 – 18	Fine to coarse GRAVEL, and medium to fine sand, little silt, trace coarse sand	9.6	11.8	GP-GM		NP	- - -	- - -	- - -	- - -	- - -	- - -
	S-10	20 – 22	Fine to medium SAND, trace silt, trace coarse sand, trace gravel.	13.6	8.2	SP-SM		NP	- - -	- - -	- - -	- - -	- - -	- - -

Notes:
1)USCS - Unified Soil Classification System

SUMMARY OF LABORATORY TESTING RESULTS

SUBSURFACE EVALUATION AT EASWICK NEIGHBORHOOD
PHILADELPHIA, PENNSYLVANIA

USACE Contract No. W912BU-11-D0005, Task Order 0011

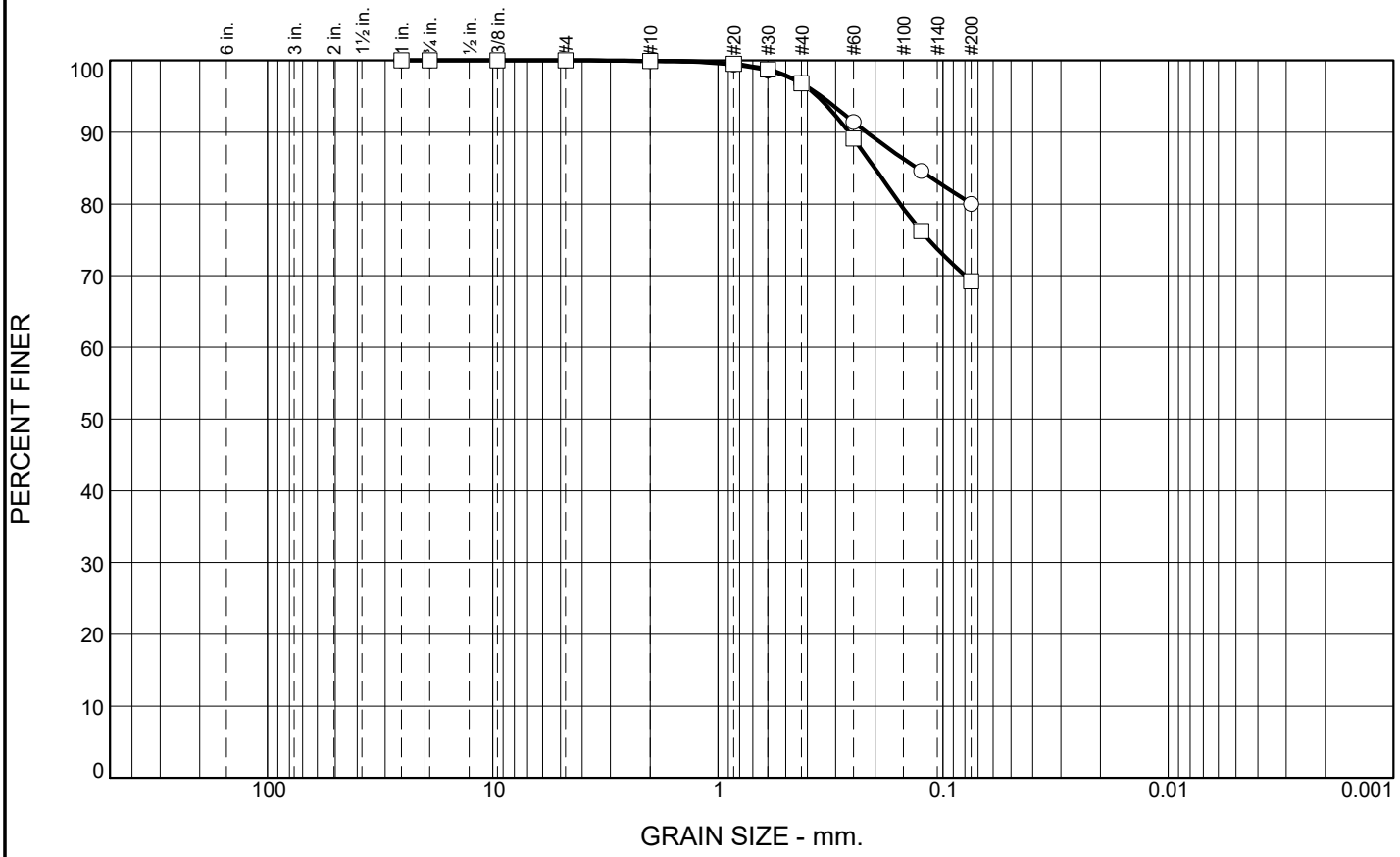
Test Boring Number	Sample #	Sample Depth (feet)	Visual Description [1]	Natural Moisture Content [2] (ASTM D 2216) %	Less Than No. 200 Sieve (ASTM D 1140) %	USCS Classification (ASTM D 2487)	Atterberg Limits (ASTM D 4318)		Triaxial Compression "Q" Test (ASTM D2850)	Triaxial Compression "R" Test (ASTM D4767)		Consolidation Test (ASTM D 2435)		
							Liquid Limit	Plasticity Index	Total c = (ksf) ϕ = °	Total c = (ksf) ϕ = °	Effective c' = (ksf) ϕ' = °	P_c (ksf)	C_c	C_r
BH-3A	S-9	16 – 18	SILT, trace fine to medium sand.	64.8	96.5	MH	46	15	- - -	- - -	- - -	- - -	- - -	- - -
BH-3D	T-1	19.5 – 21.5	SILT, trace fine to medium sand.	80.3	95.0	MH	113	48	Q c = 0.99	c = 1.00 Φ = 10.0	c' = 0.00 Φ' = 56.3	2.8	0.79	0.09
	T-3	27.5 – 29.5	Fine to medium SAND and SILT, trace coarse sand.	50.8	48.5	SM	51	17	Q c = 0.43	c = 0.60 Φ = 20.0	c' = 0.00 Φ' = 44.3	2.9	1.05	0.12
	S-5	30 – 32	Fine to medium SAND, little silt, trace coarse sand, trace gravel.	18.0	19.7	SM		NP	- - -	- - -	- - -	- - -	- - -	- - -

Notes:
1)USCS - Unified Soil Classification System

APPENDIX H

LABORATORY TESTING RESULTS

Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	0.0	20.0	80.0		ML	31	25	6
□	0.0	0.0	30.8	69.2		ML	25	24	1

SIEVE inches size	○	□
1"	100.0	100.0
3/4"	100.0	100.0
3/8"	100.0	100.0
GRAIN SIZE		
D_{60}		
D_{30}		
D_{10}		
COEFFICIENTS		
C_c		
C_u		

SIEVE number size	○	□
#4	100.0	100.0
#10	99.9	99.9
#20	99.4	99.5
#30	98.6	98.7
#40	96.8	96.8
#60	91.4	89.1
#120	84.6	76.2
#200	80.0	69.2

Material Description

○ SILT, little fine sand, trace medium sand.

□ SILT, some fine sand, trace medium sand.

REMARKS:

○ Moisture Content as Received: 21.3%

□ Moisture Content as Recieved: 23.8%

○ Source of Sample: BH-1 Depth: 2'-4' Sample Number: S-2

□ Source of Sample: BH-1 Depth: 4'-6' Sample Number: S-3

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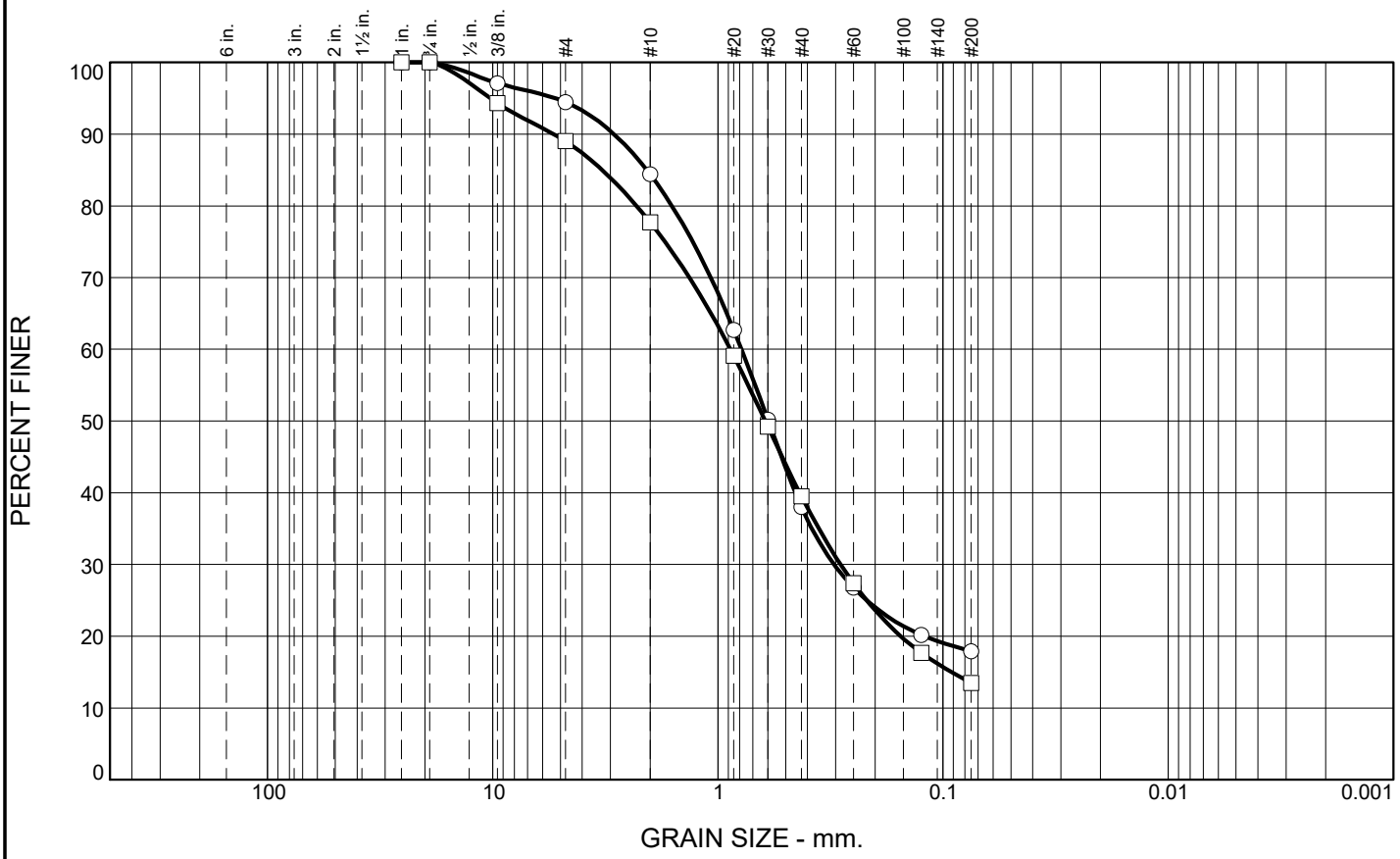
Client: U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Project No.: 8919.GM Chkd: BJD 10/13

Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	5.6	76.5	17.9		SM		NP	
□	0.0	11.0	75.5	13.5		SM		NP	

SIEVE inches size	○ PERCENT FINER	□ PERCENT FINER
1"	100.0	100.0
3/4"	100.0	100.0
3/8"	97.1	94.3
GRAIN SIZE		
D_{60}	0.7853	0.8791
D_{30}	0.3046	0.2850
D_{10}		
COEFFICIENTS		
C_c		
C_u		

SIEVE number size	○ PERCENT FINER	□ PERCENT FINER
#4	94.4	89.0
#10	84.4	77.7
#20	62.7	59.1
#30	50.2	49.2
#40	38.0	39.5
#60	26.8	27.4
#120	20.2	17.7
#200	17.9	13.5

Material Description

○ Medium to fine SAND, little silt, trace coarse sand, trace gravel.

□ Medium to fine SAND, little silt, little coarse sand, little gravel.

REMARKS:

○ Moisture Content as Received: 21.5%

□ Moisture Content as Received: 15.7%

○ Source of Sample: BH-1 Depth: 8'-10' Sample Number: S-5

□ Source of Sample: BH-1 Depth: 13.5'-14.5' Sample Number: S-8A

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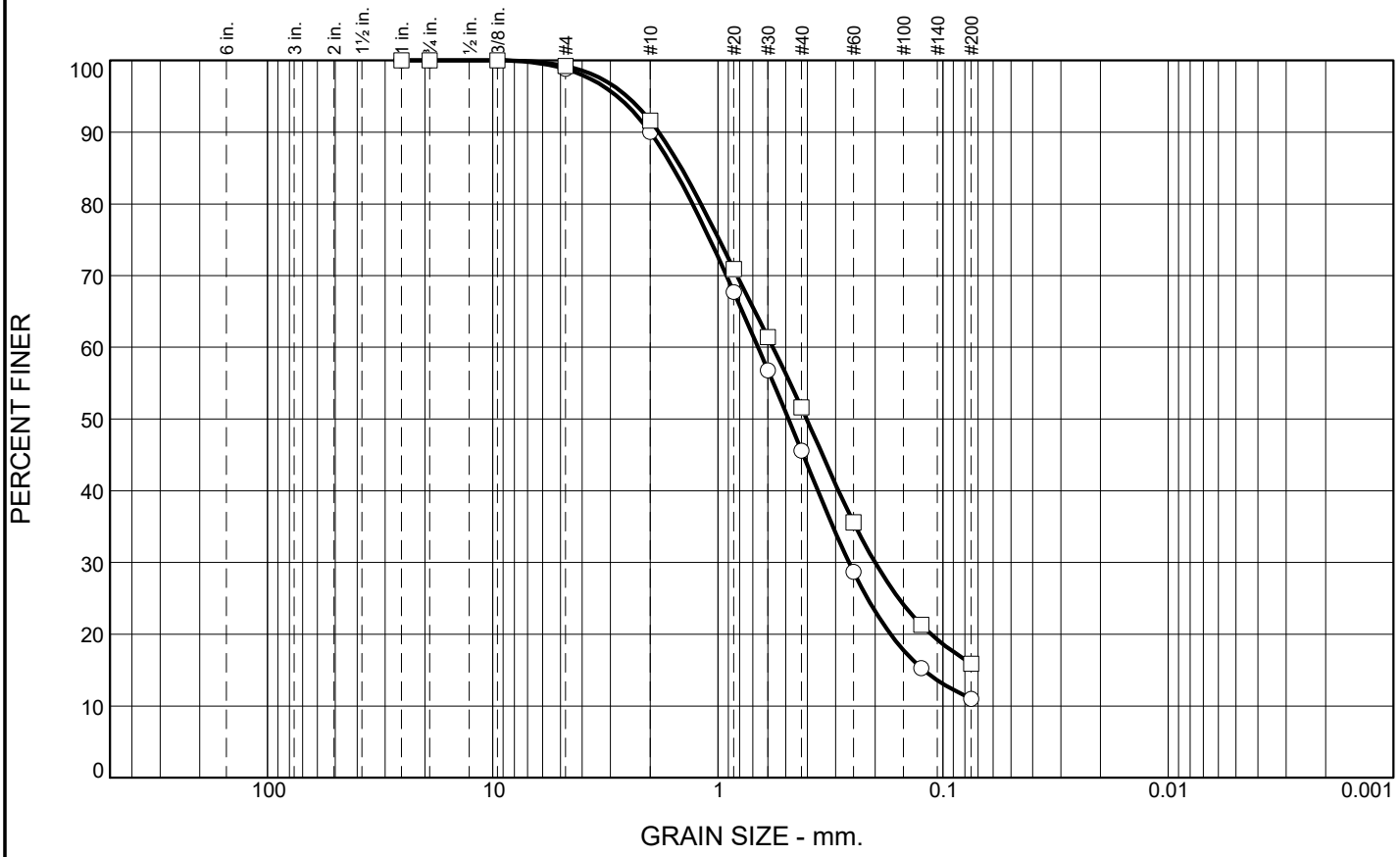
Project No.: 8919.GM Chkd: BJD 10/13

Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	1.2	87.8	11.0		SW-SM		NP	
□	0.0	0.8	83.3	15.9		SM		NP	

SIEVE inches size	PERCENT FINER ○	PERCENT FINER □
1"	100.0	100.0
3/4"	100.0	100.0
3/8"	100.0	100.0
GRAIN SIZE		
D_{60}	0.6637	0.5703
D_{30}	0.2618	0.2004
D_{10}		
COEFFICIENTS		
C_c		
C_u		

SIEVE number size	PERCENT FINER ○	PERCENT FINER □
#4	98.8	99.2
#10	90.0	91.6
#20	67.7	70.9
#30	56.8	61.4
#40	45.6	51.6
#60	28.7	35.6
#120	15.3	21.3
#200	11.0	15.9

Material Description

○ Medium to fine SAND, little silt, trace coarse sand, trace gravel.

□ Medium to fine SAND, little silt, trace coarse sand.

REMARKS:

○ Moisture Content as Received: 16.1%

□ Moisture content as Received: 16.6%

○ Source of Sample: BH-1 Depth: 17.5'-19.5' Sample Number: S-10

□ Source of Sample: BH-1 Depth: 25.5'-27.5' Sample Number: S-14

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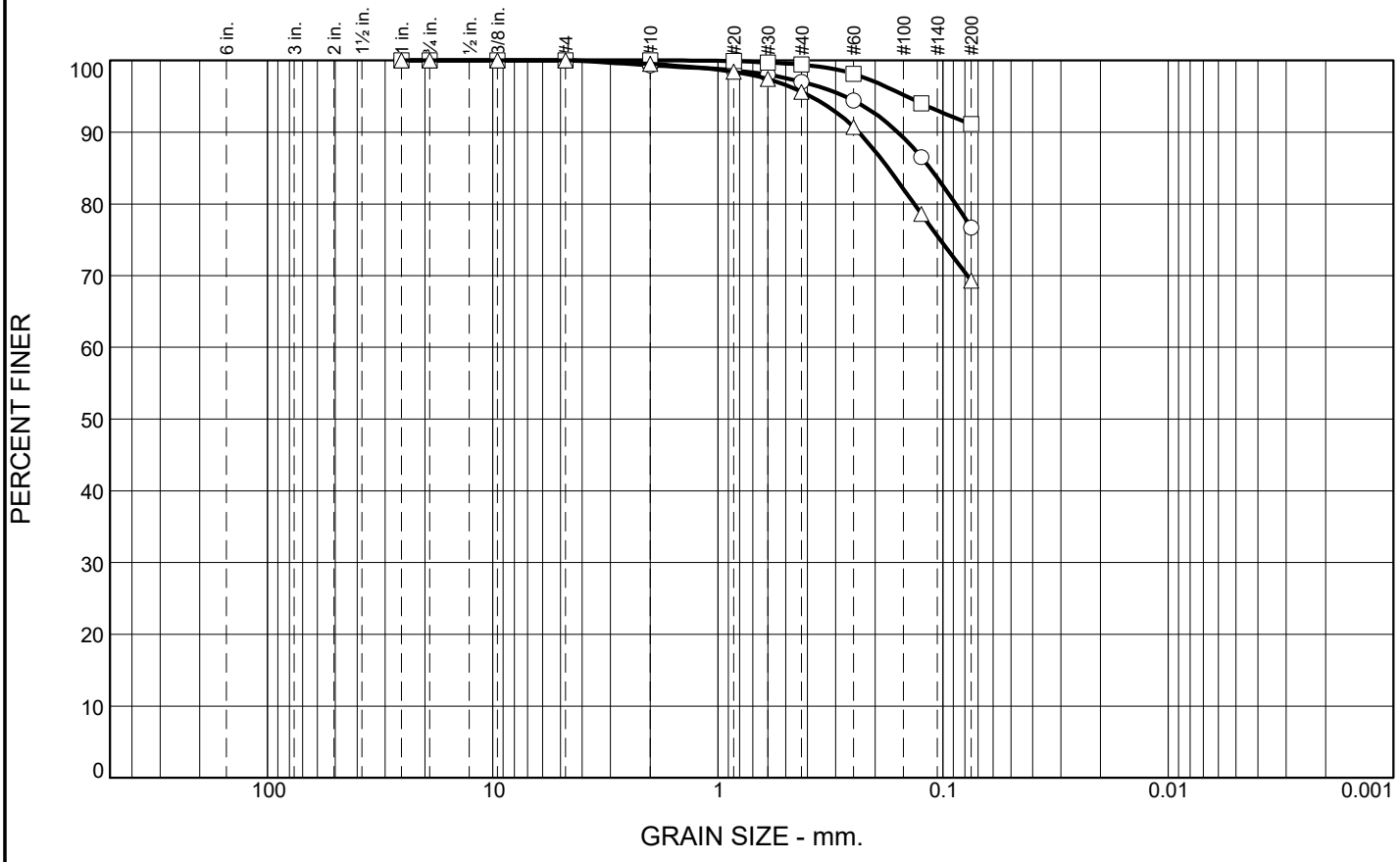
Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	0.0	23.3	76.7		ML	23	21	2
□	0.0	0.0	8.9	91.1		ML	49	31	18
△	0.0	0.0	30.7	69.3		CL-ML	25	20	5

SIEVE inches size	PERCENT FINER ○	□	△
1"	100.0	100.0	100.0
3/4"	100.0	100.0	100.0
3/8"	100.0	100.0	100.0
	GRAIN SIZE		
D_{60}			
D_{30}			
D_{10}			
	COEFFICIENTS		
C_c			
C_u			

SIEVE number size	PERCENT FINER ○	□	△
#4	100.0	100.0	100.0
#10	99.3	100.0	99.5
#20	98.6	99.9	98.4
#30	98.0	99.7	97.4
#40	97.0	99.4	95.6
#60	94.4	98.1	90.7
#120	86.5	94.0	78.6
#200	76.7	91.1	69.3

Material Description

○ SILT, little fine sand, trace medium sand.

□ SILT, trace fine sand.

△ CLAY/SILT, some fine sand, trace medium sand.

REMARKS:

○ Moisture Content as Recieved: 21.0%

□ Moisture Content as Recieved: 42.7%

△ Moisture Content as Received: 25.0%

○ Source of Sample: BH-2 Depth: 2'-4' Sample Number: S-2

□ Source of Sample: BH-2 Depth: 10'-12' Sample Number: T-1

△ Source of Sample: BH-2 Depth: 14'-15' Sample Number: S-7A

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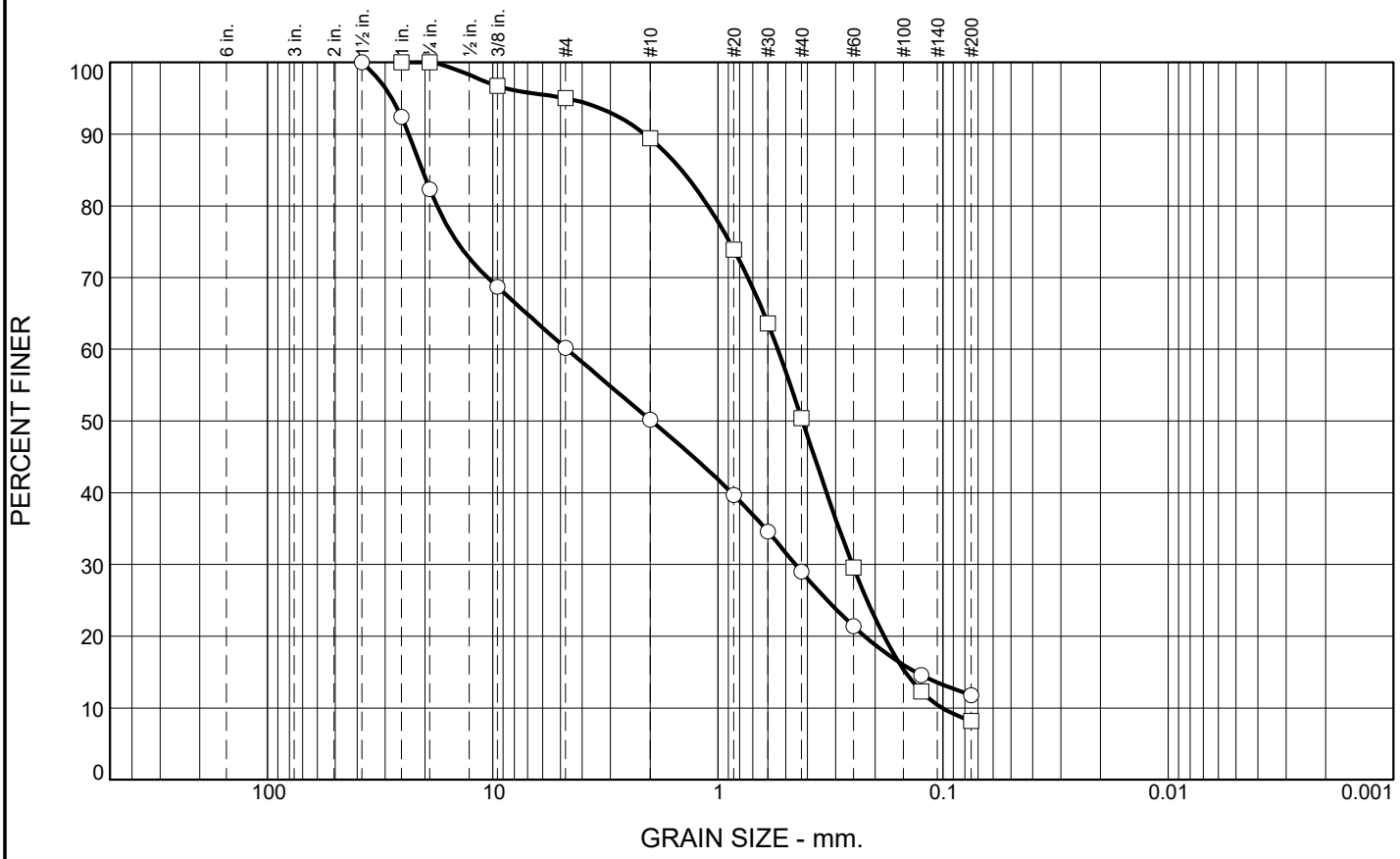
Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	39.8	48.4	11.8		GP-GM		NP	
□	0.0	5.0	86.8	8.2		SP-SM		NP	

SIEVE inches size	○	□
1 1/2"	100.0	
1"	92.4	100.0
3/4"	82.3	100.0
3/8"	68.7	96.7
GRAIN SIZE		
D_{60}	4.6704	0.5426
D_{30}	0.4522	0.2529
D_{10}		0.1009
COEFFICIENTS		
C_c		1.17
C_u		5.38

SIEVE number size	○	□
#4	60.2	95.0
#10	50.2	89.4
#20	39.7	73.9
#30	34.6	63.6
#40	29.0	50.4
#60	21.4	29.6
#120	14.6	12.3
#200	11.8	8.2

Material Description

○ Fine to coarse GRAVEL and medium to fine SAND, little silt, trace coarse sand.

□ Fine to medium SAND, trace silt, trace coarse sand, trace gravel.

REMARKS:

○ Moisture Content as Received: 9.6%

□ Moisture Content as Received: 13.6%

○ Source of Sample: BH-2 Depth: 16'-18' Sample Number: S-8

□ Source of Sample: BH-2 Depth: 20'-22' Sample Number: S-10

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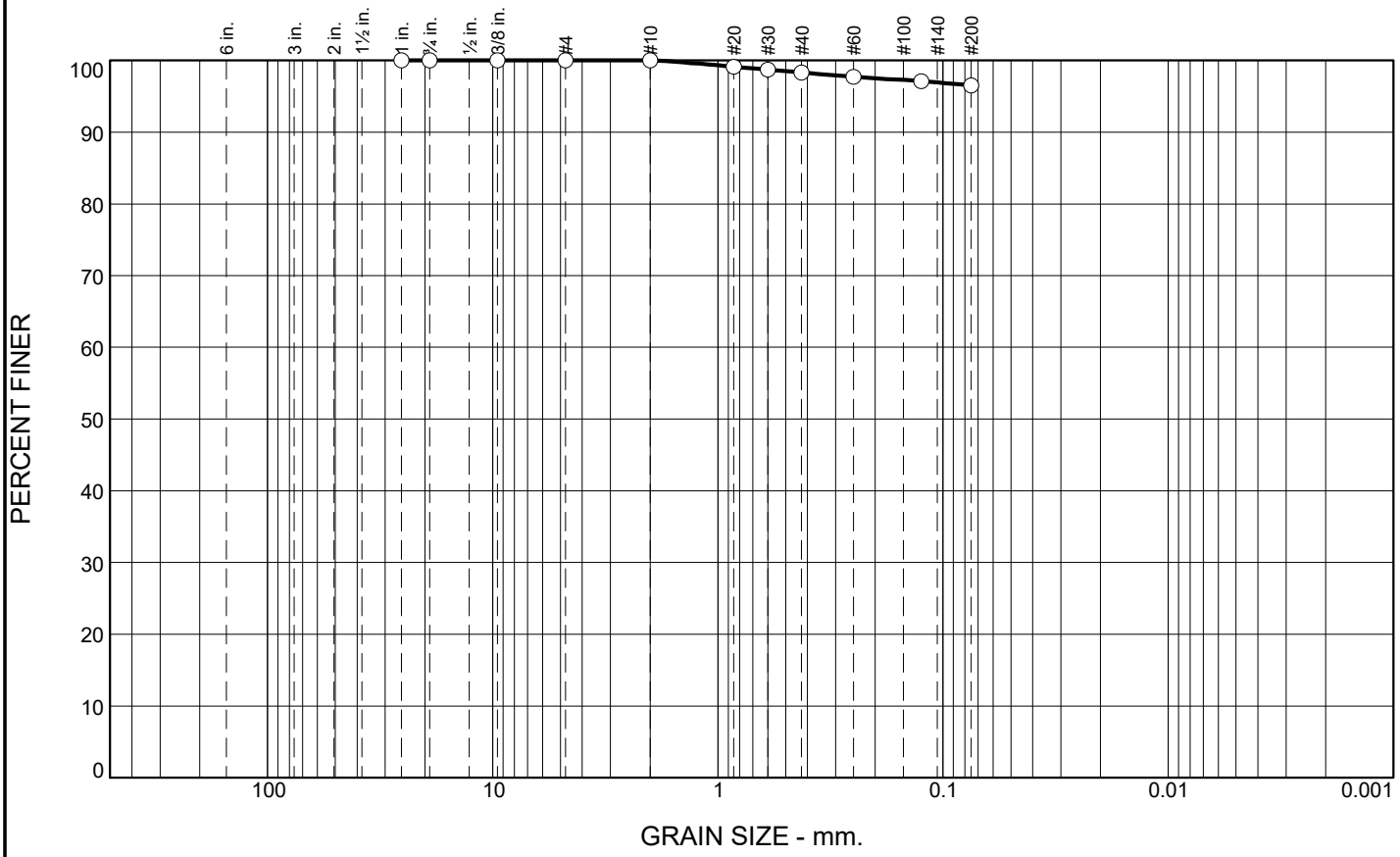
Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	0.0	3.5	96.5		MH	56	41	15

SIEVE inches size	PERCENT FINER ○		
1"	100.0		
3/4"	100.0		
3/8"	100.0		
	GRAIN SIZE		
D_{60}			
D_{30}			
D_{10}			
	COEFFICIENTS		
C_c			
C_u			

SIEVE number size	PERCENT FINER ○		
#4	100.0		
#10	100.0		
#20	99.1		
#30	98.7		
#40	98.3		
#60	97.7		
#120	97.1		
#200	96.5		

Material Description

○ SILT, trace fine to medium sand.

REMARKS:

○ Moisture Content as Received: 64.8%

○ Source of Sample: BH-3A Depth: 16'-18' Sample Number: S-9

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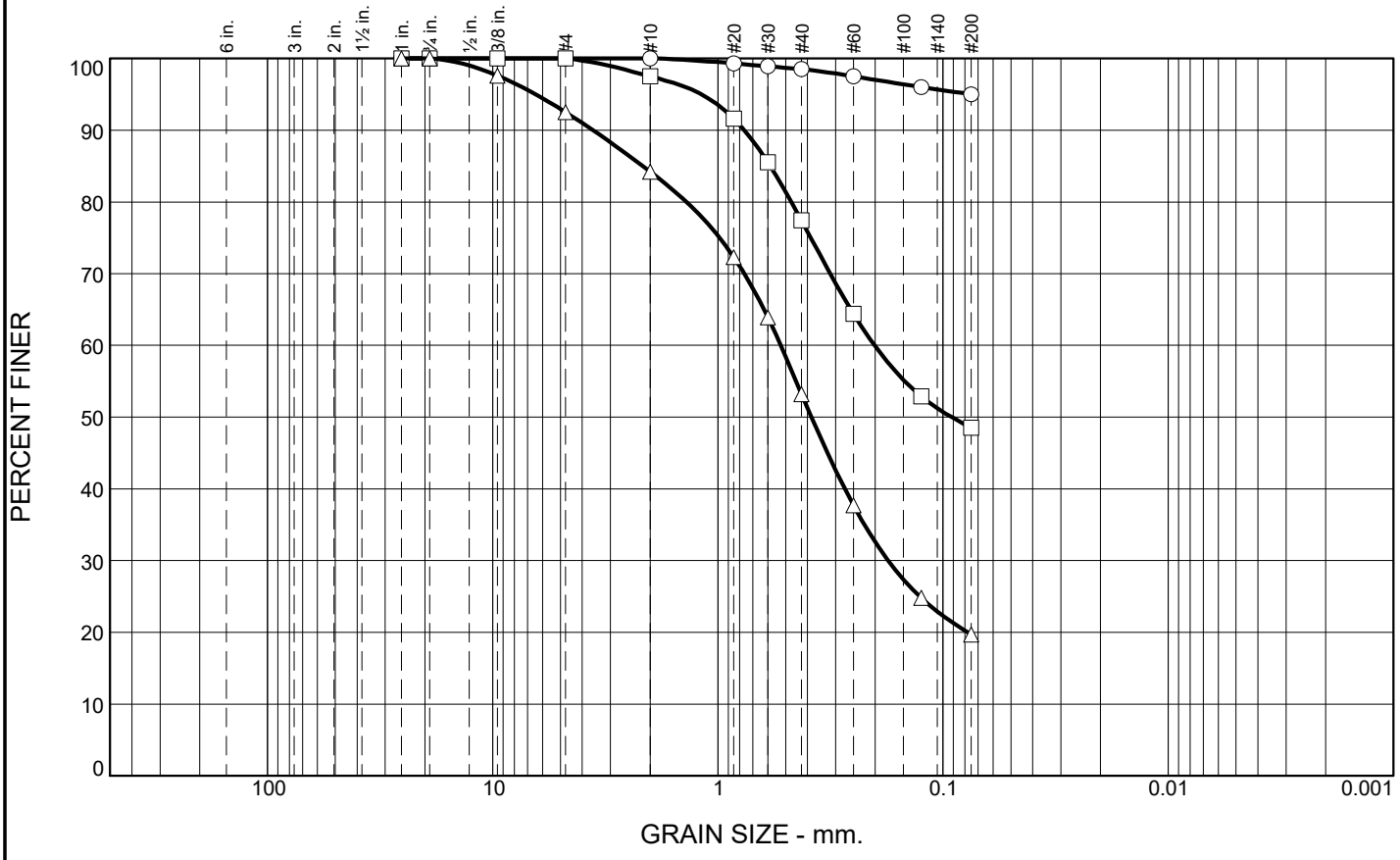
Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PL	PI
○	0.0	0.0	5.0	95.0		MH	113	65	48
□	0.0	0.0	51.5	48.5		SM	51	34	17
△	0.0	7.5	72.8	19.7		SM		NP	

SIEVE inches size	PERCENT FINER ○	□	△
1"	100.0	100.0	100.0
3/4"	100.0	100.0	100.0
3/8"	100.0	100.0	97.6
	GRAIN SIZE		
D_{60}		0.2014	0.5264
D_{30}			0.1752
D_{10}			
	COEFFICIENTS		
C_c			
C_u			

SIEVE number size	PERCENT FINER ○	□	△
#4	100.0	100.0	92.5
#10	100.0	97.5	84.2
#20	99.3	91.6	72.3
#30	98.9	85.5	63.9
#40	98.5	77.4	53.2
#60	97.5	64.4	37.7
#120	96.0	52.9	24.8
#200	95.0	48.5	19.7

Material Description

○ SILT, trace fine to medium sand.

□ Fine to medium SAND and SILT , trace coarse sand.

△ Fine to medium SAND, little silt, trace coarse sand, traced gravel.

REMARKS:

○ Moisture Content as Received: 80.3%

□ Moisture Content as Recieved: 50.8%

△ Moisture Content as Received: 18.0%

○ Source of Sample: BH-3D Depth: 19.5'-21.5' Sample Number: T-1

□ Source of Sample: BH-3D Depth: 27.5'-29.5' Sample Number: T-3

△ Source of Sample: BH-3D Depth: 30'-32' Sample Number: S-5

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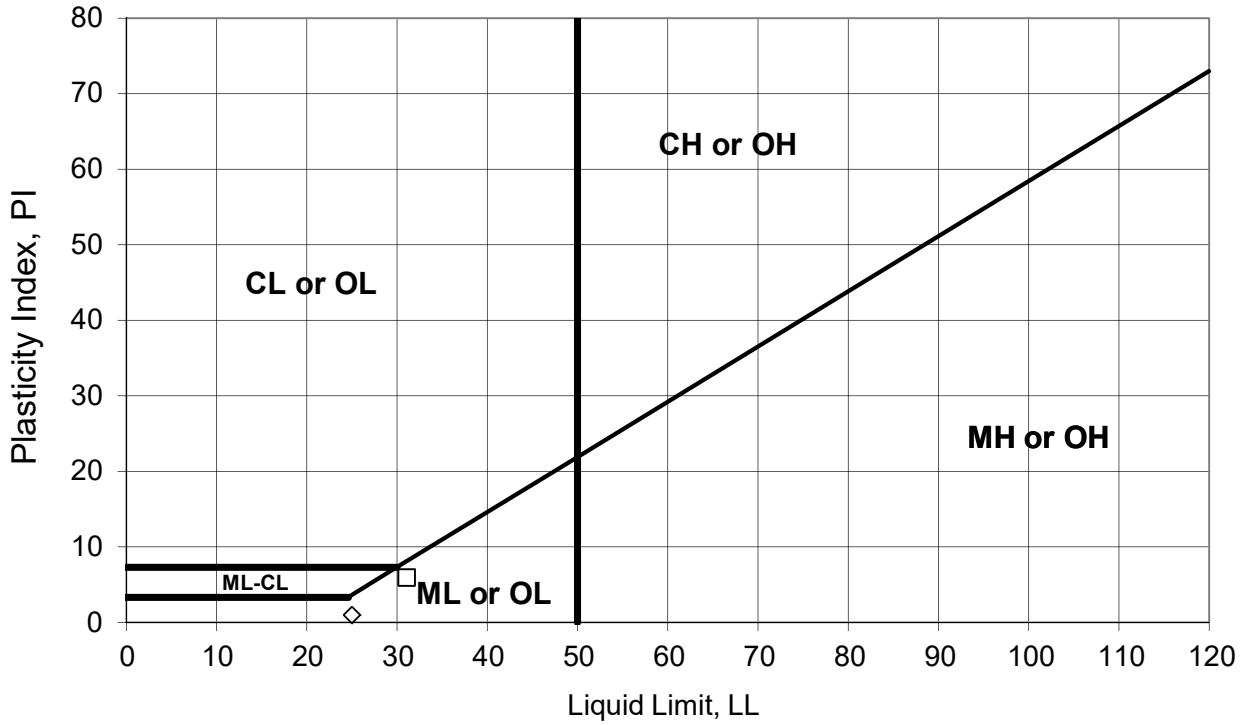
Project No.: 8919.GM Chkd: BJD 10/13

ATTERBERG LIMITS SUMMARY



Boring No.	Sample #	Depth (feet)	Description	Moisture Content	LL	PL	PI	USCS [1]	Symbol
BH-1	S-2	2 - 4	SILT, little fine sand, trace medium sand	21.3	31	25	6	ML	□
	S-3	4- 6	SILT, some fine sand, trace medium sand	23.8	25	24	1	ML	◇
	S-5	8 - 10	Medium to fine SAND, little silt, trace coarse sand, trace gravel.	21.5		NP		SM	×
	S-8A	13.5 - 14.5	Medium to fine SAND, little silt, little coarse sand, little gravel.	15.7		NP		SM	△
	S-10	17.5 - 19.5	Medium to fine SAND, little silt, trace coarse sand, trace gravel.	16.1		NP		SW-SM	✳
	S-14	25.5 - 27.5	Medium to fine SAND, little silt, trace coarse sand.	16.6		NP		SM	+

NOTES:

[1] USCS - Unified Soil Classification System

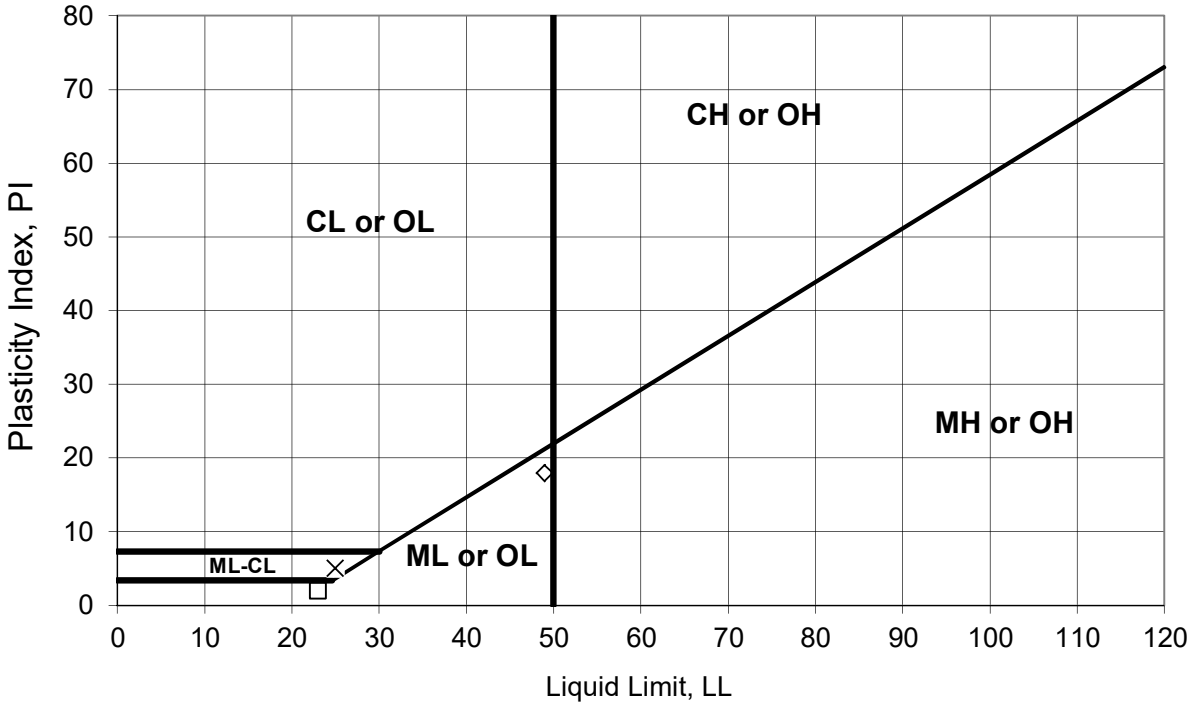
DUFFIELD ASSOCIATES

Client: US Army Corps of Engineers
Project: Subsurface Explortions at Eastwick Neighborhood, Philadelphia, Philadelphia County, Pennsylvania

USACE Contract No.: W912BU-11-D-0005, Task Order No. 0011

Project No.: 8919.GM Chk'd/Date: BJD /October 2013

ATTERBERG LIMITS SUMMARY



Boring No.	Sample #	Depth (feet)	Description	Moisture Content	LL	PL	PI	USCS [1]	Symbol
BH-2	S-2	2 - 4	SILT, little fine sand, trace medium sand.	21.0	23	21	2	ML	□
	T-1	10 - 12	SILT, trace fine sand	42.7	49	31	18	ML	◇
	S-7A	14 - 15	CLAY/SILT, some fine sand, trace medium sand.	25.0	25	20	5	CL-ML	×
	S-8	16 - 18	Fine to coarse GRAVEL, and medium to fine sand, little silt, trace coarse sand	9.6		NP		GP-GM	△
	S-10	20 - 22	Fine to medium SAND, trace silt, trace coarse sand, trace gravel.	13.6		NP		SP-SM	✳

NOTES:

[1] USCS - Unified Soil Classification System

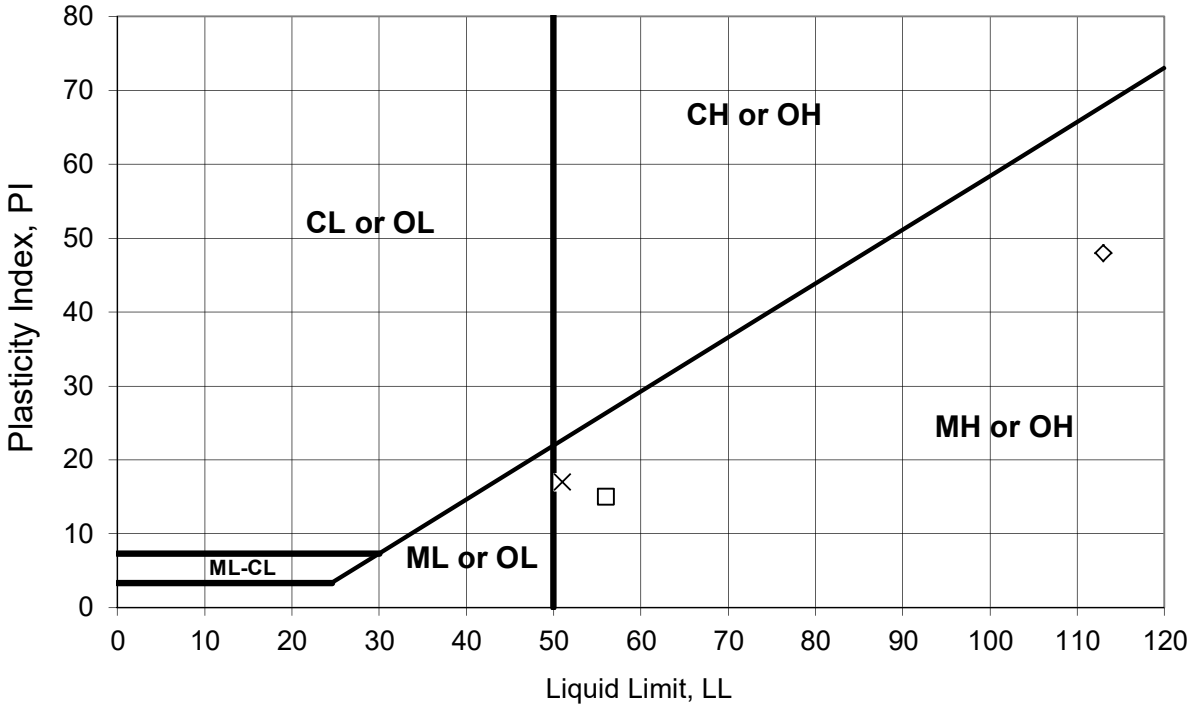
DUFFIELD ASSOCIATES

Client: US Army Corps of Engineers
Project: Subsurface Explortions at Eastwick Neighborhood, Philadelphia, Philadelphia County, Pennsylvania

USACE Contract No.: W912BU-11-D-0005, Task Order No. 0011

Project No.: 8919.GM Chk'd/Date: BJD /October 2013

ATTERBERG LIMITS SUMMARY



Boring No.	Sample #	Depth (feet)	Description	Moisture Content	LL	PL	PI	USCS [1]	Symbol
BH-3A	S-9	16 - 18	SILT, trace fine to medium sand.	64.8	56	41	15	MH	□
BH-3D	T-1	19.5 - 21.5	SILT, trace fine to medium sand.	80.3	113	65	48	MH	◇
	T-2	27.5 - 29.5	Fine to medium SAND and SILT, trace coarse sand.	50.8	51	34	17	SM	×
	S-5	30 - 32	Fine to medium SAND, little silt, trace coarse sand, trace gravel.	18.0		NP		SM	△

NOTES:

[1] USCS - Unified Soil Classification System

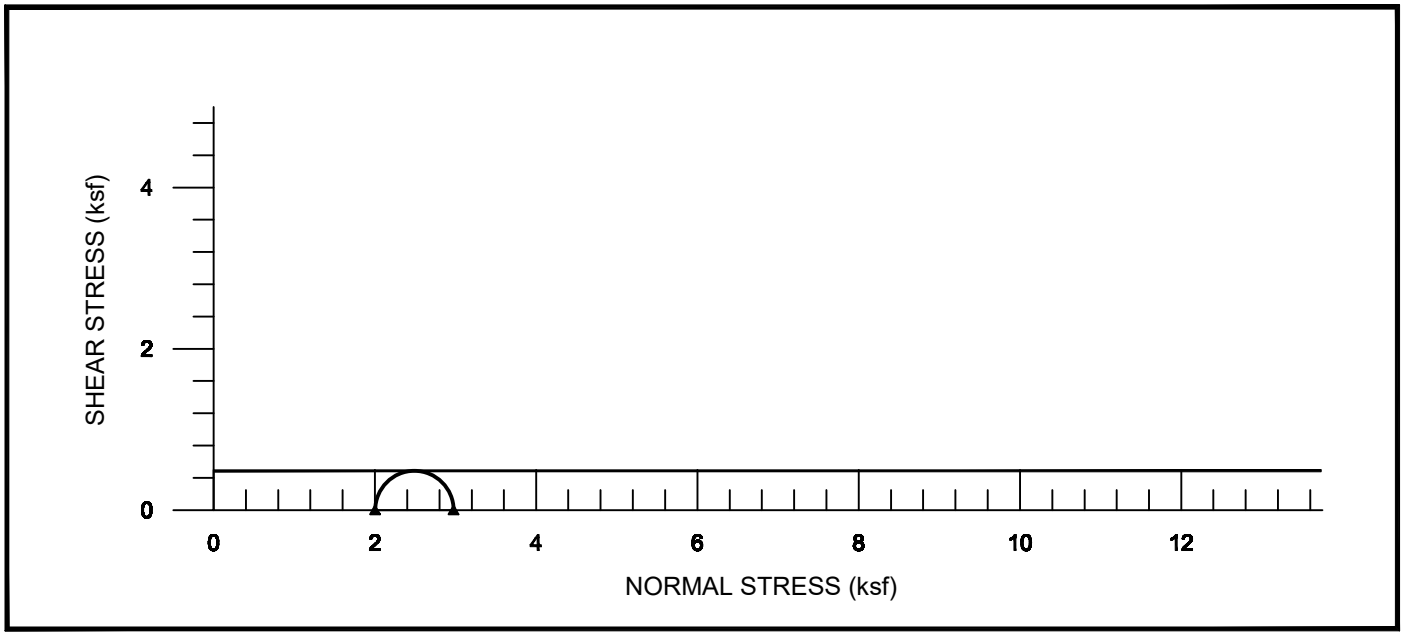
DUFFIELD ASSOCIATES

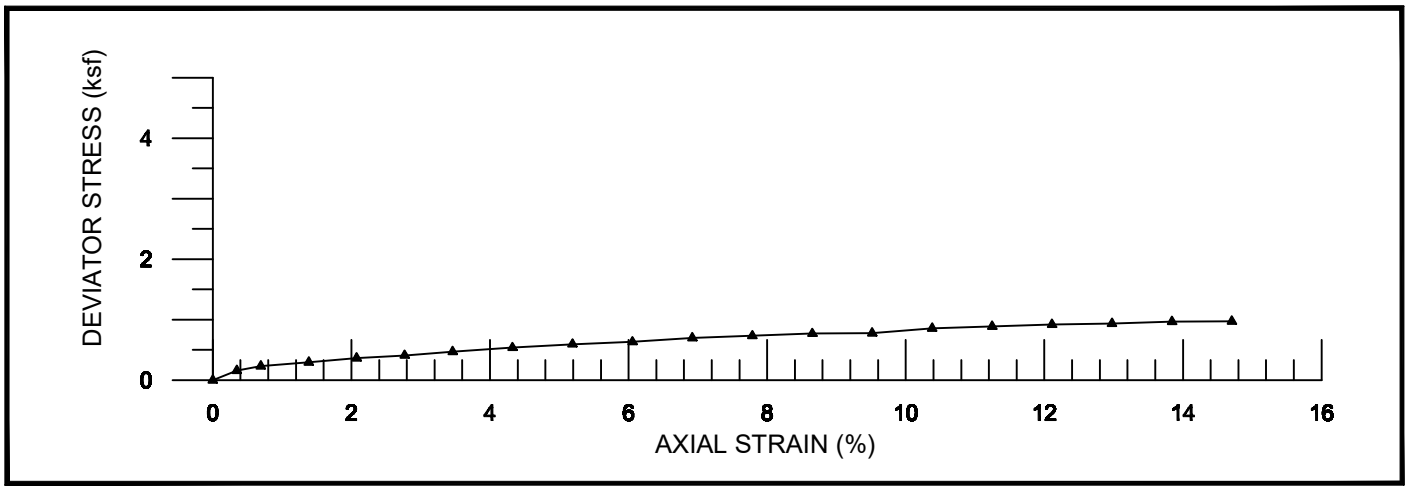
Client: US Army Corps of Engineers
Project: Subsurface Explortions at Eastwick Neighborhood, Philadelphia, Philadelphia County, Pennsylvania

USACE Contract No.: W912BU-11-D-0005, Task Order No. 0011

Project No.: 8919.GM Chk'd/Date: BJD /October 2013

TRIAXIAL COMPRESSION TEST, "Q" (ASTM D2850)





c = 0.49 (ksf)

Sample No.: 1

Minor Principal Stress (ksf): 2.00
Max. Deviator Stress (ksf): 0.97

Initial Height (in.): 2.89
Initial Diameter (in): 1.40

Saturation B Parameter (%): 100.0
Initial Moisture (%): 52.7
Dry Unit Weight (pcf): 66.7
Final Moisture (%): 45.2

Failure Sketch:



Sample Identification: BH-2: T-1 (10'-12')
Sample Description: Dark gray SILT, trace fine sand.

% Passing No. 200 Sieve: 91.1
Liquid Limit: 49
Plastic Limit: 31
Plastic Index: 18
USCS Class: ML

Checked by/Date: BJD /October 2013

LEGEND:
▲ Sample 1

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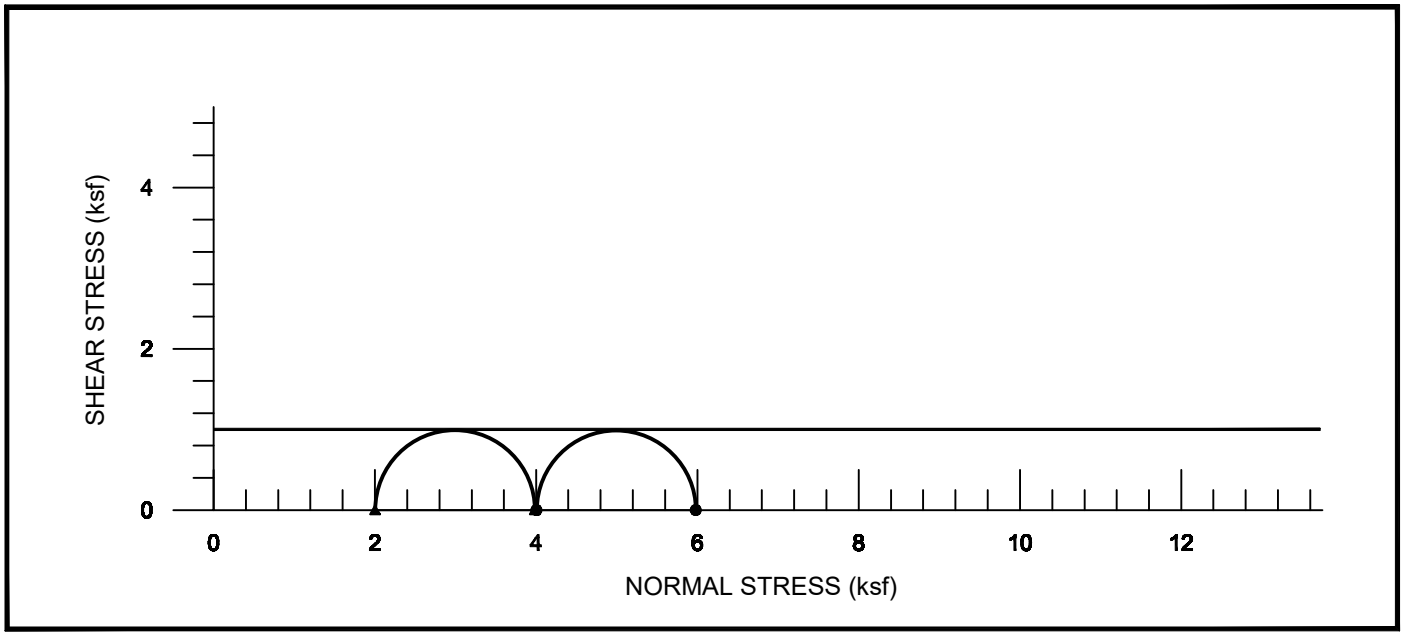
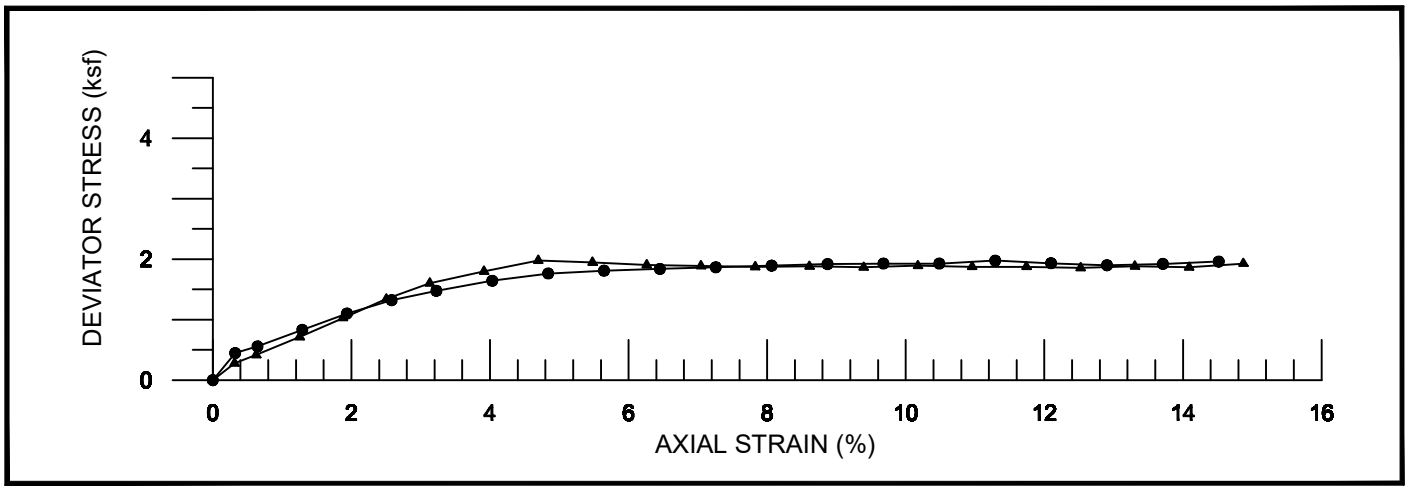
Client: U.S. Army Corps of Engineers
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania.
(USACE Contract No. W912BU-11-D-0005, Task Order 0011)
Project No.: 8919.GM

TRIAXIAL COMPRESSION TEST, "Q" (ASTM D2850)





c = 0.99 (ksf)

Sample No.:	1	2
Minor Principal Stress (ksf):	2.00	4.00
Max. Deviator Stress (ksf):	1.98	1.98
Initial Height (in.):	3.19	3.10
Initial Diameter (in):	1.40	1.40
Saturation B Parameter (%):	100.0	99.0
Initial Moisture (%):	80.7	92.7
Dry Unit Weight (pcf):	50.9	46.3
Final Moisture (%):	91.0	99.1
Failure Sketch:		

Sample Indentification: BH-3D: T-1 (19.5'-21.5')
Sample Description: Grayish Brown SILT, trace fine to medium sand.

% Passing No. 200 Sieve:	95.0
Liquid Limit:	113
Plastic Limit:	65
Plastic Index:	48
USCS Class:	MH

Checked by/Date: BJD /October 2013

LEGEND:
- ▲ Sample 1
- ● Sample 2

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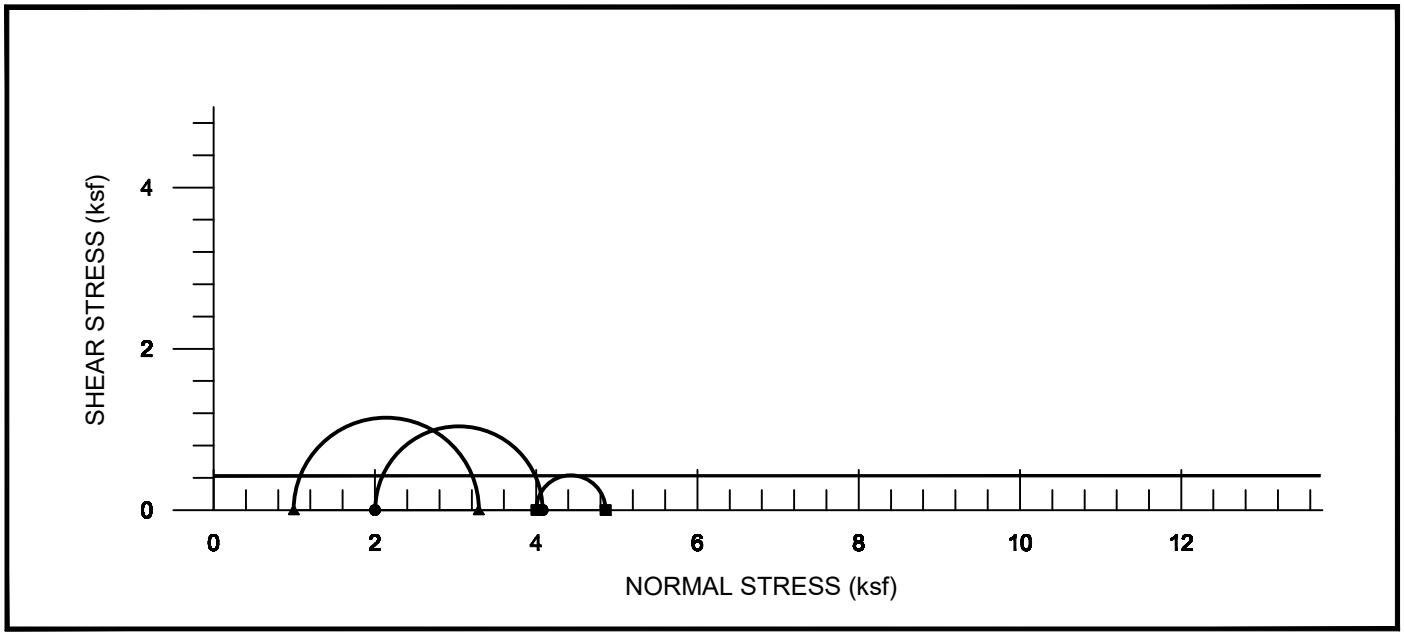
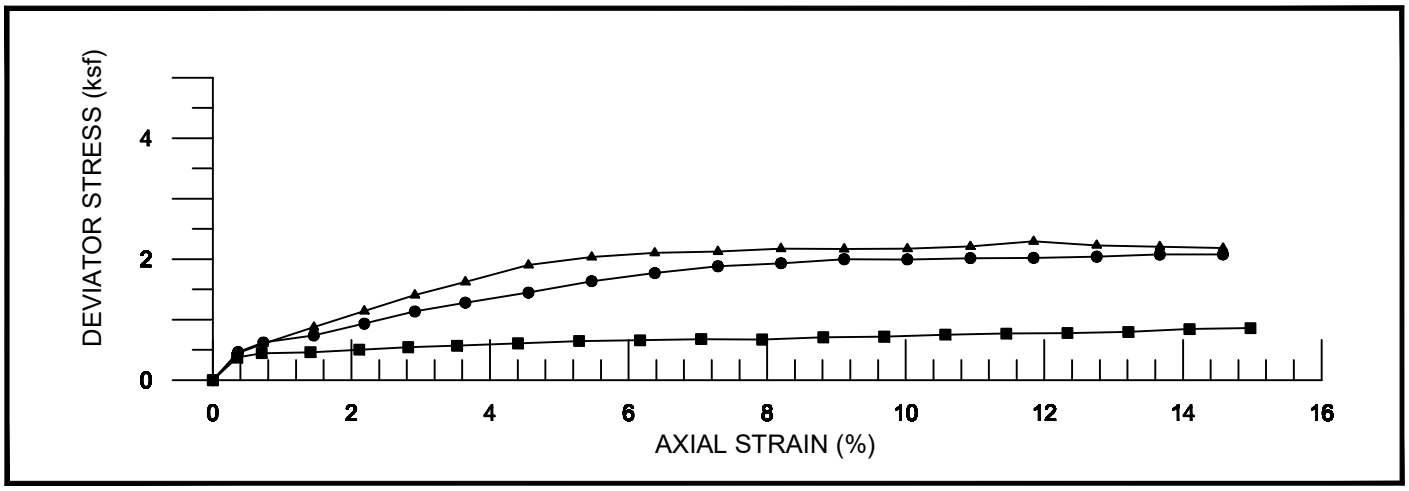
TRIAXIAL COMPRESSION TEST, "Q" (ASTM D2850)





c = 0.43 (ksf)

Sample No.:	1	2	3
Minor Principal Stress (ksf):	1.00	2.00	4.00
Max. Deviator Stress (ksf):	2.29	2.08	0.86
Initial Height (in.):	2.74	2.74	2.84
Initial Diameter (in):	1.40	1.40	1.40
Saturation B Parameter (%):	100.0	100.0	100.0
Initial Moisture (%):	99.8	104.2	101.5
Dry Unit Weight (pcf):	44.5	42.7	42.5
Final Moisture (%):	101.3	107.2	102.2

Failure Sketch:



Sample Indentification: BH-3: T-3 (27.5'-29.5')
Sample Description: Greenish Gray fine to medium SAND and SILT, trace coarse sand.

% Passing No. 200 Sieve:	48.5
Liquid Limit:	51
Plastic Limit:	34
Plastic Index:	17
USCS Class:	SM

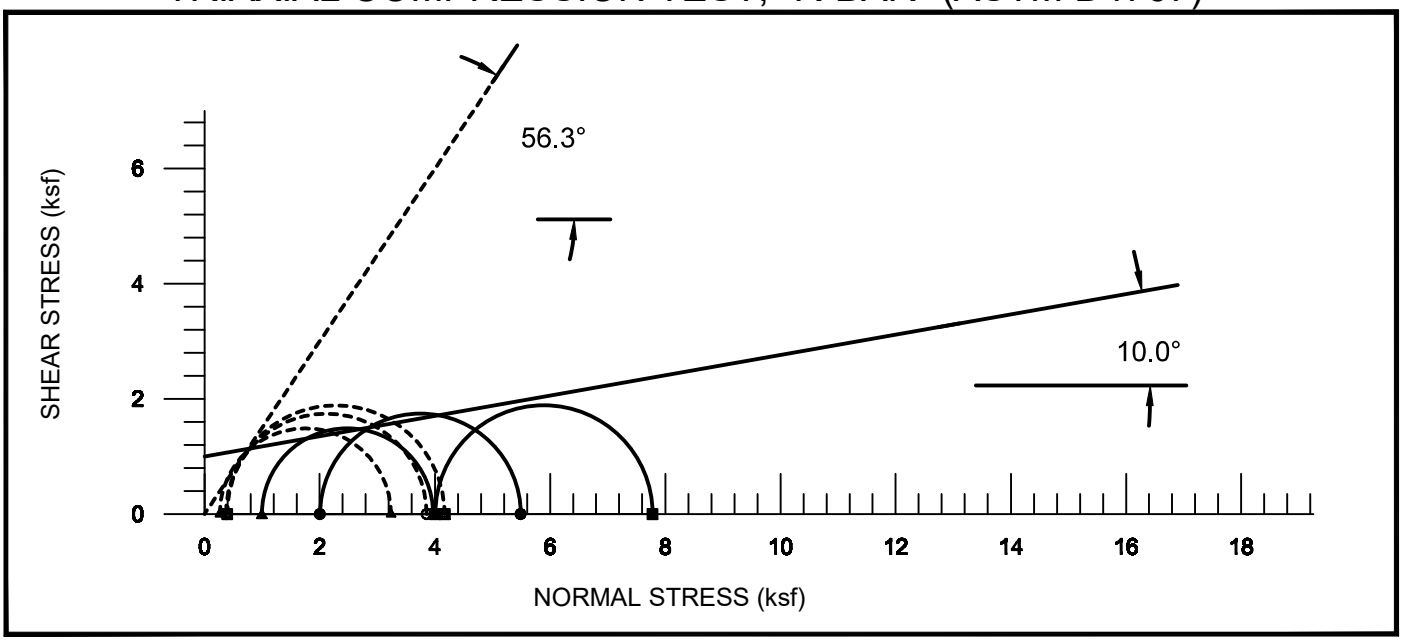
Checked by/Date: BJD /October 2013

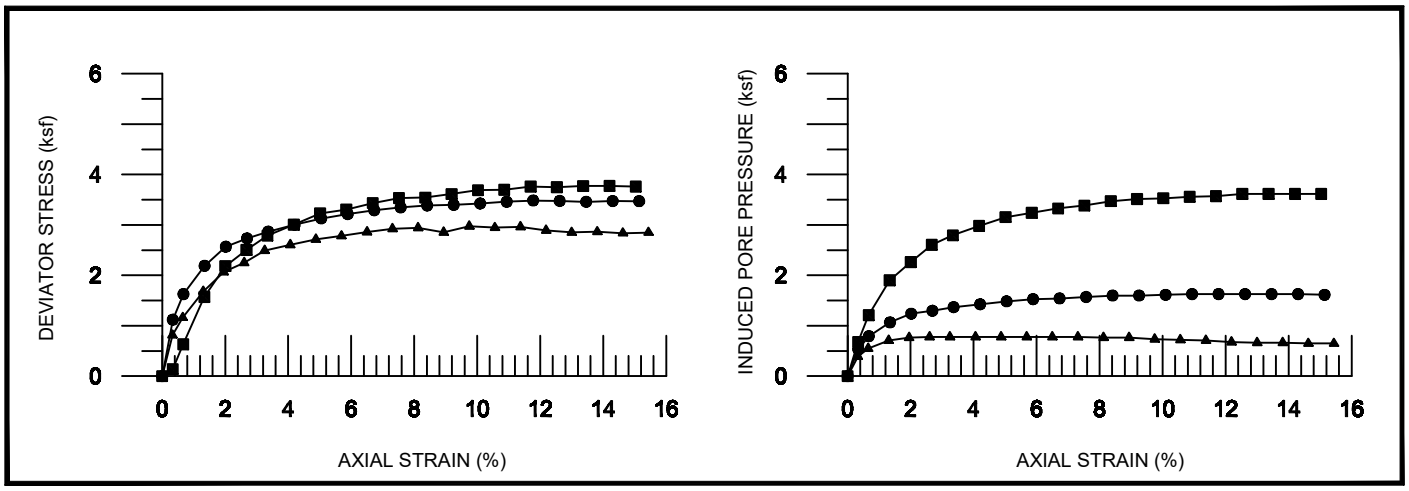
LEGEND:
- ▲ Sample 1
- ● Sample 2
- ■ Sample 3

DUFFIELD ASSOCIATES

Client: U.S. Army Corps of Engineers
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania.
(USACE Contract No. W912BU-11-D-0005, Task Order 0011)
Project No.: 8919.GM

TRIAXIAL COMPRESSION TEST, "R-BAR" (ASTM D4767)





ϕ = 10.0° ϕ' = 56.3°
c = 1.00 (ksf) c' = 0.00 (ksf)

Sample No.:	1	2	3
Minor Principal Stress (ksf):	1.00	2.00	4.00
Max. Deviator Stress (ksf):	2.97	3.48	3.77
Initial Height (in.):	3.12	3.06	3.11
Initial Diameter (in):	1.40	1.40	1.40
Consolidated Height (in.):	3.08	2.97	2.99
Saturation B Parameter (%):	100.0	100.0	100.0
Initial Moisture (%):	76.8	83.6	102.0
Dry Unit Weight (pcf):	52.4	49.5	43.1
Final Moisture (%):	78.2	79.0	90.3
Failure Sketch:			

Sample Indentification: BH-3D: T-1 (19.5'-21.5')
Sample Description: Grayish brown SILT, trace fine to medium sand.

% Passing No. 200 Sieve:	95.0
Liquid Limit:	113
Plastic Limit:	65
Plastic Index:	48
USCS Class:	MH

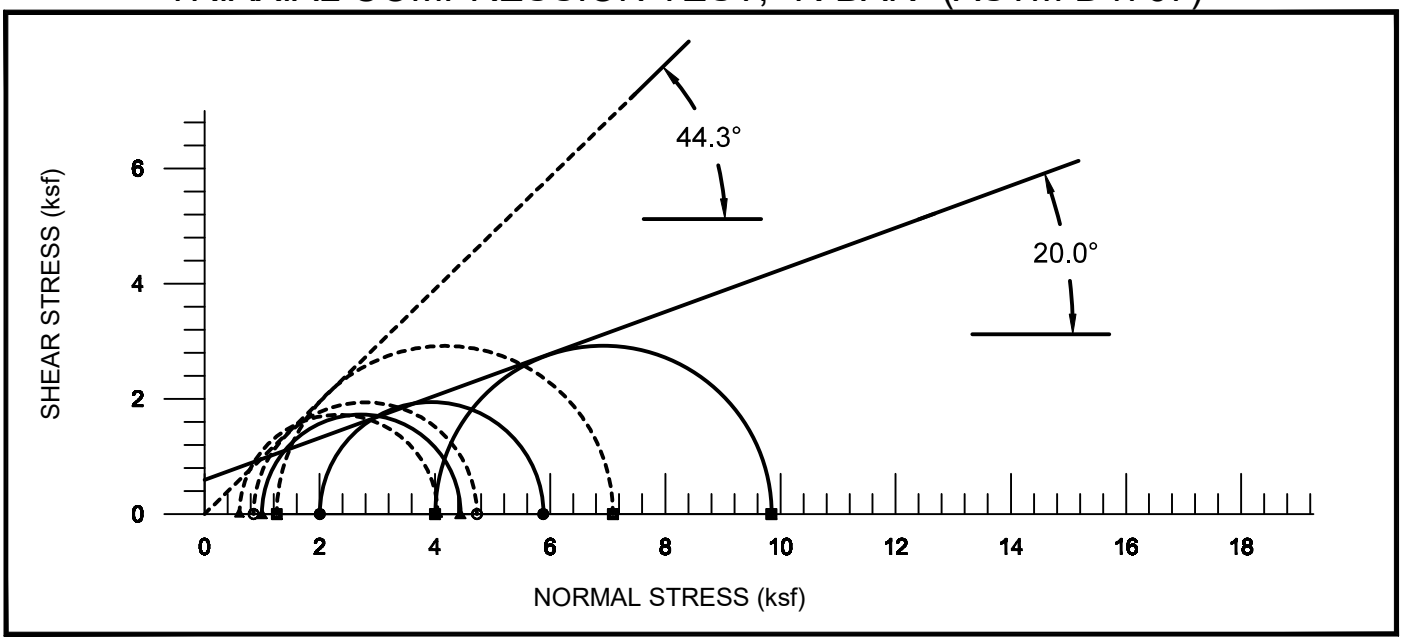
Checked by/Date: BJD /October 2013

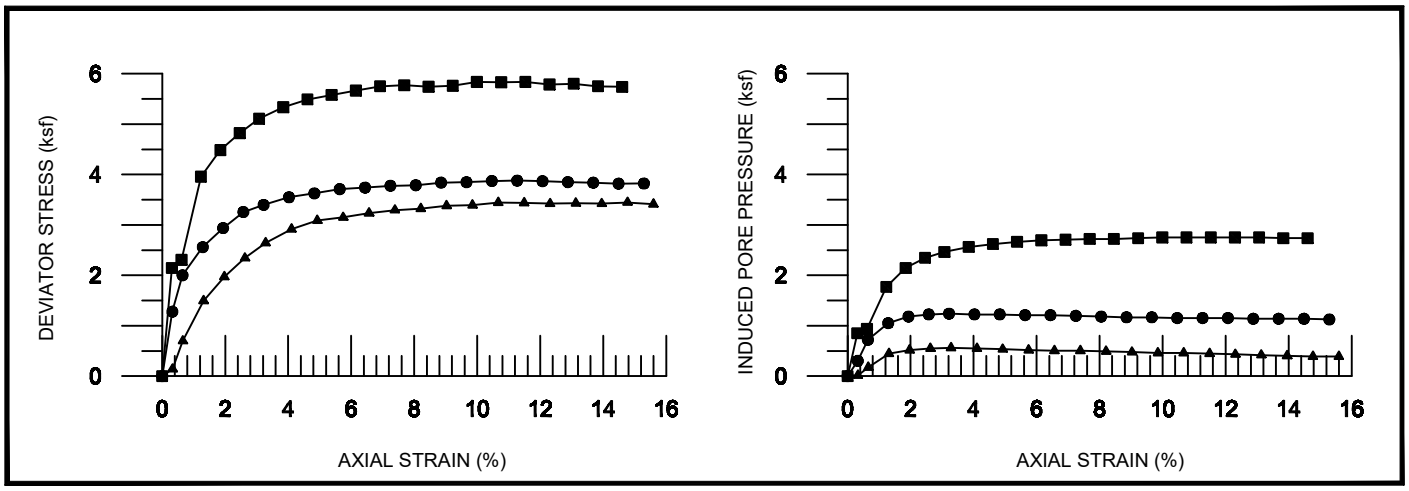
LEGEND:
- Sample 1
- Sample 2
- Sample 3

DUFFIELD ASSOCIATES

Client: U.S. Army Corps of Engineers
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania.
(USACE Contract No. W912BU-11-D-0005, Task Order 0011)
Project No.: 8919.GM

TRIAXIAL COMPRESSION TEST, "R-BAR" (ASTM D4767)

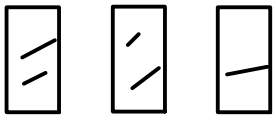




ϕ = 20.0° ϕ' = 44.3°
c = 0.60 (ksf) c' = 0.00 (ksf)

Sample No.:	1	2	3
Minor Principal Stress (ksf):	1.00	2.00	4.00
Max. Deviator Stress (ksf):	3.45	3.88	5.84
Initial Height (in.):	3.08	3.13	3.29
Initial Diameter (in):	1.40	1.40	1.40
Consolidated Height (in.):	3.05	3.11	3.25
Saturation B Parameter (%):	100.0	100.0	100.0
Initial Moisture (%):	50.8	26.7	39.5
Dry Unit Weight (pcf):	68.2	93.8	80.6
Final Moisture (%):	45.6	26.7	31.8

Failure Sketch:



Sample Indentification: BH-3D: T-3 (27.5'-29.5')
Sample Description: Greenish gray fine to medium SAND and SILT, trace coarse sand.

% Passing No. 200 Sieve:	48.5
Liquid Limit:	51
Plastic Limit:	34
Plastic Index:	17
USCS Class:	SM

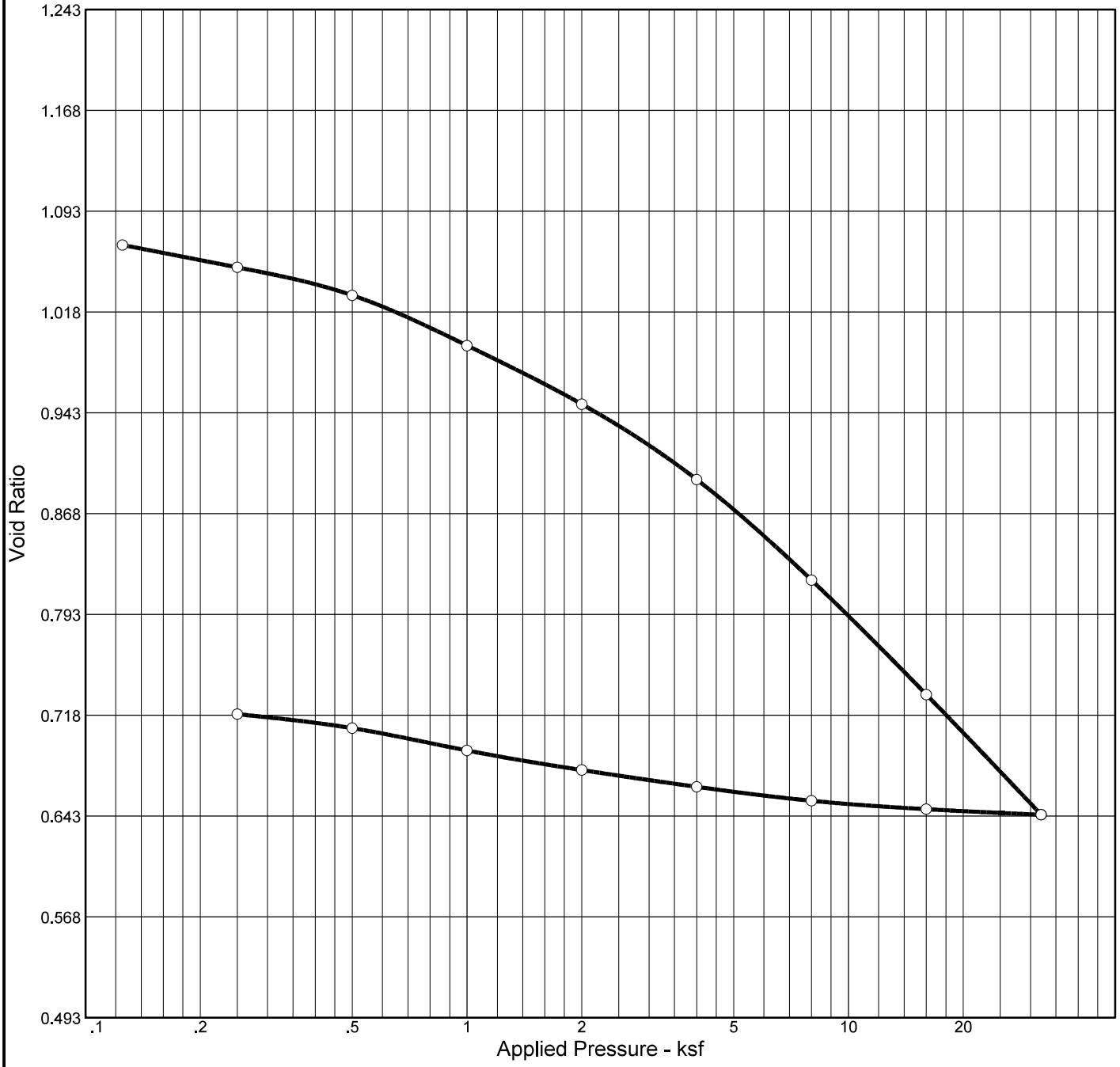
Checked by/Date: BJD /October 2013

LEGEND:
- Sample 1
- Sample 2
- Sample 3

DUFFIELD ASSOCIATES

Client: U.S. Army Corps of Engineers
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania.
(USACE Contract No. W912BU-11-D-0005, Task Order 0011)
Project No.: 8919.GM

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_r	Initial Void Ratio
Saturation	Moisture									
105.0 %	42.7 %	79.6	49	18	2.65		1.01	0.28	0.04	1.078

MATERIAL DESCRIPTION	USCS	AASHTO
SILT, trace fine sand.	ML	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

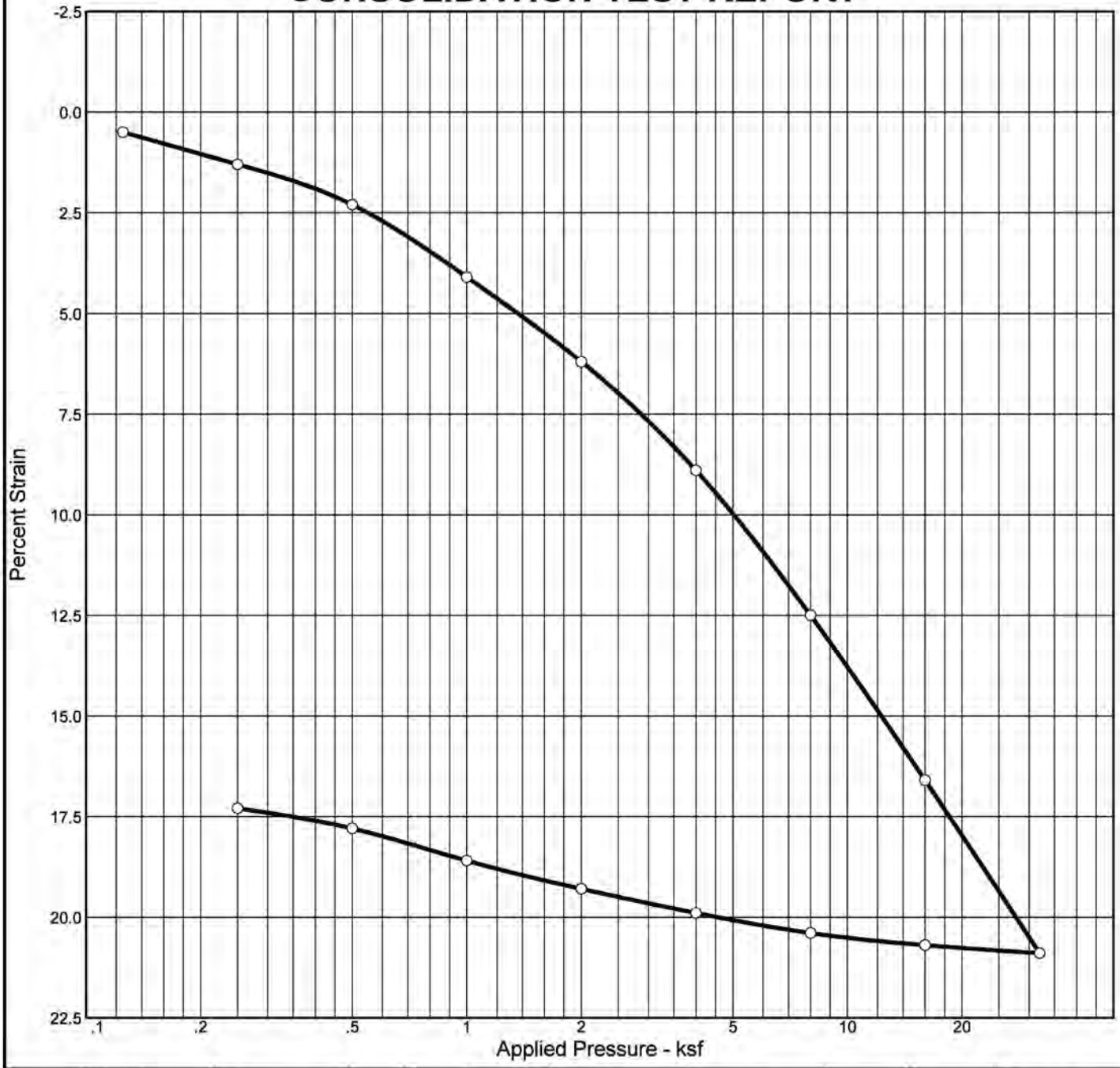
Source: BH-2 **Sample No.:** T-1 **Elev./Depth:** 10'-12'

Remarks:

DUFFIELD ASSOCIATES
5400 Limestone Rd
Wilmington, DE 19808
P. 302.239.6634
F. 302.239.8485
email: duffield@duffnet.com

Chkd: BJD 10/13

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C'_c	C'_r	Initial Void Ratio
Saturation	Moisture									
105.0 %	42.7 %	79.6	49	18	2.65		1.01	0.14	0.03	1.078

MATERIAL DESCRIPTION	USCS	AASHTO
SILT, trace fine sand.	ML	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-2 **Sample No.:** T-1 **Elev./Depth:** 10'-12'

Remarks:

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email: duffield@duffnet.com

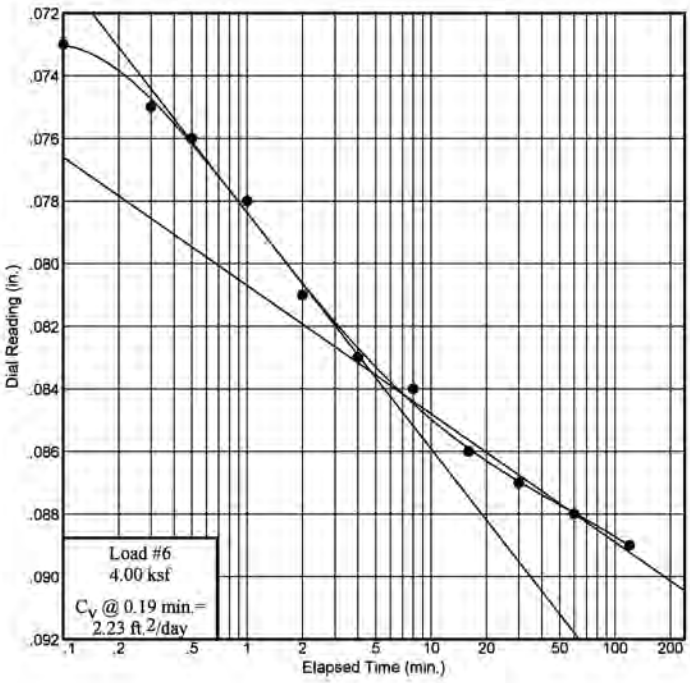
Chkd:

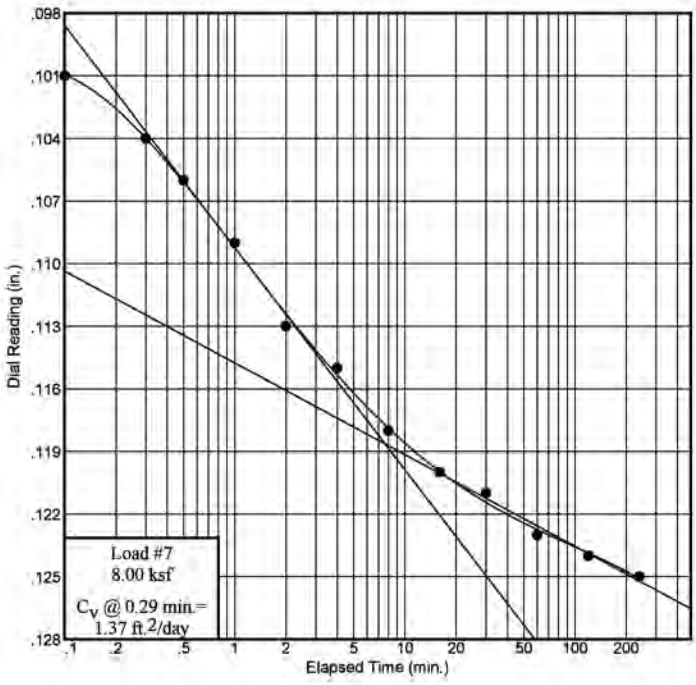
Dial Reading vs. Time

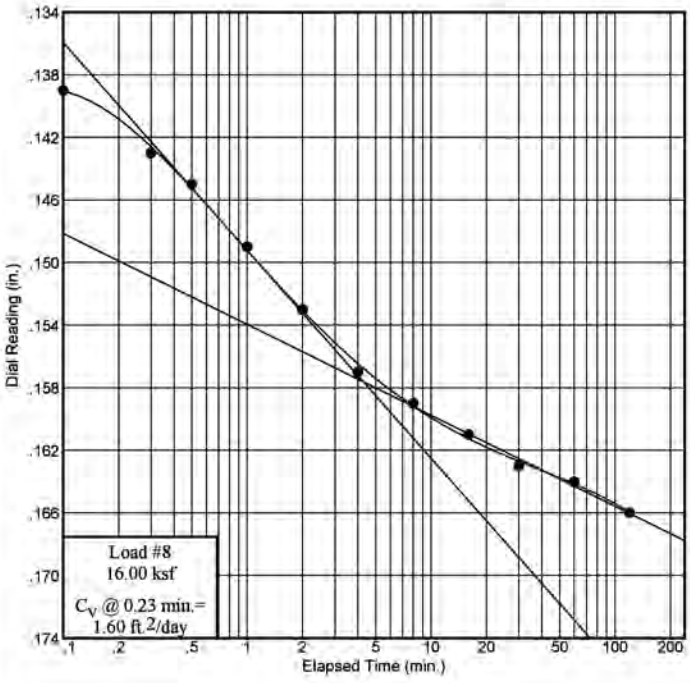
Project No.: 8919.GM

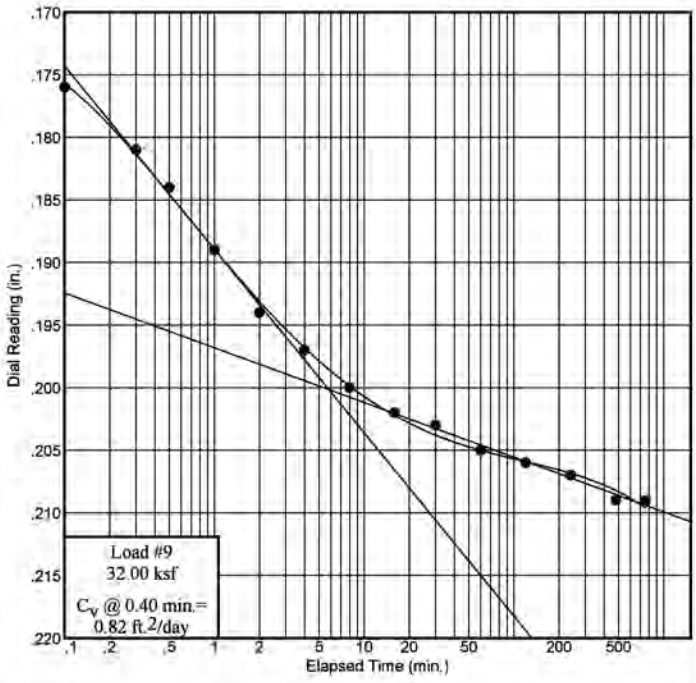
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-2 Sample No.: T-1 Elev./Depth: 10'-12'









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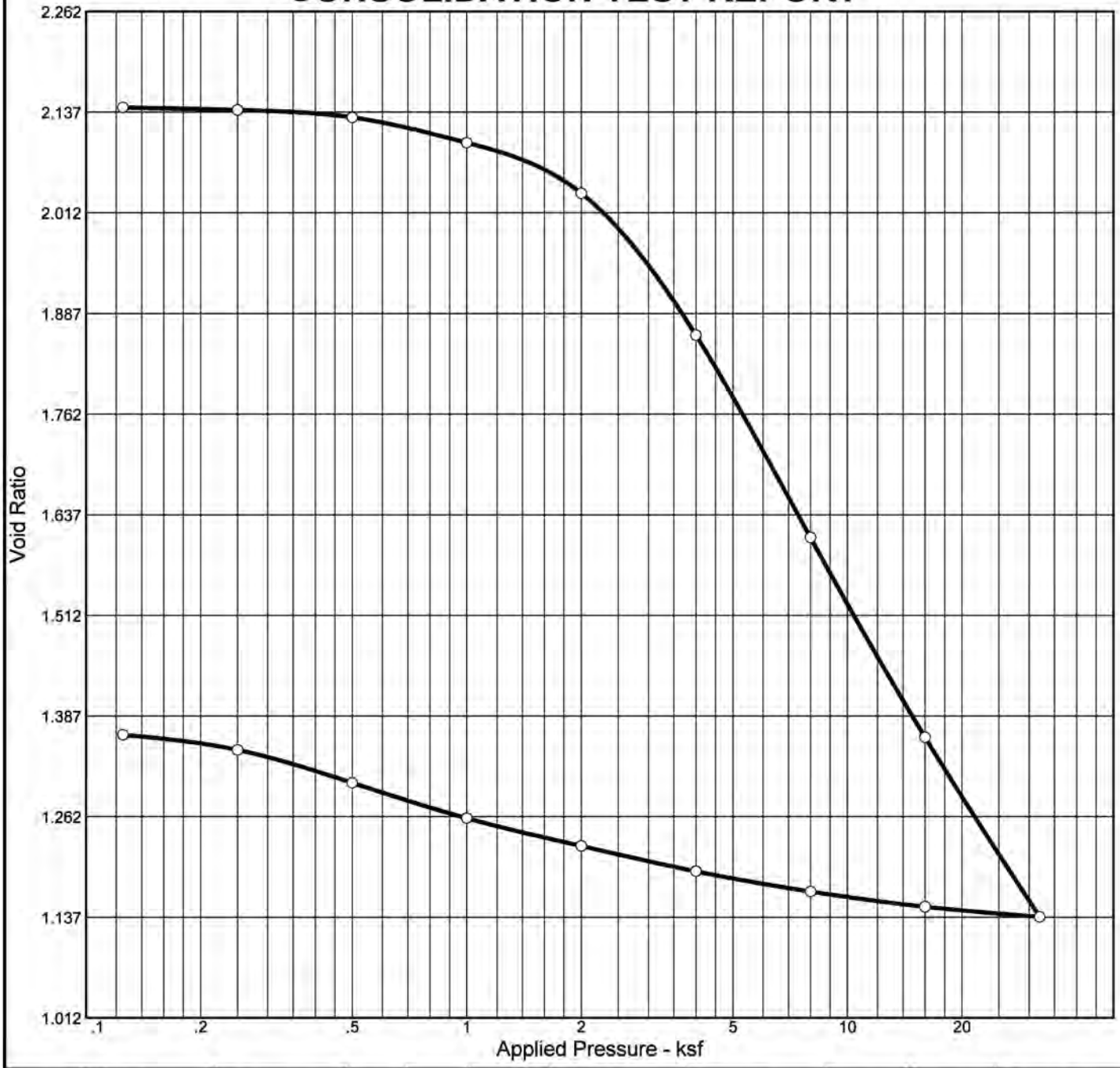
Chkd:

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_r	Initial Void Ratio
Saturation	Moisture									
99.3 %	80.3 %	52.6	113	48	2.65		2.80	0.79	0.09	2.143

MATERIAL DESCRIPTION	USCS	AASHTO
SILT, trace fine to medium sand.	MH	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D **Sample No.:** T-1 **Elev./Depth:** 19.5'-21.5'

Remarks:

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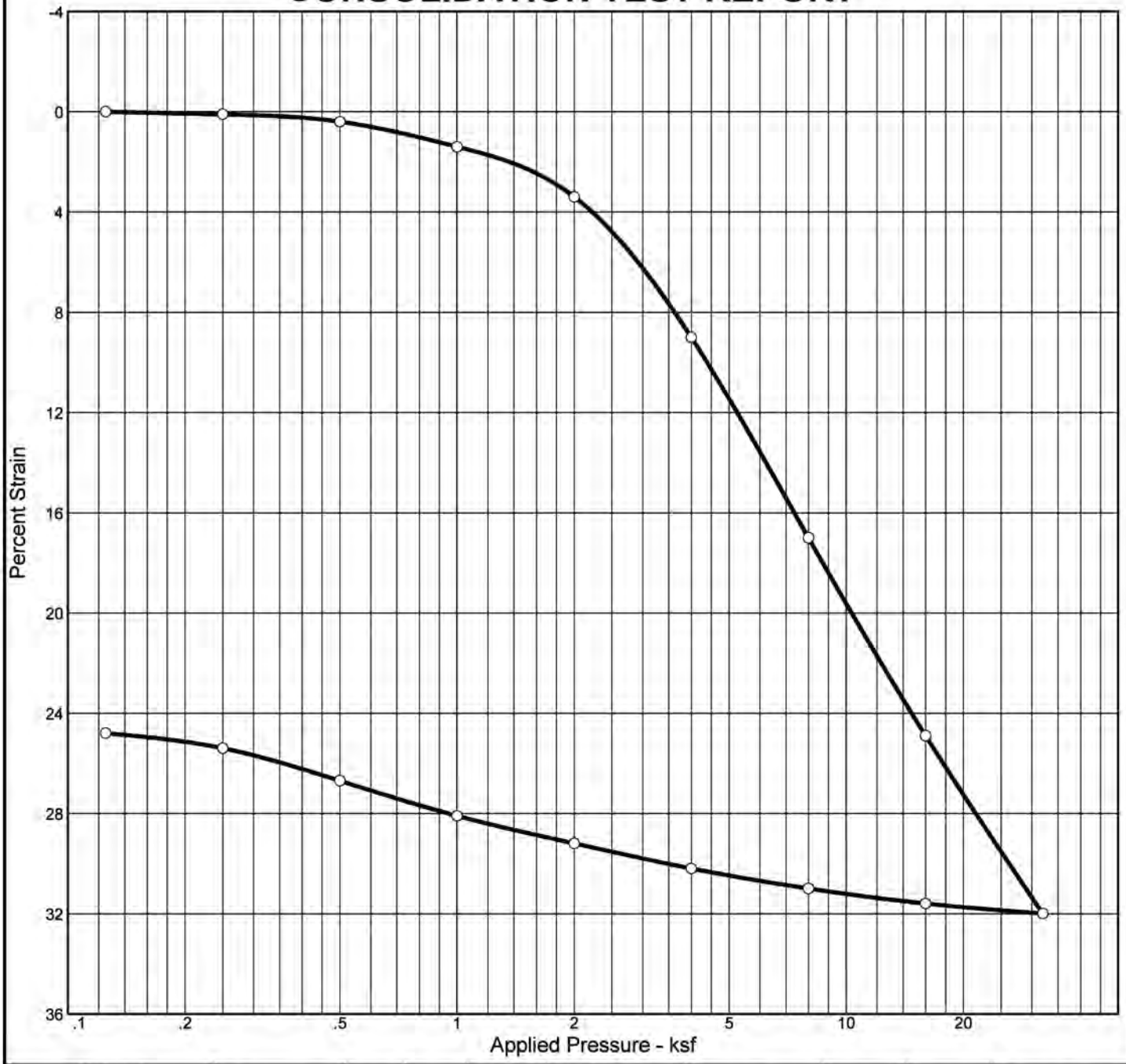
email: duffield@duffnet.com

Chkd: BJD 10/13

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C'_c	C'_r	Initial Void Ratio
Saturation	Moisture									
99.3 %	80.3 %	52.6	113	48	2.65		2.80	0.25	0.05	2.143

MATERIAL DESCRIPTION	USCS	AASHTO
SILT, trace fine to medium sand.	MH	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D **Sample No.:** T-1 **Elev./Depth:** 19.5'-21.5'

Remarks:

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F. 302.239.8485
email: duffield@duffnet.com

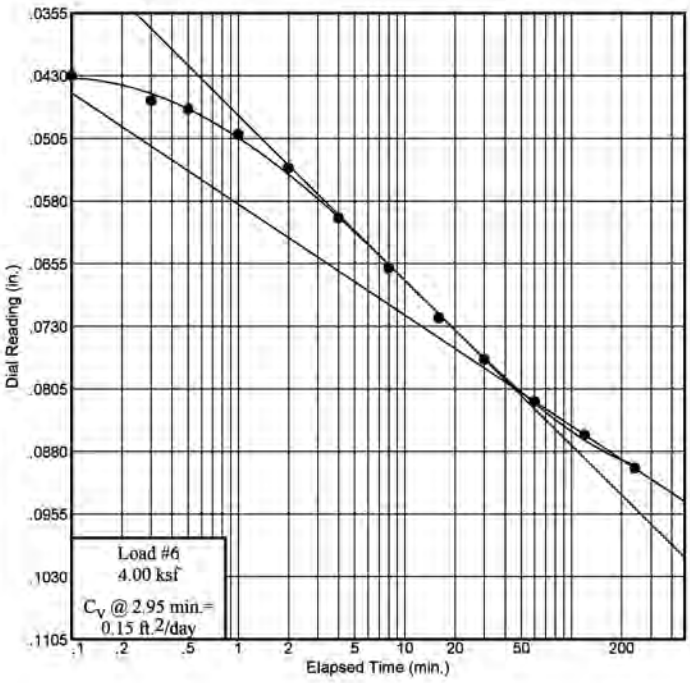
Chkd:

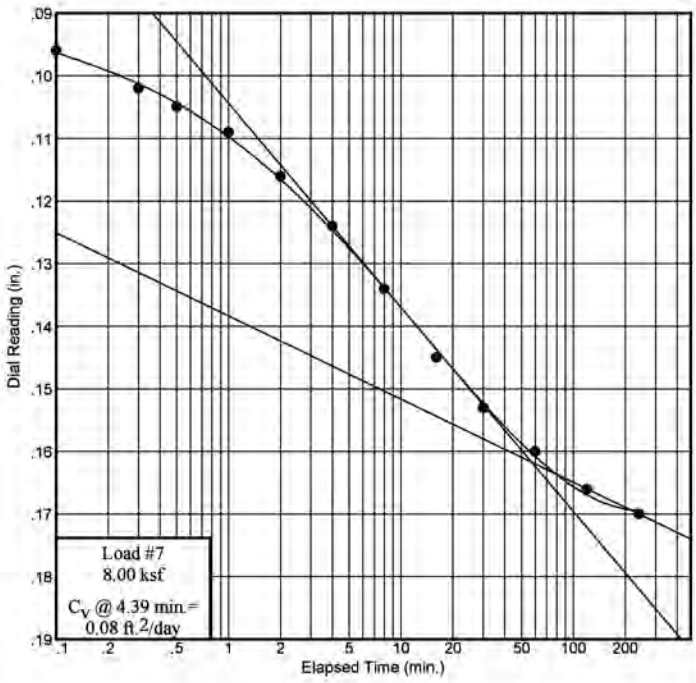
Dial Reading vs. Time

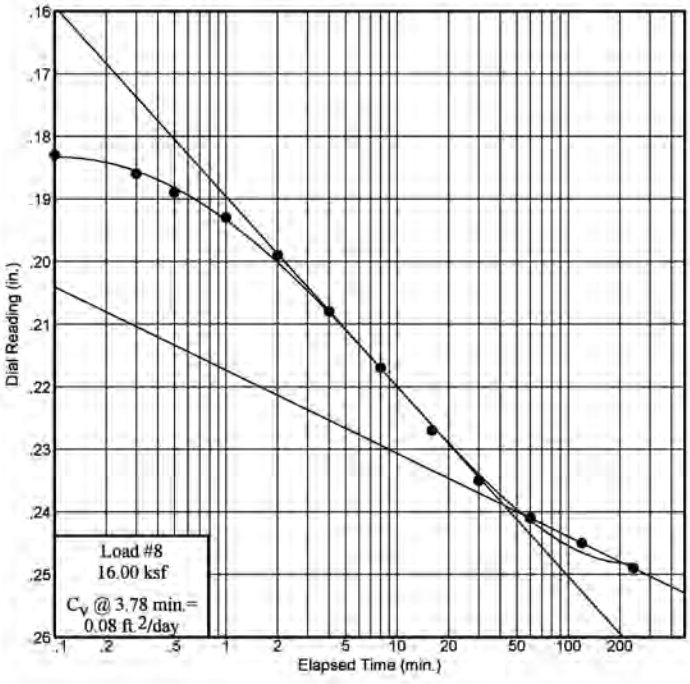
Project No.: 8919.GM

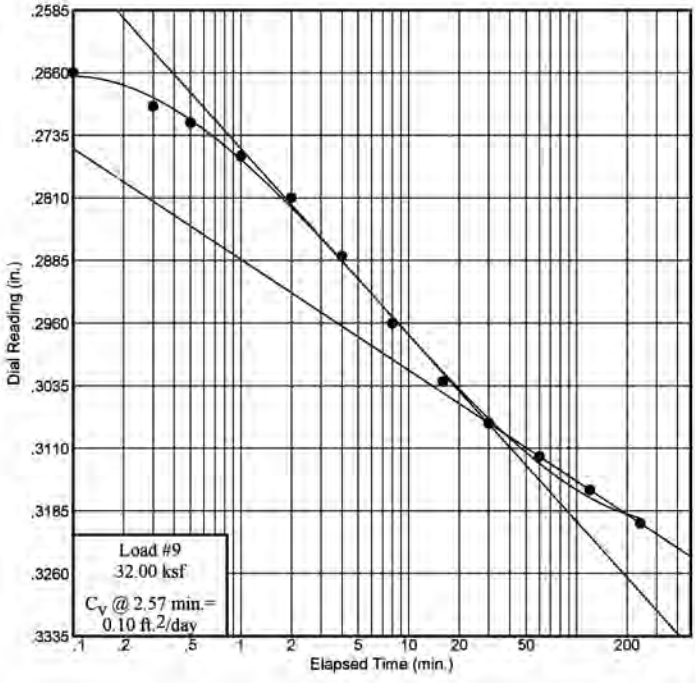
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D Sample No.: T-1 Elev./Depth: 19.5'-21.5'









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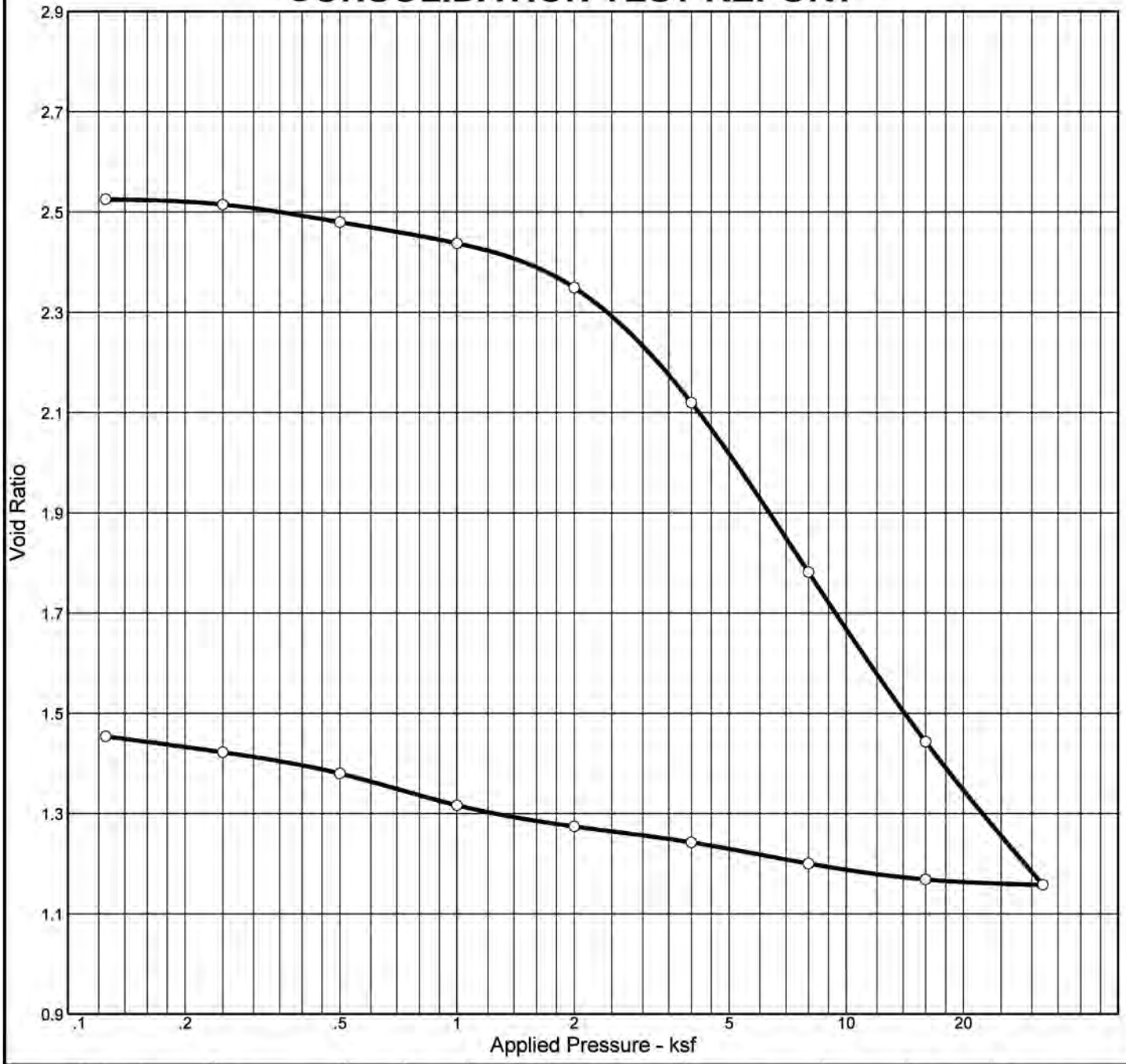
Chkd:

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_r	Initial Void Ratio
Saturation	Moisture									
95.3 %	90.8 %	46.9	51	17	2.65		2.93	1.05	0.12	2.525

MATERIAL DESCRIPTION	USCS	AASHTO
Fine to medium SAND and SILT , trace coarse sand.	SM	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D **Sample No.:** T-3 **Elev./Depth:** 27.5'-29.5'

Remarks:

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P. 302.239.6634
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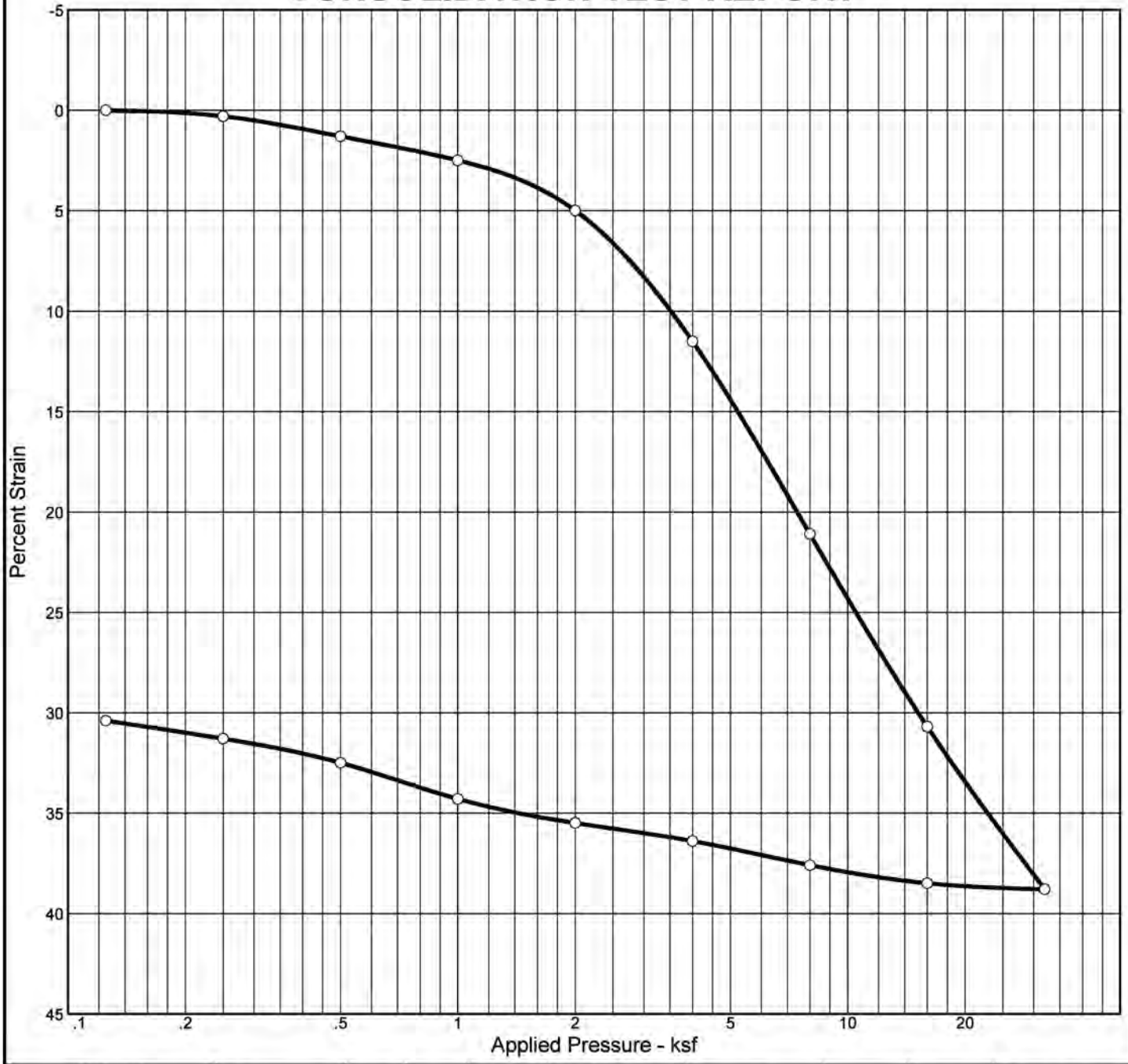
Chkd: BJD 10/13

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C'_c	C'_r	Initial Void Ratio
Saturation	Moisture									
95.3 %	90.8 %	46.9	51	17	2.65		2.93	0.25	0.03	2.525

MATERIAL DESCRIPTION	USCS	AASHTO
Fine to medium SAND and SILT , trace coarse sand.	SM	

Project No. 8919.GM **Client:** U.S. Army Corps of Engineers

Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D **Sample No.:** T-3 **Elev./Depth:** 27.5'-29.5'

Remarks:

Chkd:

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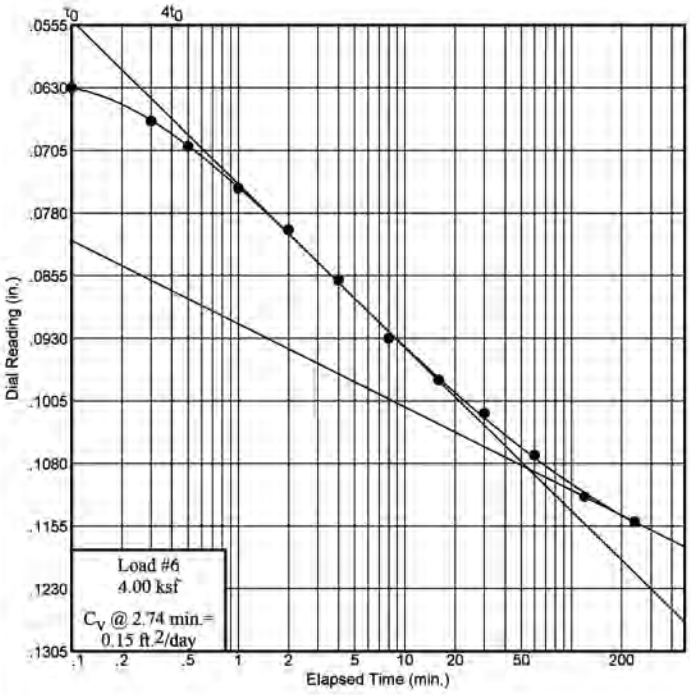
email: duffield@duffnet.com

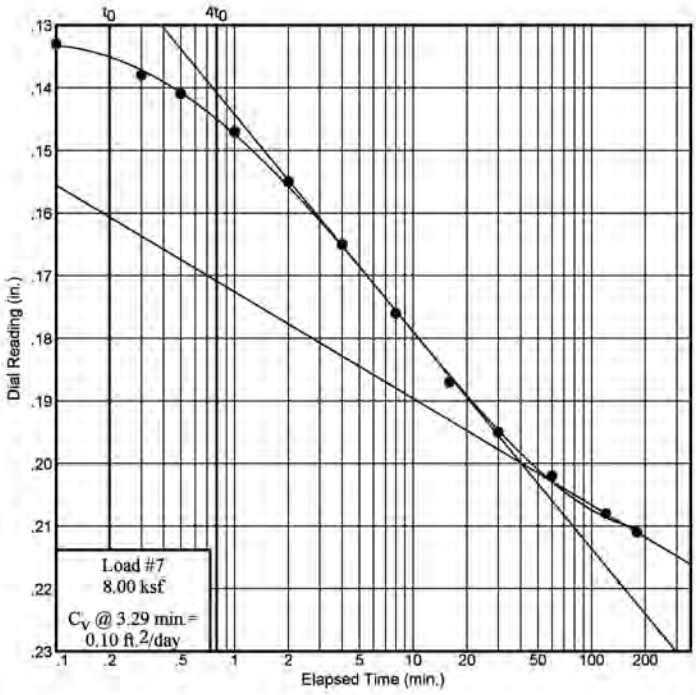
Dial Reading vs. Time

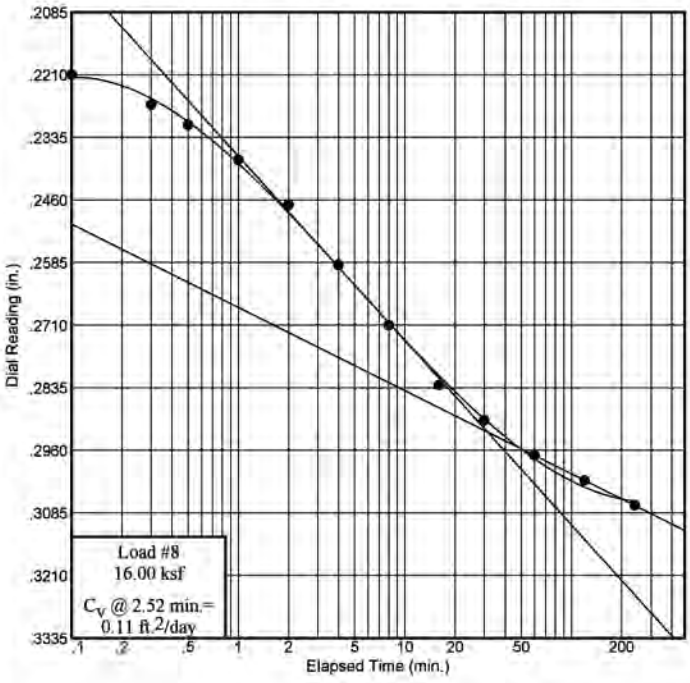
Project No.: 8919.GM

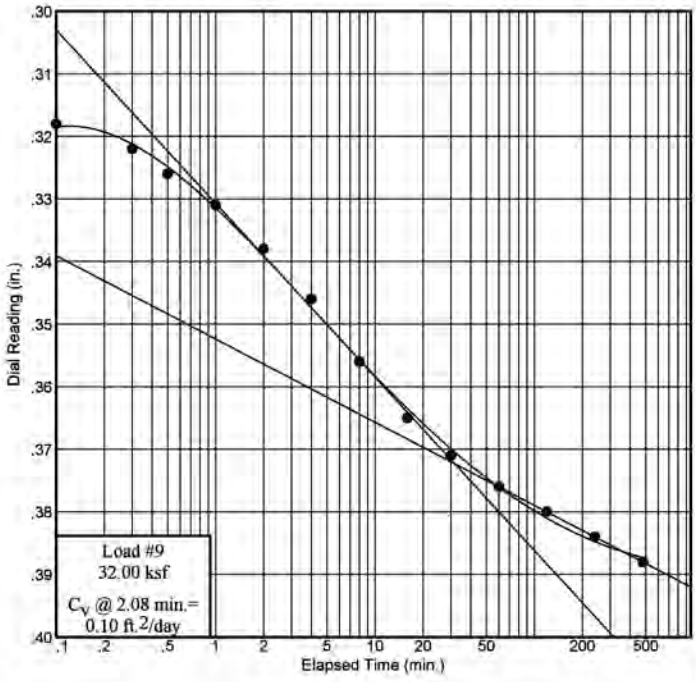
Project: Subsurface Exploration at Eastwick, Philadelphia, Pennsylvania
USACE Contract No. W912BU-11-D-005, Task Order No. 0011

Source: BH-3D Sample No.: T-3 Elev./Depth: 27.5'-29.5'









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F: 302.239.8485
email: duffield@duffnet.com

Chkd:

APPENDIX I

EASTWICK METADATA

Metadata:

- Identification_Information
- Metadata_Reference_Information

Identification_Information:
Citation:
Citation_Information:
Originator: Duffield Associates, Inc.
Originator: 5400 Limestone Road
Originator: Wilmington, DE 19808
Originator: Tel. 302-239-6634
Originator: Fax 302-239-8485
Publication_Date: Unknown
Title: Required element.
Geospatial_Data_Presentation_Form: Required element.
Description:
Abstract:
Geotechnical Invesigation, test boring and as performed survey (X,Y,Z) to evaluate subsurface conditions at the Eastwick Neighborhood in Philadelphia, Pennslvania Site Evalualuation Project
Purpose:
As part of this Geotechnical Investigation 3 Standard Penetration Test (SPT) borings were performed at the site. The purpose of performing the borings was to collect disturbed and undisturbed soil samples for the purposes of evaluating the engineering properties of the subsurface conditions. As part of the investigation the ground surface elevation and physical location (i.e., northing and easting) of each test boring was performed.
Supplemental_Information:
Included with the Geotechnical Investigation Report:1) A plan of the site was prepared in a GIS database, which includes the test boring locations. The base map was obtained by 2012 PA aerial photography and the coordinate system is Pennsylvainia South State Plane Coordinates (NAD83).2) Test boring logs were prepared in gINT format and converted to AutoCAD files as required by the Scope of Services for this contract. Information on the boring logs include subsurface stratigraphy, soil descriptions, horizontal location and vertical reference.3) A table in Microsoft Word format that summarizes the test boring designation, surveyed "as-performed" location and soil surface elevation.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: Unknown
Ending_Date: Unknown
Currentness_Reference:
Required element.
Status:
Progress: Required element.
Maintenance_and_Update_Frequency: Required element.

Spatial_Domain:
Description_of_Geographic_Extent:
Along the Darby and Cobbs Creek in Philadephia between S. 78th Street and South 84th Street in Philadelphia, Pennsylvania
Bounding_Coordinates:
West_Bounding_Coordinate: -75.25492
East_Bounding_Coordinate: -75.24534
North_Bounding_Coordinate: 39.907701
South_Bounding_Coordinate: 39.899410
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: Geology
Theme_Keyword: Soils
Place:
Place_Keyword_Thesaurus: None
Place_Keyword: Eastwick, Philadelphia, Pennsylvania
Access_Constraints: None
Use_Constraints:
None
Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: U.S. Army Coprs of Engineers, Philadelphia District
Contact_Person: Conor McCafferty
Contact_Position: Geotechnical Engineer
Contact_Address:
Address_Type: mailing
Address: US Army Corps of Engineers
Address: Philadelphia District
Address: Wanamaker Building
Address: 100 Penn Square East
City: Philadelphia
State_or_Province: PA
Postal_Code: 19107-3396
Contact_Voice_Telephone: 215-656-6672

Back to Top

Metadata_Reference_Information:
Metadata_Date: 20130421
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Required element.
Contact_Address:
Address_Type: Required element.
City: Required element.
State_or_Province: Required element.
Postal_Code: Required element.

Contact_Voice_Telephone: Required element.
Metadata_Standard_Name: FGDC Biological Data Profile of the Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001.1-1999

Back to Top

APPENDIX J

GENERAL NOTES

GENERAL NOTES

DUFFIELD ASSOCIATES uses the following definitions and terminology to classify and correlate the field and laboratory samples.

VISUAL UNIFIED CLASSIFICATIONS: The soil samples are described by color, major constituent, modifiers (by percentage), and density (or consistency). Coarse Grained or Granular Soils have more than 50% of their dry weight retained on a No. 200 sieve; they are described as: boulders, cobbles, gravel or sand. Fine Grained Soils have less than 50% of their dry weight retained on a No. 200 sieve; they are described as: clays or clayey silts if they are cohesive and silts if they are noncohesive. In addition to gradation, granular soils are defined on the basis of their relative in-place density and fine grained soils on the basis of their strength or consistency and their plasticity.

The Unified Soil Classification symbols are:

COARSE GRAINED SOILS

GW - Well graded gravels
GP - Poorly graded gravels
GM - Silty gravels
GC - Clayey gravels
SW - Well graded sands
SP - Poorly graded sands
SM - Silty sands
SC - Clayey sands

FINE GRAINED SOILS

ML - Silts of low plasticity
CL - Clays of low to medium plasticity
OL - Organic silt clays of low plasticity
MH - Silts of high plasticity
CH - Clays of high plasticity
OH - Organic silt clays of high plasticity
PT - Peat and highly organic soils

SIZE DESCRIPTION

F - Fine
M - Medium
C - Coarse
G - Gravel

MODIFIERS (PERCENTAGE)

Tr -	Trace	1 - 10%
Ltl -	Little	11 - 20%
Some		21 - 35%
& -	And	36 - 50%

COLOR

Or - Orange
Yel - Yellow
Br - Brown
Blk - Black
Gr - Gray
R - Red
Vc - Varicolored
Dk - Dark
Lt - Light

DENSITY: COARSE GRAINED SOILS

Very loose	4 blows/ft or less
Loose	5 to 10 blows/ft
Medium	11 to 30 blows/ft
Dense	31 to 50 blows/ft
Very Dense	51 blows/ft or more

CONSISTENCY: FINE GRAINED SOILS

Very soft	2 blows/ft or less
Soft	3 to 4 blows/ft
Medium	5 to 8 blows/ft
Stiff	9 to 15 blows/ft
Very stiff	16 to 30 blows/ft
Hard	31 blows/ft or more

NOTE: The Standard Penetration Test "N" value is the number of blows per foot of a 140 pound hammer falling 30 inches on a 2 inch O.D. split spoon sampler, except where otherwise noted.

USEPA Subsurface Exploration

Attachment I:
Geotechnical Evaluation and Design

Attachment I:
Geotechnical Evaluation and Design

GEOTECHNICAL REPORT

(DRAFT – ISSUED FOR 90% DESIGN PACKAGE)

For
REMEDIAL DESIGN
- OPERABLE UNIT 1 -
CLEARVIEW LANDFILL - SOILS AND WASTE
LOWER DARBY CREEK AREA
SUPERFUND SITE

DARBY TOWNSHIP, DELAWARE AND
PHILADELPHIA COUNTIES
PENNSYLVANIA

EPA Contract Number EP-S3-07-04
Work Assignment Number 061-RDRD-D366
Tetra Tech Project Number G01067

January 2018

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GEOTECHNICAL REPORT

1.0 INTRODUCTION

This report was prepared to discuss the results of geotechnical investigation performed during the Remedial Design (RD) for the Lower Darby Creek Area (LDCA) site - Operable Unit 1 (OU1). The primary component of the remedy is construction of the evapotranspiration (ET) cover, which requires stabilization of adjacent creek banks and steep slopes of the landfill for remedy's integrity. As further discussed in other parts of the Basis of Design Report (BDR), the final grading of the landfill cover was made to meet slope stability, while large cuts or fills were avoided to minimize potential exposure of construction workers to waste materials and significant increase of the water surface elevation (WSEL) within the 100-year floodplain. As such, retaining structures were designed to support steep slopes at the base of the landfill cover, and to improve stability of creek banks together with other in-stream restoration features.

The landfill slopes were analyzed to assess global stability of the landfill under various loading conditions. The report also summarizes geotechnical laboratory testing results for dredged materials from the U.S. Army Corps of Engineers (USACE) confined disposal facilities being evaluated as potential borrow sources for the ET cover.

2.0 PURPOSE AND SCOPE OF STUDY

This report presents recommendations for design and construction of the mechanically stabilized earth (MSE) block wall to support steep slopes of the landfill and crib walls to provide localized protection of steep creek banks. Design details for other in-stream stabilization features such as the log vane and mud sill are provided in Attachment L. The proposed retaining structures and their approximate lengths for MSE and crib walls are listed in Table 2.1, and shown in the design drawings in Attachment A of the BDR.

Table 2.1: Total Length of Proposed Structures

Type of Wall	Number of Walls	Total Length
MSE	1	2,370
Crib Walls	4	1,510

3.0 FIELD EXPLORATION

Two geotechnical field investigations were conducted to identify the types and extents of soils and waste at and below the elevation of the proposed structures, and to obtain the engineering properties of the soils for use in performing the engineering design for the retaining structures and their foundations, as described below:

- Field Investigation 1 (February 8 and 9, 2017): A Tetra Tech field engineer obtained multiple grab samples in gallon bags along the alignment for the crib walls and MSE walls.

- Field Investigation 2 (March 6 to 10, 2017): Twenty-five geotechnical borings were drilled to depths on the order of 25 feet along the alignment for the crib walls and MSE walls. Samples were collected in split spoon samples, from the auger cuttings, and in relatively undisturbed Shelby tube samplers.

The location of the borings and grab samples are show on Drawing No. 1155-1 in Appendix A. Locations of the exploratory borings and grab samples were marked in the field by Tetra Tech personnel based on the proposed wall locations. Borings were advanced through the overburden soils with a track-mounted drill rig equipped with 8¼-inch diameter hollow-stem augers and were logged by a Tetra Tech representative.

Samples of the subsurface materials were obtained with 2-inch outside-diameter split-spoon samplers driven into the various strata using a 140-pound hammer falling 30 inches. The standard penetration test was performed in accordance with the American Society for Testing and Materials (ASTM) Method D1586 to determine the penetration resistance (N value), which indicate the relative density or consistency of the soils. Bulk samples of soil were obtained from the hollow-stem augers at select locations. Depths at which the samples were obtained and the penetration resistance values are shown on the logs of exploratory borings.

The geotechnical boring logs are included in Appendix B. Boring B-506 was not drilled due to access issues. Pictures of the field investigation and site soils and waste are included in Appendix C.

4.0 LABORATORY TESTING

A Tetra Tech geotechnical engineer inventoried the laboratory samples and assigned specific laboratory tests, to obtain the data to be used in engineering design of the ET cover and retaining walls, as well as to

develop the design drawings and specifications for construction. In addition, two five-gallon bucket samples obtained from the USACE confined disposal facilities were tested for various soil parameters.

Laboratory testing was performed on the following number of samples:

- 15 grab samples obtained from hand-dug test pits
- 30 samples from 21 geotechnical borings
- 2 five-gallon bucket samples from USACE confined disposal facilities

Samples obtained during the field exploration were taken to Tetra Tech's laboratory. Representative samples were selected for testing to determine the physical and engineering properties of the soils in general accordance with ASTM or other approved procedures. It should be noted that the soils tested were obtained from intervals that sometimes included a significant percentage of waste/debris. The percent waste/debris within the borings is denoted on the logs of the borings in Appendix B.

Table D-1 in Appendix D lists the station location, design feature, and the laboratory testing results. Figures 1 through 66 and Appendix D include the resultant laboratory data from the two geotechnical investigations and borrow source samples.

5.0 ENGINEERING ANALYSIS AND RECOMMENDATIONS

This section discusses 1) slope stability analysis for the landfill slopes, 2) steep slope stabilization methods where walls cannot be constructed, 3) log crib wall design, and 4) mechanically stabilized earth (MSE) wall design.

5.1 SLOPE STABILITY ANALYSIS

Slope stability analyses were conducted to analyze the landfill mass as well as the stability of the final cover system. The analyses were conducted in general accordance with the Resource Conservation and Recovery Act (RCRA) Subtitle D landfill standards.

5.1.1 Critical Cross-Section for Assessment

The critical cross-section for assessment is the landfill section anticipated to be the most susceptible to failure based on appropriate engineering considerations, including loading conditions. Several critical cross-sections were analyzed to assess the steepest cover slope, the greatest slope height, global stability of retaining walls, and localized areas with various combinations of these conditions. The sections analyzed

represent grading as steep as 2H:1V (50%). Since these analysis were completed, site grading plans have been revised such that no surfaces, with the exception of the steep slopes discussed in the next section, are steeper than 3H:1V (33%). The locations of the critical sections are shown in Appendix E.

5.1.2 Seismic Condition

The design seismic event for RCRA landfills is defined as the peak ground acceleration for a seismic event with a 2% probability of exceedance in 50 years (2,475 year return period). The U.S. Geological Survey (USGS) National Seismic Hazard Mapping Program (NSHMP) Interactive Deaggregation website was used to provide the design ground acceleration relating to the design seismic event, which at the Lower Darby Creek landfill site for the above return period is 0.112g, for a site on rock with an average shear wave velocity of 760 m/s in the top 100 feet.

5.1.3 Subsurface Material Properties

Shear strength and engineering properties for the waste were obtained from literature recommendations (Shear Strength of Municipal Solid Waste, Bray et. al, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, June 2009). Shear strength and engineering properties for the soil cover are based on the laboratory testing conducted and presented in Appendix D. Table 5.1 includes the assumed strength properties for the slope analyses.

Table 5.1: Assumed Soil and Waste Properties

Soil Layer	Shear Strength		Total Unit Weight
	C	Phi	γ
	psf	degrees	pcf
Waste	313	35	75
Cover Soil	21	36	88

5.1.4 Method of Analysis

Slope stability safety factors were calculated using Slide version 7.017. Slide is a two-dimensional slope stability program which analyzes the stability of slip surfaces using vertical slice limit equilibrium methods. Calculations were conducted using Spencer's method as it fully satisfies all conditions of equilibrium. Both circular and non-circular potential failure surfaces were evaluated.

Soil strength parameters used in the analysis were selected based on the soil conditions encountered and testing of actual materials as previously stated above. These soil strength parameters represent consolidated-drained conditions appropriate for modelling long-term loading conditions. These soil properties are reasonably conservative assumptions based on comparisons with the engineering index properties of the materials and the written descriptions of the materials. All user input parameters and the results of the seepage analysis and safety factor computations are presented in Appendix E.

5.1.5 Conclusions

The results of the slope stability assessment indicate the proposed slopes meet the minimum required safety factors. The results of the assessment are presented in Table 5.2.

Table 5.2: Global Stability Factors of Safety for Critical Slope Sections

Section	Loading Condition	Safety Factor	
		Required	Calculated
Section 1	Static, Circular	1.500	2.017
Section 1	Pseudo-Static, Circular	1.000	1.605
Section 2	Static, Circular	1.500	2.026
Section 2	Pseudo-Static, Circular	1.000	1.414
Section 3	Static, Circular – Entire Slope	1.500	1.887
Section 3	Pseudo-Static, Circular – Entire Slope	1.000	1.485
Section 3	Static, Circular – Upper Slope (44%)	1.500	1.880
Section 3	Pseudo-Static, Circular – Upper Slope (44%)	1.000	1.480
Section 3	Static, Block – Upper Slope (44%)	1.500	2.342
Section 3	Pseudo-Static, Block – Upper Slope (44%)	1.000	1.903
Section 4	Static, Circular – 49% Slope	1.500	1.962
Section 4	Pseudo-Static – 49% Slope	1.000	1.530
Section 4	Static, Block – 49% Slope	1.500	2.376
Section 4	Pseudo-Static, Block – 49% Slope	1.000	1.762

5.2 NON-MSE STEEP SLOPE STABILIZATION

One isolated location near the access road toward the creek is currently sloped at almost 2H:1V. This area is within a 100-year floodplain and contains large amount of concrete debris on the surface. In addition, this area has been in place for over 20 years with no indication of slope instability. Therefore, only surficial enhancement will be made with non-MSE reinforced materials (e.g., geogrids with live stakes and/or seed mix) to increase stability over time, while keeping the existing grade at 2H:1V. Details for steep slope stabilization features are provided in the project design drawings, and the project landscaping plans provide vegetation details. As discussed in the previous section, the stability of multiple slopes as steep as 2H:1V were analyzed for this site, and the resulting factors of safety were all greater than required. Therefore, the global slope stability of this isolated 2:1 slope is satisfactory, and the proposed non-MSE reinforcement materials will provide protection from surficial erosion.

5.3 LOG CRIB WALLS

Log crib walls will be located at the following locations along the creek and constructed with the following approximate maximum heights:

Log Crib Wall No.	Stream Station (approx)	Wall Height (ft)	Embedment (ft)	Total Height (ft)
1	6+10 to 7+90	11	3	14
2	8+50 to 9+40	11	3	14
3	16+90 to 24+10	11	3	14
4	38+20 to 45+47	8 to 11	3	11-14

All log crib walls were designed with an exposed height of 11 feet and an additional embedment of 3 feet, although some sections may have an exposed height of less than 11 feet. The log crib walls were designed with a front face batter of 1:6 (horizontal:vertical). The embedment depth of three feet exceeds the predicted scour depth and was established for foundation stability. No vehicular traffic or other live loads are expected above the wall near the face. The log crib walls are not a structural component of the landfill final cover system; therefore, seismic parameters were not analyzed.

5.3.1 Log Materials

The crib walls will be made of logs. Per the project requirements, logs will not be treated, which increases the susceptibility to damage from dry-rot fungi and wood damaging insects. Portions of the exposed logs

may maintain moisture contents required for dry-rot fungi (~30%) due to the tidal influence stream elevations. All logs will be exposed to earth and susceptible to insect degradation. The impacts of wood species resistant to insect degradation are negligible.

The EPA's experience has been such that log degradation is minimal. Further, the EPA does not desire the use of treated lumber due to the potential for treatment chemicals to leach into the stream water. Concrete crib wall members have also been eliminated from consideration by the EPA due to aesthetics, cost, and their experience with durability in similar environments. The walls have been designed using whole logs rather than square cut dimensional timbers for aesthetics and resistance to degradation.

5.3.2 Subsurface Profile

Exploratory borings B-508, B-510, B-515, B-518, B-23, B-24, B-25, and B-526 were drilled within the footprints of the log crib walls. The laboratory testing indicates the retained soil (soil behind the wall) profile will consist of silty sand to sandy silt, and sandy elastic silt with varying percentages of waste/debris as noted in the boring logs included in Appendix B. For design, the material was modelled with a total unit weight of 100 pounds per cubic feet (pcf) and a friction angle of 26 degrees based on laboratory testing from borings B-510 and B-515. The foundation soils (soil below the base of the wall) generally consist of sandy silt to elastic silt. These materials were modelled with a total unit weight of 95 pcf and a friction angle of 28 degrees based on the same laboratory testing. A slightly higher friction angle was used to represent the 18-inch thick layer of gravel that will be placed below the log crib walls.

The borings generally indicate subsurface water elevations corresponding with the adjacent stream elevation; however, exploratory borings B-523 and B-524 indicate water levels above the adjacent stream elevation. Hydrostatic forces from high groundwater can result in excessive forces on the crib wall. Permeable backfill will be used for the crib walls to prevent hydrostatic forces from occurring; therefore, no design water surcharge load was applied to the wall.

5.3.3 Wall Backfill

The log crib wall will be constructed with an open face design (not a solid wall face) which is conducive to drainage of the internal wall backfill during tidal water elevation changes. The material used to backfill within the log cribbing must be coarse enough to allow drainage. On-site sand (if available) or imported sand should be used as backfill and have a maximum of 25% passing the No. 200 sieve and a maximum particle size of 3 inches.

5.3.4 Design

The log crib walls were designed based on NAVFAC DM-7.02 “Foundations and Earth Structures” (U.S. Navy, 1986) for gravity retaining walls. Internal crib wall components were designed based on design information from the NRCS, USFS, and “Timber Crib Retaining Structures” (Schuster, Jones, Sack, & Smart, 1975). A single section was analyzed composed of the greatest wall height (Crib Wall No. 1) and most critical properties. Design was based on the following properties in Table 5.3:

Table 5.3: Log Crib Wall Assumed Soil Properties

	Retained Soil	Foundation Soil	Internal Wall
Total Unit Weight (pcf)	100	95	100
Friction Angle (degrees)	26	28	32
Cohesion (psf)	0	0	0

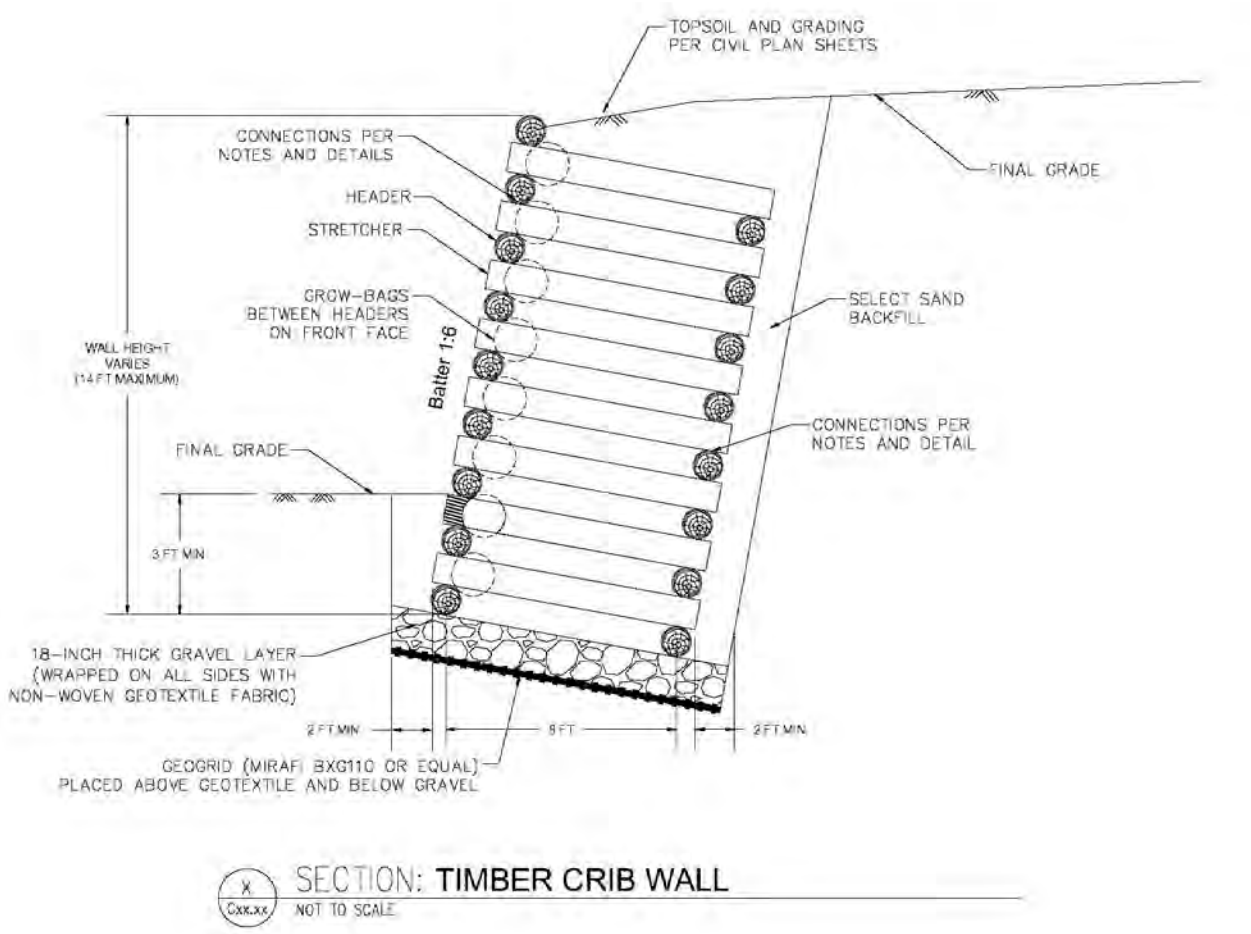
The factor of safety against sliding was determined to be 2.65 (1.30 required). The factor of safety against overturning was 2.9 (1.50 required). The factor of safety against bearing capacity failure was calculated to be greater than 6 (3.0 required). The global stability factor of safety was analyzed and discussed in the slope stability section previously.

Header logs run parallel to the face of the wall. Stretcher logs run perpendicular to the face of the wall connecting the front headers to the back headers. The log components have the following properties:

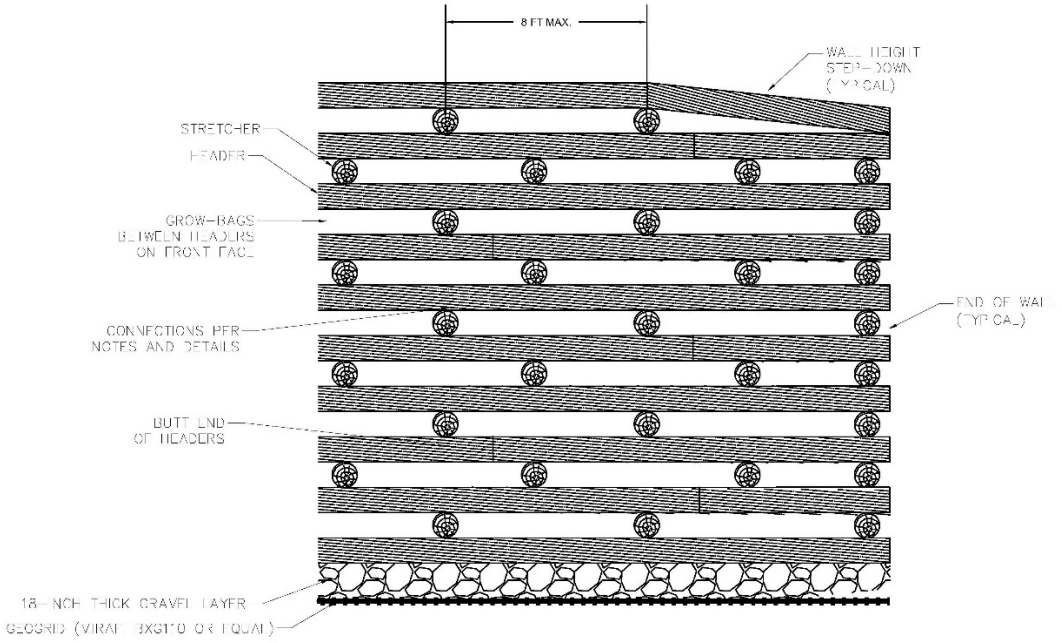
- Diameter: 8 to 12 inches
- Header Length: 16 ft minimum.
- Stretcher Length: 10 ft minimum.
- Species: Southern Pine, Cedar, Larch, Douglas Fir, Red Oak, or Equivalent.
- Maximum Stretcher Spacing: 8 ft.
- Header spacing front to back: 8 ft.

Connections between the header and stretcher logs are made using #6 rebar, a ¾-inch drift pin, or equivalent steel device. The connection is made by inserting the rebar/pin through a hole which penetrates a minimum of 3 logs (typically two headers and a stretcher).

The annulus between header logs will be filled with grow bags to promote vegetative growth on the face of the wall. Alternatively, the annulus can be filled with filler logs or the wall face can be backfilled with large rock. The crib wall design calculations, plan sheet, and special provision are included in Appendix F.



LOG WALL CROSS SECTION



LOG WALL FACE ELEVATION

5.4 REDI-ROCK MECHANICALLY STABLIZED EARTH (MSE) WALLS

Redi-Rock® walls (manufactured by Redi-Rock International) are located at the toe of north and west landfill slopes about 50 feet off the stream channel and above the 100-year flood elevation. These walls are located at the approximate stream stations 9+75 to 36+25. The Redi-Rock walls vary in exposed height generally from 7 feet to 10 feet with a 2-foot embedment at the toe (total design wall height of 9 feet to 12 feet). Some shorter walls may be present at the start or end of the walls.

These walls are considered as a structural component of the landfill final cover system; therefore, they must be designed to withstand a seismic acceleration of 0.112g as detailed within the Slope Stability section of this report. Redi-Rock produces 28-inch deep units for mechanically stabilized earth (MSE) walls (geogrid reinforced) and units as deep as 60-inches for gravity retaining walls (no geogrid). Due to the seismic conditions and steep back slopes at this site, walls with a design height greater than 7.5 feet, which includes most of the Redi-Rock walls at this site, must consist of MSE walls.

5.4.1 Subsurface Profile

Exploratory borings B-503, B-511, B-512, B-523, B-516, and B-519 through B-22 were drilled in the vicinity of the MSE walls. The laboratory testing on samples of soil obtained from the borings indicates silty sand

with varying amounts of gravel. The percent of gravel indicated in the laboratory test results may have been restricted due to the size of the sampler used to obtain the samples. A hand excavated grab sample, GB 13, was obtained from the MSE wall vicinity and indicates a significantly higher percentage of gravel is present (37% vs 11 to 16% in the sampler samples). The exploratory boring logs also indicate portions of the subsurface consist of predominately municipal solid waste materials. Published shear strength parameters for waste materials include a friction angle of 36 degrees and a cohesion of 125 psf ("Shear Strength of Municipal Solid Waste for Stability Analyses", Stark et al., 2009). Based on the presence of gravelly soils and waste, the MSE walls were designed based on retained and foundation soils with a friction angle of 30 degrees and a cohesion of zero. The total unit weight of the retained soil is assumed to be 110 pcf based on laboratory testing conducted on grab sample GB 13. Waste and silty soil, where present, typically have a lower (less conservative) total unit weight.

5.4.2 Wall Backfill

The MSE wall has been designed based on the reinforced fill consisting of on-site sand (if available) or imported sand having a maximum of 25% passing the No. 200 sieve and a maximum particle size of 3 inches with an angle of friction of 34 degrees. This material is critical in the lower 5 ft (lowest 3 layers of reinforcement) of the wall backfill to provide drainage and friction for sliding resistance. If adequate quantities of this material are not available on-site, material with a higher fines content and lower friction angle could be used for the upper elevations. This may result in slightly longer reinforcement lengths. The special provision outlines the requirements for the MSE wall, and the wall will be designed by a contractor.

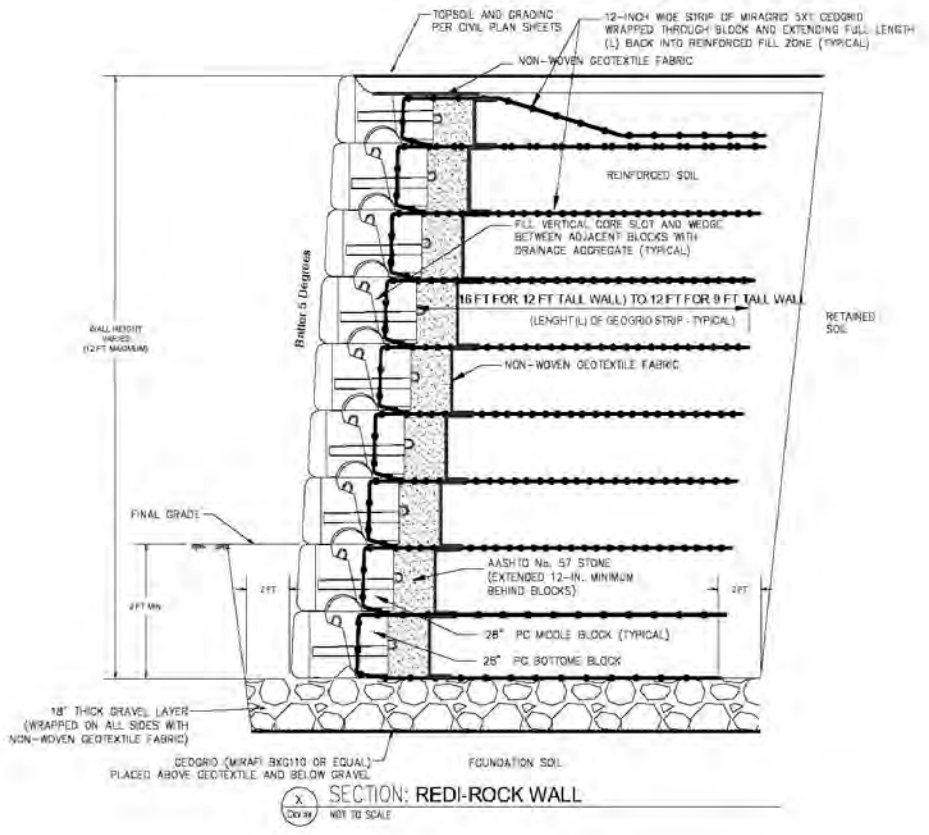
5.4.3 Wall Design

The MSE wall design was based on "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume I and II " (Publication No. FHWA-NHI-10-024 and FHWA-NHI-10-025) and "AASHTO LRFD Specifications for Highway Bridges, Section 11." The design was based on the following properties in Table 5.4:

Table 5.4 MSE Wall Design Properties

Parameter	Retained Soil	Foundation Soil	Reinforced Soil
Total Unit Weight (pcf)	110	95	110
Friction Angle (degrees)	30	30	34
Cohesion (psf)	0	0	0

The minimum embedment depth is 2 feet. The batter is Redi-Rock's standard 5 degrees. The backslope above the wall was assumed to be 24.5° (45%), which represents the steepest grading along the wall (since the time of these analyses, grading plans have changed such that slopes above the wall will not exceed 3H:1V (18.3° or 33%) which will reduce horizontal loading on the wall). The modular concrete blocks are typically filled with stone having a total unit weight on the order of 100 to 130 pcf. The concrete portion of the block typically has a unit weight on the order of 143 pcf. For this design, a concrete and in-fill combined unit weight of 120 pcf was assigned, which represents the lowest values typical for Redi-Rock units. Redi-Rock standard 12-inch wide Mirafi uniaxial geogrid strips were assumed for reinforcement. For each reinforcement layer and for the overall wall, all Capacity/Demand Ratios (CDR) exceed the required 1.0 (bearing capacity, connection strength, geogrid strength, pullout resistance, and direct sliding). The eccentricity (e/L) is below the maximum allowable 0.25. The minimum global stability factors of safety were 1.579 static (1.5 minimum required) and 1.398 seismic (1.0 minimum required). The MSE wall design output, plan sheet and special provision are included in Appendix G.

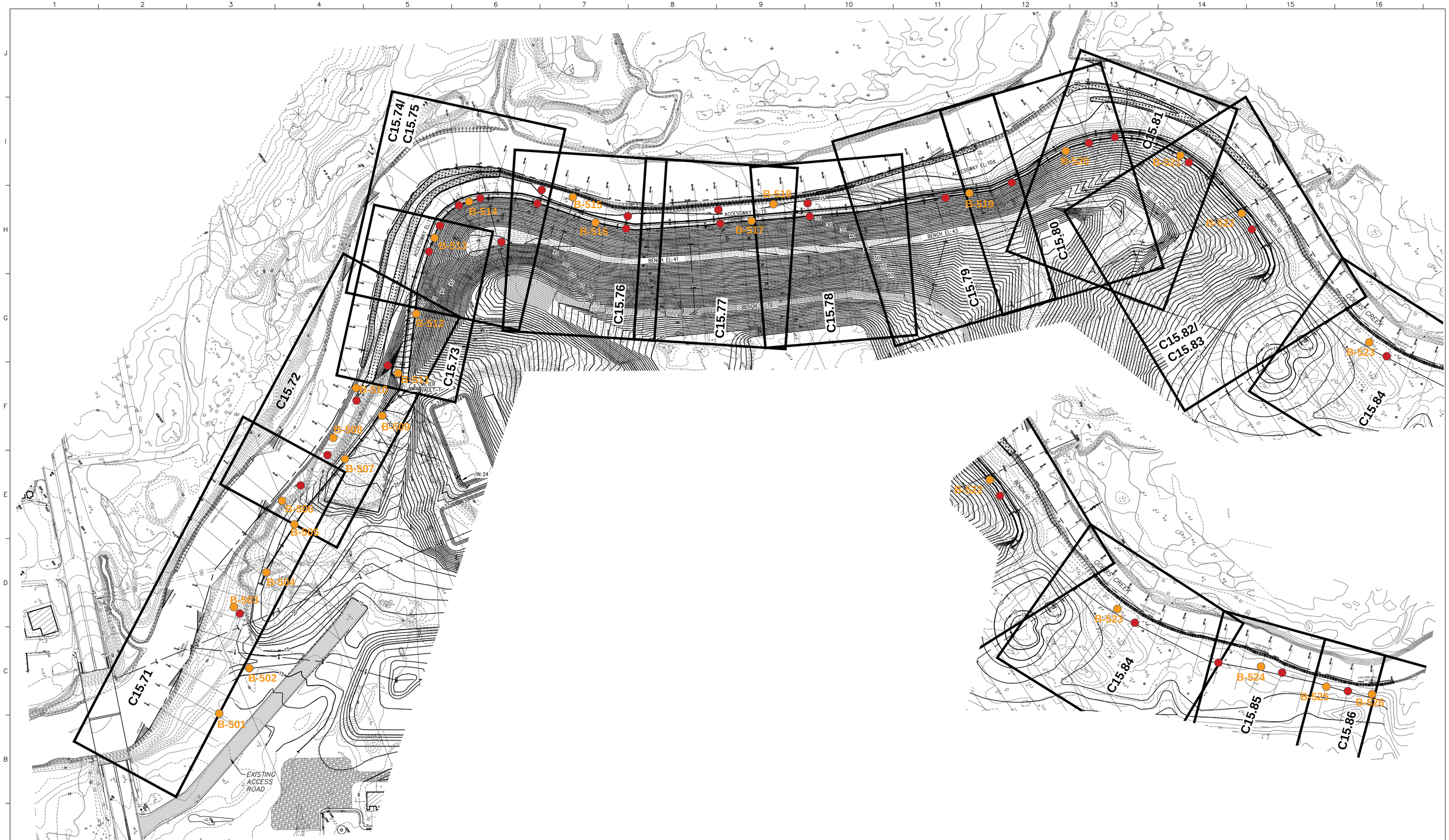


REDI ROCK WALL CROSS-SECTION

6.0 LIMITATIONS

This study has been conducted in accordance with generally accepted geotechnical engineering practices in the region where the work was conducted. The conclusions and recommendations submitted in this report are based upon the design data submitted to Tetra Tech, data obtained from the exploratory borings drilled at the location indicated, and the proposed construction discussed in this report. The nature and extent of subsurface variations across the site may not become evident until construction. During construction, soil, or water conditions appear to be different from those described herein, EPA should be advised immediately so that the recommendations can be re-evaluated.

APPENDIX A: BORING AND GRAB SAMPLE LOCATIONS – DRAWING NO. 1155-1



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DRAFT

MARK	DATE	DESCRIPTION	BY
	10/25/17	90% DESIGN SUBMISSION	JCK/WJM

CLEARVIEW LANDFILL
LOWER DARBY, PENNSYLVANIA

LOCATION OF GEOTECHNICAL BORINGS AND GRAB SAMPLES

SCALE: AS NOTED

DATE:	–DRAFT–
PROJECT NO.:	112G07477
DESIGNED BY:	ARB
DRAWN BY:	BH
CHECKED BY:	CSG
SHEET:	1 OF X

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1155–1

P:\T–Z\Tetra Tech NUS Inc\114–571155X – Lower Darby Creek GT\Common\Jason Report and Docs\CADD FILES\112G07477–C1570–CREEK–1_UPDATED.dwg NWK ARIC.HOTALING 12/15/2017 1:15:03 PM

APPENDIX B: LOGS OF BORINGS (B-501 THROUGH B-526, B-506 NOT DRILLED)

2525 Palmer Street, Suite 2
Missoula, MT 59808
Phone: (406)543-3045
Fax:

LOG OF BORING

Boring B-501

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location Coordinates**
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/6/17	**Date Finished:** 3/6/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		1 - 2 - 4		Silty CLAY, medium stiff, moist, gray.	0.3						
5			38		1 - 50/0.3ft		Silty SAND, loose to very dense, moist, gray to black, fine to coarse grained, subangular, Concrete and wood debris. Auger refusal at 14 due to wood debris. Wood debris had very strong creosote odor. 30% soil. 70% debris.							
10			67		5 - 4 - 6									
			83		15 - 50/0.1ft		Boring Depth: 14.0 ft, *Elevation:*	14.0						

Water Level Observations		Remarks:
After Drilling: 14.0 ft	During Drilling: Not Recorded	
	After Drilling: Not Recorded	

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LOG OF BORING

Boring B-502

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location Coordinates**
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/6/17	**Date Finished:** 3/6/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			47		3 - 3 - 3		Silty CLAY, medium stiff, moist, brown to gray, medium plasticity.	0.3						
5			80		4 - 6 - 6		Silty SAND with clay, loose to very dense, moist to very moist, gray to black, fine to coarse grained, subangular, Construction debris present. 20% soil, 80% debris.							
10			33		50/0.3ft									
							Sandy SILT with clay, medium stiff, wet to wet, gray to black, non plastic, Wood debris with heavy hydrocarbon odor. 10% soil, 90% debris.	12.0						
15			13		2 - 2 - 3									
							Silty CLAY, very soft, wet to wet, gray to black, high plasticity, Stiff. Plastic. No debris.	17.0						
20			100		1 - 1 - 1									
25			100		1 - 1 - 1			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
After Drilling: Not Recorded	During Drilling: 13.0 ft	
	After Drilling: Not Recorded	

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LOG OF BORING

Boring B-503

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location Coordinates**
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/6/17	**Date Finished:** 3/6/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			67		1 - 2 - 2		Silty CLAY, soft, moist, brown, medium plasticity.	0.3						
							Silty CLAY, very soft to medium stiff, very moist to very moist, brown to gray, high plasticity.							
5			100		2 - 1 - 1									
								6.0						
							Silty CLAY, very soft to medium stiff, wet to wet, brown to gray, high plasticity.							
10			100		1 - 1 - 1									
15			100		1 - 1 - 1									
								19.0						
20			100		1 - 3 - 4		Silty SAND, very loose to loose, wet, gray, fine to coarse grained, subrounded, Well graded sand.							
								24.0						
25			100		1 - 1 - 1		Silty CLAY, very soft, wet, gray, high plasticity.	25.0						

Boring Depth: 25.0 ft, *Elevation:*

no debris encountered

Water Level Observations		Remarks:
During Drilling: 6.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-504

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.899994 **Coordinates** E: -75.255425
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			33		3 - 6 - 50		Silty SAND with clay, very loose to very dense, moist to moist, brown to black, fine to coarse grained, subangular, Construction debris present from 0-22'. Majoity of subsurface is construction debris. 40% soil, 60% debris.							
5			20		7 - 6 - 3									
10			67		6 - 4 - 2									
15			67		3 - 2 - 4									
20			33		1 - 1 - 1			22.0						
							Clayey SILT with gravel, soft, wet to wet, gray to black, low plasticity, Appears to be native material.							
25			33		2 - 1 - 3			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-505

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location Coordinates**
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/6/17	**Date Finished:** 3/6/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		6 - 10 - 9		Silty SAND with gravel, loose to medium dense, moist, brown to gray, fine to coarse grained, subangular, Majority of subsurface is concrete, metal, wood and residenital landfill debris. Inconsistent drilling conditions. Hard drilling, then easy, followed by hard. 20% soil, 80% debris.							
5			20		8 - 5 - 5									
10			7		3 - 6 - 4									
							▽	14.0						
15			20		1 - 2 - 1		Silty SAND with gravel, loose to medium dense, wet to wet, brown to gray, fine to coarse grained, subangular, Majority of subsurface is concrete, metal, wood and residenital landfill debris. Inconsistent drilling conditions. Hard drilling, then easy, followed by hard. 20% soil, 80% debris.							
20			20		3 - 3 - 3									
25			13		2 - 2 - 1			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
▽ During Drilling: 14.0 ft	▽ After Drilling: Not Recorded	
▼ After Drilling: Not Recorded		

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Boring B-507

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.901054 **Coordinates** E: -75.255829
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			64		10 - 11 - 50/0.1ft		Silty SAND with clay, very loose to very dense, moist to moist, brown to black, subangular, Very little soil. Mostly debris contaning, but not limited to, concrete, cardboard, metal, bricks and carpet. Auger refusal at 17' bgs. 10% soil, 90% debris.							
5			53		2 - 5 - 3									
10			33		8 - 7 - 3									
15			20		2 - 1 - 1									
			0		50/0.3ft			17.0						

Boring Depth: 17.0 ft, *Elevation:*

Water Level Observations		Remarks:
After Drilling: Not Recorded	During Drilling: Not Recorded	
	After Drilling: Not Recorded	

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Boring B-508

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.900917 **Coordinates** E: -75.256065
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		1 - 2 - 2		Sandy, Silty SILT with gravel, soft to medium stiff, moist, brown to gray, non plastic, Fill material with construction debris. 60% soil, 40% debris.							
5			100		2 - 3 - 4									
10			100		2 - 1 - 2			10.0						
							Silty CLAY, very soft to soft, wet, gray, low plasticity, Appears to be native material. ▽							
								14.0						
15			100		1 - 1 - 1		Silty CLAY, very soft, wet, gray to brown, medium plasticity, Native material containing woody fiber.							
20			100		1 - 1 - 1									
25			100		1 - 1 - 1			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
▽ During Drilling: 12.0 ft	▽ After Drilling: Not Recorded	
▼ After Drilling: Not Recorded		

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Boring B-509

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.901237 **Coordinates** E: -75.256027
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			100		50/0.3ft		Silty SAND with clay, very loose to very dense, moist to moist, gray to black, fine to coarse grained, subangular, Very little soil. Mainly debris containing concrete, bricks, household items, wood and metal. 20% soil, 80% debris.							
5			20		5 - 1 - 2									
10			47		6 - 5 - 4									
15			27		6 - 2 - 11									
20			33		7 - 4 - 5									
25			20		8 - 2 - 3			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-510

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.901173 **Coordinates** E: -75.256279
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			47		1 - 2 - 1		Silty SAND with gravel, very loose, moist to moist, brown to gray, fine to coarse grained, subangular, Fill material. Some construction debris such as concrete and bricks present. 70% soil, 30% debris.							
5			67		2 - 1 - 2									
10			67		2 - 1 - 1									
							▽	12.0						
							Silty CLAY, soft, wet, gray, high plasticity, Appears to be native material.							
15			53		1 - 1 - 2									
								18.0						
							Clayey SILT, very soft, wet to wet, brown, medium plasticity, Clayey silt to silty clay, lower plasticity than above. Some wood fibers present.							
20			100		1 - 1 - 1									
								22.0						
25			100		1 - 1 - 1									
							Silty CLAY, soft, wet, gray, high plasticity, Change in color and increase in plasticity.							
							Boring Depth: 25.0 ft, *Elevation:*							

Water Level Observations		Remarks:
▽ During Drilling: 12.0 ft	▼ After Drilling: Not Recorded	
▼ After Drilling: Not Recorded		

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Boring B-511

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.901485 **Coordinates** E: -75.256111
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			33		3 - 7 - 10		Sandy, Silty SILT with clay, soft to very stiff, moist to very moist, gray to black, non plastic, Fill material containing few litte soil. Majority of subsurface is construction and residential debris. 20% soil, 80% debris.							
5			33		2 - 2 - 1									
10			20		5 - 2 - 3									
15			47		1 - 2 - 4									
20			20		8 - 2 - 2									
25			53		1 - 2 - 4			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 18.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-512

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.901722 **Coordinates** E: -75.256432
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/7/17	**Date Finished:** 3/7/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			47		2 - 4 - 4		Sandy SILT with clay, soft to very stiff, moist to very moist, gray to black, non plastic, Fill material with construction and wood debris 70% soil, 30% debris.							
5			33		8 - 7 - 15									
10			20		2 - 2 - 5									
15			20		2 - 3 - 2									
20			20		6 - 10 - 6									
25			13		1 - 2 - 2			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 20.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-513

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.902203 **Coordinates** E: -75.256966
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		1 - 1 - 1		Silty SAND with clay, very loose, moist, brown, fine to medium grained.	0.5						
							Sandy SILT with clay, very soft to medium stiff, very moist, brown to black, non plastic, Construction and residential debris mixed with sandy silt. 80% soil to 9' bgs, then 10% soil to 17' bgs.							
5			87		1 - 1 - 1									
10			20		2 - 2 - 2									
15			20		5 - 3 - 5									
								17.0						
							Clayey SILT with sand, very soft, wet, brown to gray, high plasticity, Appears to be native material. Soft. Attempted to push shelby tube at 26' bgs, but no recovery..							
20			100		1 - 1 - 1									
25			100		1 - 1 - 1									
								26.0						

Boring Depth: 26.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 14.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-514

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.902409 **Coordinates** E: -75.257034
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			20		1 - 1 - 4		Sandy SILT, medium stiff, moist.	0.3						
							Sandy SILT with clay, very soft to stiff, moist to very moist, brown to black, non plastic, Majority of subface is buried construction debris. Very little soil. 20% soil, 80% debris.							
5			20		2 - 2 - 4									
10			20		4 - 3 - 3									
15			20		11 - 5 - 6									
								19.0						
20			80		1 - 1 - 1		Clayey SILT with sand, very soft, wet, brown to gray, medium plasticity, Appears to be native material. Shelby attempted 23-25, but no recovery..						
25			87		1 - 1 - 1			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 17.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-515

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.902966 **Coordinates** E: -75.256607
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			47		1 - 1 - 2		Sandy SILT, medium stiff, moist, brown.	0.2						
							Silty SAND, very loose to loose, moist, brown to brown, fine to medium grained, subrounded, No buried debris encountered.							
5			80		3 - 2 - 3									
								8.0						
							Clayey SILT with sand, very soft to medium stiff, moist to very moist, gray, medium plasticity, 90% soil, 10% debris.						
10			47		1 - 1 - 3									
15			100		1 - 1 - 1									
								18.0						
							Clayey SILT, soft to very soft, very moist to wet, low plasticity.							
20			100		1 - 1 - 1									
			100											
25			100		2 - 3 - 2			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 12.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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LOG OF BORING

Boring B-516

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.90303 **Coordinates** E: -75.256477
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			33		1 - 1 - 1		Very loose, moist. Silty SAND, very loose, moist, brown, fine to medium grained, subrounded, 20% soil, 80% debris.	0.2						
5			47		2 - 3 - 1									
							Sandy SILT with clay, soft, moist to wet, gray, non plastic, Fill material. Metal and woody debris present in soil. 50% soil.	8.0						
10			87		6 - 2 - 1									
15			67		1 - 1 - 3									
							Clayey SILT, very stiff, wet, gray to black, Heavily impacted material containg wood fibers. Heavy odor rotting municipal waste. 20% soil.	16.0						
20			100		3 - 9 - 9									
							Clayey SILT, very moist, brown, Appears to be native material. Less impacted..	23.0						
25			100		1 - 2 - 2			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-517

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.903854 **Coordinates** E: -75.255508
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			33		1 - 1 - 1		Very loose, moist to moist.	0.2						
							Silty SAND with gravel, very loose to loose, moist, brown to brown, fine to medium grained, subrounded, Contains construction and residential debris. 70% soil.							
5			80		3 - 3 - 2									
10			20		1 - 2 - 1									
								12.0						
							Sandy SILT with clay, soft to stiff, wet, gray to black, non plastic, Contains woody construction debris. 70% soil.							
15			33		5 - 4 - 5									
20			20		3 - 2 - 2									
25			33		3 - 3 - 3			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-518

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.903984 **Coordinates** E: -75.255638
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/8/17	**Date Finished:** 3/8/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
							Very loose, moist.	0.2						
			87		1 - 2 - 1		Silty SAND, very loose, very moist to wet, brown to brown, subangular, low plasticity, Contains municipal debris. 20% soil.							
5			20		1 - 2 - 1									
								9.0						
10			100		1 - 1 - 1		Silty CLAY, very soft, very moist to wet, gray, low plasticity, Appears to be native material. No debris observed.. ▽						
15			100		1 - 1 - 1									
								17.0						
							Gravelly SAND with silt, medium dense to very dense, wet to wet, brown to gray, fine to medium grained, subrounded.						
20			53		16 - 23 - 34									
25			87		3 - 7 - 7			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
▽ During Drilling: 11.0 ft	▼ After Drilling: Not Recorded	
▼ After Drilling: Not Recorded		

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Boring B-519

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.905056 **Coordinates** E: -75.254738
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			20		6 - 10 - 15		Clayey SILT, very stiff, moist, brown, low plasticity.	0.2						
							Silty SAND with gravel, very loose to medium dense, moist, brown, fine to medium grained, subangular, Very little soil. Mainly residential debris. 20% soil.							
5			13		1 - 1 - 0									
								9.0						
10			87		2 - 1 - 1		Clayey SILT, very soft to very stiff, very moist to wet, gray, low plasticity, Small amount of buried debris. 90% soil.						
15			20		17 - 10 - 8			15.0						
							Gravelly SAND with silt, medium dense to dense, wet, gray to brown, fine to coarse grained, subrounded, Well graded sand. Appears to be native material. No buried debris.						
20			87		12 - 17 - 22									
25			80		2 - 10 - 14			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Encountered	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-520

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.90567 **Coordinates** E: -75.254669
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		1 - 2 - 1		Clayey SILT, soft, moist, brown.	0.2						
							Sandy SILT, very soft to medium stiff, moist to very moist, non plastic, Very little soil, mainly buried residential debis. 20% soil.							
5			13		1 - 0 - 1									
10			53		5 - 5 - 3									
								13.0						
							Clayey SILT with gravel, medium stiff, wet, gray, non plastic, Minor amounts of buried debris 90% soil.							
15			20		1 - 2 - 6									
								18.0						
20			53		19 - 14 - 25		Gravelly SAND with silt, dense, wet, brown, subrounded, Appears to be native material without debris.							
25			80		11 - 18 - 26			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
After Drilling: Not Recorded	During Drilling: 13.0 ft	
	After Drilling: Not Recorded	

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Boring B-521

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.906227 **Coordinates** E: -75.254135
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			33		1 - 0 - 1		Clayey SILT, very soft, moist, brown.	0.3						
							Sandy SILT, very soft to hard, moist to very moist, brown to gray, Majority of subsurfacevis buried construction and residential debris. Approx 10% soil.							
5			27		4 - 3 - 1									
			0		50/0.4ft									
10														
							Silty SAND with gravel, loose to very dense, very moist to wet, brown to black, fine to medium grained, subrounded, Buried wood debris with soil. Approx 50% debris.	12.0						
15			67		3 - 1 - 4									
20			47		7 - 23 - 40			20.0						
							Gravelly SAND with silt, dense to very dense, wet, brown to gray, fine to coarse grained, subrounded, Native material without debris.							
25			87		12 - 15 - 20			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 15.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-522

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.906376 **Coordinates** E: -75.253403
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			87		1 - 1 - 2		Clayey SILT, soft, moist.	0.3						
							Silty SAND with gravel, very loose to loose, moist to very moist, brown to brown, fine to medium grained, subrounded, Buried construction and residential debris. Approximately 25% soil, 75% debris..							
5			20		2 - 1 - 5									
10			53		3 - 2 - 4									
							Clayey SILT with gravel, very soft to soft, wet, gray, Contains approx 50% soil, 50% debris..	14.0						
15			7		2 - 1 - 3									
20			100		2 - 1 - 1									
							Clayey SILT, soft, very moist, brown, non plastic, Appears to be native material. No debris..	22.0						
25			100		1 - 1 - 2			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
After Drilling: Not Recorded	During Drilling: 17.0 ft	
	After Drilling: Not Recorded	

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Boring B-523

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.906536 **Coordinates** E: -75.251946
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		5 - 4 - 7		Clayey SILT, stiff, moist, brown.	0.3						
							Sandy SILT with clay, very soft to stiff, wet to very moist, brown, non plastic, Some construction debris present. Approx 75% soil.							
5			33		2 - 1 - 0		▽	5.0						
							Silty CLAY, very soft, wet, brown to gray, medium plasticity, No debris observed. Appears to be native material. Not ablevto collect a shelby tube v.							
10			87		1 - 1 - 0									
15			100		0 - 0 - 0			15.0						
							Sandy SILT with clay, very soft, wet, gray, non plastic.							
20			100		0 - 0 - 0									
								22.0						
							Silty SAND with gravel, medium dense, wet, gray, fine to medium grained, subrounded.							
25			87		5 - 5 - 6			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
▽ During Drilling: 5.0 ft	▽ After Drilling: Not Recorded	
▼ After Drilling: Not Recorded		

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Boring B-524

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.907021 **Coordinates** E: -75.250877
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/9/17	**Date Finished:** 3/9/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			73		3 - 6 - 3		Clayey SILT, moist.	0.3						
							Sandy SILT with gravel, very soft to hard, moist, brown, non plastic, Some construction debris present. Approx 85% soil..							
5			47		2 - 5 - 4									
10			87		1 - 0 - 1									
15			80		1 - 17 - 23		Silty SAND with gravel, dense, wet, brown, angular to subrounded.	15.0						
								18.0						
20			38		30 - 50/0.3ft		Very dense, very moist, angular, Weathered bedrock (gneiss). Competency increasing with depth..							
25			63		24 - 50/0.3ft			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: 8.0 ft	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-525

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.907341 **Coordinates** E: -75.250427
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/10/17	**Date Finished:** 3/10/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			53		1 - 2 - 3		Clayey SILT, medium stiff, moist, brown.	0.2						
							Silty SAND, very loose to loose, moist, brown, fine to medium grained, angular to subrounded, No debris.							
5			67		2 - 1 - 1			5.0						
							Sandy, Silty SAND with silt, very loose to loose, moist, brown to gray, angular, Micaeous Silty sand, sandy silt, non-plastic. No debris.							
10			100		1 - 2 - 3			10.0						
							Clayey SILT, medium stiff to hard, moist, gray, non plastic, Micaeous. No debris.							
15			53		4 - 16 - 23			15.0						
							Silty SAND, medium dense to dense, moist, brown to gray, angular, Micaeous. No debris.							
20			20		9 - 12 - 16			20.0						
							Sandy, Silty SAND, medium dense to very dense, moist, brown to gray, angular, Heavily weathered schist, some relic schist features present.							
25			100		25 - 50/0.3ft			25.0						

Boring Depth: 25.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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Boring B-526

TETRA TECH

Project: Clearview Landfill		**Rig:** Geoprobe **Hammer:** Auto	**Boring Location** N: 39.907589 **Coordinates** E: -75.250206
Project Number: 114-571155		**Boring Diameter:** 6 in	**System:** Decimal Degrees **Datum:** NAD83 — **Top of Boring Elevation:**
Date Started: 3/10/17	**Date Finished:** 3/10/17	**Drilling Fluid:** None	**Abandonment Method:** Backfilled with Cuttings
Driller: Hynes Drilling **Logger:** Daniel Earnest		**Location:**	

Depth (ft) / Elev. (ft)	Operation	Sample Type	Recovery (%)	RQD (%)	Blow Count	Lithology	Material Description	Depth (ft) / Elev. (ft)	MC (%)	LL	PL	-200 (%)	DD	Remarks and Other Tests
			80		2 - 4 - 5		Clayey SILT, stiff, moist, brown.	0.2						
							Silty SAND with gravel, loose, moist, brown, angular.							
5			67		5 - 4 - 4									
							Clayey SILT, medium stiff to hard, moist, tan to gray, non plastic, Some relic schist banding present..	8.0						
10			100		3 - 2 - 3									
			100		50/0.4ft		Silty SAND, very dense, moist, tan to gray, Heavily weatheted schist. Auger refusal at 22' bgs..	14.0						
15														
			100		50/0.1ft									
20								22.0						

Boring Depth: 22.0 ft, *Elevation:*

Water Level Observations		Remarks:
During Drilling: Not Recorded	After Drilling: Not Recorded	
After Drilling: Not Recorded		

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APPENDIX C: GEOTECHNICAL INVESTIGATION PICTURES

Clearview Landfill
Geotechnical Investigation Photos
Lower Darby Creek Area



PHOTOGRAPH 1 B-501 Looking East



PHOTOGRAPH 2 B-503 Looking West



PHOTOGRAPH 3 B-505 Looking South



PHOTOGRAPH 4 B-507 Looking North



PHOTOGRAPH 5 B-509 Looking West



PHOTOGRAPH 6 B-511 Looking North

Clearview Landfill
Geotechnical Investigation Photos
Lower Darby Creek Area



PHOTOGRAPH 7 B-514 Looking East



PHOTOGRAPH 8 B-516 Looking Northeast



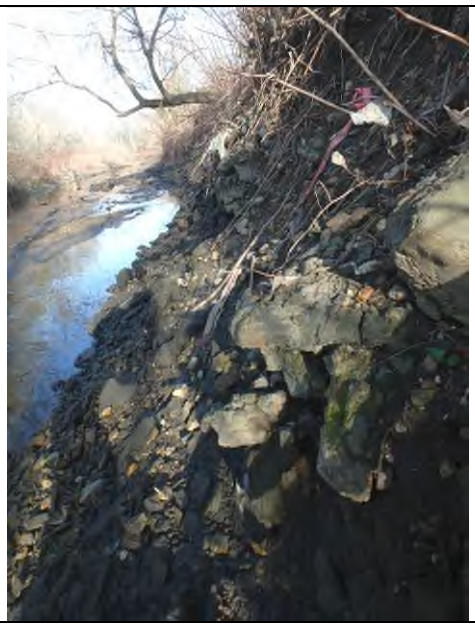
PHOTOGRAPH 9 B-518 Looking Southwest



PHOTOGRAPH 10 B-520 Looking North



PHOTOGRAPH 11 B-524 Looking Southwest



PHOTOGRAPH 12 Typical Crib Wall Slopes Along Creek

APPENDIX D: LABORATORY SUMMARY TABLE D-1 AND LABORATORY TESTING DATA

TABLE D-1
SUMMARY OF LABORATORY TEST RESULTS

Lower Darby Creek Superfund Site

Project No. 114-571155

SAMPLE LOCATION				NATURAL MOISTURE CONTENT (%)	ATTERBERG LIMITS		GRADATION		PERCENT PASSING NO. 200 SIEVE	OTHER TESTS	SAMPLE DESCRIPTION/CLASSIFICATION
BORING	DEPTH (ft)	STATION	FEATURE		LIQUID LIMIT	PLASTICITY INDEX	GRAVEL (%)	SAND (%)			
GB 1	0-2	6+60	Toe of Crib	56	51	8	4	51	45		Silty Sand
GB 2	0-2	9+50	Toe of Crib	129	68	1	0	59	41		Silty Sand
GB 3	0-2	21+00	Toe of Crib	45	NV	NP	0	24	76		Silt with Sand
GB 4	0-2	24+00	Toe of Crib	51	33	3	0	60	40		Silty Sand
GB 5	0-2	3+30	Crib Bank	29	51	6	28	46	26		Silty Sand with Gravel
GB 6	0-2	8+70	Crib Bank	20	39	4	34	46	20	Resistivity = 3,700 ohm-cm pH = 8.2 Sulfate Content < 0.01%	Silty Sand with Gravel
GB 7	0-2	17+00	Crib Bank	10	NV	NP	2	93	5	Sulfate Content < 0.01%	Poorly Graded Sand with Silt
GB 8	0-2	23+00	Crib Bank	10	NV	NP	3	88	9		Poorly Graded Sand with Silt
GB 9	0-2	41+50	Block Wall	33	36	10	0	45	55	Resistivity = 4,500 ohm-cm pH = 7.4 Sulfate Content < 0.01%	Sandy Silt
GB 10	0-2	44+50	Crib Bank	40	43	14	0	25	75	Resistivity = 3,850 ohm-cm pH = 6.6 Sulfate Content < 0.01%	Silt with Sand
GB 12	0-2	15+50	MSE Wall	18	NV	NP	9	79	12		Poorly-graded Sand with Silt
GB 13	0-2	27+50	Gabion Wall	34	NV	NP	37	46	17	Maximum Dry Density: 97.4 pcf at 17.8% moisture	Silty Sand with Gravel
GB 14	0-2	31+00	MSE Wall	19	42	7	23	53	24		Silty Sand with Gravel
GB 15	0-2	7+60	Steep Slope	43	NV	NP	20	58	22		Silty Sand with Gravel

TABLE D-1
SUMMARY OF LABORATORY TEST RESULTS

Lower Darby Creek Superfund Site

Project No. 114-571155

SAMPLE LOCATION				NATURAL MOISTURE CONTENT (%)	ATTERBERG LIMITS		GRADATION		PERCENT PASSING NO. 200 SIEVE	OTHER TESTS	SAMPLE DESCRIPTION/CLASSIFICATION
BORING	DEPTH (ft)	STATION	FEATURE		LIQUID LIMIT	PLASTICITY INDEX	GRAVEL (%)	SAND (%)			
GB 16	0-2	15+50	Steep Slope	11	NV	NP	17	64	19		Silty Sand with Gravel
B-501	9 - 10.5	1+00	Leachate Trench	17	34	8	34	40	26		Silty Sand with Gravel
B-502	19 - 20.5	2+00	Leachate Trench	63	50	18	0	44	56		Sandy Elastic Silt
B-503	4-5.5	3+25	MSE Wall	38	41	12	1	30	69		Sandy Silt
B-503	19-20.5	3+25	MSE Wall	33	NV	NP	1	83	16		Silty Sand
B-508	4 - 5.5	7+80	Crib Wall	27	46	5	7	72	21		Silty Sand
B-508	9 - 10.5	7+80	Crib Wall	55	34	9	6	58	36		Silty Sand
B-509	9-10.5	8+80	Leachate Trench	28	NV	NP	38	47	15		Silty Sand with Gravel
B-510	12-18	9+20	Crib Wall	45	52	16	0	24	76	Maximum Dry Density: 80.2 pcf at 30.6% moisture	Elastic Silt with Sand
B-510	14-15.5	9+20	Crib Wall		47	16	0	49	51		Sandy Silt
B-511	4 - 5.5	9+70	MSE Wall	19	NV	NP	35	49	16		Silty Sand with Gravel
B-511	14-15.5	9+70	MSE Wall	37	NV	NP	17	67	16		Silty Sand with Gravel
B-512	4 - 5.5	11+00	Gabion Wall	14	NV	NP	17	53	30		Silty Sand with Gravel
B-512	9 - 10.5	11+00	Gabion Wall	26	NV	NP	11	62	27		Silty Sand
B-513	4-5.5	13+10	MSE Wall	45	NV	NP	2	74	24		Silty Sand
B-513	9 - 10.5	13+10	MSE Wall	33	NV	NP	0	81	19		Silty Sand
B-515	14 - 15.5	17+75	Crib Wall	38	31	3	0	92	8		Poorly Graded Sand with Silt
B-515	22-24	17+75	Crib Wall	106	76	14	0	11	89	P_c= 1.9 ksf C_c= 0.91 ϕ= 26.6 c= 0.91	Elastic Silt

TABLE D-1
SUMMARY OF LABORATORY TEST RESULTS

Lower Darby Creek Superfund Site

Project No. 114-571155

SAMPLE LOCATION				NATURAL MOISTURE CONTENT (%)	ATTERBERG LIMITS		GRADATION		PERCENT PASSING NO. 200 SIEVE	OTHER TESTS	SAMPLE DESCRIPTION/CLASSIFICATION
BORING	DEPTH (ft)	STATION	FEATURE		LIQUID LIMIT	PLASTICITY INDEX	GRAVEL (%)	SAND (%)			
B-516	9 - 10.5	18+25	MSE Wall	47	NV	NP	11	63	26		Silty Sand
B-518	9 - 10.5	22+25	Crib Wall	41	NV	NP	1	35	64		Sandy Silt
B-519	14 - 15.5	26+50	Gabion Wall	35	36	7	6	48	46		Silty Sand
B-520	9 - 10.5	28+50	Gabion Wall	31	NV	NP	16	51	33		Silty Sand with gravel
B-521	14 - 15.5	32+75	MSE Wall	30	NV	NP	24	47	29		Silty Sand with Gravel
B-522	9 - 10.5	35+00	MSE Wall	27	45	8	24	58	18		Silty Sand with Gravel
B-523	0 - 1.5	39+00	Block Wall	18	36	4	42	38	20		Silty Gravel with Sand
B-523	9 - 10.5	39+00	Block Wall	63	54	16	1	47	52		Sandy Elastic Silt
B-524	4 - 5.5	42+50	Block Wall	21	NV	NP	14	56	30		Silty Sand
B-524	5-10	42+50	Block Wall		34	7	10	57	33	Maximum Dry Density: 106.5 pcf at 15.4% moisture	Silty Sand
B-524	9 - 10.5	42+50	Block Wall	36	36	5	13	45	42		Silty Sand
B-525	9 - 10.5	44+00	Crib Wall	36	37	8	0	44	56		Sandy Silt
B-526	9 - 10.5	45+00	Crib Wall	18	21	3	0	45	55		Sandy Silt
Oldmans	Bulk	N.A.	Cover Material	33	63	26	0	13	87	Perm at 85% compaction: 1.53 x 10^-4 cm/sec C = 0.74 ksf Phi = 34.0 Maximum Dry Density: 78.8 pcf at 34.6%	USCS: Elastic Silt USDA: Silty Clay Loam Organic Content: 8.30%

TABLE D-1
SUMMARY OF LABORATORY TEST RESULTS

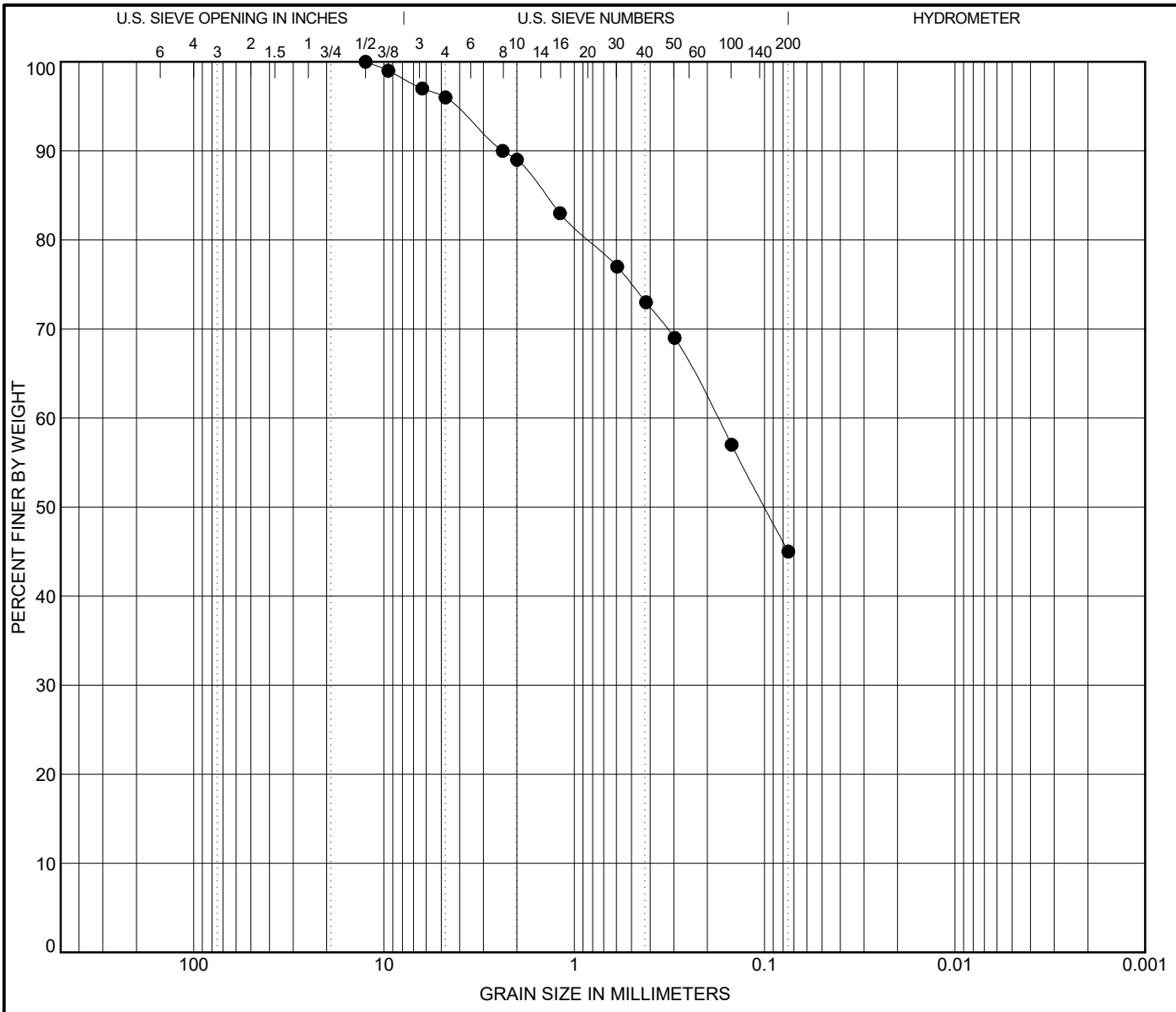
Lower Darby Creek Superfund Site

Project No. 114-571155

SAMPLE LOCATION				NATURAL MOISTURE CONTENT (%)	ATTERBERG LIMITS		GRADATION		PERCENT PASSING NO. 200 SIEVE	OTHER TESTS	SAMPLE DESCRIPTION/CLASSIFICATION
BORING	DEPTH (ft)	STATION	FEATURE		LIQUID LIMIT	PLASTICITY INDEX	GRAVEL (%)	SAND (%)			
Pedrick-town Lower	Bulk	N.A.	Cover Material		60	19	0	9	91	Perm at 85% compaction: 9.04 x 10^-5 cm/sec C = 0.01 ksf Phi = 36.2 Maximum Dry Density: 75.1 pcf at 38.3%	USCS: Elastic Silt USDA: Silty Clay Loam Organic Content: 9.05%

Abbreviations:

P_c = Preconsolidation Pressure
C_c = Modified Compresson Index
ϕ = Peak Angle of Internal Friction, Phi
c = Cohesion
CBR = California Bearing Ratio



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/2 in	100
3/8 in	99
1/4 in	97
No. 4	96
No. 8	90
No. 10	89
No. 16	83
No. 30	77
No. 40	73
No. 50	69
No. 100	57
No. 200	45

Specimen Identification
GB 1 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**51**	**43**	**8**		

% Gravel	% Sand	% Silt	% Clay
4	51	45	

D100	D60	D30	D10
12.5	0.177		

TETRA TECH

GRAIN SIZE DISTRIBUTION

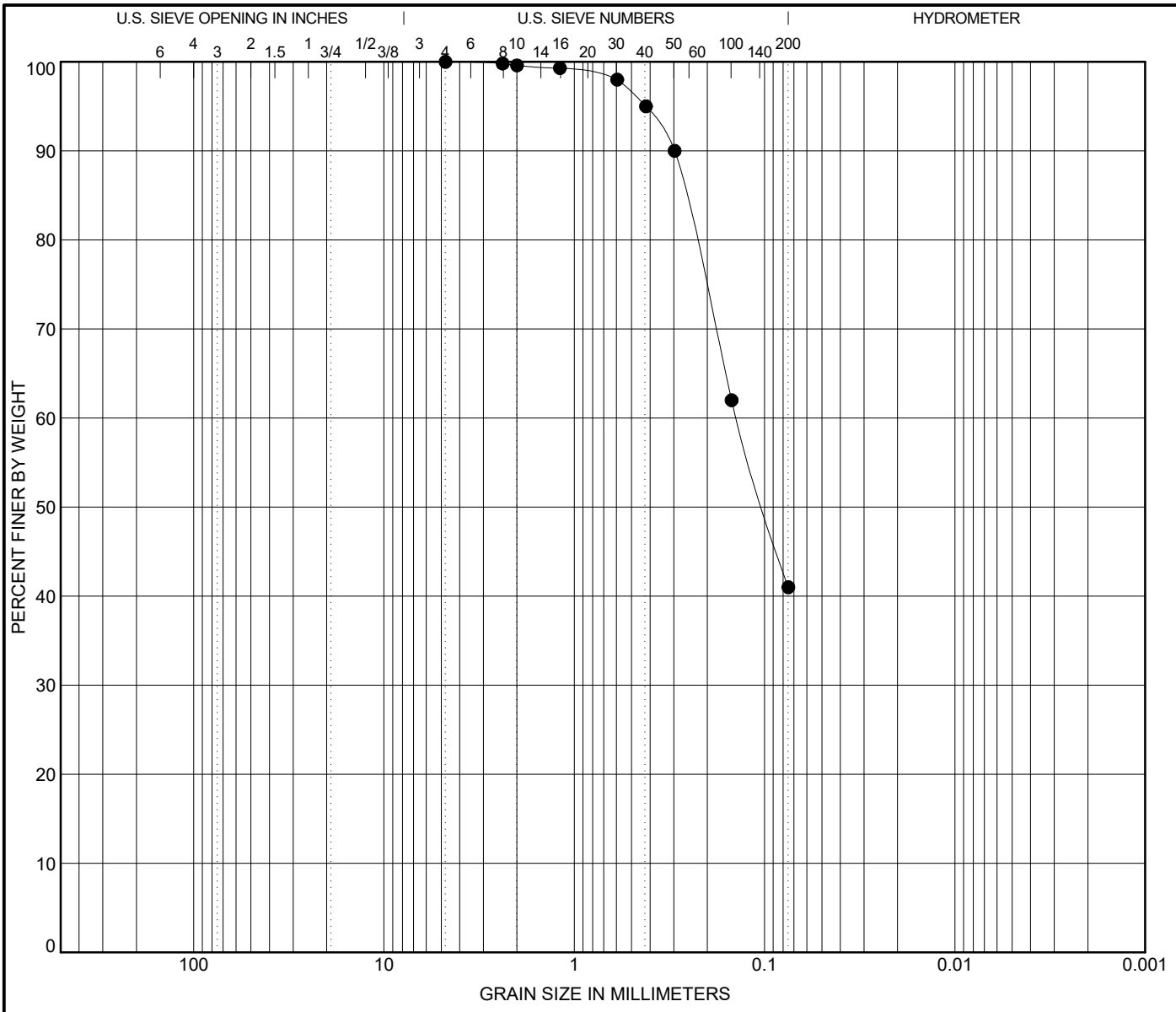
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 6+60 - Toe of Crib

Number: 114-571155 Figure No. 1

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99.8
No. 10	99.6
No. 16	99.3
No. 30	98
No. 40	95
No. 50	90
No. 100	62
No. 200	41

Specimen Identification
GB 2 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**68**	**67**	**1**		

% Gravel	% Sand	% Silt	% Clay
0	59	41	

D100	D60	D30	D10
4.75	0.14		

TETRA TECH

GRAIN SIZE DISTRIBUTION

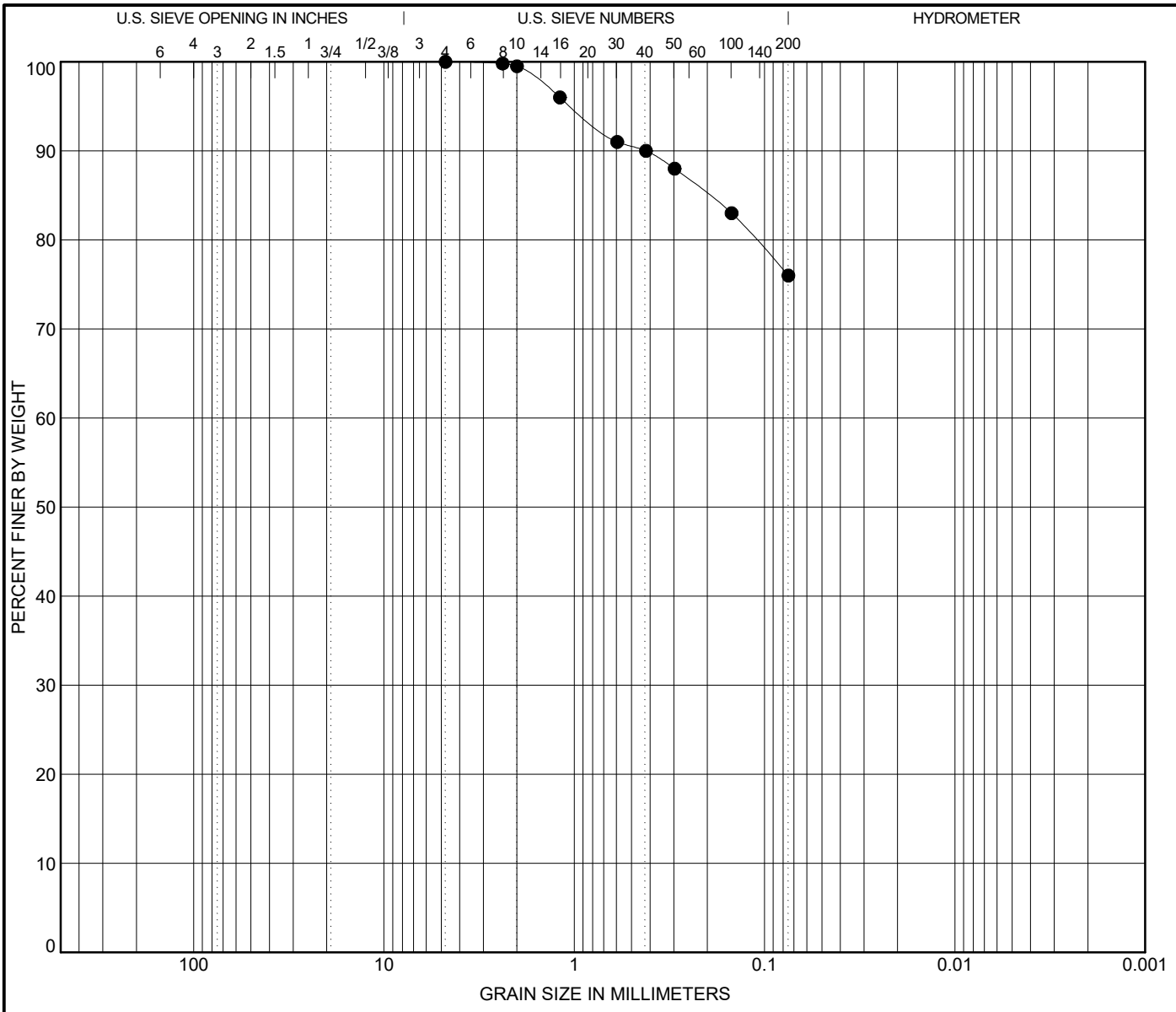
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 9+50 - Toe of Crib

Number: 114-571155 Figure No. 2

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99.8
No. 10	99.5
No. 16	96
No. 30	91
No. 40	90
No. 50	88
No. 100	83
No. 200	76

Specimen Identification
GB 3 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILT with SAND(ML)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
0	24	76	

D100	D60	D30	D10
4.75			

GRAIN SIZE DISTRIBUTION

TETRA TECH

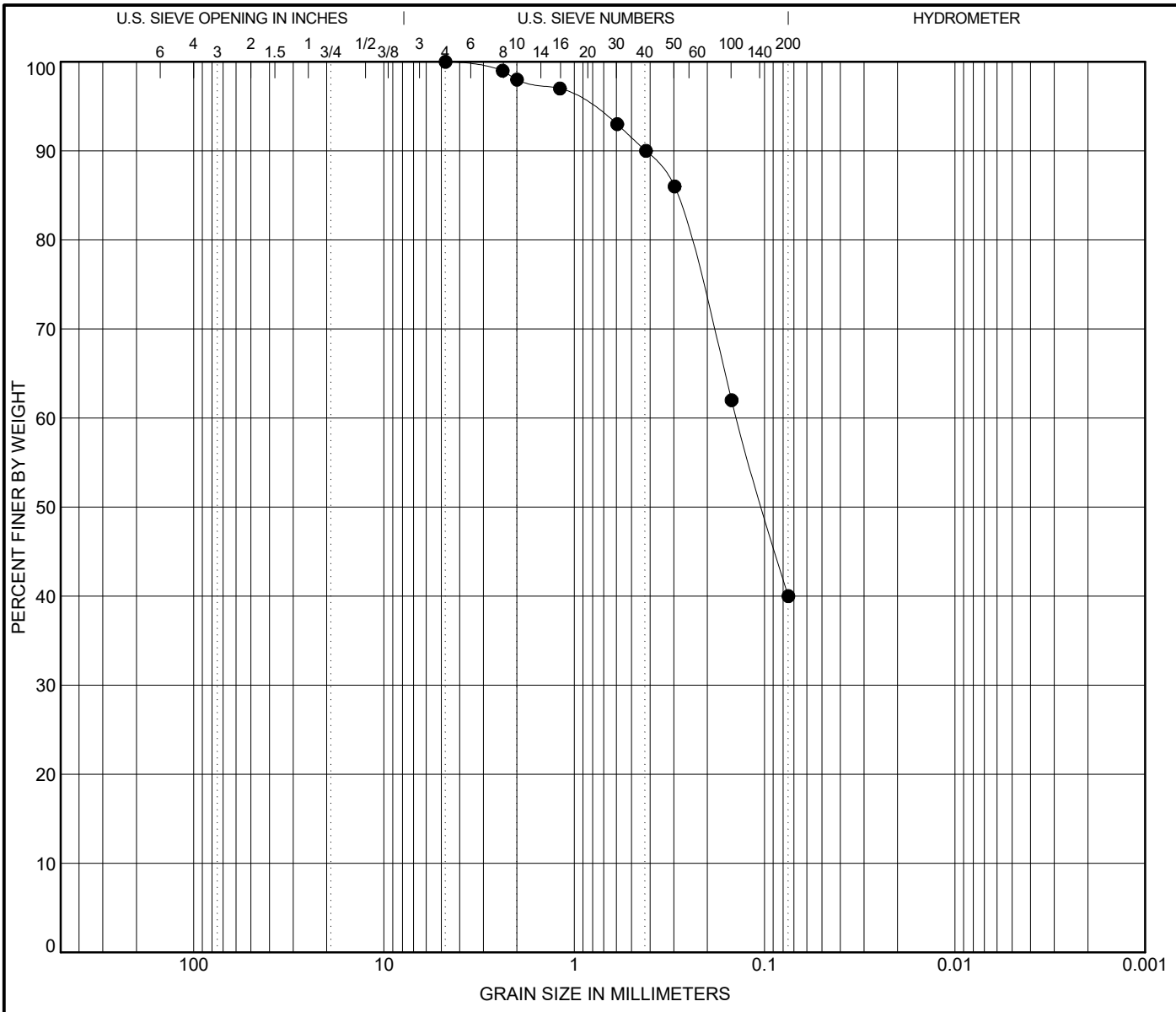
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 21+00 - Toe of Crib

Number: 114-571155 Figure No. 3

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99
No. 10	98
No. 16	97
No. 30	93
No. 40	90
No. 50	86
No. 100	62
No. 200	40

Specimen Identification
GB 4 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**33**	**30**	**3**		

% Gravel	% Sand	% Silt	% Clay
0	60	40	

D100	D60	D30	D10
4.75	0.14		

TETRA TECH

GRAIN SIZE DISTRIBUTION

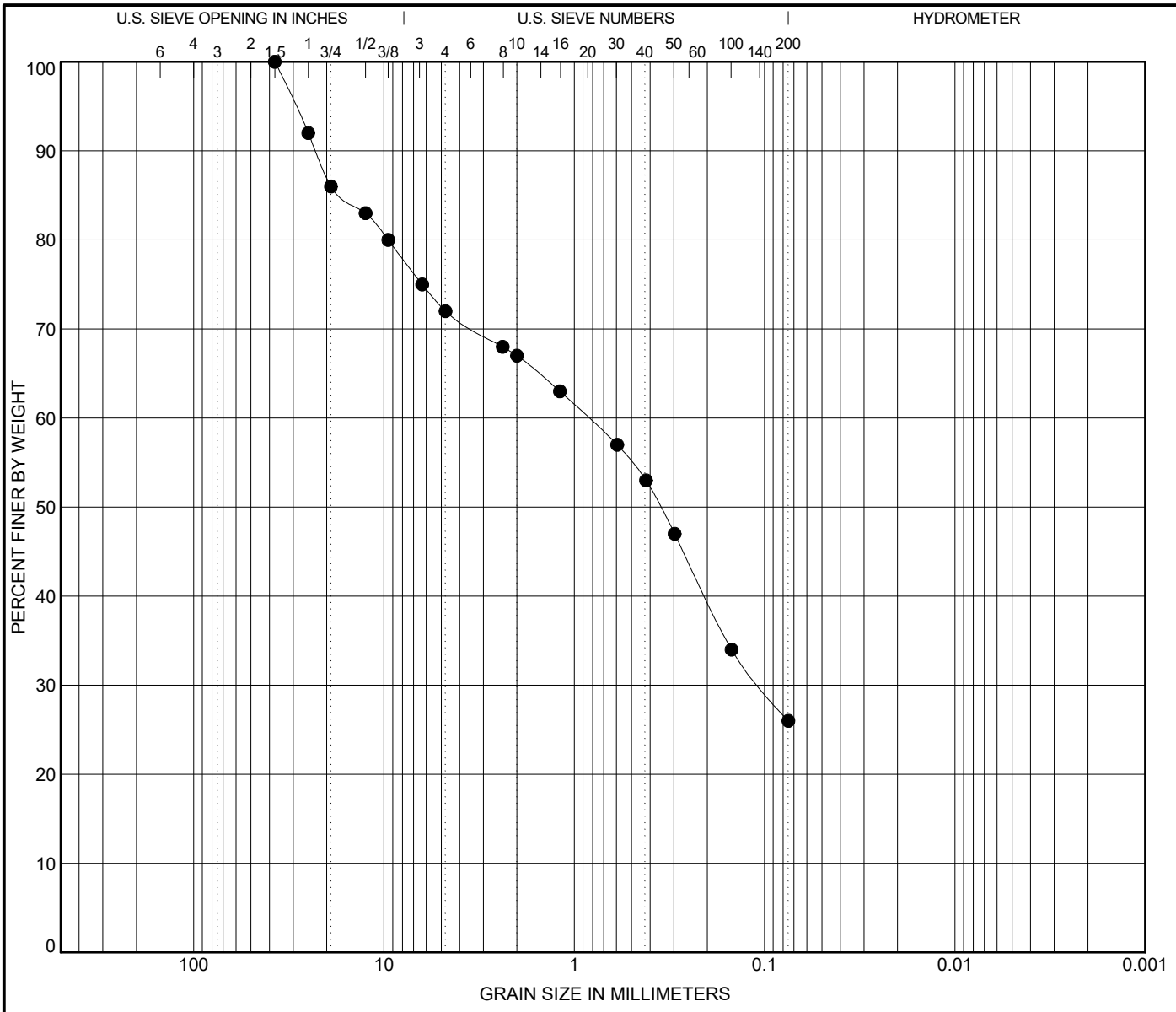
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 24+00 - Toe of Crib

Number: 114-571155 Figure No. 4

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	92
3/4 in	86
1/2 in	83
3/8 in	80
1/4 in	75
No. 4	72
No. 8	68
No. 10	67
No. 16	63
No. 30	57
No. 40	53
No. 50	47
No. 100	34
No. 200	26

Specimen Identification
GB 5 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**51**	**45**	**6**		

% Gravel	% Sand	% Silt	% Clay
28	46	26	

D100	D60	D30	D10
37.5	0.841	0.106	

TETRA TECH

GRAIN SIZE DISTRIBUTION

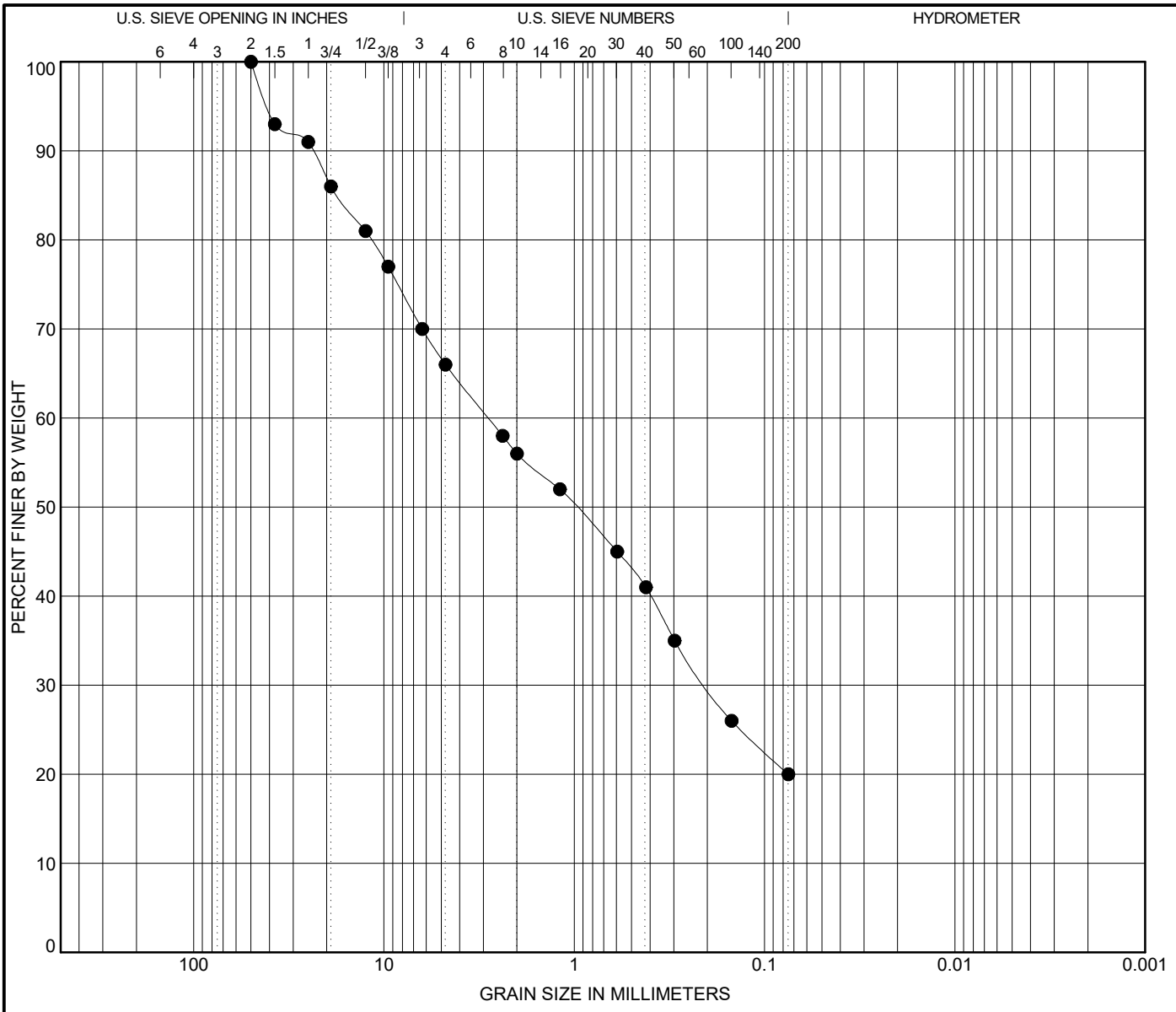
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 3+30 - Crib Bank

Number: 114-571155 Figure No. 5

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
2 in	100
1.5 in	93
1 in	91
3/4 in	86
1/2 in	81
3/8 in	77
1/4 in	70
No. 4	66
No. 8	58
No. 10	56
No. 16	52
No. 30	45
No. 40	41
No. 50	35
No. 100	26
No. 200	20

Specimen Identification
GB 6 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**39**	**35**	**4**		

% Gravel	% Sand	% Silt	% Clay
34	46	20	

D100	D60	D30	D10
50	2.829	0.202	

TETRA TECH

GRAIN SIZE DISTRIBUTION

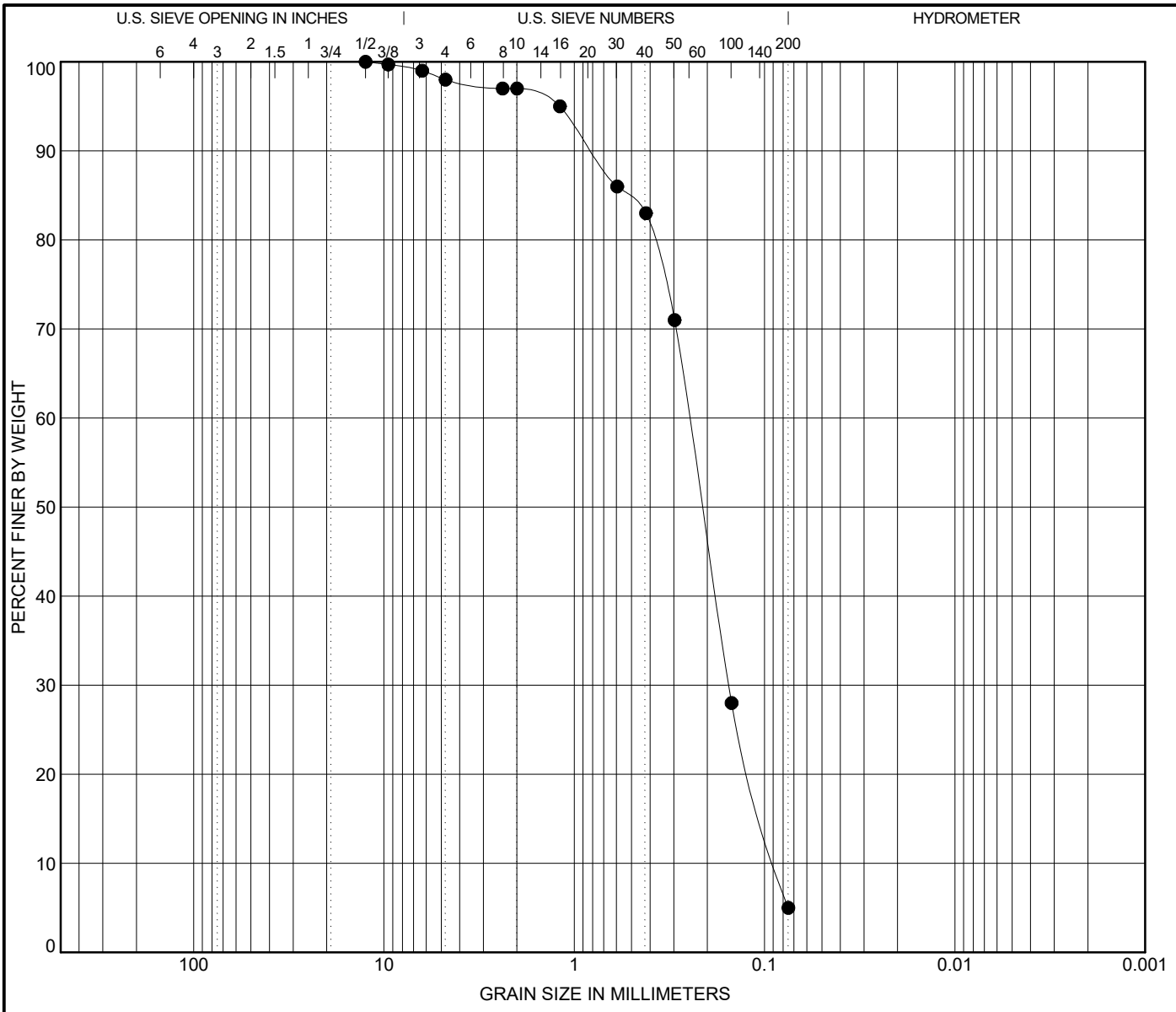
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 8+70 - Crib Bank

Number: 114-571155 Figure No. 6

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/2 in	100
3/8 in	99.7
1/4 in	99
No. 4	98
No. 8	97
No. 10	97
No. 16	95
No. 30	86
No. 40	83
No. 50	71
No. 100	28
No. 200	5

Specimen Identification
GB 7 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
POORLY GRADED SAND with SILT(SP-SM)	**NV**	**NV**	**NP**	**1.09**	**2.86**

% Gravel	% Sand	% Silt	% Clay
2	93	5	

D100	D60	D30	D10
12.5	0.249	0.154	0.087

GRAIN SIZE DISTRIBUTION

TETRA TECH

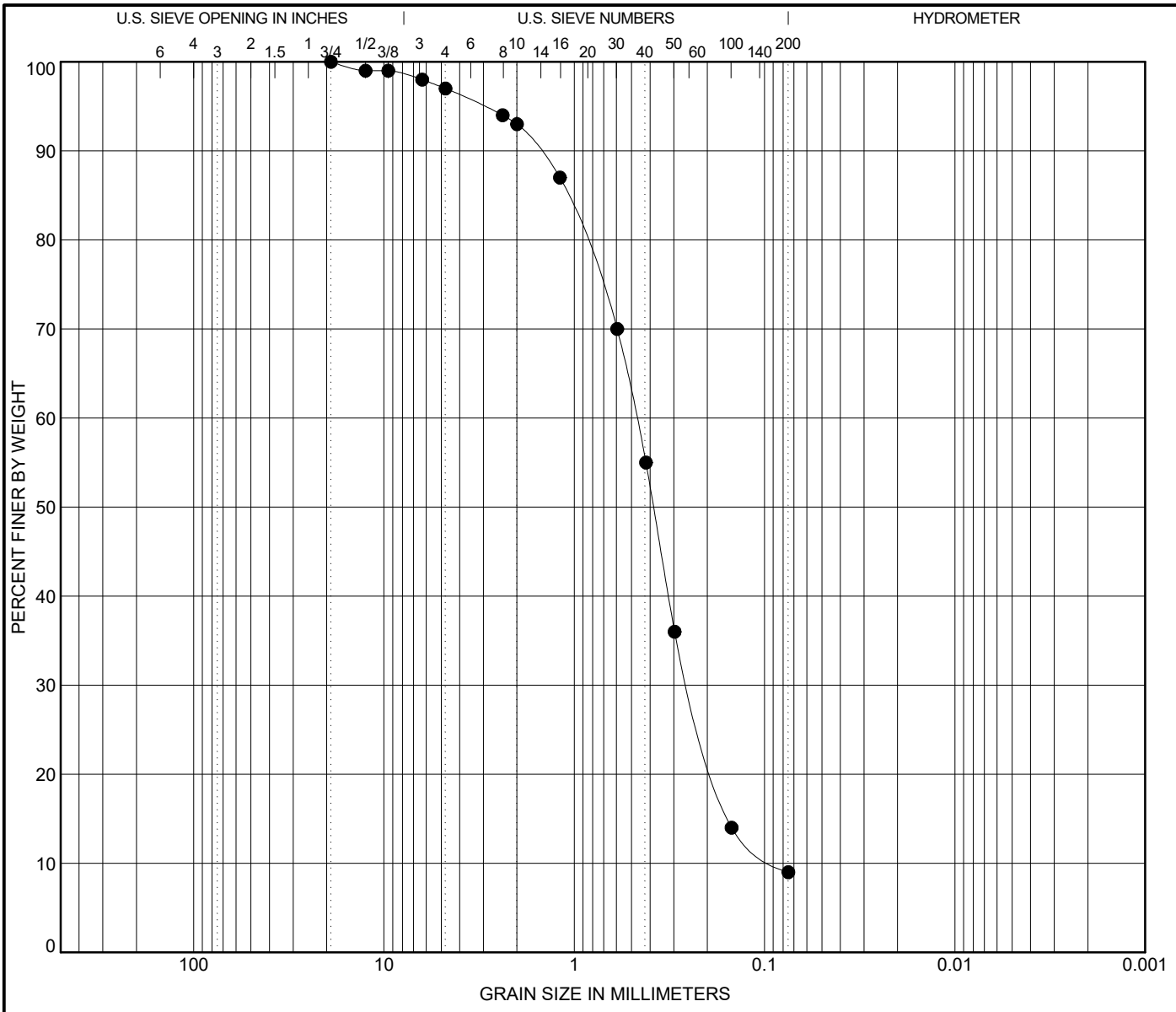
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 17+00 - Crib Bank

Number: 114-571155 Figure No. 7

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
3/4 in	100
1/2 in	99
3/8 in	99
1/4 in	98
No. 4	97
No. 8	94
No. 10	93
No. 16	87
No. 30	70
No. 40	55
No. 50	36
No. 100	14
No. 200	9

Specimen Identification
GB 8 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
POORLY GRADED SAND with SILT(SP-SM)	**NV**	**NV**	**NP**	**1.49**	**5.48**

% Gravel	% Sand	% Silt	% Clay
3	88	9	

D100	D60	D30	D10
19	0.472	0.246	0.086

TETRA TECH

GRAIN SIZE DISTRIBUTION

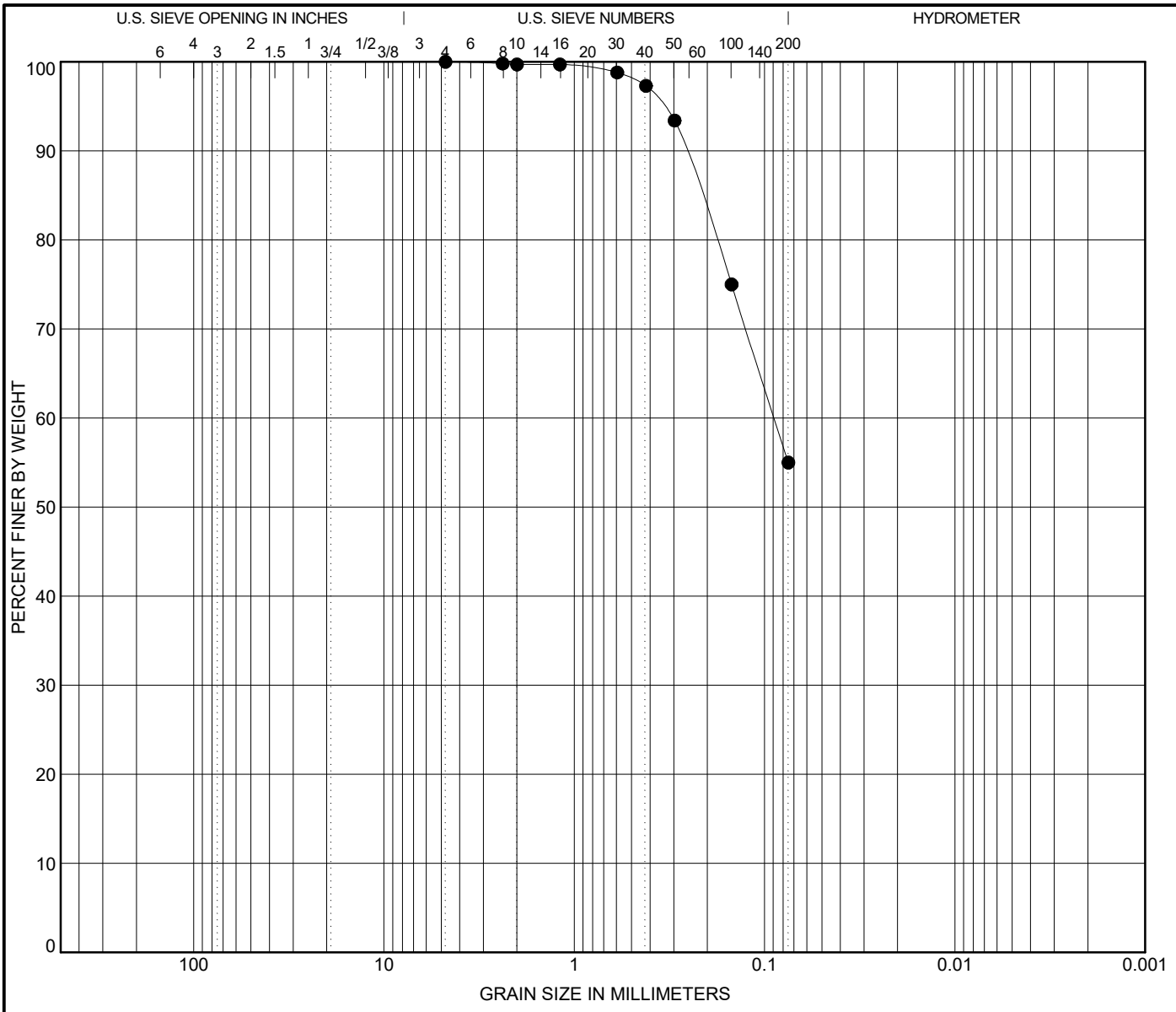
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 23+00 - Crib Bank

Number: 114-571155 Figure No. 8

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99.8
No. 10	99.7
No. 16	99.7
No. 30	98.8
No. 40	97.3
No. 50	93.4
No. 100	75
No. 200	55

Specimen Identification
GB 9 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**36**	**26**	**10**		

% Gravel	% Sand	% Silt	% Clay
0	45	55	

D100	D60	D30	D10
4.75	0.089		

TETRA TECH

GRAIN SIZE DISTRIBUTION

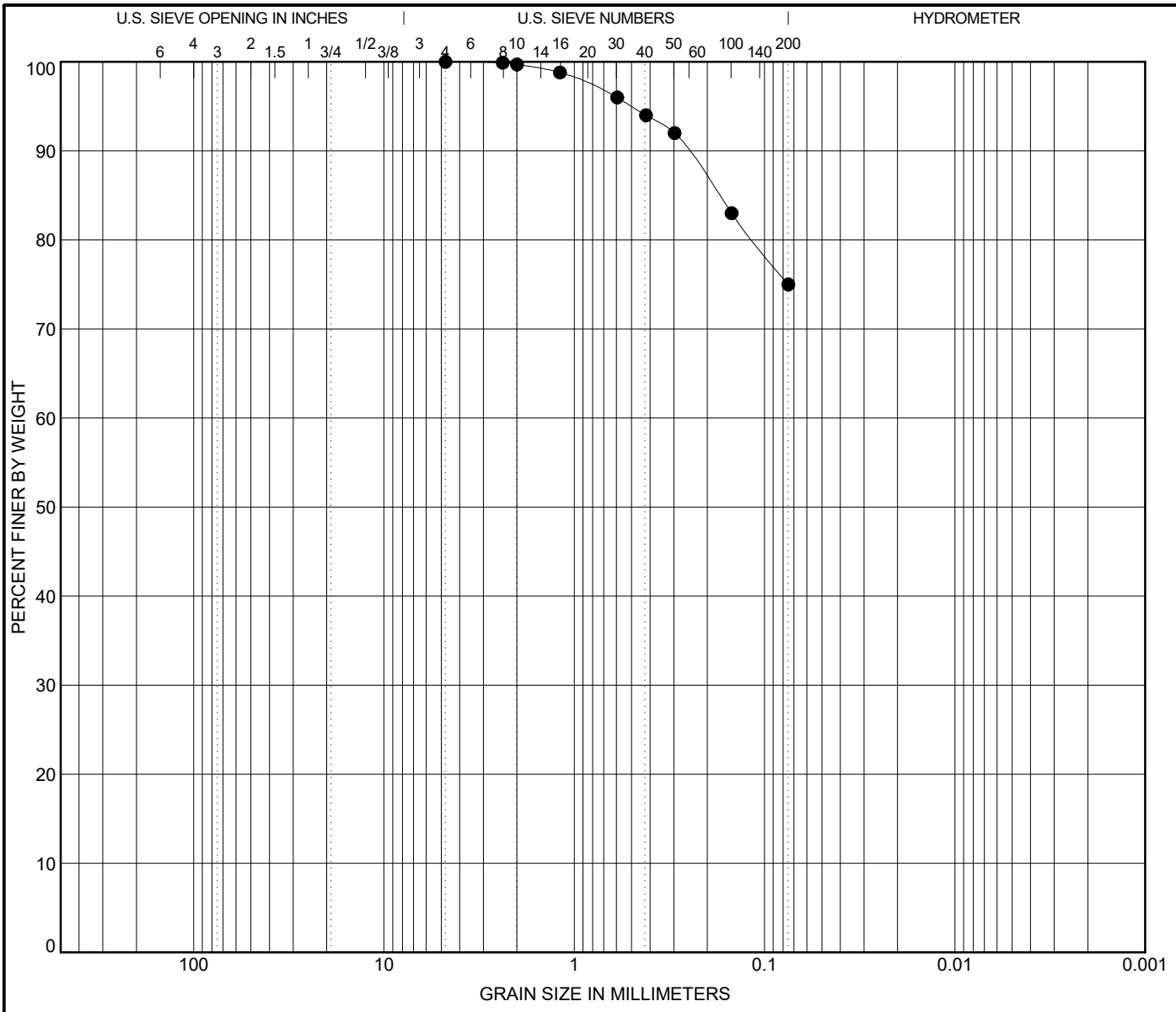
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 41+50 - Block Wall

Number: 114-571155 Figure No. 9

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99.9
No. 10	99.7
No. 16	98.8
No. 30	96
No. 40	94
No. 50	92
No. 100	83
No. 200	75

Specimen Identification
GB 10 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILT with SAND(ML)	**43**	**29**	**14**		

% Gravel	% Sand	% Silt	% Clay
0	25	75	

D100	D60	D30	D10
4.75			

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site, Client:

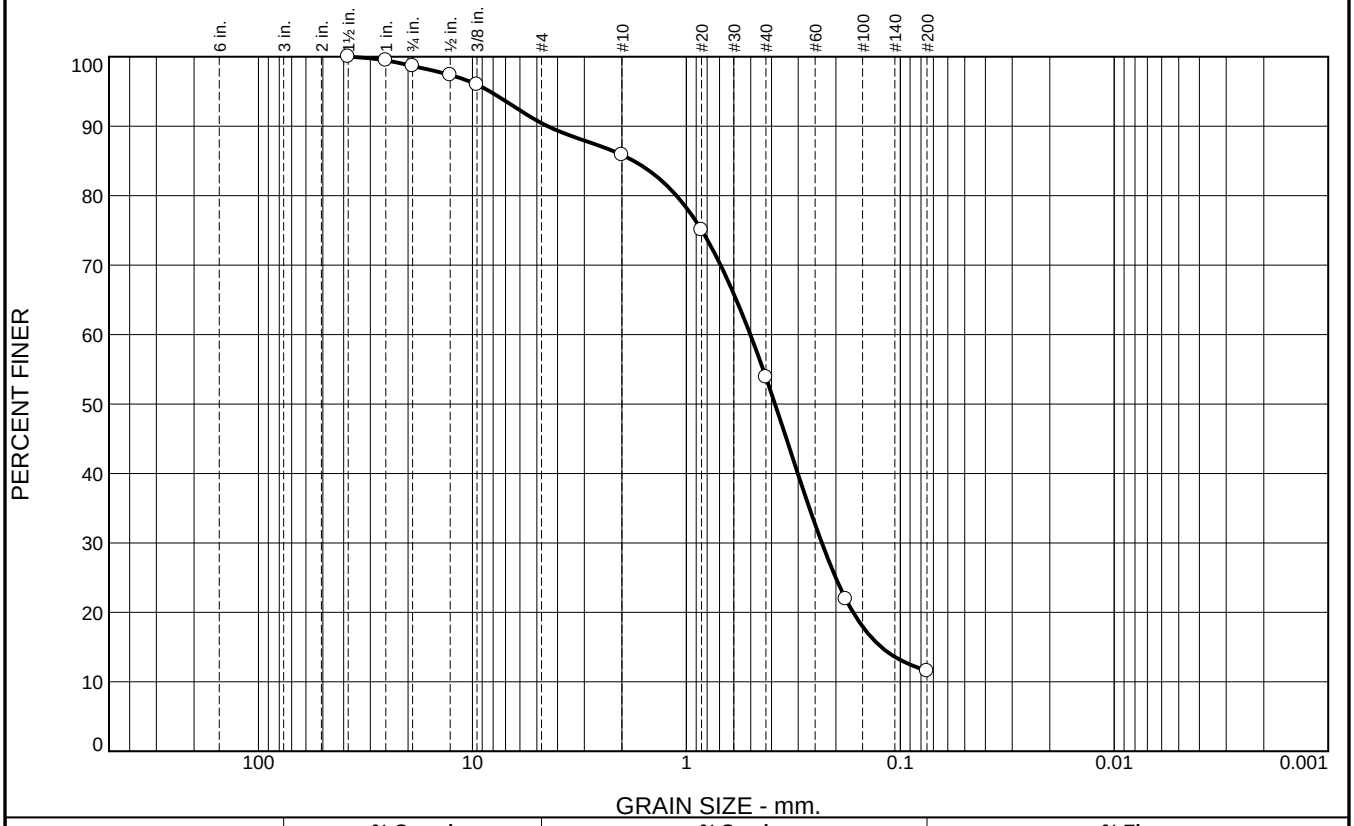
Location: STA 44+50 - Crib Bank

Number: 114-571155 Figure No. 10

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	1.3	8.3	4.5	32.0	42.3	11.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	99.5		
0.75	98.7		
0.50	97.4		
0.375	96.0		
#4	90.4		
#10	85.9		
#20	75.1		
#40	53.9		
#80	21.9		
#200	11.6		

* (no specification provided)

Soil Description

Poorly-graded SAND with Silt

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 4.4584 D_{85}= 1.7613 D_{60}= 0.5025
D_{50}= 0.3853 D_{30}= 0.2327 D_{15}= 0.1226
D_{10}= C_u= C_c=

Classification

USCS= SP-SM AASHTO= A-2-4(0)

Remarks

Source of Sample: Station 15+50 **Depth:** 0-2 feet **Specimen ID:** GB 11

Date:

Tetra Tech

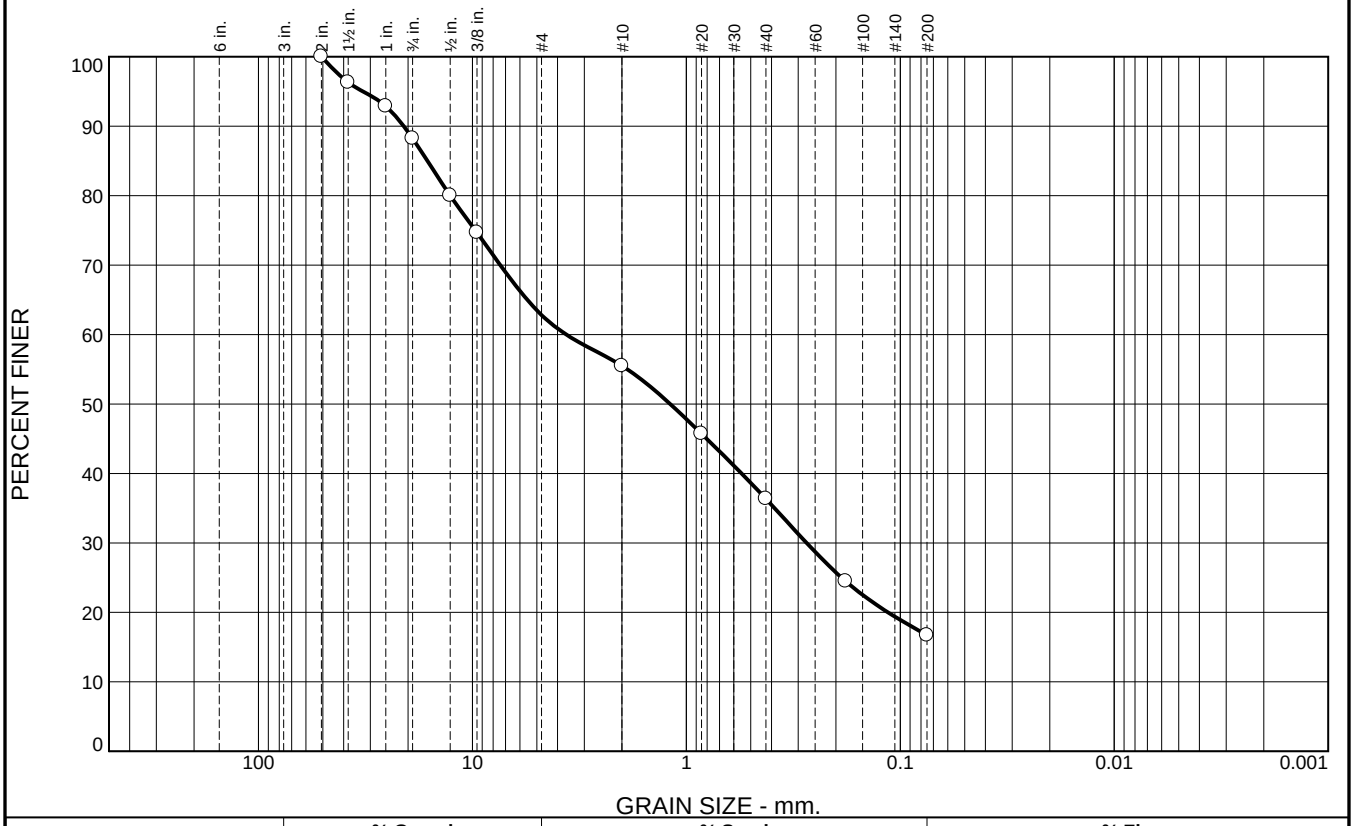
Billings, MT

Client:

Project: Clearview Landfill

Project No: 114-571155 **Figure** 11

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	11.8	25.4	7.3	19.1	19.7	16.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2	100.0		
1.5	96.3		
1	92.9		
0.75	88.2		
0.5	80.0		
0.375	74.7		
#4	62.8		
#10	55.5		
#20	45.7		
#40	36.4		
#80	24.5		
#200	16.7		

* (no specification provided)

Soil Description

Silty SAND with Gravel

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 20.9616 D_{85}= 16.2316 D_{60}= 3.6435
D_{50}= 1.1898 D_{30}= 0.2741 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO= A-1-b

Remarks

Source of Sample: Station 27+50 **Depth:** 0-2 feet **Specimen ID:** GB 12

Date:

Tetra Tech

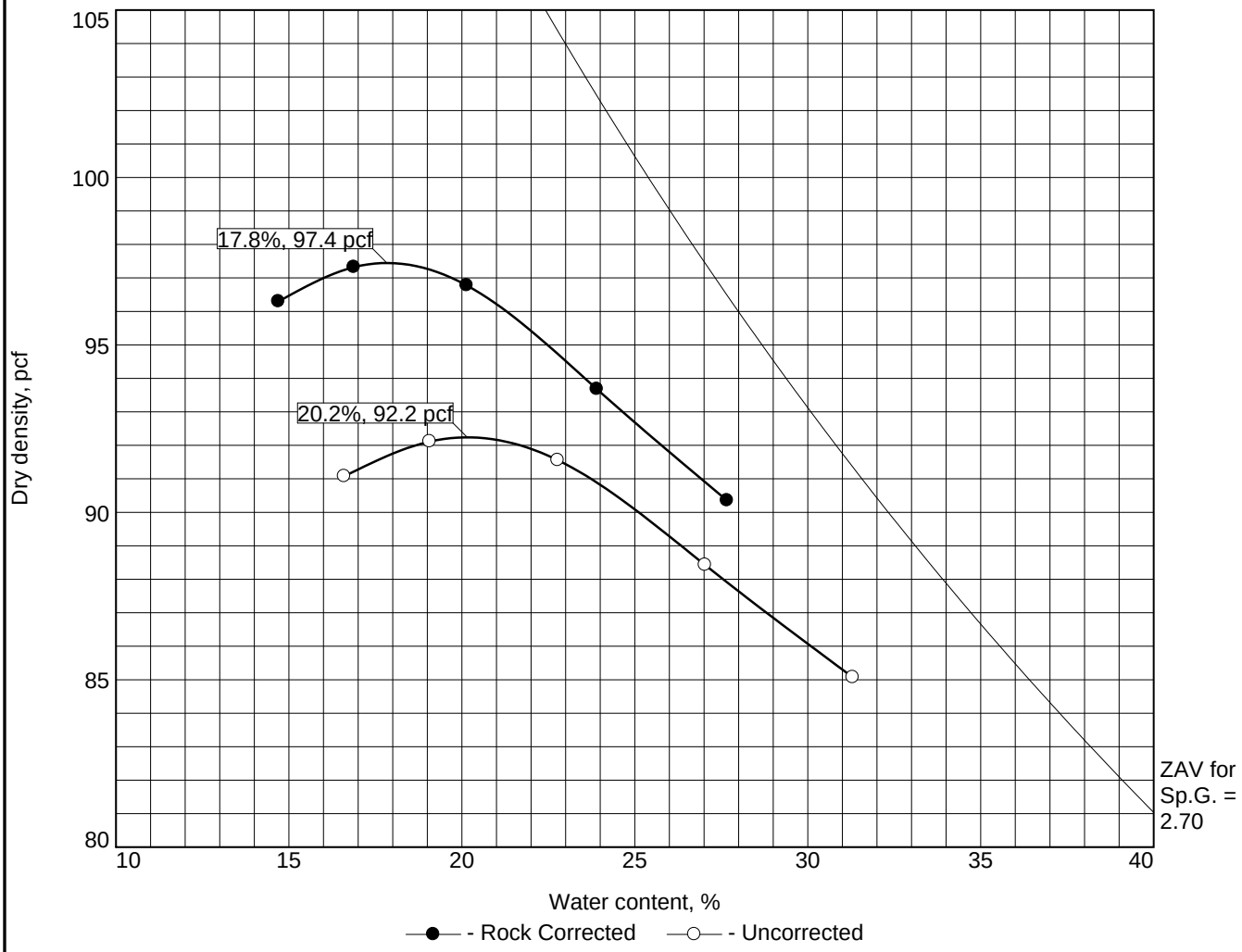
Billings, MT

Client:

Project: Clearview Landfill

Project No: 114-571155 **Figure** 12

COMPACTION TEST REPORT



Test specification: ASTM D 698-12 Method C Standard
ASTM D 4718-87 Oversize Corr. Applied to Each Test Point

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in.	% < No.200
	USCS	AASHTO						
0-2 feet	SM	A-1-b		2.70	NV	NP	11.8	16.7

ROCK CORRECTED TEST RESULTS	UNCORRECTED	MATERIAL DESCRIPTION
Maximum dry density = 97.4 pcf	92.2 pcf	Silty SAND with Gravel
Optimum moisture = 17.8 %	20.2 %	

Project No. 114-571155 **Client:**
Project: Clearview Landfill

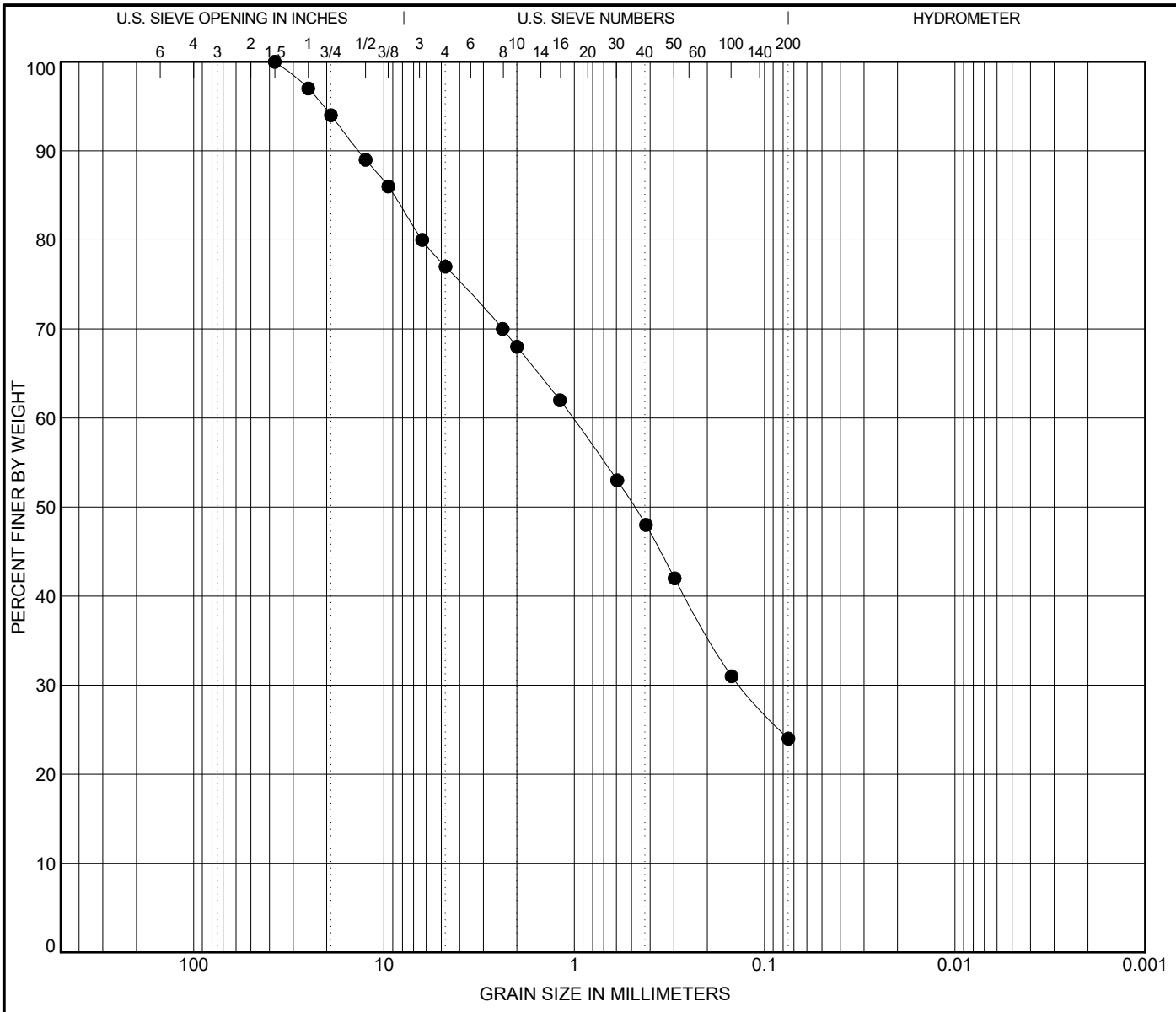
○**Source of Sample:** Station 27+50 **Specimen ID:** GB 12

Tetra Tech

Billings, MT

Remarks:

Figure 13



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	97
3/4 in	94
1/2 in	89
3/8 in	86
1/4 in	80
No. 4	77
No. 8	70
No. 10	68
No. 16	62
No. 30	53
No. 40	48
No. 50	42
No. 100	31
No. 200	24

Specimen Identification
GB 13 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**42**	**35**	**7**		

% Gravel	% Sand	% Silt	% Clay
23	53	24	

D100	D60	D30	D10
37.5	1.02	0.135	

TETRA TECH

GRAIN SIZE DISTRIBUTION

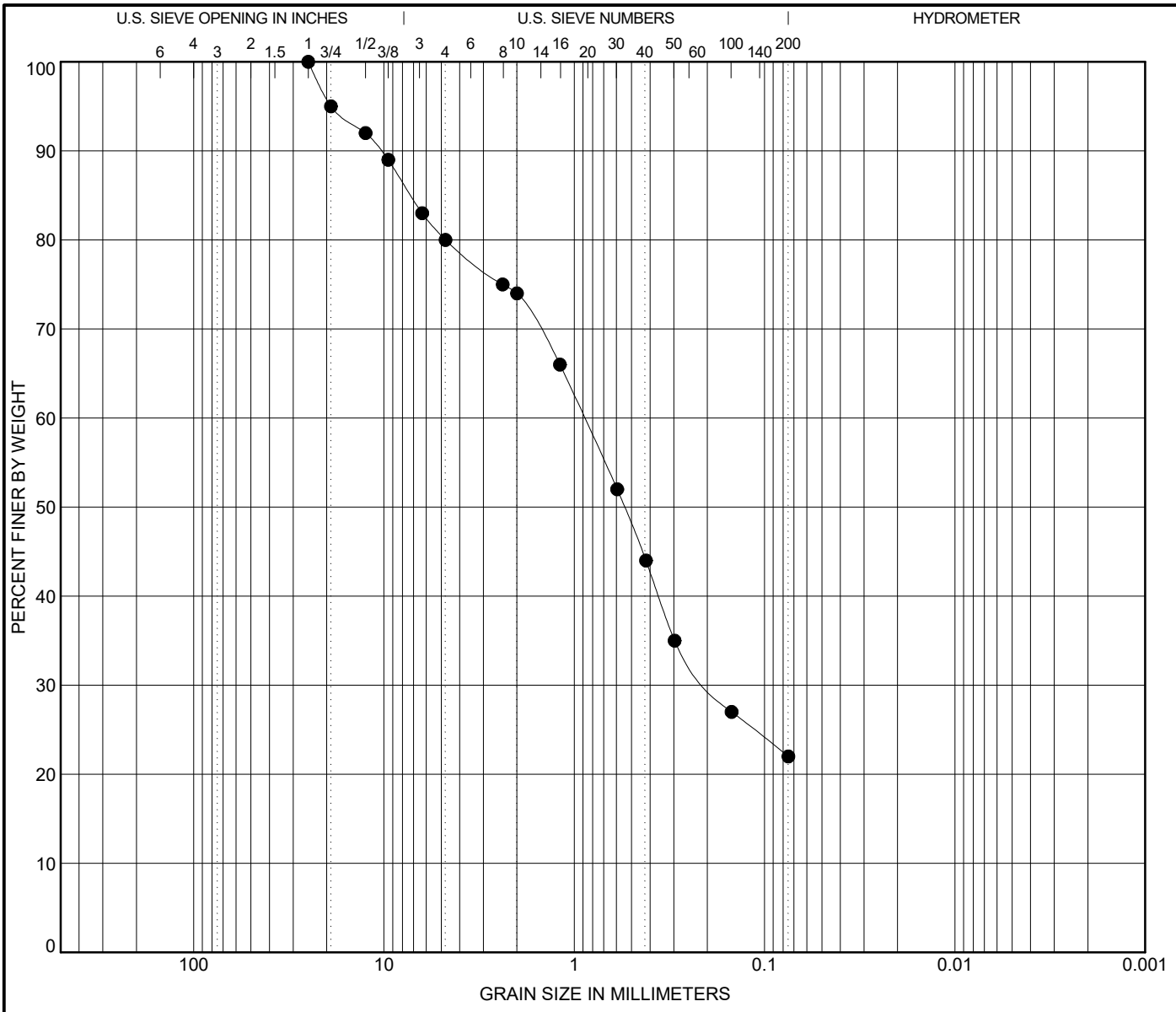
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 31+00 - MSE Wall

Number: 114-571155 Figure No. 14

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	95
1/2 in	92
3/8 in	89
1/4 in	83
No. 4	80
No. 8	75
No. 10	74
No. 16	66
No. 30	52
No. 40	44
No. 50	35
No. 100	27
No. 200	22

Specimen Identification
GB 14 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
20	58	22	

D100	D60	D30	D10
25	0.884	0.193	

TETRA TECH

GRAIN SIZE DISTRIBUTION

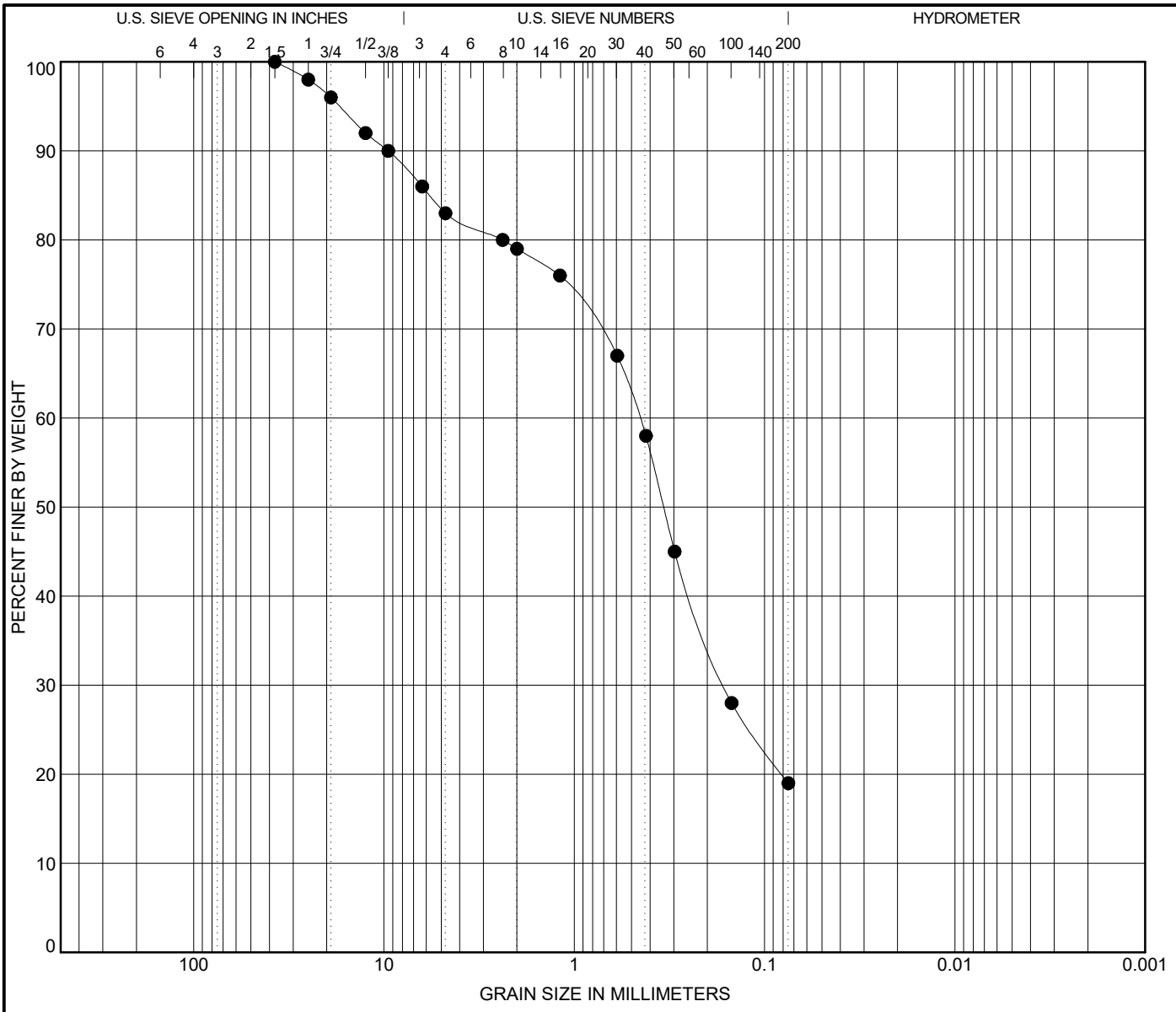
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 7+60 - Steep Slopes

Number: 114-571155 Figure No. 15

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	98
3/4 in	96
1/2 in	92
3/8 in	90
1/4 in	86
No. 4	83
No. 8	80
No. 10	79
No. 16	76
No. 30	67
No. 40	58
No. 50	45
No. 100	28
No. 200	19

Specimen Identification
GB 15 (0 - 2 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
17	64	19	

D100	D60	D30	D10
37.5	0.454	0.162	

TETRA TECH

GRAIN SIZE DISTRIBUTION

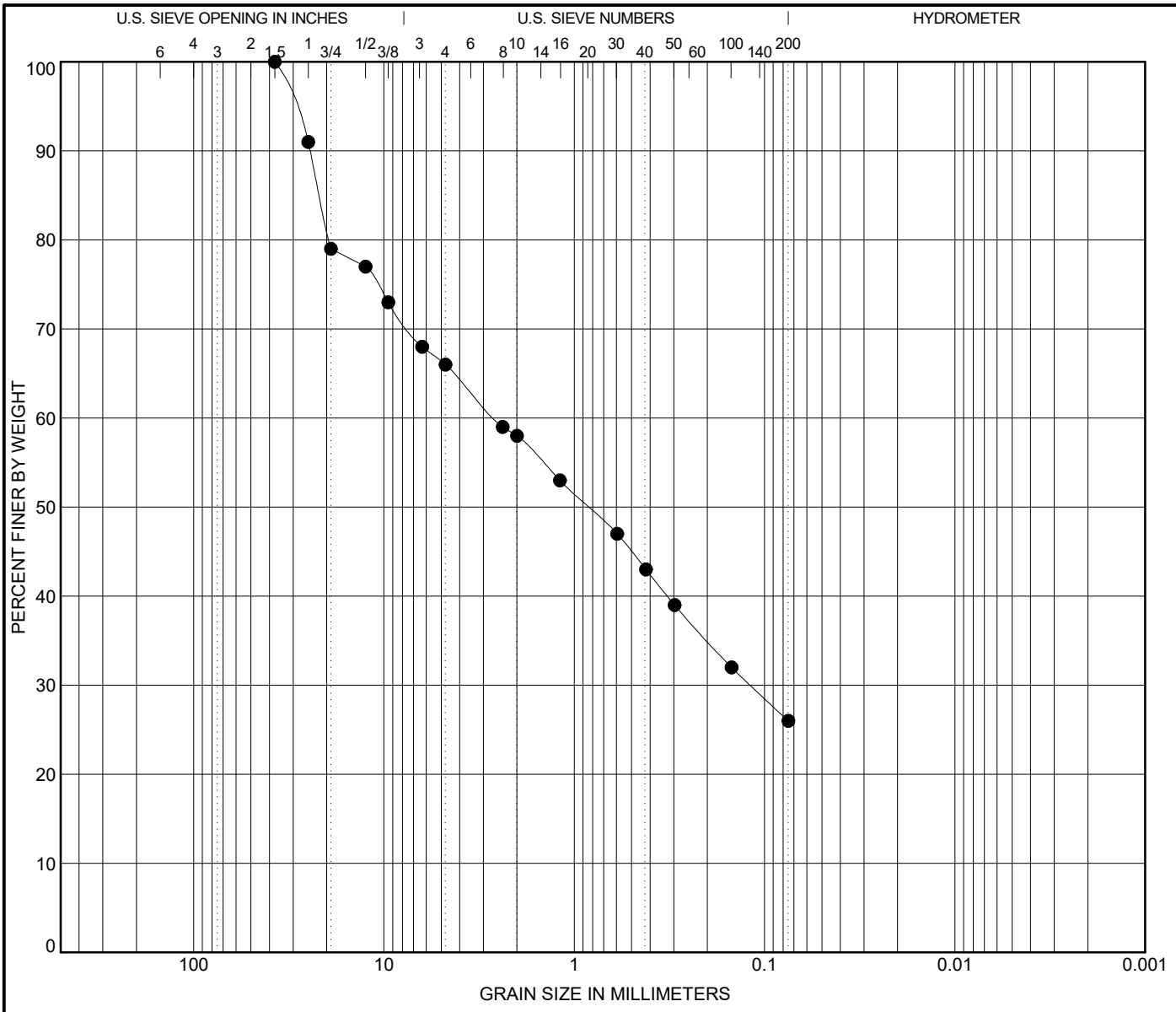
Project: Lower Darby Creek Superfund Site, Client:

Location: STA 15+50 - Steep Slopes

Number: 114-571155 Figure No. 16

GRAB SAMPLES.GPJ ` 5-1-17 ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	91
3/4 in	79
1/2 in	77
3/8 in	73
1/4 in	68
No. 4	66
No. 8	59
No. 10	58
No. 16	53
No. 30	47
No. 40	43
No. 50	39
No. 100	32
No. 200	26

Specimen Identification
B-501 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**34**	**26**	**8**		

% Gravel	% Sand	% Silt	% Clay
34	40	26	

D100	D60	D30	D10
37.5	2.627	0.119	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

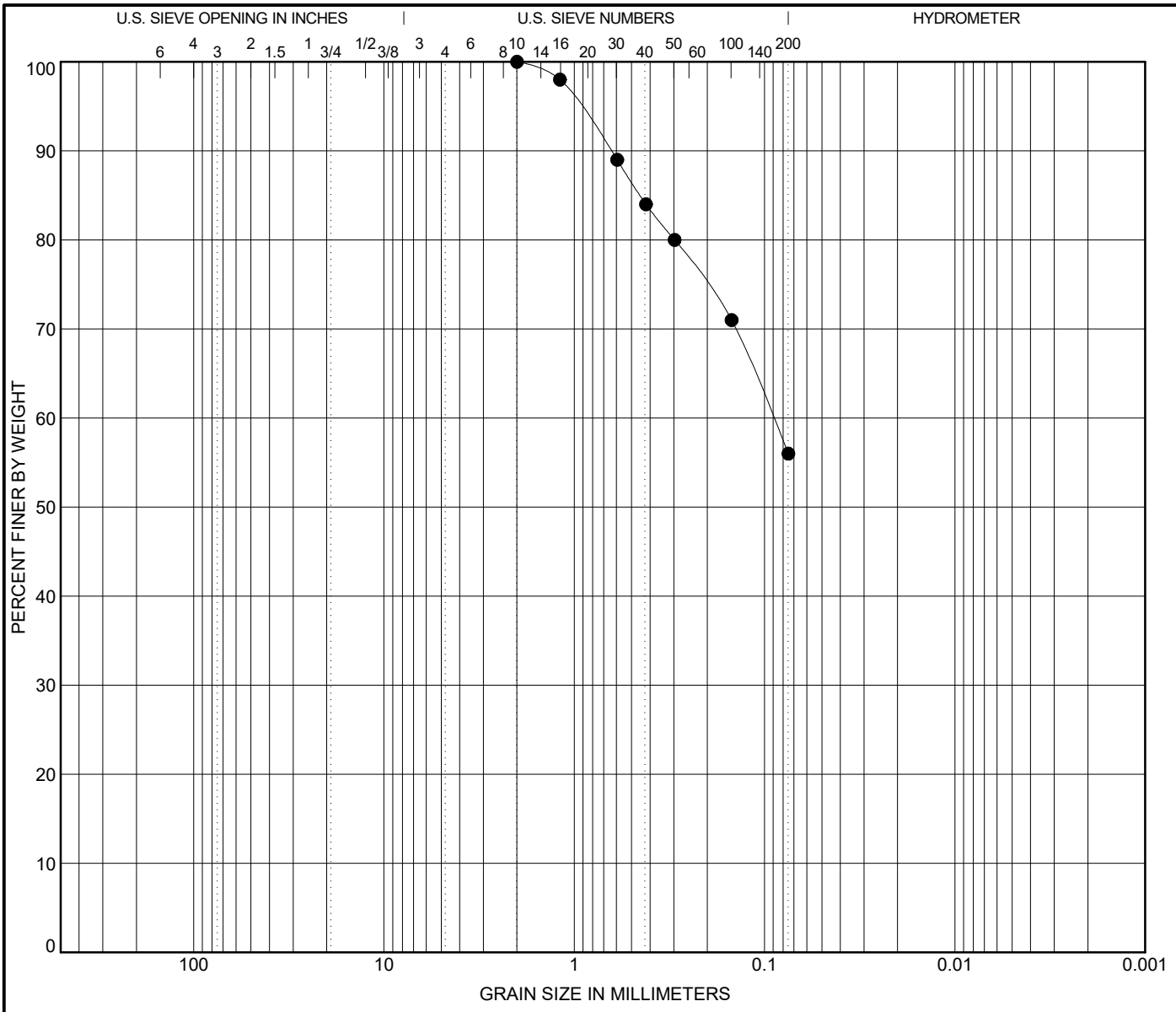
Location: 1+00 Leachate Trench

Number: 114-571155

Figure No. 17

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 10	100
No. 16	98
No. 30	89
No. 40	84
No. 50	80
No. 100	71
No. 200	56

Specimen Identification
B-502 - (19 - 20.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY ELASTIC SILT(MH)	**50**	**32**	**18**		

% Gravel	% Sand	% Silt	% Clay
0	44	56	

D100	D60	D30	D10
2	0.09		

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

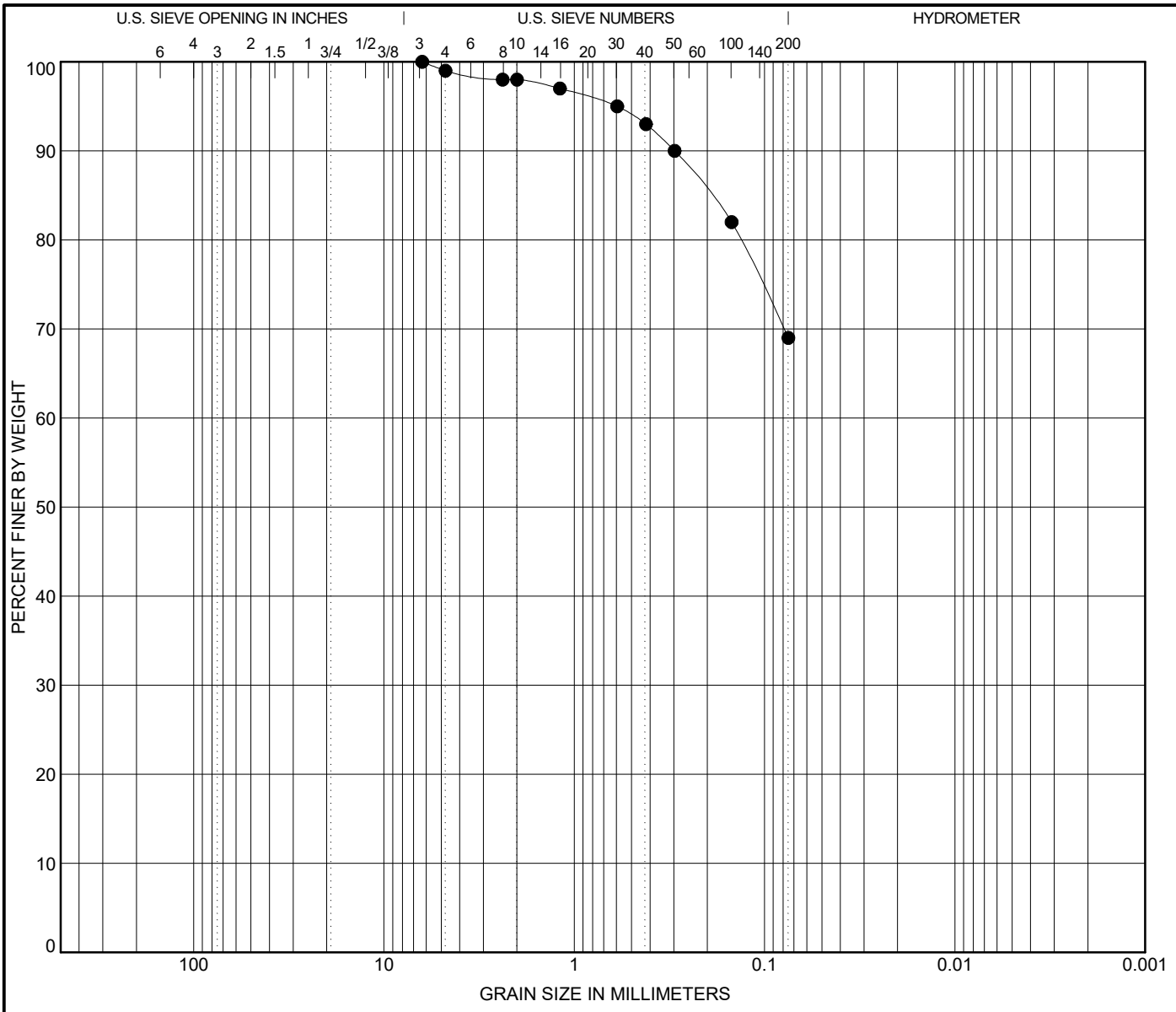
Location: STA 2+00 - Leachate Trench

Number: 114-571155

Figure No. 18

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/4 in	100
No. 4	99
No. 8	98
No. 10	98
No. 16	97
No. 30	95
No. 40	93
No. 50	90
No. 100	82
No. 200	69

Specimen Identification
B-503 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**41**	**29**	**12**		

% Gravel	% Sand	% Silt	% Clay
1	30	69	

D100	D60	D30	D10
6.3			

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

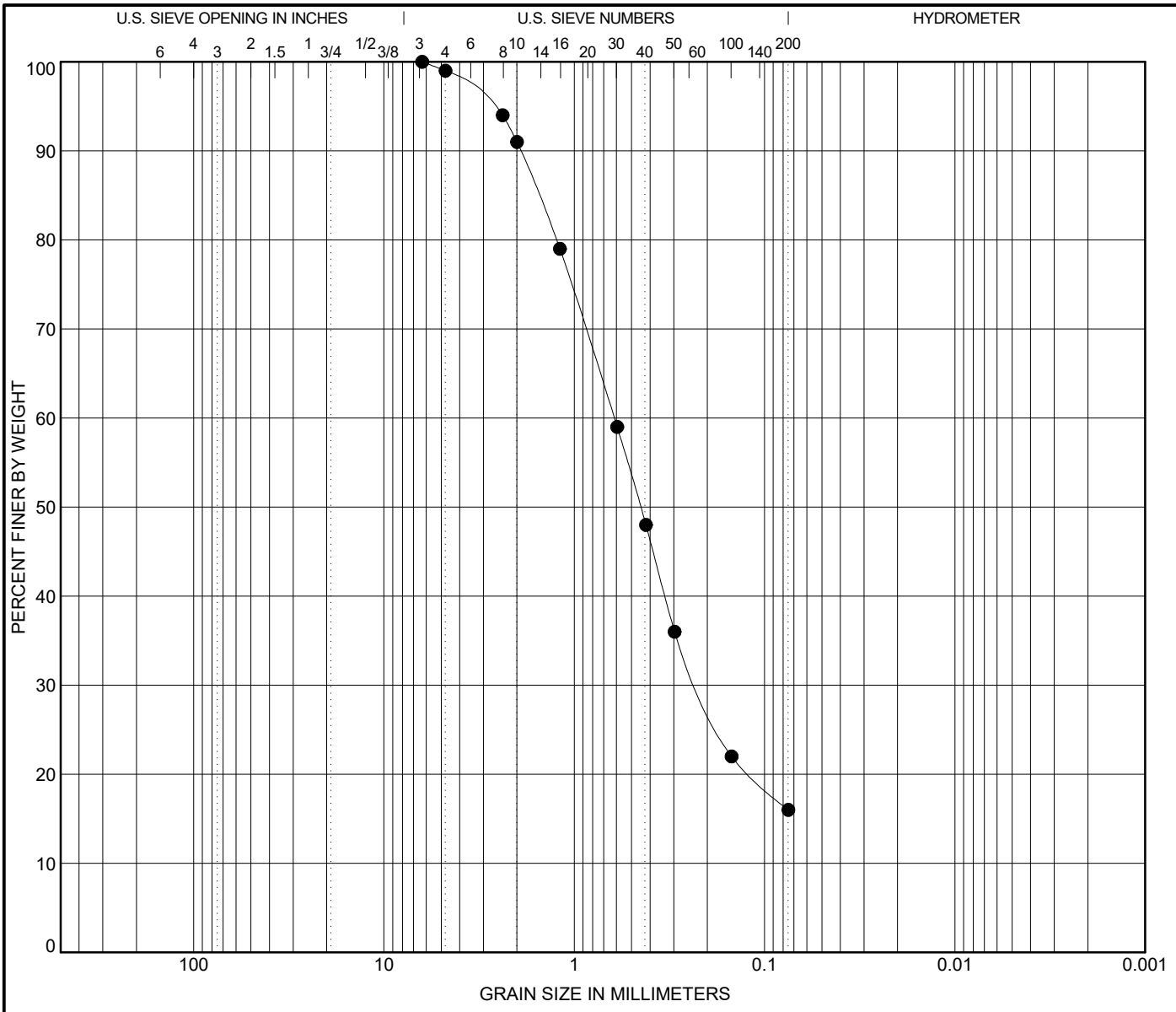
Location: STA 3+25 - MSE Wall

Number: 114-571155

Figure No. 19

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/4 in	100
No. 4	99
No. 8	94
No. 10	91
No. 16	79
No. 30	59
No. 40	48
No. 50	36
No. 100	22
No. 200	16

Specimen Identification
B-503 - (19 - 20.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
1	83	16	

D100	D60	D30	D10
6.3	0.616	0.221	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

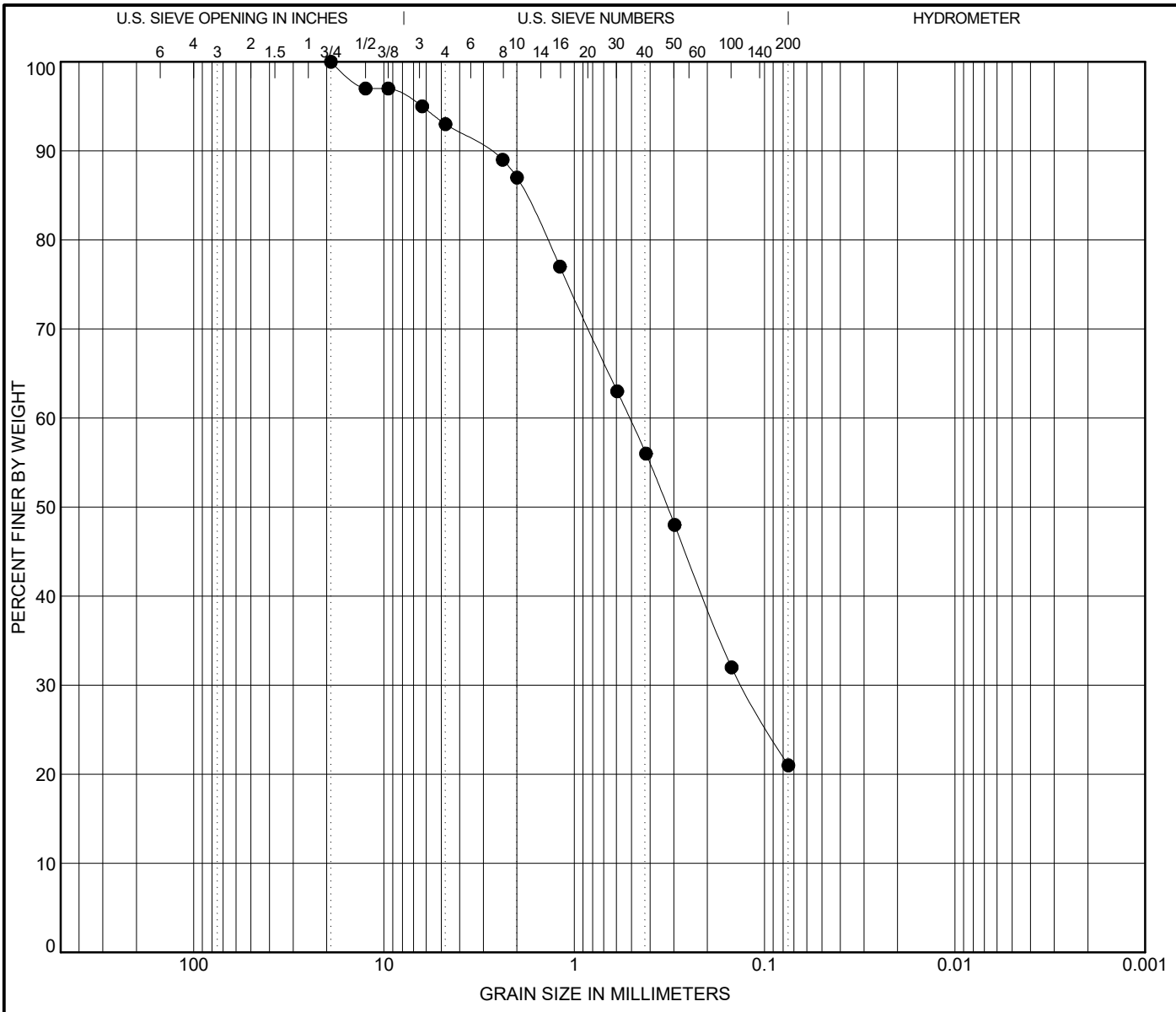
Location: STA 3+25 - MSE Wall

Number: 114-571155

Figure No. 20

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
3/4 in	100
1/2 in	97
3/8 in	97
1/4 in	95
No. 4	93
No. 8	89
No. 10	87
No. 16	77
No. 30	63
No. 40	56
No. 50	48
No. 100	32
No. 200	21

Specimen Identification
B-508 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**46**	**41**	**5**		

% Gravel	% Sand	% Silt	% Clay
7	72	21	

D100	D60	D30	D10
19	0.512	0.132	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

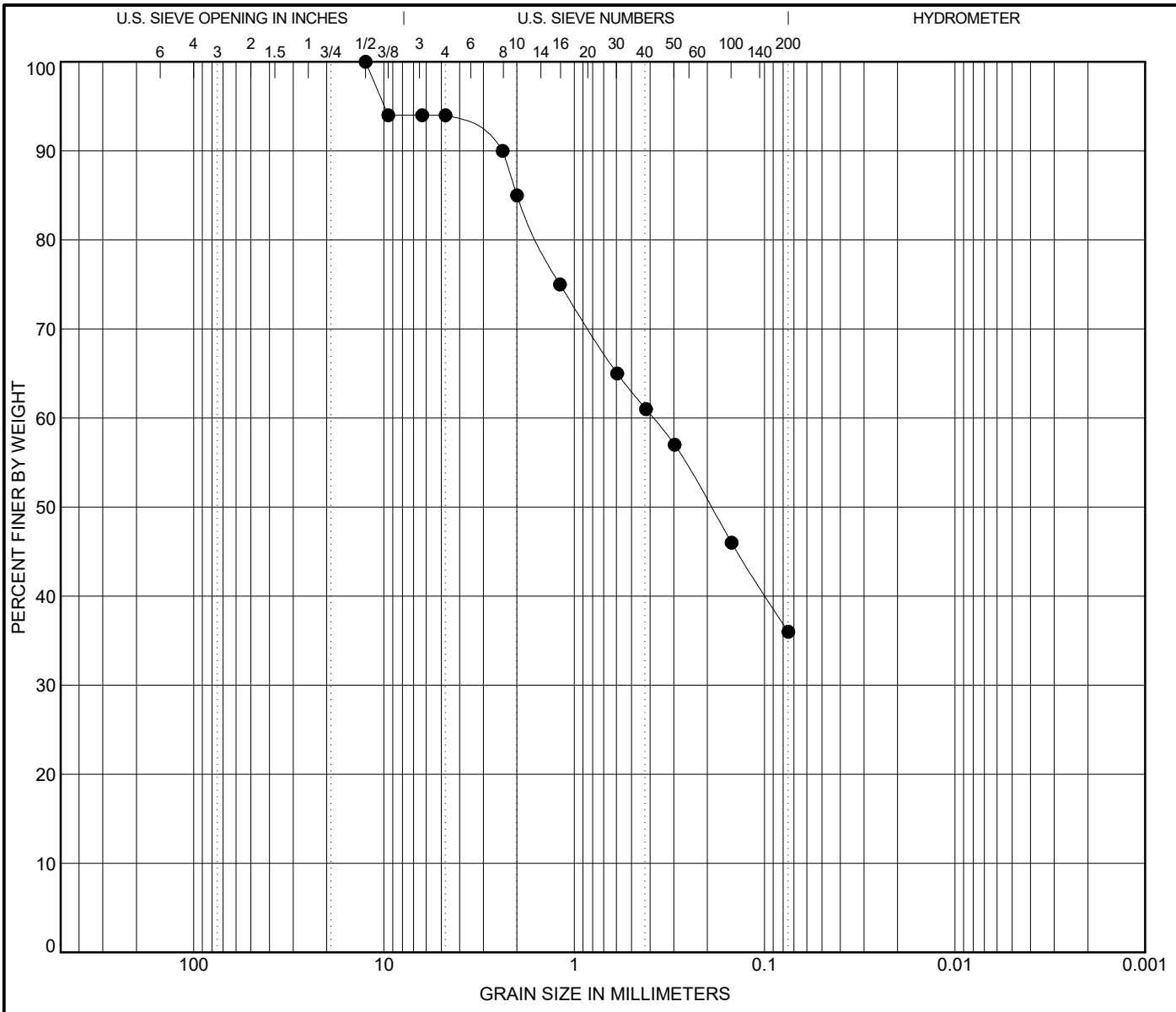
Location: STA 1+80 - Crib Wall

Number: 114-571155

Figure No. 21

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/2 in	100
3/8 in	94
1/4 in	94
No. 4	94
No. 8	90
No. 10	85
No. 16	75
No. 30	65
No. 40	61
No. 50	57
No. 100	46
No. 200	36

Specimen Identification
B-508 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**34**	**25**	**9**		

% Gravel	% Sand	% Silt	% Clay
6	58	36	

D100	D60	D30	D10
12.5	0.385		

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

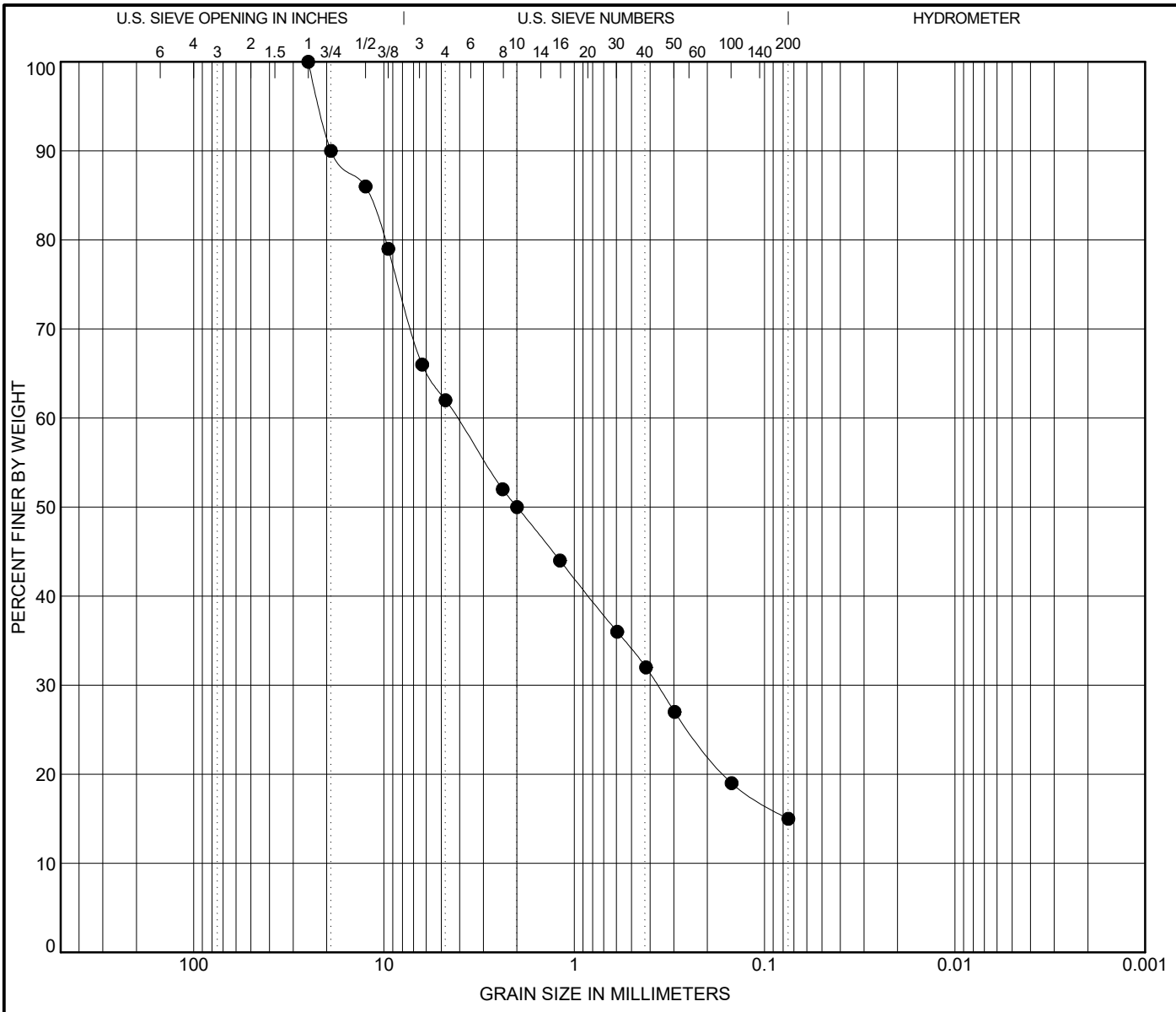
Location: STA 1+80 - Crib Wall

Number: 114-571155

Figure No. 22

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	90
1/2 in	86
3/8 in	79
1/4 in	66
No. 4	62
No. 8	52
No. 10	50
No. 16	44
No. 30	36
No. 40	32
No. 50	27
No. 100	19
No. 200	15

Specimen Identification
B-509 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
38	47	15	

D100	D60	D30	D10
25	4.137	0.366	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

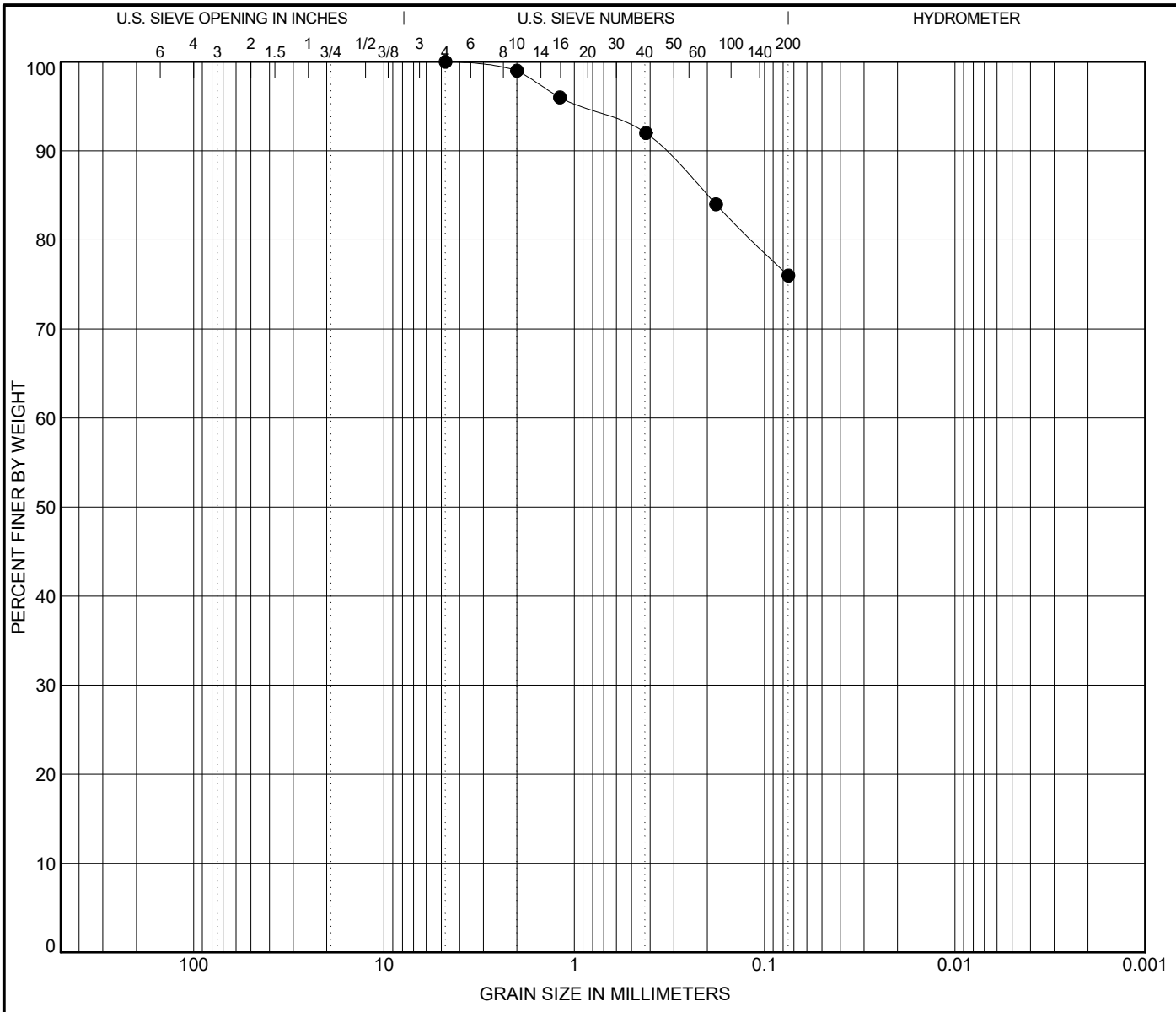
Location: STA 8+80 - Leachate Trench

Number: 114-571155

Figure No. 23

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 10	99
No. 16	96
No. 40	92
No. 80	84
No. 200	76

Specimen Identification
B-510 - (12 - 18 ft)

Classification	LL	PL	PI	Cc	Cu
ELASTIC SILT with SAND(MH)	**52**	**36**	**16**		

% Gravel	% Sand	% Silt	% Clay
0	24	76	

D100	D60	D30	D10
4.75			

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

Location: STA 9+20 - Crib Wall

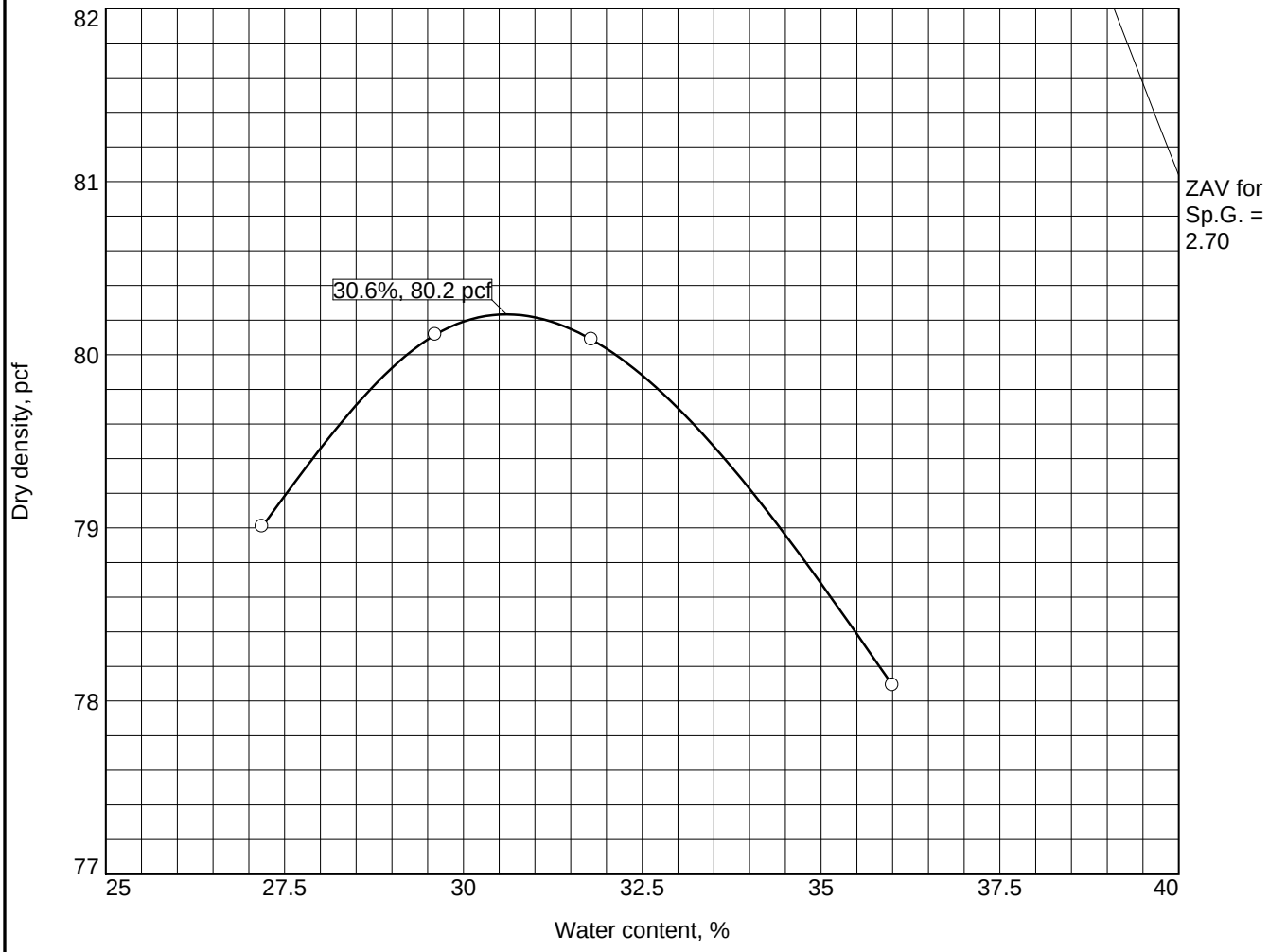
Number: 114-571155

Figure No. 24

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)

COMPACTION TEST REPORT



Test specification: ASTM D 698-12 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > #4	% < No.200
	USCS	AASHTO						
12' - 18'	MH	A-7-5(14)		2.70	52	16	0.0	75.6

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 80.2 pcf Optimum moisture = 30.6 %	Elastic SILT with Sand

Project No. 114-571155 **Client:**
Project: Clearview Landfill

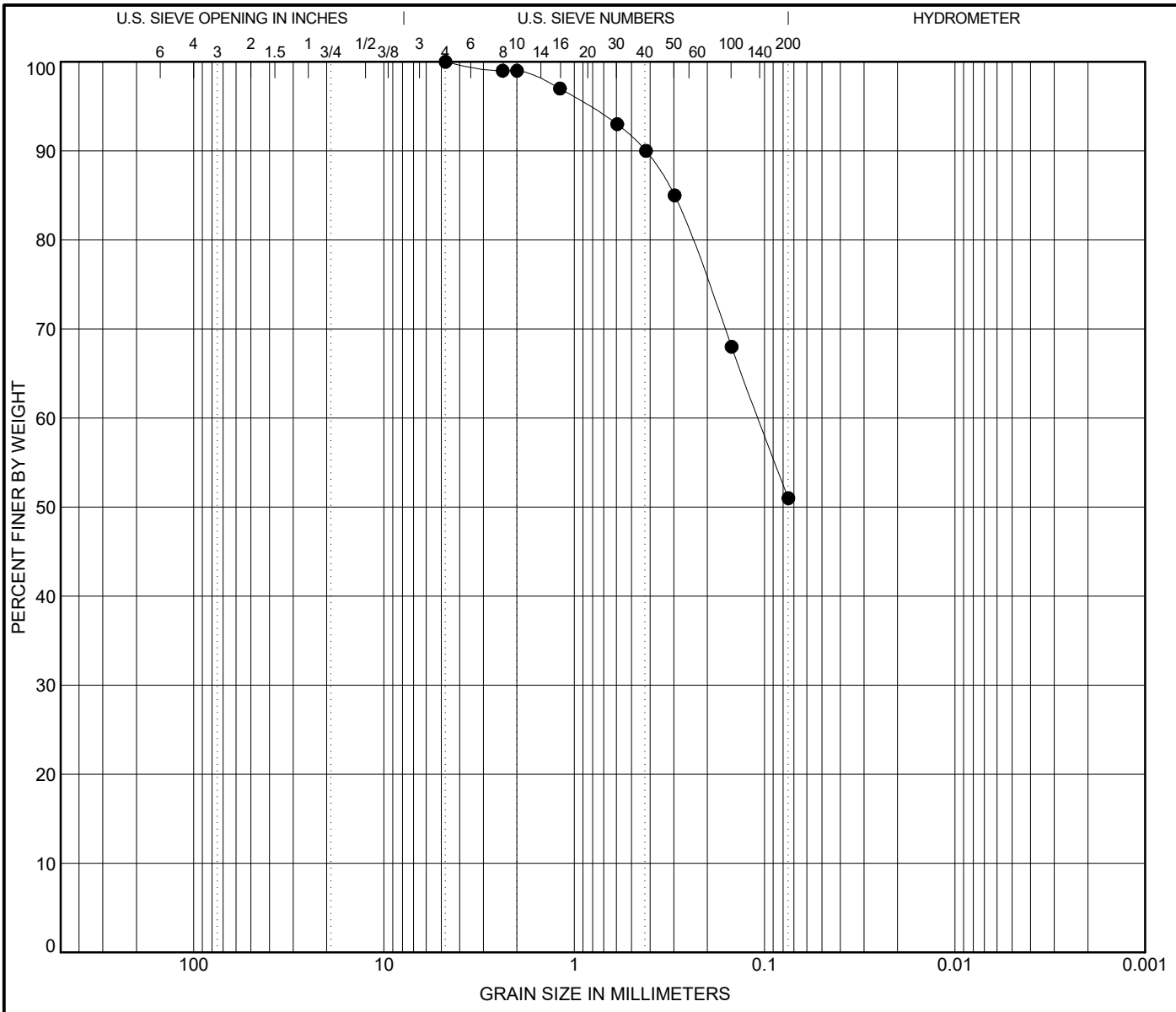
○**Source of Sample:** B-510

Tetra Tech

Billings, MT

Remarks:

Figure 25



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	99
No. 10	99
No. 16	97
No. 30	93
No. 40	90
No. 50	85
No. 100	68
No. 200	51

Specimen Identification
B-510 - (14 - 15.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**47**	**31**	**16**		

% Gravel	% Sand	% Silt	% Clay
0	49	51	

D100	D60	D30	D10
4.75	0.108		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

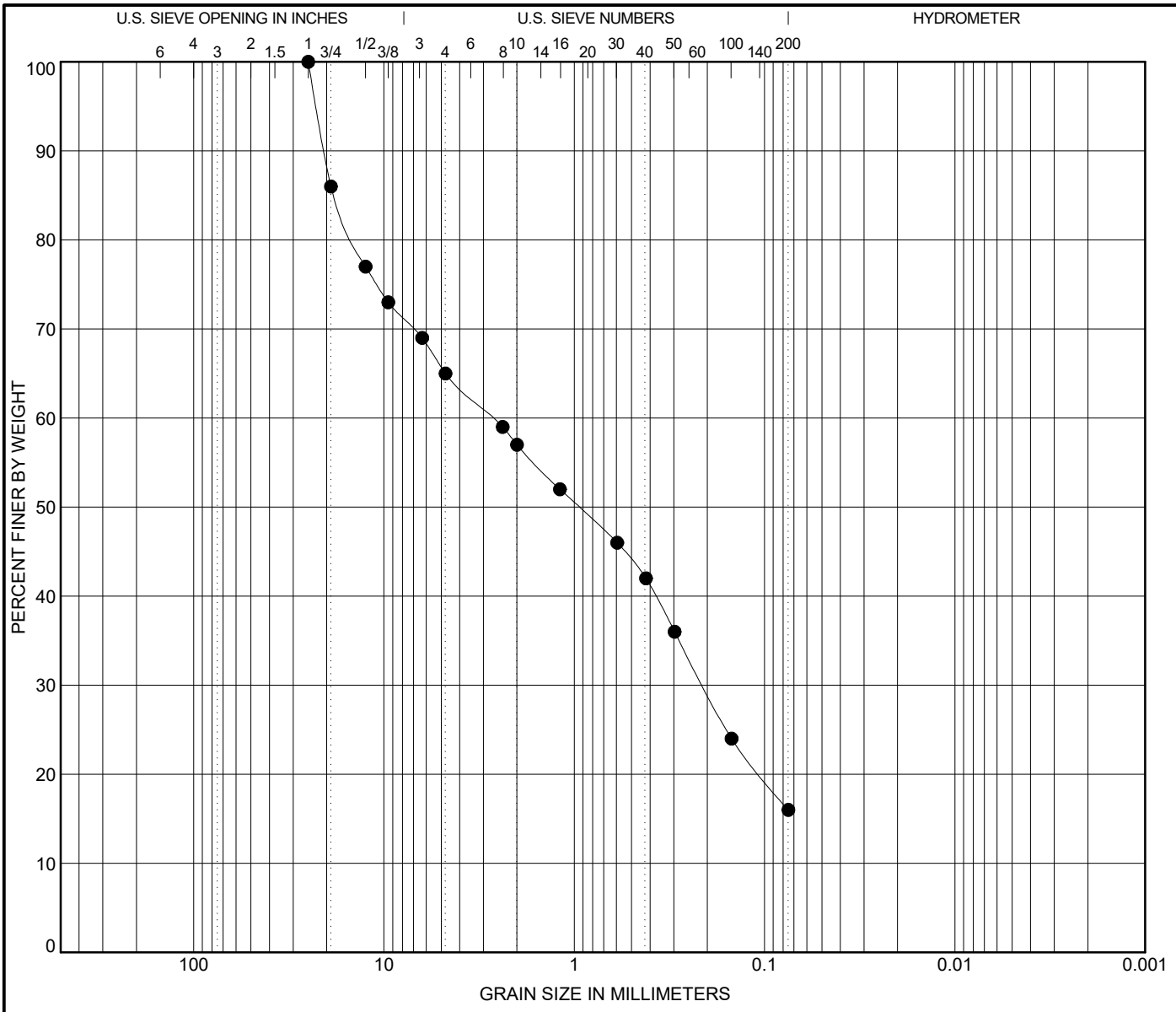
Location: STA 9+20 - Crib Wall

Number: 114-571155

Figure No. 26

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	86
1/2 in	77
3/8 in	73
1/4 in	69
No. 4	65
No. 8	59
No. 10	57
No. 16	52
No. 30	46
No. 40	42
No. 50	36
No. 100	24
No. 200	16

Specimen Identification
B-511 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
35	49	16	

D100	D60	D30	D10
25	2.671	0.21	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

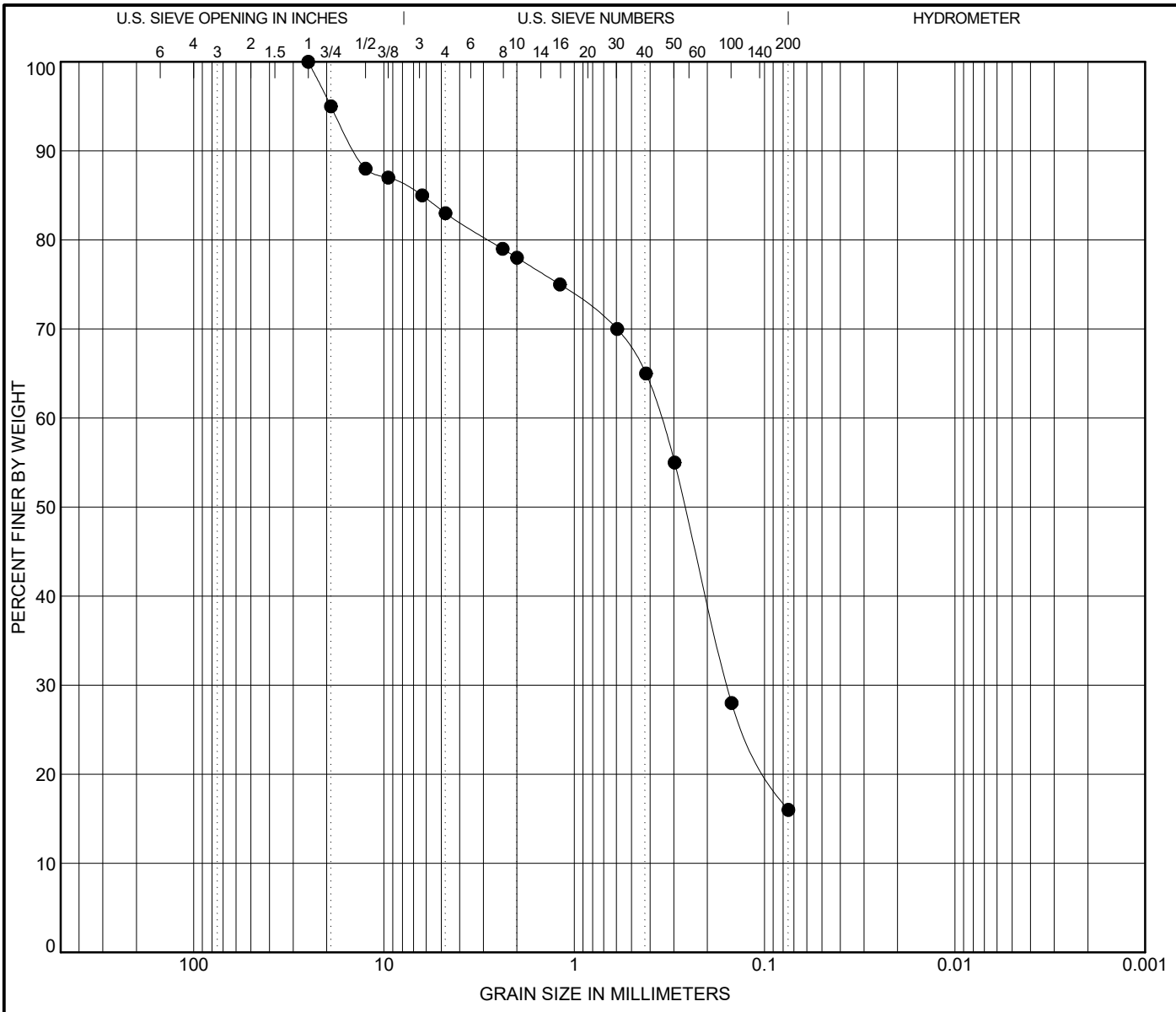
Location: STA 9+70 - MSE Wall

Number: 114-571155

Figure No. 27

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	95
1/2 in	88
3/8 in	87
1/4 in	85
No. 4	83
No. 8	79
No. 10	78
No. 16	75
No. 30	70
No. 40	65
No. 50	55
No. 100	28
No. 200	16

Specimen Identification
B-511 - (14 - 15.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
17	67	16	

D100	D60	D30	D10
25	0.353	0.157	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

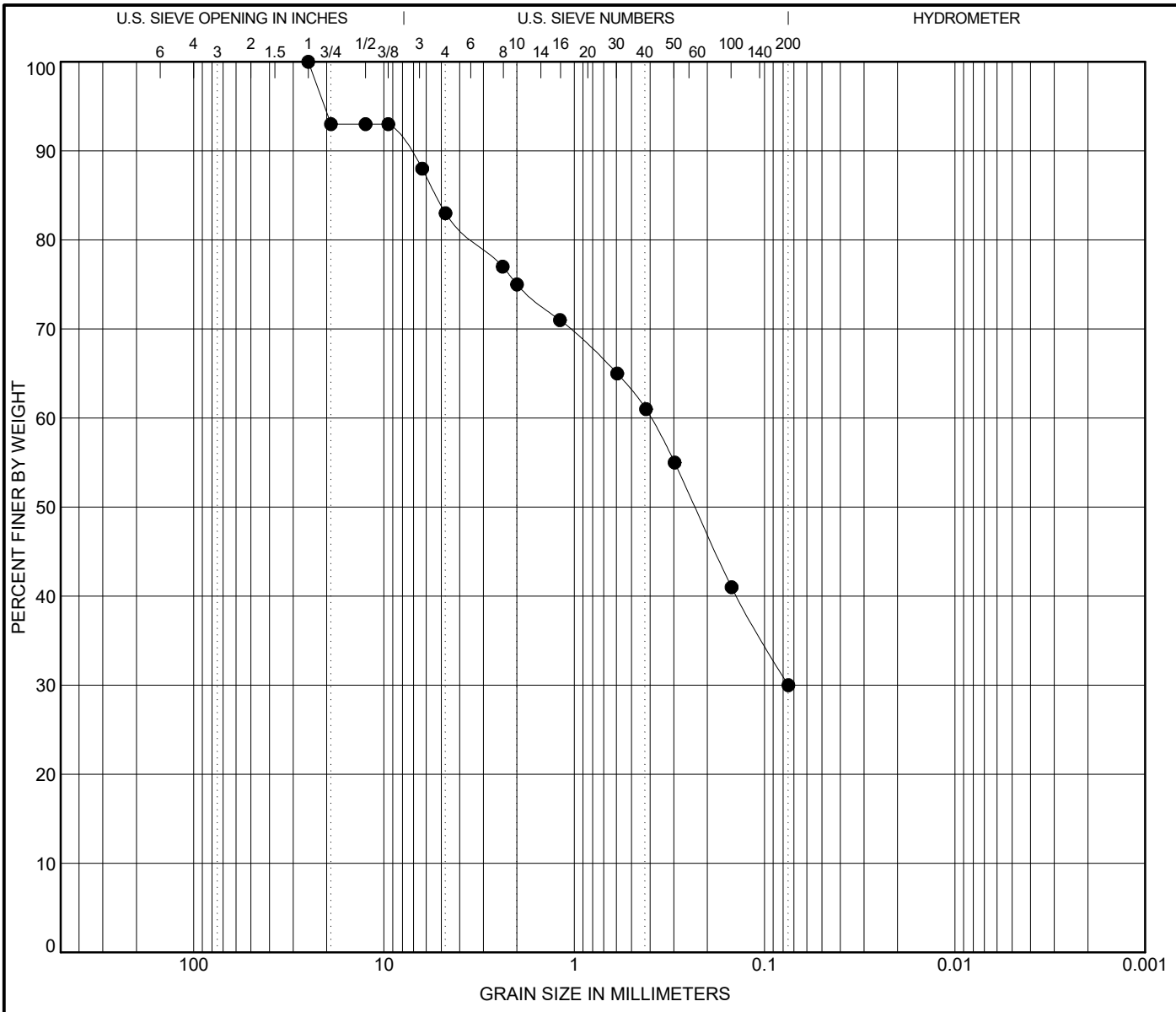
Location: STA 9+70 - MSE Wall

Number: 114-571155

Figure No. 28

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	93
1/2 in	93
3/8 in	93
1/4 in	88
No. 4	83
No. 8	77
No. 10	75
No. 16	71
No. 30	65
No. 40	61
No. 50	55
No. 100	41
No. 200	30

Specimen Identification
B-512 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
17	53	30	

D100	D60	D30	D10
25	0.396	0.075	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

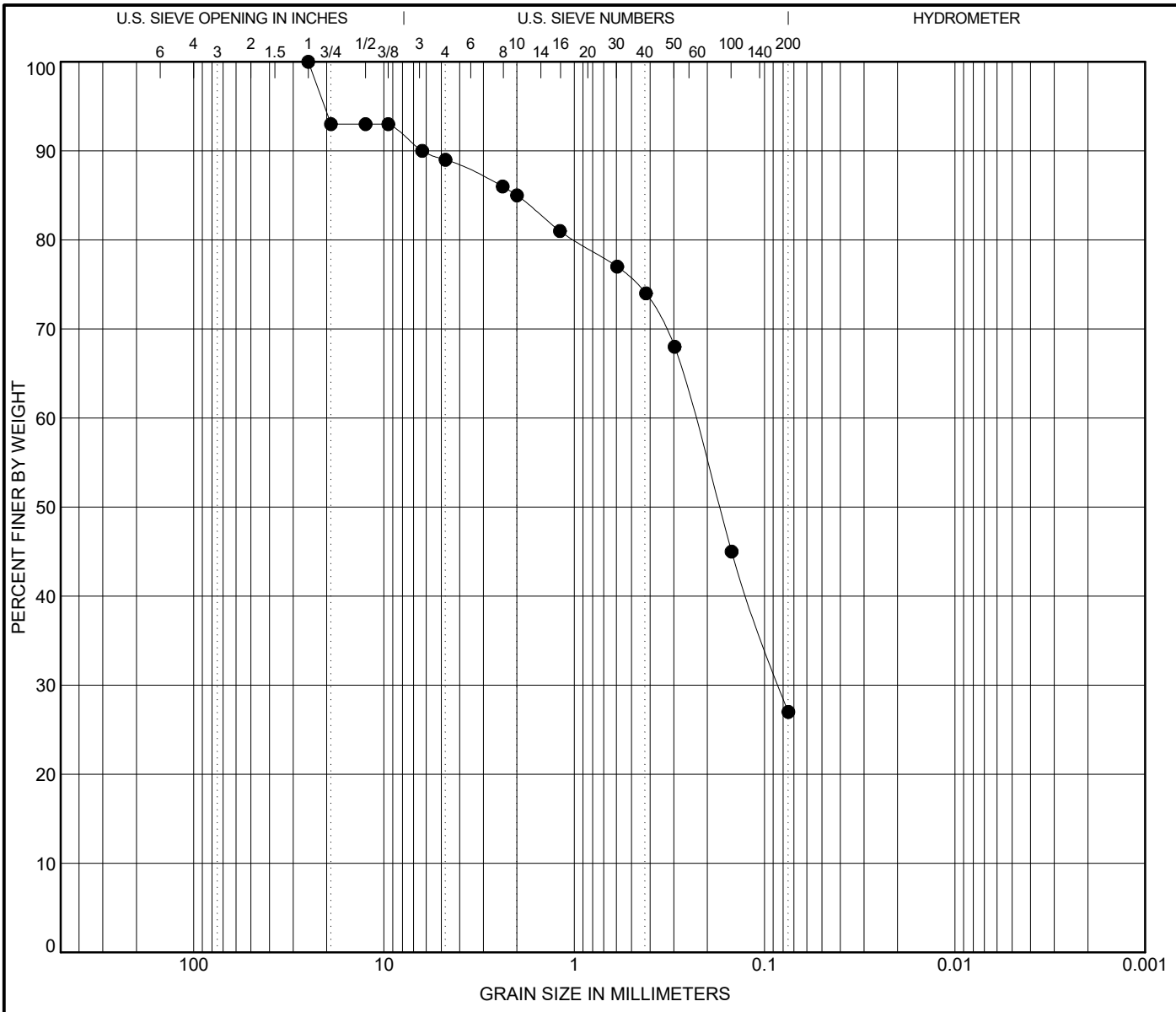
Location: STA 11+00 - Gabion Wall

Number: 114-571155

Figure No. 29

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	93
1/2 in	93
3/8 in	93
1/4 in	90
No. 4	89
No. 8	86
No. 10	85
No. 16	81
No. 30	77
No. 40	74
No. 50	68
No. 100	45
No. 200	27

Specimen Identification
B-512 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
11	62	27	

D100	D60	D30	D10
25	0.234	0.084	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

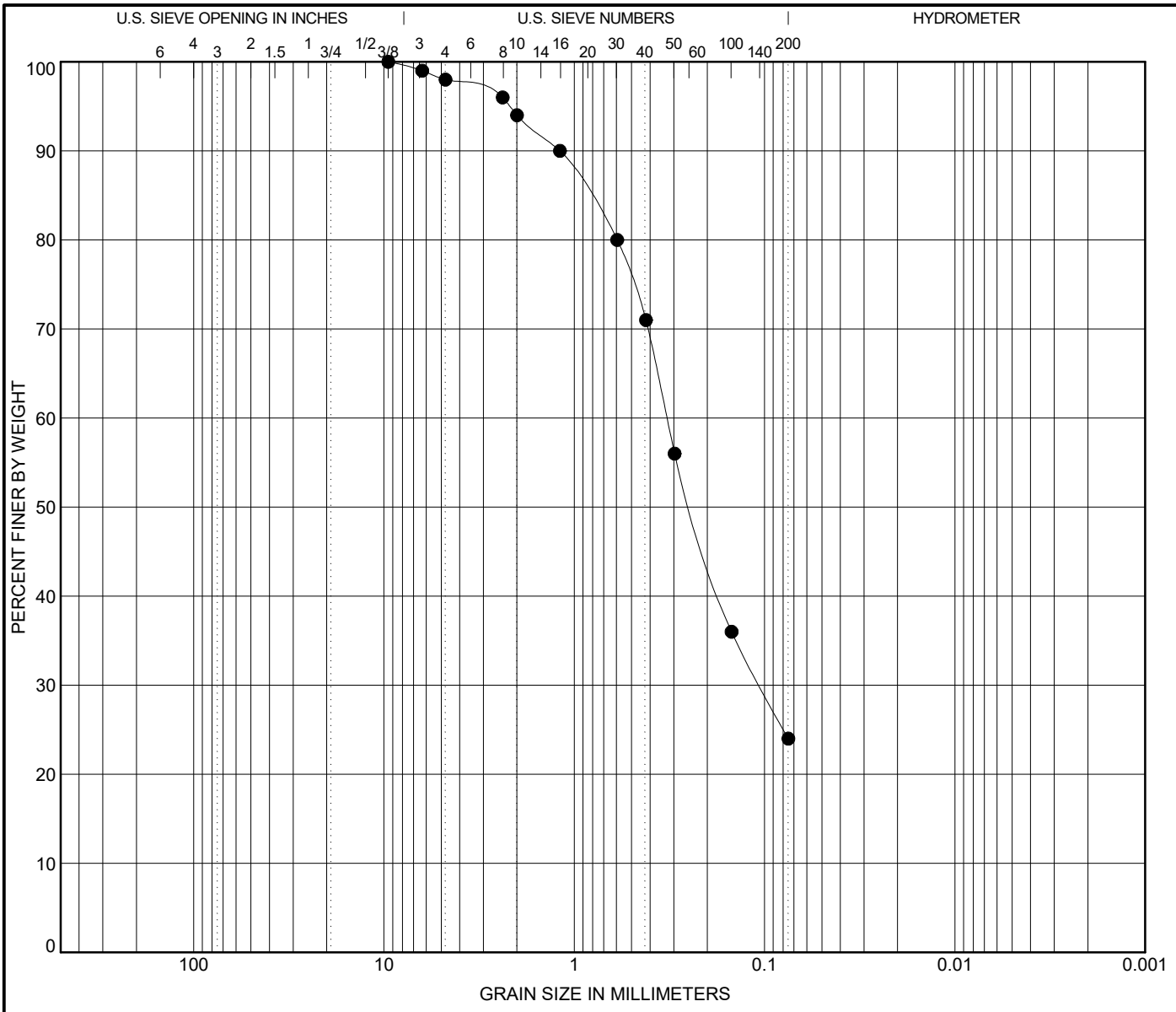
Location: STA 11+00 - Gabion Wall

Number: 114-571155

Figure No. 30

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
3/8 in	100
1/4 in	99
No. 4	98
No. 8	96
No. 10	94
No. 16	90
No. 30	80
No. 40	71
No. 50	56
No. 100	36
No. 200	24

Specimen Identification
B-513 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
2	74	24	

D100	D60	D30	D10
9.5	0.326	0.106	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

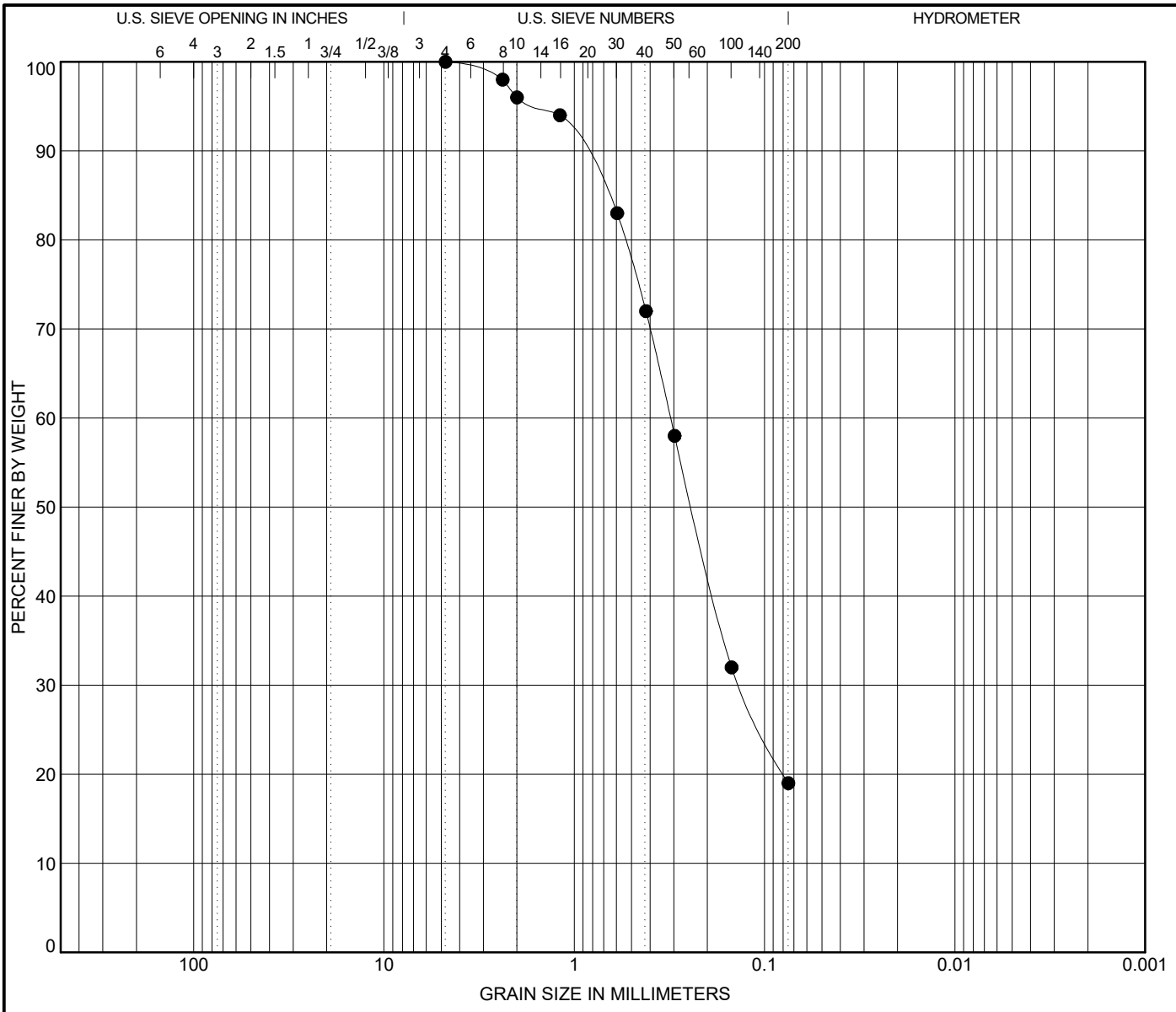
Location: STA 13+10 - MSE Wall

Number: 114-571155

Figure No. 31

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 8	98
No. 10	96
No. 16	94
No. 30	83
No. 40	72
No. 50	58
No. 100	32
No. 200	19

Specimen Identification
B-513 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
0	81	19	

D100	D60	D30	D10
4.75	0.312	0.134	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

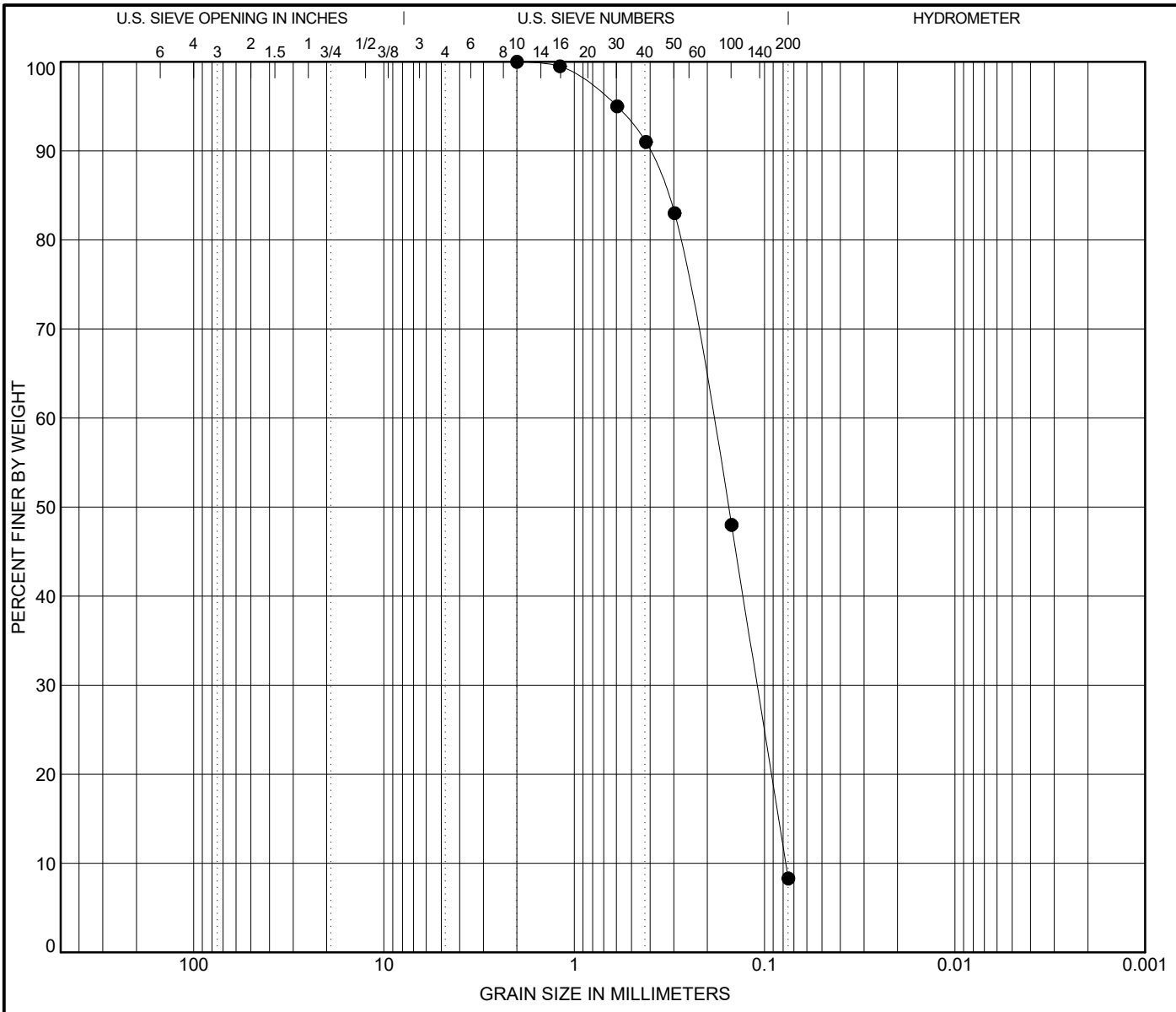
Location: STA 13+10 - MSE Wall

Number: 114-571155

Figure No. 32

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 10	100
No. 16	99.5
No. 30	95
No. 40	91
No. 50	83
No. 100	48
No. 200	8.3

Specimen Identification
B-515 - (14 - 15.5 ft)

Classification	LL	PL	PI	Cc	Cu
POORLY GRADED SAND with SILT(SP-SM)	**31**	**28**	**3**	**0.82**	**2.44**

% Gravel	% Sand	% Silt	% Clay
0	92	8	

D100	D60	D30	D10
2	0.189	0.109	0.077

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

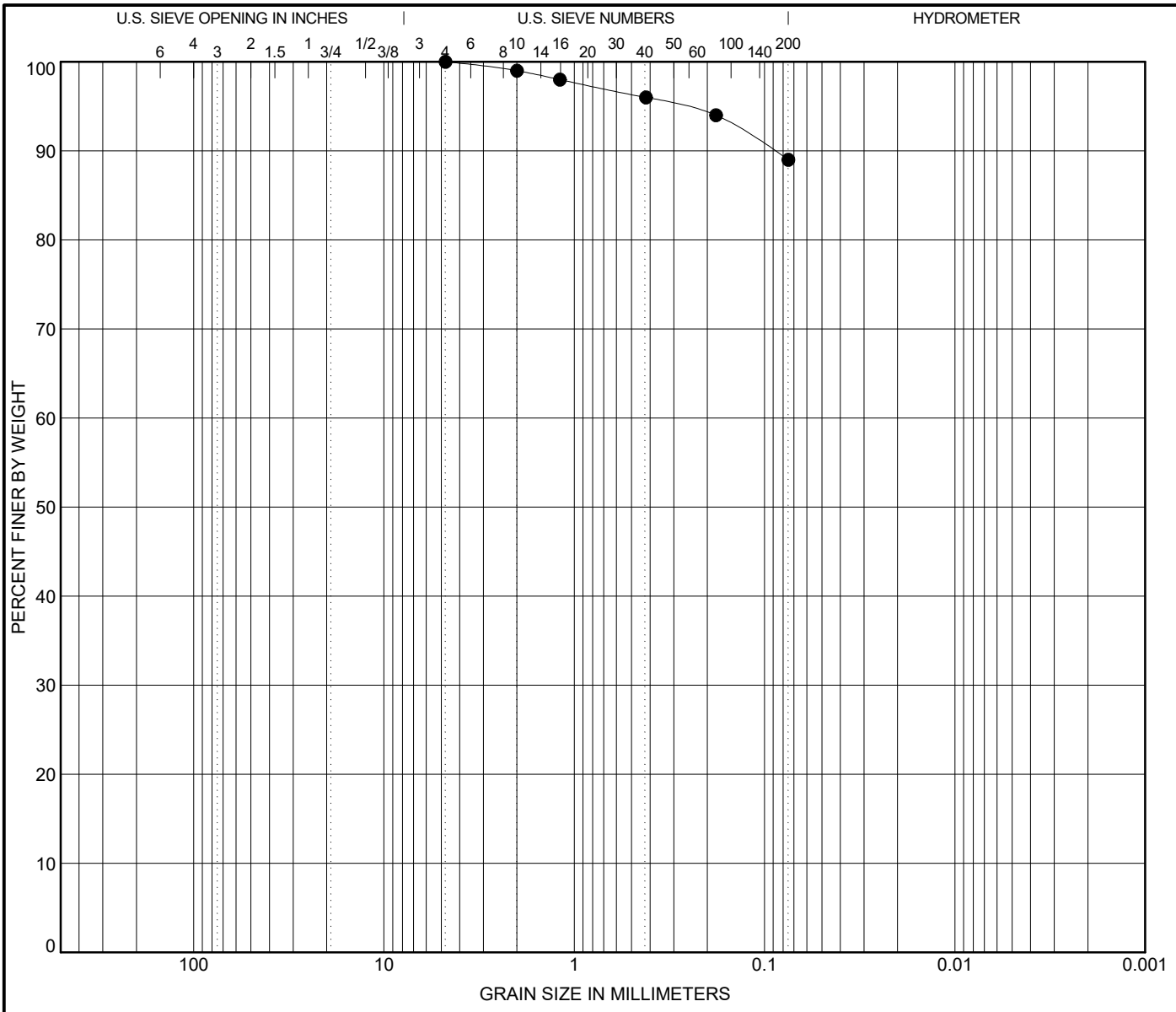
Location: STA 17+75 - Crib Wall

Number: 114-571155

Figure No. 33

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 4	100
No. 10	99
No. 16	98
No. 40	96
No. 80	94
No. 200	89

Specimen Identification
B-515 - (22 - 24 ft)

Classification	LL	PL	PI	Cc	Cu
ELASTIC SILT(MH)	**76**	**62**	**14**		

% Gravel	% Sand	% Silt	% Clay
0	11	89	

D100	D60	D30	D10
4.75			

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

Location: STA 17+75 - Crib Wall

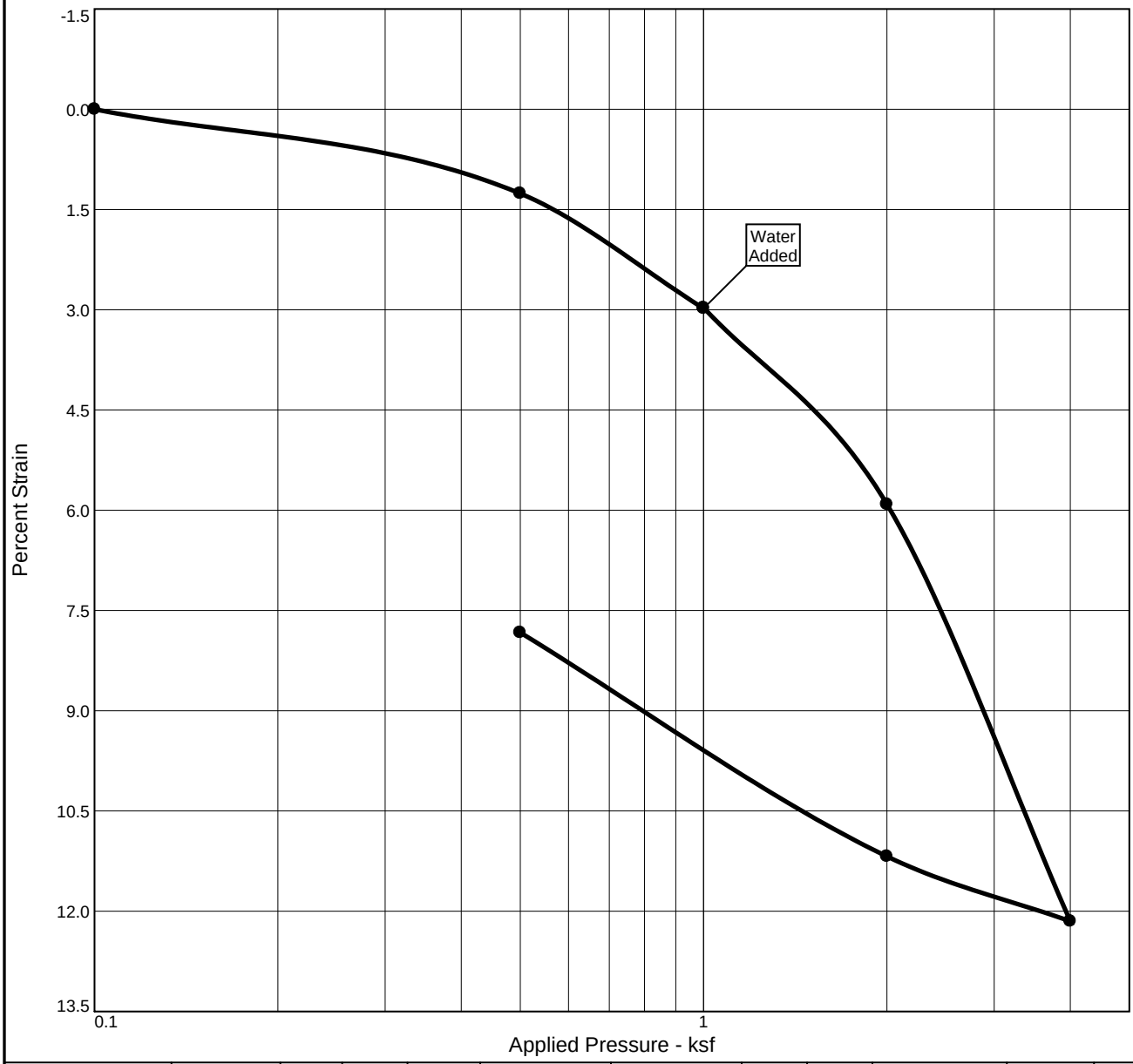
Number: 114-571155

Figure No. 34

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_s	Swell Press. (ksf)	Swell %	e_o
Sat.	Moist.											
87.5 %	105.8 %	39.5	76	14	2.70		1.9	0.91	0.19	1.0	0.0	3.264

MATERIAL DESCRIPTION	USCS	AASHTO
Elastic SILT	MH	A-7-5(23)

Project No. 114-571155 **Client:**

Project: Clearview Landfill

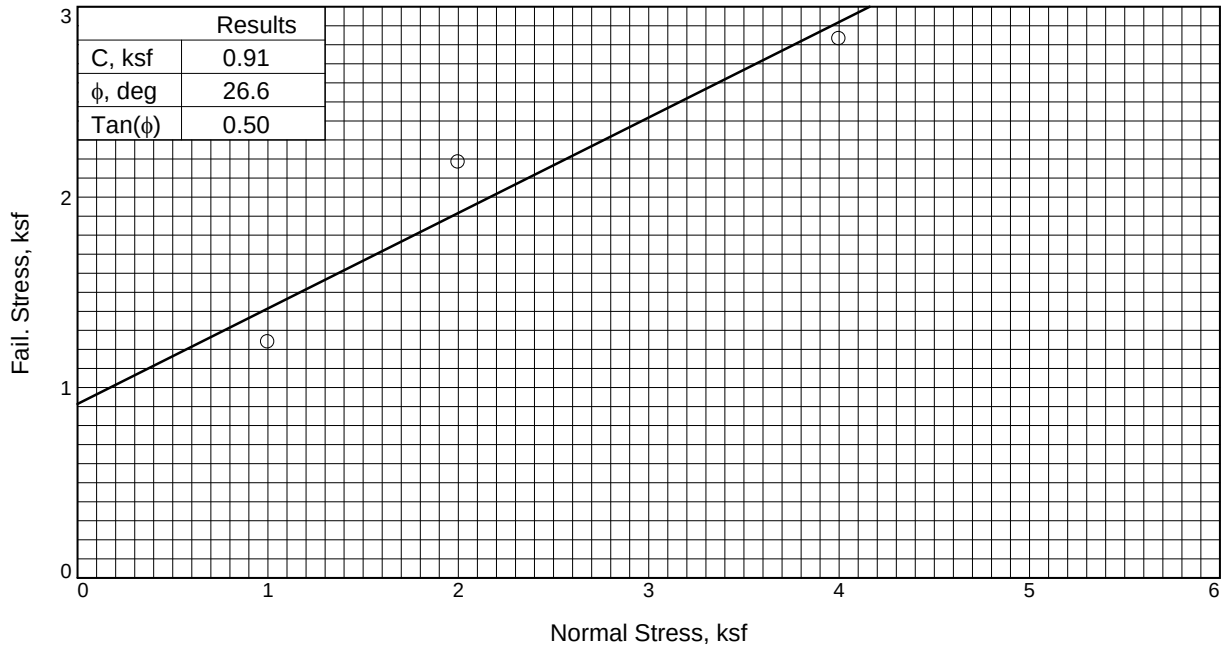
Source of Sample: B-515 **Depth:** 22' - 24'

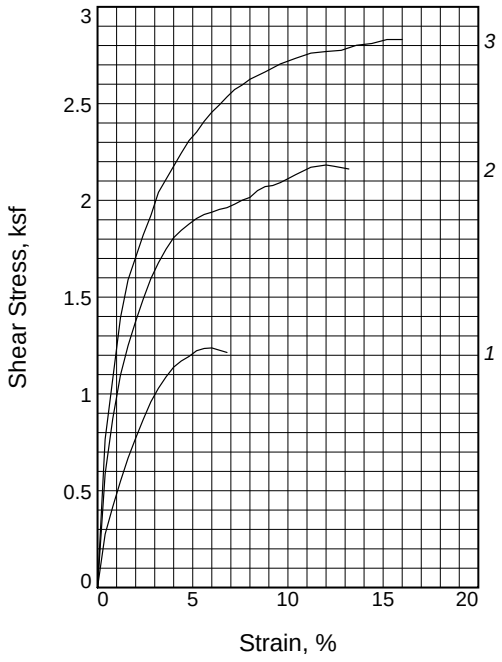
Tetra Tech

Billings, MT

Remarks:

Figure 35





Sample No.		1	2	3
Initial	Water Content, %	105.8	105.8	105.8
	Dry Density, pcf	39.4	43.3	41.4
	Saturation, %	87.2	98.7	92.9
	Void Ratio	3.2747	2.8926	3.0751
	Diameter, in.	2.50	2.50	2.50
	Height, in.	1.00	1.00	1.00
At Test	Water Content, %	115.3	97.3	90.7
	Dry Density, pcf	40.9	46.4	48.8
	Saturation, %	99.7	99.8	99.7
	Void Ratio	3.1229	2.6330	2.4557
	Diameter, in.	2.50	2.50	2.50
	Height, in.	0.96	0.93	0.85
Normal Stress, ksf		1.00	2.00	4.00
Fail. Stress, ksf		1.24	2.18	2.83
Strain, %		6.0	12.0	15.2
Ult. Stress, ksf				
Strain, %				
Strain rate, in./min.		0.01	0.01	0.01

Sample Type:

Description: Elastic SILT

LL= 76 **PL=** 62 **PI=** 14

Assumed Specific Gravity= 2.70

Remarks:

Figure 36

Client:

Project: Clearview Landfill

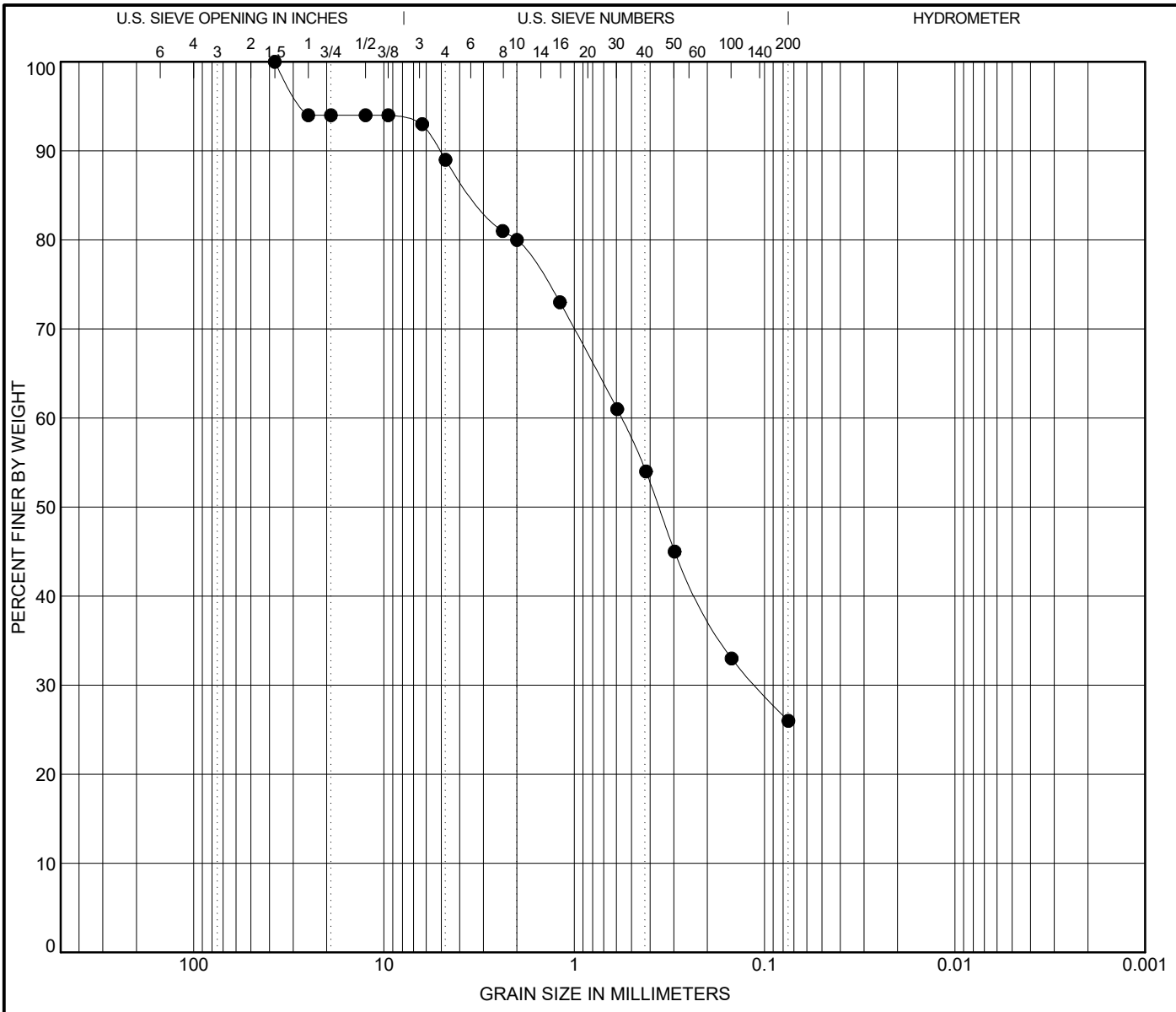
Source of Sample: B-515 **Depth:** 22' - 24'

Proj. No.: 114-571155 **Date Sampled:**

DIRECT SHEAR TEST REPORT

Tetra Tech

Billings, MT



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	94
3/4 in	94
1/2 in	94
3/8 in	94
1/4 in	93
No. 4	89
No. 8	81
No. 10	80
No. 16	73
No. 30	61
No. 40	54
No. 50	45
No. 100	33
No. 200	26

Specimen Identification
B-516 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
11	63	26	

D100	D60	D30	D10
37.5	0.566	0.111	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

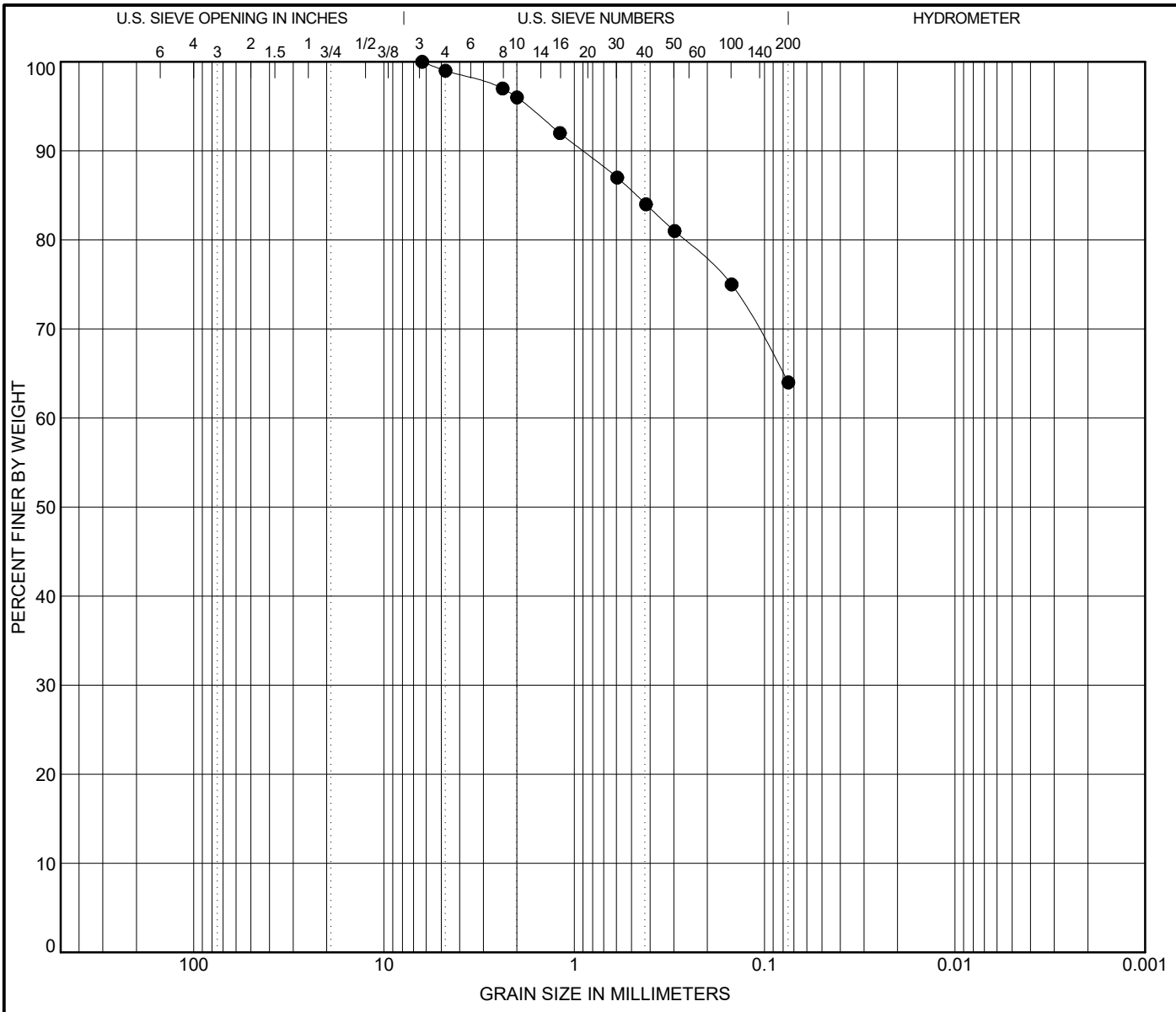
Location: STA 18+25 - MSE Wall

Number: 114-571155

Figure No. 37

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/4 in	100
No. 4	99
No. 8	97
No. 10	96
No. 16	92
No. 30	87
No. 40	84
No. 50	81
No. 100	75
No. 200	64

Specimen Identification
B-518 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
1	35	64	

D100	D60	D30	D10
6.3			

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

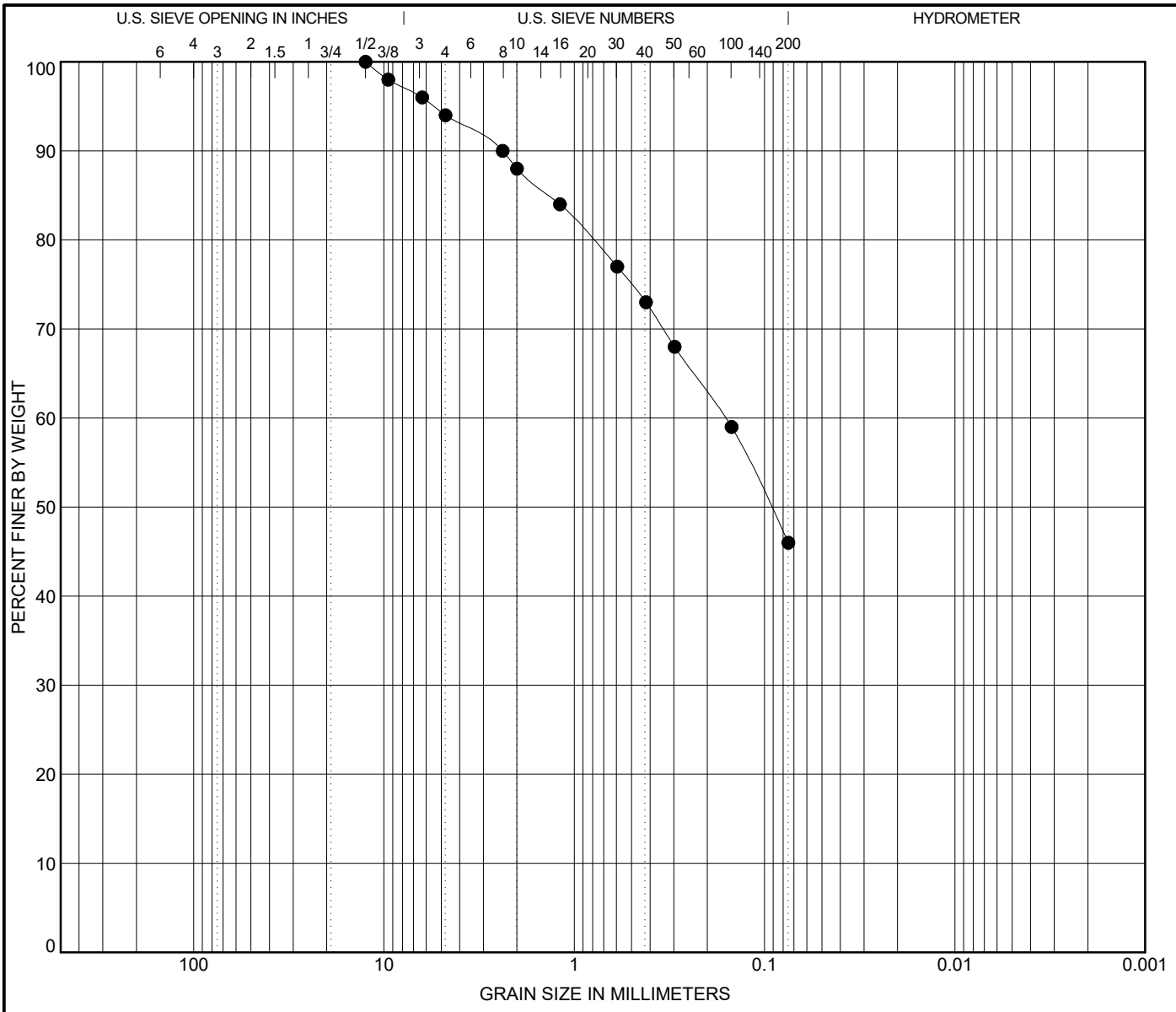
Location: STA 22+25 - Crib Wall

Number: 114-571155

Figure No. 38

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/2 in	100
3/8 in	98
1/4 in	96
No. 4	94
No. 8	90
No. 10	88
No. 16	84
No. 30	77
No. 40	73
No. 50	68
No. 100	59
No. 200	46

Specimen Identification
B-519 - (14 - 15.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**36**	**29**	**7**		

% Gravel	% Sand	% Silt	% Clay
6	48	46	

D100	D60	D30	D10
12.5	0.161		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

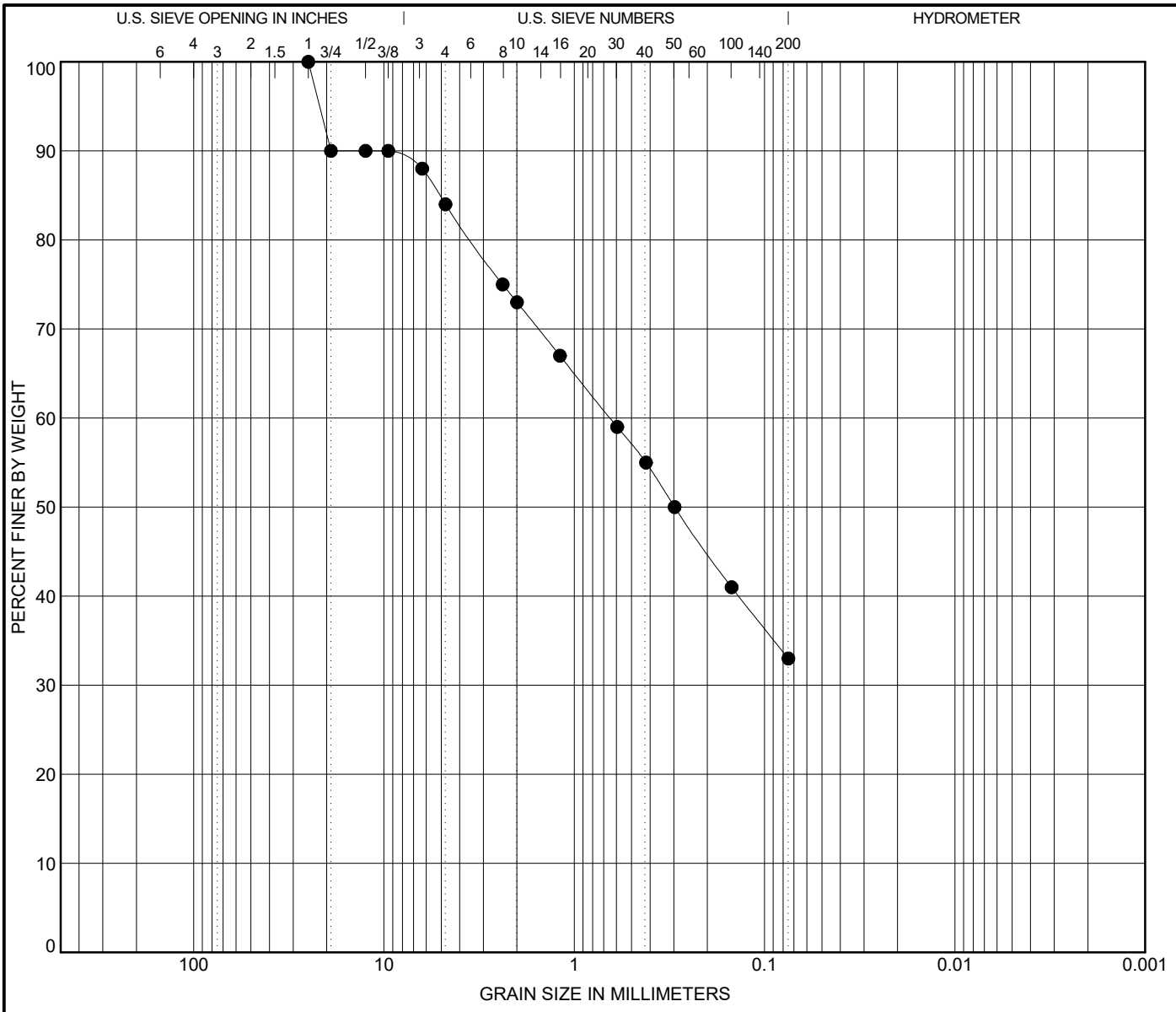
Location: STA 26+50 - Gabion Wall

Number: 114-571155

Figure No. 39

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	90
1/2 in	90
3/8 in	90
1/4 in	88
No. 4	84
No. 8	75
No. 10	73
No. 16	67
No. 30	59
No. 40	55
No. 50	50
No. 100	41
No. 200	33

Specimen Identification
B-520 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
16	51	33	

D100	D60	D30	D10
25	0.649		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

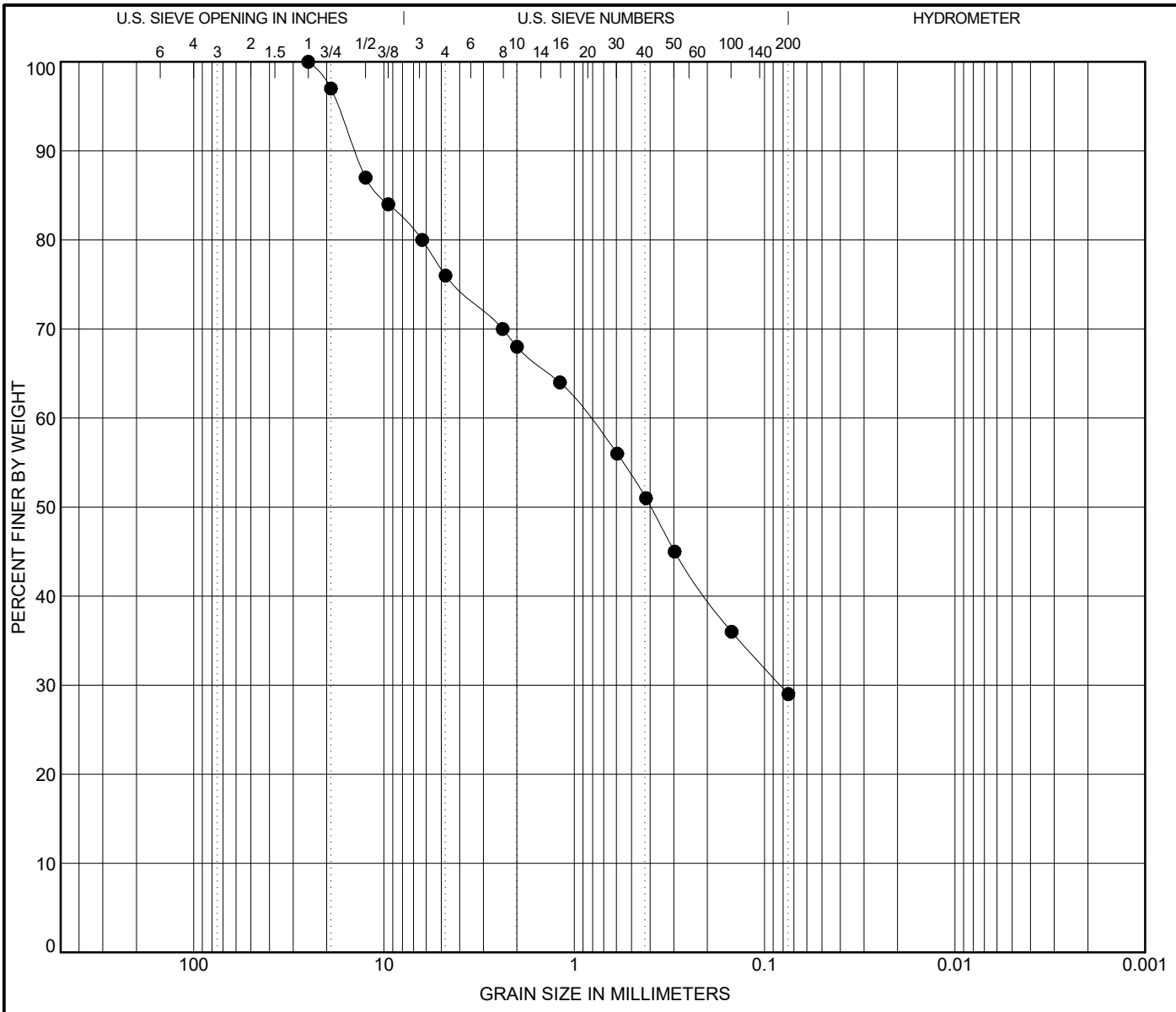
Location: STA 28+50 - Gabion Wall

Number: 114-571155

Figure No. 40

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	97
1/2 in	87
3/8 in	84
1/4 in	80
No. 4	76
No. 8	70
No. 10	68
No. 16	64
No. 30	56
No. 40	51
No. 50	45
No. 100	36
No. 200	29

Specimen Identification
B-521 - (14 - 15.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
24	47	29	

D100	D60	D30	D10
25	0.841	0.083	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

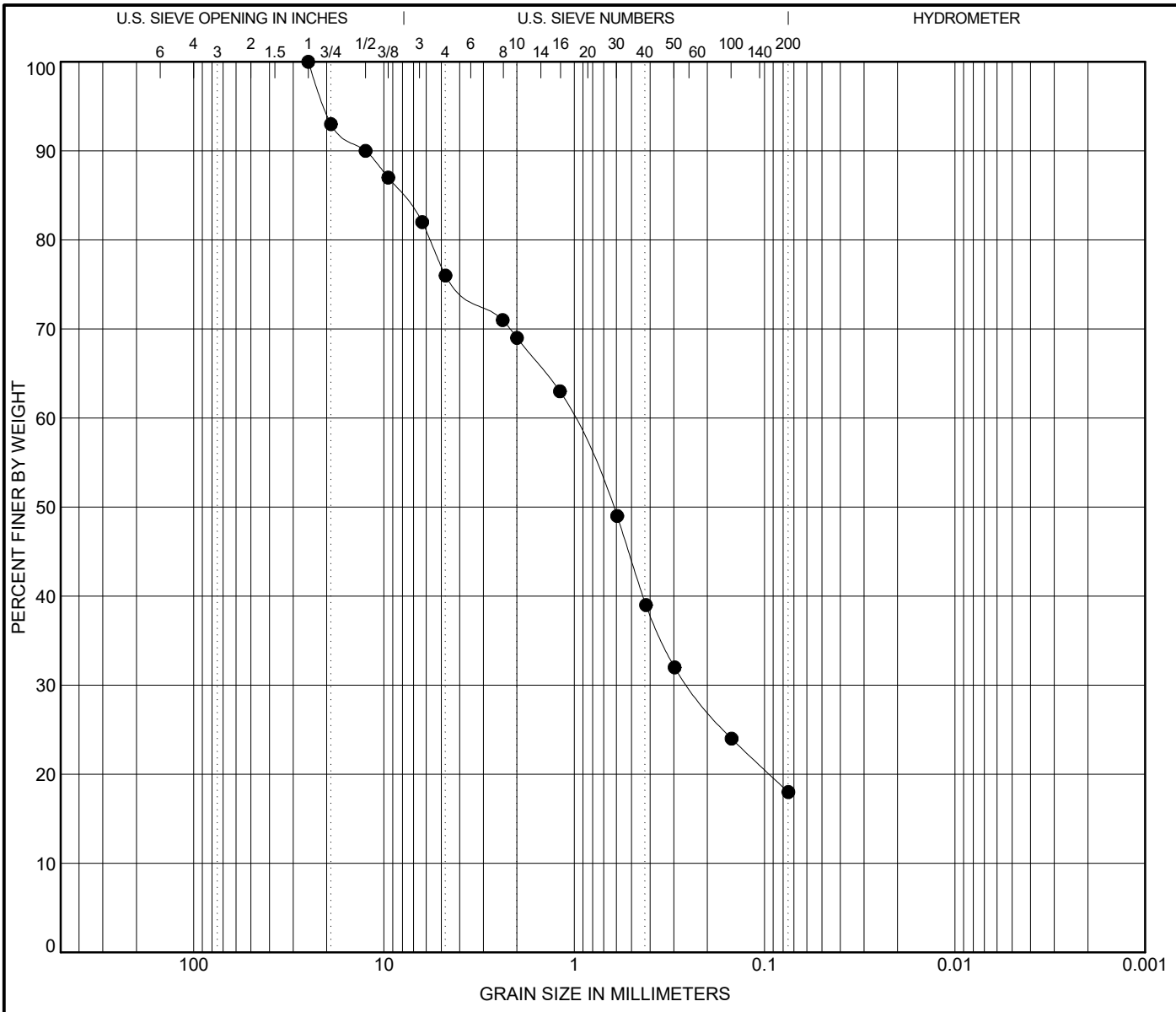
Location: STA 32+75 - MSE Wall

Number: 114-571155

Figure No. 41

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	93
1/2 in	90
3/8 in	87
1/4 in	82
No. 4	76
No. 8	71
No. 10	69
No. 16	63
No. 30	49
No. 40	39
No. 50	32
No. 100	24
No. 200	18

Specimen Identification
B-522 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND with GRAVEL(SM)	**45**	**37**	**8**		

% Gravel	% Sand	% Silt	% Clay
24	58	18	

D100	D60	D30	D10
25	1.026	0.25	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

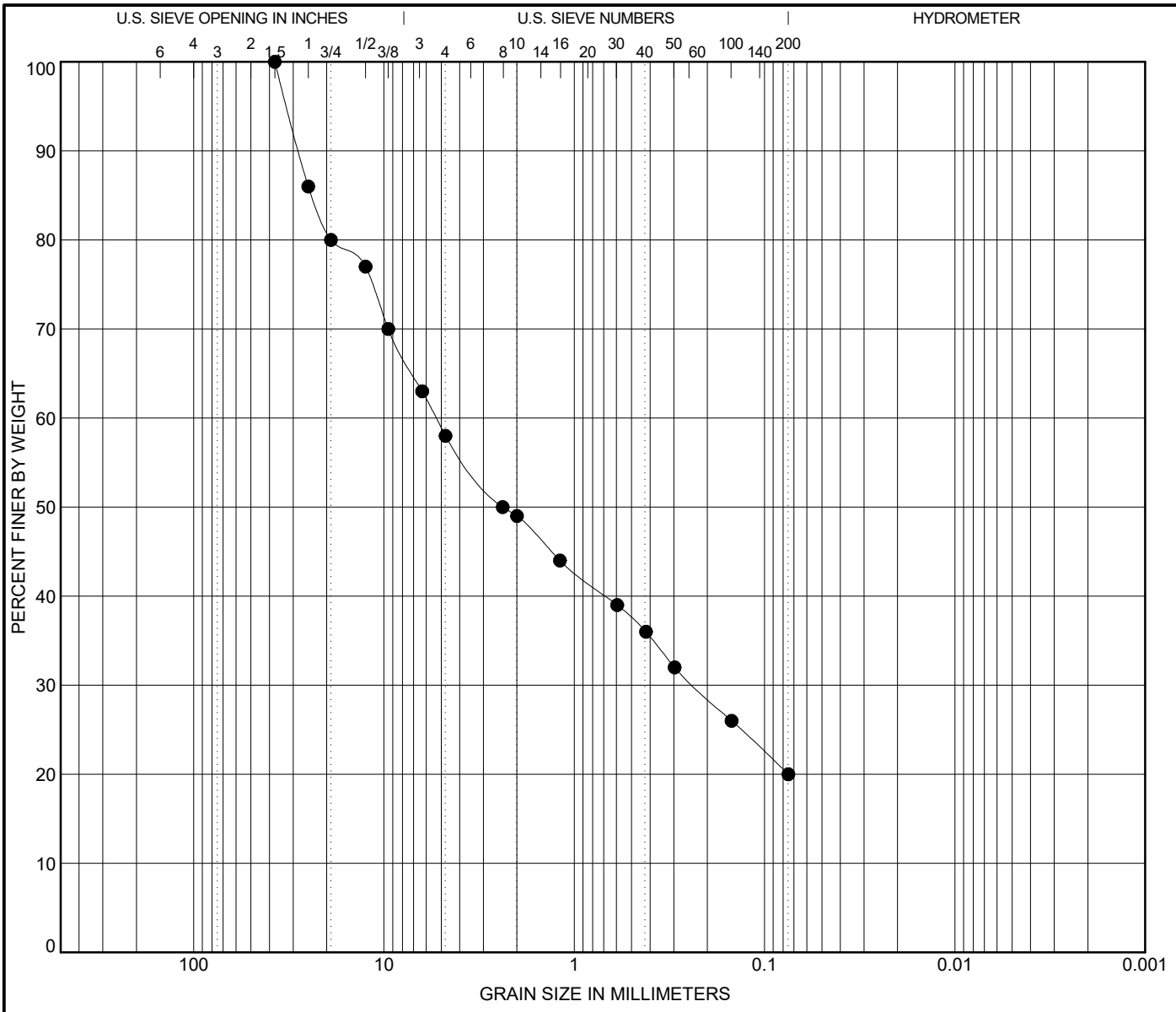
Location: STA 35+00 - MSE Wall

Number: 114-571155

Figure No. 42

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1.5 in	100
1 in	86
3/4 in	80
1/2 in	77
3/8 in	70
1/4 in	63
No. 4	58
No. 8	50
No. 10	49
No. 16	44
No. 30	39
No. 40	36
No. 50	32
No. 100	26
No. 200	20

Specimen Identification
B-523 - (0 - 1.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY GRAVEL with SAND(GM)	**36**	**32**	**4**		

% Gravel	% Sand	% Silt	% Clay
42	38	20	

D100	D60	D30	D10
37.5	5.318	0.236	

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

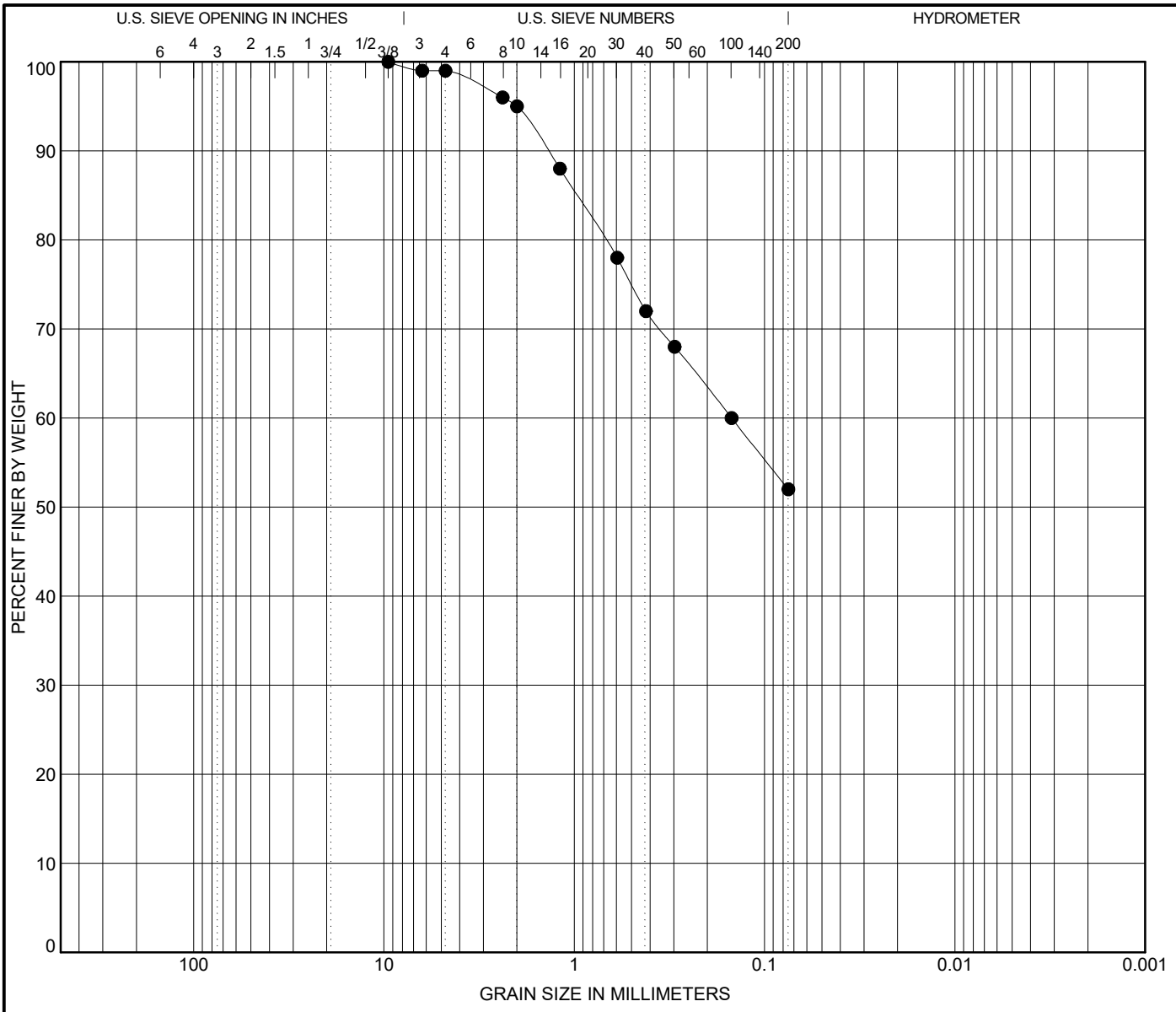
Location: STA 39+00 - Block Wall

Number: 114-571155

Figure No. 43

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
3/8 in	100
1/4 in	99
No. 4	99
No. 8	96
No. 10	95
No. 16	88
No. 30	78
No. 40	72
No. 50	68
No. 100	60
No. 200	52

Specimen Identification
B-523 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY ELASTIC SILT(MH)	**54**	**38**	**16**		

% Gravel	% Sand	% Silt	% Clay
1	47	52	

D100	D60	D30	D10
9.5	0.149		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

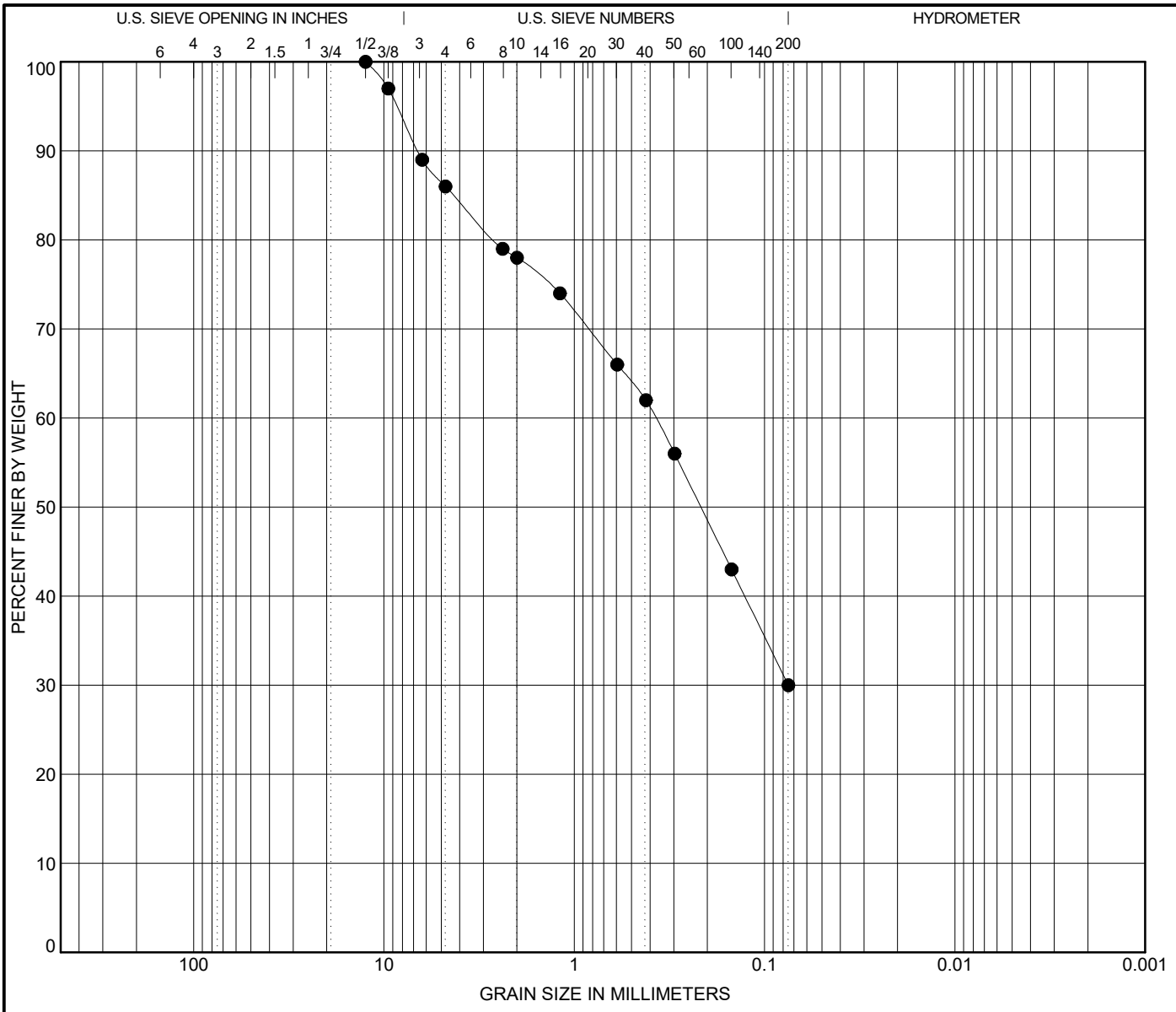
Location: STA 39+00 - Block Wall

Number: 114-571155

Figure No. 44

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1/2 in	100
3/8 in	97
1/4 in	89
No. 4	86
No. 8	79
No. 10	78
No. 16	74
No. 30	66
No. 40	62
No. 50	56
No. 100	43
No. 200	30

Specimen Identification
B-524 - (4 - 5.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**NV**	**NV**	**NP**		

% Gravel	% Sand	% Silt	% Clay
14	56	30	

D100	D60	D30	D10
12.5	0.374	0.075	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

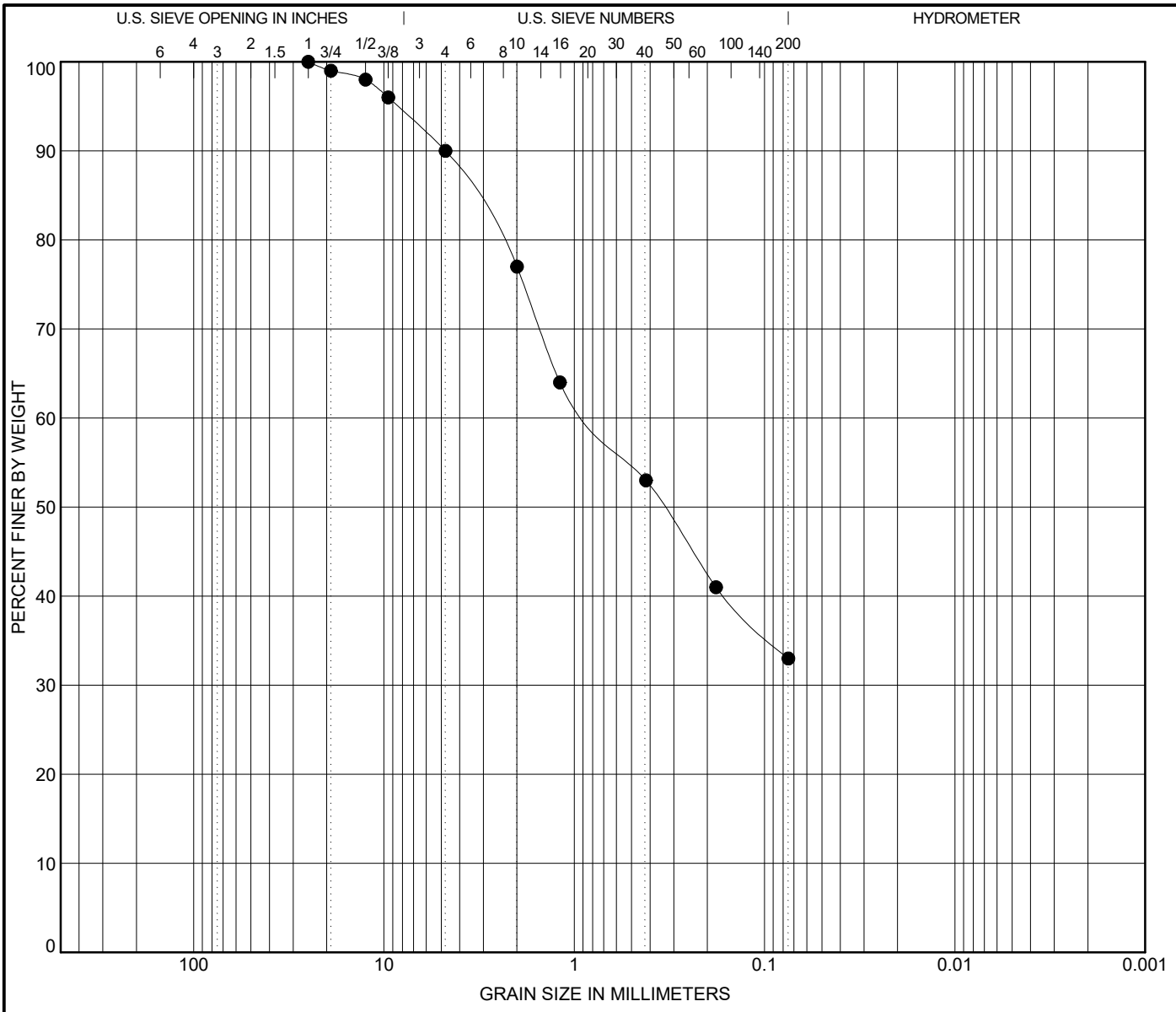
Location: STA 42+50 - Block Wall

Number: 114-571155

Figure No. 45

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
1 in	100
3/4 in	99
1/2 in	98
3/8 in	96
No. 4	90
No. 10	77
No. 16	64
No. 40	53
No. 80	41
No. 200	33

Specimen Identification
B-524 - (5 - 10 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**34**	**27**	**7**		

% Gravel	% Sand	% Silt	% Clay
10	57	33	

D100	D60	D30	D10
25	0.815		

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

Location: STA 42+50 - Block Wall

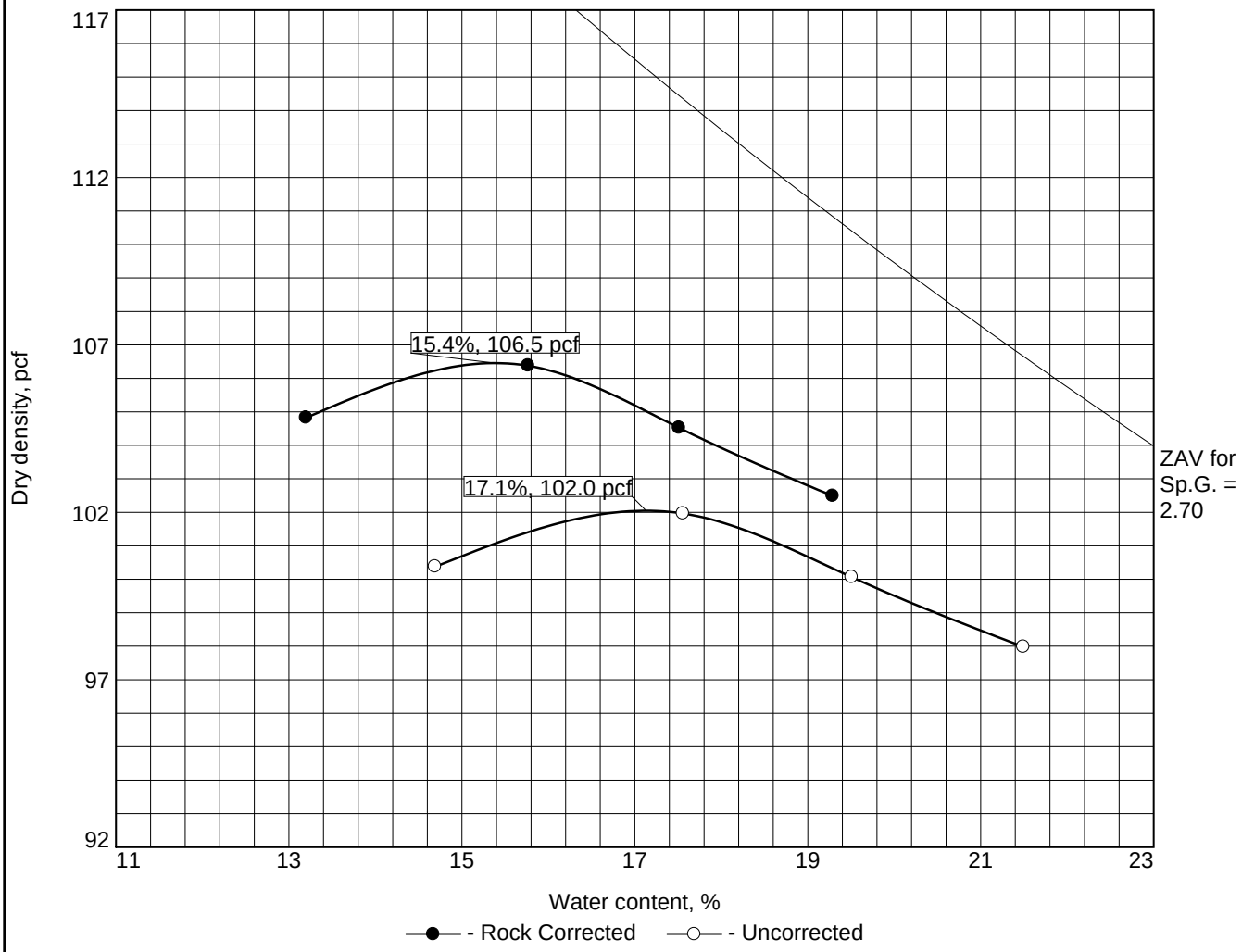
Number: 114-571155

Figure No. 46

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)

COMPACTION TEST REPORT



Test specification: ASTM D 698-07 Method A Standard
ASTM D 4718-87 Oversize Corr. Applied to Each Test Point

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > #4	% < No.200
	USCS	AASHTO						
5' - 10'	SM	A-2-4(0)		2.70	34	7	10.5	32.8

ROCK CORRECTED TEST RESULTS	UNCORRECTED	MATERIAL DESCRIPTION
Maximum dry density = 106.5 pcf	102.0 pcf	Silty SAND
Optimum moisture = 15.4 %	17.1 %	

Project No. 114-571155 **Client:**
Project: Clearview Landfill

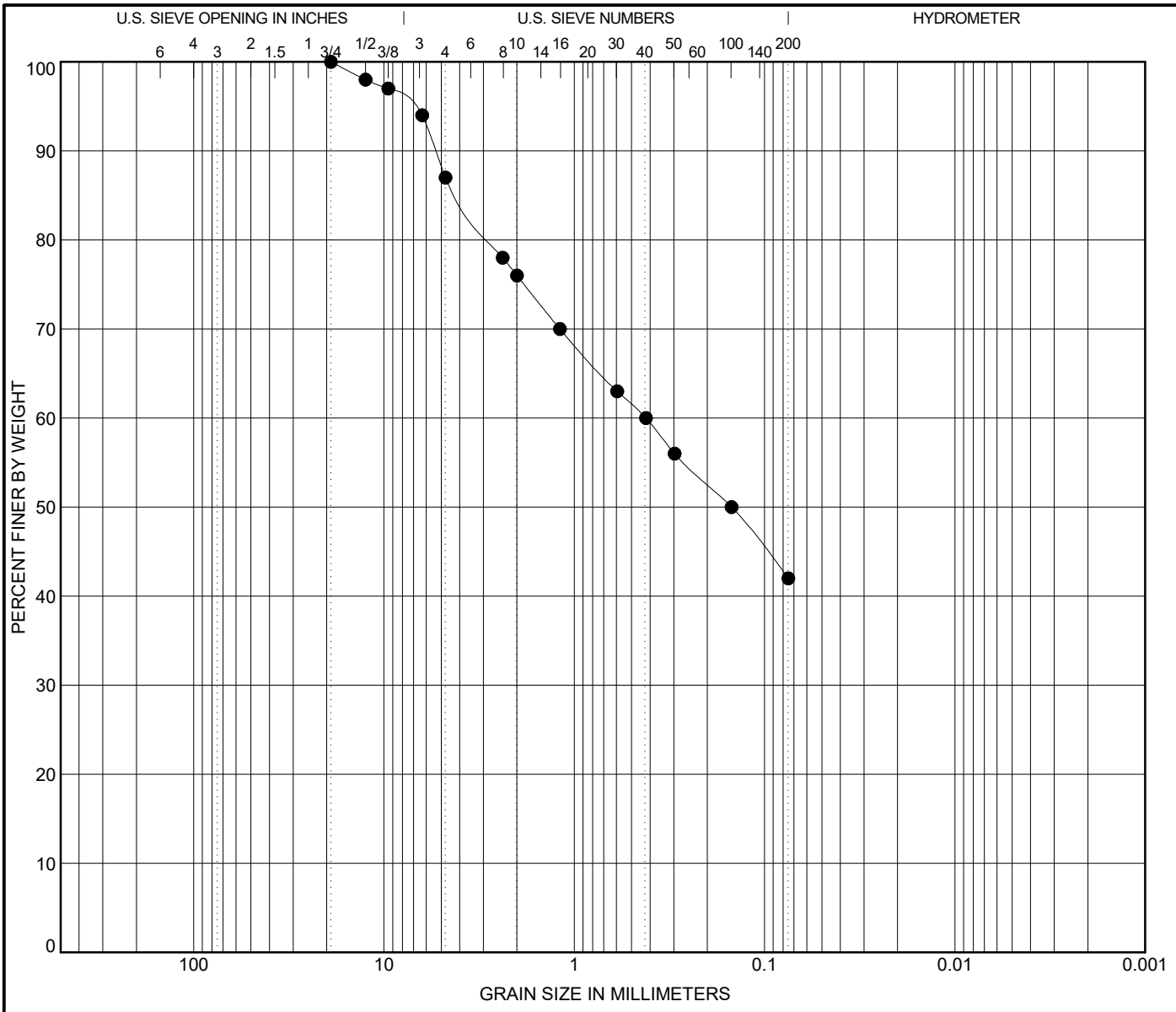
○**Source of Sample:** B-524

Tetra Tech

Billings, MT

Remarks:

Figure 47



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
3/4 in	100
1/2 in	98
3/8 in	97
1/4 in	94
No. 4	87
No. 8	78
No. 10	76
No. 16	70
No. 30	63
No. 40	60
No. 50	56
No. 100	50
No. 200	42

Specimen Identification
B-524 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SILTY SAND(SM)	**36**	**31**	**5**		

% Gravel	% Sand	% Silt	% Clay
13	45	42	

D100	D60	D30	D10
19	0.42		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

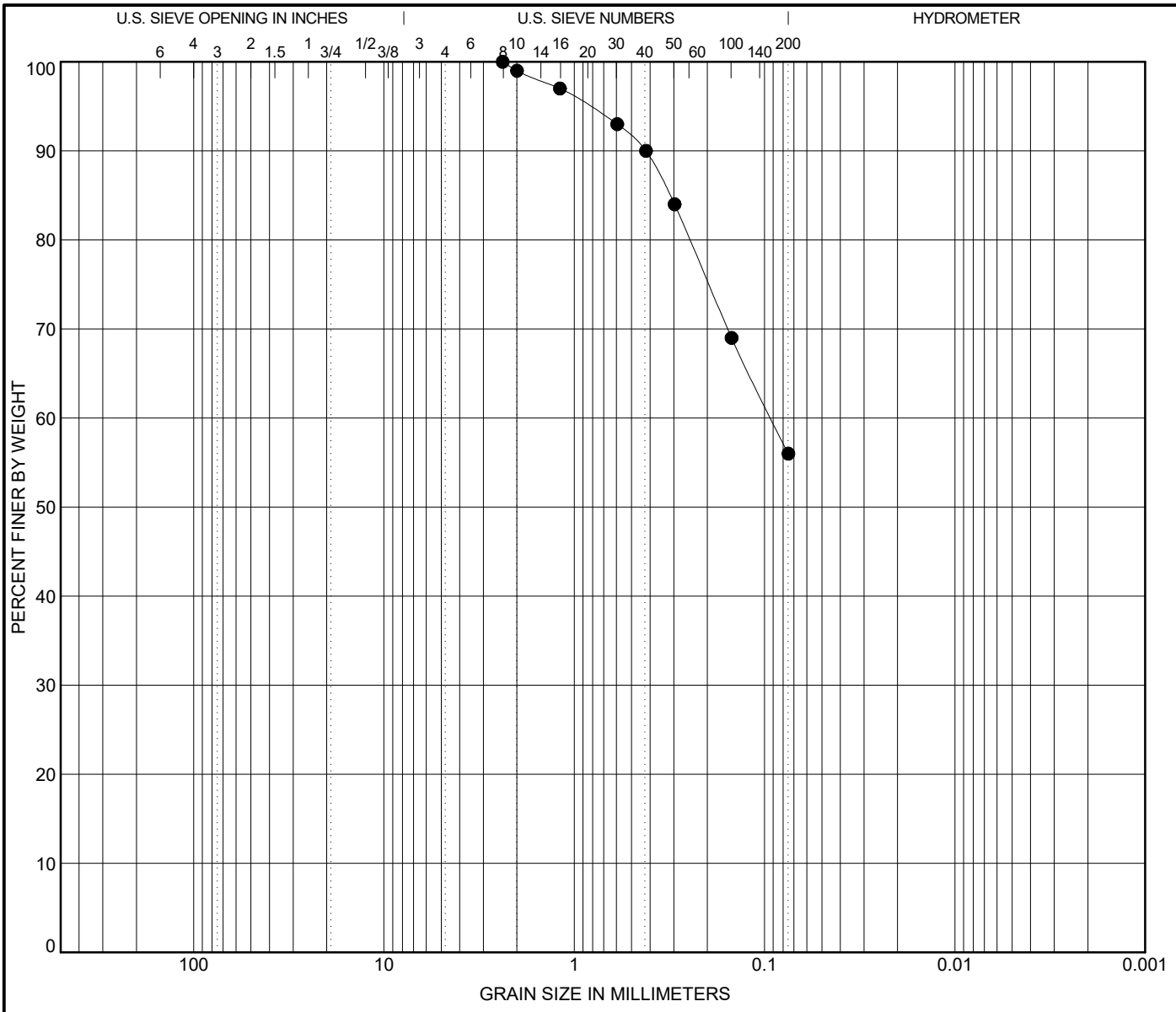
Location: STA 42+50 - Block Wall

Number: 114-571155

Figure No. 48

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 8	100
No. 10	99
No. 16	97
No. 30	93
No. 40	90
No. 50	84
No. 100	69
No. 200	56

Specimen Identification
B-525 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**37**	**29**	**8**		

% Gravel	% Sand	% Silt	% Clay
0	44	56	

D100	D60	D30	D10
2.38	0.093		

GRAIN SIZE DISTRIBUTION

TETRA TECH

Project: Lower Darby Creek Superfund Site,

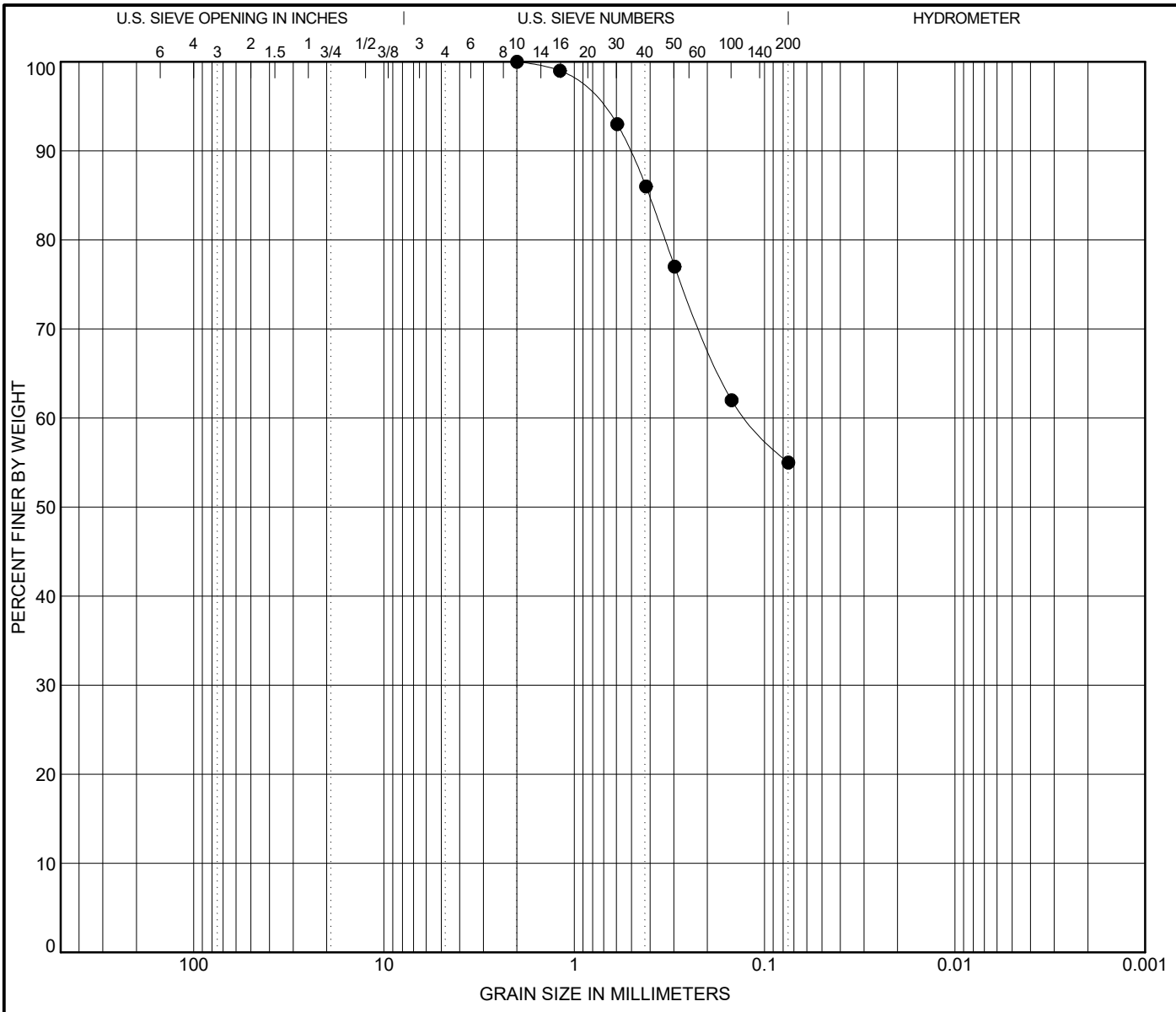
Location: STA 44+00 - Crib Wall

Number: 114-571155

Figure No. 49

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

SIEVE SIZE	% PASSING
No. 10	100
No. 16	99
No. 30	93
No. 40	86
No. 50	77
No. 100	62
No. 200	55

Specimen Identification
B-526 - (9 - 10.5 ft)

Classification	LL	PL	PI	Cc	Cu
SANDY SILT(ML)	**21**	**18**	**3**		

% Gravel	% Sand	% Silt	% Clay
0	45	55	

D100	D60	D30	D10
2	0.122		

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Lower Darby Creek Superfund Site,

Location: STA 45+00 - Crib Wall

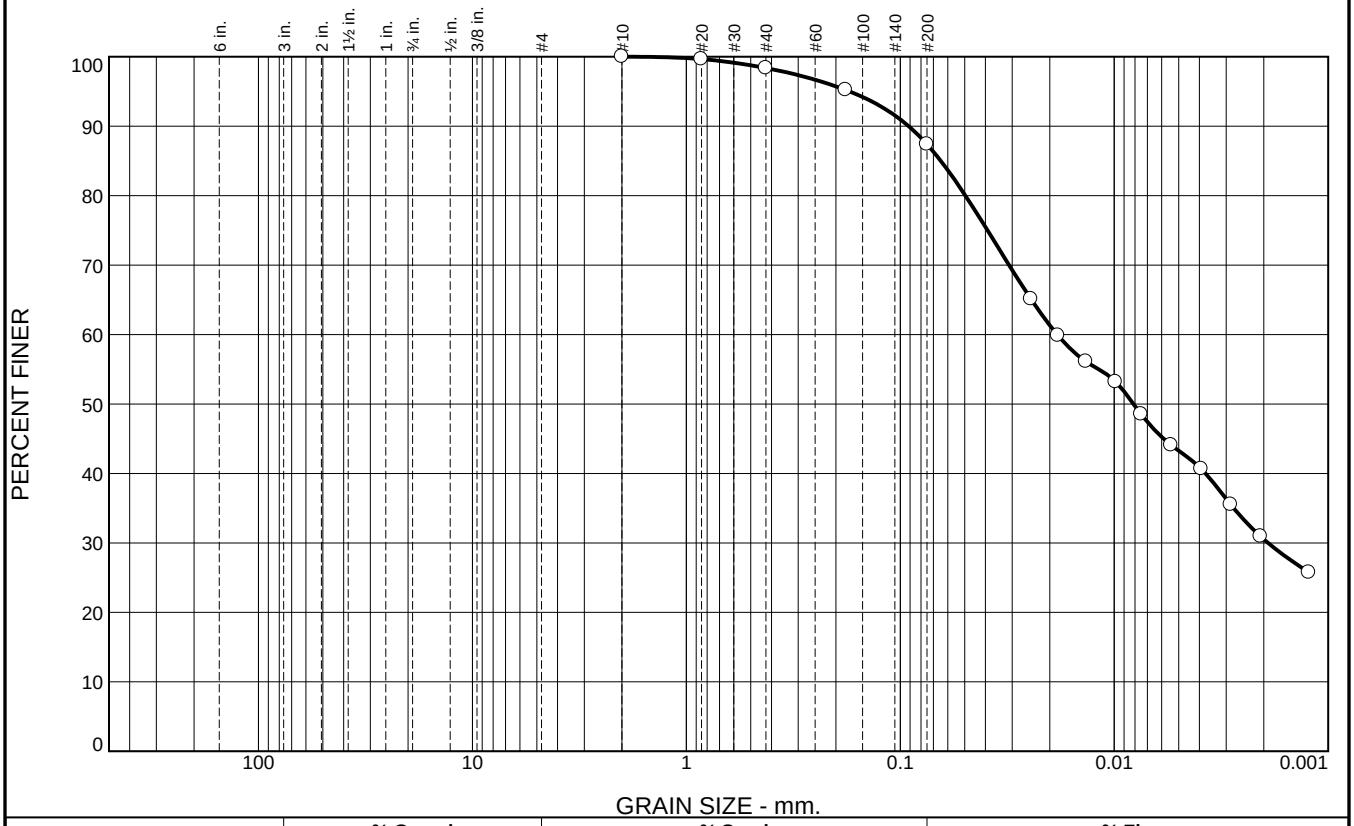
Number: 114-571155

Figure No. 50

LOWER DARBY BORING LOGS.GPJ ` 5-1-17 ` ` TT_US GRAIN SIZE (SIEVE DATA)

Revised 1-23-08 (MAT)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	1.6	11.0	44.1	43.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.6		
#40	98.4		
#80	95.2		
#200	87.4		
0.0245 mm.	65.1		
0.0183 mm.	59.9		
0.0136 mm.	56.1		
0.0099 mm.	53.2		
0.0075 mm.	48.5		
0.0054 mm.	44.1		
0.0039 mm.	40.7		
0.0029 mm.	35.5		
0.0021 mm.	31.0		
0.0012 mm.	25.7		

* (no specification provided)

Soil Description

Elastic SILT

Atterberg Limits

PL= 37 LL= 63 PI= 26

Coefficients

D_{90}= 0.0915 D_{85}= 0.0647 D_{60}= 0.0185
D_{50}= 0.0081 D_{30}= 0.0019 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= MH AASHTO= A-7-5(28)

Remarks

Source of Sample: Oldmans **Depth:** Bulk

Date: 4-18-17

Tetra Tech

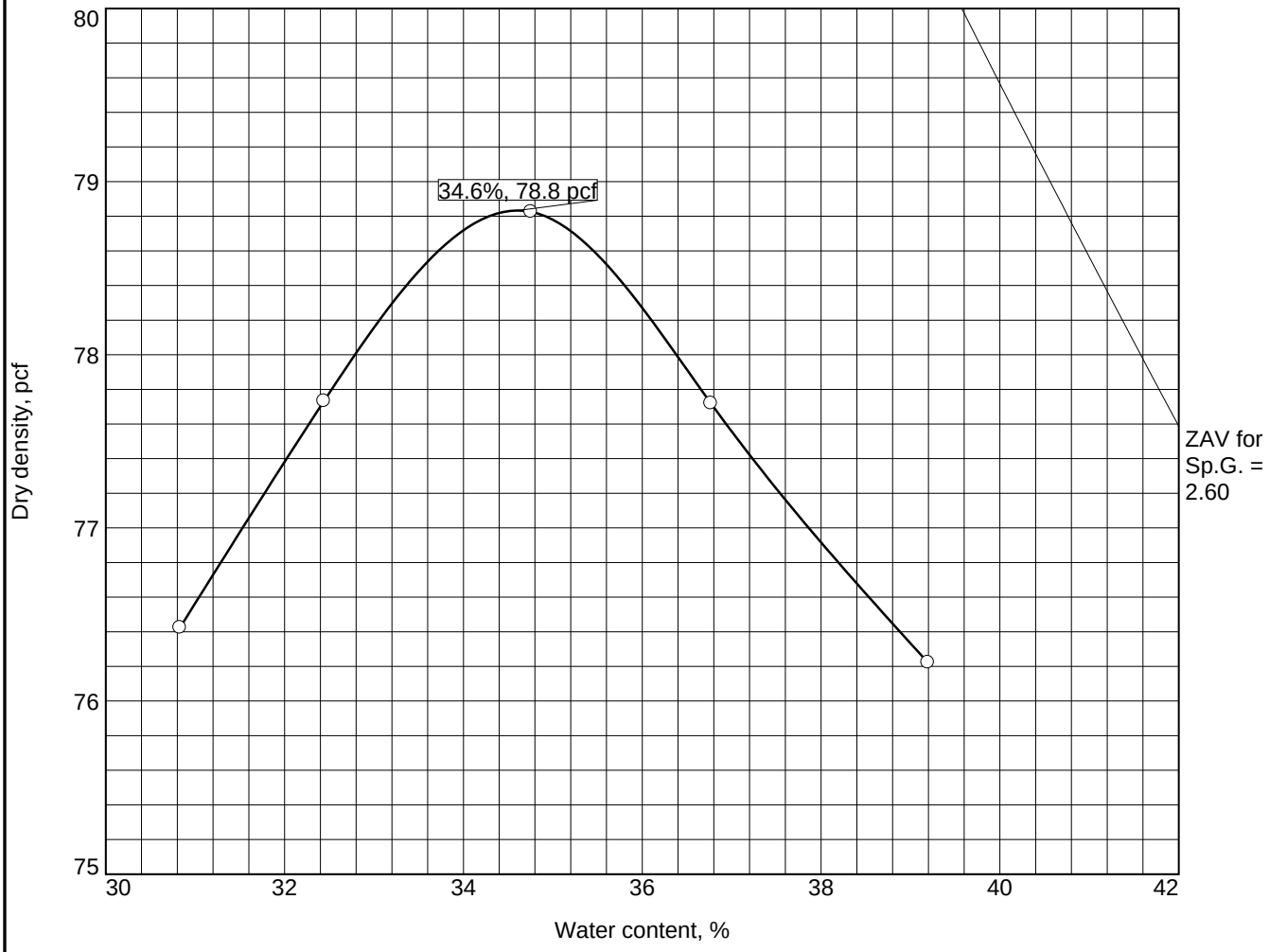
Billings, MT

Client:

Project: Clearview Landfill

Project No: 114-571155 **Figure** 51

COMPACTION TEST REPORT

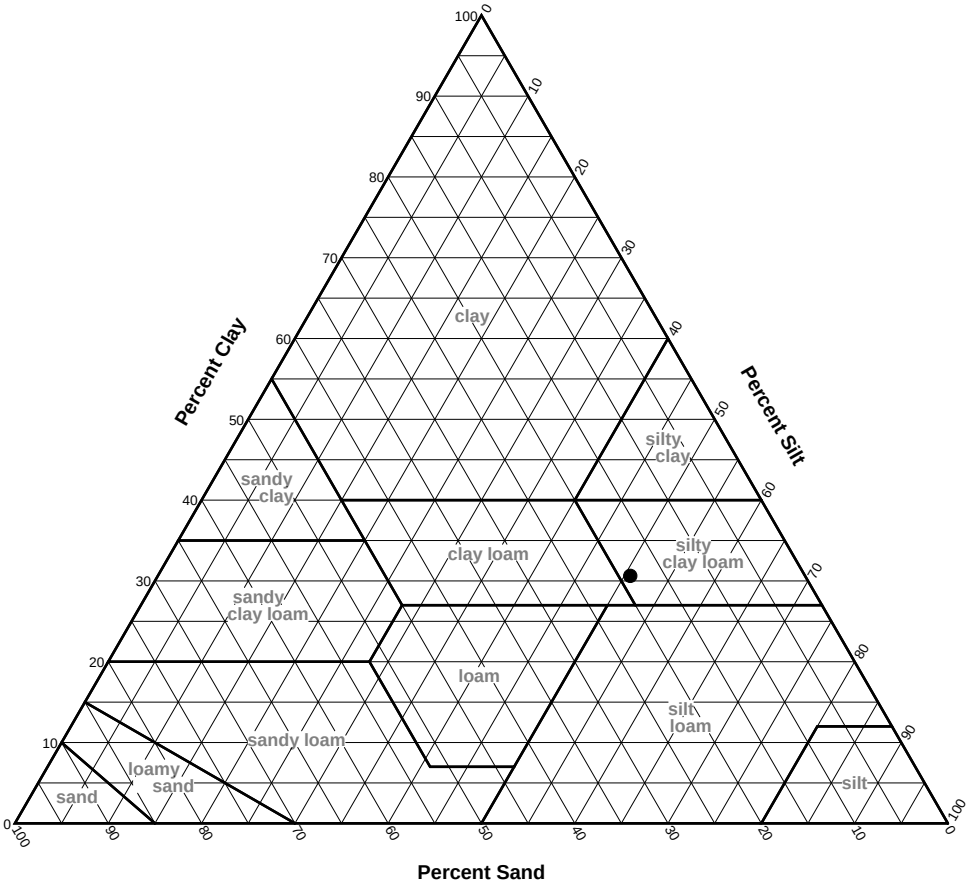


Test specification: ASTM D 698-07 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > #4	% < No.200
	USCS	AASHTO						
Bulk	MH	A-7-5(28)		2.65	63	26	0.0	87.4

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 78.8 pcf Optimum moisture = 34.6 %	Elastic SILT
Project No. 114-571155 **Client:** **Project:** Clearview Landfill ○**Source of Sample:** Oldmans	**Remarks:**
Tetra Tech **Billings, MT**	**Figure** 52

USDA Soil Classification



SOIL DATA							
	Source	Sample No.	Depth	Percentages From Material Passing a #10 Sieve			Classification
				Sand	Silt	Clay	
●	Oldmans		Bulk	18.7	50.8	30.5	Silty clay loam

Tetra Tech

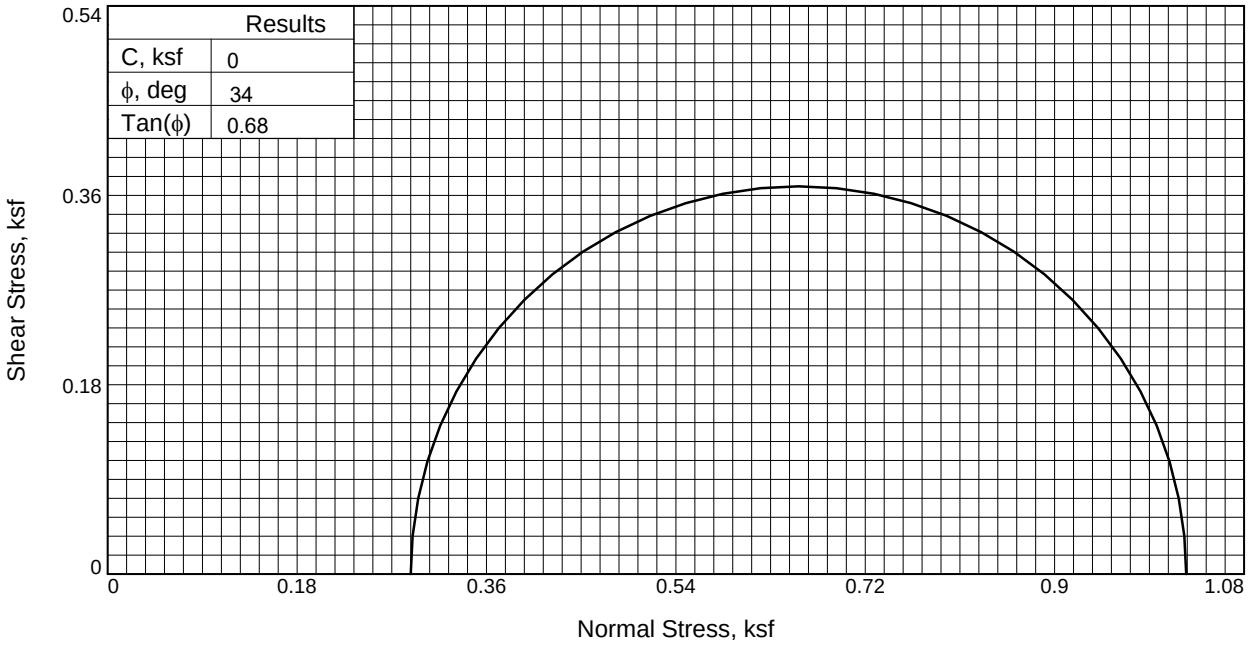
Billings, MT

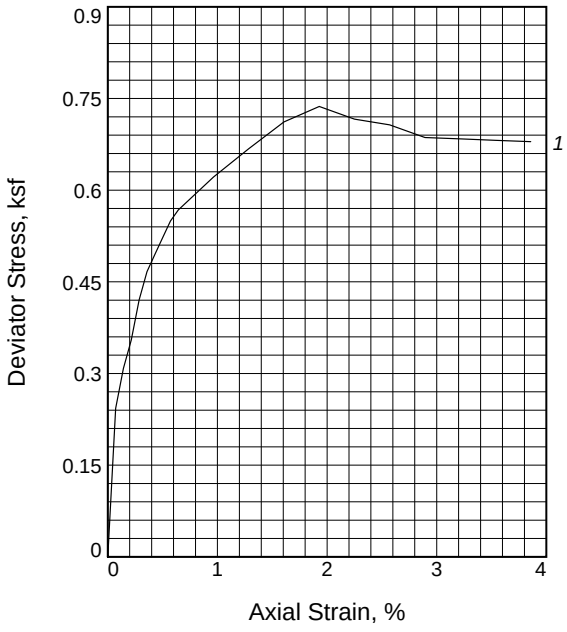
Client:

Project: Clearview Landfill

Project No.: 114-571155

Figure 53





Sample No.		1
Initial	Water Content, %	33.3
	Dry Density, pcf	68.8
	Saturation, %	62.8
	Void Ratio	1.4060
	Diameter, in.	1.40
	Height, in.	2.80
At Test	Water Content, %	53.1
	Dry Density, pcf	68.8
	Saturation, %	100.0
	Void Ratio	1.4060
	Diameter, in.	1.40
	Height, in.	2.80
Strain rate, in./min.		0.00
Back Pressure, psi		60.00
Cell Pressure, psi		62.00
Fail. Stress, ksf		0.74
Ult. Stress, ksf		
σ_1 Failure, ksf		1.03
σ_3 Failure, ksf		0.29

Type of Test:
Consolidated Drained

Sample Type: Remolded

Description: Silt

Assumed Specific Gravity= 2.65

Remarks: A strain rate of 0.0003 in/min was used.

Client:

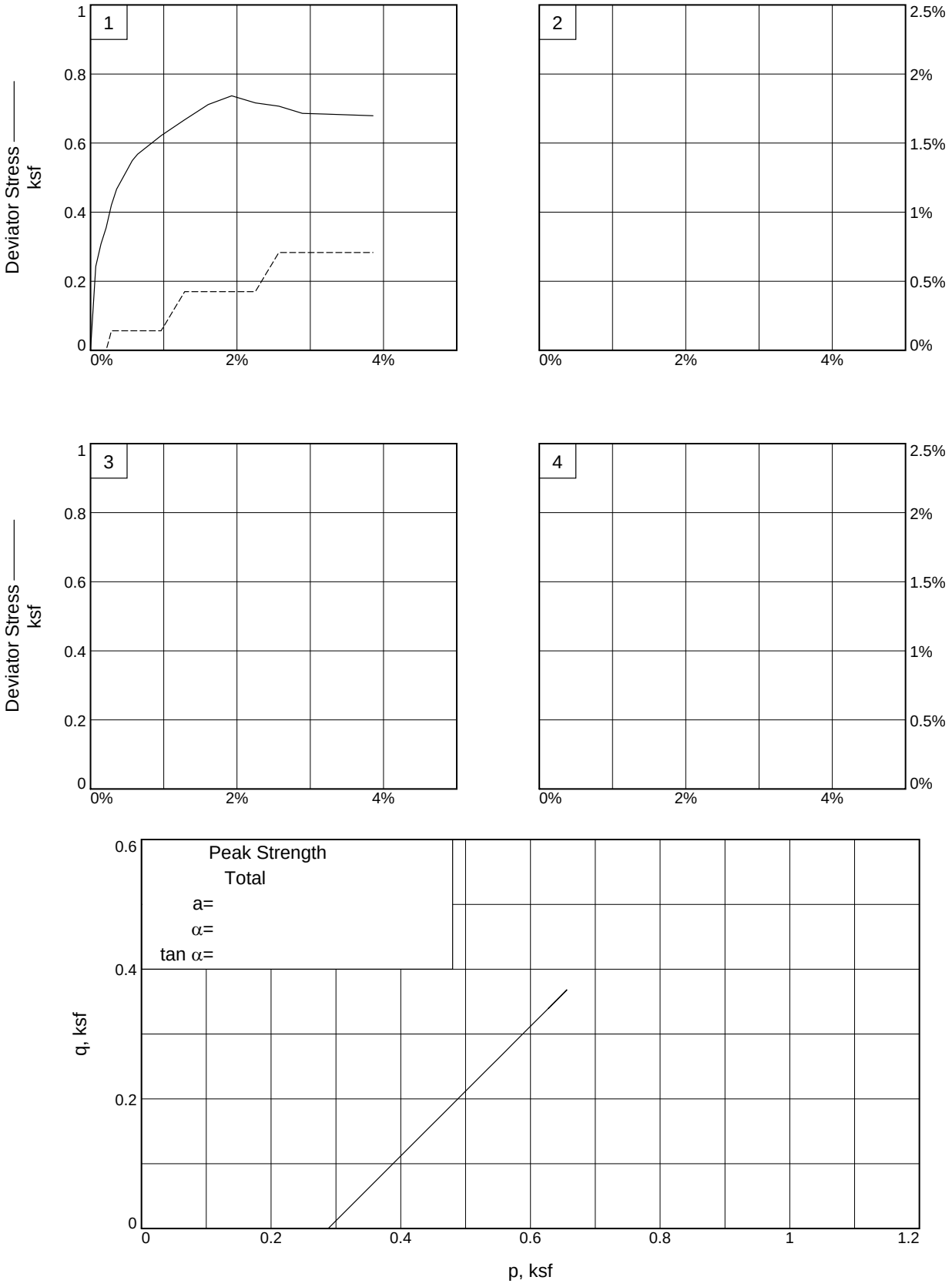
Project: Clearview Landfill

Source of Sample: Oldmans **Depth:** Bulk

Proj. No.: 114-571155 **Date Sampled:**

TRIAXIAL SHEAR TEST REPORT
Tetra Tech
Billings, MT

Figure 54



Client:

Project: Clearview Landfill

Source of Sample: Oldmans **Depth:** Bulk

Project No.: 114-571155

Figure 55

Tetra Tech

PERMEABILITY TEST REPORT

TEST DATA:
Specimen Height (cm): 7.39
Specimen Diameter (cm): 7.04
Dry Unit Weight (pcf): 68.8
Moisture Before Test (%): 33.3
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0

Sat. Pressure (psi): 60.0
Diff. Head (psi): 2.0

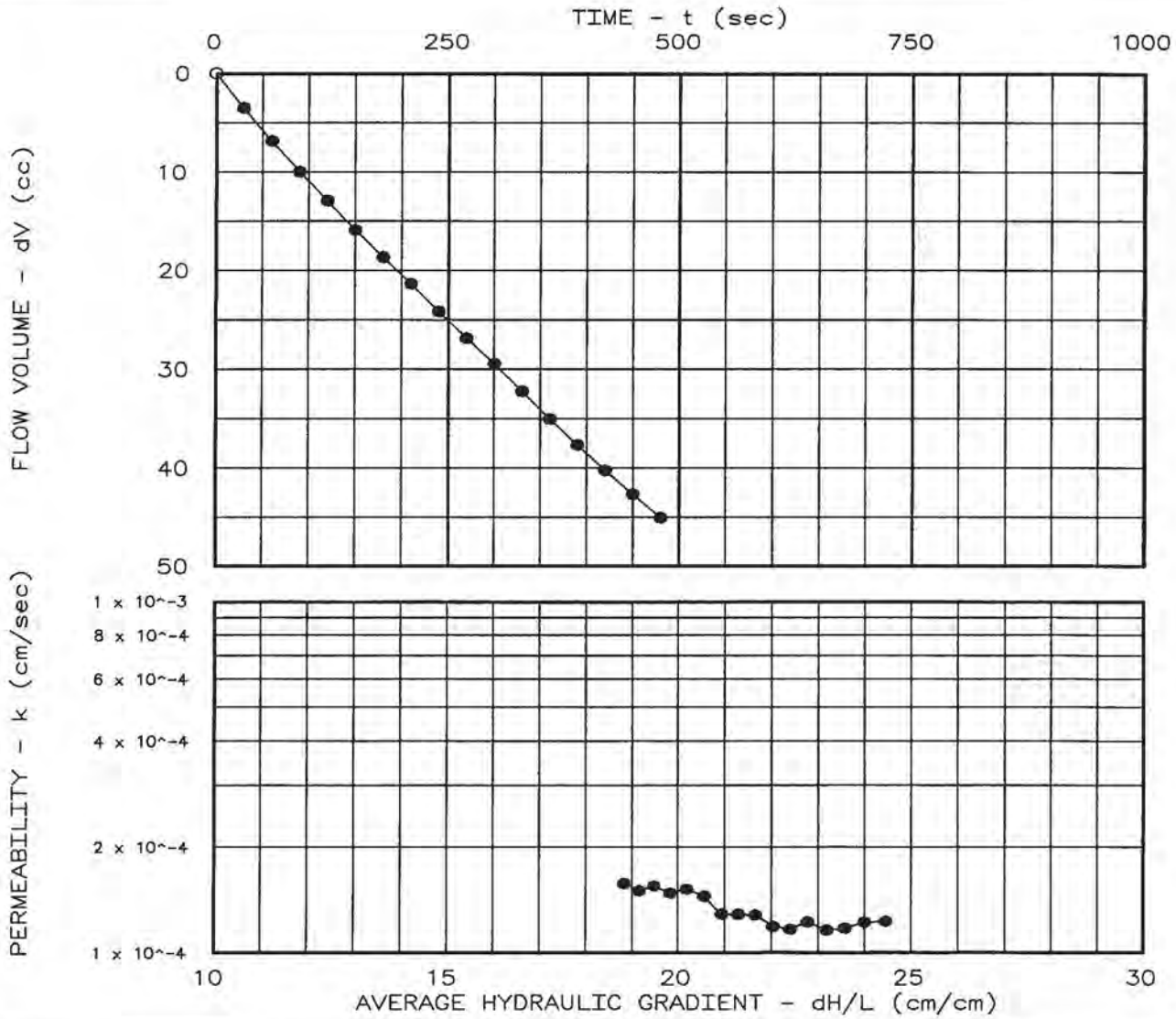
Perm. (cm/sec): 1.53 x 10^-4

SAMPLE DATA:
Sample Identification: Old Man Bulk

Visual Description: Elastic SILT

Remarks:

Maximum Dry Density (pcf): 80.9
Optimum Moisture Content (%): 33.3
ASTM(D698)
Percent Compaction: 85.0%
Permeameter type: Flexwall
Sample type: Remolded



Project: Clearview Landfill
Location:
Date: 3-27-17

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-571155
File No.: 594
Lab No.:
Tested by: OT
Checked by: TG
Test: FH - Falling head C

Figure 56

PERMEABILITY TEST DATA

PROJECT DATA

Project Name:	Clearview Landfill
File No.:	594
Project Location:	
Project No.:	114-571155
Sample Identification:	Old Man Bulk
Lab No.:	
Description:	Elastic SILT
Sample Type:	Remolded
Max. Dry Dens.:	80.9
Method (D1557/D698):	D698
Opt. Water Content:	33.3
Date:	3-27-17
Remarks:	
Permeameter Type:	Flexwall
Tested by:	OT
Checked by:	TG
Test type:	FH - Falling head C

PERMEABILITY TEST SPECIMEN DATA

	Before test:			After test:		
Diameter:	1	2		1	2	
Top:	2.770 in	in		in	in	
Middle:	in	in		in	in	
Bottom:	in	in		in	in	
Average:	2.77 in	7.04 cm		0.00 in	0.00 cm	
Length:	1	2	3	1	2	3
	2.910 in	in	in	in	in	in
Average:	2.91 in	7.39 cm		0.00 in	0.00 cm	

Moisture, Density and Sample Parameters:

Specific Gravity:	2.65		
Wet Wt. & Tare:	421.90		0.00
Dry Wt. & Tare:	316.50		0.00
Tare Wt.:	0.00		0.00
Moisture Content:	33.3 %		0.0 %
Dry Unit Weight:	68.8 pcf	85.0 % of max	0.0 pcf
Porosity:	0.5844		0.0000
Saturation:	62.8 %		0.0 %

Figure 57

FALLING HEAD PERMEABILITY TEST CONDITIONS DATA

Cell No.: 1 Panel No.: 3 Positions: 1

Run Number:	1	2
Cell Pressure:	65.0 psi	0.0 psi
Inflow Saturation Pressure:	60.0 psi	0.0 psi
Inflow Buret Area:	1.0000 cm²	1.0000 cm²
Outflow Buret Area:	1.0000 cm²	1.0000 cm²
Test Temperature:	20.0 °C	0.0 °C
Outflow Saturation Pressure:	58.0 psi	0.0 psi

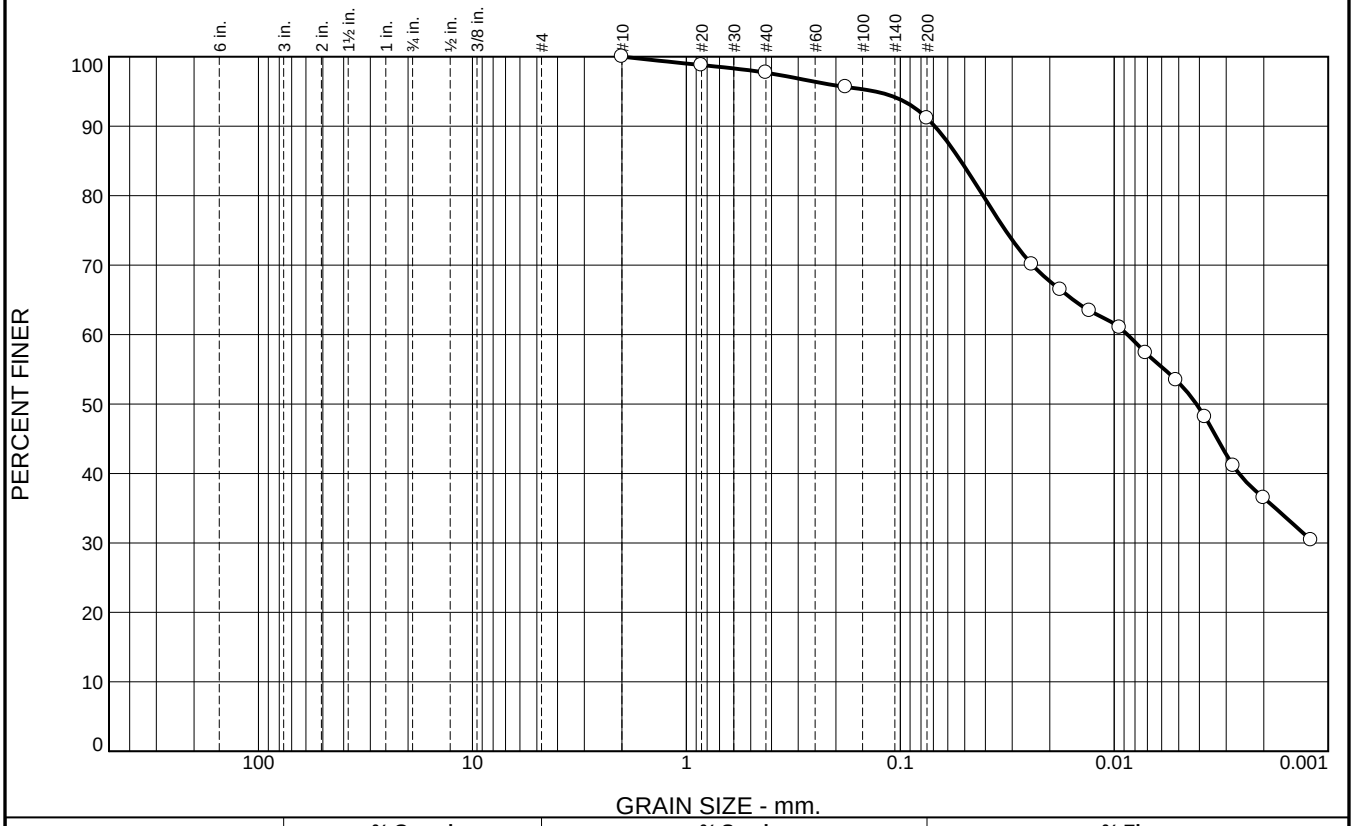
PERMEABILITY TEST READINGS DATA

CASE D X S	DATE	TIME (24 hr)	ELAPSED TIME sec	INFLOW LEVEL cm	OUTFLOW LEVEL cm	OUTFLOW/ INFLOW RATIO	PERM. K cm/sec	PERM./ RUNNING 4 AVE.
S X	3/27/ 0	8:58:00	0	3.10	46.7	0.00	0.00E 00	0.00
	3/27/ 0	8:58:30	30	6.40	43.0	1.12	1.23E-04	0.00
	3/27/ 0	8:59:00	30	9.70	39.6	1.03	1.22E-04	0.00
	3/27/ 0	8:59:30	30	12.80	36.5	1.00	1.17E-04	0.00
	3/27/ 0	9:00:00	30	15.90	33.7	0.90	1.16E-04	0.97
	3/27/ 0	9:00:30	30	18.80	30.6	1.07	1.22E-04	1.02
	3/27/ 0	9:01:00	30	21.60	27.9	0.96	1.16E-04	0.99
	3/27/ 0	9:01:30	30	24.30	25.2	1.00	1.19E-04	1.00
	3/27/ 0	9:02:00	30	27.10	22.4	1.00	1.28E-04	1.05
	3/27/ 0	9:02:30	30	29.80	19.7	1.00	1.28E-04	1.05
	3/27/ 0	9:03:00	30	32.40	17.1	1.00	1.29E-04	1.02
	3/27/ 0	9:03:30	30	35.20	14.3	1.00	1.45E-04	1.09
	3/27/ 0	9:04:00	30	38.00	11.5	1.00	1.52E-04	1.10
	3/27/ 0	9:04:30	30	40.60	8.9	1.00	1.48E-04	1.03
	3/27/ 0	9:05:00	30	43.20	6.3	1.00	1.55E-04	1.03
	3/27/ 0	9:05:30	30	45.60	3.9	1.00	1.50E-04	0.99
	3/27/ 0	9:06:00	30	48.00	1.5	1.00	1.58E-04	1.03

Average differential head = 0.0 psi, 0.0 cm H2O
Gradient = 1.883E 01 Total vol = 4.51E 01 cc Test duration = 480 sec
Permeability, K20.0° = 1.526E-04 cm/sec, K20° = 1.526E-04 cm/sec
Permeability values are incremental

Figure 58

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	2.3	6.5	38.1	53.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	98.8		
#40	97.7		
#80	95.6		
#200	91.2		
0.0243 mm.	70.1		
0.0179 mm.	66.5		
0.0131 mm.	63.4		
0.0094 mm.	61.0		
0.0071 mm.	57.4		
0.0051 mm.	53.5		
0.0038 mm.	48.2		
0.0028 mm.	41.1		
0.0020 mm.	36.5		
0.0012 mm.	30.4		

* (no specification provided)

Soil Description

Elastic SILT

Atterberg Limits

PL= 41 LL= 60 PI= 19

Coefficients

D_{90}= 0.0691 D_{85}= 0.0522 D_{60}= 0.0087
D_{50}= 0.0041 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= MH AASHTO= A-7-5(24)

Remarks

Source of Sample: Pedricktown Lower **Depth:** Bulk

Date: 4-18-17

Tetra Tech

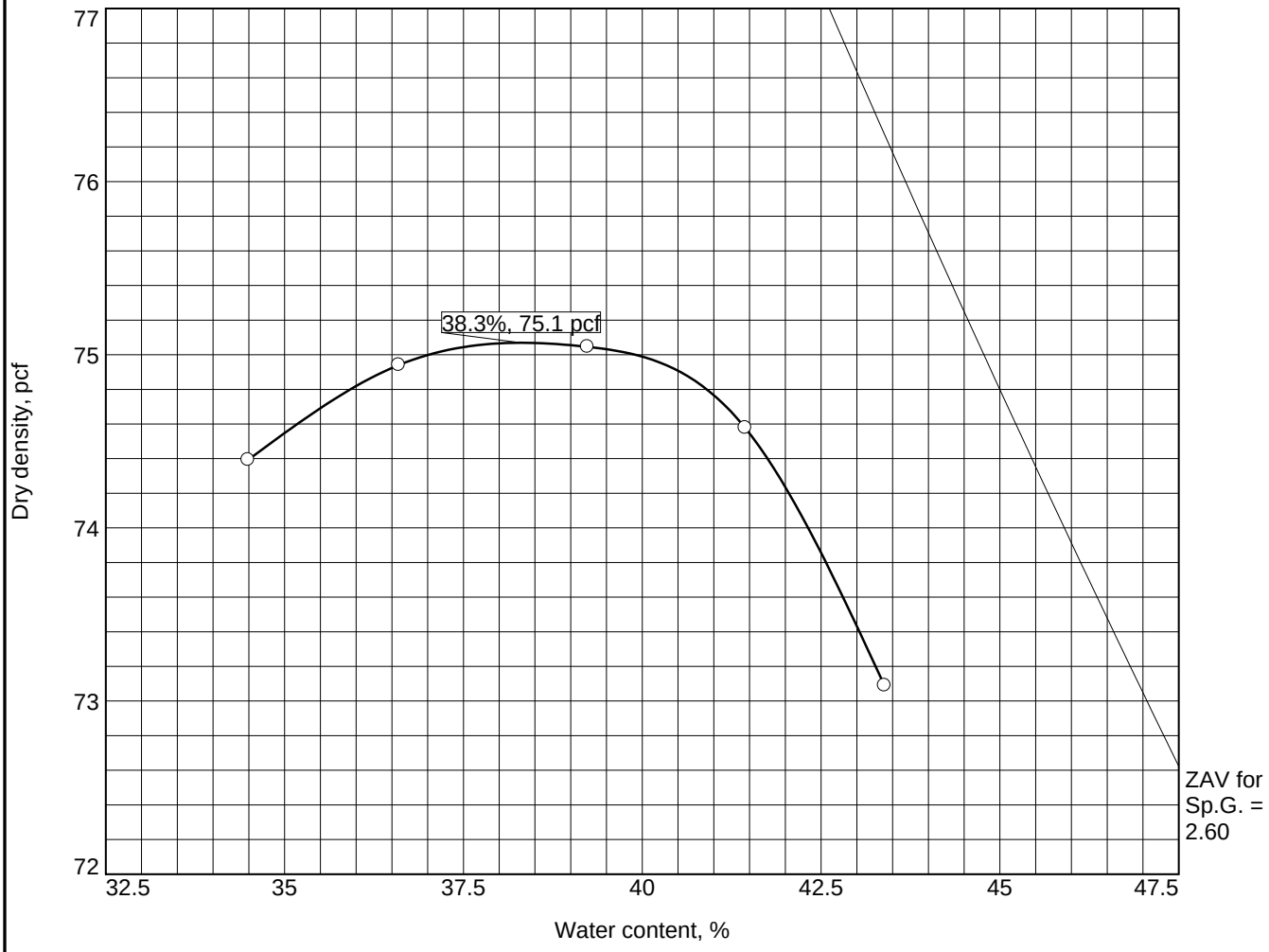
Billings, MT

Client:

Project: Clearview Landfill

Project No: 114-571155 **Figure** 59

COMPACTION TEST REPORT



Test specification: ASTM D 698-12 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > #4	% < No.200
	USCS	AASHTO						
Bulk	MH	A-7-5(24)		2.65	60	19	0.0	91.2

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 75.1 pcf Optimum moisture = 38.3 %	Elastic SILT

Project No. 114-571155 **Client:**
Project: Clearview Landfill

○**Source of Sample:** Pedricktown Lower

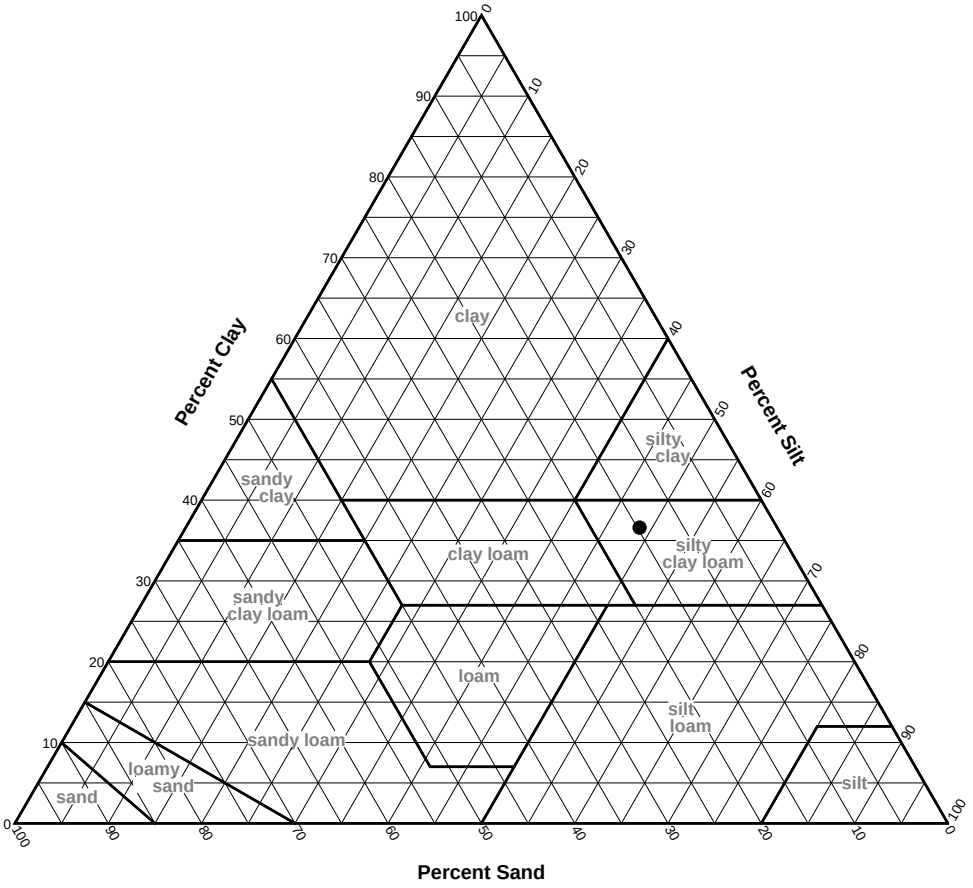
Tetra Tech

Billings, MT

Remarks:

Figure 60

USDA Soil Classification



SOIL DATA							
	Source	Sample No.	Depth	Percentages From Material Passing a #10 Sieve			Classification
				Sand	Silt	Clay	
●	Pedricktown Lower		Bulk	14.7	48.8	36.5	Silty clay loam

Tetra Tech

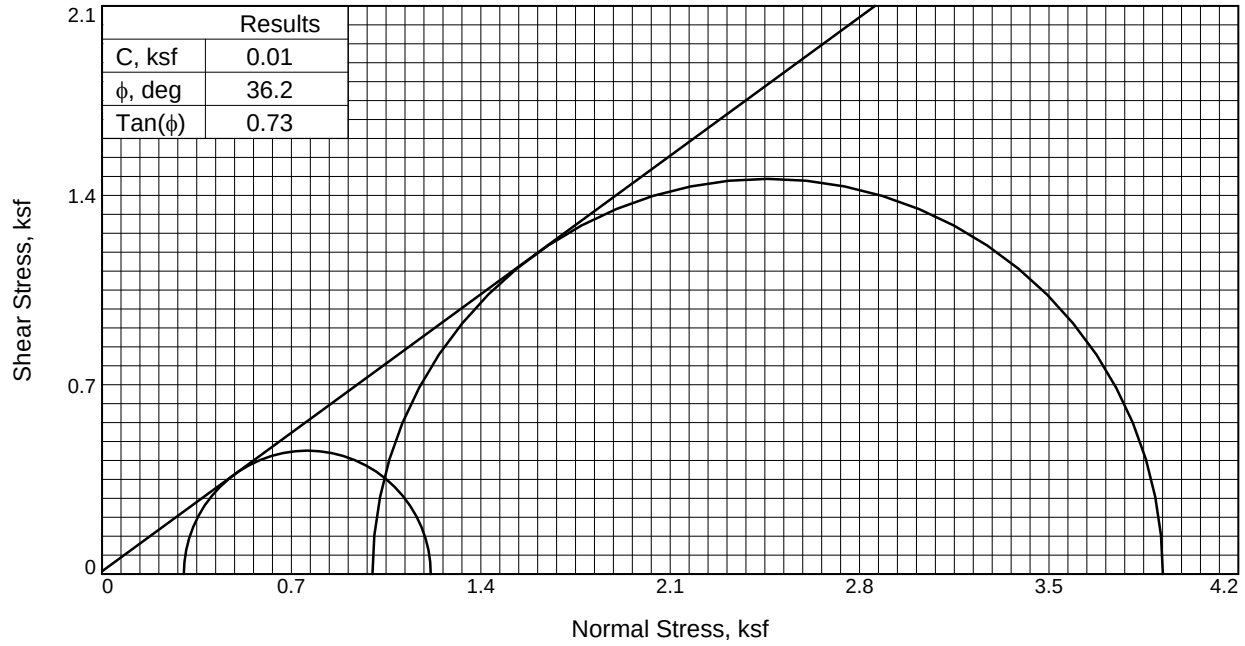
Billings, MT

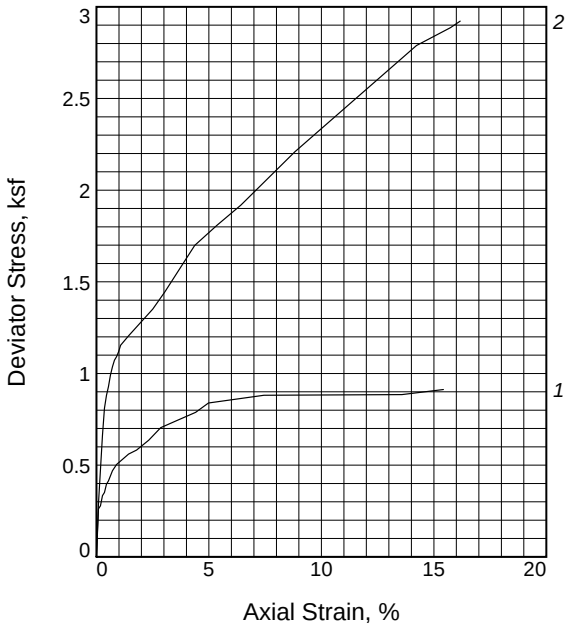
Client:

Project: Clearview Landfill

Project No.: 114-571155

Figure 61





Sample No.		1	2
Initial	Water Content, %	38.3	38.3
	Dry Density, pcf	63.8	63.8
	Saturation, %	63.8	63.8
	Void Ratio	1.5920	1.5920
	Diameter, in.	1.40	1.40
	Height, in.	2.80	2.80
At Test	Water Content, %	60.1	60.1
	Dry Density, pcf	63.8	63.8
	Saturation, %	100.0	100.0
	Void Ratio	1.5920	1.5920
	Diameter, in.	1.40	1.40
	Height, in.	2.80	2.80
Strain rate, in./min.		0.00	0.00
Back Pressure, psi		60.00	60.00
Cell Pressure, psi		62.10	66.94
Fail. Stress, ksf		0.91	2.92
Ult. Stress, ksf			
σ_1 Failure, ksf		1.22	3.92
σ_3 Failure, ksf		0.30	1.00

Type of Test:
Consolidated Drained

Sample Type: Remolded

Description: Elastic SILT

LL= 60 **PL=** 41 **PI=** 19

Assumed Specific Gravity= 2.65

Remarks: A strain rate of 0.0003 in/min was used.

Figure 62

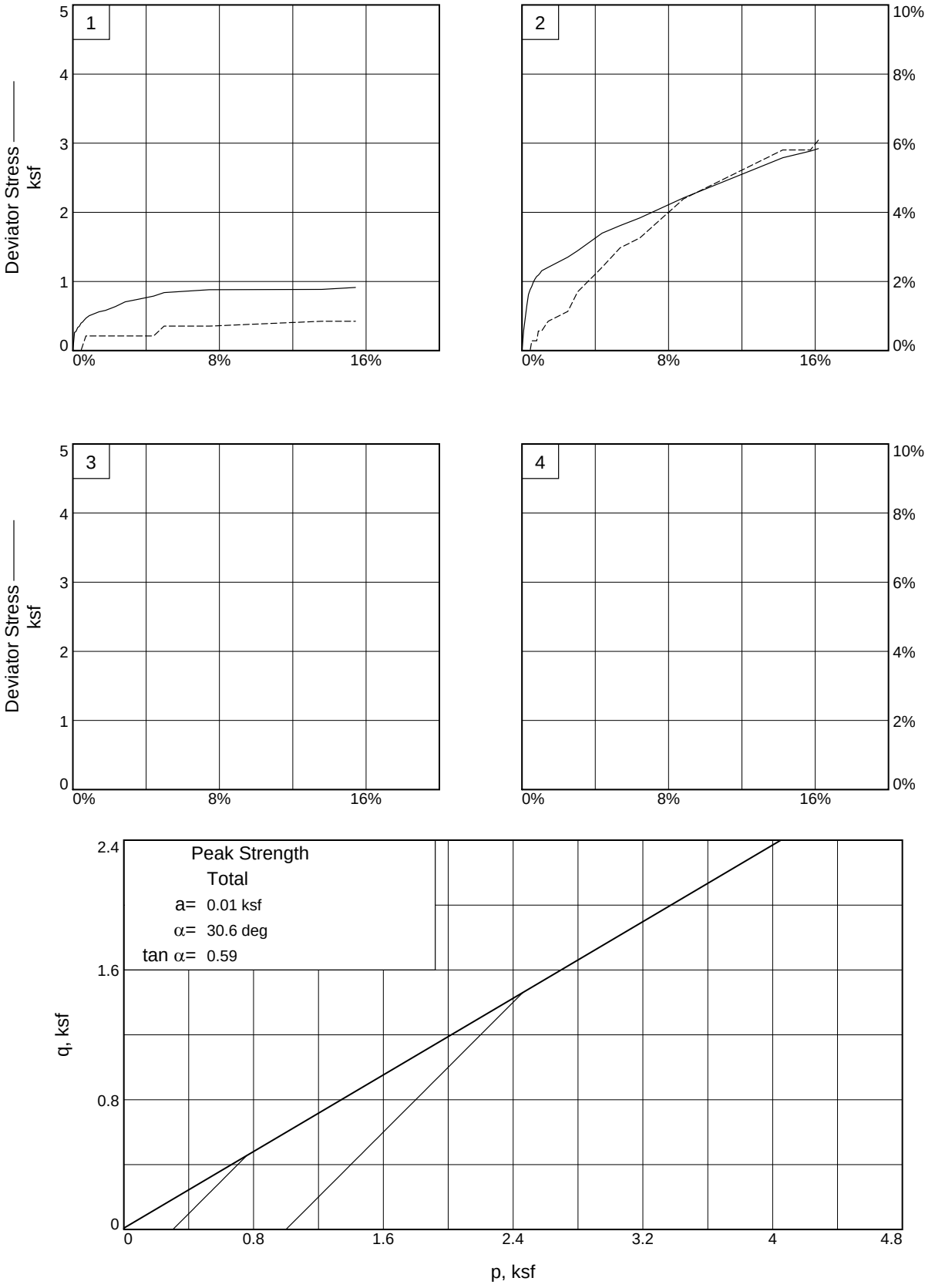
Client:

Project: Clearview Landfill

Source of Sample: Pedricktown Lower **Depth:** Bulk

Proj. No.: 114-571155 **Date Sampled:** 4-18-17

TRIAXIAL SHEAR TEST REPORT
Tetra Tech
Billings, MT



Client:

Project: Clearview Landfill

Source of Sample: Pedricktown Lower **Depth:** Bulk

Project No.: 114-571155 **Figure** 63

Tetra Tech

PERMEABILITY TEST REPORT

TEST DATA:
Specimen Height (cm): 7.39
Specimen Diameter (cm): 7.04
Dry Unit Weight (pcf): 66.2
Moisture Before Test (%): 34.9
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0

Sat. Pressure (psi): 60.0
Diff. Head (psi): 2.1

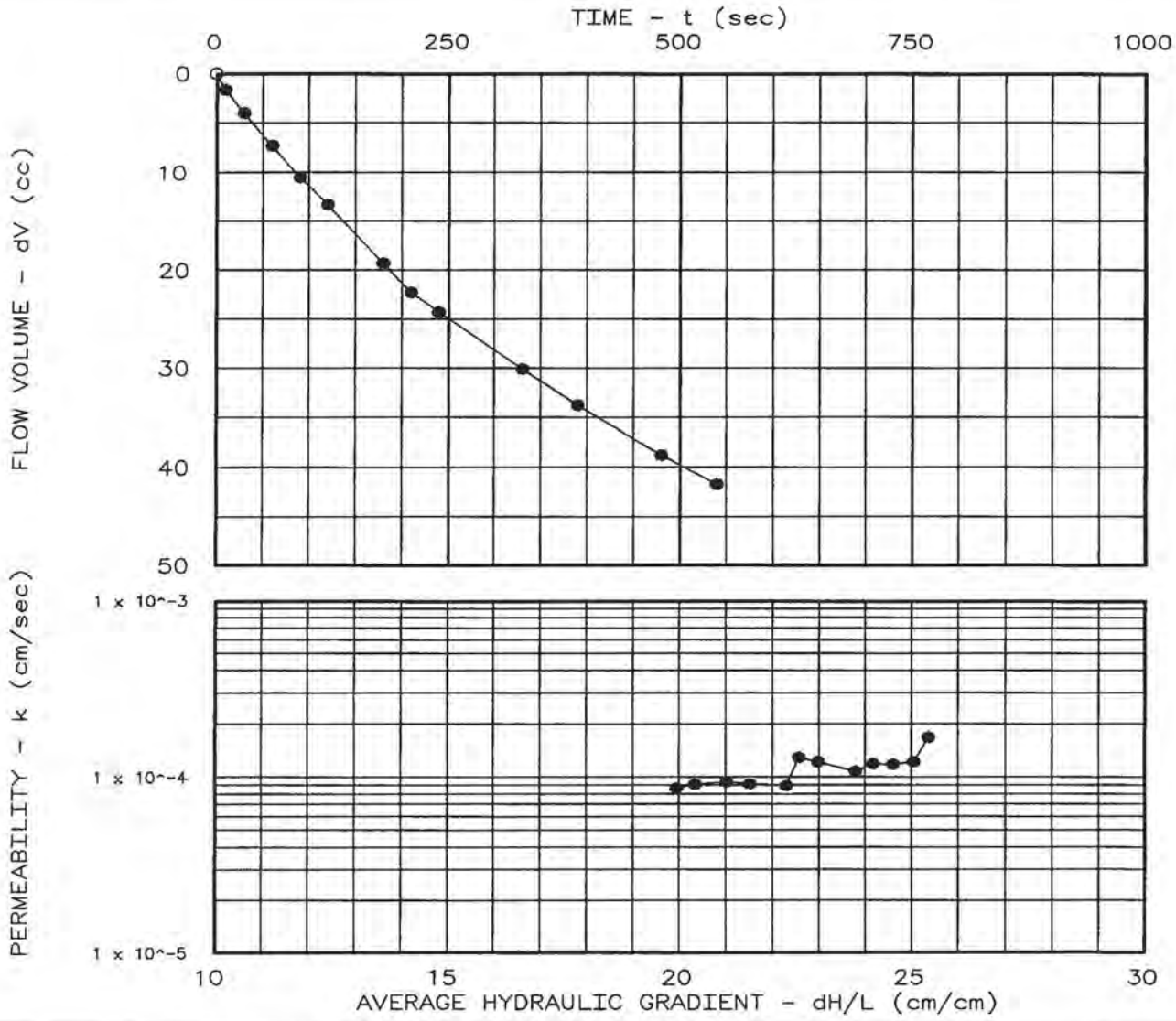
Perm. (cm/sec): 9.04 x 10^-5

SAMPLE DATA:
Sample Identification: Pedricktown Lower

Visual Description: Elastic SILT

Remarks:

Maximum Dry Density (pcf): 77.9
Optimum Moisture Content (%): 34.9
ASTM(D698)
Percent Compaction: 85.0%
Permeameter type: Flexwall
Sample type: Remolded



Project: Clearview Landfill
Location:
Date: 3-27-17

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-571155
File No.: 595
Lab No.:
Tested by: OT
Checked by: TG
Test: FH - Falling head C

Figure 64

PERMEABILITY TEST DATA

PROJECT DATA

Project Name:	Clearview Landfill
File No.:	595
Project Location:	
Project No.:	114-571155
Sample Identification:	Pedricktown Lower
Lab No.:	
Description:	Elastic SILT
Sample Type:	Remolded
Max. Dry Dens.:	77.9
Method (D1557/D698):	D698
Opt. Water Content:	34.9
Date:	3-27-17
Remarks:	
Permeameter Type:	Flexwall
Tested by:	OT
Checked by:	TG
Test type:	FH - Falling head C

PERMEABILITY TEST SPECIMEN DATA

	Before test:			After test:		
Diameter:	1	2		1	2	
Top:	2.770 in	in		in	in	
Middle:	in	in		in	in	
Bottom:	in	in		in	in	
Average:	2.77 in	7.04 cm		0.00 in	0.00 cm	
Length:	1	2	3	1	2	3
	2.910 in	in	in	in	in	in
Average:	2.91 in	7.39 cm		0.00 in	0.00 cm	

Moisture, Density and Sample Parameters:

Specific Gravity:	2.65		
Wet Wt. & Tare:	411.18		0.00
Dry Wt. & Tare:	304.80		0.00
Tare Wt.:	0.00		0.00
Moisture Content:	34.9 %		0.0 %
Dry Unit Weight:	66.2 pcf	85.0 % of max	0.0 pcf
Porosity:	0.5998		0.0000
Saturation:	61.7 %		0.0 %

Figure 65

FALLING HEAD PERMEABILITY TEST CONDITIONS DATA

Cell No.: 2 Panel No.: 3 Positions: 1

Run Number:	1	2
Cell Pressure:	65.0 psi	0.0 psi
Inflow Saturation Pressure:	60.0 psi	0.0 psi
Inflow Buret Area:	1.0000 cm²	1.0000 cm²
Outflow Buret Area:	1.0000 cm²	1.0000 cm²
Test Temperature:	20.0 °C	0.0 °C
Outflow Saturation Pressure:	58.0 psi	0.0 psi

PERMEABILITY TEST READINGS DATA

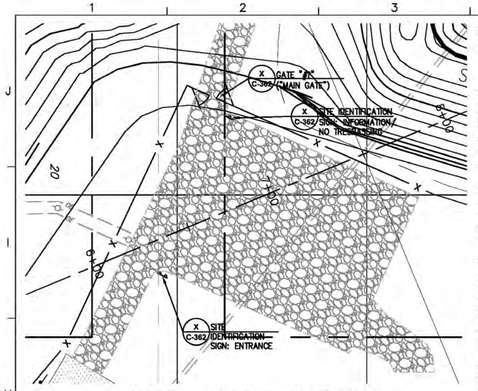
CASE D X S	DATE	TIME (24 hr)	ELAPSED TIME sec	INFLOW LEVEL cm	OUTFLOW LEVEL cm	OUTFLOW/ INFLOW RATIO	PERM. K cm/sec	PERM./ RUNNING 4 AVE.
S X	3/23/17	17:45:00	0	0.90	49.4	0.00	0.00E 00	0.00
	3/23/17	17:45:10	10	2.30	47.5	1.36	1.67E-04	0.00
	3/23/17	17:45:30	20	4.70	45.2	0.96	1.22E-04	0.00
	3/23/17	17:46:00	30	8.00	41.9	1.00	1.18E-04	0.00
	3/23/17	17:46:30	30	11.20	38.7	1.00	1.18E-04	0.90
	3/23/17	17:47:00	30	14.00	35.9	1.00	1.07E-04	0.92
	3/23/17	17:48:00	60	20.00	29.9	1.00	1.22E-04	1.05
	3/23/17	17:48:30	30	23.00	26.9	1.00	1.29E-04	1.08
	3/23/17	17:49:00	30	25.00	24.9	1.00	8.89E-05	0.80
	3/23/17	17:50:30	90	30.80	19.1	1.00	9.10E-05	0.85
	3/23/17	17:51:30	60	34.50	15.4	1.00	9.37E-05	0.93
	3/23/17	17:53:00	90	39.50	10.4	1.00	9.07E-05	1.00
	3/23/17	17:54:00	60	42.50	7.5	0.97	8.61E-05	0.95

Average differential head = 2.0 psi, 142.1 cm H2O
Gradient = 1.994E 01 Total vol = 4.18E 01 cc Test duration = 540 sec
Permeability, K20.0° = 9.037E-05 cm/sec, K20° = 9.037E-05 cm/sec
Permeability values are incremental

Figure 66

APPENDIX E: SLOPE STABILITY CRITICAL SECTIONS AND ANALYSIS

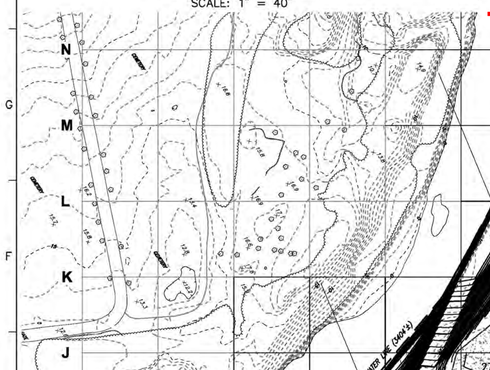
SLOPE STABILITY CRITICAL CROSS SECTIONS

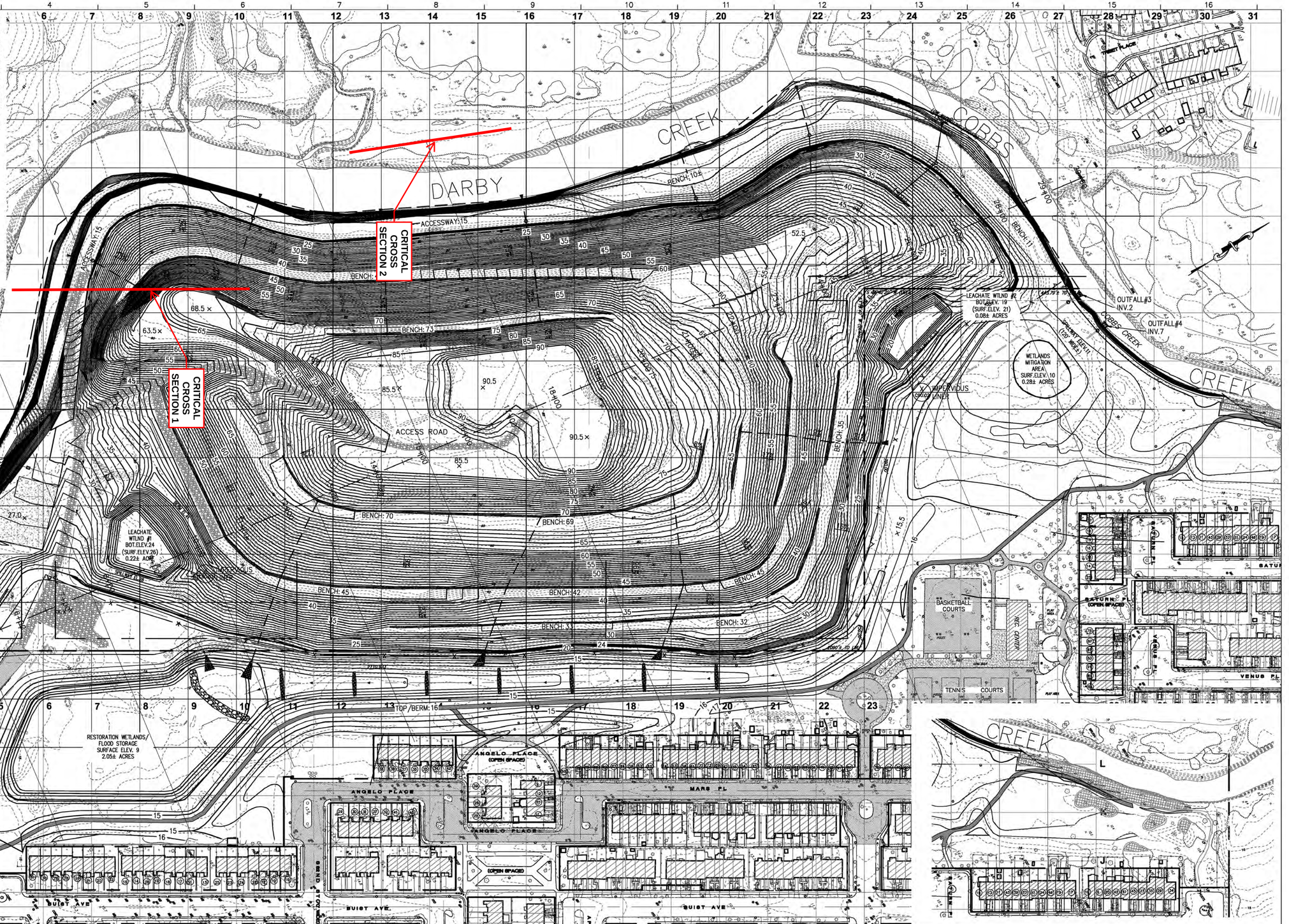


INSET: LANDFILL ENTRANCE

0 40 80

SCALE: 1" = 40'





0 100 200

SCALE: 1" = 100'

NOTES:

1) REFER TO CREEK RESTORATION SHEET SET (C15.70–C15.75) FOR ENLARGED GRADING PLANS AROUND STEEP SLOPES.

TETRA TECH

www.tetratech.com

661 ANDERSEN DRIVE – FOSTER PLAZA 7
PITTSBURGH, PA 15220
T: (412) 921-7090 | F: (412) 921-4040

DRAFT

MARK	DATE	DESCRIPTION	BY

CLEARVIEW LANDFILL
LOWER DARBY, PENNSYLVANIA

FINAL GRADING PLAN

DATE:	–DRAFT–
PROJECT NO.:	112G07477
DESIGNED BY:	ARB
DRAWN BY:	BH
CHECKED BY:	CSG
SHEET: 1 OF X	

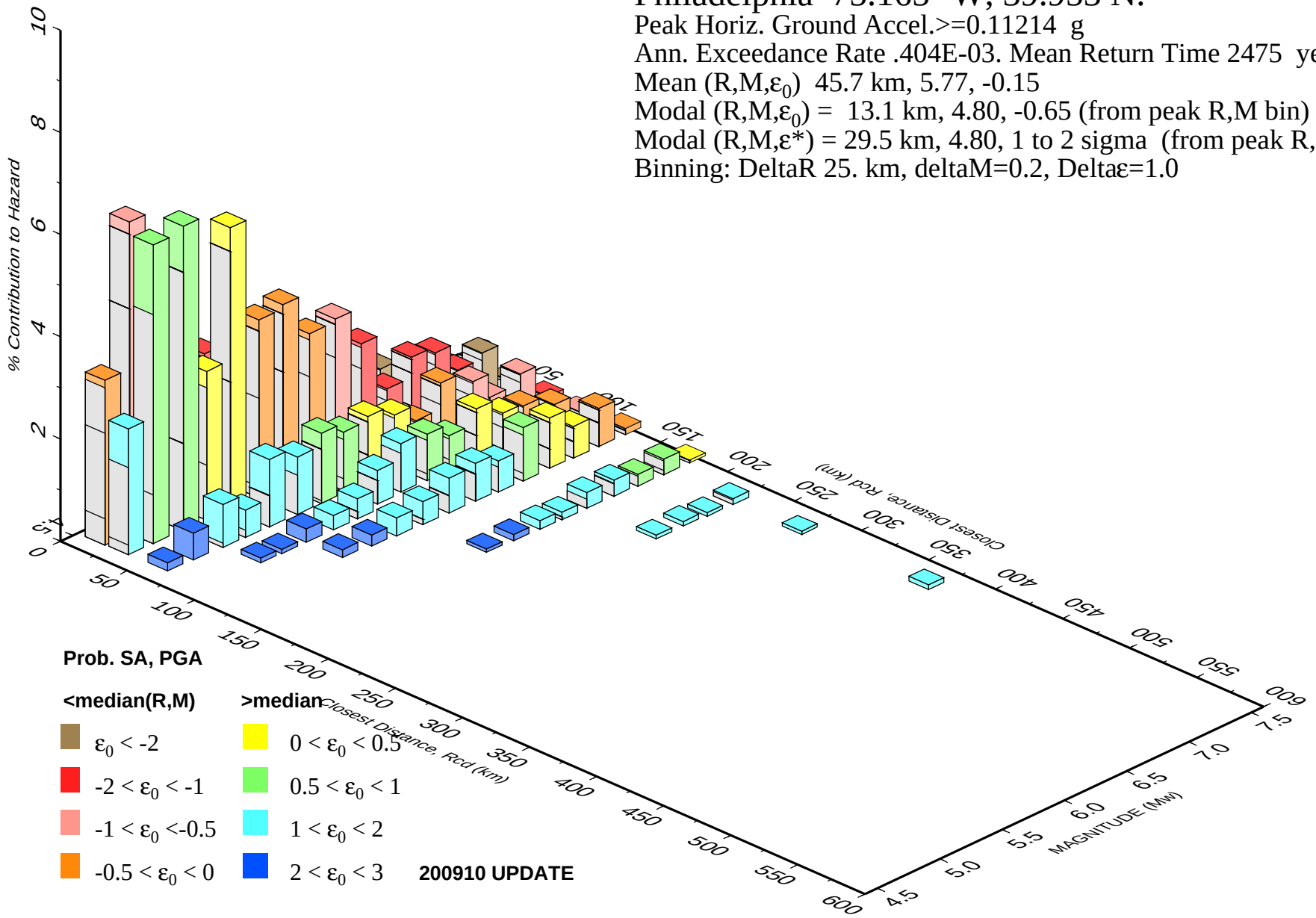
COPYRIGHT TETRA TECH INC.

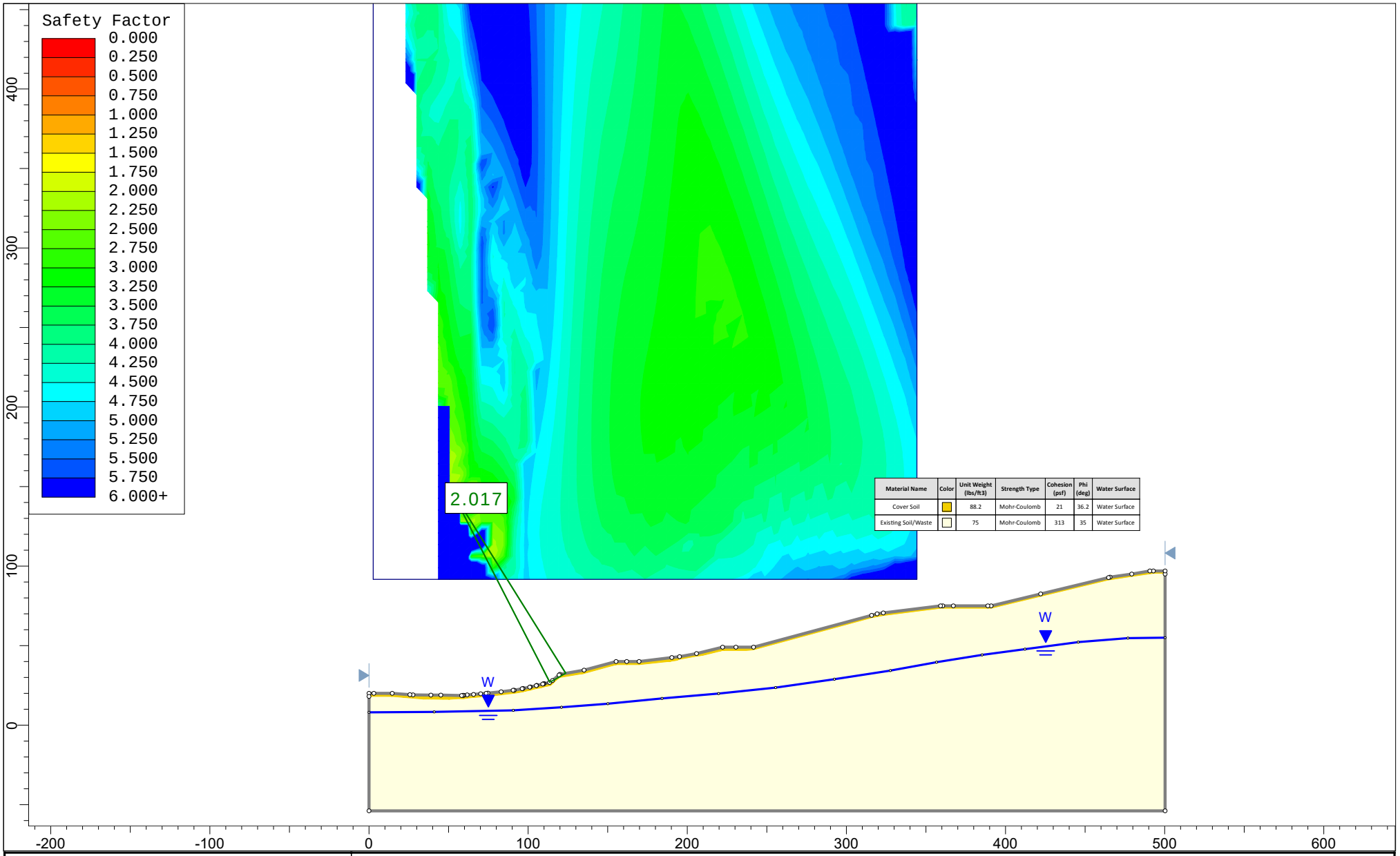
C15.11

S:\03-Projects\Federal\EPA R3 RAC Assignments\Lower Darby\112G07477 - LDCA OUT RD\Drawings\Sheets\112G07477-C1511-GRAD-FINL.dwg NWK CASEY.GRABOWSK
9/1/2016 10:18:24 AM

PSH Deaggregation on NEHRP BC rock
Philadelphia 75.165º W, 39.953 N.

Peak Horiz. Ground Accel.>=0.11214 g
Ann. Exceedance Rate .404E-03. Mean Return Time 2475 years
Mean (R,M,ε_0) 45.7 km, 5.77, -0.15
Modal (R,M,ε_0) = 13.1 km, 4.80, -0.65 (from peak R,M bin)
Modal (R,M,ε*) = 29.5 km, 4.80, 1 to 2 sigma (from peak R,M,ε bin)
Binning: DeltaR 25. km, deltaM=0.2, Deltaε=1.0

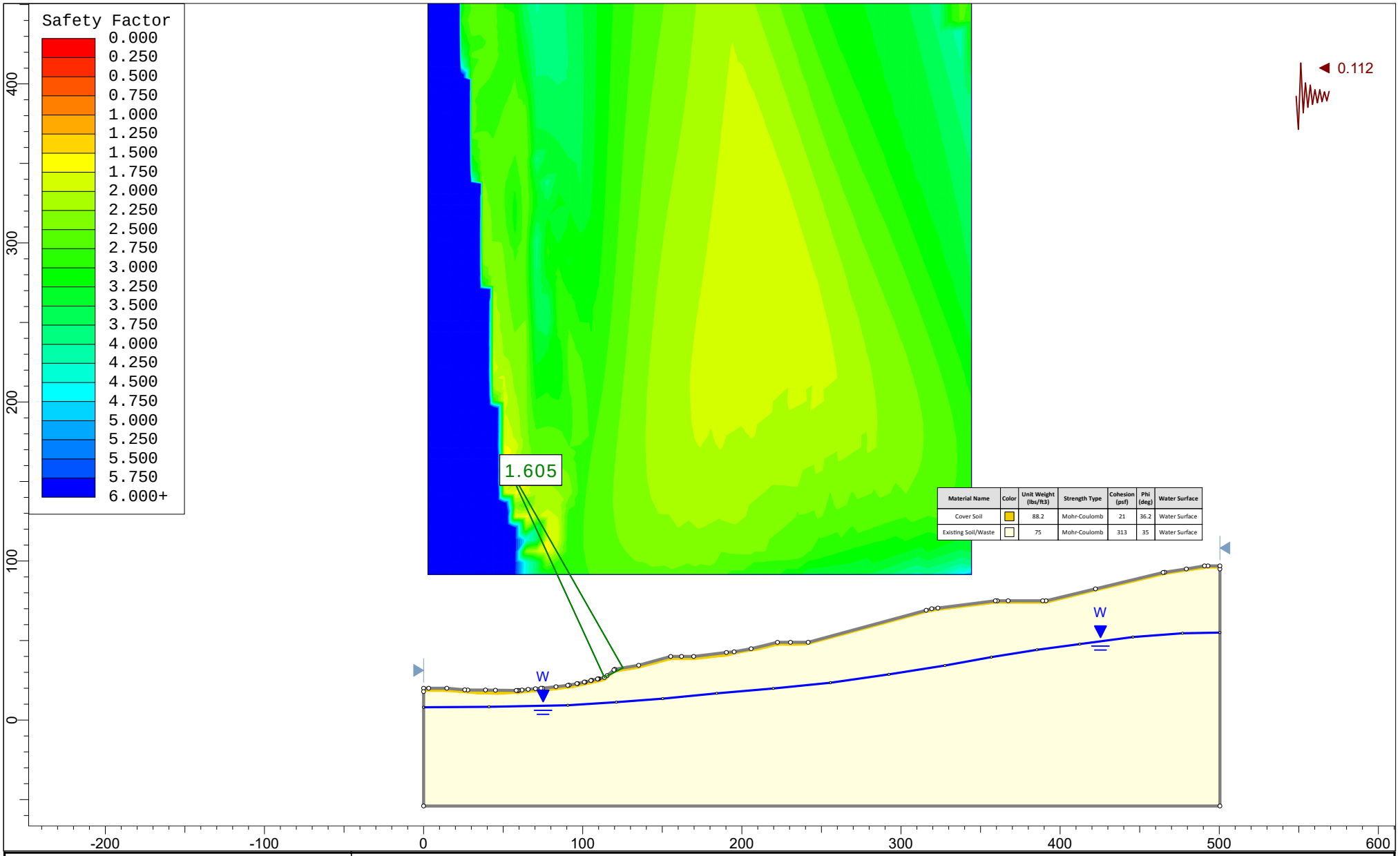




Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
Cover Soil		88.2	Mohr-Coulomb	21	36.2	Water Surface
Existing Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface

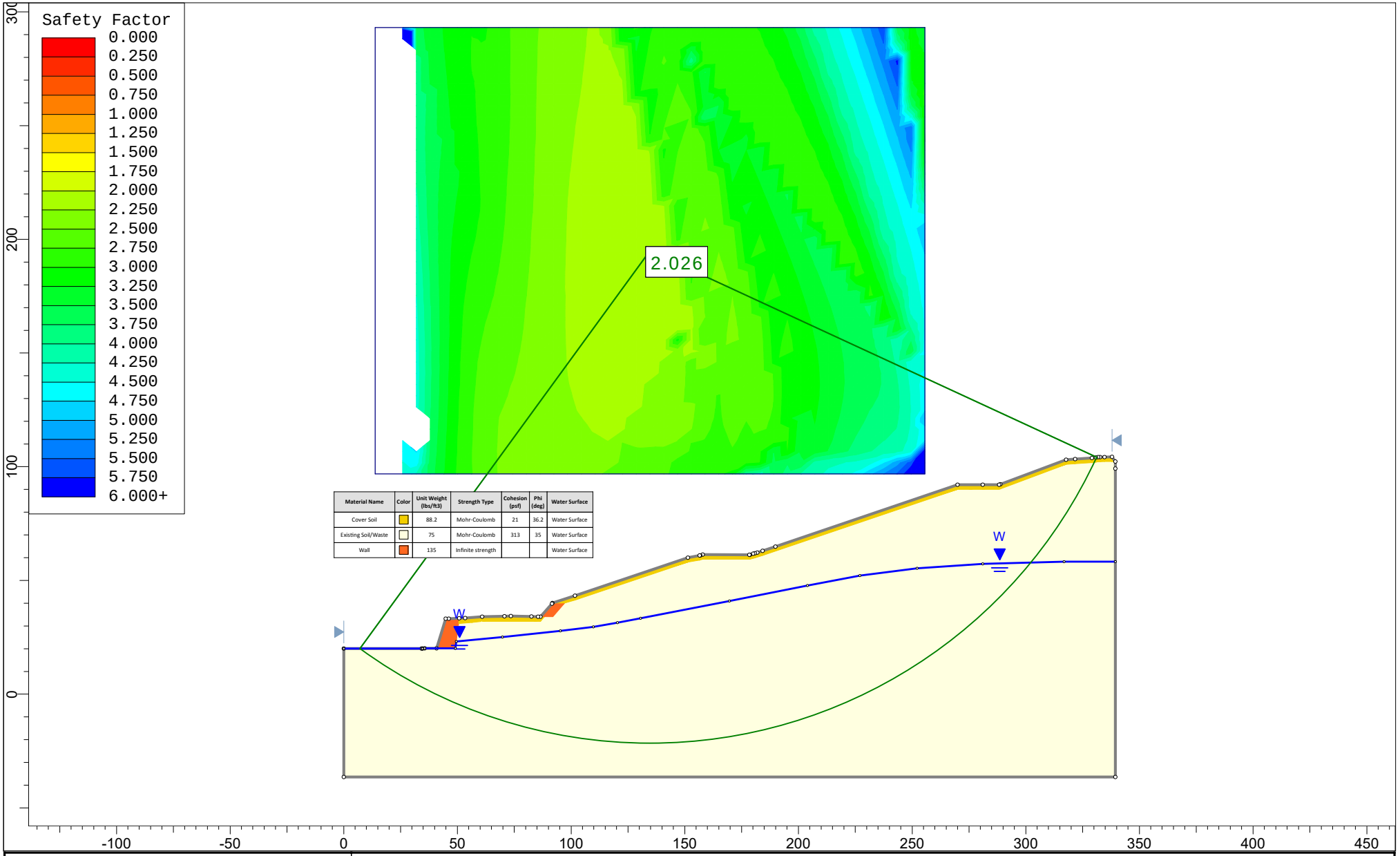
SLIDEINTERPRET 7.013

Project	Clearview Landfill - OU1		
Analysis Description	Critical Section 1		
Drawn By		Scale 1:1000	Company Tetra Tech
Date	September 2017		Comments Static, Circular



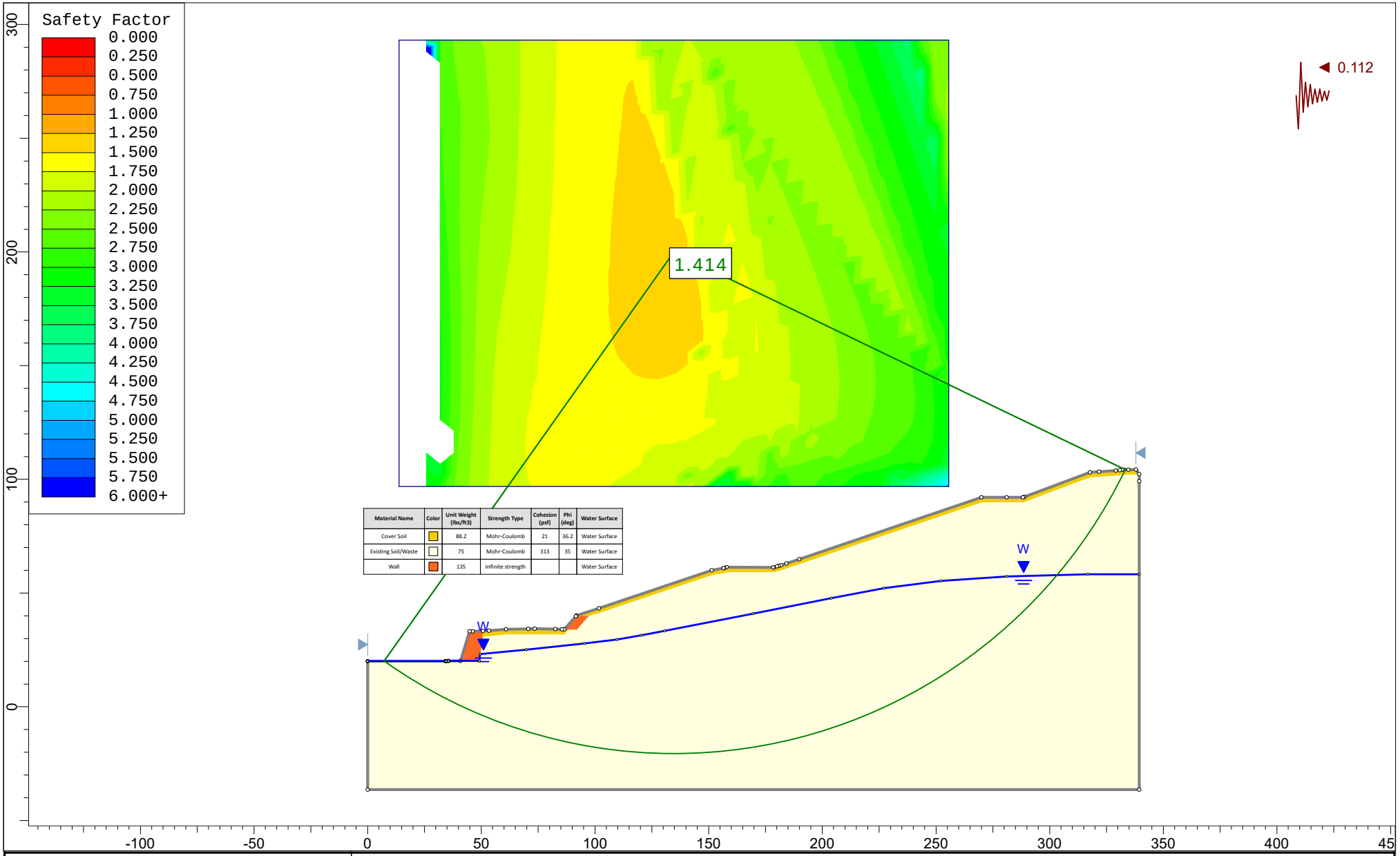
rocscience	Project: Clearview Landfill - OU1		
	Analysis Description: Critical Section 1		
	Drawn By	Scale: 1:1000	Company: Tetra Tech
	Date: September 2017		Comments: Pseudo-Static, Circular

SLIDEINTERPRET 7.013



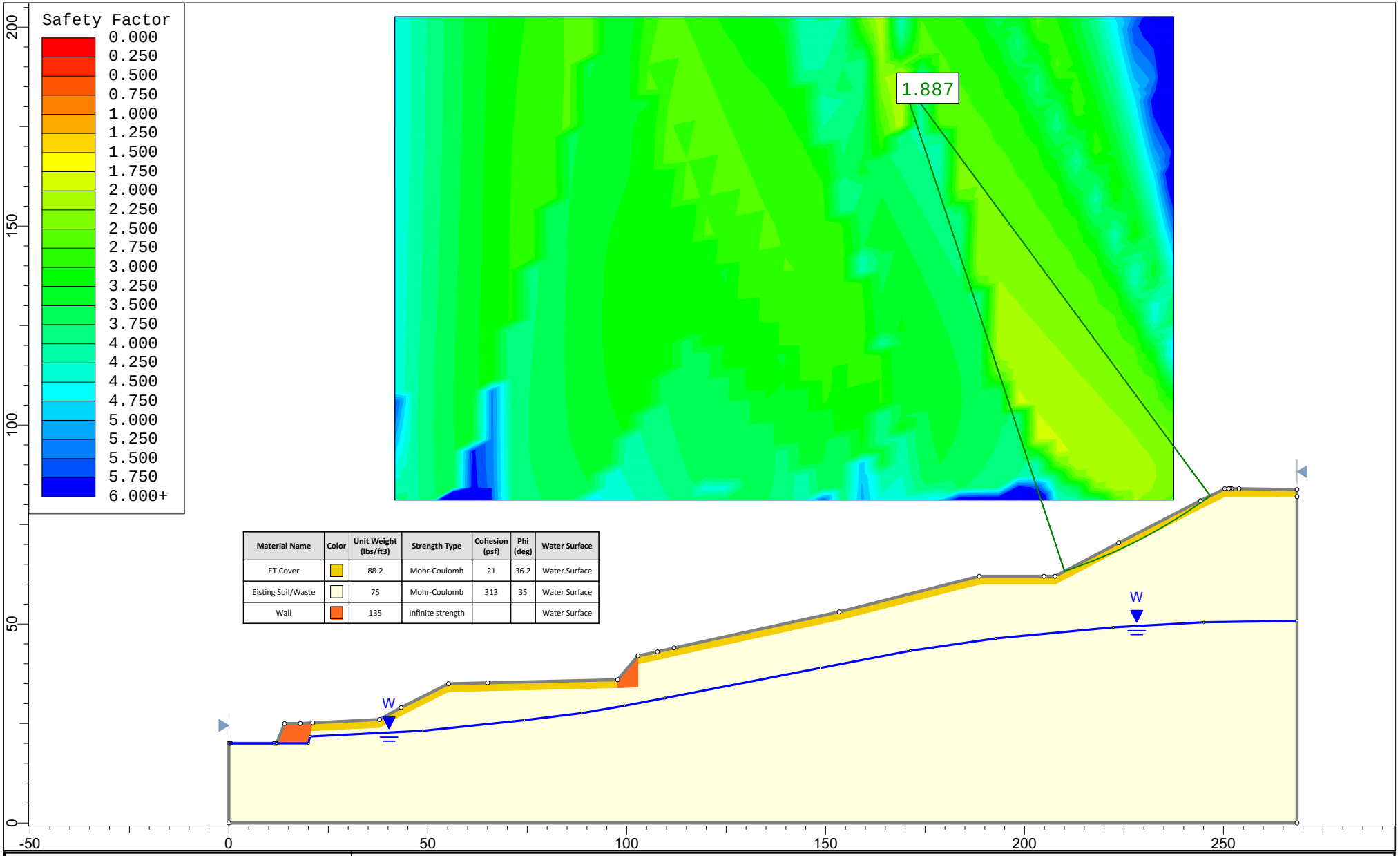
rocscience	Project: Clearview Landfill OU1		
	Analysis Description: Critical Section 2		
	Drawn By	Scale: 1:700	Company: Tetra Tech
	Date: September 2017		Comments: Static, Circular

SLIDEINTERPRET 7.013



rocscience	Project: Clearview Landfill OU1		
	Analysis Description: Critical Section 2		
	Drawn By	Scale: 1:700	Company: Tetra Tech
	Date: September 2017		Comments: Psuedo-Static, Circular

SLIDEINTERPRET 7.013

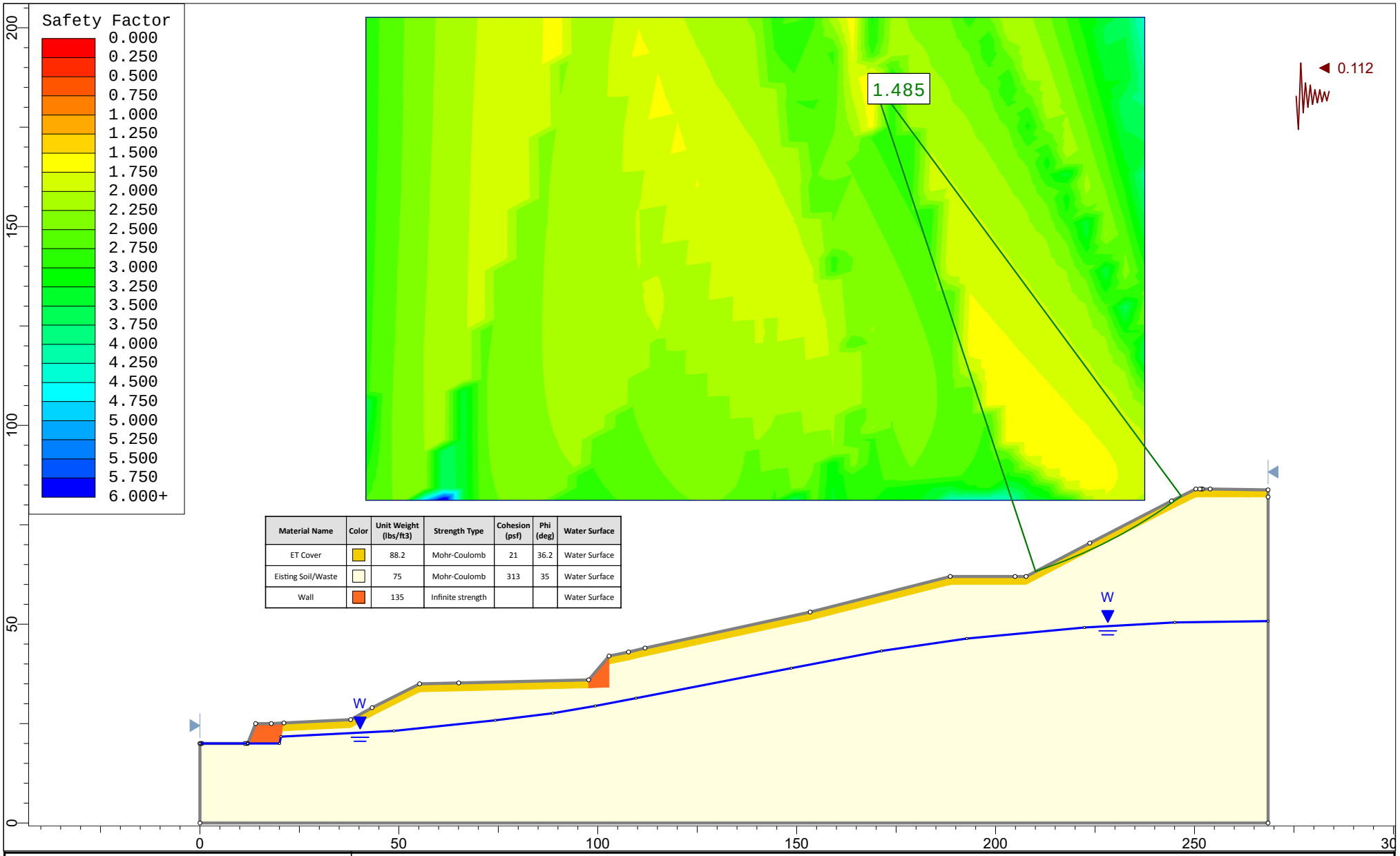


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface
Wall		135	Infinite strength			Water Surface

rocscience

SLIDEINTERPRET 7.013

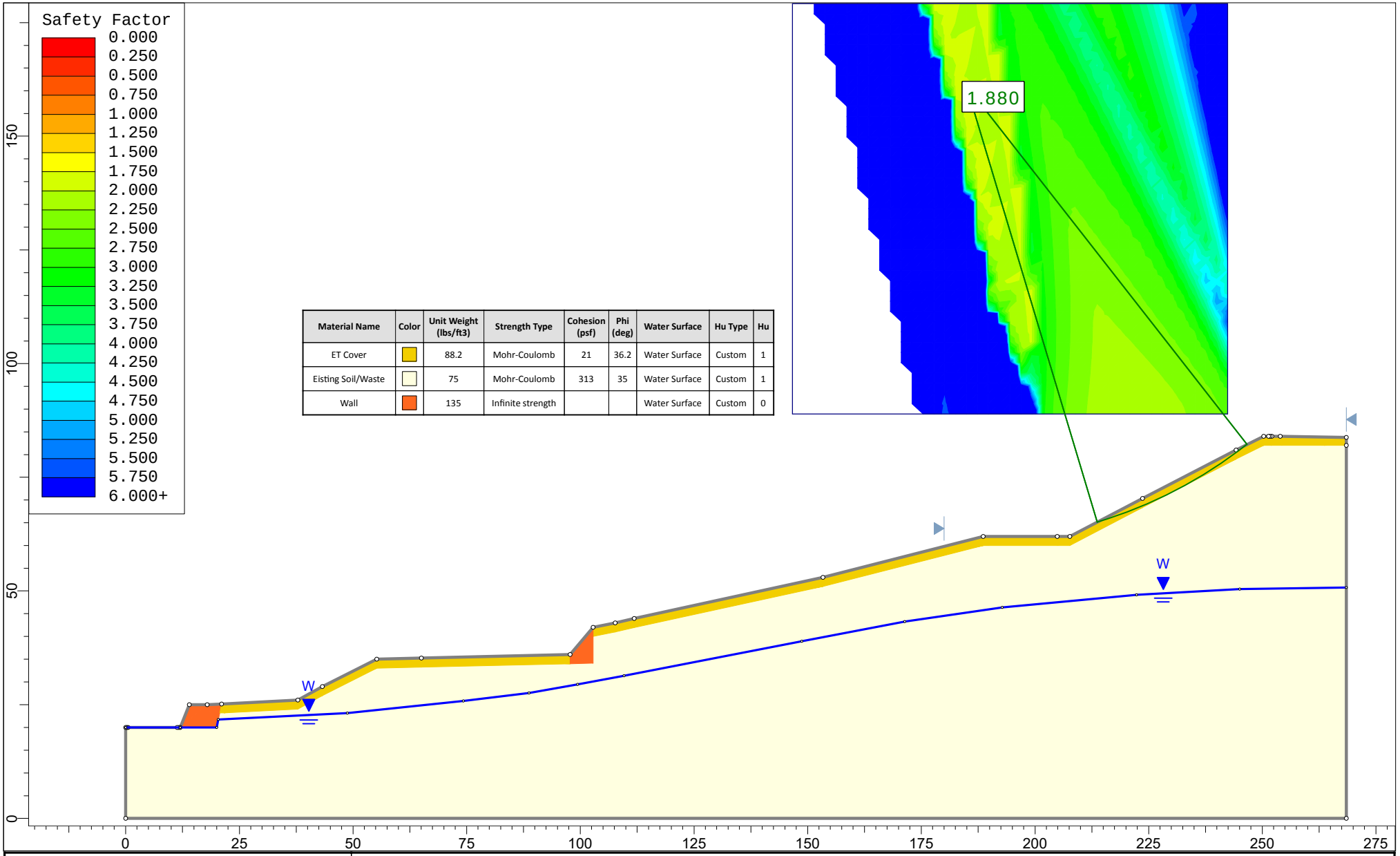
Project	Clearview Landfill OU1		
Analysis Description	Critical Section 3, Overall Slope		
Drawn By		*Scale* 1:400	*Company* Tetra Tech
Date	September 2017		*Comments* Static, Circular Analysis



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface
Wall		135	Infinite strength			Water Surface

Project	Clearview Landfill OU1		
Analysis Description	Critical Section 3, Overall Slope		
Drawn By		*Scale* 1:400	*Company* Tetra Tech
Date	September 2017		*Comments* Pseudo-Static, Circular Analysis

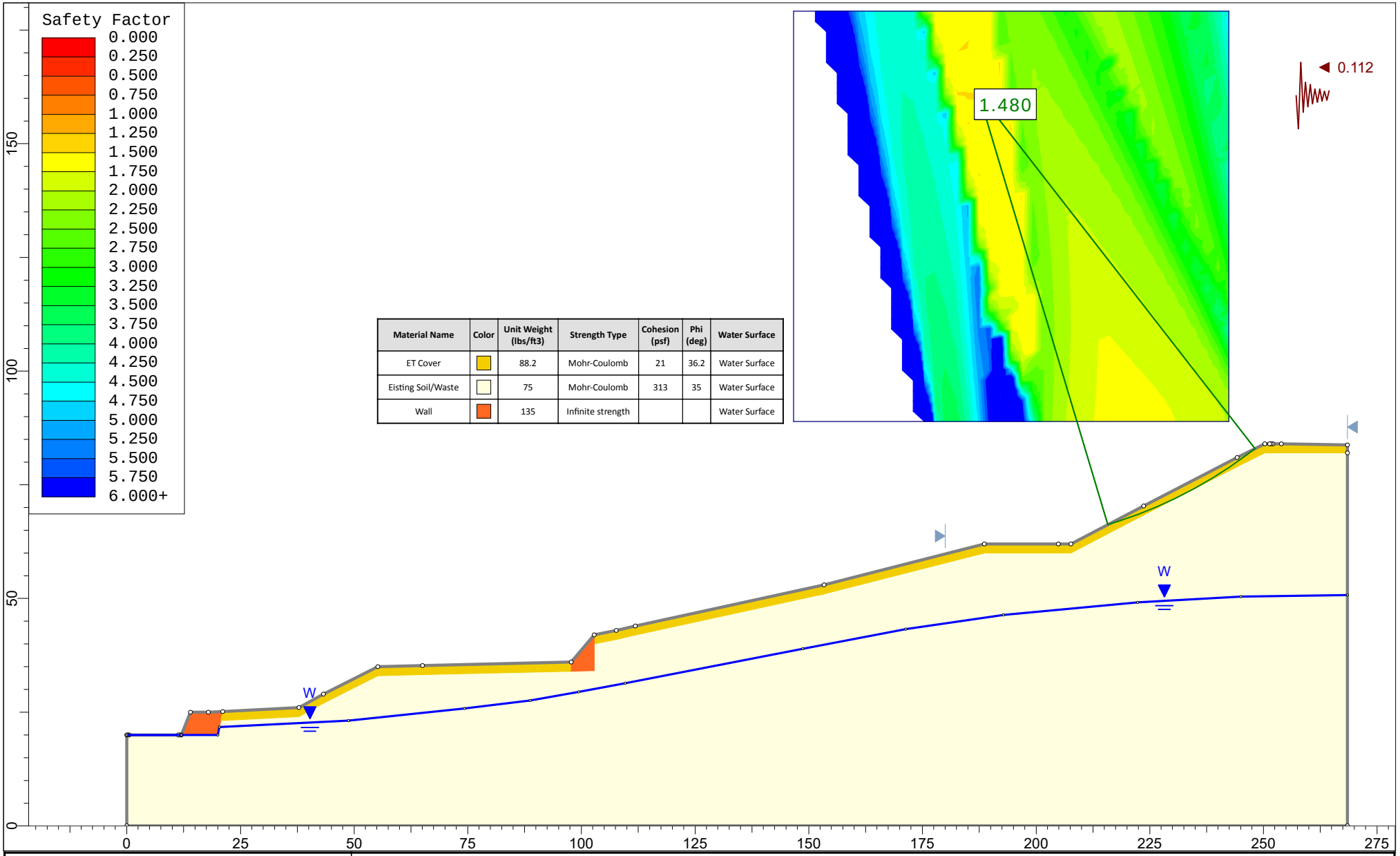
SLIDEINTERPRET 7.013



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface	Custom	1
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface	Custom	1
Wall		135	Infinite strength			Water Surface	Custom	0

rocscience	Project: Clearview Landfill OU1		
	Analysis Description: Critical Section 3, Upper Steep Slope		
	Drawn By	Scale: 1:350	Company: Tetra Tech
	Date: September 2017		Comments: Static, Circular Analysis

SLIDEINTERPRET 7.013

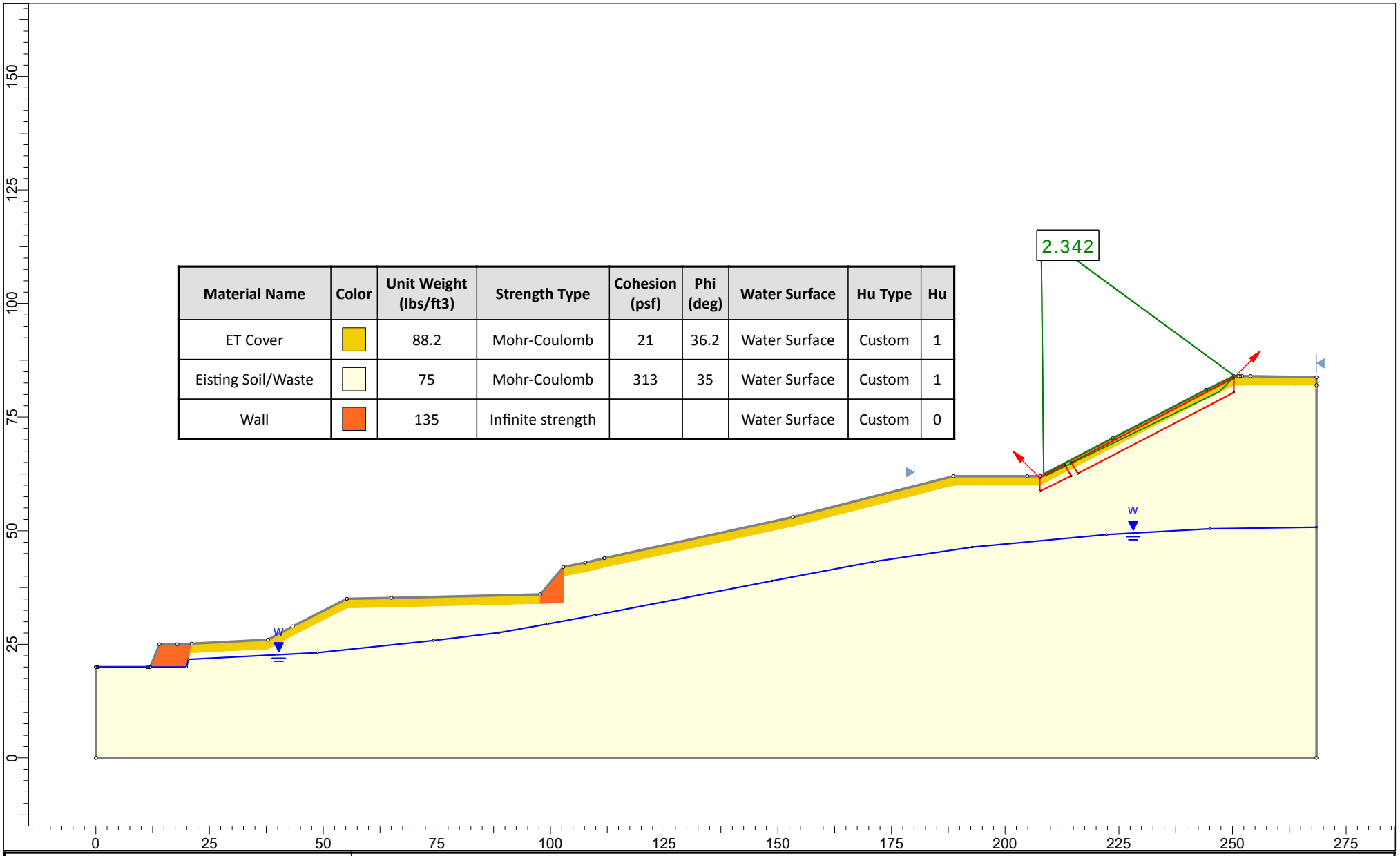


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface
Wall		135	Infinite strength			Water Surface

Project	Clearview Landfill OU1		
Analysis Description	Critical Section 3, Upper Steep Slope		
Drawn By		*Scale* 1:350	*Company* Tetra Tech
Date	September 2017		*Comments* Pseudo-Static, Circular Analysis

SLIDEINTERPRET 7.013

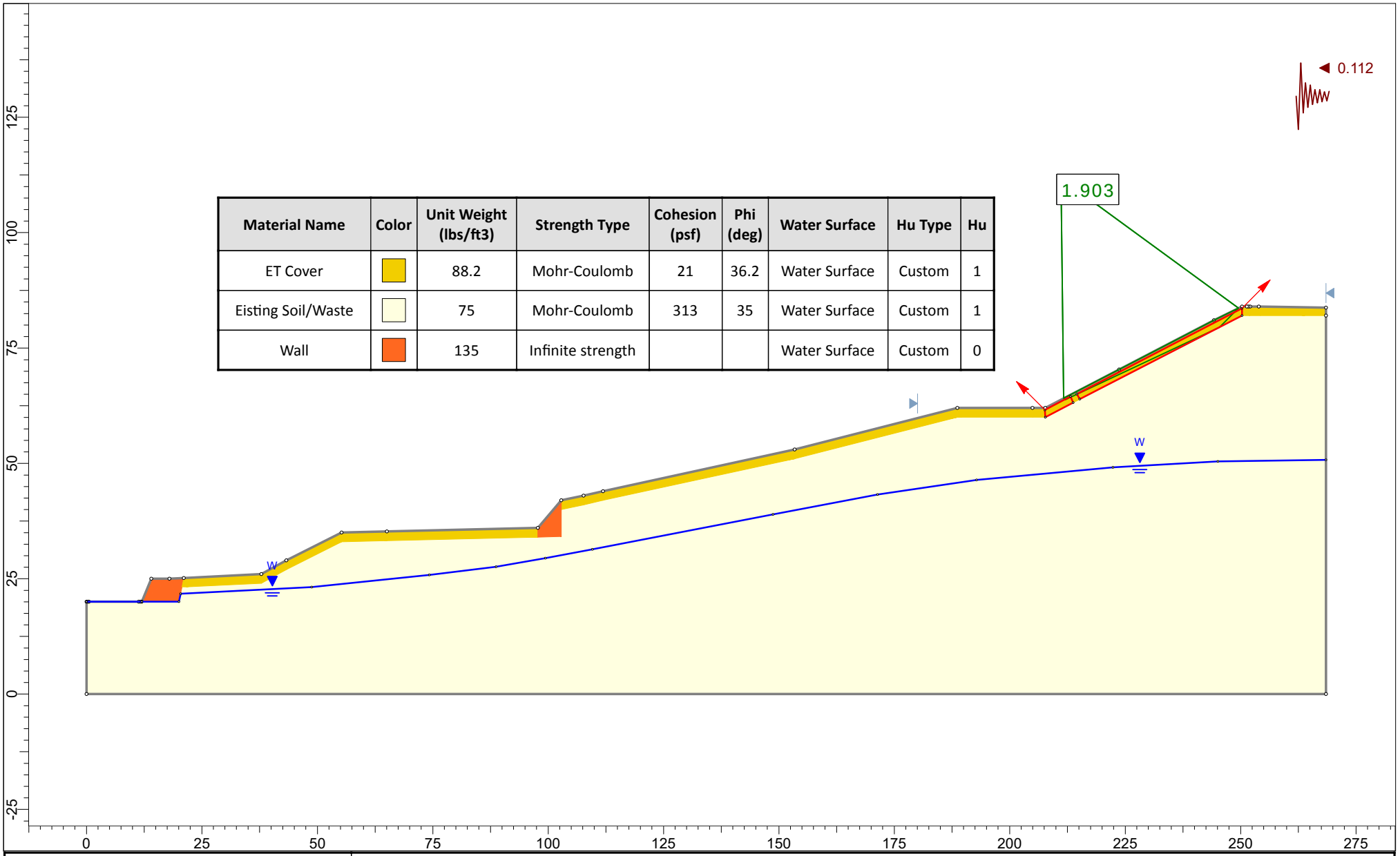
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface	Custom	1
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface	Custom	1
Wall		135	Infinite strength			Water Surface	Custom	0



Project	Clearview Landfill OU1		
Analysis Description	Critical Section 3, Upper Steep Slope		
Drawn By		Scale 1:350	Company Tetra Tech
Date	September 2017		Comments Static, Sliding Block Analysis

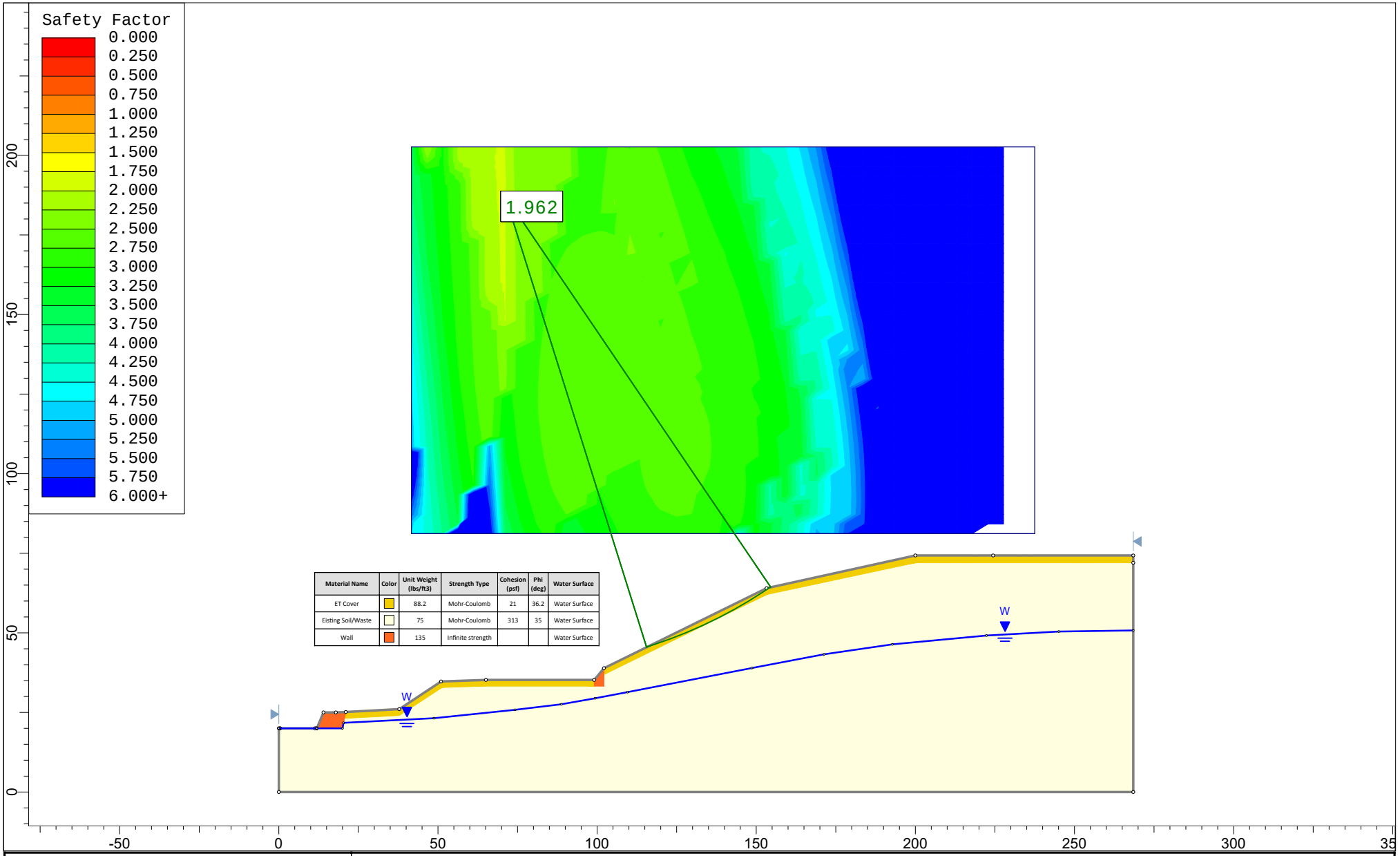
SLIDEINTERPRET 7.013

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface	Custom	1
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface	Custom	1
Wall		135	Infinite strength			Water Surface	Custom	0



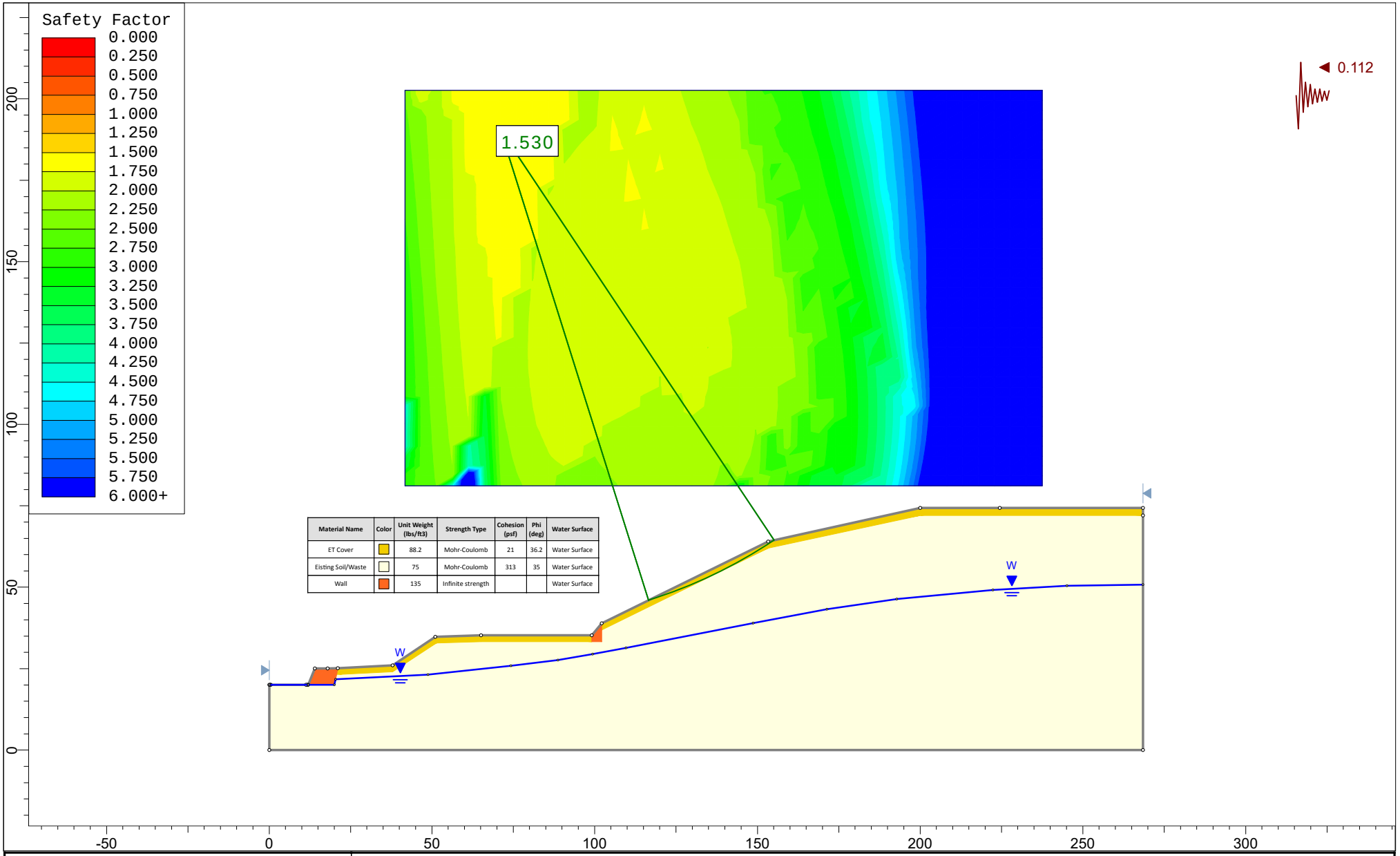
Project	Clearview Landfill OU1		
Analysis Description	Critical Section 3, Upper Steep Slope		
Drawn By		Scale 1:345	Company Tetra Tech
Date	September 2017		Comments Pseudo-Static, Sliding Block Analysis

SLIDEINTERPRET 7.013



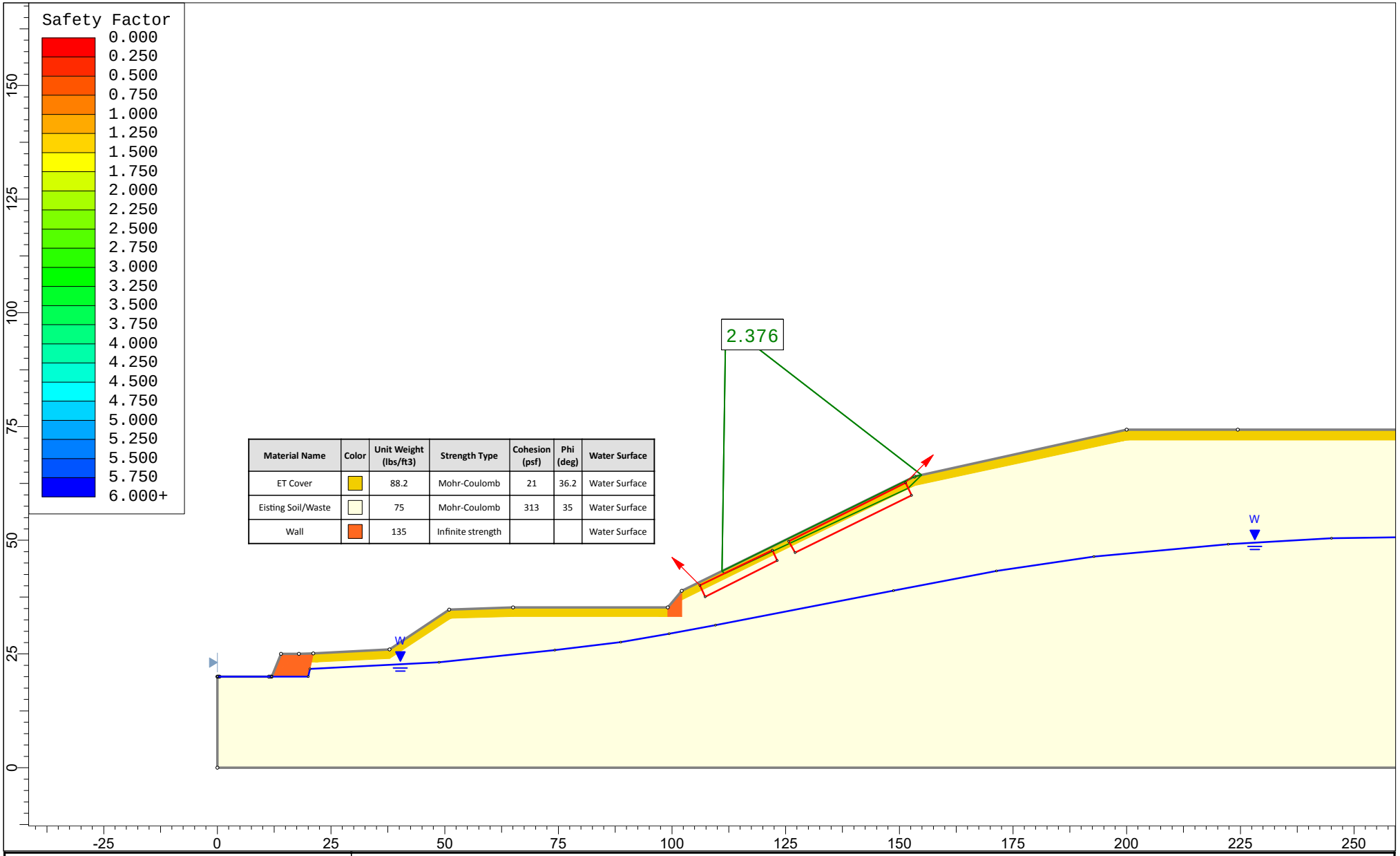
Project	Clearview Landfill OU1		
Analysis Description	Critical Section 4		
Drawn By		Scale 1:500	Company Tetra Tech
Date	September 2017		Comments Static, Circular Analysis

SLIDEINTERPRET 7.013



rocscience	Project: Clearview Landfill OU1		
	Analysis Description: Critical Section 4		
	Drawn By	Scale: 1:489	Company: Tetra Tech
	Date: September 2017		Comments: Pseudo-Static, Circular Analysis

SLIDEINTERPRET 7.013

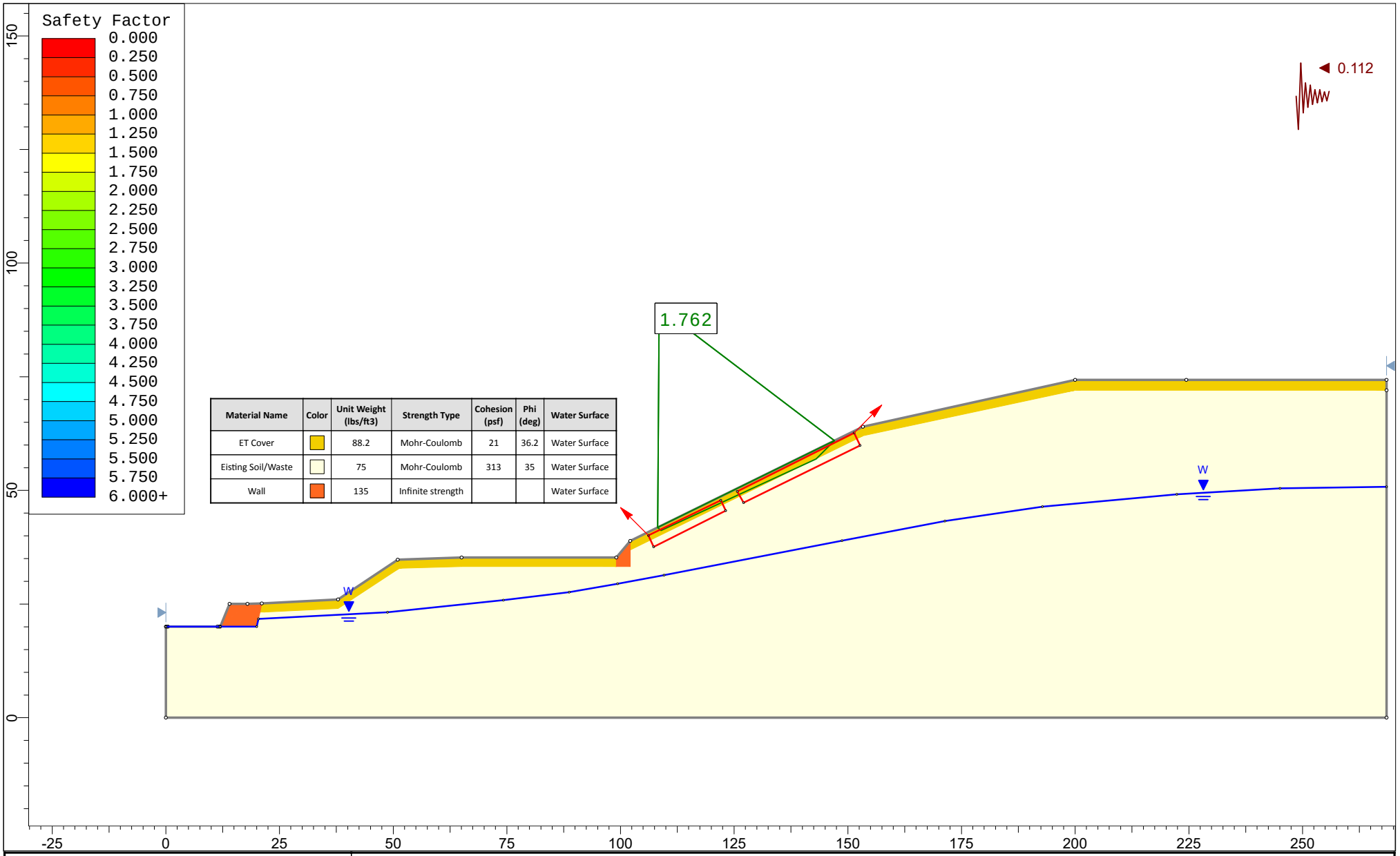


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface
Wall		135	Infinite strength			Water Surface

rocscience

SLIDEINTERPRET 7.013

Project	Clearview Landfill OU1		
Analysis Description	Critical Section 4		
Drawn By		*Scale* 1:350	*Company* Tetra Tech
Date	September 2017		*Comments* Static, Block Analysis



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
ET Cover		88.2	Mohr-Coulomb	21	36.2	Water Surface
Eisting Soil/Waste		75	Mohr-Coulomb	313	35	Water Surface
Wall		135	Infinite strength			Water Surface

Project	Clearview Landfill OU1		
Analysis Description	Critical Section 4		
Drawn By		*Scale* 1:350	*Company* Tetra Tech
Date	September 2017		*Comments* Pseudo-Static, Block Analysis

SLIDEINTERPRET 7.013

APPENDIX F: CRIB WALL DESIGN OUTPUT AND PLAN SHEET

Crib Wall Stability

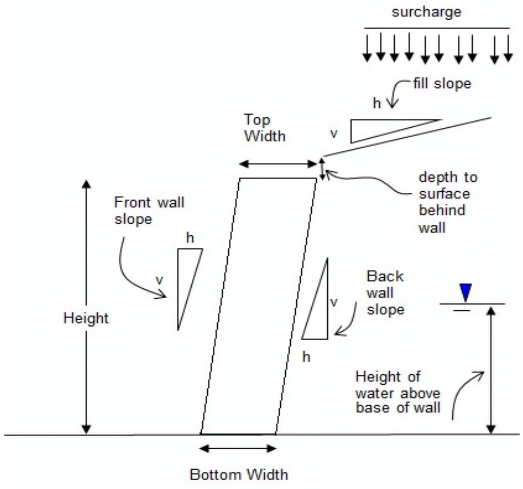
Project:	*Lower Darby Creek - Crib Wall 1*	**County/State:**	
Designer:	*Stratton*	**Checked by:**	
Date:	December, 2017	**Date:**	

Wall/Slope Dimensions

*Note: fill in values that are underlined, calculated results are in **bold red***

Height, H	14	feet		Depth to surface behind wall	0	feet
Bottom Width, Bw	8	feet		Embedment depth at toe of wall	2	feet
Top Width, Tw	8	feet				
Front Wall Slope	6	V:H*	ωf	0.17	radians	
Avg. Back Wall Slope	6	V:H*	ωb	0.17	radians	
*use 10000 for verticle wall						
Fill Slope	3.27	n	β	0.30	radians	
Surcharge	0	psf				
(for example: buildings or traffic)						

Soil Type	Angle of Internal Friction (Deg.)
Clean Sand	35
Silty Sand	30
Sandy Silt	25
Silt	20



Wall Properties

Description	Crib Infill		
γi	100	pcf	
ϕι	32	degrees	0.56 radians
μ	0.62		

Retained Soil Properties

Description	Existing Soil		
γr	125	pcf	
ϕr	34	degrees	0.59 radians
δ	22.67	degrees	0.40 radians

Height of water above base of wall

H_w 0 feet

Foundation Soil Properties

Description	Existing Soil		
γf	125	pcf	
ϕf	30	degrees	0.52 radians
cf	0	psf	

Earth Pressure Coefficient

Ka 0.23778607

Earth Forces

$P_{sh,\ above\ water}$	2687.90	lb/ft of wall
$P_{sv,\ above\ water}$	1122.53	lb/ft of wall
$P_{sh,\ below\ water\ 1}$	0.00	lb/ft of wall
$P_{sh,\ below\ water\ 2}$	0.00	
$P_{sv,\ below\ water\ 1}$	0.00	lb/ft of wall
$P_{sv,\ below\ water\ 2}$	0.00	
P_{qh}	0.00	lb/ft of wall
P_{qv}	0.00	lb/ft of wall

Water Forces

P_{wh} 0

Weight of Wall

Weight of Wall 11200 lb/ftof wall

Factor of Safety Against Sliding at the Base

FS_{sl} **2.65** *note: FS against sliding should be >1.3 min*

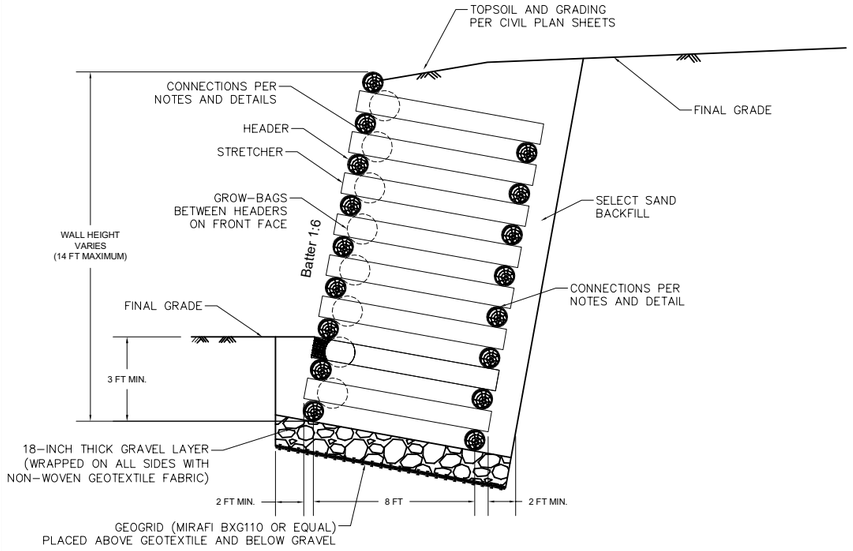
Moments Resisting		Moments Driving	
Weight	44800.00	$M_{sh,\ above\ water}$	12543.51
$M_{sv,\ above\ water}$	8980.27	$M_{sh,\ below\ water}$	0
$M_{sv,\ below\ water\ 1}$	0	$M_{sh,\ below\ water}$	0
$M_{sv,\ below\ water\ 2}$	0	M_{qh}	0
M_{qv}	0	M_{wh}	0

Factor of Safety Against Overturning about Toe

FS_{ot} **4.29** *note: FS against overturning should be >1.5 min*

Factor of Safety Against Bearing Capacity Failure

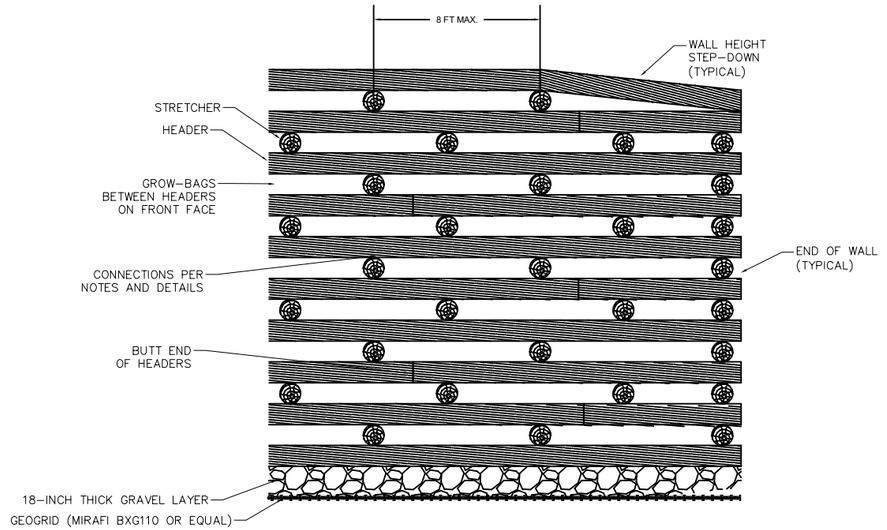
FS_{bc} **>6.00** *note: FS against bearing capacity failure should be >3.0 min*



X
Cxx.xx

SECTION: TIMBER CRIB WALL

NOT TO SCALE



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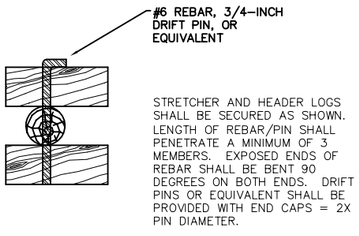
ELEVATION: FACE OF TIMBER CRIB WALL (TYPICAL)

NOT TO SCALE

TIMBER CRIB WALL NOTES

1. HEADERS AND STRETCHERS SHALL CONSIST OF UNTREATED LOGS WITH THE FOLLOWING PROPERTIES:
   - 1.1. DIAMETER: 8 TO 12 INCHES.
   - 1.2. HEADER LENGTH: 16 FT MINIMUM.
   - 1.3. STRETCHER LENGTH: 10 FT MINIMUM
   - 1.4. SPECIES: SOUTHERN PINE, CEDAR, LARCH, DOUGLAS FIR, RED OAK, OR EQUIVALENT APPROVED BY OWNER.
2. TAPER OF HEADER LOGS, IF ANY, SHALL BE ALTERNATED SUCH THAT HEADERS ARE GENERALLY HORIZONTAL THROUGHOUT THE ENTIRE FACE OF THE WALL.
3. STRETCHERS SHALL BE SLOPED SUCH THAT FRONT FACE END OF THE STRETCHER IS 12 AND 18 INCHES HIGHER IN ELEVATION THAN THE BACK END OF THE STRETCHER.
4. CONNECTION SHALL BE MADE AT ALL INTERSECTIONS OF HEADERS AND STRETCHERS, AS DETAILED, ON BOTH THE FRONT FACE AND THE BACK SIDE OF THE CRIB WALL.
5. END OF HEADER LOGS SHALL BE BETWEEN STRETCHER LOCATIONS AND SHALL BUTT TIGHTLY TOGETHER. END OF HEADER LOCATIONS SHALL BE STAGGERED VERTICALLY SUCH THAT NO PAIR OF STRETCHERS HAVE AN END OF HEADER BOTH ABOVE AND BELOW.
6. FOUNDATION EXCAVATION SHALL EXTEND TO FIRM GROUND.
7. FOUNDATION GRAVEL SHALL BE EVENLY GRADED WITH A MAXIMUM SIZE OF 6–INCHES AND A MAXIMUM OF 10% PASSING THE NO. 4 SIEVE.
8. WALL BACKFILL SHALL CONSIST OF SELECT ON–SITE SAND AND GRAVEL WITH A MAXIMUM SIZE OF 3 INCHES AND A MAXIMUM OF 25% PASSING THE NO. 200 SIEVE.
9. WALL BACKFILL SHALL BE PLACED IN THIN LIFTS AND COMPACTED TO A MINIMUM OF 85% OF MAXIMUM DRY DENSITY AS DETERMINED BY ASTM D698 (STANDARD PROCTOR). COMPACTIVE EFFORT SHALL BE LIMITED TO REDUCE PRESSURE ON THE FACE OF THE WALL.
10. GROW–BAGS:
    - 10.1. FILTREXX GROSOXX OR EQUIVALENT APPROVED BY THE OWNER.
    - 10.2. 12–INCH DIAMETER.
    - 10.3. SHALL BE PLACED TO FILL ALL VOIDS BETWEEN HEADERS AT FACE OF WALL.
    - 10.4. SHALL BE SEED AND PLANTED WITH LIVE WILLOW CUTTINGS AT A MINIMUM RATE OF 1 CUTTING PER LINEAL FT OF EACH GROW BAG.
    - 10.5. SHALL BE FILLED WITH TOPSOIL MEETING PROJECT AND MANUFACTURER'S SPECIFICATIONS.



STRETCHER AND HEADER LOGS SHALL BE SECURED AS SHOWN. LENGTH OF REBAR/PIN SHALL PENETRATE A MINIMUM OF 3 MEMBERS. EXPOSED ENDS OF REBAR SHALL BE BENT 90 DEGREES ON BOTH ENDS. DRIFT PINS OR EQUIVALENT SHALL BE PROVIDED WITH END CAPS = 2X PIN DIAMETER.

X
Cxx.xx

DETAIL: CONNECTION

NOT TO SCALE

APPENDIX G: MSE WALL DESIGN OUTPUT, PLAN SHEET AND SPECIAL PROVISION

TITLE PAGE
==========

PROJECT IDENTIFICATION: Lower Darby Creek - Redi-Rock Wall
Project Number: 117-57115x

Client:
Designer: Jason Stratton
Station Number:
Description: Redi-Rock 12 ft wall with seismic loading

Company's information:
Tetra Tech

,
Telephone #:
Fax #:
E-Mail:

File path and name: F:\114-57115x - Lower Darby Creek\MSEW Files\upper wall 12 ft.BEN

Original date and time of creating this file: December, 2017
PROGRAM MODE: ANALYSIS
of a SIMPLE STRUCTURE
using GEOGRID as reinforcing material.

SOIL DATA
REINFORCED SOIL
Unit weight, gamma = 110.0 lb/ft ³
Design value of internal angle of friction, phi = 34.0 °
RETAINED SOIL
Unit weight, gamma = 110.0 lb/ft ³
Design value of internal angle of friction, phi = 30.0 °
FOUNDATION SOIL (Considered as an equivalent uniform soil)
Equivalent unit weight, gamma_equiv. = 95.0 lb/ft ³
Equivalent internal angle of friction, phi_equiv. = 30.0 °
Equivalent cohesion, c_equiv. = 0.0 lb/ft ²
Water table does not affect bearing capacity

LATERAL EARTH PRESSURE COEFFICIENTS
Ka (internal stability) = 0.2827 (if batter is less than 10°, Ka is calculated from eq. 15. Otherwise, eq. 38 is utilized)
Inclination of internal slip plane, ksii = 62.00° (see Fig. 28 in DEMO 82).
Ka (external stability) = 0.4724 (if batter is less than 10°, Ka is calculated from eq. 16. Otherwise, eq. 17 is utilized)

BEARING CAPACITY
Bearing capacity coefficients (calculated by MSEW): Nc = 30.14
N_gamma = 22.40

SEISMICITY
Note: specified alpha-sub-zero combined with I and delta produced a square root of -0.08 in eq. 37a.
MSEW set this square root to ZERO so that the Kae could be calculated. Be aware that the end results are likely erroneous and ARE PROVIDED FOR INFORMATION ONLY
Maximum ground acceleration coefficient, Alpha_o = 0.10
Kae (Alpha_o > 0) = 1.0431
Kae (Alpha_o = 0) = 0.4106
d Kae = 0.6326 (see eq. 37 in DEMO 82)
Seismic soil-geogrid friction coefficient, F* is 80.0% of its specified static value.

INPUT DATA: Geogrids (Analysis)

D A T A	Geogrid type #1	Geogrid type #2	Geogrid type #3	Geogrid type #4	Geogrid type #5
Tult [lb/ft]	4700.0	N/A	N/A	N/A	N/A
Durability reduction factor, RFd	1.1	N/A	N/A	N/A	N/A
Install.-damage reduc. fact., RFid	1.40	N/A	N/A	N/A	N/A
Creep reduction factor, RFc	1.58	N/A	N/A	N/A	N/A
CDR-overall for strength	N/A	N/A	N/A	N/A	N/A
Coverage ratio, Rc	0.522	N/A	N/A	N/A	N/A
Friction angle along geogrid-soil interface, ro	24.22	N/A	N/A	N/A	N/A
Pullout resistance factor, F*	0.7·tan(ph)	N/A	N/A	N/A	N/A
Scale-effect correc. factor, alpha	0.8	N/A	N/A	N/A	N/A

Variation of Lateral Earth Pressure Coefficient With Depth

Z	K / Ka
0 ft	1.00
3.3 ft	1.00
6.6 ft	1.00
9.8 ft	1.00
13.1 ft	1.00
16.4 ft	1.00
19.7 ft	1.00

INPUT DATA: Facia and Connection (Analysis)

FACIA type: Facing enabling frictional connection of reinforcement (e.g., modular concrete blocks, gabions)
Depth/height of block is 2.33/1.50 ft. Horizontal distance to Center of Gravity of block is 1.18 ft.
Average unit weight of block is gamma_f = 120.40 lb/ft ^{3}

Z / Hd	To-static / Tmax or To-seismic / Tmd
0.00	1.00
0.25	1.00
0.50	1.00
0.75	1.00
1.00	1.00

To-static, To-seismic = connection force, static and superimposed dynamic component, respectively.

Geogrid Type #1	Geogrid Type #2	Geogrid Type #3	Geogrid Type #4	Geogrid Type #5

upper wall 12 ft

Sigma	CRult	Sigma	CRult	Sigma	CRult	Sigma	CRult	Sigma	CRult
1000.0	1.00	N/A		N/A		N/A		N/A	
2000.0	1.00	N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
Sigma	CRcr	Sigma	CRcr	Sigma	CRcr	Sigma	CRcr	Sigma	CRcr
0.0	0.84	N/A		N/A		N/A		N/A	
1000.0	0.84	N/A		N/A		N/A		N/A	
2000.0	0.84	N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	

Where: Sigma = Confining stress in between stacked blocks [lb/ft²]
CRult = Tc-ult / Tult-geogrid
CRcr = Tcre / Tult-geogrid
In seismic analysis, long term strength is reduced to 80% of its static value.

D A T A (for connection only)	Type #1	Type #2	Type #3	Type #4	Type #5
Connection strength reduction factor,RFd	1.56	N/A	N/A	N/A	N/A
Creep reduction factor, RFc	N/A	N/A	N/A	N/A	N/A

INPUT DATA: Geometry and Surcharge loads (of a SIMPLE STRUCTURE)

Design height, Hd 12.00 [ft] {Embedded depth is E = 2.00 ft, and height above top of finished
bottom grade is H = 10.00 ft }
Batter, omega 5.0 [deg]
Backslope, beta 24.0 [deg]
Backslope rise 50.0 [ft] Broken back equiv. angle, I = 24.00° (see Fig. 25 in DEMO 82)

U N I F O R M S U R C H A R G E
Uniformly distributed dead load is 0.0 [lb/ft ²]

ANALYSIS: CALCULATED FACTORS (Static conditions)

Bearing capacity, CDR = 4.28, Foundation Interface: Direct sliding, CDR = 1.464, Eccentricity, e/L = 0.0221.

upper wall 12 ft

GEOGRID #	Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connect. strength]	CDR [geogrid strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccent. e/L
1	0.00	16.00	1	2.80	2.04	2.043	20.609	1.413	0.0221
2	1.50	16.00	1	1.53	1.11	1.114	10.086	1.490	0.0051
3	3.00	16.00	1	1.74	1.27	1.268	9.969	1.577	-0.0115
4	4.50	16.00	1	2.01	1.47	1.471	9.897	1.673	-0.0281
5	6.00	16.00	1	2.40	1.75	1.751	9.927	1.779	-0.0453
6	7.50	16.00	1	2.96	2.16	2.164	10.135	1.895	-0.0641
7	9.00	16.00	1	3.88	2.83	2.830	10.676	2.015	-0.0866
8	10.50	16.00	1	4.20	3.07	3.068	9.002	2.125	-0.1170

ANALYSIS: CALCULATED FACTORS (Seismic conditions)

Bearing capacity, CDR = 2.88, Foundation Interface: Direct sliding, CDR = 1.047, Eccentricity, e/L = 0.1103.

GEOGRID #	Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connect. strength]	CDR [geogrid strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccent. e/L
1	0.00	16.00	1	2.31	2.23	2.233	16.315	1.010	0.1103
2	1.50	16.00	1	1.41	1.33	1.333	9.105	1.093	0.0745
3	3.00	16.00	1	1.59	1.50	1.503	8.878	1.193	0.0410
4	4.50	16.00	1	1.82	1.72	1.723	8.661	1.313	0.0096
5	6.00	16.00	1	2.12	2.02	2.018	8.483	1.458	-0.0202
6	7.50	16.00	1	2.54	2.44	2.436	8.372	1.635	-0.0493
7	9.00	16.00	1	3.17	3.07	3.072	8.367	1.843	-0.0796
8	10.50	16.00	1	3.42	3.32	3.315	7.010	2.059	-0.1151

BEARING CAPACITY for GIVEN LAYOUT

upper wall 12 ft

	STATIC	SEISMIC	UNITS
Ultimate bearing capacity, q-ult	10948	9237	[lb/ft ²]
Meyerhof stress, sigma_v	2557.6	3206.2	[lb/ft ²]
Eccentricity, e	0.09	1.32	[ft]
Eccentricity, e/L	0.005	0.083	
CDR calculated	4.28	2.88	
Base length	16.00	16.00	[ft]

DIRECT SLIDING for GIVEN LAYOUT

Along reinforced and foundation soils interface: CDR-static = 1.464 and CDR-seismic = 1.047

#	Geogrid Elevation [ft]	Geogrid Length [ft]	CDR Static	CDR Seismic	Geogrid type #
1	0.00	16.00	1.413	1.010	1
2	1.50	16.00	1.490	1.093	1
3	3.00	16.00	1.577	1.193	1
4	4.50	16.00	1.673	1.313	1
5	6.00	16.00	1.779	1.458	1
6	7.50	16.00	1.895	1.635	1
7	9.00	16.00	2.015	1.843	1
8	10.50	16.00	2.125	2.059	1

ECCENTRICITY for GIVEN LAYOUT

Along reinforced and foundation soils interface: e/L static = 0.0221 and e/L seismic = 0.1103

#	Geogrid Elevation [ft]	Geogrid Length [ft]	e/L Static	e/L Seismic	Geogrid type #
1	0.00	16.00	0.0221	0.1103	1
2	1.50	16.00	0.0051	0.0745	1
3	3.00	16.00	-0.0115	0.0410	1
4	4.50	16.00	-0.0281	0.0096	1
5	6.00	16.00	-0.0453	-0.0202	1
6	7.50	16.00	-0.0641	-0.0493	1
7	9.00	16.00	-0.0866	-0.0796	1
8	10.50	16.00	-0.1170	-0.1151	1

RESULTS for STRENGTH

#	Geogrid Elevation [ft]	Tavilable [lb/ft]	Tmax [lb/ft]	Tmd [lb/ft]	Specified minimum CDR static	Actual calculated CDR static	Specified minimum CDR seismic	Actual calculated CDR seismic
1	0.00	1663	424.92	147.62	N/A	2.043	N/A	2.233
2	1.50	1663	778.99	141.47	N/A	1.114	N/A	1.333

upper wall 12 ft

3	3.00	1663	684.53	135.32	N/A	1.268	N/A	1.503
4	4.50	1663	590.07	129.17	N/A	1.471	N/A	1.723
5	6.00	1663	495.61	123.03	N/A	1.751	N/A	2.018
6	7.50	1663	401.15	116.88	N/A	2.164	N/A	2.436
7	9.00	1663	306.68	110.73	N/A	2.830	N/A	3.072
8	10.50	1663	282.91	104.58	N/A	3.068	N/A	3.315

RESULTS for CONNECTION (static conditions)

#	Geogrid Elevat. [ft]	Connect. force, To [lb/ft]	Reduc. factor connec long term, CRult	Reduc. factor connec short term CRcr	Available connect. strength, [lb/ft]	Available Geogrid strength, Tavail. [lb/ft]	CDR connection strength Spec.	CDR connection strength Actu.	CDR Geogrid strength Spec.	CDR Geogrid strength Actu.
1	0.00	425	1.00	0.84	2278	1848	N/A	2.80	N/A	2.04
2	1.50	779	1.00	0.84	2278	1848	N/A	1.53	N/A	1.11
3	3.00	685	1.00	0.84	2278	1848	N/A	1.74	N/A	1.27
4	4.50	590	1.00	0.84	2278	1848	N/A	2.01	N/A	1.47
5	6.00	496	1.00	0.84	2278	1848	N/A	2.40	N/A	1.75
6	7.50	401	1.00	0.84	2278	1848	N/A	2.96	N/A	2.16
7	9.00	307	1.00	0.84	2278	1848	N/A	3.88	N/A	2.83
8	10.50	283	1.00	0.84	2278	1848	N/A	4.20	N/A	3.07

RESULTS for CONNECTION (seismic conditions)

#	Geogrid Elevat. [ft]	Connect. force, To [lb/ft]	Reduc. factor connec long term, CRult	Reduc. factor connec short term CRcr	Available connect. strength, [lb/ft]	Available Geogrid strength, Tavail. [lb/ft]	CDR connection strength Spec.	CDR connection strength Actu.	CDR Geogrid strength Spec.	CDR Geogrid strength Actu.
1	0.00	573	1.00	0.67	2430	1848	N/A	2.31	N/A	2.23
2	1.50	920	1.00	0.67	2430	1848	N/A	1.41	N/A	1.33
3	3.00	820	1.00	0.67	2430	1848	N/A	1.59	N/A	

upper wall 12 ft

1.50										
4	4.50	719	1.00	0.67	2430	1848	N/A	1.82	N/A	
1.72										
5	6.00	619	1.00	0.67	2430	1848	N/A	2.12	N/A	
2.02										
6	7.50	518	1.00	0.67	2430	1848	N/A	2.54	N/A	
2.44										
7	9.00	417	1.00	0.67	2430	1848	N/A	3.17	N/A	
3.07										
8	10.50	387	1.00	0.67	2430	1848	N/A	3.42	N/A	
3.32										

RESULTS for PULLOUT

#	Geogrid Elevation [ft]	Coverage Ratio	Tmax [lb/ft]	Tmd [lb/ft]	Le [ft]	La [ft]	Avail. Static Pullout Pr [lb/ft]	Specif. Static CDR	Actual Static CDR	Avail. Seismic Pullout Pr [lb/ft]	Specif. Seismic CDR	Actual Seismic CDR
1	0.00	0.522	425	148	16.00	0.00	8757.4	N/A	20.609	9341.2	N/A	16.315
2	1.50	0.522	779	141	15.33	0.67	7857.0	N/A	10.086	8380.8	N/A	9.105
3	3.00	0.522	685	135	14.67	1.33	6823.9	N/A	9.969	7278.9	N/A	8.878
4	4.50	0.522	590	129	14.00	2.00	5839.8	N/A	9.897	6229.1	N/A	8.661
5	6.00	0.522	496	123	13.33	2.67	4919.8	N/A	9.927	5247.8	N/A	8.483
6	7.50	0.522	401	117	12.67	3.33	4065.8	N/A	10.135	4336.8	N/A	8.372
7	9.00	0.522	307	111	12.00	4.00	3274.1	N/A	10.676	3492.4	N/A	8.367
8	10.50	0.522	283	105	11.34	4.66	2546.7	N/A	9.002	2716.5	N/A	7.010

GLOBAL STABILITY

A horizontal seismic coefficient, Kh, equal to 0.100 has been applied.
The seismic force is applied at the center of the sliding mass.

STATIC CONDITIONS:
For the specified reinforcement layer, the calculated minimum Fs is 1.579
(it corresponds to a critical circle at Xc = -21.38, Yc = 85.86 and R = 88.49 [ft] where (x=0, y=0) is taken at the TOE or Xc = 78.62, Yc = 1085.86 and R = 88.49 [ft] when the terrain coordinate system is used as shown in the table below.)

SEISMIC CONDITIONS:
For the specified reinforcement layer, the calculated minimum Fs is 1.398
(it corresponds to a critical circle at Xc = -21.38, Yc = 85.86 and R = 88.49 [ft] where (x=0, y=0) is taken at the TOE or Xc = 78.62, Yc = 1085.86 and R = 88.49 [ft] when the terrain coordinate system is used as shown in the table below.)

TERRAIN/WATER PROFILE

Point	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11

upper wall 12 ft

Soil layer #1: gamma = 100.00 [lb/ft ³] Phi = 26.0° c = 900.00 [lb/ft ²]

x [ft]	0.0	6.6	13.1	19.7	26.2	100.0	120.0	140.0	150.0	220.0	328.1
y [ft]	997.0	997.0	997.0	997.0	997.0	1000.0	1002.0	1022.0	1032.0	1065.0	1065.2

TITLE PAGE
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PROJECT IDENTIFICATION: Lower Darby Creek - Redi-Rock Wall
Project Number: 117-57115x

Client:
Designer: Jason Stratton
Station Number:
Description: Redi-Rock 9 ft wall with seismic loading

Company's information:
Tetra Tech

,
Telephone #:
Fax #:
E-Mail:

File path and name: F:\114-57115x - Lower Darby Creek\MSEW Files\upper wall 9 ft.BEN

Original date and time of creating this file: December, 2017
PROGRAM MODE: ANALYSIS
of a SIMPLE STRUCTURE
using GEOGRID as reinforcing material.

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RETAINED SOIL
Unit weight, gamma = 110.0 lb/ft ^{3}
Design value of internal angle of friction, phi = 30.0 °
FOUNDATION SOIL (Considered as an equivalent uniform soil)
Equivalent unit weight, gamma_equiv. = 95.0 lb/ft ^{3}
Equivalent internal angle of friction, phi_equiv. = 30.0 °
Equivalent cohesion, c_equiv. = 0.0 lb/ft ^{2}
Water table does not affect bearing capacity

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Bearing capacity coefficients (calculated by MSEW): Nc = 30.14
N_gamma = 22.40

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MSEW set this square root to ZERO so that the Kae could be calculated. Be aware that the end results are likely erroneous and ARE PROVIDED FOR INFORMATION ONLY
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Kae (Alpha_o > 0) = 1.0431
Kae (Alpha_o = 0) = 0.4106
d Kae = 0.6326 (see eq. 37 in DEMO 82)
Seismic soil-geogrid friction coefficient, F* is 80.0% of its specified static value.

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Durability reduction factor, RFd	1.1	N/A	N/A	N/A	N/A
Install.-damage reduc. fact., RFid	1.40	N/A	N/A	N/A	N/A
Creep reduction factor, RFc	1.58	N/A	N/A	N/A	N/A
CDR-overall for strength	N/A	N/A	N/A	N/A	N/A
Coverage ratio, Rc	0.522	N/A	N/A	N/A	N/A
Friction angle along geogrid-soil interface, ro	24.22	N/A	N/A	N/A	N/A
Pullout resistance factor, F*	0.7·tan(ph)	N/A	N/A	N/A	N/A
Scale-effect correc. factor, alpha	0.8	N/A	N/A	N/A	N/A

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19.7 ft	1.00

INPUT DATA: Facia and Connection (Analysis)

FACIA type: Facing enabling frictional connection of reinforcement (e.g., modular concrete blocks, gabions)
Depth/height of block is 2.33/1.50 ft. Horizontal distance to Center of Gravity of block is 1.18 ft.
Average unit weight of block is gamma_f = 120.40 lb/ft ^{3}

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0.25	1.00
0.50	1.00
0.75	1.00
1.00	1.00

To-static, To-seismic = connection force, static and superimposed dynamic component, respectively.

Geogrid Type #1 Geogrid Type #2 Geogrid Type #3 Geogrid Type #4 Geogrid Type #5

upper wall 9 ft

Sigma	CRult	Sigma	CRult	Sigma	CRult	Sigma	CRult	Sigma	CRult
1000.0	1.00	N/A		N/A		N/A		N/A	
2000.0	1.00	N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
Sigma	CRcr	Sigma	CRcr	Sigma	CRcr	Sigma	CRcr	Sigma	CRcr
0.0	0.84	N/A		N/A		N/A		N/A	
1000.0	0.84	N/A		N/A		N/A		N/A	
2000.0	0.84	N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	
N/A		N/A		N/A		N/A		N/A	

Where: Sigma = Confining stress in between stacked blocks [lb/ft²]
CRult = Tc-ult / Tult-geogrid
CRcr = Tcre / Tult-geogrid
In seismic analysis, long term strength is reduced to 80% of its static value.

D A T A (for connection only)	Type #1	Type #2	Type #3	Type #4	Type #5
Connection strength reduction factor,RFd	1.56	N/A	N/A	N/A	N/A
Creep reduction factor, RFc	N/A	N/A	N/A	N/A	N/A

INPUT DATA: Geometry and Surcharge loads (of a SIMPLE STRUCTURE)

Design height, Hd 9.00 [ft] {Embedded depth is E = 2.00 ft, and height above top of finished
bottom grade is H = 7.00 ft }
Batter, omega 5.0 [deg]
Backslope, beta 24.0 [deg]
Backslope rise 50.0 [ft] Broken back equiv. angle, I = 24.00° (see Fig. 25 in DEMO 82)

U N I F O R M S U R C H A R G E
Uniformly distributed dead load is 0.0 [lb/ft ²]

ANALYSIS: CALCULATED FACTORS (Static conditions)

Bearing capacity, CDR = 4.28, Foundation Interface: Direct sliding, CDR = 1.464, Eccentricity, e/L = 0.0221.

upper wall 9 ft

#	GEOGRID Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connect. strength]	CDR [geogrid strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccent. e/L
1	0.00	12.00	1	3.77	2.75	2.749	15.602	1.413	0.0221
2	1.50	12.00	1	2.12	1.55	1.548	7.539	1.518	-0.0004
3	3.00	12.00	1	2.55	1.86	1.862	7.433	1.640	-0.0225
4	4.50	12.00	1	3.20	2.34	2.335	7.445	1.779	-0.0453
5	6.00	12.00	1	4.29	3.13	3.131	7.697	1.935	-0.0710
6	7.50	12.00	1	4.98	3.64	3.636	6.556	2.091	-0.1055

ANALYSIS: CALCULATED FACTORS (Seismic conditions)

Bearing capacity, CDR = 2.88, Foundation Interface: Direct sliding, CDR = 1.047, Eccentricity, e/L = 0.1103.

#	GEOGRID Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connect. strength]	CDR [geogrid strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccent. e/L
1	0.00	12.00	1	3.11	3.00	3.004	12.347	1.010	0.1103
2	1.50	12.00	1	1.96	1.85	1.848	6.786	1.125	0.0631
3	3.00	12.00	1	2.31	2.19	2.192	6.556	1.270	0.0199
4	4.50	12.00	1	2.83	2.69	2.694	6.372	1.458	-0.0202
5	6.00	12.00	1	3.63	3.49	3.493	6.276	1.701	-0.0591
6	7.50	12.00	1	4.15	4.01	4.005	5.249	1.989	-0.1022

BEARING CAPACITY for GIVEN LAYOUT

	STATIC	SEISMIC	UNITS
Ultimate bearing capacity, q-ult	8211	6928	[lb/ft ²]
Meyerhof stress, sigma_v	1918.2	2404.7	[lb/ft ²]
Eccentricity, e	0.06	0.99	[ft]
Eccentricity, e/L	0.005	0.083	
CDR calculated	4.28	2.88	
Base length	12.00	12.00	[ft]

DIRECT SLIDING for GIVEN LAYOUT

Along reinforced and foundation soils interface: CDR-static = 1.464 and CDR-seismic = 1.047

#	Geogrid Elevation [ft]	Geogrid Length [ft]	CDR Static	CDR Seismic	Geogrid type #
1	0.00	12.00	1.413	1.010	1
2	1.50	12.00	1.518	1.125	1
3	3.00	12.00	1.640	1.270	1
4	4.50	12.00	1.779	1.458	1
5	6.00	12.00	1.935	1.701	1
6	7.50	12.00	2.091	1.989	1

ECCENTRICITY for GIVEN LAYOUT

Along reinforced and foundation soils interface: e/L static = 0.0221 and e/L seismic = 0.1103

#	Geogrid Elevation [ft]	Geogrid Length [ft]	e/L Static	e/L Seismic	Geogrid type #
1	0.00	12.00	0.0221	0.1103	1
2	1.50	12.00	-0.0004	0.0631	1
3	3.00	12.00	-0.0225	0.0199	1
4	4.50	12.00	-0.0453	-0.0202	1
5	6.00	12.00	-0.0710	-0.0591	1
6	7.50	12.00	-0.1055	-0.1022	1

RESULTS for STRENGTH

#	Geogrid Elevation [ft]	Tavilable [lb/ft]	Tmax [lb/ft]	Tmd [lb/ft]	Specified minimum CDR static	Actual calculated CDR static	Specified minimum CDR seismic	Actual calculated CDR seismic
1	0.00	1663	315.74	109.82	N/A	2.749	N/A	3.004
2	1.50	1663	560.63	103.72	N/A	1.548	N/A	1.848
3	3.00	1663	466.17	97.62	N/A	1.862	N/A	2.192
4	4.50	1663	371.71	91.53	N/A	2.335	N/A	2.694
5	6.00	1663	277.24	85.43	N/A	3.131	N/A	3.493
6	7.50	1663	238.75	79.33	N/A	3.636	N/A	4.005

RESULTS for CONNECTION (static conditions)

#	Geogrid Elevat. [ft]	Connect. force, To [lb/ft]	Reduc. factor connec long term, CRult	Reduc. factor connec short term, CRcr	Available connect. strength, [lb/ft]	Available Geogrid strength, Tavail. [lb/ft]	CDR connection strength Spec.	CDR connection strength Actu.	CDR Geogrid strength Spec.	CDR Geogrid strength Actu.
1	0.00	316	1.00	0.84	2278	1848	N/A	3.77	N/A	2.75
2	1.50	561	1.00	0.84	2278	1848	N/A	2.12	N/A	1.55
3	3.00	466	1.00	0.84	2278	1848	N/A	2.55	N/A	1.86
4	4.50	372	1.00	0.84	2278	1848	N/A	3.20	N/A	2.34
5	6.00	277	1.00	0.84	2278	1848	N/A	4.29	N/A	3.13
6	7.50	239	1.00	0.84	2278	1848	N/A	4.98	N/A	3.64

RESULTS for CONNECTION (seismic conditions)

#	Geogrid Elevat. [ft]	Connect. force, To [lb/ft]	Reduc. factor connec long term, CRult	Reduc. factor connec short term, CRcr	Available connect. strength, [lb/ft]	Available Geogrid strength, Tavail. [lb/ft]	CDR connection strength Spec.	CDR connection strength Actu.	CDR Geogrid strength Spec.	CDR Geogrid strength Actu.
1	0.00	426	1.00	0.67	2430	1848	N/A	3.11	N/A	3.00
2	1.50	664	1.00	0.67	2430	1848	N/A	1.96	N/A	1.85
3	3.00	564	1.00	0.67	2430	1848	N/A	2.31	N/A	2.19
4	4.50	463	1.00	0.67	2430	1848	N/A	2.83	N/A	2.69
5	6.00	363	1.00	0.67	2430	1848	N/A	3.63	N/A	3.49
6	7.50	318	1.00	0.67	2430	1848	N/A	4.15	N/A	4.01

RESULTS for PULLOUT

#	Geogrid Elevation	Coverage Ratio	Tmax [lb/ft]	Tmd [lb/ft]	Le [ft]	La [ft]	Avail. Static	Specif. Static	Actual Static	Avail. Seismic	Specif. Seismic	Actual Seismic

					upper wall 9 ft							
	[ft]					Pullout Pr [lb/ft]	CDR			Pullout Pr [lb/ft]	CDR	
1	0.00	0.522	316	110	12.00	0.00	4926.0	N/A	15.602	5254.4	N/A	12.347
2	1.50	0.522	561	104	11.33	0.67	4226.7	N/A	7.539	4508.5	N/A	6.786
3	3.00	0.522	466	98	10.67	1.33	3465.0	N/A	7.433	3696.0	N/A	6.556
4	4.50	0.522	372	92	10.00	2.00	2767.4	N/A	7.445	2951.9	N/A	6.372
5	6.00	0.522	277	85	9.33	2.67	2134.0	N/A	7.697	2276.2	N/A	6.276
6	7.50	0.522	239	79	8.67	3.33	1565.4	N/A	6.556	1669.7	N/A	5.249

GLOBAL STABILITY

A horizontal seismic coefficient, Kh, equal to 0.100 has been applied.
The seismic force is applied at the center of the sliding mass.

STATIC CONDITIONS:
For the specified reinforcement layer, the calculated minimum Fs is 1.573
(it corresponds to a critical circle at Xc = -7.59, Yc = 58.92 and R = 59.40 [ft] where (x=0, y=0) is taken at the TOE or Xc = 92.41, Yc = 1058.92 and R = 59.40 [ft] when the terrain coordinate system is used as shown in the table below.)

SEISMIC CONDITIONS:
For the specified reinforcement layer, the calculated minimum Fs is 1.400
(it corresponds to a critical circle at Xc = -7.59, Yc = 58.92 and R = 59.40 [ft] where (x=0, y=0) is taken at the TOE or Xc = 92.41, Yc = 1058.92 and R = 59.40 [ft] when the terrain coordinate system is used as shown in the table below.)

TERRAIN/WATER PROFILE

Point	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Soil layer #1: gamma = 100.00 [lb/ft ^{3}] Phi = 26.0° c = 900.00 [lb/ft ^{2}]											
x [ft]	0.0	6.6	13.1	19.7	26.2	100.0	120.0	140.0	150.0	220.0	328.1
y [ft]	997.0	997.0	997.0	997.0	997.0	1000.0	1002.0	1022.0	1027.0	1060.0	1065.0

Gravity Wall Stability

Project:	*Gravity Redi-Rock Wall - 7.5 ft*	**County/State:**	
Designer:	*Stratton*	**Checked by:**	
Date:	December, 2017	**Date:**	

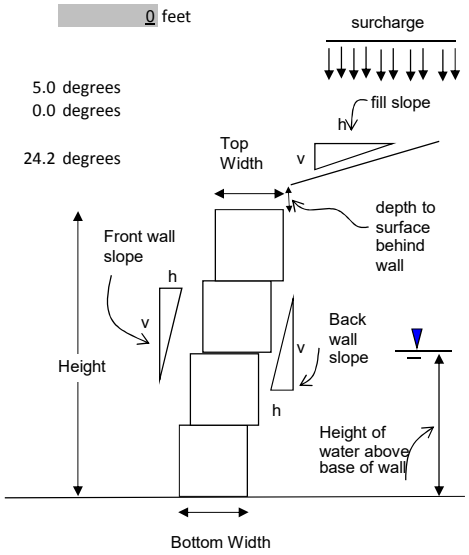
Bottom block standard 5 ft width

Wall/Slope Dimensions

*Note: fill in values that are underlined, calculated results are in **bold red***

Height, H	7.5	feet		Depth to surface behind wall	0	feet
Bottom Width, Bw	5	feet				
Top Width, Tw	2.333	feet				
Front Wall Slope	11.4	V:H*	ωf	0.09 radians	5.0	degrees
Avg. Back Wall Slope	10000	V:H*	ωb	0.00 radians	0.0	degrees
*use 10000 for verticle wall						
Fill Slope	2.22	n	β	0.42 radians	24.2	degrees
Surcharge	0	psf				
(for example: buildings or traffic)						
Horizontal Acc, kh	0.112	g				
Vertical Acc, kv	0	g				

Soil Type	Angle of Internal Friction (Deg.)
Clean Sand	35
Silty Sand	30
Sandy Silt	25
Silt	20



Wall Properties

Description	Redi-Rock Filled Units		
γi	120	pcf	
ϕt	34	degrees	0.59 radians
μ	0.67		

Retained Soil Properties

Description	Drainfill and Crushed Coral		
γr	110	pcf	
ϕr	30	degrees	0.52 radians
δ	20.00	degrees	0.35 radians

Height of water above base of wall

H_w 0 feet

Seismic Factors

Θ	0.00195	in radians
Ψ	1.68095	

Foundation Soil Properties

Description	Drainfill		
γf	95	pcf	
ϕf	30	degrees	0.52 radians
cf	0	psf	

Earth Pressure Coefficient

Ka 0.47269289 Kae 0.47628961

Earth Forces			Water Forces		Seismic Forces	
$P_{sh,\ above\ water}$	1374.20	lb/ft of wall	P_{wh}	0	Pae	1473.52 lb/ft of wall
$P_{sv,\ above\ water}$	500.17	lb/ft of wall				
$P_{sh,\ below\ water\ 1}$	0.00	lb/ft of wall				
$P_{sh,\ below\ water\ 2}$	0.00					
$P_{sv,\ below\ water\ 1}$	0.00	lb/ft of wall				
$P_{sv,\ below\ water\ 2}$	0.00					
P_{qh}	0.00	lb/ft of wall				
P_{qv}	0.00	lb/ft of wall				

Weight of Wall

Weight of Wall 4500 lb/ftof wall

Factor of Safety Against Sliding at the Base

$FS_{sl\ (Seismic)}$ **2.10** *note: FS against sliding should be >1.3 min*

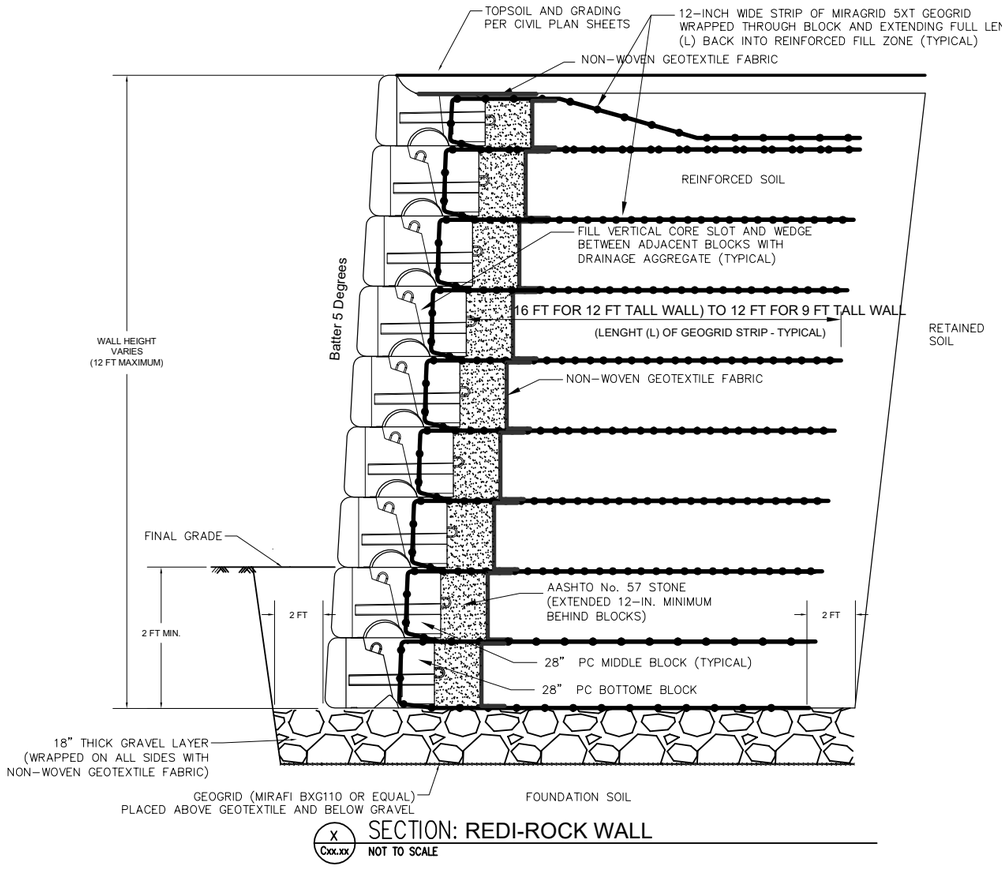
$FS_{sl\ (Seismic)}$ **1.01** *note: FS against sliding (Seismic) should be >1.0 min*

Moments Resisting		Moments Driving		(Seismic)
Weight	11250.00	$M_{sh,\ above\ water}$	3435.50	3683.80
$M_{sv,\ above\ water}$	2500.84	$M_{sh,\ below\ water}$	0	
$M_{sv,\ below\ water\ 1}$	0	$M_{sh,\ below\ water}$	0	
$M_{sv,\ below\ water\ 2}$	0	M_{qh}	0	
M_{qv}	0	M_{wh}	0	

Factor of Safety Against Overturning about Toe

FS_{ot} **4.00** *note: FS against overturning should be >1.5 min*

Fsot (Seismic) **1.93** *note: FS against overturning (Seismic) should be >1.0 min*



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Cxx.xx

SECTION: REDI-ROCK WALL

NOT TO SCALE

REDI-ROCK WALL NOTES

1. WALL SHALL CONSIST OF REDI-ROCK WALL OR AN APPROVED EQUIVALENT PRODUCT WITH GEOGRID REINFORCEMENT.
2. BLOCK SHALL BE "LIMESTONE FACE" WITH MINIMUM HEIGHT OF 18-INCHES AND MINIMUM DEPTH OF 28 INCHES.
3. CONTRACTOR SHALL PROVIDE THE RETAINING WALL DESIGN. NOTED BLOCK SIZES AND GEOGRID TYPE AND LENGTH ARE PRELIMINARY DESIGN FOR EXAMPLES PURPOSES ONLY.
4. FOUNDATION GRAVEL SHALL BE EVENLY GRADED WITH A MAXIMUM SIZE OF 6-INCHES AND A MAXIMUM OF 10% PASSING THE NO. 4 SIEVE.
5. WALL BACKFILL SHALL CONSIST OF SELECT ON-SITE SAND AND GRAVEL WITH A MAXIMUM SIZE OF 3 INCHES AND A MAXIMUM OF 25% PASSING THE NO. 200 SIEVE.
6. WALL BACKFILL SHALL BE PLACED IN THIN LIFTS AND COMPACTED TO A MINIMUM OF 95% OF MAXIMUM DRY DENSITY AS DETERMINED BY ASTM D698 (STANDARD PROCTOR).

SPECIAL PROVISIONS – REDI-ROCK WALL

A. Description. Furnish all materials, labor, and equipment necessary to design and construct Mechanically Stabilized Earth (MSE) retaining wall(s) in accordance with these specifications and the lines, grades, and dimensions shown on the plans or otherwise established by the Project Manager. Have a Professional Engineer licensed in Pennsylvania oversee the retaining wall design and sign and seal the design calculations and drawings.
   1. Preliminary dimensions given on the plans are for estimating purposes only.
   2. Produce a design for a MSE system that will establish:
      a) Bottom elevation of leveling pad and MSE wall
      b) Reinforcement type, locations and lengths
      c) Type and dimensions of facing materials
      d) Reinforcement connection to facing
      e) Size of concrete and/or crushed aggregate leveling pad.
      f) Quantity and specifications of reinforced backfill
      g) A drainage system that will provide free drainage behind the reinforced soil mass.
      h) A design that takes into account interferences such as guardrail posts, manholes, and pipes behind, passing through, or under the wall.

B. Available Information. Available information developed by the Owner or by the Owner's duly authorized representative includes the following items:
   1. Project Geotechnical Report.
   2. Boring Logs for borings that were obtained in the area of the MSE Wall(s) are included in the Special Provisions.
   3. Contract Drawings including detailed drawings, plan and profile drawings, and cross-section drawings for the proposed retaining wall. These drawings will show right of way and construction limits, utilities, wall appurtenances, and drainage pipes.
   4. Design Soil Properties. Use the following soil properties to design the MSE walls:

	Total Unit Weight, pcf	Angle of Internal Friction,	Cohesion, psf
Reinforced Soil	110	34	0
Retained Soil	110	30	0
Foundation Soil	95	30	0

C. MSE Retaining Wall Design Requirements.
   1. Design the wall(s) in accordance with the most current AASHTO LRFD Specifications for Highway Bridges, Section 11, including current interim specifications for retaining walls, and using the applicable resistance and load factors for mechanically stabilized earth walls. Additionally, follow the guidelines given in the most current editions of the FHWA Manuals titled Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes — Volume I and II (Publication No. FHWA-NHI-10-024 and FHWA-NHI-10-025) and Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Publication No. FHWA-NHI-00-044. The following exceptions and additions apply.
   2. The design life of the MSE wall is 75 years.
   3. The required minimum wall embedment is 3 feet.
   4. Ensure internal stability and provide analysis at critical sections that clearly show the Capacity/Demand Ratio equal to or greater than 1.0 for tensile resistance and pullout resistance.
   5. The Owner evaluated the proposed wall layout and determined adequate external stability and bearing capacity. Provide analyses at critical sections that clearly show the

Capacity/Demand Ratio equal to or greater than 1.0 for global stability, compound stability, sliding, eccentricity, and bearing capacity.

6. Design the wall with the maximum vertical distance between reinforcement layers of 2 feet.
7. Design the wall with the minimum length of reinforcement equal to 0.7 times the design wall height, 8 feet, or to the limits shown on the Plans, whichever is greater.
8. Design the wall to tolerate total settlements of 1 inch.
9. Design a drainage system behind the reinforced soil mass to drain water from the backfill and prevent hydrostatic pressure buildup within the reinforced zone.
10. Provide backfill soil behind the MSE wall (retained soil) having greater than 50 percent retained on the No. 4 screen (ASTM sand or gravel).
11. Design a wall batter to be from $^1/_4$ to $^1/_2$ inch per foot at the end of construction.
12. Design the wall to account for wall appurtenances and for interference such as driven pile, guard rail posts, utilities, and pipes.
13. Locate the face of walls as shown in the plans unless otherwise approved by the Project Manager.
14. Materials. Use materials meeting the following requirements to construct the MSE wall.
    a) Concrete for Leveling Pads and Coping. Provide Concrete for leveling pads and coping.
    b) Reinforced Backfill Material. Use material meeting the requirements of these Special Provisions and the following additional requirements:
        I. Gradation. For reinforced soil within the MSE wall, use soil meeting the following gradation requirements:

US Sieve Size	Percent Passing
3 inch	100
No. 200	0 – 25

        II. Provide a minimum of 35% of the +No. 4 material with at least one mechanically fractured face.
        III. Backfill material shall have a minimum internal friction angle of 34 degrees.
        IV. Electrochemical Properties. Use reinforced soil meeting the following electrochemical requirements:
            (a) For Steel Reinforcements:

Requirements	Test Methods
Resistivity >3,000 ohm-cm	AASHTO T-288
pH 5-10	AASHTO T-289
Chlorides <100 parts per million	AASHTO T-291
Sulfates <200 parts per million	AASHTO T-290
Organic Content <1%	AASHTO T-267

            (b) For Geosynthetic Reinforcements:

Requirements	Test Methods
Polyester (PET) 3<pH<9	AASHTO T-289
Polyolefin (PP &HDPE) pH>3	AASHTO T-289

            (c) If the resistivity is greater than or equal to 5000 ohm-cm, the chloride and sulfates requirements may be waived.
        V. Soundness. Use materials that are substantially free of shale or other soft, poor durability particles. Use material having a magnesium sulfate soundness loss of less than 30 percent after four cycles, measured in accordance with AASHTO T-104, or a sodium sulfate less of less than 15 percent after five cycles determined in accordance with AASHTO T-104.
    c) Reinforcement Material. Use reinforcement material that will not degrade over the design life of the structure. When specifying the reinforcement material, use the criteria given in the FHWA Publication Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Publication No. FHWA-NHI-00-044.

d) Facing. Use modular block facing as indicated on the plan sheets. Use modular concrete blocks in conformance with ASTM C 1372, Standard Specification for Segmental Retaining Wall Units. Modular block units shall have a minimum height of 18 inches.
   I. Rejection - Units will be rejected for failure to meet any of the requirements specified above. Repair or replace units with any of the following defects.
      (a) Defects that indicate imperfect molding.
      (b) Defects that indicate honeycombing or open texture concrete.
      (c) Cracked or severely chipped panels.
      (d) Any damage that prevents a satisfactory joint between panels.

e) Backfill Material. Provide backfill soil behind the MSE wall (retained soil) having greater than 50 percent retained on the No. 4 screen (ASTM sand or gravel).

15. Retaining Wall Design Submittals. At least 30 calendar days before the planned start of wall excavation, submit complete design calculations and working drawings to the Onwer for review. Include all details, dimensions, quantities, ground profiles, and cross-sections necessary to construct the wall. Verify the limits of the wall and ground survey data before preparing drawings.

a) Design Calculations. Submit design calculations to include, but not be limited to, the following items:
   I. Applicable code requirements and design references.
   II. Retaining wall critical design cross-section geometry including soil strata and location, magnitude, and direction of design slope or external surcharge loads and piezometric levels along with the Capacity Demand Ratios for, long-term conditions.
   III. Design parameters including drained and undrained soil shear strengths (friction angle and cohesion), unit weights, and any other assumptions for each soil strata along with reinforcing material properties, and facing materials.
   IV. Capacity Demand Ratios calculated from LRFD.
   V. Design calculation sheets with the project number, wall location, stationing, date of preparation, initials of designer and checker, and page number at the top of each page. Provide an index page with the design calculations.
   VI. Design notes including an explanation of any symbols and computer programs used in the design.
   VII. Design calculations for wall facing units, connection pins, and reinforcing material, and connections between the reinforcing material and the facing.
   VIII. Other design calculations.

b) Working Drawings. Provide drawings designed, signed and sealed by a registered Professional Engineer licensed in the State of Pennsylvania. Include on the working drawings the following items as a minimum:
   I. A plan view of the wall(s) identifying:
   II. A reference baseline and elevation datum.
   III. The offset from the construction centerline or baseline to the face of the wall at its base at all changes in horizontal alignment.
   IV. Beginning and end of wall stations.
   V. Right-of-way and permanent or temporary construction easement limits, location of all known active and abandoned existing utilities, adjacent structures or other potential interferences within the limits of the wall excavation. The centerline of any drainage structure or drainage pipe behind, passing through, or passing under the wall.
   VI. An elevation view of the wall(s) identifying:
   VII. The elevation at the top of the wall, at all horizontal and vertical break points, and at least every 20 feet along the wall.
   VIII. Elevations at the wall base.
   IX. Beginning and end of wall stations.
   X. The distance along the face of the wall to all steps in the wall base.
   XI. Wall elevation view showing the location of wall drainage elements along the wall length.
   XII. Existing and finish grade profiles both behind and in front of the wall.

XIII. Specifications for reinforcing material and connection pins.
XIV. General notes for constructing the wall including construction sequencing, wall excavation, foundation preparation, wall erection, backfill placement and any other special construction requirements.
XV. Horizontal and vertical curve data affecting the wall and wall control points. Match lines or other details to relate wall stationing to centerline stationing.
XVI. A listing of the summary of quantities on the elevation drawing of each wall showing estimated square feet of wall face areas.
XVII. Retaining wall typical sections including excavation elevations, and wall face batter.
XVIII. Details, dimensions, and schedules for all connection pins, facing, and reinforcement materials.
XIX. Details and dimensions for wall appurtenances such as barriers, guardrails, coping, drainage gutters, fences, signage, etc.
XX. Details for constructing walls around utilities and drainage facilities (if applicable).
XXI. Details for terminating walls and adjacent slope construction.
XXII. Clearly show all details and requirements to place guardrail posts.

c) Have a Professional Engineer licensed in Pennsylvania sign and seal the drawings and calculations. If the retaining wall Contractor uses a Consultant designer subcontractor or manufacturer's representative to prepare the design, the retaining wall Contractor still has overall contract responsibility for both the design and the construction.
d) Submit 3 sets of the wall drawings to the Owner with the initial submission. The Owner Section will review the Contractor's submittals within 20 calendar days after receipt of a complete submission. If revisions are necessary, make the necessary corrections and resubmit 3 revised sets. After the drawings have been reviewed and found acceptable, furnish 5 sets of the drawings. Do not begin wall construction or incorporate materials into the work until the submittal requirements are satisfied and found acceptable to the Owner. Changes or deviations from the accepted submittals must be re-submitted and reviewed. No adjustments in contract time will be allowed due to incomplete submittals.
e) Revise the drawings when plan dimensions are revised due to field conditions or for other reasons. Within 30 days after completion of the work, submit as-built drawings to the Project Manager. Provide revised design calculations signed by a Registered Professional Engineer for all design changes made during the construction of the wall.

16. Construction Requirements. Construct the wall according to the approved set of working drawings, the special provisions, and the appropriate sections of the Project Specifications.
    a) Reinforced Backfill Source Approval. At least 30 calendar days before beginning MSE wall construction, submit a sample from the proposed borrow source for backfill material.
    b) Reinforcement Source Approval. Submit a manufacturer's certificate of compliance signed by an authorized manufacturer's official stating that the reinforcement material meets the requirements specified in the working drawings. Submit a sample at least 5 feet in length by the full reinforcement width for testing. After the sample and the required information have been submitted to the Project Manager, allow 30 calendar days for evaluation. Remove and replace any material not meeting the specified requirements at the Contractor's expense.
    c) Have a technical representative of the wall manufacturer on site during the beginning of MSE wall construction to ensure that the wall is installed properly.
    d) Excavation. Complete the excavation in reasonably close conformity to the limits and construction stages shown on the plans. The contractor is responsible for temporary excavation support (as required).
    e) Foundation Preparation. Grade the foundation for the structure level for a width equal to the length of reinforcement plus 1 foot or as shown on the plans. Prior to wall construction, prepare foundation area as indicated on the project drawings (overexcvation and backfill).

I. After placement of the leveling pad concrete, allow it to cure a minimum of 12 hours before placing wall panels or modular block units.

f) Backfill Placement. Place backfill following each course of facing. Place backfill in such a manner to avoid any disturbance of the wall materials or misalignment of the facing or reinforcing element. Remove and replace any wall materials that become damaged during construction at Contractor's expense. At each reinforcement level, place and compact the backfill to the level of the connection before placing the reinforcement. Place, spread, and compact backfill in such a manner that minimizes development of wrinkles in or movement of the reinforcement. Place backfill near the facing to assure that no voids exist directly beneath the reinforcing elements. Place backfill in maximum 8 inch loose lifts. Compact backfill to a minimum of 95 percent of the maximum density determined by ASTM D698 within +/- 2 percent of the optimum moisture content. Compact the backfill within 4 feet of the wall face using a lightweight mechanical tamper, roller, or vibratory system. At the end of each day's operation, slope the level of the backfill away from the wall facing to rapidly direct runoff away from the face. Do not allow surface water from adjacent areas to enter the wall construction site.

g) Reinforcement Placement. At each reinforcement level, place and compact the backfill to the level of the reinforcement. Place reinforcement on a smooth horizontal surface. Pull the reinforcement material tight before covering it with backfill. If using a geosynthetic reinforcement, orientation of geosynthetic reinforcement is critical since the strength of geosynthetic reinforcement varies with direction. Use soil piles, pins, or the manufacturer's approved method to hold the reinforcement material tight during backfill placement. Do not operate equipment directly on the reinforcement material. Do not splice or overlap geosynthetic reinforcement in the principal strength direction.

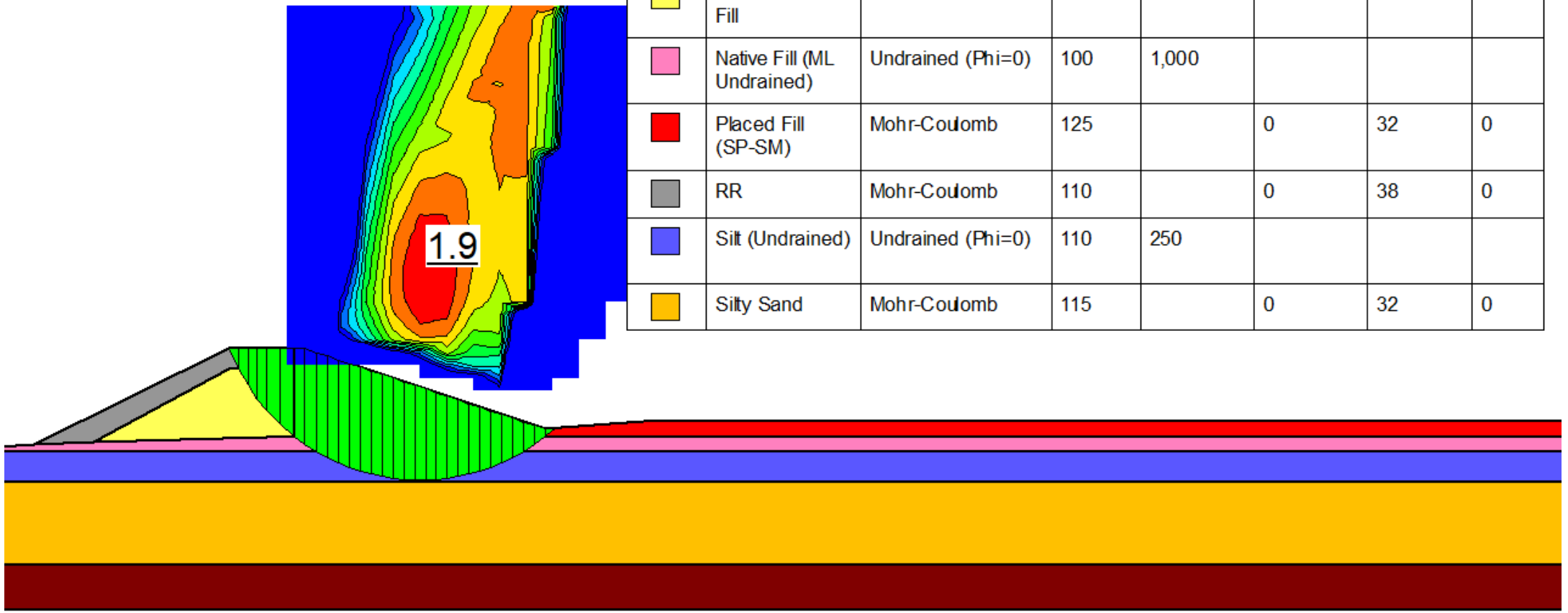
h) Modular Block Fill. Fill the voids in all modular blocks with aggregate satisfying the following gradation:

US Sieve Size	Percent Passing
1 inch	100
% inch	50-75
No. 4	0-60
No. 40	0-50
No. 200	0 - 5

i) Wall Batter. The completed wall has a vertical tolerance not exceeding 1/2 inch per 10 feet of wall height from the batter shown on the approved set of working drawings.

j) Corrective Action. If any defects are found in the wall, begin repairing the wall by a method approved by the Owner. Within seven calendar days of determining the need for wall repairs, submit four copies of calculations and working drawings, stamped by a Professional Engineer licensed in Pennsylvania, to the Project Manager for modifications to the wall caused by the remedial action. Furnish all material and labor necessary to correct the wall at no cost to the Department.

Geostudio Figures

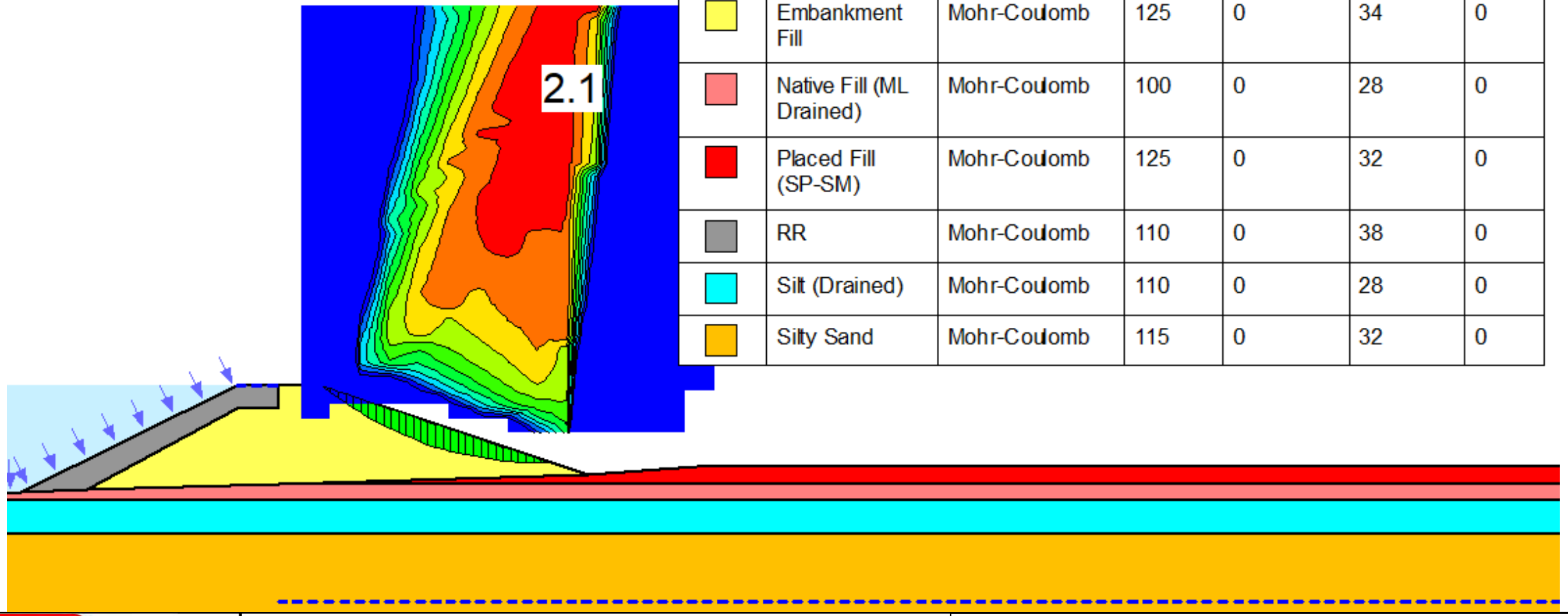


Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Total Cohesion (psf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)					
	Embankment Fill	Mohr-Coulomb	125		0	34	0
	Native Fill (ML Undrained)	Undrained (Phi=0)	100	1,000			
	Placed Fill (SP-SM)	Mohr-Coulomb	125		0	32	0
	RR	Mohr-Coulomb	110		0	38	0
	Silt (Undrained)	Undrained (Phi=0)	110	250			
	Silty Sand	Mohr-Coulomb	115		0	32	0

US Army Corps of Engineers®

Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-1, End-of-Construction SLOPE/W Analysis	Checked By: Earl Fisher, PE
US Army Corps of Engineers, Philadelphia District	8/11/23

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)				
	Embankment Fill	Mohr-Coulomb	125	0	34	0
	Native Fill (ML Drained)	Mohr-Coulomb	100	0	28	0
	Placed Fill (SP-SM)	Mohr-Coulomb	125	0	32	0
	RR	Mohr-Coulomb	110	0	38	0
	Silt (Drained)	Mohr-Coulomb	110	0	28	0
	Silty Sand	Mohr-Coulomb	115	0	32	0



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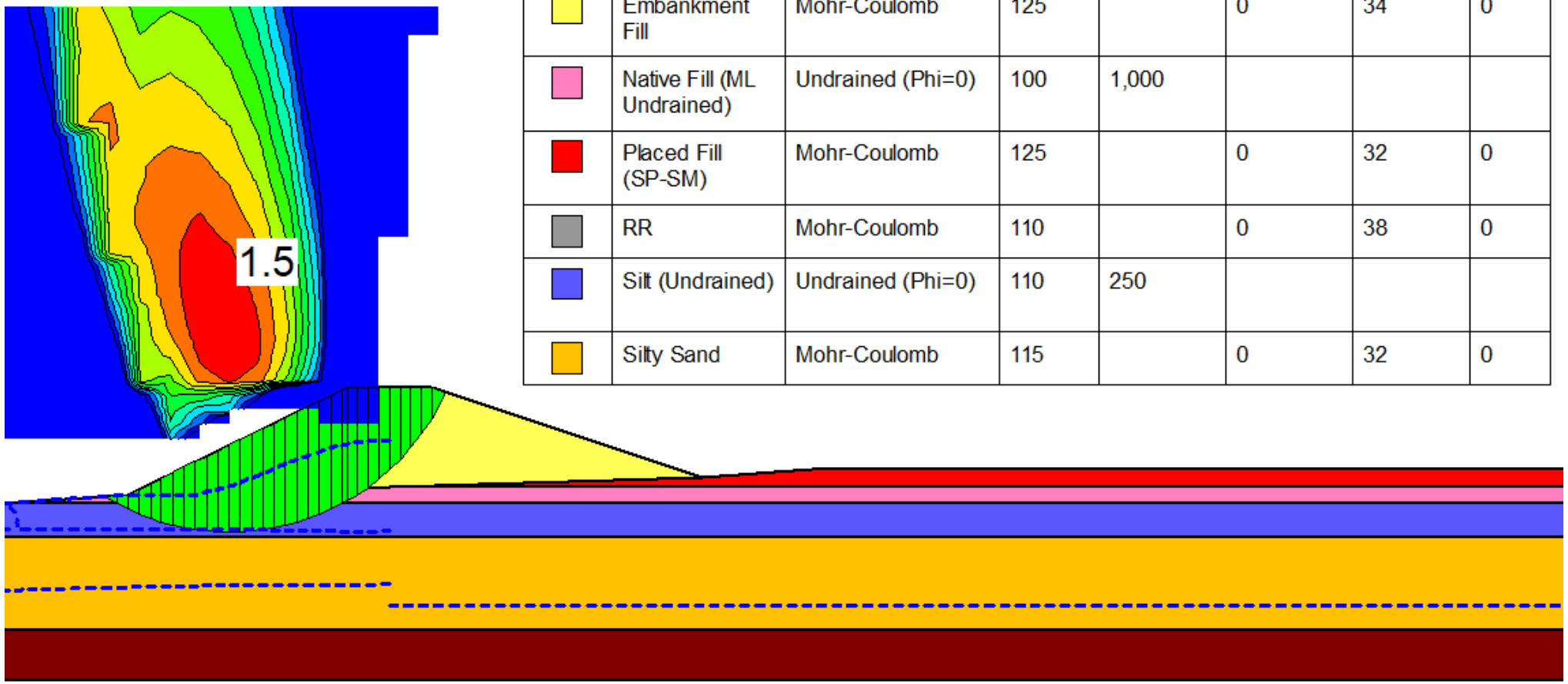
Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-1, Long-term (Steady State Seepage) SLOPE/W Analysis	Checked By: Earl Fisher, PE
US Army Corps of Engineers, Philadelphia District	8/11/23

Color	Name	Slope Stability Material Model	Unit Weight (p	Total Cohesion	Effective Cohesion	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)					
	Embankment Fill	Mohr-Coulomb	125		0	34	0
	Native Fill (ML Undrained)	Undrained (Phi=0)	100	1,000			
	Placed Fill (SP-SM)	Mohr-Coulomb	125		0	32	0
	RR	Mohr-Coulomb	110		0	38	0
	Silt (Undrained)	Undrained (Phi=0)	110	250			
	Silty Sand	Mohr-Coulomb	115		0	32	0

7.54331, 6.074803 in



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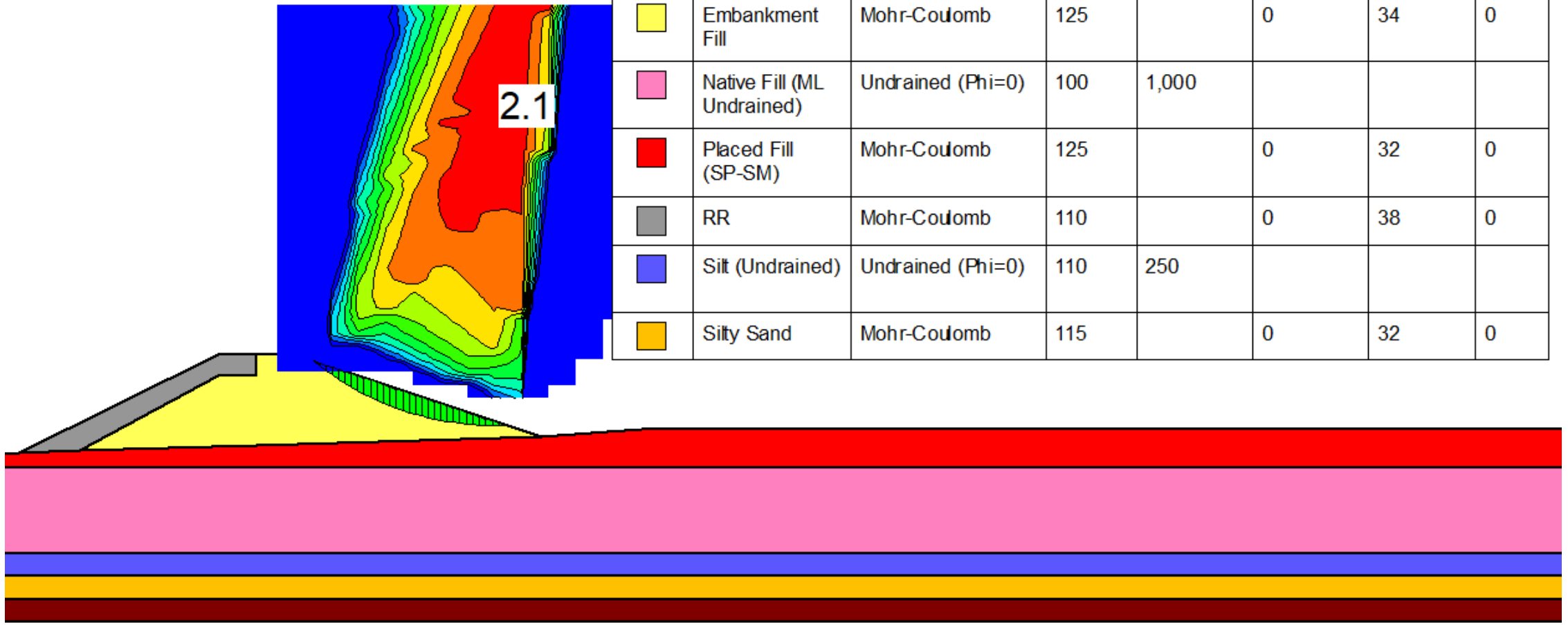
Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-1, Rapid Drawdown SLOPE/W Analysis	Checked By: Earl Fisher, PE
US Army Corps of Engineers, Philadelphia District	8/11/23



Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Total Cohesion (psf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)					
	Embankment Fill	Mohr-Coulomb	125		0	34	0
	Native Fill (ML Undrained)	Undrained (Phi=0)	100	1,000			
	Placed Fill (SP-SM)	Mohr-Coulomb	125		0	32	0
	RR	Mohr-Coulomb	110		0	38	0
	Silt (Undrained)	Undrained (Phi=0)	110	250			
	Silty Sand	Mohr-Coulomb	115		0	32	0

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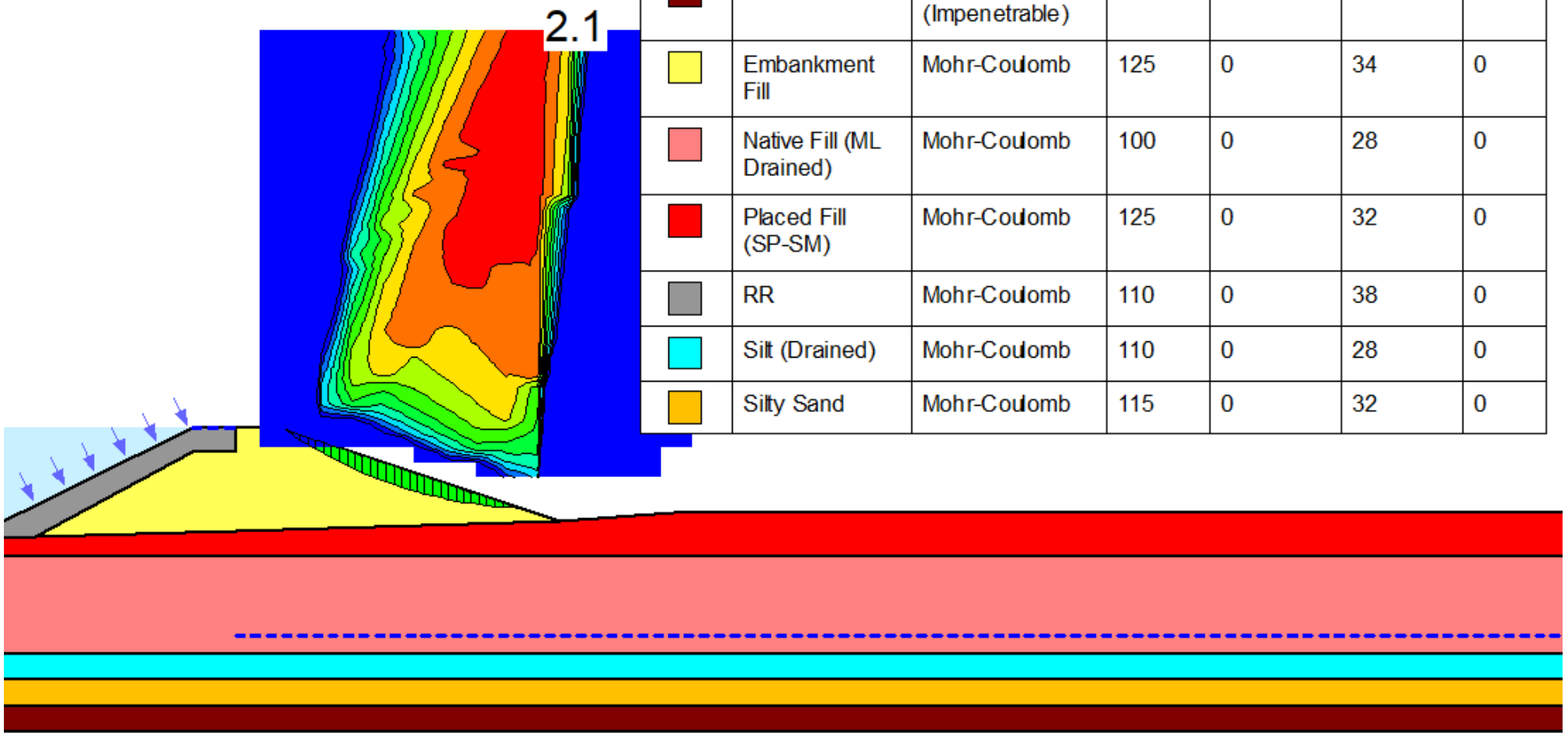
Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-2, End-of-Construction SLOPE/W Analysis	Checked By: Earl Fisher, PE
US Army Corps of Engineers, Philadelphia District	8/11/23



Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)				
	Embankment Fill	Mohr-Coulomb	125	0	34	0
	Native Fill (ML Drained)	Mohr-Coulomb	100	0	28	0
	Placed Fill (SP-SM)	Mohr-Coulomb	125	0	32	0
	RR	Mohr-Coulomb	110	0	38	0
	Silt (Drained)	Mohr-Coulomb	110	0	28	0
	Silty Sand	Mohr-Coulomb	115	0	32	0

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Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-2, Long-term (Steady State Seepage) SLOPE/W Analysis	Checked By: Earl Fisher, PE
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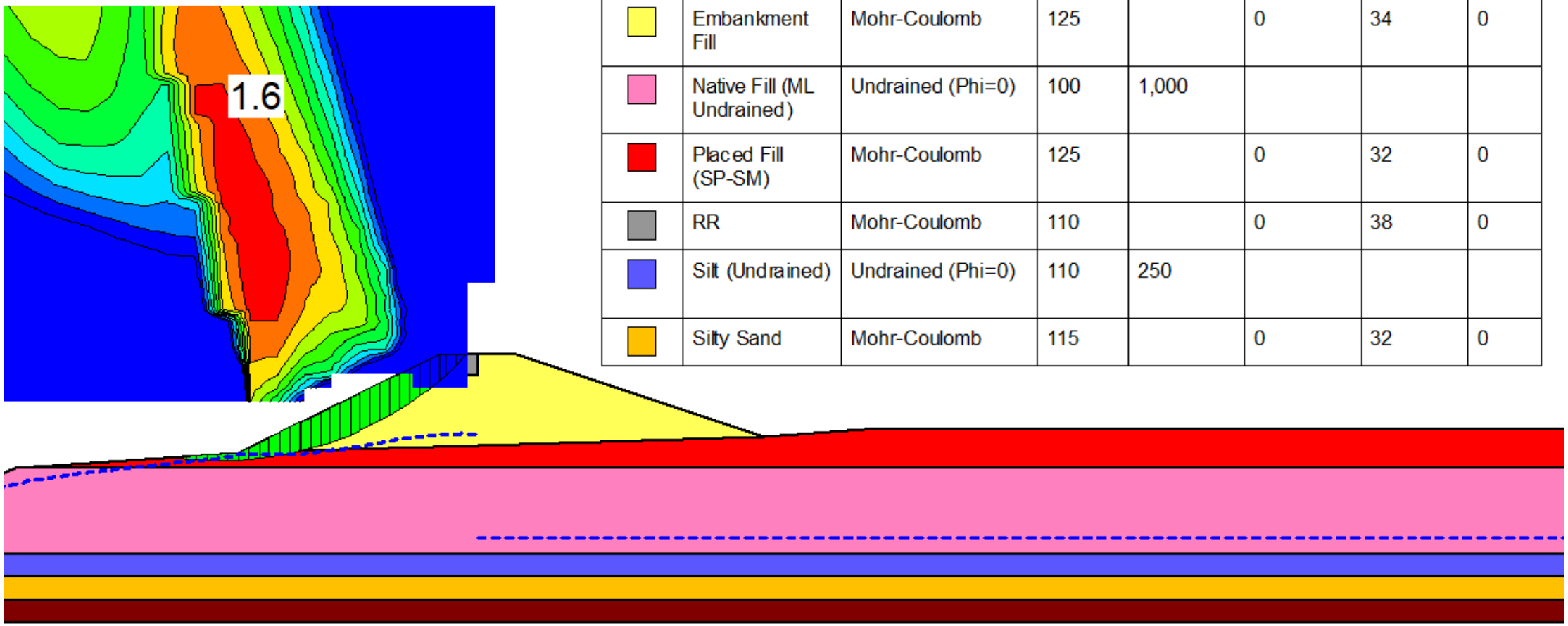

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Total Cohesion (psf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi-B (°)
	Bedrock	Bedrock (Impenetrable)					
	Embankment Fill	Mohr-Coulomb	125		0	34	0
	Native Fill (ML Undrained)	Undrained (Phi=0)	100	1,000			
	Placed Fill (SP-SM)	Mohr-Coulomb	125		0	32	0
	RR	Mohr-Coulomb	110		0	38	0
	Silt (Undrained)	Undrained (Phi=0)	110	250			
	Silty Sand	Mohr-Coulomb	115		0	32	0

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Eastwick FRM Feasibility Study	Designed By: Conor McCafferty, PE, PhD
BH-2, Rapid Drawdown SLOPE/W Analysis	Checked By:
US Army Corps of Engineers, Philadelphia District	8/11/23

Geostudio Reports

BH-1 Case I - Short Term

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:07:47 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1 Case I - Short Term

Kind: SLOPE/W
Analysis Type: Spencer
Settings
- PWP Conditions from: (none)
- Unit Weight of Water: 62.430189 pcf

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Grid and Radius
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No
- Tension Crack Option: (none)

Distribution
- F of S Calculation Option: Constant

Advanced
- Geometry Settings
  - Minimum Slip Surface Depth: 2 ft
  - Number of Slices: 30
- Factor of Safety Convergence Settings
  - Maximum Number of Iterations: 100

Tolerable difference in F of S: 0.001

Solution Settings

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 125 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 34 °

Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 125 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 32 °

Phi-B: 0 °

Silt (Undrained)

Slope Stability Material Model: Undrained (Phi=0)

Unit Weight: 110 pcf

Total Cohesion: 250 psf

Silty Sand

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 115 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 32 °

Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 110 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 38 °

Phi-B: 0 °

Native Fill (ML Undrained)

Slope Stability Material Model: Undrained (Phi=0)

Unit Weight: 100 pcf
Total Cohesion: 1,000 psf

Slip Surface Grid

Upper Left: (-15, 70) ft
Lower Left: (-15, 19) ft
Lower Right: (91, 19) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-13, 26) ft
Upper Right Coordinate: (142, 25) ft
Lower Left Coordinate: (-13, -2) ft
Lower Right Coordinate: (142, -2) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft
Point 9	-200 ft	-10 ft

Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft
Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft
Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Regions

	Material	Points	Area
Region 1	Silt (Undrained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Undrained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Undrained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Undrained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Slip Results

Slip Surfaces Analysed: 8021 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 2.2
Volume: 85.734989 ft³
Weight: 10,716.874 lbf
Resisting Moment: 317,199.3 lbf·ft
Activating Moment: 142,911.36 lbf·ft
Resisting Force: 6,618.1173 lbf

Activating Force: 2,980.4835 lbf
Slip Rank: 175 of 29,791 slip surfaces
Exit: (34.655611, 14.783905) ft
Entry: (2.5028188, 24.7) ft
Radius: 45.169726 ft
Center: (30.933333, 59.8) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	3.1271141 ft	24.212212 ft	0 psf	43.991092 psf	29.672366 psf	0 psf	0 psf	Embankment Fill
Slice 2	4.3757047 ft	23.270549 ft	0 psf	132.0829 psf	89.091038 psf	0 psf	0 psf	Embankment Fill
Slice 3	5.5295645 ft	22.456427 ft	0 psf	195.08078 psf	131.58365 psf	0 psf	0 psf	Embankment Fill
Slice 4	6.5886934 ft	21.757295 ft	0 psf	231.98798 psf	156.47787 psf	0 psf	0 psf	Embankment Fill
Slice 5	7.6478224 ft	21.099778 ft	0 psf	265.98419 psf	179.4086 psf	0 psf	0 psf	Embankment Fill
Slice 6	8.7069514 ft	20.481785 ft	0 psf	297.04666 psf	200.3605 psf	0 psf	0 psf	Embankment Fill
Slice 7	9.7660803 ft	19.901476 ft	0 psf	325.1515 psf	219.31746 psf	0 psf	0 psf	Embankment Fill
Slice 8	10.825209 ft	19.357229 ft	0 psf	350.27293 psf	236.26207 psf	0 psf	0 psf	Embankment Fill
Slice 9	11.884338 ft	18.847603 ft	0 psf	372.38251 psf	251.17517 psf	0 psf	0 psf	Embankment Fill
Slice 10	12.943467 ft	18.37132 ft	0 psf	391.44858 psf	264.0354 psf	0 psf	0 psf	Embankment Fill
Slice 11	14.002596 ft	17.92724 ft	0 psf	407.43571 psf	274.81886 psf	0 psf	0 psf	Embankment Fill
Slice 12	15.061725 ft	17.514349 ft	0 psf	420.30411 psf	283.4987 psf	0 psf	0 psf	Embankment Fill
Slice 13	16.120854 ft	17.13174 ft	0 psf	430.00918 psf	290.04485 psf	0 psf	0 psf	Embankment Fill
Slice 14	17.179983 ft	16.778605 ft	0 psf	436.50096 psf	294.42361 psf	0 psf	0 psf	Embankment Fill
Slice 15	18.239112 ft	16.454223 ft	0 psf	439.72358 psf	296.5973 psf	0 psf	0 psf	Embankment Fill
Slice 16	19.298241 ft	16.157951 ft	0 psf	439.61474 psf	296.52388 psf	0 psf	0 psf	Embankment Fill
Slice 17	20.35737 ft	15.889222 ft	0 psf	436.105 psf	294.15653 psf	0 psf	0 psf	Embankment Fill
Slice 18	21.416499 ft	15.647531 ft	0 psf	429.11719 psf	289.4432 psf	0 psf	0 psf	Embankment Fill
Slice 19	22.475628 ft	15.432436 ft	0 psf	418.56564 psf	282.32609 psf	0 psf	0 psf	Embankment Fill
Slice 20	23.534757 ft	15.243552 ft	0 psf	404.35533 psf	272.74112 psf	0 psf	0 psf	Embankment Fill
Slice 21	24.593886 ft	15.080547 ft	0 psf	386.38098 psf	260.61726 psf	0 psf	0 psf	Embankment Fill

Slice 22	25.653015 ft	14.943138 ft	0 psf	364.52597 psf	245.87587 psf	0 psf	0 psf	Embankment Fill
Slice 23	26.712144 ft	14.831091 ft	0 psf	338.6612 psf	228.42986 psf	0 psf	0 psf	Embankment Fill
Slice 24	27.771273 ft	14.744216 ft	0 psf	308.64368 psf	208.18279 psf	0 psf	0 psf	Embankment Fill
Slice 25	28.830402 ft	14.682367 ft	0 psf	274.31501 psf	185.02781 psf	0 psf	0 psf	Embankment Fill
Slice 26	29.889531 ft	14.645443 ft	0 psf	235.49958 psf	158.84648 psf	0 psf	0 psf	Embankment Fill
Slice 27	30.94866 ft	14.633381 ft	0 psf	192.00256 psf	129.50736 psf	0 psf	0 psf	Embankment Fill
Slice 28	32.007789 ft	14.646162 ft	0 psf	143.60746 psf	96.864453 psf	0 psf	0 psf	Embankment Fill
Slice 29	33.066918 ft	14.683807 ft	0 psf	90.073419 psf	60.755288 psf	0 psf	0 psf	Embankment Fill
Slice 30	34.126047 ft	14.746378 ft	0 psf	31.131993 psf	20.998795 psf	0 psf	0 psf	Embankment Fill

BH-1 Case II - Rapid Drawdown

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:25:25 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1 Case II - Rapid Drawdown

Kind: SLOPE/W
Parent: BH-1 Transient Seepage
Analysis Type: Spencer
Settings
    PWP Conditions from Parent Analysis: BH-1 Transient Seepage [(all)]
    Unit Weight of Water: 62.430189 pcf
Slip Surface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack Option: (none)
Distribution
    F of S Calculation Option: Constant
Advanced
    Geometry Settings
        Minimum Slip Surface Depth: 2 ft
        Number of Slices: 30
    Factor of Safety Convergence Settings

Maximum Number of Iterations: 100
Tolerable difference in F of S: 0.001
Solution Settings
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 34 °
Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

Silt (Undrained)

Slope Stability Material Model: Undrained (Phi=0)
Unit Weight: 110 pcf
Total Cohesion: 250 psf

Silty Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 38 °
Phi-B: 0 °

Native Fill (ML Undrained)

Slope Stability Material Model: Undrained (Phi=0)
Unit Weight: 100 pcf
Total Cohesion: 1,000 psf

Slip Surface Grid

Upper Left: (-79, 69.673715) ft
Lower Left: (-79, 18.673715) ft
Lower Right: (27, 18.673715) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-152, 26.464081) ft
Upper Right Coordinate: (3, 25.236282) ft
Lower Left Coordinate: (-152, -7.914297) ft
Lower Right Coordinate: (3, -7.914297) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft

Point 9	-200 ft	-10 ft
Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft
Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft
Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Regions

	Material	Points	Area
Region 1	Silt (Undrained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Undrained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Undrained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Undrained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Slip Results

Slip Surfaces Analysed: 12658 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 1.7
Volume: 86.050107 ft³
Weight: 9,650.8057 lbf
Resisting Moment: 302,840.11 lbf·ft
Activating Moment: 180,401.22 lbf·ft

Resisting Force: 5,832.5783 lbf
Activating Force: 3,472.7746 lbf
Slip Rank: 90 of 29,791 slip surfaces
Exit: (-30.636467, 12.210439) ft
Entry: (-0.96507942, 24.7) ft
Radius: 47.325714 ft
Center: (-33.066667, 59.473715) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	-30.129923 ft	12.241934 ft	-13.006146 psf	27.527575 psf	21.506899 psf	0 psf	0 psf	RR
Slice 2	-29.116835 ft	12.315857 ft	-17.612846 psf	79.436223 psf	62.062379 psf	0 psf	0 psf	RR
Slice 3	-28.103747 ft	12.411701 ft	-23.59022 psf	126.45156 psf	98.794788 psf	0 psf	0 psf	RR
Slice 4	-27.090659 ft	12.529602 ft	-30.944835 psf	168.83738 psf	131.91022 psf	0 psf	0 psf	RR
Slice 5	-26.077571 ft	12.669726 ft	-39.686429 psf	206.83215 psf	161.59498 psf	0 psf	0 psf	RR
Slice 6	-25.064483 ft	12.832273 ft	-49.827682 psf	240.65172 psf	188.01773 psf	0 psf	0 psf	RR
Slice 7	-24.051395 ft	13.01748 ft	-61.383529 psf	270.4918 psf	211.33136 psf	0 psf	0 psf	RR
Slice 8	-23.038307 ft	13.225618 ft	-74.370404 psf	296.53002 psf	231.67465 psf	0 psf	0 psf	RR
Slice 9	-22.025219 ft	13.456998 ft	-88.800887 psf	318.92779 psf	249.1737 psf	0 psf	0 psf	RR
Slice 10	-21.012131 ft	13.711974 ft	-104.61675 psf	337.83191 psf	263.94321 psf	0 psf	0 psf	RR
Slice 11	-19.999043 ft	13.990942 ft	-121.27311 psf	353.37607 psf	276.08764 psf	0 psf	0 psf	RR
Slice 12	-19.009415 ft	14.28676 ft	-129.74438 psf	364.67255 psf	245.97474 psf	0 psf	0 psf	Embankment Fill
Slice 13	-18.043249 ft	14.598772 ft	-124.82217 psf	376.90602 psf	254.22632 psf	0 psf	0 psf	Embankment Fill
Slice 14	-17.077082 ft	14.933925 ft	-110.98341 psf	386.0006 psf	260.36069 psf	0 psf	0 psf	Embankment Fill
Slice 15	-16.110916 ft	15.292747 ft	-103.0649 psf	392.03706 psf	264.43233 psf	0 psf	0 psf	Embankment Fill
Slice 16	-15.144749 ft	15.67582 ft	-93.855023 psf	395.08948 psf	266.49122 psf	0 psf	0 psf	Embankment Fill
Slice 17	-14.178582 ft	16.083787 ft	-79.390954 psf	395.22584 psf	266.58319 psf	0 psf	0 psf	Embankment Fill
Slice 18	-13.212416 ft	16.517357 ft	-71.454382 psf	392.50857 psf	264.75037 psf	0 psf	0 psf	Embankment Fill
Slice 19	-12.246249 ft	16.977315 ft	-61.475826 psf	386.99508 psf	261.03148 psf	0 psf	0 psf	Embankment Fill
Slice 20	-11.280083 ft	17.464528 ft	-56.844232 psf	378.7383 psf	255.46221 psf	0 psf	0 psf	Embankment Fill

Slice 21	-10.313916 ft	17.979957 ft	-57.983017 psf	367.7871 psf	248.07553 psf	0 psf	0 psf	Embankment Fill
Slice 22	-9.3477496 ft	18.524668 ft	-62.359997 psf	354.18684 psf	238.90204 psf	0 psf	0 psf	Embankment Fill
Slice 23	-8.381583 ft	19.099847 ft	-70.318211 psf	337.97986 psf	227.9703 psf	0 psf	0 psf	Embankment Fill
Slice 24	-7.4154164 ft	19.706819 ft	-87.66646 psf	319.20594 psf	215.30712 psf	0 psf	0 psf	Embankment Fill
Slice 25	-6.4492499 ft	20.347063 ft	-98.907194 psf	297.90287 psf	200.93802 psf	0 psf	0 psf	Embankment Fill
Slice 26	-5.4830833 ft	21.022244 ft	-120.12351 psf	274.10705 psf	184.88754 psf	0 psf	0 psf	Embankment Fill
Slice 27	-4.5813106 ft	21.684395 ft	-160.30526 psf	231.96773 psf	156.46421 psf	0 psf	0 psf	Embankment Fill
Slice 28	-3.6296976 ft	22.423415 ft	-214.94168 psf	166.09457 psf	129.7673 psf	0 psf	0 psf	RR
Slice 29	-2.5638503 ft	23.296161 ft	-263.13742 psf	99.59137 psf	77.809306 psf	0 psf	0 psf	RR
Slice 30	-1.4980031 ft	24.222745 ft	-317.87962 psf	32.88058 psf	25.689124 psf	0 psf	0 psf	RR

BH-1 Case II Steady-State Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:07:56 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1 Case II Steady-State Seepage

Kind: SEEP/W
Analysis Type: Steady-State
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10
- Unit Weight of Water: 62.430189 pcf
- Bulk Modulus of Pore-Fluid: 43,511,321 psf

Steps
Starting Time: 0 d
Duration: 0 d
Ending Time: 0 d

Materials

Bedrock

Hydraulic
Hydraulic Material Model: (none)

Embankment Fill

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand
Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt

K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Flood

Category: Hydraulic
Kind: Water Total Head 24.7 ft
Review: No

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft³/sec
Review: Yes

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)
Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)
Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)

Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %
Segment Curvature: 100 %

Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)

Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf

Num. Points: 20

Silt

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-08 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-08)
Data Point: (0.38282598, 3.2808382e-08)
Data Point: (0.70171264, 3.2808297e-08)
Data Point: (1.2862257, 3.2807803e-08)
Data Point: (2.357627, 3.2804918e-08)
Data Point: (4.3214847, 3.2787918e-08)
Data Point: (7.9211981, 3.2687878e-08)
Data Point: (14.519403, 3.2098343e-08)
Data Point: (26.613786, 2.8709381e-08)
Data Point: (48.782557, 1.4646413e-08)
Data Point: (89.417486, 8.7943611e-10)
Data Point: (163.90053, 5.7661633e-12)
Data Point: (300.42651, 2.2210716e-14)
Data Point: (550.67599, 8.0699426e-17)
Data Point: (1,009.3785, 2.9157388e-19)
Data Point: (1,850.1713, 1.0529291e-21)
Data Point: (3,391.3282, 3.8021442e-24)
Data Point: (6,216.2392, 1.3729513e-26)
Data Point: (11,394.247, 4.9577335e-29)
Data Point: (20,885.434, 1.7905327e-31)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-08 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)

Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)
Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)
Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)

Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)
Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %

Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function

Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)

Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.082479468
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.082479468
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.082479468)
Data Point: (0.38282598, 0.020807732)
Data Point: (0.70171264, 0.0044354516)
Data Point: (1.2862257, 0.001664852)
Data Point: (2.357627, 0.0012015262)
Data Point: (4.3214847, 0.0010239021)
Data Point: (7.9211981, 0.00088882819)
Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)

Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft
Point 9	-200 ft	-10 ft
Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft
Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft

Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Lines

	Start Point	End Point	Hydraulic Boundary	Length	Angle
Line 1	7	5	Drainage	13.038 ft	4.4 °
Line 2	5	6	Drainage	150 ft	0 °
Line 3	11	1	Flood	7.6158 ft	23.2 °
Line 4	4	3	Flood	95 ft	0 °
Line 5	3	2	Flood	20.006 ft	1.43 °
Line 6	13	4		1 ft	90 °
Line 7	7	16	Drainage	33.742 ft	-18.5 °
Line 8	16	18		5 ft	0 °
Line 9	18	15	Flood	5 ft	0 °
Line 10	18	19		2.7 ft	90 °
Line 11	19	12		9 ft	90 °
Line 12	19	20		5 ft	0 °
Line 13	12	21		23.013 ft	1.91 °
Line 14	9	22		200 ft	0 °
Line 15	22	10		200 ft	0 °
Line 16	13	23		200 ft	0 °
Line 17	23	14		200 ft	0 °
Line 18	17	21		8.0025 ft	1.43 °
Line 19	12	7		37.014 ft	1.55 °
Line 20	12	25		2 ft	90 °
Line 21	24	25		200 ft	0 °
Line 22	1	26	Flood	14.297 ft	4.01 °
Line 23	26	17	Flood	14.774 ft	4.01 °
Line 24	25	26		45.738 ft	0 °
Line 25	11	27		67 ft	0 °
Line 26	27	8		200 ft	0 °
Line 27	6	28		2 ft	90 °
Line 28	28	24		2 ft	90 °
Line 29	28	12		200 ft	0 °
Line 30	15	17	Flood	28.921 ft	26 °
Line 31	21	20		20.479 ft	28.5 °
Line 32	8	24		4 ft	90 °
Line 33	27	25		4 ft	90 °

Line 34	27	23		11 ft	90 °
Line 35	22	23		6 ft	90 °
Line 36	11	2	Flood	20.353 ft	27.8 °
Line 37	13	9		6 ft	90 °
Line 38	14	8		11 ft	90 °
Line 39	10	14		6 ft	90 °

Regions

	Material	Points	Area
Region 1	Silt (Drained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Drained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Drained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Drained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Mesh Properties

Global Element Size: 1 ft

BH-1 Case III Steady-State Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:07:56 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1 Case III Steady-State Seepage

Kind: SEEP/W
Analysis Type: Steady-State
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10
- Unit Weight of Water: 62.430189 pcf
- Bulk Modulus of Pore-Fluid: 43,511,321 psf

Steps
Starting Time: 0 d
Duration: 0 d
Ending Time: 0 d

Materials

Bedrock

Hydraulic
Hydraulic Material Model: (none)

Embankment Fill

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand
Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt

K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Flood

Category: Hydraulic
Kind: Water Total Head 24.7 ft
Review: No

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft³/sec
Review: Yes

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)
Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)
Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)

Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %
Segment Curvature: 100 %

Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)

Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf

Num. Points: 20

Silt

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-08 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-08)
Data Point: (0.38282598, 3.2808382e-08)
Data Point: (0.70171264, 3.2808297e-08)
Data Point: (1.2862257, 3.2807803e-08)
Data Point: (2.357627, 3.2804918e-08)
Data Point: (4.3214847, 3.2787918e-08)
Data Point: (7.9211981, 3.2687878e-08)
Data Point: (14.519403, 3.2098343e-08)
Data Point: (26.613786, 2.8709381e-08)
Data Point: (48.782557, 1.4646413e-08)
Data Point: (89.417486, 8.7943611e-10)
Data Point: (163.90053, 5.7661633e-12)
Data Point: (300.42651, 2.2210716e-14)
Data Point: (550.67599, 8.0699426e-17)
Data Point: (1,009.3785, 2.9157388e-19)
Data Point: (1,850.1713, 1.0529291e-21)
Data Point: (3,391.3282, 3.8021442e-24)
Data Point: (6,216.2392, 1.3729513e-26)
Data Point: (11,394.247, 4.9577335e-29)
Data Point: (20,885.434, 1.7905327e-31)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-08 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)

Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)
Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)
Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)

Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)
Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %

Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function

Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)

Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.082479468
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.082479468
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.082479468)
Data Point: (0.38282598, 0.020807732)
Data Point: (0.70171264, 0.0044354516)
Data Point: (1.2862257, 0.001664852)
Data Point: (2.357627, 0.0012015262)
Data Point: (4.3214847, 0.0010239021)
Data Point: (7.9211981, 0.00088882819)
Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)

Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft
Point 9	-200 ft	-10 ft
Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft
Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft

Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Lines

	Start Point	End Point	Hydraulic Boundary	Length	Angle
Line 1	7	5	Drainage	13.038 ft	4.4 °
Line 2	5	6	Drainage	150 ft	0 °
Line 3	11	1	Flood	7.6158 ft	23.2 °
Line 4	4	3	Flood	95 ft	0 °
Line 5	3	2	Flood	20.006 ft	1.43 °
Line 6	13	4		1 ft	90 °
Line 7	7	16	Drainage	33.742 ft	-18.5 °
Line 8	16	18		5 ft	0 °
Line 9	18	15	Flood	5 ft	0 °
Line 10	18	19		2.7 ft	90 °
Line 11	19	12		9 ft	90 °
Line 12	19	20		5 ft	0 °
Line 13	12	21		23.013 ft	1.91 °
Line 14	9	22		200 ft	0 °
Line 15	22	10		200 ft	0 °
Line 16	13	23		200 ft	0 °
Line 17	23	14		200 ft	0 °
Line 18	17	21		8.0025 ft	1.43 °
Line 19	12	7		37.014 ft	1.55 °
Line 20	12	25		2 ft	90 °
Line 21	24	25		200 ft	0 °
Line 22	1	26	Flood	14.297 ft	4.01 °
Line 23	26	17	Flood	14.774 ft	4.01 °
Line 24	25	26		45.738 ft	0 °
Line 25	11	27		67 ft	0 °
Line 26	27	8		200 ft	0 °
Line 27	6	28		2 ft	90 °
Line 28	28	24		2 ft	90 °
Line 29	28	12		200 ft	0 °
Line 30	15	17	Flood	28.921 ft	26 °
Line 31	21	20		20.479 ft	28.5 °
Line 32	8	24		4 ft	90 °
Line 33	27	25		4 ft	90 °

Line 34	27	23		11 ft	90 °
Line 35	22	23		6 ft	90 °
Line 36	11	2		20.353 ft	27.8 °
Line 37	13	9		6 ft	90 °
Line 38	14	8		11 ft	90 °
Line 39	10	14		6 ft	90 °

Regions

	Material	Points	Area
Region 1	Silt (Drained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Drained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Drained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Drained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Mesh Properties

Global Element Size: 1 ft

BH-1 Transient Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:18:50 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1 Transient Seepage

Kind: SEEP/W
Parent: BH-1 Case II Steady-State Seepage
Analysis Type: Transient
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Initial PWP Conditions from Parent Analysis: BH-1 Case II Steady-State Seepage [(last)]
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10

Unit Weight of Water: 62.430189 pcf
Bulk Modulus of Pore-Fluid: 43,511,321 psf

Settings

Exclude cumulative values: No

Steps

Starting Time: 0 d
Duration: 1 d
# of Steps: 10
Step Generation Method: Exponential
Initial Increment Size: 0.01 d
Save Steps Every: 1

Materials

Bedrock

Hydraulic

Hydraulic Material Model: (none)

Embankment Fill

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Undrained)

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt
K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand

Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Undrained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft^3/sec
Review: Yes

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)
Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)

Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)
Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec

Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-08 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-08)
Data Point: (0.38282598, 3.2808382e-08)
Data Point: (0.70171264, 3.2808297e-08)
Data Point: (1.2862257, 3.2807803e-08)
Data Point: (2.357627, 3.2804918e-08)
Data Point: (4.3214847, 3.2787918e-08)
Data Point: (7.9211981, 3.2687878e-08)
Data Point: (14.519403, 3.2098343e-08)
Data Point: (26.613786, 2.8709381e-08)
Data Point: (48.782557, 1.4646413e-08)
Data Point: (89.417486, 8.7943611e-10)
Data Point: (163.90053, 5.7661633e-12)
Data Point: (300.42651, 2.2210716e-14)
Data Point: (550.67599, 8.0699426e-17)
Data Point: (1,009.3785, 2.9157388e-19)
Data Point: (1,850.1713, 1.0529291e-21)
Data Point: (3,391.3282, 3.8021442e-24)
Data Point: (6,216.2392, 1.3729513e-26)
Data Point: (11,394.247, 4.9577335e-29)
Data Point: (20,885.434, 1.7905327e-31)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-08 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)

Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)
Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)

Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)
Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)
Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35

Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862

Data Points: Matric Suction (psf), Volumetric Water Content
- Data Point: (0.20885434, 0.35025549)
- Data Point: (0.38282598, 0.35025549)
- Data Point: (0.70171264, 0.35025549)
- Data Point: (1.2862257, 0.35025549)
- Data Point: (2.357627, 0.35025549)
- Data Point: (4.3214847, 0.35025549)
- Data Point: (7.9211981, 0.35025549)
- Data Point: (14.519403, 0.35025549)
- Data Point: (26.613786, 0.33009011)
- Data Point: (48.782557, 0.2005121)
- Data Point: (89.417486, 0.086942648)
- Data Point: (163.90053, 0.046460124)
- Data Point: (300.42651, 0.035109584)
- Data Point: (550.67599, 0.029980303)
- Data Point: (1,009.3785, 0.025919266)
- Data Point: (1,850.1713, 0.022256425)
- Data Point: (3,391.3282, 0.018953185)
- Data Point: (6,216.2392, 0.016015159)
- Data Point: (11,394.247, 0.013431662)
- Data Point: (20,885.434, 0.011178458)

Estimation Properties
- Vol. WC Estimation Method: Grain Size Function
- Saturated Water Content: 0.35
- Sample Material: Clay
- Liquid Limit: 10 %
- Diameter at 10% passing: 0.07
- Diameter at 60% passing: 1
- Maximum Suction: 20,885.434 psf
- Minimum Suction: 0.20885434 psf
- Num. Points: 20

RR

Model: Vol WC Data Point Function

Function: Volumetric Water Content vs. Water Pressure
- Compressibility: 0 /psf
- Saturated Water Content: 0.082479468
- Curve Fit to Data: 100 %
- Segment Curvature: 100 %

Porosity: 0.082479468

Data Points: Matric Suction (psf), Volumetric Water Content
- Data Point: (0.20885434, 0.082479468)
- Data Point: (0.38282598, 0.020807732)
- Data Point: (0.70171264, 0.0044354516)
- Data Point: (1.2862257, 0.001664852)
- Data Point: (2.357627, 0.0012015262)
- Data Point: (4.3214847, 0.0010239021)
- Data Point: (7.9211981, 0.00088882819)

Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)
Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft
Point 9	-200 ft	-10 ft
Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft

Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft
Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Lines

	Start Point	End Point	Hydraulic Boundary	Length	Angle
Line 1	7	5	Drainage	13.038 ft	4.4 °
Line 2	5	6	Drainage	150 ft	0 °
Line 3	11	1	Drainage	7.6158 ft	23.2 °
Line 4	4	3	Drainage	95 ft	0 °
Line 5	3	2	Drainage	20.006 ft	1.43 °
Line 6	13	4		1 ft	90 °
Line 7	7	16		33.742 ft	-18.5 °
Line 8	16	18		5 ft	0 °
Line 9	18	15		5 ft	0 °
Line 10	18	19		2.7 ft	90 °
Line 11	19	12		9 ft	90 °
Line 12	19	20		5 ft	0 °
Line 13	12	21		23.013 ft	1.91 °
Line 14	9	22		200 ft	0 °
Line 15	22	10		200 ft	0 °
Line 16	13	23		200 ft	0 °
Line 17	23	14		200 ft	0 °
Line 18	17	21		8.0025 ft	1.43 °
Line 19	12	7		37.014 ft	1.55 °
Line 20	12	25		2 ft	90 °
Line 21	24	25		200 ft	0 °
Line 22	1	26	Drainage	14.297 ft	4.01 °
Line 23	26	17	Drainage	14.774 ft	4.01 °
Line 24	25	26		45.738 ft	0 °
Line 25	11	27		67 ft	0 °
Line 26	27	8		200 ft	0 °
Line 27	6	28		2 ft	90 °
Line 28	28	24		2 ft	90 °
Line 29	28	12		200 ft	0 °
Line 30	15	17	Drainage	28.921 ft	26 °
Line 31	21	20		20.479 ft	28.5 °

Line 32	8	24		4 ft	90 °
Line 33	27	25		4 ft	90 °
Line 34	27	23		11 ft	90 °
Line 35	22	23		6 ft	90 °
Line 36	11	2	Drainage	20.353 ft	27.8 °
Line 37	13	9		6 ft	90 °
Line 38	14	8		11 ft	90 °
Line 39	10	14		6 ft	90 °

Regions

	Material	Points	Area
Region 1	Silt (Undrained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Undrained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Undrained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Undrained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Mesh Properties

Global Element Size: 1 ft

BH-1Case III - Long Term

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:08:04 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-1Case III - Long Term

Kind: SLOPE/W
Parent: BH-1 Case III Steady-State Seepage
Analysis Type: Bishop
Settings
    PWP Conditions from Parent Analysis: BH-1 Case III Steady-State Seepage [(last)]
    Unit Weight of Water: 62.430189 pcf
Slip Surface
    Direction of movement: Left to Right
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack Option: (none)
Distribution
    F of S Calculation Option: Constant
Advanced
    Geometry Settings
        Minimum Slip Surface Depth: 2 ft
        Number of Slices: 30
    Factor of Safety Convergence Settings

Maximum Number of Iterations: 100
Tolerable difference in F of S: 0.001

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 34 °
Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

Silty Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 38 °
Phi-B: 0 °

Silt (Drained)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 28 °
Phi-B: 0 °

Native Fill (ML Drained)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 100 pcf
Effective Cohesion: 0 psf

Effective Friction Angle: 28 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-15, 70) ft
Lower Left: (-15, 19) ft
Lower Right: (91, 19) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-13, 26) ft
Upper Right Coordinate: (142, 25) ft
Lower Left Coordinate: (-13, -2) ft
Lower Right Coordinate: (142, -2) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH1

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	7 ft
Point 9	-200 ft	-10 ft

Point 10	200 ft	-10 ft
Point 11	-67 ft	7 ft
Point 12	0 ft	13 ft
Point 13	-200 ft	-4 ft
Point 14	200 ft	-4 ft
Point 15	-5 ft	24.7 ft
Point 16	5 ft	24.7 ft
Point 17	-31 ft	12.033333 ft
Point 18	0 ft	24.7 ft
Point 19	0 ft	22 ft
Point 20	-5 ft	22 ft
Point 21	-23 ft	12.233333 ft
Point 22	0 ft	-10 ft
Point 23	0 ft	-4 ft
Point 24	200 ft	11 ft
Point 25	0 ft	11 ft
Point 26	-45.7377 ft	11 ft
Point 27	0 ft	7 ft
Point 28	200 ft	13 ft

Regions

	Material	Points	Area
Region 1	Silt (Drained)	25,26,1,11,27	243.37 ft²
Region 2	Bedrock	23,13,9,22	1,200 ft²
Region 3	Placed Fill (SP-SM)	7,5,6,28,12	338 ft²
Region 4	RR	20,19,18,15,17,21	85.867 ft²
Region 5	Embankment Fill	7,16,18,19,12	243.2 ft²
Region 6	Bedrock	14,23,22,10	1,200 ft²
Region 7	Silty Sand	8,27,23,14	2,200 ft²
Region 8	Silt (Drained)	24,25,27,8	800 ft²
Region 9	Native Fill (ML Drained)	17,21,12,25,26	53.864 ft²
Region 10	Silty Sand	27,11,2,3,4,13,23	969.5 ft²
Region 11	Native Fill (ML Drained)	24,25,12,28	400 ft²
Region 12	Embankment Fill	19,20,21,12	127.92 ft²

Slip Results

Slip Surfaces Analysed: 8646 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 2.2
Volume: 85.734989 ft³
Weight: 10,716.874 lbf
Resisting Moment: 317,212.52 lbf·ft
Activating Moment: 142,911.36 lbf·ft
Slip Rank: 127 of 29,791 slip surfaces

Exit: (34.655611, 14.783905) ft
Entry: (2.5028188, 24.7) ft
Radius: 45.169726 ft
Center: (30.933333, 59.8) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	3.1271141 ft	24.212212 ft	-1,578.1227 psf	49.274672 psf	33.236186 psf	0 psf	0 psf	Embankment Fill
Slice 2	4.3757047 ft	23.270549 ft	-1,519.3346 psf	146.35047 psf	98.714638 psf	0 psf	0 psf	Embankment Fill
Slice 3	5.5295645 ft	22.456427 ft	-1,468.5087 psf	214.06364 psf	144.38775 psf	0 psf	0 psf	Embankment Fill
Slice 4	6.5886934 ft	21.757295 ft	-1,424.8618 psf	252.36346 psf	170.22131 psf	0 psf	0 psf	Embankment Fill
Slice 5	7.6478224 ft	21.099778 ft	-1,383.8129 psf	286.90242 psf	193.51812 psf	0 psf	0 psf	Embankment Fill
Slice 6	8.7069514 ft	20.481785 ft	-1,345.2315 psf	317.75631 psf	214.32934 psf	0 psf	0 psf	Embankment Fill
Slice 7	9.7660803 ft	19.901476 ft	-1,309.0027 psf	344.99281 psf	232.70059 psf	0 psf	0 psf	Embankment Fill
Slice 8	10.825209 ft	19.357229 ft	-1,275.0252 psf	368.67181 psf	248.67227 psf	0 psf	0 psf	Embankment Fill
Slice 9	11.884338 ft	18.847603 ft	-1,243.2092 psf	388.84575 psf	262.27977 psf	0 psf	0 psf	Embankment Fill
Slice 10	12.943467 ft	18.37132 ft	-1,213.4747 psf	405.55997 psf	273.55365 psf	0 psf	0 psf	Embankment Fill
Slice 11	14.002596 ft	17.92724 ft	-1,185.7508 psf	418.85301 psf	282.51992 psf	0 psf	0 psf	Embankment Fill
Slice 12	15.061725 ft	17.514349 ft	-1,159.9739 psf	428.75686 psf	289.20015 psf	0 psf	0 psf	Embankment Fill
Slice 13	16.120854 ft	17.13174 ft	-1,136.0876 psf	435.2972 psf	293.61167 psf	0 psf	0 psf	Embankment Fill
Slice 14	17.179983 ft	16.778605 ft	-1,114.0413 psf	438.49356 psf	295.76764 psf	0 psf	0 psf	Embankment Fill
Slice 15	18.239112 ft	16.454223 ft	-1,093.79 psf	438.35947 psf	295.6772 psf	0 psf	0 psf	Embankment Fill
Slice 16	19.298241 ft	16.157951 ft	-1,075.2937 psf	434.90257 psf	293.34549 psf	0 psf	0 psf	Embankment Fill
Slice 17	20.35737 ft	15.889222 ft	-1,058.5169 psf	428.12463 psf	288.77371 psf	0 psf	0 psf	Embankment Fill
Slice 18	21.416499 ft	15.647531 ft	-1,043.4281 psf	418.02158 psf	281.95912 psf	0 psf	0 psf	Embankment Fill
Slice 19	22.475628 ft	15.432436 ft	-1,029.9997 psf	404.58348 psf	272.89501 psf	0 psf	0 psf	Embankment Fill
Slice 20	23.534757 ft	15.243552 ft	-1,018.2076 psf	387.79443 psf	261.57065 psf	0 psf	0 psf	Embankment Fill
Slice 21	24.593886 ft	15.080547 ft	-1,008.0312 psf	367.63243 psf	247.9712 psf	0 psf	0 psf	Embankment Fill
Slice	25.653015	14.943138	-999.4527	344.06921	232.07761			Embankment

22	ft	ft	psf	psf	psf	0 psf	0 psf	Fill
Slice 23	26.712144 ft	14.831091 ft	-992.45756 psf	317.07002 psf	213.86643 psf	0 psf	0 psf	Embankment Fill
Slice 24	27.771273 ft	14.744216 ft	-987.03393 psf	286.5933 psf	193.30962 psf	0 psf	0 psf	Embankment Fill
Slice 25	28.830402 ft	14.682367 ft	-983.17273 psf	252.59033 psf	170.37433 psf	0 psf	0 psf	Embankment Fill
Slice 26	29.889531 ft	14.645443 ft	-980.86752 psf	215.00483 psf	145.02259 psf	0 psf	0 psf	Embankment Fill
Slice 27	30.94866 ft	14.633381 ft	-980.1145 psf	173.77242 psf	117.21098 psf	0 psf	0 psf	Embankment Fill
Slice 28	32.007789 ft	14.646162 ft	-980.91241 psf	128.82005 psf	86.890219 psf	0 psf	0 psf	Embankment Fill
Slice 29	33.066918 ft	14.683807 ft	-983.26259 psf	80.065262 psf	54.004701 psf	0 psf	0 psf	Embankment Fill
Slice 30	34.126047 ft	14.746378 ft	-987.16891 psf	27.415412 psf	18.491929 psf	0 psf	0 psf	Embankment Fill

BH-2 Case I - Short Term

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:07:42 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Case I - Short Term

Kind: SLOPE/W
Analysis Type: Spencer
Settings
- PWP Conditions from: (none)
- Unit Weight of Water: 62.430189 pcf

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Grid and Radius
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No
- Tension Crack Option: (none)

Distribution
- F of S Calculation Option: Constant

Advanced
- Geometry Settings
  - Minimum Slip Surface Depth: 2 ft
  - Number of Slices: 30
- Factor of Safety Convergence Settings
  - Maximum Number of Iterations: 100

Tolerable difference in F of S: 0.001

Solution Settings

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 125 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 34 °

Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 125 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 32 °

Phi-B: 0 °

Silt (Undrained)

Slope Stability Material Model: Undrained (Phi=0)

Unit Weight: 110 pcf

Total Cohesion: 250 psf

Silty Sand

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 115 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 32 °

Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 110 pcf

Effective Cohesion: 0 psf

Effective Friction Angle: 38 °

Phi-B: 0 °

Native Fill (ML Undrained)

Slope Stability Material Model: Undrained (Phi=0)

Unit Weight: 100 pcf
Total Cohesion: 1,000 psf

Slip Surface Grid

Upper Left: (-15, 70) ft
Lower Left: (-15, 19) ft
Lower Right: (91, 19) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-13, 26) ft
Upper Right Coordinate: (142, 25) ft
Lower Left Coordinate: (-13, -2) ft
Lower Right Coordinate: (142, -2) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft
Point 9	-200 ft	7 ft

Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft
Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Undrained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Undrained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Undrained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Undrained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Slip Results

Slip Surfaces Analysed: 7932 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 2.2
Volume: 85.734989 ft³
Weight: 10,716.874 lbf
Resisting Moment: 317,199.3 lbf·ft
Activating Moment: 142,911.36 lbf·ft
Resisting Force: 6,618.1173 lbf
Activating Force: 2,980.4835 lbf
Slip Rank: 107 of 29,791 slip surfaces
Exit: (34.655611, 14.783905) ft
Entry: (2.5028188, 24.7) ft
Radius: 45.169726 ft
Center: (30.933333, 59.8) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	3.1271141 ft	24.212212 ft	0 psf	43.991092 psf	29.672366 psf	0 psf	0 psf	Embankment Fill
Slice 2	4.3757047 ft	23.270549 ft	0 psf	132.0829 psf	89.091038 psf	0 psf	0 psf	Embankment Fill
Slice 3	5.5295645 ft	22.456427 ft	0 psf	195.08078 psf	131.58365 psf	0 psf	0 psf	Embankment Fill
Slice 4	6.5886934 ft	21.757295 ft	0 psf	231.98798 psf	156.47787 psf	0 psf	0 psf	Embankment Fill
Slice 5	7.6478224 ft	21.099778 ft	0 psf	265.98419 psf	179.4086 psf	0 psf	0 psf	Embankment Fill
Slice 6	8.7069514 ft	20.481785 ft	0 psf	297.04666 psf	200.3605 psf	0 psf	0 psf	Embankment Fill
Slice 7	9.7660803 ft	19.901476 ft	0 psf	325.1515 psf	219.31746 psf	0 psf	0 psf	Embankment Fill
Slice 8	10.825209 ft	19.357229 ft	0 psf	350.27293 psf	236.26207 psf	0 psf	0 psf	Embankment Fill
Slice 9	11.884338 ft	18.847603 ft	0 psf	372.38251 psf	251.17517 psf	0 psf	0 psf	Embankment Fill
Slice 10	12.943467 ft	18.37132 ft	0 psf	391.44858 psf	264.0354 psf	0 psf	0 psf	Embankment Fill
Slice 11	14.002596 ft	17.92724 ft	0 psf	407.43571 psf	274.81886 psf	0 psf	0 psf	Embankment Fill
Slice 12	15.061725 ft	17.514349 ft	0 psf	420.30411 psf	283.4987 psf	0 psf	0 psf	Embankment Fill
Slice 13	16.120854 ft	17.13174 ft	0 psf	430.00918 psf	290.04485 psf	0 psf	0 psf	Embankment Fill
Slice 14	17.179983 ft	16.778605 ft	0 psf	436.50096 psf	294.42361 psf	0 psf	0 psf	Embankment Fill
Slice 15	18.239112 ft	16.454223 ft	0 psf	439.72358 psf	296.5973 psf	0 psf	0 psf	Embankment Fill
Slice 16	19.298241 ft	16.157951 ft	0 psf	439.61474 psf	296.52388 psf	0 psf	0 psf	Embankment Fill

Slice 17	20.35737 ft	15.889222 ft	0 psf	436.105 psf	294.15653 psf	0 psf	0 psf	Embankment Fill
Slice 18	21.416499 ft	15.647531 ft	0 psf	429.11719 psf	289.4432 psf	0 psf	0 psf	Embankment Fill
Slice 19	22.475628 ft	15.432436 ft	0 psf	418.56564 psf	282.32609 psf	0 psf	0 psf	Embankment Fill
Slice 20	23.534757 ft	15.243552 ft	0 psf	404.35533 psf	272.74112 psf	0 psf	0 psf	Embankment Fill
Slice 21	24.593886 ft	15.080547 ft	0 psf	386.38098 psf	260.61726 psf	0 psf	0 psf	Embankment Fill
Slice 22	25.653015 ft	14.943138 ft	0 psf	364.52597 psf	245.87587 psf	0 psf	0 psf	Embankment Fill
Slice 23	26.712144 ft	14.831091 ft	0 psf	338.6612 psf	228.42986 psf	0 psf	0 psf	Embankment Fill
Slice 24	27.771273 ft	14.744216 ft	0 psf	308.64368 psf	208.18279 psf	0 psf	0 psf	Embankment Fill
Slice 25	28.830402 ft	14.682367 ft	0 psf	274.31501 psf	185.02781 psf	0 psf	0 psf	Embankment Fill
Slice 26	29.889531 ft	14.645443 ft	0 psf	235.49958 psf	158.84648 psf	0 psf	0 psf	Embankment Fill
Slice 27	30.94866 ft	14.633381 ft	0 psf	192.00256 psf	129.50736 psf	0 psf	0 psf	Embankment Fill
Slice 28	32.007789 ft	14.646162 ft	0 psf	143.60746 psf	96.864453 psf	0 psf	0 psf	Embankment Fill
Slice 29	33.066918 ft	14.683807 ft	0 psf	90.073419 psf	60.755288 psf	0 psf	0 psf	Embankment Fill
Slice 30	34.126047 ft	14.746378 ft	0 psf	31.131993 psf	20.998795 psf	0 psf	0 psf	Embankment Fill

BH-2 Case II - Rapid Drawdown

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:18:31 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Case II - Rapid Drawdown

Kind: SLOPE/W
Parent: BH-2 Transient Seepage
Analysis Type: Spencer
Settings
    PWP Conditions from Parent Analysis: BH-2 Transient Seepage [(all)]
    Unit Weight of Water: 62.430189 pcf
Slip Surface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack Option: (none)
Distribution
    F of S Calculation Option: Constant
Advanced
    Geometry Settings
        Minimum Slip Surface Depth: 2 ft
        Number of Slices: 30
    Factor of Safety Convergence Settings

Maximum Number of Iterations: 100
Tolerable difference in F of S: 0.001
Solution Settings
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 34 °
Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

Silt (Undrained)

Slope Stability Material Model: Undrained (Phi=0)
Unit Weight: 110 pcf
Total Cohesion: 250 psf

Silty Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 38 °
Phi-B: 0 °

Native Fill (ML Undrained)

Slope Stability Material Model: Undrained (Phi=0)
Unit Weight: 100 pcf
Total Cohesion: 1,000 psf

Slip Surface Grid

Upper Left: (-79, 69.673715) ft
Lower Left: (-79, 18.673715) ft
Lower Right: (27, 18.673715) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-152, 26.464081) ft
Upper Right Coordinate: (3, 25.236282) ft
Lower Left Coordinate: (-152, -7.914297) ft
Lower Right Coordinate: (3, -7.914297) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft

Point 9	-200 ft	7 ft
Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft
Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Undrained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Undrained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Undrained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Undrained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Slip Results

Slip Surfaces Analysed: 12399 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 1.7
Volume: 86.050107 ft³
Weight: 9,650.8057 lbf
Resisting Moment: 302,840.11 lbf·ft
Activating Moment: 180,401.22 lbf·ft
Resisting Force: 5,832.5783 lbf
Activating Force: 3,472.7746 lbf
Slip Rank: 43 of 29,791 slip surfaces
Exit: (-30.636467, 12.210439) ft
Entry: (-0.96507942, 24.7) ft
Radius: 47.325714 ft
Center: (-33.066667, 59.473715) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	-30.129923 ft	12.241934 ft	-27.390514 psf	27.527575 psf	21.506899 psf	0 psf	0 psf	RR
Slice 2	-29.116835 ft	12.315857 ft	-32.000286 psf	79.436223 psf	62.062379 psf	0 psf	0 psf	RR
Slice 3	-28.103747 ft	12.411701 ft	-37.978628 psf	126.45156 psf	98.794788 psf	0 psf	0 psf	RR
Slice 4	-27.090659 ft	12.529602 ft	-45.333133 psf	168.83738 psf	131.91022 psf	0 psf	0 psf	RR
Slice 5	-26.077571 ft	12.669726 ft	-54.074422 psf	206.83215 psf	161.59498 psf	0 psf	0 psf	RR
Slice 6	-25.064483 ft	12.832273 ft	-64.215341 psf	240.65172 psf	188.01773 psf	0 psf	0 psf	RR
Slice 7	-24.051395 ft	13.01748 ft	-75.770804 psf	270.4918 psf	211.33136 psf	0 psf	0 psf	RR
Slice 8	-23.038307 ft	13.225618 ft	-88.756981 psf	296.53002 psf	231.67465 psf	0 psf	0 psf	RR
Slice 9	-22.025219 ft	13.456998 ft	-103.1788 psf	318.92779 psf	249.1737 psf	0 psf	0 psf	RR
Slice 10	-21.012131 ft	13.711974 ft	-118.92303 psf	337.83191 psf	263.94321 psf	0 psf	0 psf	RR
Slice 11	-19.999043 ft	13.990942 ft	-135.21338 psf	353.37607 psf	276.08764 psf	0 psf	0 psf	RR
Slice 12	-19.009415 ft	14.28676 ft	-144.25752 psf	364.67255 psf	245.97474 psf	0 psf	0 psf	Embankment Fill
Slice 13	-18.043249 ft	14.598772 ft	-140.85423 psf	376.90602 psf	254.22632 psf	0 psf	0 psf	Embankment Fill
Slice 14	-17.077082 ft	14.933925 ft	-127.49868 psf	386.0006 psf	260.36069 psf	0 psf	0 psf	Embankment Fill
Slice 15	-16.110916 ft	15.292747 ft	-121.49626 psf	392.03706 psf	264.43233 psf	0 psf	0 psf	Embankment Fill
Slice	-15.144749	15.67582	-112.33711	395.08948	266.49122	0 psf	0 psf	Embankment

16	ft	ft	psf	psf	psf			Fill
Slice 17	-14.178582 ft	16.083787 ft	-94.886666 psf	395.22584 psf	266.58319 psf	0 psf	0 psf	Embankment Fill
Slice 18	-13.212416 ft	16.517357 ft	-85.587006 psf	392.50857 psf	264.75037 psf	0 psf	0 psf	Embankment Fill
Slice 19	-12.246249 ft	16.977315 ft	-72.78731 psf	386.99508 psf	261.03148 psf	0 psf	0 psf	Embankment Fill
Slice 20	-11.280083 ft	17.464528 ft	-65.487465 psf	378.7383 psf	255.46221 psf	0 psf	0 psf	Embankment Fill
Slice 21	-10.313916 ft	17.979957 ft	-64.352856 psf	367.7871 psf	248.07553 psf	0 psf	0 psf	Embankment Fill
Slice 22	-9.3477496 ft	18.524668 ft	-66.798759 psf	354.18684 psf	238.90204 psf	0 psf	0 psf	Embankment Fill
Slice 23	-8.381583 ft	19.099847 ft	-73.099009 psf	337.97986 psf	227.9703 psf	0 psf	0 psf	Embankment Fill
Slice 24	-7.4154164 ft	19.706819 ft	-88.467564 psf	319.20594 psf	215.30712 psf	0 psf	0 psf	Embankment Fill
Slice 25	-6.4492499 ft	20.347063 ft	-98.532026 psf	297.90287 psf	200.93802 psf	0 psf	0 psf	Embankment Fill
Slice 26	-5.4830833 ft	21.022244 ft	-121.24181 psf	274.10705 psf	184.88754 psf	0 psf	0 psf	Embankment Fill
Slice 27	-4.5813106 ft	21.684395 ft	-161.04191 psf	231.96773 psf	156.46421 psf	0 psf	0 psf	Embankment Fill
Slice 28	-3.6296976 ft	22.423415 ft	-215.78465 psf	166.09457 psf	129.7673 psf	0 psf	0 psf	RR
Slice 29	-2.5638503 ft	23.296161 ft	-263.92137 psf	99.59137 psf	77.809306 psf	0 psf	0 psf	RR
Slice 30	-1.4980031 ft	24.222745 ft	-318.62043 psf	32.88058 psf	25.689124 psf	0 psf	0 psf	RR

BH-2 Case II Steady-State Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:08:04 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Case II Steady-State Seepage

Kind: SEEP/W
Analysis Type: Steady-State
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10
- Unit Weight of Water: 62.430189 pcf
- Bulk Modulus of Pore-Fluid: 43,511,321 psf

Steps
Starting Time: 0 d
Duration: 0 d
Ending Time: 0 d

Materials

Bedrock

Hydraulic
Hydraulic Material Model: (none)

Embankment Fill

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand
Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt

K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Flood

Category: Hydraulic
Kind: Water Total Head 24.7 ft
Review: No

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft³/sec
Review: Yes

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)
Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)
Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)

Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %
Segment Curvature: 100 %

Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)

Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf

Num. Points: 20

Silt

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-08 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-08)
Data Point: (0.38282598, 3.2808382e-08)
Data Point: (0.70171264, 3.2808297e-08)
Data Point: (1.2862257, 3.2807803e-08)
Data Point: (2.357627, 3.2804918e-08)
Data Point: (4.3214847, 3.2787918e-08)
Data Point: (7.9211981, 3.2687878e-08)
Data Point: (14.519403, 3.2098343e-08)
Data Point: (26.613786, 2.8709381e-08)
Data Point: (48.782557, 1.4646413e-08)
Data Point: (89.417486, 8.7943611e-10)
Data Point: (163.90053, 5.7661633e-12)
Data Point: (300.42651, 2.2210716e-14)
Data Point: (550.67599, 8.0699426e-17)
Data Point: (1,009.3785, 2.9157388e-19)
Data Point: (1,850.1713, 1.0529291e-21)
Data Point: (3,391.3282, 3.8021442e-24)
Data Point: (6,216.2392, 1.3729513e-26)
Data Point: (11,394.247, 4.9577335e-29)
Data Point: (20,885.434, 1.7905327e-31)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-08 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)

Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)
Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)
Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)

Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)
Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %

Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function

Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)

Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.082479468
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.082479468
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.082479468)
Data Point: (0.38282598, 0.020807732)
Data Point: (0.70171264, 0.0044354516)
Data Point: (1.2862257, 0.001664852)
Data Point: (2.357627, 0.0012015262)
Data Point: (4.3214847, 0.0010239021)
Data Point: (7.9211981, 0.00088882819)
Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)

Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft
Point 9	-200 ft	7 ft
Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft

Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Lines

	Start Point	End Point	Length	Angle	Hydraulic Boundary
Line 1	11	13	3 ft	90 °	
Line 2	14	12	3 ft	90 °	
Line 3	7	5	13.038 ft	4.4 °	Drainage
Line 4	5	6	150 ft	0 °	Drainage
Line 5	6	8	5 ft	90 °	
Line 6	8	10	3 ft	90 °	
Line 7	16	1	7.6158 ft	23.2 °	Flood
Line 8	4	3	95 ft	0 °	Flood
Line 9	3	2	20.006 ft	1.43 °	Flood
Line 10	11	18	3 ft	90 °	
Line 11	18	4	1 ft	90 °	
Line 12	19	12	3 ft	90 °	
Line 13	21	23	28.921 ft	26 °	Flood
Line 14	7	22	33.742 ft	-18.5 °	Drainage
Line 15	22	24	5 ft	0 °	
Line 16	24	21	5 ft	0 °	Flood
Line 17	25	16	14.997 ft	27.8 °	Flood
Line 18	24	26	2.7 ft	90 °	
Line 19	26	17	9 ft	90 °	
Line 20	26	27	5 ft	0 °	
Line 21	17	28	23.013 ft	1.91 °	
Line 22	27	28	20.479 ft	28.5 °	
Line 23	13	29	200 ft	0 °	
Line 24	29	14	200 ft	0 °	
Line 25	12	30	200 ft	0 °	
Line 26	30	11	200 ft	0 °	

Line 27	30	29	3 ft	90 °	
Line 28	1	23	29.071 ft	4.01 °	Flood
Line 29	23	28	8.0025 ft	1.43 °	
Line 30	17	7	37.014 ft	1.55 °	
Line 31	2	31	3.2137 ft	27.8 °	Flood
Line 32	31	25	2.1424 ft	27.8 °	Flood
Line 33	10	32	8 ft	90 °	
Line 34	32	19	3 ft	90 °	
Line 35	19	33	200 ft	0 °	
Line 36	33	18	200 ft	0 °	
Line 37	30	33	3 ft	90 °	
Line 38	32	34	200 ft	0 °	
Line 39	34	31	82.158 ft	0 °	
Line 40	33	34	3 ft	90 °	
Line 41	1	35	60 ft	0 °	
Line 42	35	8	200 ft	0 °	
Line 43	34	35	11 ft	90 °	
Line 44	35	17	3 ft	90 °	

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Drained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Drained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Drained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Drained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Mesh Properties

Global Element Size: 1 ft

BH-2 Case III - Long Term

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:07:54 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Case III - Long Term

Kind: SLOPE/W
Parent: BH-2 Case III Steady-State Seepage
Analysis Type: Bishop
Settings
    PWP Conditions from Parent Analysis: BH-2 Case III Steady-State Seepage [(last)]
    Unit Weight of Water: 62.430189 pcf
Slip Surface
    Direction of movement: Left to Right
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack Option: (none)
Distribution
    F of S Calculation Option: Constant
Advanced
    Geometry Settings
        Minimum Slip Surface Depth: 2 ft
        Number of Slices: 30
    Factor of Safety Convergence Settings

Maximum Number of Iterations: 100
Tolerable difference in F of S: 0.001

Materials

Bedrock

Slope Stability Material Model: Bedrock (Impenetrable)

Embankment Fill

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 34 °
Phi-B: 0 °

Placed Fill (SP-SM)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

Silty Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

RR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 38 °
Phi-B: 0 °

Silt (Drained)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 28 °
Phi-B: 0 °

Native Fill (ML Drained)

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 100 pcf
Effective Cohesion: 0 psf

Effective Friction Angle: 28 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-15, 70) ft
Lower Left: (-15, 19) ft
Lower Right: (91, 19) ft
Grid Horizontal Increment: 30
Grid Vertical Increment: 30

Slip Surface Radius

Upper Left Coordinate: (-13, 26) ft
Upper Right Coordinate: (142, 25) ft
Lower Left Coordinate: (-13, -2) ft
Lower Right Coordinate: (142, -2) ft
Number of Increments: 30
Use Left Projection: No
Left Projection Angle: 135 °
Use Right Projection: No
Right Projection Angle: 45 °

Slip Surface Limits

Left Coordinate: (-200, -3) ft
Right Coordinate: (200, 15) ft

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft
Point 9	-200 ft	7 ft

Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft
Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Drained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Drained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Drained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Drained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Slip Results

Slip Surfaces Analysed: 8630 of 29791 converged

Current Slip Surface

Slip Surface: 23,480
Factor of Safety: 1.7
Volume: 85.734989 ft³
Weight: 10,716.874 lbf
Resisting Moment: 247,576.19 lbf·ft
Activating Moment: 142,911.36 lbf·ft
Slip Rank: 665 of 29,791 slip surfaces
Exit: (34.655611, 14.783905) ft
Entry: (2.5028188, 24.7) ft
Radius: 45.169726 ft
Center: (30.933333, 59.8) ft

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	3.1271141 ft	24.212212 ft	-264.34194 psf	46.752849 psf	31.535195 psf	0 psf	0 psf	Embankment Fill
Slice 2	4.3757047 ft	23.270549 ft	-209.60147 psf	139.26628 psf	93.936294 psf	0 psf	0 psf	Embankment Fill
Slice 3	5.5295645 ft	22.456427 ft	-163.86176 psf	204.22853 psf	137.75388 psf	0 psf	0 psf	Embankment Fill
Slice 4	6.5886934 ft	21.757295 ft	-125.81194 psf	241.31916 psf	162.77183 psf	0 psf	0 psf	Embankment Fill
Slice 5	7.6478224 ft	21.099778 ft	-91.379262 psf	274.95447 psf	185.45913 psf	0 psf	0 psf	Embankment Fill
Slice 6	8.7069514 ft	20.481785 ft	-60.120233 psf	305.17951 psf	205.84618 psf	0 psf	0 psf	Embankment Fill
Slice 7	9.7660803 ft	19.901476 ft	-31.818287 psf	332.03405 psf	223.9598 psf	0 psf	0 psf	Embankment Fill
Slice 8	10.825209 ft	19.357229 ft	-6.2675863 psf	355.55248 psf	239.82318 psf	0 psf	0 psf	Embankment Fill
Slice 9	11.884338 ft	18.847603 ft	16.659109 psf	378.31782 psf	243.94188 psf	0 psf	0 psf	Embankment Fill
Slice 10	12.943467 ft	18.37132 ft	37.065191 psf	398.05088 psf	243.48792 psf	0 psf	0 psf	Embankment Fill
Slice 11	14.002596 ft	17.92724 ft	55.218932 psf	413.86279 psf	241.90834 psf	0 psf	0 psf	Embankment Fill
Slice 12	15.061725 ft	17.514349 ft	71.210063 psf	425.84048 psf	239.20124 psf	0 psf	0 psf	Embankment Fill
Slice 13	16.120854 ft	17.13174 ft	85.126997 psf	434.05976 psf	235.35812 psf	0 psf	0 psf	Embankment Fill
Slice 14	17.179983 ft	16.778605 ft	97.017317 psf	438.58154 psf	230.38798 psf	0 psf	0 psf	Embankment Fill
Slice 15	18.239112 ft	16.454223 ft	106.98434 psf	439.46385 psf	224.26026 psf	0 psf	0 psf	Embankment Fill
Slice 16	19.298241 ft	16.157951 ft	115.12064 psf	436.7536 psf	216.94417 psf	0 psf	0 psf	Embankment Fill
Slice 17	20.35737 ft	15.889222 ft	121.47265 psf	430.4842 psf	208.43093 psf	0 psf	0 psf	Embankment Fill

Slice 18	21.416499 ft	15.647531 ft	126.07861 psf	420.68061 psf	198.71156 psf	0 psf	0 psf	Embankment Fill
Slice 19	22.475628 ft	15.432436 ft	128.96294 psf	407.35934 psf	187.78074 psf	0 psf	0 psf	Embankment Fill
Slice 20	23.534757 ft	15.243552 ft	130.12026 psf	390.52807 psf	175.64728 psf	0 psf	0 psf	Embankment Fill
Slice 21	24.593886 ft	15.080547 ft	129.55775 psf	370.18908 psf	162.30788 psf	0 psf	0 psf	Embankment Fill
Slice 22	25.653015 ft	14.943138 ft	127.21282 psf	346.33502 psf	147.79979 psf	0 psf	0 psf	Embankment Fill
Slice 23	26.712144 ft	14.831091 ft	123.05787 psf	318.95541 psf	132.13456 psf	0 psf	0 psf	Embankment Fill
Slice 24	27.771273 ft	14.744216 ft	116.95814 psf	288.0312 psf	115.39024 psf	0 psf	0 psf	Embankment Fill
Slice 25	28.830402 ft	14.682367 ft	108.79626 psf	253.54142 psf	97.631843 psf	0 psf	0 psf	Embankment Fill
Slice 26	29.889531 ft	14.645443 ft	98.193106 psf	215.45979 psf	79.097378 psf	0 psf	0 psf	Embankment Fill
Slice 27	30.94866 ft	14.633381 ft	84.450832 psf	173.7663 psf	60.244046 psf	0 psf	0 psf	Embankment Fill
Slice 28	32.007789 ft	14.646162 ft	66.853585 psf	128.45928 psf	41.553565 psf	0 psf	0 psf	Embankment Fill
Slice 29	33.066918 ft	14.683807 ft	44.556584 psf	79.559117 psf	23.609506 psf	0 psf	0 psf	Embankment Fill
Slice 30	34.126047 ft	14.746378 ft	17.067945 psf	27.101875 psf	6.7679709 psf	0 psf	0 psf	Embankment Fill

BH-2 Case III Steady-State Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 42
Date: 08/11/2023
Time: 10:59:18 AM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:59:39 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Case III Steady-State Seepage

Kind: SEEP/W
Analysis Type: Steady-State
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10
- Unit Weight of Water: 62.430189 pcf
- Bulk Modulus of Pore-Fluid: 43,511,321 psf

Steps
Starting Time: 0 d
Duration: 0 d
Ending Time: 0 d

Materials

Bedrock

Hydraulic
Hydraulic Material Model: (none)

Embankment Fill

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand
Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt

K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Drained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Flood

Category: Hydraulic
Kind: Water Total Head 24.7 ft
Review: No

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft³/sec
Review: Yes

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)
Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)
Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)

Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %
Segment Curvature: 100 %

Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)

Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf

Num. Points: 20

Silt

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-08 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-08)
Data Point: (0.38282598, 3.2808382e-08)
Data Point: (0.70171264, 3.2808297e-08)
Data Point: (1.2862257, 3.2807803e-08)
Data Point: (2.357627, 3.2804918e-08)
Data Point: (4.3214847, 3.2787918e-08)
Data Point: (7.9211981, 3.2687878e-08)
Data Point: (14.519403, 3.2098343e-08)
Data Point: (26.613786, 2.8709381e-08)
Data Point: (48.782557, 1.4646413e-08)
Data Point: (89.417486, 8.7943611e-10)
Data Point: (163.90053, 5.7661633e-12)
Data Point: (300.42651, 2.2210716e-14)
Data Point: (550.67599, 8.0699426e-17)
Data Point: (1,009.3785, 2.9157388e-19)
Data Point: (1,850.1713, 1.0529291e-21)
Data Point: (3,391.3282, 3.8021442e-24)
Data Point: (6,216.2392, 1.3729513e-26)
Data Point: (11,394.247, 4.9577335e-29)
Data Point: (20,885.434, 1.7905327e-31)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-08 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)

Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)
Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)
Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)

Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)
Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %

Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function

Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)

Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.082479468
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.082479468
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.082479468)
Data Point: (0.38282598, 0.020807732)
Data Point: (0.70171264, 0.0044354516)
Data Point: (1.2862257, 0.001664852)
Data Point: (2.357627, 0.0012015262)
Data Point: (4.3214847, 0.0010239021)
Data Point: (7.9211981, 0.00088882819)
Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)

Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft
Point 9	-200 ft	7 ft
Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft

Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Lines

	Start Point	End Point	Length	Angle	Hydraulic Boundary
Line 1	11	13	3 ft	90 °	
Line 2	14	12	3 ft	90 °	
Line 3	7	5	13.038 ft	4.4 °	Drainage
Line 4	5	6	150 ft	0 °	Drainage
Line 5	6	8	5 ft	90 °	
Line 6	8	10	3 ft	90 °	
Line 7	16	1	7.6158 ft	23.2 °	Flood
Line 8	4	3	95 ft	0 °	Flood
Line 9	3	2	20.006 ft	1.43 °	Flood
Line 10	11	18	3 ft	90 °	
Line 11	18	4	1 ft	90 °	
Line 12	19	12	3 ft	90 °	
Line 13	21	23	28.921 ft	26 °	Flood
Line 14	7	22	33.742 ft	-18.5 °	Drainage
Line 15	22	24	5 ft	0 °	
Line 16	24	21	5 ft	0 °	Flood
Line 17	25	16	14.997 ft	27.8 °	Flood
Line 18	24	26	2.7 ft	90 °	
Line 19	26	17	9 ft	90 °	
Line 20	26	27	5 ft	0 °	
Line 21	17	28	23.013 ft	1.91 °	
Line 22	27	28	20.479 ft	28.5 °	
Line 23	13	29	200 ft	0 °	
Line 24	29	14	200 ft	0 °	
Line 25	12	30	200 ft	0 °	
Line 26	30	11	200 ft	0 °	

Line 27	30	29	3 ft	90 °	
Line 28	1	23	29.071 ft	4.01 °	Flood
Line 29	23	28	8.0025 ft	1.43 °	
Line 30	17	7	37.014 ft	1.55 °	
Line 31	2	31	3.2137 ft	27.8 °	Flood
Line 32	31	25	2.1424 ft	27.8 °	Flood
Line 33	10	32	8 ft	90 °	
Line 34	32	19	3 ft	90 °	
Line 35	19	33	200 ft	0 °	
Line 36	33	18	200 ft	0 °	
Line 37	30	33	3 ft	90 °	
Line 38	32	34	200 ft	0 °	
Line 39	34	31	82.158 ft	0 °	
Line 40	33	34	3 ft	90 °	
Line 41	1	35	60 ft	0 °	
Line 42	35	8	200 ft	0 °	
Line 43	34	35	11 ft	90 °	
Line 44	35	17	3 ft	90 °	

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Drained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Drained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Drained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Drained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Mesh Properties

Global Element Size: 1 ft

BH-2 Transient Seepage

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File Information

File Version: 11.03
Title: Eastwick Levee
Created By: McCafferty, Conor M CIV USARMY CENAP (USA)
Last Edited By: McCafferty, Conor M CIV USARMY CENAP (USA)
Revision Number: 41
Date: 08/03/2023
Time: 02:51:01 PM
Tool Version: 11.3.0.23668
File Name: Levee.gsz
Directory: I:\Civil Works\Planning Studies\Eastwick Landuse Planning\Feasibility Study\Calculations\Levee\
Last Solved Date: 08/11/2023
Last Solved Time: 10:10:53 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

BH-2 Transient Seepage

Kind: SEEP/W
Parent: BH-2 Case II Steady-State Seepage
Analysis Type: Transient
Physics
- Water Transfer
  - Free convection: thermal effects: No
  - Free convection: solute effects: No
  - Vapor transfer: isothermal: No
  - Vapor transfer: thermal: No

Water Settings
- Initial PWP Conditions from Parent Analysis: BH-2 Case II Steady-State Seepage [(last)]
- Maximum Number of Iterations: 500
- Maximum Difference: 0.005
- Significant Digits: 2
- Max # of Reviews: 10
- Under-Relaxation Criteria
  - Initial Rate: 1
  - Minimum Rate: 0.1
  - Rate Reduction Factor: 0.65
  - Reduction Frequency (iterations): 10

Unit Weight of Water: 62.430189 pcf
Bulk Modulus of Pore-Fluid: 43,511,321 psf

Settings

Exclude cumulative values: No

Steps

Starting Time: 0 d
Duration: 1 d
# of Steps: 10
Step Generation Method: Exponential
Initial Increment Size: 0.01 d
Save Steps Every: 1

Materials

Bedrock

Hydraulic

Hydraulic Material Model: (none)

Embankment Fill

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Embankment
K-Function: Embankment
Ky'/Kx' Ratio: 1
Rotation: 0 °

Placed Fill (SP-SM)

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silt (Undrained)

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silt
K-Function: Silt
Ky'/Kx' Ratio: 1
Rotation: 0 °

Silty Sand

Hydraulic

Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Silty Sand
K-Function: Silty Sand

Ky'/Kx' Ratio: 1
Rotation: 0 °

RR

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: RR
K-Function: RR
Ky'/Kx' Ratio: 1
Rotation: 0 °

Native Fill (ML Undrained)

Hydraulic
Hydraulic Material Model: Saturated / Unsaturated
Vol. WC. Function: Fill
K-Function: Fill
Ky'/Kx' Ratio: 1
Rotation: 0 °

Boundary Conditions

Drainage

Category: Hydraulic
Kind: Water Rate 0 ft^3/sec
Review: Yes

Drawdown

Category: Hydraulic
Kind: Water Total Head 0 ft
Review: No

Water K Functions

Embankment

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-06 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-06)
Data Point: (0.38282598, 3.2808382e-06)
Data Point: (0.70171264, 3.2808297e-06)
Data Point: (1.2862257, 3.2807803e-06)
Data Point: (2.357627, 3.2804918e-06)
Data Point: (4.3214847, 3.2787918e-06)

Data Point: (7.9211981, 3.2687878e-06)
Data Point: (14.519403, 3.2098343e-06)
Data Point: (26.613786, 2.8709381e-06)
Data Point: (48.782557, 1.4646413e-06)
Data Point: (89.417486, 8.7943611e-08)
Data Point: (163.90053, 5.7661633e-10)
Data Point: (300.42651, 2.2210716e-12)
Data Point: (550.67599, 8.0699426e-15)
Data Point: (1,009.3785, 2.9157388e-17)
Data Point: (1,850.1713, 1.0529291e-19)
Data Point: (3,391.3282, 3.8021442e-22)
Data Point: (6,216.2392, 1.3729513e-24)
Data Point: (11,394.247, 4.9577335e-27)
Data Point: (20,885.434, 1.7905327e-29)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-06 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)

Data Point: (20,885.434, 1.7905327e-28)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function

Volume Water Content Function: Embankment

Saturated Kx: 3.2808399e-05 ft/sec

Maximum Suction: 20,885.434 psf

Minimum Suction: 0.20885434 psf

Num. Points: 20

Silt

Model: Hyd K Data Point Function

Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %

Segment Curvature: 100 %

Saturated Kx: 3.2808396e-08 ft/sec

Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)

Data Point: (0.20885434, 3.2808396e-08)

Data Point: (0.38282598, 3.2808382e-08)

Data Point: (0.70171264, 3.2808297e-08)

Data Point: (1.2862257, 3.2807803e-08)

Data Point: (2.357627, 3.2804918e-08)

Data Point: (4.3214847, 3.2787918e-08)

Data Point: (7.9211981, 3.2687878e-08)

Data Point: (14.519403, 3.2098343e-08)

Data Point: (26.613786, 2.8709381e-08)

Data Point: (48.782557, 1.4646413e-08)

Data Point: (89.417486, 8.7943611e-10)

Data Point: (163.90053, 5.7661633e-12)

Data Point: (300.42651, 2.2210716e-14)

Data Point: (550.67599, 8.0699426e-17)

Data Point: (1,009.3785, 2.9157388e-19)

Data Point: (1,850.1713, 1.0529291e-21)

Data Point: (3,391.3282, 3.8021442e-24)

Data Point: (6,216.2392, 1.3729513e-26)

Data Point: (11,394.247, 4.9577335e-29)

Data Point: (20,885.434, 1.7905327e-31)

Estimation Properties

Hyd. K-Function Estimation Method: Van Genuchten Function

Volume Water Content Function: Embankment

Saturated Kx: 3.2808399e-08 ft/sec

Maximum Suction: 20,885.434 psf

Minimum Suction: 0.20885434 psf

Num. Points: 20

Silty Sand

Model: Hyd K Data Point Function

Function: Water X-Conductivity vs. Water Pressure

Curve Fit to Data: 100 %

Segment Curvature: 100 %
Saturated Kx: 3.2808396e-05 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 3.2808396e-05)
Data Point: (0.38282598, 3.2808382e-05)
Data Point: (0.70171264, 3.2808297e-05)
Data Point: (1.2862257, 3.2807803e-05)
Data Point: (2.357627, 3.2804918e-05)
Data Point: (4.3214847, 3.2787918e-05)
Data Point: (7.9211981, 3.2687878e-05)
Data Point: (14.519403, 3.2098343e-05)
Data Point: (26.613786, 2.8709381e-05)
Data Point: (48.782557, 1.4646413e-05)
Data Point: (89.417486, 8.7943611e-07)
Data Point: (163.90053, 5.7661633e-09)
Data Point: (300.42651, 2.2210716e-11)
Data Point: (550.67599, 8.0699426e-14)
Data Point: (1,009.3785, 2.9157388e-16)
Data Point: (1,850.1713, 1.0529291e-18)
Data Point: (3,391.3282, 3.8021442e-21)
Data Point: (6,216.2392, 1.3729513e-23)
Data Point: (11,394.247, 4.9577335e-26)
Data Point: (20,885.434, 1.7905327e-28)
Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 3.2808399e-05 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Hyd K Data Point Function
Function: Water X-Conductivity vs. Water Pressure
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Saturated Kx: 0.32808396 ft/sec
Data Points: Matric Suction (psf), Water X-Conductivity (ft/sec)
Data Point: (0.20885434, 0.32808396)
Data Point: (0.38282598, 0.32808382)
Data Point: (0.70171264, 0.32808297)
Data Point: (1.2862257, 0.32807803)
Data Point: (2.357627, 0.32804918)
Data Point: (4.3214847, 0.32787918)
Data Point: (7.9211981, 0.32687878)
Data Point: (14.519403, 0.32098343)
Data Point: (26.613786, 0.28709381)
Data Point: (48.782557, 0.14646414)

Data Point: (89.417486, 0.0087943612)
Data Point: (163.90053, 5.7661626e-05)
Data Point: (300.42651, 2.221071e-07)
Data Point: (550.67599, 8.0699395e-10)
Data Point: (1,009.3785, 2.9157372e-12)
Data Point: (1,850.1713, 1.0529285e-14)
Data Point: (3,391.3282, 3.8021412e-17)
Data Point: (6,216.2392, 1.3729499e-19)
Data Point: (11,394.247, 4.9577296e-22)
Data Point: (20,885.434, 1.7905455e-24)

Estimation Properties
Hyd. K-Function Estimation Method: Van Genuchten Function
Volume Water Content Function: Embankment
Saturated Kx: 0.32808399 ft/sec
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Vol. Water Content Functions

Embankment

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35012423
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35012423
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3499982)
Data Point: (0.38282598, 0.3499982)
Data Point: (0.70171264, 0.3499982)
Data Point: (1.2862257, 0.3499982)
Data Point: (2.357627, 0.3499982)
Data Point: (4.3214847, 0.3499982)
Data Point: (7.9211981, 0.3499982)
Data Point: (14.519403, 0.3499982)
Data Point: (26.613786, 0.34981107)
Data Point: (48.782557, 0.31033131)
Data Point: (89.417486, 0.16174383)
Data Point: (163.90053, 0.068338377)
Data Point: (300.42651, 0.041807674)
Data Point: (550.67599, 0.03399731)
Data Point: (1,009.3785, 0.029260226)
Data Point: (1,850.1713, 0.025155373)
Data Point: (3,391.3282, 0.021450213)
Data Point: (6,216.2392, 0.018141719)

Data Point: (11,394.247, 0.015223967)
Data Point: (20,885.434, 0.012674561)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 0.5
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Fill

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)

Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07

Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silt

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.35025361
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.35025361
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.3497727)
Data Point: (0.38282598, 0.3497727)
Data Point: (0.70171264, 0.3497727)
Data Point: (1.2862257, 0.3497727)
Data Point: (2.357627, 0.3497727)
Data Point: (4.3214847, 0.3497727)
Data Point: (7.9211981, 0.3497727)
Data Point: (14.519403, 0.3497727)
Data Point: (26.613786, 0.3497727)
Data Point: (48.782557, 0.3497727)
Data Point: (89.417486, 0.3497727)
Data Point: (163.90053, 0.3497727)
Data Point: (300.42651, 0.3497727)
Data Point: (550.67599, 0.3490377)
Data Point: (1,009.3785, 0.3202179)
Data Point: (1,850.1713, 0.25868007)
Data Point: (3,391.3282, 0.21094169)
Data Point: (6,216.2392, 0.18084199)
Data Point: (11,394.247, 0.15981838)
Data Point: (20,885.434, 0.14301065)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 30 %
Diameter at 10% passing: 0.007
Diameter at 60% passing: 0.07
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Silty Sand

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure

Compressibility: 0 /psf
Saturated Water Content: 0.3500862
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.3500862
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.35025549)
Data Point: (0.38282598, 0.35025549)
Data Point: (0.70171264, 0.35025549)
Data Point: (1.2862257, 0.35025549)
Data Point: (2.357627, 0.35025549)
Data Point: (4.3214847, 0.35025549)
Data Point: (7.9211981, 0.35025549)
Data Point: (14.519403, 0.35025549)
Data Point: (26.613786, 0.33009011)
Data Point: (48.782557, 0.2005121)
Data Point: (89.417486, 0.086942648)
Data Point: (163.90053, 0.046460124)
Data Point: (300.42651, 0.035109584)
Data Point: (550.67599, 0.029980303)
Data Point: (1,009.3785, 0.025919266)
Data Point: (1,850.1713, 0.022256425)
Data Point: (3,391.3282, 0.018953185)
Data Point: (6,216.2392, 0.016015159)
Data Point: (11,394.247, 0.013431662)
Data Point: (20,885.434, 0.011178458)
Estimation Properties
Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.35
Sample Material: Clay
Liquid Limit: 10 %
Diameter at 10% passing: 0.07
Diameter at 60% passing: 1
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

RR

Model: Vol WC Data Point Function
Function: Volumetric Water Content vs. Water Pressure
Compressibility: 0 /psf
Saturated Water Content: 0.082479468
Curve Fit to Data: 100 %
Segment Curvature: 100 %
Porosity: 0.082479468
Data Points: Matric Suction (psf), Volumetric Water Content
Data Point: (0.20885434, 0.082479468)
Data Point: (0.38282598, 0.020807732)

Data Point: (0.70171264, 0.0044354516)
Data Point: (1.2862257, 0.001664852)
Data Point: (2.357627, 0.0012015262)
Data Point: (4.3214847, 0.0010239021)
Data Point: (7.9211981, 0.00088882819)
Data Point: (14.519403, 0.00077131353)
Data Point: (26.613786, 0.00066788252)
Data Point: (48.782557, 0.00057698848)
Data Point: (89.417486, 0.00049727967)
Data Point: (163.90053, 0.00042750281)
Data Point: (300.42651, 0.00036651427)
Data Point: (550.67599, 0.00031328394)
Data Point: (1,009.3785, 0.00026689113)
Data Point: (1,850.1713, 0.00022651702)
Data Point: (3,391.3282, 0.00019143507)
Data Point: (6,216.2392, 0.00016100198)
Data Point: (11,394.247, 0.00013464879)
Data Point: (20,885.434, 0.00011187265)

Estimation Properties

Vol. WC Estimation Method: Grain Size Function
Saturated Water Content: 0.2
Sample Material: Clay
Liquid Limit: 0 %
Diameter at 10% passing: 50
Diameter at 60% passing: 500
Maximum Suction: 20,885.434 psf
Minimum Suction: 0.20885434 psf
Num. Points: 20

Geometry

Name: BH2

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	-60 ft	10 ft
Point 2	-85 ft	-2.5 ft
Point 3	-105 ft	-3 ft
Point 4	-200 ft	-3 ft
Point 5	50 ft	15 ft
Point 6	200 ft	15 ft
Point 7	37 ft	14 ft
Point 8	200 ft	10 ft
Point 9	-200 ft	7 ft

Point 10	200 ft	7 ft
Point 11	-200 ft	-7 ft
Point 12	200 ft	-7 ft
Point 13	-200 ft	-10 ft
Point 14	200 ft	-10 ft
Point 15	-200 ft	24.7 ft
Point 16	-67 ft	7 ft
Point 17	0 ft	13 ft
Point 18	-200 ft	-4 ft
Point 19	200 ft	-4 ft
Point 20	238 ft	-21 ft
Point 21	-5 ft	24.7 ft
Point 22	5 ft	24.7 ft
Point 23	-31 ft	12.033333 ft
Point 24	0 ft	24.7 ft
Point 25	-80.26316 ft	-1e-06 ft
Point 26	0 ft	22 ft
Point 27	-5 ft	22 ft
Point 28	-23 ft	12.233333 ft
Point 29	0 ft	-10 ft
Point 30	0 ft	-7 ft
Point 31	-82.15789 ft	-1 ft
Point 32	200 ft	-1 ft
Point 33	0 ft	-4 ft
Point 34	0 ft	-1 ft
Point 35	0 ft	10 ft

Lines

	Start Point	End Point	Length	Angle	Hydraulic Boundary
Line 1	11	13	3 ft	90 °	
Line 2	14	12	3 ft	90 °	
Line 3	7	5	13.038 ft	4.4 °	Drainage
Line 4	5	6	150 ft	0 °	Drainage
Line 5	6	8	5 ft	90 °	
Line 6	8	10	3 ft	90 °	
Line 7	16	1	7.6158 ft	23.2 °	Drainage
Line 8	4	3	95 ft	0 °	Drawdown
Line 9	3	2	20.006 ft	1.43 °	Drawdown
Line 10	11	18	3 ft	90 °	
Line 11	18	4	1 ft	90 °	
Line 12	19	12	3 ft	90 °	
Line 13	21	23	28.921 ft	26 °	Drainage
Line 14	7	22	33.742 ft	-18.5 °	Drainage
Line 15	22	24	5 ft	0 °	
Line 16	24	21	5 ft	0 °	
Line 17	25	16	14.997 ft	27.8 °	Drainage
Line 18	24	26	2.7 ft	90 °	
Line 19	26	17	9 ft	90 °	

Line 20	26	27	5 ft	0 °	
Line 21	17	28	23.013 ft	1.91 °	
Line 22	27	28	20.479 ft	28.5 °	
Line 23	13	29	200 ft	0 °	
Line 24	29	14	200 ft	0 °	
Line 25	12	30	200 ft	0 °	
Line 26	30	11	200 ft	0 °	
Line 27	30	29	3 ft	90 °	
Line 28	1	23	29.071 ft	4.01 °	Drainage
Line 29	23	28	8.0025 ft	1.43 °	
Line 30	17	7	37.014 ft	1.55 °	
Line 31	2	31	3.2137 ft	27.8 °	Drawdown
Line 32	31	25	2.1424 ft	27.8 °	Drawdown
Line 33	10	32	8 ft	90 °	
Line 34	32	19	3 ft	90 °	
Line 35	19	33	200 ft	0 °	
Line 36	33	18	200 ft	0 °	
Line 37	30	33	3 ft	90 °	
Line 38	32	34	200 ft	0 °	
Line 39	34	31	82.158 ft	0 °	
Line 40	33	34	3 ft	90 °	
Line 41	1	35	60 ft	0 °	
Line 42	35	8	200 ft	0 °	
Line 43	34	35	11 ft	90 °	
Line 44	35	17	3 ft	90 °	

Regions

	Material	Points	Area
Region 1	Bedrock	11,13,29,30	600 ft²
Region 2	Placed Fill (SP-SM)	28,23,1,35,17	106.73 ft²
Region 3	Silty Sand	18,11,30,33	600 ft²
Region 4	Silt (Undrained)	31,2,3,4,18,33,34	372.87 ft²
Region 5	RR	21,23,28,27,26,24	85.867 ft²
Region 6	Embankment Fill	7,22,24,26,17	243.2 ft²
Region 7	Embankment Fill	17,26,27,28	127.92 ft²
Region 8	Bedrock	14,12,30,29	600 ft²
Region 9	Native Fill (ML Undrained)	1,16,25,31,34,35	787.13 ft²
Region 10	Silty Sand	12,19,33,30	600 ft²
Region 11	Silt (Undrained)	19,32,34,33	600 ft²
Region 12	Native Fill (ML Undrained)	32,10,8,35,34	2,200 ft²
Region 13	Placed Fill (SP-SM)	8,6,5,7,17,35	938 ft²

Mesh Properties

Global Element Size: 1 ft

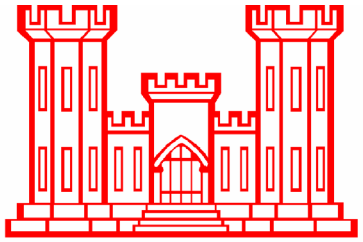
GGEO-ENVIRONMENTAL/HTRW DOCUMENTATION SUB-APPENDIX IV

EASTWICK
CAP SECTION 205
FLOOD RISK MANAGEMENT STUDY
CITY OF PHILADELPHIA
PENNSYLVANIA

FEASIBILITY PHASE

PHILADELPHIA, PENNSYLVANIA

DRAFT - AUGUST 2023



U.S. Army Corps of Engineers
Philadelphia District

REMEDIAL DESIGN
BASIS OF DESIGN REPORT
(Final)

- OPERABLE UNIT 1 -

CLEARVIEW LANDFILL - SOILS AND WASTE

LOWER DARBY CREEK AREA SUPERFUND SITE

DARBY TOWNSHIP, DELAWARE &
PHILADELPHIA COUNTIES
PENNSYLVANIA

EPA Contract Number EP-S3-07-04
Work Assignment Number 061-RDRD-D366

Prepared for:
United States Environmental Protection Agency, Region 3
Philadelphia, PA

Prepared by:
Tetra Tech, Inc.
240 Continental Drive, Suite 200
Newark, DE 19713

DECEMBER 2018

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BASIS OF DESIGN REPORT

for

- OPERABLE UNIT 1 -
CLEARVIEW LANDFILL - SOILS AND WASTE
LOWER DARBY CREEK AREA
SUPERFUND SITE

Darby Township, Delaware & Philadelphia Counties
Pennsylvania

EPA Contract Number EP-S3-07-04
Work Assignment Number 061-RDRD-D366
Tetra Tech Project Number G07477

Tetra Tech, Inc.
240 Continental Drive, Suite 200
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DECEMBER 2018

SUBMITTED BY:

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Attachment S: Operation and Monitoring (O&M) Plan
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ACRONYMS

ACE	Army Corps of Engineers
APE	Areas of Potential Effect
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
DCCD	Delaware County Conservation District
BDR	Basis of Design Report
BMPs	Best Management Practices
BTAG	Biological Technical Assistance Group (EPA)
CAA	Clean Air Act
C&D	Construction and Demolition
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
C.F.R.	Code of Federal Regulations
COC	Contaminant(s) of Concern
cpd	Cubic Feet per Day
CVLF	Clearview Landfill
EPA	Environmental Protection Agency
E&S	Erosion and Sediment
ESC	Erosion and Sediment Control
ESCP	Erosion and Sediment Control Plan
ET	Evapotranspiration
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
GMWs	Gas Monitoring Wells
HDPE	High Density Polyethylene
HEC-RAS	Hydrologic Engineering Centers River Analysis System
ICIAP	Institutional Control Implementation and Assurance Plan
IC	Institutional Controls
ISM	Incremental Sampling Method
LEL	Lower Explosive Level
LFG	Landfill Gas
LOD	Limit of Disturbance
LOMCs	Letter of Map Changes
LTMP	Long Term Monitoring Plan
O&M	Operation and Maintenance
OMP	Operations & Maintenance Plan
OSHA	Occupational Safety and Health Administration
OU	Operable Unit
Mg	Megagrams
MSW	Municipal Solid Waste
NAAQS	National Ambient Air Quality Standards
NAPLs	Non-aquious Phase Liquids
NOI	Notice of Intent
NMOC	Nonmethane Organic Compounds
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
OU	Operable Unit
PAHs	Poly-aromatic Hydrocarbons
PADEP	Pennsylvania Department of Environmental Protection
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PennDOT	Pennsylvania Department of Transportation
PCBs	Polychlorinated Biphenols
PDI	Pre-Design Investigation

PFBC	Pennsylvania Fish and Boat Commission
PGC	Pennsylvania Game Commission
PNDI	Pennsylvania Natural Diversity Inventory
PTW	Principal Threat Waste
PWD	Philadelphia Water Department
QC	Quality Control
RA	Remedial Action
RAC	Remedial Action Contract
RAOs	Remedial Action Objectives
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RI	Remedial Investigation
ROD	Record of Decision
SEFA	Spreadsheets for Environmental Footprint Analysis
SHPO	State Historic Preservation Office
SIA	Southern Industrial Area
SSF	Sub-Surface Flow
SU	Sampling Units
SVOCs	Semi-volatile Organic Compounds
TSCA	Toxic Substances Control Act
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency (EPA)
USFWS	United States (US) Fish and Wildlife Service
VOCs	Volatile Organic Compounds

1.0 INTRODUCTION

1.1 AUTHORITY AND PURPOSE

Tetra Tech, Inc. (Tetra Tech) prepared this pre-final Basis of Design Report (BDR) for the Operable Unit 1 (OU1) of the Lower Darby Creek Area (LDCA) Superfund Site - Clearview Landfill (CVLF) in Darby Township, Delaware and Philadelphia Counties, Pennsylvania, under the United States Environmental Protection Agency (EPA) Work Assignment No. 061-RDRD-D366, Remedial Action Contract (RAC) No. EP-S3-07-04. This BDR includes details of the remedial design (RD) to implement the remedial components selected in the Record of Decision (ROD) for contaminated soil, landfill waste, and shallow leachate (mixed with shallow groundwater). The contamination in groundwater, surface water, and sediment associated with CVLF is being investigated under a separate operable unit (i.e., OU3).

The purpose of this BDR is to present a basis of design narrative, assumptions, and parameters for the RD; explain how Applicable or Relevant and Appropriate Requirements (ARARs) will be met; and make provision of RD drawings, technical specifications, and remedial action (RA) cost estimate, and schedule. The BDR package was developed incrementally: 30% (submitted in November, 2015), 60% (submitted in September, 2016), pre-final (submitted in February, 2018), and final (August 2018). This revised final BDR (100%) is “Issued for Bid”, pending any minor revisions. Once the Bid is awarded, the final BDR will be “Issued for Construction”, pending minor contracting or technical clarifications.

The BDR report is organized as follows:

- Section 1 Introduction: Presents the purpose and an overview of the remedy.
- Section 2 Site Background: Presents the site background.
- Section 3 Remedial Action Objectives and Design Criteria: Presents the Remedial Action Objectives (RAOs), performance standards, the ARARs, and how the design complies with these requirements.
- Section 4 Basis of Design: Presents the basis of design for the various components of the remedy.
- Section 5 Substantive Regulatory Notification Requirements: Presents substantive regulatory notification requirements applicable to the OU1 RA.
- Section 6 Drawings and Specifications: Presents a list of the design drawings and the method for developing technical specifications. The design drawings developed to the pre-final level and select technical specifications are included as Attachments A and B, respectively.

- Section 7 Cost Estimate: Presents the estimated costs associated with the OU1 RA.
- Section 8 Project Execution and Construction Schedule: Presents the project delivery and the projected construction schedule, as well as tentative construction sequence.
- Section 9 Easements and Access Agreements: Describes and lists the easements and access agreement requirements.

1.2 OVERVIEW OF REMEDY

EPA selected the following as the proposed remedy for LDCA OU1 in the ROD (EPA, 2014), to address landfill waste, contaminated soils, and shallow leachate seeps along the creek bank. The major components of the remedy include:

- Pre-design investigation (PDI) to delineate limits of waste and contaminated soils. The details of activities associated with the PDI are available in the Sampling and Analysis Plan (SAP) (Tetra Tech, 2015).
- Installation, maintenance and monitoring of an Evapotranspiration (ET) cover system over approximately 50 acres, including relocation of on-site business and demolition of all structures within the cover boundary, site grading, and stormwater and erosion & sediment (E&S) controls along the east bank of Darby and Cobbs Creeks.
- Removal and off-site disposal of principal threat wastes (PTWs) remaining on-site.
- Excavation and consolidation of wastes and contaminated soils above cleanup levels within and beneath the ET Cover.
- Construction and maintenance of a leachate collection trench along the creek banks, and construction, maintenance, and monitoring of a treatment wetland to comply with discharge requirements.
- Long-term monitoring of groundwater, leachate, landfill gas, surface water and sediment, to evaluate performance and effectiveness of the remedy.
- Land and groundwater use restrictions to be implemented and maintained through institutional controls (ICs), and engineering controls to protect the integrity of the selected remedy, including the ET cover, leachate collection trench, and treatment wetland, and prevent exposure to soils outside of the ET cover above cleanup levels. Additional fishing advisories may also be required. Signs will be placed along the stream bank to warn fisherman of all fishing advisories and the potential risks from fish consumption. An Institutional Control Implementation and Assurance Plan (ICIAP) will be developed for OU1 during the RA to ensure that appropriate land and groundwater use restrictions are implemented, monitored, and maintained by future land owners.

2.0 SITE BACKGROUND

2.1 SITE LOCATION AND DESCRIPTION

The Site is located in both Delaware and Philadelphia Counties (Figure 1). The closest cross-street intersection to the main site entrance is 84th Street and Lindbergh Blvd., Philadelphia, PA (Figure 2). The majority of the CVLF is located in Darby Township (Delaware County); however, the Site is physically separated from the rest of the Township by Darby and Cobbs Creeks. The CVLF is geographically closer to Philadelphia, PA, and a portion of the Site wastes and impacted soils are known to be present in Eastwick Regional Park (City Park), which is within Philadelphia County. Residents in nearby Philadelphia communities (Eastwick neighborhood) can directly access City Park and CVLF. The Site encompasses approximately 44 acres in Darby Township and 20 acres in Philadelphia. It is bounded by Darby and Cobbs Creeks to the west, 84th Street to the South, and the Eastwick Neighborhood to the southeast, east, and northeast.

2.2 SOILS AND GEOLOGY

Soils in the vicinity of the CVLF have been heavily disturbed through many years of urban land use and are generally described as "Made Land" per classification by the U. S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). Surficial geology in the area is generally unconsolidated sedimentary deposits that consist of gravelly sand with some interbedded clay and silt. In addition, part of the area has been extensively filled with fine-grained sediment, dredged material, construction and demolition (C&D) debris, and flood deposits. Soil types and descriptions are further described in the remedial investigation (RI) report (Tetra Tech, May 2011) and Feasibility Study (FS) report (Tetra Tech, October 2012), and the Stormwater Management Report (Attachment P).

The Site is situated on unconsolidated Coastal Plain sediments (Quaternary Trenton Gravel at the surface) overlying bedrock of the Wissahickon Formation. Bedrock was encountered at depths ranging from approximately 18 feet in the Eastwick neighborhood to as deep as about 44 feet at the southern part of the Landfill during the RI.

2.3 HYDROGEOLOGY AND SURFACE HYDROLOGY

In general, groundwater regionally flows from the northeast to the southwest direction toward the Delaware River. The southern portion of the CVLF is underlain by Trenton Aquifer and the northern part of the CVLF

is underlain by the Wissahickon Aquifer. Both are water table aquifers (i.e., an aquifer which is not confined under pressure; therefore, the water level in a well is the same as the water table outside the well.)

Locally, groundwater in the Coastal Plain sediments aquifer flows towards nearby surface water bodies including the Darby, Cobbs, and Hermesprota Creeks located west of the Landfill. Groundwater within the CVLF is mounded and as a result flows radially outward from the center. Groundwater in the bedrock aquifer(s) flows in an eastward direction. Groundwater gradients are typically low in this type of aquifer (e.g., hydraulic gradient of about 10 feet per mile or less). According to the EPA Aquifer Classification System in the Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy, Final Draft (USEPA, 1986), the aquifers underlying the CVLF are classified as Class I aquifers due to the presence of the John Heinz National Wildlife Refuge (NWR) within 2 miles of the Landfill. As per Section 3.3.1 of the guidelines, the aquifer is classified as Class I when the groundwater is "ecologically vital," and supports a sensitive ecological system and a unique habitat such as the John Heinz NWR.

All known residents in the Delaware and Philadelphia Counties are supplied with potable water by a public water supplier, the City of Philadelphia Water Department (PWD). No drinking water wells are known to exist in this area on the Pennsylvania side of the Delaware River.

The CVLF is completely surrounded by the 100- and 500-year floodplains, and the west side of the Landfill abuts the floodway. Flooding in Darby and Cobbs Creeks, and the surrounding low-lying areas (including Eastwick neighborhood) is a major concern.

2.4 LANDFILL STRATIGRAPHY AND WASTE

An extensive investigation has been conducted by EPA at the CVLF to determine the extent of contamination that is present as a result of historical landfilling activity, and continued during the PDI. The geology and stratigraphy of the Site are described briefly below (from the ground surface downward):

Clearview Landfill

- Fill soil, concrete, and construction debris up to approximately 20 feet thick at ground surface.
- Landfill wastes up to 75 feet thick at the highest point (center) of the Landfill, including undifferentiated garbage, miscellaneous wastes, and fill soils.
- A discontinuous peat layer (an organic-rich marsh deposit) present in many boreholes, with a thickness of 1 to 3 feet.

- 10- to 15-foot thick layers (in total) of sand, gravel, silt, and clays, similar in description to natural Trenton Gravel deposits, but often difficult to distinguish from overlying fill soils.
- Wissahickon Formation rock, consisting of micaceous schist (with distinctive muscovite mica). The Wissahickon Formation typically showed a highly-weathered upper rock zone grading into harder, less-weathered deeper bedrock.

City Park

- 1- to 2-foot thick (thicker in places) fill soil at ground surface. In some areas, particularly the northern open field of City Park, there is only a very thin soil fill cover. Aerial photographs indicate that the City Park area was largely covered with thick landfill waste and re-graded.
- Landfill wastes with 8 to 12 feet thickness (at least) in the formerly existed marshland below the current City Park area.
- A discontinuous natural organic peat layer (an organic-rich marsh deposit) with a thickness of 1 to 3 feet.
- Discontinuous sand, silts, and clays, with a total thickness of 10 to 15 feet. This layer lies above bedrock. These apparently natural soils are similar in description to natural Trenton Gravel deposits, but are often difficult to distinguish from overlying fill soils.
- Wissahickon Formation rock, consisting of micaceous schist (with distinctive muscovite mica). The Wissahickon Formation typically showed a highly-weathered upper rock zone grading into harder, less-weathered deeper bedrock.

Eastwick Neighborhood

- Re-worked fill soil and demolition debris in one-to-two feet thickness (thicker in places) at ground surface. Demolition debris is common (bricks, wood, etc.) and appears to be a relic of demolition of structures that pre-dated the current Eastwick Neighborhood townhouse construction in the mid-1970s and/or was imported as fill material during the construction/redevelopment of the Eastwick Neighborhood in the 1970s. There is a greater percentage of debris and non-soil fill material south of S. 80th St. North of S. 80th St., surface soils have little or no debris present and the soil is primarily a fine silty soil.
- A 15- to 25-foot thick (in total) layer of discontinuous sand, silts, and clays. This layer lies above bedrock. These appear to be natural soils that are similar in description to natural Trenton Gravel deposits.

- Wissahickon Formation rock, consisting of micaceous schist (with distinctive muscovite mica). The Wissahickon Formation typically showed a highly-weathered upper rock zone grading into harder, less-weathered deeper bedrock.

2.5 LANDFILL AND SOIL GAS

Volatile Organic Compounds (VOCs), mostly petroleum-related VOCs, and landfill-related gas components were the primary compounds detected throughout the Landfill study area. Methane was widely detected, but consistently at much lower concentrations (typically less than 5% of all landfill gases by volume) except for several vapor well locations within City Park. Additional soil gas screening for methane was conducted at various depths of the vapor wells with a landfill gas meter, as well as inside the groundwater monitoring well casings. No significant pressure built inside the wells was observed. Methane investigation was further conducted during the PDI and its findings are discussed in the PDI report (Attachment G).

2.6 SURFACE AND SUBSURFACE SOILS

Inorganics, semi-volatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and metals were the principle classes of contaminants detected in surface and subsurface soils. The key contaminants with regard to their distribution, frequency of occurrence and relative magnitude in concentrations consist of lead, benzo(a)pyrene, and PCBs. With the exception of several SVOCs (mostly polycyclic aromatic hydrocarbons [PAHs]), contaminant concentrations generally decreased with depth. Other Site-related contaminants followed similar distribution patterns.

Free-product oil or non-aqueous phase liquids (NAPLs) were noted during drilling of several borings and wells within the Landfill waste. However, analytical results of groundwater samples from these boreholes and monitoring wells were not indicative of NAPLs being present in significant quantities or acting as major source of groundwater contamination.

Details regarding site contamination are available in the RI/FS reports, and site contamination was further studied or confirmed as part of the PDI. The PDI report discusses these activities and findings in detail. In general, up to top 2 feet of surface soils in the City Park contain at least one of contaminants of concern (COCs) above their soil cleanup levels selected in the OU1 ROD, typically for PAHs. Subsurface soils in the City Park are also contaminated and/or underlain by waste. Moreover, extensive PAH contamination has been identified in surface soil in residential yards near the Landfill and in Eastwick neighborhood. Residential yard excavation and additional sampling activities are on-going under Removal Action.

2.7 STORMWATER RUNOFF AND SEDIMENT

Stormwater runoff on the CVLF drains either toward Darby and Cobbs Creeks, or inland toward the City Park. Significant ponding of water occurs in low lying portions of the Site after high precipitation events. Stormwater and surface sediment will be inherently addressed via installation of the ET cover and the integration of stormwater management and creek bank restoration.

2.8 GROUNDWATER

Extensive groundwater sampling was conducted as part of the OU1 RI. However, significant data gap existed to determine the extent of impacted groundwater when the extent of other contaminated media, which are subject to this RD, was concluded. Therefore, groundwater investigation continued and is being conducted under the OU3 RI/FS. Groundwater is not addressed in the OU1 RD.

3.0 REMEDIAL ACTION OBJECTIVES AND DESIGN CRITERIA

3.1 REMEDIAL ACTION OBJECTIVES

The primary goals of the selected remedy for LDCA OU1 are to reduce contaminant concentrations to levels that do not present an unacceptable risk to human health and the environment, prevent contact with the Landfill wastes, and reduce the amount of contamination being released by the Landfill into groundwater and surface water. To accomplish these goals, the following remedial action objectives (RAOs) have been established in the ROD:

- Prevent human and ecological receptor exposure to contaminated soils and landfill materials that pose an unacceptable risk.
- Prevent erosion and surface runoff of soils and wastes to reduce migration of contaminants.
- Reduce the infiltration rate of precipitation into the Landfill waste to less than 1.0×10^{-5} centimeters/second (cm/sec) or an equivalent standard of performance.
- Control and capture seasonal leachate seeps above the mean high tide elevation of adjacent creeks that are migrating into the adjacent Darby and Cobbs Creeks.
- Reduce the concentrations of regulated substances in collected leachate below the surface water discharge limits established by National Pollution Discharge Elimination System (NPDES).
- Reduce, to acceptable levels, risks to aquatic benthic receptors by reducing the discharge of site-related contaminants to surface waters and sediments in Darby and Cobbs Creeks.

- Prevent the accumulation and off-site migration of Landfill gases and VOC vapors above the levels established in 40 C.F.R. § 258.23(a), Explosive Gases Control.
- Prevent unacceptable risks by site-related contaminants due to human consumption of fish from surface water adjacent to the Landfill.

3.2 PERFORMANCE STANDARDS

The matrix for attainment of the RAOs will be accomplishment of specific performance standards for each of the RD components. These performance standards are described in the ROD (Attachment D) and briefly summarized below.

Performance Standards for PDI

- Collect additional sample data to confirm that exceedances of cleanup levels in soils are not present outside the planned the ET cover area and only C&D debris are present in the subsurface soils.

- Collect background soil samples (i.e., Suffolk Park, approximately 0.9 miles east of CVLF) to evaluate regional anthropogenic background levels of PAHs in soils not impacted by the Landfill. Based on sampling results, reevaluate and refine PAH cleanup levels in soils as appropriate.

- Conduct an additional archaeological evaluation to determine the potential presence of cultural resources within the Areas of Potential Effect (APE) in any portions to be disturbed by the selected remedy. The evaluation shall be conducted in accordance with the applicable portions of the National Historic Preservation Act, 18 C.F.R. §380.14

- Fully delineate Landfill waste boundary and thickness. Soil cores are collected along the edge of the planned Landfill cover and offset by appropriate distance toward Eastwick neighborhood. Boring are advanced until clean fill/native soil has been identified or refusal.

- Evaluate existing Landfill cover soil. Borings are drilled in the select locations within the CVLF and advanced to a depth of the underlying trash, to assess the thickness of the existing soil cover.

Performance Standards for ET Cover

- Determine how much water must be stored by the ET Cover, based on meteorological conditions at the Site, the proposed cover profile, and water balance simulation using appropriate computer models.

- Collect performance data for the ET cover with respect to drainage and other factors. 40 C.F.R. § 258.60(a)(1) requires that a final cover for a municipal solid waste (MSW) landfill have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1.0×10^{-5} cm/sec, whichever is less. This requirement is being waived using the "Equivalent Standard of Performance" under CERCLA §121(d)(4)(D), 42 U.S.C. § 9621(d)(4)(D). The ET cover is expected to achieve this performance standard incrementally over time and that progress shall be evaluated during the first five-year review for which five years of monitoring data is available after the remedy is determined to be operational and functional. Direct performance monitoring of the cover is required. Pan lysimeters or an equivalent shall be installed on the top deck, side slopes and in other variations within the cover design. These data will be used to evaluate the ET cover's performance on, at minimum, an annual basis. The ET cover shall provide an Equivalent Standard of Performance to achieve the relevant and appropriate requirement in 40 C.F.R. §258.60(a)(1) by ensuring the drainage rate from the bottom of the ET cover is no greater than the value, which results from multiplying the total final acreage of the ET cover by 9,237 gallons/day.

- Relocate any businesses still operating on the Landfill within the boundaries of the ET Cover at the commencement of the RA. On-site businesses shall be permanently relocated and the structures used by them vacated and demolished as they physically block and will interfere with the selected remedy. Relocation of businesses/tenants will be performed pursuant to the Uniform Relocation Act, 42 U.S. Code §§ 4601 et seq., and regulations promulgated pursuant thereto at 49 C.F.R Part 24.

- Evaluate the proposed design for the ET cover final elevation and elevations of other remedial components for potential flooding impacts to the 100-year floodplain, as a minimum. Potential impacts from potential sea level rise over the lifetime of the remedy shall be taken into consideration as part of the RD. The final ET cover shall not significantly increase the 100-year flood height or stream velocity as is required by 25 PA Code § 106.31(a)(1). Additional relevant and appropriate requirements in 25 PA Code § 106.31-.32 shall be met by the final ET cover.

- Evaluate the final grade of the ET cover to ensure adequate and stable slope. The slopes will be terraced as needed for erosion control and successful vegetation.

- Incorporate stormwater management controls to the ET cover. Stormwater management controls and surface drainage features such as swales will be incorporated into the design. The stormwater controls shall meet the applicable requirements of the Pennsylvania Water Quality Standards 25 PA Code, Chapter 93 and the applicable requirements of 40 C.F.R. § 122.26 and 40 C.F.R. § 122.44(h)(i)(4).

- Stabilize portions of the creek banks along Darby and Cobbs Creeks to ensure remedy's integrity. Stabilization products and materials that allow for full slope vegetation of native species shall be used to the extent practicable. Periodic monitoring for damage or degradation of these banks shall be included in the long-term monitoring program.

- Conduct landfill gas monitoring during construction and long-term monitoring to ensure the concentration of methane gas generated does not exceed 25% of the lower explosive limit (LEL) for methane in any structures on the landfill and that the concentration of methane gas does not exceed the LEL for methane at the landfill cover boundary.

Performance Standards for Excavation and Disposal of Principal Threat Wastes

- Develop and submit a plan to EPA Region III, Land and Chemicals Division, Office of Toxics and Pesticides, which documents the basis for using a risk-based approach as described in the ROD to address PCB principal threat wastes and other criteria required by 40 C.F.R. § 761.61(c). The plan shall provide justification for the approach's equivalency with 40 C.F.R. § 761.61(a) and will demonstrate that there is no greater risk posed by this approach when compared to the requirements in 40 C.F.R. § 761.61(a) or (b).

- Characterize the wastes with PCBs above 100 mg/kg as required by the selected off-site treatment/disposal facility to determine if treatment of PCBs is practicable. PCBs above 100 mg/kg will be excavated and sent off-site for treatment (if practicable) and/or disposal.

Performance Standards for Excavation and Consolidation of Wastes and Contaminated Soils

- Perform excavation of contaminated soils above cleanup goals established in the ROD. Initial excavations will be to a depth of at least 24 inches. Exposed soils will be iteratively sampled to

evaluate attainment of cleanup levels. Confirmatory samples shall be collected from excavation floor and sidewalls. After completion of excavation activities, a minimum of 24 inches of clean fill will be used to restore the surface to the appropriate grade and elevation.

- If excavation of soils is not practicable, the ET cover will be extended over the area and/or institutional controls (ICs) will be put in place to prevent future unacceptable risks. These determinations will be made during the RD and will rely on the findings from the RI and PDI.

Performance Standards for Leachate Collection Trench and Leachate Treatment Wetlands

- Construct a trench along the Landfill's western perimeter adjacent to Darby and Cobbs Creek banks. The trench will be excavated down to the mean high tide elevation of the creeks. Leachate collected in the trench will be conveyed to leachate treatment wetlands prior to discharging to creek surface water.

- Design and construct the engineered subsurface flow (SSF) treatment wetlands with the ability to treat and/or remove regulated substances in leachate and to achieve NPDES permit equivalent discharge standards. Characteristics of local natural wetlands should be used as model for the constructed wetland.

- A synthetic liner will be used to seal the bottom of the SSF treatment wetlands to avoid possible contamination of groundwater and also to prevent groundwater from infiltrating into the wetland. The SSF treatment wetlands can serve as the cover system.

Performance Standards for Long-term Monitoring

- Collect and analyze samples from groundwater, collected leachate, landfill gas, surface water, treatment wetlands effluent, and creek sediment at multiple locations. The specific locations and frequency of sampling shall be as determined in the Long-Term Monitoring Plan (LTMP), which will be updated as necessary.

- Develop and implement an Operation and Maintenance Plan (OMP) detailing activities for operating, inspecting and maintaining all components of the remedy. These activities should include regular inspections and maintenance on an as-needed basis.

3.3 COMPLIANCE WITH REGULATIONS

As partly discussed in Section 3.2, the remedy will attain all ARARs identified in the ROD. The ARARs for the RD are listed in Table 41 of the ROD and provided as Attachment D of this report.

3.4 ADDITIONAL DESIGN CRITERIA

In addition to achieving the RAOs, meeting performance standards, and complying with ARARs, the following additional general design criteria were established:

- Protect the health and safety for workers, visitors, and neighboring residents during construction.
- Minimize or eliminate significant grading or disturbance of waste materials to limit potential exposure risks to workers and public during construction.
- Optimize cover soil conditions for root penetration and tree growth.
- Conduct a water balance to properly design the cover system that reduces infiltration, yet provides adequate moisture to nourish vegetation.
- Develop soil cover specifications that allow for a range of materials types and sources to be used.
- Develop a monitoring system that provide reliable, accurate, and dependable monitoring and test results.
- Utilize on-site materials, to the extent possible, to minimize traffic resulting from hauling significant amount of fill materials to the Site.
- Provide a construction sequence (phase) that optimizes construction efficiency, and
- Establish a final RD that accommodates reuse of the Site consistent with the EPA approved reuse scenario if a reuse scenario is identified.

4.0 BASIS OF DESIGN

4.1 PRE-DESIGN INVESTIGATION

To develop accurate design plans and specifications for the RA, the vertical and lateral extent of waste and contaminated soils need to be delineated. PDI activities commenced in October, 2015 and conducted extensive site-wide field sampling in accordance with the Performance Standards described in Section 3.2. The sampling results and findings are provided in the PDI report as Attachment G.

The primary goal of PDI was to:

- Delineate the extent of contaminated soils above the cleanup levels and waste (other than C&D debris) outside the planned ET cover.
- Ensure that contaminated soils exceeding cleanup levels are not present outside the planned the ET cover.
- Determine the volume of contaminated soils that needs to be excavated and consolidated under the landfill cover.
- Locate potential borrow sources suitable for the cover system and evaluate their chemical and soil properties.
- Evaluate thickness of the existing soil cover present in the Landfill to determine additional thickness of cover materials required to construct the ET cover.

The following activities were also performed as part of the PDI. Each activity is described briefly.

4.1.1 Topographic Survey

During the OU1 RI, aerial survey was performed for the entire LDCA Superfund Site (1,000+ acres including CVLF, Folcroft Landfill, and John Heinz NWR at Tinicum). In April 2015, Land & Mapping Services, LLC and a professional land surveyor in the Commonwealth of Pennsylvania were retained to update an aerial photograph of the Site and the surrounding area, and perform ground survey of the CVLF area. These topographic survey data were used for the base map (e.g., Existing Conditions Plan) and all other design drawings provided in this report.

4.1.2 Flood Study

The landfill is surrounded by the 100-year floodplain and adjacent to a floodway in the creek. The minimum requirement from the Federal Emergency Management Agency (FEMA) is to demonstrate that the RD and RA will not create adverse conditions in or around the floodplain or floodway during storm events. A hydraulic model of the Darby and Cobbs Creeks was developed using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) computer program. A floodplain analysis focusing on the Site and surrounding flood-prone areas was conducted for both the existing and proposed RD conditions. The model compared the water surface elevations (WSEL) under the two conditions, to demonstrate whether the RD has adverse impacts on the floodplain. The model results are provided in Attachment Q.

The FEMA effective base flood elevations (BFE) and WSEL were used to calibrate the existing model. The FEMA Flood Insurance Study (FIS) map was updated for the project area, based on the hydrologic

and hydraulic models that the FEMA developed in 1970 and 1975, respectively. Table 1 shows the results of the model calibration with differences in the WSE of no more than +/- 0.5 foot at the upstream and downstream ends of the model, except for the 500-year flood event for the upstream boundary on Darby Creek because the FEMA model included a railroad bridge that no longer exists. Other variations in WSE between the HEC-RAS model and FEMA FIS are likely due to the updated geometry and increased resolution used in the HEC-RAS model. Moreover, the FEMA FIS model had only one cross-section between the confluence with Cobbs Creek and Hook Road Bridge, which is slightly downstream of the CVLF. The HEC-RAS model has 16 cross-sections within this same area. This provides a more detailed representation of the river system, including low areas in the floodplain that cannot be represented with a single cross-section. Differences in channel geometry, Manning's n values, and flow routing have the most significant impact on the WSEL shown in Table 1. These differences in the existing condition model represent current conditions of the Darby and Cobbs Creek river system around the project area. The FEMA-calibrated model represents the existing conditions that correspond to the effective BFE in the FIS. This model was used as the basis for the river simulations for the RD.

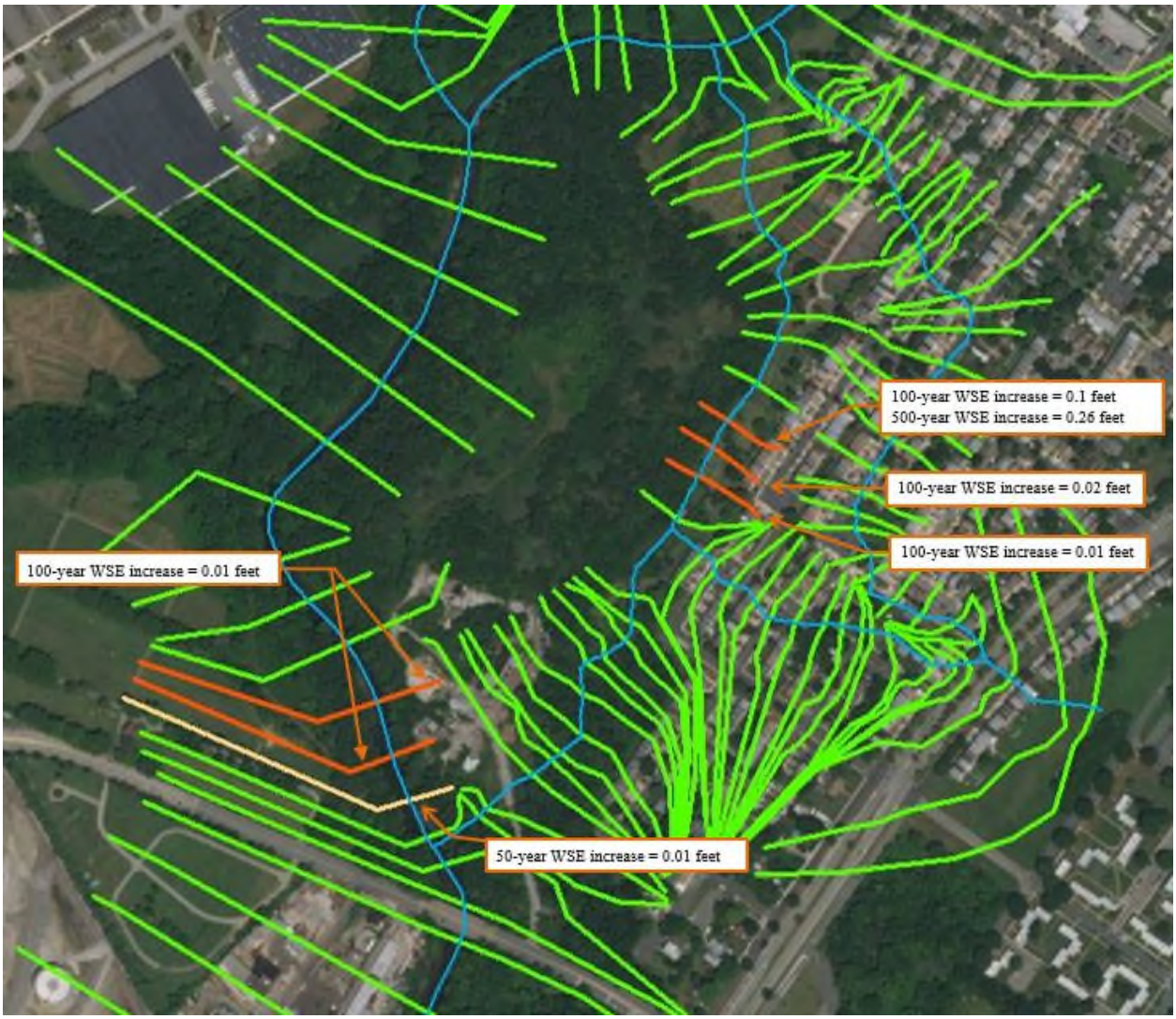
Table 1 HEC-RAS Model Calibration Results

Darby Upstream of Confluence with Cobbs Creek			
Frequency Storm Event	FEMA WSEL Downstream of Railroad Bridge (FEMA FIS Station 36890) NAVD88	Modeled Existing WSEL HEC-RAS Station 32569	WSE Difference
500	25.8	24.6	-1.2
100	20.9	20.7	0.2
50	18.9	19.1	0.2
10	14.9	15.3	0.4
Cobbs Upstream of Confluence with Darby Creek			
Frequency Storm Event	FEMA WSEL Downstream of FIS Cross Section B (1360 feet U/S Darby Junction)	Modeled Existing WSEL HEC-RAS Station 1360.326	WSE Difference
500	22.7	22.9	0.2
100	19.4	19.8	0.4
50	17.8	18.3	0.5
10	14.2	14.5	0.3
Darby Downstream Boundary			
Frequency Storm Event	FEMA WSEL FEMA FIS Station 18340 (Approximately 12,145 feet D/S of Hook Road Bridge)	Modeled Existing WSEL HEC-RAS Station 14002	WSE Difference

500	14	14	0
100	9.9	9.9	0
50	8.3	8.3	0
10	6.9	6.9	0

All WSE values are vertical datum NAVD88 and reported in feet.

To simulate the impact of the RD on the surrounding flood-prone area, the design modifications were incorporated into the calibrated model to represent proposed conditions. The following figure shows part of the cross-sections used in the model and highlights those with an increase in WSEL under proposed conditions.



In general, the proposed conditions lowered most of WSELs within the floodplain and floodway during the

100-year and smaller storm events, except slight increase in one area along Darby Creek and another area along the neighborhood side of the Landfill outside the floodway. These increases were minimal and did not increase flood inundation boundaries. Therefore, a Letter-of-Map-Changes (LOMC) application to FEMA is not anticipated. A flood analysis was also performed for the 0.2 percent-annual-chance flood elevation (i.e., the 500-year storm event) and potential impact due to sea level rise as per an advisory for federal actions per the guidelines for Executive Orders 11988 and 13690. The model indicated that only one cross-section in the neighborhood side would increase WSEL by 0.26 feet during the 500-year storm event. Collectively, the RD would comply with FEMA requirements for construction within flood-prone areas.

4.1.3 Wetlands Delineation

A wetland delineation was performed within the CVLF project area. The wetlands delineation report was submitted as part of the 30% BDR and is considered final (Attachment H). A summary of the report is stated below, and the potential impact to the wetlands by the remedy is depicted on the construction drawings, and the proposed mitigation are discussed further in subsequent sections.

Four existing wetland areas were identified. These areas are further described in the wetlands delineation report, including exhibits:

- Wetland 1 (W1): The largest wetland identified on the project area (1.88 acres), a palustrine forested wetland impounded between the landfill access road and Eastwick, within City Park.
- Wetland 2 (W2): A small, undrained emergent wetland within the western plot of the pilot nursery (0.04 acres).
- Wetland 3 (W3): A small, undrained emergent wetland in the northern open field of City Park, near the boundary with the landfill footprint. This wetland is part of a periodically mowed and maintained park lawn (0.19 acres).
- Wetland 4 (W4): A narrow, forested floodplain terrace along Darby Creek, just north of the 84th St. Bridge (0.24 acres).

It was determined during the delineation that several areas suspected of being wetlands, most notably 1) the vast majority of the low-lying, flat areas between the base of the landfill and Darby Creek, and 2) the phragmites on top of the landfill, were not jurisdictional wetlands; therefore, are not classified as wetlands in the report. These areas generally lacked the hydrology and/or dominant wetland vegetation necessary to meet wetland criteria. The phragmites was likely introduced to the landfill in the soil cover material.

4.1.4 Cultural Resources Delineation

A Phase 1A archaeological literature review and field reconnaissance were previously conducted to identify potential cultural resources that might be affected by future remedial activities (Tetra Tech, March 2011). Information obtained in the course of public meetings held for the project suggested that two historic resources, potentially eligible for listing in the National Register of Historic Places, may be located near the southern boundary of CVLF. These resources include a tunnel for the transportation of slaves and a graveyard dating back to the 18th century, and described briefly below:

- Extensive review of historic maps, aerial photographs, and city/county records revealed that the graveyard has existed until 1930 when the City of Philadelphia extended Buist Avenue to 84th Street. The graveyard location is now covered by an abandoned portion of Buist Avenue near 84th Street.

- The purported tunnel leading from a house located on the corner of Chelwynde Avenue along 84th Street to Darby Creek was not found on any published historic maps. While the location of structures on the hand-drawn map can be verified using aerial photographs and historic maps, no further evidence has been found regarding the tunnel location. Aerial photographs show the destruction of the structure on 84th Street and Chelwynde Avenue to have occurred at some point before 1970. 84th Street was also rerouted over the area of the tunnel during bridge reconstruction in the 1970s. City of Philadelphia survey plans in 1970 show the widening of 84th Street disturbed the area where a segment of the tunnel was depicted on the hand-drawn map. Urbanization of the area has significantly disturbed the potential location of the tunnel.

Based on the review, it was concluded that both resources had been destroyed by urbanization of the area and no longer extant. Therefore, the proposed RA activities would have no further effect on any archaeological sites or historic resources. However, it may be prudent to have an archaeological monitor present during the RA when working in the vicinity of these areas, which are referred to as the Area of Potential Effect (APE). If human remains were discovered during excavation, the coroner and the Pennsylvania State Historic Preservation Office (SHPO) should be notified.

4.1.5 Threatened and Endangered Species Survey

In December 2016, a Pennsylvania National Diversity Inventory (PNDI) environmental review was submitted to determine if there may be potential impacts to threatened and endangered and/or special species and resources within the project area. The response from state and federal agencies, including US Fish and

Wildlife Service (USFWS), Pennsylvania Department of Conservation and Natural Resources (DCNR) Bureau of Forestry, Pennsylvania Fish and Boat Commission (PFBC), and the Pennsylvania Game Commission (PGC) indicated that no impact would be anticipated; therefore, no further review or coordination with these agencies would be required. This response represents the most up-to-date review of the PNDI data file and is valid for two (2) years. The PNDI response letters from the review agencies are in Attachment E.

4.2 SITE PREPARATION AND DEMOLITION

To optimize construction efficiency and E&S controls, a construction sequence (phase) was developed with five areas, as shown on the drawing (see Attachment A). Depending on funding availability, construction can start in any of the following areas independently:

- Area A: Creek side of the landfill
- Area B: Eastwick side of the landfill
- Area C: North side of the landfill including northern City Park
- Area D: Southern City Park area (south of the landfill near the access road)
- Area E: Darby and Cobbs Creek banks.

Each designated area is further explained in Section 8. Construction sequence developed for each area during the RD is also presented in Section 8.

4.2.1 Site Preparation

Site preparation will occur at the start of RA construction. Site preparation activities include, but are not limited to, preliminary E&S controls, tree protection, temporary site security fence, personnel and equipment decontamination facilities, construction of a stabilized entrance and site access roads, lay-down and storage areas, construction trailers, sanitary facilities, and connection of temporary power and communications (telephone and internet). Temporary site access roads and bulk E&S features (such as sediment basins) will continue to be constructed throughout the project area in phases.

The temporary facilities area (laydown and staging areas, decontamination pad, construction trailers, etc.) will be located in the southern industrial area (SIA) and/or around the Command Post being used for the on-going Residential Yard Remedial Action. Several existing businesses in the SIA, mostly auto-repair garages, will be permanently relocated prior to or at the start of the RA by the U.S. Army Corps of Engineer (USACE) as a support agency to EPA. At the end of the RA, demobilization will happen in a similar manner, but in reverse order, including any remaining site restoration.

4.2.2 Demolition and Disposal

Prior to construction of the ET cover in any portion of the landfill, on-site businesses in the SIA shall be permanently relocated and the structures used by them will be demolished. Any above-ground structural items or bulky items that are deemed to be non-contaminated and salvageable may be considered for transport to an off-site recycling facility if appropriate.

Any hazardous materials and waste encountered during demolition must be properly managed. Proper management, including identification and accumulation prior to disposal, is the responsibility of the RA contractor. All disposal shall be through, coordinated by, or approved by EPA.

The buildings subject to demolition have been used for auto repair, trash hauling, and paving materials/equipment storage, and salvage operations. The following hazardous waste may be anticipated during demolition in the SIA:

- Asbestos: An asbestos survey of any buildings that are scheduled for demolition shall be conducted to identify both friable and non-friable asbestos containing materials. The survey shall be conducted prior to the start of demolition under the supervision of a Pennsylvania-licensed asbestos consultant. Individuals performing asbestos surveys must be certified as EPA asbestos inspectors through a Pennsylvania-approved training provider. A draft copy of the survey must be reviewed by EPA for completeness. A copy of the survey must be kept on-site until demolition activities are completed.

- Lead Paint: A lead paint survey must be provided for any building constructed prior to 1980 and for any exterior structure (i.e. painted handrails) that may be affected by a construction project, regardless of age. Materials identified as having lead paint must be further characterized to determine if they are subject to hazardous waste disposal restrictions. Lead survey information must be provided to EPA and the RA contractor must comply with applicable training requirements as required by the Occupational Safety and Health Administration (OSHA) and the EPA.

- PCB Caulking: Samples of caulking in buildings constructed prior to 1978 must be analyzed for the presence of PCBs if the material will be impacted by demolition activities. Caulking containing concentrations of PCBs equal to or greater than 50 mg/kg shall be handled and disposed of as hazardous waste.

- Lamp Ballasts: All ballasts (PCB and non-PCB) must be collected in approved containers for disposal. PCB ballasts must be segregated from non-PCB ballasts. Collection containers (e.g., 55-gallon barrels) must be labeled and closed during accumulation.

- Lamps and Light Bulbs: Fluorescent and high-intensity discharge (HID) bulbs, and other specialty bulbs which may also contain mercury must be collected and handled carefully. All spent lamps or the container which they are in must be labeled clearly.

- Mercury-Containing Equipment: There are many types of equipment that contain elemental mercury. Examples include heating and air conditioning thermostats, tilt switches used in silent light switches, pressure gauges, displacement/plunger relays, flow meters, float switches, and drain traps. Before disposing of any of these types of equipment, mercury-containing devices should be identified and handled with caution to prevent spillage. Devices should be handled intact, sealed, and packaged to prevent breakage. All used mercury-containing equipment must be labeled clearly.

- Batteries: Storage batteries and car batteries, and other batteries which contain hazardous metals such as mercury, lead, silver and cadmium must be collected for proper disposal. All used batteries must be clearly labeled during accumulation. Bagging small batteries in non-conductive material will help prevent fires.

- Aerosol Cans: Spent aerosol cans and auto body paints must be collected for proper disposal.

- Electronics: Disposal of electronic waste should be coordinated with EPA.

- Motor Oil and Fuels: Any motor oils and fuels remaining on-site must be collected and disposed of or recycled properly.

- Abandoned Cylinders: Any cylinders left on-site after relocation must be characterized for their content and disposed of properly.

- Abandoned Vehicles: All vehicles should be recycled (if practicable) or disposed of at the permitted facilities.

Unless stated otherwise, concrete foundations and large concrete pad in the SIA will be left in-place throughout the RA to serve as part of the construction laydown area. The concrete foundations will be

crushed and consolidated as fill at the end of the RA. The large concrete pad is designated to remain, and can serve as a staging area for long-term operation and monitoring (O&M). Its surface may need to be repaired at the end of the RA, and require partial depth repair (e.g., cutting out the damaged concrete, cleaning or replacing reinforcing steel, and replacing the concrete) and/or overlays (covering up the surface cracks with a repair mortar) to remain functional and durable.

Demolition may also include selective excavation and retrieval of bulky items from other areas, including a large south wetland and Darby and Cobbs Creeks in preparation of the larger excavation of construction efforts. Consolidation of large items such as corroded vehicles, shopping carts, abandoned fuel tanks, weathered asphalt, and tires may impact the future integrity of the remedy. Therefore, these items will be disposed of at an off-site facility.

4.3 LANDFILL COVER

4.3.1 Site Clearing

Clearing and partial grubbing within the limits of disturbance (LOD) will be performed prior to site grading and waste excavation. The primary nesting season for migratory birds varies greatly among species and geographic locations, but generally extends from early April up to late August. Therefore, large tree cutting is not allowed during this nesting season per the Migratory Bird Treaty Act (MBTA). A phased landfill cell approach will be employed to avoid clear-cutting the landfill. The Contractor should clear areas within each phased cell to the extent that E&S controls can be properly maintained and achieve the necessary performance. Removed trees, shrubs, grass and other vegetation will be chipped and used as mulch and/or soil amendments in appropriate locations. Equipment on-site will be used to turn and mix the pile on a regular basis to promote the generation of mulch. Chipped vegetation may be mixed with the cover material in the area where long-term slope stability is not concerned, and such that vegetation/mulch will not degrade and allow for extensive differential settlement that may destabilize the new cover.

Prior to clearing, the RA contractor will discuss with EPA regarding specific trees that would remain on steep slopes or where grading allows preservation. These trees will be marked with 1-inch wide orange marking paint around the trunk at the height of proposed final grade and 4 inches above it, and pruned with no branches longer than 3 inches prior to earth work. A minimum height to remain above finished grades ranges from 10 to 12 feet. The remaining stumps and root mass will provide bird perches, subsoil support, potential vegetative sucker regrowth, and structural steep slope stability. Trees that are located in areas where grading or filling is not necessary will also be identified and marked by EPA prior to clearing, and/or a protective buffer established to prevent unnecessary damage or harm.

In addition, invasive species have been observed throughout the Clearview Landfill, including *Phragmites australis* (common reed) being the most common invasive species on-site and *Lythrum salicaria* (purple loosestrife). Prior to grading and excavation, Phragmites (and other invasive species) will be treated with Glyphosate-based herbicides safe for aquatic applications per DCNR guidelines (PADCNR, 2016) or other treatments offering similar performance. The application should be done allowing sufficient time for root death before site disturbance.

4.3.2 Waste Excavation and Placement

Existing subgrade will be compacted to minimize the extent of differential settlement within the cover area and to provide a stable base for the cover. After initial site clearing and grubbing but prior to placement of relocated excavated materials within the cover area, the landfill surface will be compacted with a minimum of two to four machine passes, depending on selected compaction equipment and types of soils encountered. The purpose of the compaction effort is to increase load-bearing capacity, prevent soil settling and frost damage, provide stability, and reduce water seepage, swelling, and contraction. All excavated and relocated materials (waste and soil) resulting from grading of the Landfill will be placed evenly in maximum 12- to 18-inch horizontal lifts and compacted properly to establish cover subgrades. After reaching cover subgrade elevations, another compaction effort will be performed over the landfill surface and resulting compaction will be field tested with the nuclear density gauge or equivalent in accordance with technical specifications for earthwork and foundation.

4.3.3 Dewatering

The RA contractor shall develop a Dewatering Plan at the start of RA. Dewatering of standing water in low-lying areas around the landfill (e.g., “Wetland 1” in Attachment H, Wetlands Delineation Report) may be required prior to site grading in or around these areas. These pools and ponds are typically present seasonally (during a wet period or storm event). Several ponded stormwater samples collected from these low-lying areas during the RI were analyzed for contaminants (e.g., VOCs, SVOCs, pesticides, PCBs, and metals), and indicated low levels of arsenic only. In the case dewatering from these areas is required, pumped water can be conveyed to a constructed infiltration area(s) located within the landfill boundary and infiltrated. Depending on topography, infiltration areas can be created with a low soil berm or compost socks within the waste boundary, ensuring that (1) the water infiltrates prior to reaching surface water bodies, non-contaminated areas, or the maintained portions of the City Park, and (2) potential exposure of residents to the water is prevented before it infiltrates. This practice has previously been implemented on several occasions to manage the water generated during the installation of bedrock monitoring wells at the site.

The Dewatering Plan shall also discuss dewatering of leachate. It is anticipated that low strength and low volume of leachate will be encountered during landfill perimeter activities (creek bank restoration and leachate collection trench excavation) and grading. Similar to ponded water management, leachate will be pumped into an infiltration area created within the Landfill for infiltration. The anticipated volume of leachate captured during perimeter excavation work is nominal compared to the amount of precipitation currently infiltrated; therefore, it is not anticipated that infiltration will compromise the structural integrity of the landfill. The RA contractor shall determine the maximum quantity of water that can be conveyed to a constructed filtration area, based on dimensions of a pit and soil characteristic parameters (e.g., saturated hydraulic conductivity, porosity, field capacity, etc.) Alternatively, the RA Contractor can containerize leachate and dispose of it off-site.

A study by Calder and Stark (2010) reported that hazardous exothermic chemical reactions can develop when aluminum waste placed in a landfill contacts with alkaline water (pH>8), and that a landfill receiving 80% by weight of incinerated waste experienced elevated temperature. Although the content of aluminum waste in CVLF is unknown, all borings installed throughout the Landfill did not encounter aluminum waste to date. Moreover, the EPA Hydrological Evaluation of Landfill Performance (HELP) model indicated that approximately 35% (i.e., ~53,000 gal/day) of precipitation is currently being infiltrated through the Landfill. Collectively, it is unlikely that the proposed dewatering practice would pose a risk for aluminum-related reactions because the pH of leachate is neutral, the amount of aluminum (if any) is small, and large amount of precipitation has been infiltrated with no chemical reactions observed. As contingency, the RA contractor is required to explain how to address aluminum or other reactive waste encountered during construction in the WP.

4.3.4 Site Grading

The Landfill is a mound relative to surrounding grades, with an irregular (bumpy) topographic surface. The existing CVLF side slopes are relatively steep (typically ranging from 25% to 33% or greater), and the Landfill has an approximate 80-foot rise without defined terracing. The existing topography of the Site is depicted on the existing conditions plan in Attachment A.

The final grades of the landfill cover were established at no less than 3% and no greater than 33%, and incorporated reverse slope benches at least 15 feet wide at intervals up to the entire slope of the Landfill. These benches were placed in accordance with guidance provided in the Pennsylvania Department of Transportation (PennDOT) Bureau of Maintenance and Operations Publication No. 464 (Maintenance Field Reference for Erosion and Sediment Controls). Benches are used to decrease runoff flow length, collect runoff from slopes, and discharge to collector channels and pipes. Benches are sized to convey the 25-

year storm during construction and the 100-year storm after construction. The vertical spacing and slope of the benches is based on Table 17 in the PennDOT Publication No. 464, as shown below:

Slope	Max. Vertical Spacing Between Benches
2H:1V	20 ft
3H:1V	35 ft
4H:1V	45 ft

Table 17: Bench Spacing

This general grading basis is also consistent with the requirements of 40 C.F.R. Section 258 and EPA's guidance for closing MSW landfills. While the general shape of the Landfill will remain, surficial grading (cuts and fills typically up to 3 feet) is required to meet slope stability. Deep cuts or large fills were avoided where possible.

Interim (sub-grade) grading and final grading of CVLF are mostly determined by the landfill side slopes and tie-in to the grade in Darby and Cobbs Creeks, as well as the regulatory requirement to avoid filling in the surrounding floodplain. The proposed grading will direct surface water runoff away from the landfill and convey upstream surface water ("run-on") around the cover. Proposed cover subgrades and final grades at the Site are provided in Attachment A.

To minimize the amount of cut and fill required to establish cover subgrades, the grading plans were generally developed as follows:

- All on-site cut material will be placed below the cover as fill. Materials generated during construction of stormwater basins, and creek bank stabilization and E&S control features, and removal of contaminated soils outside the limits of the cover will also be consolidated below the cover. No soil or waste excavated at the Site will be disposed of off-site except where explicitly noted (see "Principal Threat Wastes" and "Demolition and Disposal" sections).

- To minimize the exposure to hazardous materials and wastes, and the necessary handling of excavated waste material, cut depths within the landfill area have been minimized. The proposed subgrade as shown on the interim grading plan was established partly based on the known extents and depths of waste within the Landfill. There are areas of the Landfill that do require cut into the existing waste.

- Cut-and-Fill calculations (Attachment M) indicate that fill will be required to achieve the proper

subgrade in some areas. These areas utilize borrow sources as well as excavated material from the area outside the Landfill (e.g., City Park) and mulched existing trees from the Landfill (mixed with the cover soil for nutrient or on top of soils for weed suppression as much as practical). Cut-and-Fill calculations considered the followings:

- Estimated volume of soils generated from excavation of top 2 feet of contaminated soils in City Park outside the planned landfill cover or within the limits of waste
- Estimated volume of material generated from excavation and placement of leachate collection trench
- Estimated volume of material generated from excavation and placement of retaining wall
- Estimated volume of material generated from excavation and placement of storm drain outlet pipes

They can be used for the following information:

- Landfill capacity to consolidate all excavated materials under the cover
- Estimate of borrow source required to complete the final grade of the ET cover
- General locations of cut and fill for establishment of interim and final grades of the cover

4.3.5 Cover System Components

The ET cover consists of a thick layer of relatively fine-grained soil capable of supporting vegetation. Soil types used for construction of the ET cover include silty sands, silts, and clayey silts. The ET cover exploits two characteristics of fine-grained soils: (i) high water storage capacity and (ii) low hydraulic conductivity, even at high degrees of saturation. High soil water storage capacity allows storage of water within the cover until it can later be removed by ET. Low hydraulic conductivity limits advancement of the wetting front into the cover during seasonal wet periods (rainfall or snow melt). The cover should be sufficiently thick such that the soil water content does not increase near the base of the cover, and all changes in soil water storage should occur in the upper portion of the cover. Otherwise, percolation through the cover system can occur. The required cover thickness is a function of the frequency and intensity of precipitation, the unsaturated hydraulic properties of the soil, the type and vigor of vegetative cover, the rate at which water can be removed by ET, and other factors. The ET cover is often provided with surface treatment (e.g., mycorrhizae fungi and/or other amendments; see Section 4.7) to promote rapid vegetative growth and provide erosion protection.

The ET cover system for the CVLF was designed to: (1) minimize the amount of precipitation into the waste mass, thereby reducing the amount of leachate produced; (2) reduce the potential for physical contact with the waste and contaminated soil; and (3) reduce the potential for exposure of the waste due to erosion and off-site migration of contaminants. To meet all these objectives, the required thickness of the cover was determined by the water balance model (GeoStudio® VADOSE/W™), based on the cover soil water storage capacity to retain infiltrating water until it can be removed via evaporation and transpiration by healthy vegetation such as trees and shrubs planted on top. The water balance model report is provided in Attachment R.

The ET cover consists of foundation and soil cover layers, and densely planted trees. The required thickness of the cover varies from 2 to 4 feet, depending on the existing soil cover thickness and a final grade slope in the subject area. To determine the areas requiring additional cover material, the existing soil cover thickness throughout the landfill was determined during the PDI.

Foundation Layer

The existing landfill surface will be re-graded to prepare a compacted foundation layer during interim grading. The foundation layer serves to provide grade control for cover system construction, adequate bearing capacity for overlying layers, a firm subgrade for compaction of overlying layers, and to cover all exposed waste after establishment of the subgrades. Existing cover soil will be used for the foundation layer, and waste material (in some locations) will also be considered part of the foundation layer if deemed appropriate in the field. Depending on locations, up to 36 inches of fill material will be added to construct the foundation layer. The fill material will be mostly imported from off-site, and can be coarse- and fine-grained soil. The cut-and-fill analysis (Attachment M) indicates that approximately 8,000 cubic yards of fill material will be required to establish a foundation layer. Potential borrow sources and their requirements are further discussed in a later section.

Cover Soil Layer

To complete the ET cover, another soil cover layer will be placed over the foundation layer during final grading. This layer is “moderately” compacted (e.g., 85% to 90% compaction) and its thickness varies between 24 and 36 inches. The cover soil layer serves as a base for plant root systems and a water storage for infiltrated water until removed by ET.

The cover soil layer materials will be imported from off-site, and include relatively fine-grained soils such as silty sands, silts, and clayey silts. The surface treatment may be provided to promote vegetative growth

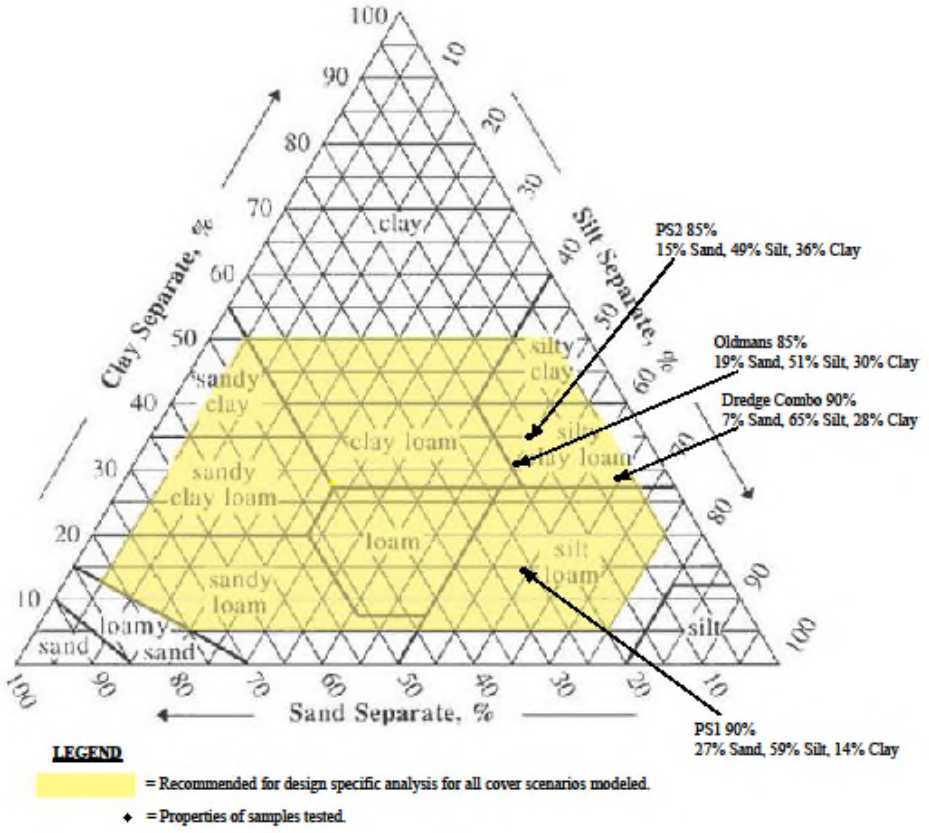
and reduce the potential for erosion by water or wind. In general, the greater the percentage of fines in a soil, the greater the water storage capacity and thus the thinner thickness is required to store a given amount of water. Soils with a large fraction of clay are typically not used due to the potential for desiccation cracking of the clay. Cracks provide preferential pathways for infiltrating water to bypass the clay matrix and thereby bypass storage. In addition, there is somewhat less available water for plants in clays than in silty soils. Approximately 313,000 cubic yards of fill material will be required to construct a cover soil layer with an average thickness of 2 feet over 66 acres.

Vegetation

This top surface layer of the cover system is commonly called an erosion control layer, which typically includes vegetated topsoil to minimize erosion and promote transpiration of water back to the atmosphere. Selection of plant species is an important consideration in the establishment of fully functional ET cover system. The timing of seeding and planting is also important to successful establishment of vegetation. Details on cover planting is discussed in Section 4.7.

4.3.6 Borrow Sources

According to cut-and-fill calculations (including consolidation of all excavated soil within the LOD), approximately 353,000 cubic yards of fill/cover materials would be imported from off-site to construct the ET cover. Soil textures suitable for the cover soil layer (and the foundation layer) were determined by a water balance model (Attachment R), and include USDA textural classes such as sandy loam, loam, sandy clay loam, silty clay loam, loamy sand and silt loam, as highlighted in the following figure (excerpted from the water balance model report in Attachment R).



Although the predicted hydraulic performance for various soil texture mixtures within the highlighted area was generally satisfactory, borrow sources with high clay content (e.g., > 45%) are less desirable due to potential for development of preferential flow paths caused by desiccation and/or freeze-thaw cycling. Silt was also considered less desirable due to the potential for soil loss by wind and water erosion. When a borrow source has been selected, a minimum of one laboratory testing report per 5,000 cubic yards of material is required in accordance with the American Society for Testing and Materials (ASTM) methods, including:

- Organic Content (ASTM D2974)
- Natural Moisture Content (ASTM D2216)
- Atterberg Limits (ASTM D4318)
- Grain-size Distribution (Sieve and Hydrometer, ASTM D422)
- Unified Soil Classification System (USCS) Classification (ASTM D2487)
- USDA Classification
- Standard Proctor (ASTM D698)
- Hydraulic Conductivity (ASTM D5084) at approximately 85%, 90% and 95% compaction

- Consolidated Drained Triaxial Shear Test (ASTM D7181) on a remolded sample at approximately 85%, 90% and 95% compaction of its maximum dry density, with an effective confining pressure of 2 psi.

Moreover, the RA contractor will be required to provide certification of compliance that chemical properties of each borrow source for the cover soil layer shall not exceed, as a minimum:

- OU1 Soil Clean-up Levels (Table C of the ROD)
- EPA Region 3 Biological Technical Assistance Group (BTAG) Ecologically Protective Backfill Values (May 2014)

In addition to above minimum criteria, the RA contractor will be required to provide certification of compliance of imported soils, if applicable, for:

- "Clean Fill" criteria specified in Pennsylvania Department of Environmental Protection(PADEP) "Management of Fill" guidance, Document No. 258-2182-773 (December 20, 2014)
- Requirements of PADEP General Permit WMGR096 for beneficial use of residual waste (December 2013), or
- Requirements of Pennsylvania General Permit WMGR046 (July 2010)

Chemical analyses and testing frequency required are specified in the respective permit documents (Attachment N), and should be described as part of the RA WP in accordance with the current version of the documents. Note that use of regulated fill under PADEP General Permits WMGR096 and WMGR046 entails significant use limitations.

Moreover, the material used for the top six inches of the cover should not have residual seed bank (sterilized or without viable weed seed), and must pass a weed germination test (i.e., sprouting <5% of the test tray area) unless an alternative approach is approved by EPA. A bench test must be conducted for 15 days at 75° F under lights for 10 hours per day. The results of the test together with the source of the materials must be submitted prior to be used as topsoil.

A general description of a weed seed germination test required for the materials used as topsoil is provided below. The RA contractor can use alternative methods upon approval.

- Collect five samples per every 3,000 cubic yards of the materials, and combine and mix them to make at least 1 gallon (4 liters) of one composite sample. Remove any large debris (except rhizomes) from the sample.
- Samples can be stored up to 5 days after collection if they are stored wet (60% moisture) in plastic bags at 4° C.
- Fill two test trays (1 ft x 1 ft) with a depth of about 1 inch and record the total sample volume used.
- Place the trays in a warm location where the temperature is maintained at or above 75° F, with full sunlight (or full spectrum lamp equivalent) for at least 10 hours a day.
- Mist the trays routinely to keep soil moist.
- Maintain sprouting conditions for at least 15 days.
- Measure the sprouted area of the tray and record any observations such as types of weeds.
- Calculate the percent weed germination by sprouted area/total tray area x 100.

The stockpiles that have passed the test should be covered with a plastic liner to keep them relatively free of "new" weed seeds until used. The materials that have not been tested or failed to pass the test can still be used at depths below 6 inches of the cover if they meet other criteria discussed previously.

Furthermore, to ensure soil fertility, borrow source samples must be tested for nutrient content by the standard fertility analysis. Each sample is analyzed for water pH, Mehlich buffer lime requirement, macro/micro nutrients (for phosphorus, potassium, magnesium, calcium, zinc, copper, and sulfur) by the Mehlich 3 test, and for nitrate, nitrogen, ammonium nitrogen, organic matter, total carbon, and soluble salts by optional tests. The final report includes the chemical analysis of the sample along with lime and fertilizer recommendations. The samples will be shipped to county offices of Penn State Extension with a submission form that can be downloaded from http://agsci.psu.edu/aasl/soil-testing/soil-fertility-testing. The Crop Codes (4 digits) for testing are 7030 (Hardwood-to plants) for woodlot and 6300 (To Plant) for landscaping plants - Group 2.

4.3.7 Evaluation of Potential Borrow Sources

As a potential borrow source for the project, bulk samples of dredged materials from the U.S. Army Corps of Engineers (USACE) confined disposal facility adjacent to the Delaware River were tested to determine physical and chemical properties as well as the engineering index and properties discussed in Section 4.3.6 during RD. The laboratory testing results are summarized in Table 2, and the report is included in Attachment I.

The organic content of borrow source samples was analyzed to determine if vegetation can be established

when this material is used. In addition to erosion controls, vegetation promotes transpiration of water back to the atmosphere, and provides a leaf cover or canopy above the soil cover that reduce rainfall impact and decreases wind velocity at the soil surface. It is important to know the water content of the borrow source so that the need for wetting or drying the material prior to required compaction can be identified. Particle size analysis (sieve and hydrometer test) was performed to determine if soil textures of borrow sources are suitable for the cover soil layer (and the foundation layer), as discussed in Section 4.3.6. Moisture-density relationships (a.k.a., compaction curve) were developed using a standard compaction (Proctor) test. The hydraulic conductivity of compacted samples of borrow material was measured to verify that the material can be compacted to achieve the required low hydraulic conductivity. Soil strength tests were conducted to develop shear strength parameters to be used in the slope and foundation stability analyses for the long-term consolidated condition.

Reduced soil compaction in an ET cover is desirable because it can increase water storage capacity and promote plant root growth. Borrow source samples were remolded to 85%, 90%, and 95% of their maximum dry density to assess hydraulic conductivity and shear strength at the anticipated lower and upper field-compaction limits for the ET cover.

Table 2. Borrow Source Test Results

Parameter	Sample ID			
	Pederick South (#1 North)	Pederick South (#2 South)	Oldmans	Wilmington South
Organic Content	5.76%	9.28%	7.95%	9.51%
Natural Moisture Content	46.8%	53.9%	40.9%	86.6%
Atterberg Limits	LL=36; PL=27; PI=9	LL=58; PL=43; PI=15	LL=51; PL=40; PI=11	LL=61; PL=47; PI=14
Standard Proctor	• Max. Dry Density: 88.2 lb/ft^3 • Opt. Moisture: 26.4%	• Max. Dry Density: 77.9 lb/ft^3 • Opt. Moisture: 34.9%	• Max. Dry Density: 80.9 lb/ft^3 • Opt. Moisture: 33.3%	• Max. Dry Density: 74.7 lb/ft^3 • Opt. Moisture: 38.3%
USCS Classification	ML	MH	MH	MH
USDA Classification	Silt Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
Grain-Size	% Sand: 26.9 % Silt: 58.7 % Clay: 14.3	% Sand: 5.5 % Silt: 66.4 % Clay: 28.1	% Sand: 8.7 % Silt: 62.8 % Clay:28.5	% Sand: 4.3 % Silt: 71.2 % Clay: 24.5
Hydraulic Conductivity	• 4.61E-06 cm/s (90% Compaction) • 4.54E-06 cm/s (95% Compaction)	• 9.04E-5 cm/s (85% Compaction) • 2.6E-06 cm/s (90% Compaction) • 9.2E-07 cm/s (95% Compaction)	• 1.53E-4 cm/s (85% Compaction) • 2.08E-06 cm/s (90% Compaction) • 7.05E-07 cm/s (95% Compaction)	• 1.2E-06 cm/s (90% Compaction) • 5.2E-07 cm/s (95% Compaction)
Consolidated Drained Triaxial Shear	• ϕ=35.8° (90% Compaction) • ϕ=44.6° (95% Compaction)	• ϕ=36.2° (85% Compaction) • ϕ=31.3° (90% Compaction)	• ϕ=34° (85% Compaction) • ϕ=43.0° (90% Compaction)	• ϕ=32.3° (90% Compaction) • ϕ=50.8° (95% Compaction)

Parameter	Sample ID			
	Pederick South (#1 North)	Pederick South (#2 South)	Oldmans	Wilmington South
		• ϕ=34.9° (95% Compaction)	• ϕ=42.6° (95% Compaction)	
Notes: 1) LL = Liquid Limit; PL = Plastic Limit; PI = LL – PL 2) MH = Elastic Silt; ML = Silt with Sand 3) ϕ (phi) = Internal Angle of Friction (consolidated-drained)				

Results of laboratory testing indicated that these borrow sources are classified as silt loam or silty clay loam per the USDA soil texture classification, and conform to cover material specifications for parameters such as percentage fines and the plasticity index. The chemical analyses indicated that concentrations of regulated substances were below the clean-up levels, BTAG backfill values, and PADEP General Permit WMGR046 values. Therefore, these borrow sources are considered acceptable for use as cover material.

The organic content of the borrow sources are also considered acceptable for potential use as topsoil (typically 2-3% for lawns; 4-6% for landscaping). The material hydraulic conductivity of these borrow sources are all less than 1 x 10E-5 cm/s at both a 90% and 95% compaction, thereby meeting federal ARARs for hydraulic conductivity for a landfill cover system. The material hydraulic conductivity at 85% compaction, which is more desirable for the ET cover, was greater than 1 x 10E-5 cm/sec. However, the water balance model results (Attachment R) indicated that infiltration rate of these materials at 85% compaction would meet “Equivalent Standard of Performance” (Section 3.2) when the ET cover becomes fully established with planned vegetation. The in-situ moisture content of the potential borrow sources may be too high to achieve proper compaction during interim and final grading. Therefore, these materials will have to be initially dried (e.g., repeatedly scarified and turned over) and compacted during favorable weather conditions to meet project compaction criteria during placement.

Results of the consolidated-drained (CD) triaxial shear tests were used to evaluate stability of the ET cover on the landfill side slopes using these materials. Factors that influence slope stability of the cover system include its vertical and lateral slope dimension, steepness of inclination, internal shear strength parameters of the soil comprising the cover, and interface friction characteristics. Slope instability could result in sliding or sloughing of the cover system if the slope is too steep. Slope stability is commonly demonstrated by a factor of safety (FS), which is defined as the ratio between the resisting forces and driving forces along a failure surface. When the FS falls below 1.0, the slope is considered on the verge of failure. A minimum FS of 1.3 is generally considered marginal for long-term static conditions of a soil cover system (without a geosynthetic layer); however, a FS of 1.5 is more desirable.

The cover system will be placed on slopes having an inclination with a ratio of 3H (horizontal):1V (vertical)

or less. A 3H-to-1V slope is generally considered inherently stable for most soil types. Infinite slope stability analyses were conducted to conservatively check stability of cover soils over the landfill side slopes. The infinite slope stability FS is defined as tan (ϕ) divided by tan(i), where "i" is inclination of an infinite slope and ϕ is the internal angle of friction of the cover soil. Based on laboratory CD triaxial shear test results and a 3H-to-1V slope inclination, infinite slope stability analyses indicated the FS-values greater than 1.5 for all borrow source samples tested, as summarized in Table 3.

Table 3. Infinite Slope Stability Factor of Safety (FS)

Sample ID	Internal Angle of Friction (Phi)	Infinite Slope Stability Factor of Safety (FS)
Pederick South (#1 North)	ϕ=35.8° (at 90% Compaction)	2.16
	ϕ=44.6° (at 95% Compaction)	2.96
Pederick South (#2 South)	ϕ=36.2° (at 85% Compaction)	2.20
	ϕ=31.3° (at 90% Compaction)	1.82
	ϕ=34.9° (at 95% Compaction)	2.09
Oldmans	ϕ=34° (at 85% Compaction)	2.02
	ϕ=43.0° (at 90% Compaction)	2.80
	ϕ=42.6° (at 95% Compaction)	2.76
Wilmington South	ϕ=32.3° (at 90% Compaction)	1.90
	ϕ=50.8° (at 95% Compaction)	3.68
Notes: 1) ϕ = Internal Angle of Friction (consolidated drained) 2) FS = tan (ϕ)/tan(i), where "i" is inclination of an infinite slope (3H:1V)		

The landfill was generally graded to have its surface slope to be no steeper than 3H:1V (see the final grading plan in Attachment A). One location near the access road toward the creek is currently sloped at almost 2H:1V. This area is within a 100-year floodplain and contains large amount of C&D debris on the surface. This slope has been present over several decades with no indication of slope instability. Therefore, only surficial enhancement will be made with non-mechanically stabilized earth (MSE) reinforced materials (e.g., geogrids with live stakes and/or seed mix) to increase stability over time, while keeping the existing grade. Steep slope stabilization is further discussed in Section 4.6.

These materials were not tested for weed seed germination; however, appear to have seed bank based on dense vegetation observed on the surface of stockpiles. If they will be used as topsoil (top 6" of the ET cover), they need to be tested after treatment (or screening) to demonstrate there are no viable seeds. The materials from the areas with invasive species rhizomes (e.g., phragmites and knotweed) should not be used as topsoil. One incremental sampling method (ISM) sample (with a minimum of 50 increments) will be collected per every 10,000 cubic yards and tested in accordance with the method described in Section 4.3.6. If the material was covered immediately after dredging or has been covered for a prolonged

period (if documented), it would not require testing. In addition, as buried materials are exposed, they should be covered with a plastic liner to keep them relatively free of “new” weed seeds. Even if these materials fail to pass the test, they can still be used at depths below 6 inches of the cover since they meet other criteria discussed previously.

4.3.8 Global Stability of the Landfill

During RD, four cross-sections with slope stability of concern were analyzed to assess global stability of the landfill under various loading conditions. The locations of the cross-sections are shown on Figure 1 of the global stability analysis report in Attachment I. Note that the grading used for this analysis was revised and the slopes in these cross-sections are no longer steeper than 3H-to-1V, as shown in the final grading plan. The U.S. Geological Survey (USGS) National Seismic Hazard Mapping Program (NSHMP) Interactive Deaggregation website was used to determine the peak ground acceleration (PGA) of 0.112 g for CVLF relating to the design seismic event with 2% probability of exceedance in 50 years (2,475-year return period) for the Resource Conservation and Recovery Act (RCRA) landfills. Shear strength and engineering properties for the waste and the cover material were based on literature recommendations and the laboratory testing results, respectively. Seepage within the embankment under steady-state conditions and embankment stability safety factors were evaluated using Slide version 7.017 by RocScience, Inc. The results of the slope stability assessment indicated that the minimum required FS for various loading conditions were met, as summarized in Table 4.

Table 4. Global Stability Assessment Results

Cross-Section	Loading Condition	Factor of Safety (FS)	
		Required	Calculated
1	Static, Circular	1.500	2.017
1	Pseudo-Static, Circular	1.000	1.605
2	Static, Circular	1.500	2.026
2	Pseudo-Static, Circular	1.000	1.414
3	Static, Circular – Entire Slope	1.500	1.887
3	Pseudo-Static, Circular – Entire Slope	1.000	1.485
3	Static, Circular – Upper Slope (44%)	1.500	1.880
3	Pseudo-Static, Circular – Upper Slope (44%)	1.000	1.480
3	Static, Block – Upper Slope (44%)	1.500	2.342
3	Pseudo-Static, Block – Upper Slope (44%)	1.000	1.903
4	Static, Circular – 49% Slope	1.500	1.962

Cross-Section	Loading Condition	Factor of Safety (FS)	
		Required	Calculated
4	Pseudo-Static – 49% Slope	1.000	1.530
4	Static, Block – 49% Slope	1.500	2.376
4	Pseudo-Static, Block – 49% Slope	1.000	1.762

4.3.9 Landfill Gas Management System

The purpose of a landfill gas (LFG) management system is to control the migration and emission of LFG to ensure that it does not pose a threat to human health or the environment. Various regulations such as RCRA Subtitle D LFG requirements (40 CFR Parts 257 and 258) and Pennsylvania regulations (25 PA Code, Chapter 273) include provisions that require:

1. The concentration of methane gas generated by the facility shall not exceed 25% of the LEL for methane (e.g., 1.25% methane by volume) in facility structures (excluding LFG control or recovery system components).
2. The concentration of methane gas migrating from the landfill shall not exceed the LEL for methane (e.g., 5% by volume for methane) at the landfill boundary.

During the RI, soil gas and LFG sampling was performed extensively to determine their off-site migration potential. Methane and VOCs were frequently detected in soil gas sample locations at and near the Landfill although methane content at most locations was generally less than 5% by volume. Soil gas samples collected from six vapor monitoring wells in City Park contained methane content ranging up to 75% by volume at times; however, the differential of ambient-to-soil gas pressure was low. There are no known anecdotal reports of actual complaints resulting from soil gas accumulation or with odors within the residential properties nearby to date. EPA performed a screening indoor air modeling with soil gas data collected several times during the RI. EPA also collected sub-slab soil vapor, and indoor and outdoor air samples; evaluated the potential vapor intrusion in nearby homes; and found that there is no vapor intrusion occurring and no unacceptable risk to residents.

LFG emissions are regulated under the authority of the Clean Air Act (CAA). Federal regulations (40 CFR. Parts 51, 52, and 60) require active LFG emission controls (i.e., LFG collection and treatment) for landfills that meet ALL of the following four criteria:

- Landfills that receive MSW;
- Landfills that were in operation after November 8, 1987;

- Landfills that exceed a maximum design capacity of 2,500,000 megagrams (Mg) (approximately 2,750,000 tons); and
- Landfills that exceed a maximum non-methane organic compounds (NMOC) emission rate of 50 Mg per year (approximately 55 tons/yr)

Since the CVLF does not meet all of the above criteria, an active collection and treatment system would not be required. Consequently, a passive LFG venting system should be adequate for controlling and removing potential LFG as part of the remedy.

The LFG management system at CVLF will consist of vertical gas vents placed throughout the landfill cover. Since there is no impermeable layer (e.g., geomembrane) in the cover system, the soil cover should provide enough porosity to allow the LFG to pass horizontally towards the vents.

The gas vents are located at topographic high points of the cover as well as at intermittent locations across the cover area, as depicted in the plan in Attachment A. The gas vents will be constructed with 4-inch diameter perforated Schedule 80 PVC piping in a 24-inch borehole within a gravel pack. The screen interval will be installed at varying depths in unsaturated soils. The screen interval should not exceed 15 feet in length to minimize in-hole dilution, and should not extend above 3 feet below ground surface to allow sufficient annular space to install a low permeability surface plug for preventing atmospheric dilution. A riser pipe tee will be sealed with a cap fitted with quick-connect gas line fitting for monitoring purposes. A typical vertical gas vent detail is provided on drawing in Attachment A.

Pennsylvania regulations (not ARAR) for MSW landfills require the installation of perimeter landfill gas monitoring wells (GMWs) to monitor the potential for off-site migration of LFG. Six existing vapor monitoring wells (VMs) along City Park outside the LOD can serve as GMWs.

4.3.10 Landfill Settlement

Potential differential settlement is an important concern in the landfill cover design. A large post-construction settlement is undesirable from a maintenance point of view since it may lead to surface ponding, development of cracks in the cover, and damages on other ancillary remedial components. Settlement of the MSW landfills begins rapidly as waste is placed and continues to occur for long periods thereafter. However, a large settlement typically occurs in the first few years after completing construction and is characterized with production of large quantity of LFG due to decomposition of waste fill.

Considering the age of the CVLF and differential pressures measured in soil gas in the Landfill, a large post-construction settlement due to waste decomposition is not anticipated. Besides, the Landfill is globally stable in its current state.

The grading provisions at the Landfill sufficiently accommodated potential differential settlement that may be caused by mechanical compression during consolidation, re-grading, and compaction. Engineering controls will be utilized during interim grading to compact the existing landfill surface and relocated wastes during establishment of cover subgrades. For example, after initial site clearing and grubbing, the entire surface will be compacted with a minimum of two to four passes using heavy compaction equipment prior to placement of relocated excavated materials within the area. All relocated excavated materials are to be placed evenly in horizontal lifts and compacted with a minimum of two to four passes using heavy compaction equipment. After reaching cover subgrade elevations, another compaction effort will be performed over the landfill surface. Resulting compaction will be field tested with the nuclear density gauge or equivalent in accordance with technical specifications for earthwork and foundation. A cover soil layer will be constructed similarly.

The design calls for the installation of settlement monuments after completion of cover construction, and periodic surveys to track settlement rates (changes in elevation over elapsed time between surveys) of the cover system. If significant settlement that may pose potential impact to the integrity of remedial components, corrective actions will be required, as discussed in the long-term monitoring plan.

4.4 LEACHATE COLLECTION AND TREATMENT

As part of the OU1 remedy, an on-site treatment wetland was selected to address shallow leachate seeps along the creek bank. Leachate will be collected in perforated pipes at the bottom of the collection trenches along the creek side of the landfill. Leachate collected in the trench will be conveyed to the treatment wetlands for treatment. The outlet of the treatment wetland will discharge the effluent to Darby Creek. Design calculations for the leachate collection system (LCS) and the treatment wetland are provided in Attachments J and K, respectively.

4.4.1 Leachate Collection System

The design of the LCS was based on the estimated volume (~9,250 gal/day) of leachate to be collected in the LCS with its bottom extended to the mean high tide elevation of the creeks under the spring post-construction conditions. The mean high tide line (i.e., 3 feet above mean sea level [msl]) was determined to be the demarcation elevation with respect to a distinction between leachate and groundwater for OU1;

therefore, serves as the elevation for use in the design of the LCS. Extending the bottom of the LCS below the mean high tide elevation will likely result in the collection of groundwater, which is not an approved media to be directly addressed as part of the OU1 remedy. Groundwater is being investigated separately as OU3.

The LCS is comprised of the following components:

- Collection trench backfilled with gravel, filter fabric, and perforated pipe at the bottom
- Pump stations (manhole), each with a sump pump
- Force main transfer pipe
- Electrical system (control panel, cabling/conduit)
- Monitoring wells adjacent to the LCS to monitor the elevation of leachate in the LCS

The perforated pipe at the bottom of the trench will capture and transmit collected leachate to the collection sumps. The slope of the pipe will be 0.5% to accommodate a gravity flow to the sumps that will pump water to the treatment wetland (or its pretreatment systems) through a force main.

The pumping time is controlled by a computer program such that a maximum combined pumping rate from all pump stations to the treatment wetland does not significantly exceed its design flow of 9,250 gal/day. Total head required by a pump to overcome elevation head and friction head along the force main at a design flow is approximately 50 feet.

4.4.2 Leachate Treatment Wetlands

The subsurface flow (SSF) treatment wetland will be constructed to treat leachate conveyed from the pump stations. The main advantage of a SSF system over a free water surface (FWS) wetland system is the isolation of the leachate from vectors, animals and humans. Concerns with odor, mosquitoes and pathogen transmission as well as potential bird attraction near the airport (and ecological exposure) are greatly reduced with a SSF system. The wetland system was designed to reduce effluent concentrations of regulated contaminants below the PADEP's preliminary effluent limits (PELs), as summarized in Table 5. A copy of PELs is provided in Attachment K. A National Pollutant Discharge Elimination System (NPDES) permit application must be filed with PADEP prior to commencing the discharge of treated water to the creek.

Based on the PELs and leachate quality data (collected in 2016 during the PDI), the treatment wetland

needs to primarily reduce concentrations of carbonaceous 5-day biochemical oxygen demand ($cBOD_5$), total suspended solid (TSS), nitrogen, and iron in influent, and increase dissolved oxygen (DO) in effluent prior to discharging to the creeks. A series of process units were designed for leachate treatment, including a filtration system, a water storage tank, and aerobic/anaerobic SSF wetlands. Each process unit is designed for a specific target pollutant; however, it likely removes other pollutants concomitantly. Additional removal capacity of each process unit for constituents other than a primary target pollutant was not quantified during the design phase; however, it will be determined as part of long-term monitoring activity.

A high level of TSS and iron will likely cause frequent maintenance for the SSF wetland due to potential clogging of the void spaces in the media. Therefore, a large portion of TSS and iron associated with particulates will be initially removed by filtration before entering into the SSF wetland. The primary SSF wetland is designed to remove BOD_5 in anaerobic (anoxic) condition. Its effluent containing high ammonia nitrogen is nitrified in the secondary aerobic SSF wetland subsequently, and recycled back to the primary SSF wetland for denitrification. Effluent from the secondary SSF wetland will be discharged to the creek. Design of each process unit is discussed in detail in Attachment K.

Table 5. PADEP Preliminary Effluent Limits (October 23, 2017)

Parameter	Concentration (mg/L) Monthly Average
$cBOD_5$	10
Total Suspended Solids	10
Total Nitrogen	Report
Ammonia Nitrogen	3.0
Dissolved Oxygen	5.0 (minimum)
Total Phosphorus	2.0
Oil and Grease	15
Iron, Total	2.0
Manganese, Total	1.0
Aluminum, Total	4.0
Copper, Total	0.15
Zinc, Total	2.1
Lead, Total	0.42
Chromium VI	Report
Barium, Total	Report
Dissolved Iron	Report
Boron, Total	Report
Cyanide, Free	Report
1,4-Dioxane	Report
PCBs	Report
PFOA	Report
PFOS	Report
pH	6.0 - 9.0 (standard unit)

$cBOD_5$ - Carbonaceous 5-day Biochemical Oxygen Demand
PCB - Polychlorinated biphenyls
PFOA - Perfluorooctanoic acid
PFOS - Perfluorooctanesulfonic acid

The treatment wetlands are located outside of the 100-year floodplain. Construction of wetland systems involves clearing and grubbing, common earth moving, excavating, backfilling, and grading. The basic containment structure of constructed wetlands consists of berms and liners. Uniform compaction of the subgrade is also important to protect the liner integrity from subsequent construction activity (e.g., liner placement and media placement) and from stress when the wetland is filled. A bottom slope of 0.5% is sufficient to drain the wetland by gravity.

The selection of plant species was made by consulting with the EPA Region 3 BTAG. For the project, *Typha latifolia* (broadleaf cattail) was recommended because it is native and a dense stand of cattail can help prevent invasive species.

4.5 CREEK BANK STABILIZATION

The majority of the eastern bank of Darby and Cobbs Creeks along CVLF is mixed fill (soil, C&D, and waste), varying in stability and deterioration. A concept plan for the restoration of the creeks within the project area was initially developed by the U.S. Fish and Wildlife Service (USFWS) and EPA Region 3 BTAG. In general, this concept plan does not propose changes to the overall stream pattern or vertical profile of the project area within the floodplain. Instead, focus is placed on utilizing in-stream structures to stabilize the banks and reduce erosive stresses in critical areas. Three types of in-stream structures are proposed: 1) mud sills; 2) log vanes; and 3) log crib walls. Detailed design reports for these restoration features are provided as Attachments I and L.

- Mudsills: Mudsills consist of wood cribbing extended from the channel bank, elevated above the channel bed. Sill logs are cantilevered from the bank face into the channel and covered with flooring and stone. Stone is often placed underneath the sill to stabilize the toe of the slope, although the stability of the sill is dependent on keying in the anchor logs to the bank. The extension of the sill into the flow of the channel reduces velocities underneath the structure, reducing shear stresses along the bank face, while also providing excellent fish refuge.

- Log vanes: Log vanes consist of natural logs secured together and backfilled with stone. Log vanes extend on an angle from the channel bed to a point along the bank, creating a ramp-like effect along the side of the channel. This ramp-like effect directs flows away from the bank face and towards the center of the channel, moving erosive velocities from the vulnerable banks to stable areas within the channel.

- Log crib walls: Log crib walls consist of parallel and perpendicular logs backfilled by soil. This lattice-type system anchors the wall into the bank while providing protection of the bank face by the logs. Log crib walls provide localized bank protection for steep banks but does not generally reduce the shear stresses along the bank, as they do not extent into the flow. The face of wood crib walls is often vegetated with dense cuttings to increase the localized roughness and reduce velocities along the bank.

During the RD, Tetra Tech performed an assessment of the current conditions of the channel bed and banks in both streams within the project area, which included an evaluation of exposed trash and debris along the banks of the landfill, and the installation of monitoring equipment to measure scour and erosion of the bed and banks. Based on this assessment, profiles on location along the restoration alignment were determined to establish anchor points for long-term stability of the structure and successful establishment of vegetation.

The stabilization effort also includes remediation of the low-lying bankfull areas near the confluence of Darby and Cobbs Creeks, as shown in the landscaping plans in Attachment A. Generally speaking, these low-lying “transition areas” will have the top 2 feet of soil removed (as soils have one or more exceedances of cleanup levels), replaced with clean fill, and replanted with appropriate woody plants (trees and shrubs) and a shade tolerant seed mix. This area will be marked by EPA during the RA.

4.6 STEEP SLOPE STABILIZATION

The existing western side slopes of CVLF are relatively steep (typically > 3H-to-1V). To re-grade this side of the Landfill at a slope of 3H-to-1V or less, significant cut into waste would be required, which may result in potential exposure of construction workers to large quantity of waste materials. Moreover, this practice would widen the cross-sections below an elevation of a 100-year floodplain (~20 feet above msl), and may reduce velocity through the cross-sectional area; therefore, potentially increase the WSEL within a 100-year floodplain, as predicted by a hydraulic model during a flood study. Accordingly, this side of the Landfill was designed to be stabilized with a MSE wall (i.e., soil constructed with artificial reinforcing) with a Redi-Rock® block facing.

MSE walls are located at the toe of landfill steep slopes approximately 50 feet away from the stream channel and above the 100-year floodplain elevation. To design this structure properly, exploratory borings were drilled in the vicinity of the planned locations and laboratory testing was conducted with representative soil samples. Boring logs indicated that portions of subsurface consist of predominantly MSW and sand/gravel soils. For this design, a concrete and in-fill combined unit weight of 120 pounds per cubic feet (pcf) was

assigned to represent the lowest values typical for Redi-Rock units. The stability analysis indicated that the designed wall would be stable under both static and seismic conditions.

This design was made based on data obtained from the exploratory borings and testing in accordance with generally accepted geotechnical engineering practices in the region where the Site is located. However, the nature and extent of subsurface variations across the Landfill may not become evident until construction. If subsurface conditions found during construction appear to be different from those described herein, the RA contractor should consult with EPA immediately so that the recommendations can be re-evaluated.

As discussed in Section 4.3.7, one location near the access road toward the creek is currently sloped at almost 2H:1V (see the landscaping plan C20.01). This area is within a 100-year floodplain and contains large amount of C&D debris on the surface. However, this area has been in place over a long duration with no indication of slope instability. Therefore, only surficial enhancement will be made with non-MSE reinforced materials (e.g., geogrids with live stakes and/or seed mix) to increase stability over time, while keeping the existing grade. The areas subject to this enhancement will be marked by EPA in the field prior to construction.

Details for steep slope stabilization features are provided in the design drawings in Attachment A. The Landscaping plans provide vegetation details.

4.7 COVER PLANTINGS

The ET cover is extended beyond the Landfill to cover contaminated soil and waste as much as practical. Some areas with contaminated soil or waste cannot be covered with a thick ET cover because they are within a 100-year floodplain, in close proximity to the residential properties, or underlain with saturated waste at depths below the groundwater table. For these areas, top 2 feet of surface soils are excavated, backfilled with clean soil to the grade, and planted with select species of grasses, trees, and shrubs, depending on their respective planned land use.

The landfill cover planting (referred to as Upland Forest in the Landscaping Plans in Attachment A) will consist of an overall surface soil layer disked to three inches and seeded with native woody tree and shrub seeds with germination taking place over time. Mycorrhizal inoculum will be used to support and accelerate growth of newly planted trees. The surface is then seeded with a no-mow seed mix to discourage weed growth. Once the permanent grass is established, the area is staked with hybrid and native poplar cuttings for propagation and rooting to create the ET cover. The tree seeds and live stakes

make up 100% of the Landfill cover surface with native trees and shrubs to facilitate the propagation. Shrubs that will be planted include those from live stakes/whips, as well as transplanted specimen. Trees with roots and bare root shrubs will be less than one percent of the planted volume. The cuttings shall be irrigated as needed (i.e., if precipitation is less than 1 inch in 7 days for the first planting year) during dry periods for rooting, and all seeds, cuttings, and live stakes will be inoculated with mycorrhizae fungi when planted to facilitate rooting and growth. The intended terminal vegetative growth is to be forest with native long-term permanent succession species.

The area within a floodplain, and part of City Park where restoration wetlands and conveyance swales (referred to as Flood Plain Forest and Wet Forest, respectively) are constructed will not be covered with a thick cover (exceeding 2 feet in thickness), but will be vegetated as part of the ET cover. Following final grading, permanent native seed mixes shall be seeded. Once vegetation is established, this area shall be planted with native trees and shrubs. Trees vary in size from bare root to 2-inch caliper, and shrubs bare root or one gallon. All plant materials will be inoculated with mycorrhizae fungi when installed to facilitate rooting and growth. The intended terminal vegetative growth in this cover area is to be native forest. The canopy cover is to be contiguous with no open water or open meadow areas. Mowing between the trees would be necessary for first 2 planting years.

Following final grading operations, City Park areas outside of floodplain and wet forest shall be seeded with permanent turf grass and planted with 100 native replacement trees at 2-inch caliper. All trees will be inoculated with mycorrhizae fungi when installed to facilitate rooting and growth. This area shall be maintained (e.g., mowing) by the City of Philadelphia.

Stream bank stabilization materials and structures (Section 4.5) are planted with native species live stakes and joint stakes bundled driven and staked into the constructed support features. All plant materials will be inoculated with mycorrhizae fungi when installed to facilitate rooting and growth. The terminal vegetation is to result in a native forested stream bank.

The ET cover requires specific vegetation to maximize ET. It is estimated that approximately 46,000 trees and shrubs comprised of multiple species will be planted to ensure the ET cover will function as designed and to maintain its long-term viability. Live stakes (cuttings) of hybrid poplar, quaking aspen, eastern cottonwood, bigtooth aspen, and black willow will be planted throughout the cover. Many of the trees are expected to originate from “pilot nurseries” developed for the project at 2 locations (1 on-site and 1 off-site). In addition to trees, seeds of oaks, hickories, pines, hawthorns, sweet gum, tulip poplar, sassafras, and a few others will be spread. The cover plant and seed list is provided as part of landscaping plans in Attachment A. Note that both on-site and off-site nurseries are currently located within the Pennsylvania

Department of Agriculture quarantine area for the Spotted Lanternfly (*Lycorma delicatula*), which is an invasive planthopper. The RA contractor (and its subcontractor) who is collecting and transporting any planting materials from the nursery to the Site must comply with the PA Department of Agriculture regulations pertaining to moving items from a quarantine area.

The recommended planting timing for various tree species and seed mixes is provided in the Landscaping Plans. The RA contractor can discuss with EPA to adjust planting timing. Note that all trees in on-site nursery should be harvested in the planting season prior to repurposing the nursery area. As discussed in Section 4.3.6, only materials that have passed a weed germination test (<5% germination) can be used as topsoil (top six inches of the cover) for planting unless an alternative approach is approved by EPA. Live stakes and whips to be planted on the ET cover can be harvested anytime when plants are dormant and ground is not frozen (between October 31 and April 15); however, prior to April is ideal. Fall/winter planting helps maximize survival and root development prior to bud break and leafing out.

Mycorrhizal inoculum will be used to support and accelerate growth of newly planted trees by greatly increasing the surface absorbing area of roots, producing a healthier root system. These specialized fungi colonize plant roots to create a symbiotic root-and-mycelial network within the surrounding soils, increasing efficiency in nutrient and water absorption to optimize plant health and vigor. To apply mycorrhizae to the trees, the end of live stakes (cuttings) are dipped in the mycorrhizae powder and planted in the pilot holes, and the holes are backfilled. Suppliers will dust all of the tree seeds prior to distribution. Heavy seeds (e.g., acorns) will be drop-spread over the disked cover soil and covered by raking, whereas light-weighted tree and shrub seeds will be spread and tracked-in.

4.8 RESTORATION WETLANDS

As discussed in Section 4.1.3, four existing wetlands were identified on-site during wetland delineation (see a full report in Attachment H). Most, if not all, of these wetlands will be disturbed during the RA to:

- Establish temporary E&S control measures.
- Remediate areas where waste encroaches wetlands and to define the edge of cover.
- Restore or reinforce creek banks.
- Construct permanent stormwater management features (i.e. swales, berms, and culverts) and complete the final grading.

The disturbed wetlands will be restored, created (mitigated), or enhanced. Wetland areas may be enhanced or restored by adding non-invasive and native wetland plantings, including herbaceous, shrub

and canopy plants. Phragmites (Common Reed) will be managed as stated in the report. Various USDA/NRCS and USACE technical resources were referenced for planting specifications, along with local planting guides and recommendations from both EPA Region 3 BTAG and a wetland specialist. Native wetland plantings will either be species present at the site or have been proven to be successful on similar regional wetland restoration projects. Details on wetland planting are shown in the Landscaping Plans (Attachment A).

Two areas near the existing wetlands (W1 and W3 in Attachment P) will be utilized and remain as sediment basins until the entire contributing drainage area is stabilized. Once all drainage areas are stabilized, these areas will be converted to restoration wetlands and receive runoff. Wetlands and conveyance swales will require special monitoring and maintenance.

The wetland W1 is approximately 1.96 acres and will receive runoff from a total drainage area of 32 acres, whereas the wetland W3 is approximately 0.45 acres and will receive runoff from a total drainage area of 11 acres. The design of these two wetlands and associated hydraulic features may need to be refined, based on the observed hydrology during the RA to ensure that the hydrologic conditions in restoration wetlands would keep soils at the bottom being saturated during growing seasons (hydric soils).

4.9 LANDSCAPING

The Landscaping Plans are provided in Attachment A. General description of landscaping after construction was provided in Section 4.7. Traditional landscaping using turf grass will be made in the maintained City Park area. Any existing trees (a total of 100 trees) will be replaced with 2-inch caliper trees that mimic existing conditions, and the hardscaping disturbed during construction will also be restored. Tree species such as Sugar Maple, Hornbeam, Dogwood, Pin Oak, Sycamore, American Elm, Sweet Bay Magnolia, and River Birch are proposed. Perimeter screening at residential lot lines is not anticipated. A cover crop mix will serve as the temporary E&S control mix for all areas.

Transitional, low-lying, flood-prone areas around the ET cover and along the creek bank will combine various woody plantings (trees and shrubs) along with a diversified, native, shade-tolerant seed mix (or mixes). Portions of these transition areas will require some maintenance for access, but will otherwise be left alone.

Landscape maintenance includes line-trimming, mowing, brush clearing, or otherwise maintaining the edges of access roads, access paths, areas around the monitoring wells and gas vents, fence lines,

stormwater culverts, toe drains, and pipe drain rip-rap areas for periodic access, inspection, or maintenance. Maintenance activity is further described in the long-term O&M plan.

4.10 STORMWATER MANAGEMENT

In general, about half of the surface runoff from the landfill drains directly into Darby Creek, and the other half drains towards City Park and surrounding low-lying areas in Eastwick neighborhood. The focus of stormwater management at the Site was to provide safe and non-erosive conveyance of the 25-year storm to tidal waters.

Conveyance swales and piping will be installed as part of the terracing and cover system to help surface water drain away from the cover during large storm events. Similar to the existing conditions, the 2 main wetland restoration areas (discussed in Section 4.8) will also serve as stormwater management areas. The HydroCAD version 10.00-17 was used to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required in accordance with the USDA Soil Conservation Service (SCS) TR-55 method. Design of the culverts and the temporary and permanent channels utilizes the Manning's Equation. Detailed stormwater analysis, including background and regulatory criteria, is provided in the Stormwater Management Report (Attachment P).

4.11 PRINCIPAL THREAT WASTE REMOVAL

Between November 2011 and September 2012, EPA conducted a removal action to remove and dispose of off-site nearly 4,000 tons of PTWs (i.e., waste with PCBs > 100 mg/kg) from the SIA. However, the areas that are currently used by businesses at the SIA were not addressed by the removal. Therefore, the ROD indicated that soil sampling will be conducted in the SIA to refine the estimated volume of remaining PTW that needs to be excavated and disposed of off-site during the RA. Upon consultation with EPA Region 3 Toxic Chemical Substance Act (TSCA) coordinator, it was determined that two subareas in the SIA should be addressed, including yellow and blue polygons in Figure 2 of ROD (EPA, 2014). This figure and excerpts from the ROD are provided in Attachment G.

Currently, sampling cannot be performed because of businesses and trailers occupying majority of this area. Once those businesses are permanently relocated as part of the RA, soil sampling at various depth intervals will be performed within these areas to delineate the extent of PTW. The RA contractor will develop and submit EPA the removal work plan, which documents the basis for an approach to address PTW and other criteria required by 40 C.F.R. § 761.61. Waste with PCB levels above 100 mg/kg will be excavated and sent off-site for treatment (if practicable) and/or disposal.

4.12 EXCAVATION AND CONSOLIDATION

The landfill ET cover was extended to cover contaminated soils and waste as much as practical, while avoiding filling in the 100-year floodplain and an encroachment on neighboring property lines. As a result, some areas with contaminated soils and waste in City Park would remain outside the planned landfill cover. The extent of these areas is delineated by the LOD on the design drawings (Attachment A) and will be addressed, as follows:

- To construct remedial components (e.g., conveyance swales and other E&S features) and/or meet the final grade requirements, the areas outside of the landfill cover within the LOD will be excavated and excavated soil will be consolidated under the landfill ET cover.

- As a minimum, the top 2 feet of contaminated soils in the area between the landfill cover boundary and the LOD, except the area with an impermeable barrier (e.g., wetlands), will be excavated, replaced with clean fill (see Section 4.3.6 for fill requirements) to the final grade, and replanted per the landscaping plan. Excavated soils will be consolidated under the landfill cover. Note that the northern City Park where a restoration wetland is constructed needs to be excavated more than 2 feet, as shown on the drawings.

- The RA contractor will collect confirmatory samples to ensure the removal of all contaminated soils outside the landfill cover.

4.13 SITE AMENITIES

4.13.1 Fence and Gates

It is anticipated that one chain-link vehicle swing gate (double 8-foot wide leaf swing gate) at the main entry point to the landfill cover area off the 84th St. access road, and another vehicular swing-arm gate will be provided at the bottom toe of the north hook of the landfill to prevent off-road vehicles from accessing the flood bank maintenance road via the City Park. The requirements of the chain-link fence and gates are provided in the construction documents; however, detail designs may vary by vendor.

Barrier plantings of trees and shrubs with thorns as a living fence are proposed within the upland and floodplain forests to limit pedestrian access from the City Park to the cover area. Barrier shrubs are proposed at the top of the stream bank structures and the MSE wall (i.e., Redi-Rock) to deter access or fall. Species such as Hawthorn, Honey Locust, Black Locust, Juniper, American Holly, Raspberry, and

American black Currant are proposed. There is no proposed fence between the landfill and Darby/Cobbs Creeks as these creeks are a natural buffer or deterrent.

4.13.2 Access Roads/Paths

The current S. 84th St. access road to the SIA will remain the Site's primary access point. The existing wearing surface is asphalt in fair condition. Any potholes or similar damage to the asphalt road during construction shall be repaired at the end of RA. At the end of the main access road, there will be a gravel parking/turn-around area outside of the main gate so that unauthorized or accidental entrants can easily turnaround and exit the area. A new access road from command post area on Buist Avenue to the top of the landfill was constructed during the removal action and will continue to be used during the RA.

The more heavily accessed roads will be bladed gravel (non-compacted), and the less travelled roads will be reinforced turf (HDPE grass pavers). One access road "loop road" will follow the low-lying flood bank area between the creek and the Landfill. There will be a swing-arm gate at the end of the road at the northern hook of the Landfill to prevent unauthorized vehicles or off-road vehicles from traversing this road through City Park.

City maintenance vehicles regularly access the City Park grounds via the 80th St. cul-de-sac through a locked swing-arm gate and drive on non-reinforced grass with medium-duty pick-up trucks. The City regularly allows EPA contractors to do the same when direct access to the northern side of the Landfill is needed for field work (groundwater sampling, etc.)

Within the landfill, additional access roads or access paths will be incorporated into the landfill benches (terracing). Several "cut-across" ramp-like grades will allow cross-access to various terraces. Turn-arounds will be provided where grades allow; however, there may be some unavoidable remote points or dead-ends due to existing steep slopes.

4.13.3 Other Amenities

Miscellaneous, common site amenities such as site signage, bollards, and guardrail were incorporated in the design. Disturbed or re-graded areas within the City Park will require relocated site-lighting, concrete sidewalks, and asphalt path, and possibly some temporary relocation and resetting of sculpture installations, plaques, benches, or similar park beautification as agreed between the EPA and City. The main walk was redesigned as a wider, shared path (bike path) to accommodate the East Coast Greenway initiative. However, EPA can only replace items if they cannot be repaired or must be destroyed as part

of the RA. These replacement items will be updated based on input from the City.

4.14 INSTITUTIONAL CONTROLS

The ICIAP will be developed by the RA contractor to address land and groundwater use restrictions. The requirements for such restrictions are based on current, reasonably anticipated uses of the Site and areas in the vicinity of the Site.

The purposes of the restrictions are to prevent exposure to unacceptable risks associated with remaining site-related contaminants, to protect the components of the selected remedy, and to prevent off-site migration of contaminants. The restrictions will be implemented through ICs which will include property use controls (such as easements and restrictive covenants, and possibly land acquisition) and governmental controls (such as zoning ordinances and local permits). The ICIAP shall identify parties responsible (i.e., federal, State or local authorities or private entities) for implementation, enforcement, and monitoring and long-term assurance of each IC including costs, both short-term and long-term, and methods to fund the costs and responsibilities for each step.

Moreover, the ICIAP shall include maps, which describe coordinates of the restricted areas depicting all areas that do not allow unlimited use/unrestricted exposure and areas where ICs have been implemented along with a schedule for implementation of the remaining ICs. The maps and information about the ICs shall be made available to the public in several ways, including being posted on the internet and in the Information Repository for the Site. In addition, the ICIAP shall identify reporting requirements associated with each IC, which include an annual review of the status and effectiveness of the ICs, as a minimum.

4.15 ENVIRONMENTAL PROTECTION

This section discusses the measures required to address environmental issues during and after construction. The design specifications require the RA contractor to comply with all substantive requirements of applicable or relevant and appropriate federal, state, and local laws and regulations concerning environmental pollution control and abatement. Prior to construction, the RA contractor will be required to submit an Environmental Control Plan, which will detail how to implement the RD in a manner to protect the environment (e.g., land/water resource protection, dust control, odor control, trash and debris disposal, etc.)

4.15.1 Protection of Land Resources

Upon completion of construction, the land resources outside the LOD will be preserved in their existing condition or restored to a condition that will not detract from the appearance of the Site. The RA contractor will confine construction activities to the following locations:

- Areas defined by the plans or specifications, specifically the LOD depicted on the drawings
- Areas to be cleared for other operations, as indicated on the drawings
- Approved quarry, borrow, and lay-down areas

Except in areas shown on the drawings or specified for clearing, the RA contractor will not deface, injure, destroy, remove, or cut trees or shrubs without EPA approval. Any trees or other landscape feature scarred or damaged during RA activities will either be restored to its original condition or replaced with items of similar type and equal value.

4.15.2 Protection of Migratory Birds

The primary nesting season for migratory birds varies greatly among species and geographic locations, but generally extends from early April up to late August. Migratory birds may seek respite within trees. The Migratory Bird Treaty Act (MBTA) of 1918 prohibits the removal of all listed species or their parts (feather, eggs, nests, etc.) from trees. Therefore, the RA contractor is not allowed to cut or trim large trees, or remove active nests within the project area during this nesting season (from April 1 to August 31).

4.15.3 Protection of Historical or Archeological Resources

The Phase 1A archaeological survey identified two Areas of Potential Effect (APE) at the Site. Approximate locations of these APEs are provided in Attachment F. The cultural resources found include a tunnel for the transportation of slaves and a graveyard dating back to the 18th century, as described in Section 4.1.4. The survey concluded that both resources had been destroyed by urbanization of the area and no longer extant; however, recommended to have an archaeological monitor present during the RA.

The RA contractor shall provide an archaeologist during any subsurface work within the APE. Any archeological resources that are potentially located in the project area will be described in the report. Care will be taken to ensure that any historical, archeological, or cultural resources discovered during construction activities are preserved. Protective devices such as off-limit markings, fencing, and

barricades will be installed to ensure that such resources are not disturbed. Should items of historical or archeological significance be discovered during construction activities, they will be carefully preserved and remain undisturbed by flagging a 50-foot radius around the discovery. The EPA will be immediately notified of the discovery. If human remains were discovered during excavation, the coroner and the Pennsylvania SHPO shall also be notified.

PENNSYLVANIA STATE HISTORIC PRESERVATION OFFICE
Commonwealth Keystone Building
400 North Street
Harrisburg, PA 17120
Phone: (717)783-8946

4.15.4 Protection of Threatened and Endangered Species

As discussed in Section 4.1.5, the response to the PNDI from the USFWS, DCNR, PFBC, and PGC indicated that there are no threatened and endangered and/or special species and resources identified within the project area, and no impact would be anticipated; therefore, no further review or coordination with these agencies would be required. This response represents the most up-to-date review of the PNDI data file during the RD and is valid for two (2) years. The consultation should be revised at the start of the RA and as necessary thereafter.

4.15.5 Protection of Water Resources

Construction activities will not pollute or create objectionable conditions in any water resources near the Site with fuels, oils, sediments, construction debris, or other harmful materials. All federal, state, and county laws and regulations concerning pollution of wetlands, rivers, and streams will be strictly observed. The RA contractor shall prepare the work plan describing how to perform in-stream work (especially during major storm and flooding events), while protecting water resources during construction of stream bank stabilization features described in Section 4.5. Grading operations and/or temporary E&S control measures such as berms, dikes, drains, sediment traps or silt fences will be used to minimize soil erosion at the construction area. An erosion and sediment control plan (ESCP) that will be implemented during the RA was prepared as part of RD (Attachment P) and discussed further in Section 4.15.8.

4.15.6 Spill Prevention

The RA contractor shall prepare the spill prevention, control, and countermeasure (SPCC) plan. The SPCC plan will be implemented to prevent a discharge of oil into adjoining creeks during fuel transfer operations. As a minimum, spill response kits equipped with sorbent materials and shovels should be available during the RA to mitigate any spills. The RA contractor will promptly notify EPA and local officials of spills and the corrective action taken.

4.15.7 Dust Control

As part of the RD, the baseline air quality monitoring plan was developed, and two rounds of ambient air quality monitoring events (August 2016 and April 2017) were conducted with well-placed upwind and downwind monitoring locations on-site and near the Site. The particulates in ambient air often contain toxic heavy metals such as lead and can be inhaled into human respiratory system. Particles less than 2.5 micrometers in diameter (PM2.5) can pose the greatest human risks and lodge deeply into the lungs due to their small size. Therefore, background concentrations of total particulates, total suspended particulate (TSP) lead, and PM2.5 were monitored.

Dust control and suppression will be implemented during the RA to minimize airborne emissions of fugitive dust or particulate matter. The RA contractor shall coordinate with EPA to develop dust action levels that are protective of workers and residents, and conduct real-time dust monitoring during construction. For the remedial action being conducted to remove contaminated soils from residential yards within or adjacent to the historic landfill footprint, EPA established the dust action level of 5 mg/m^3 for safety of workers, and 0.813 mg/m^3 for residents and visitors. Total dust was monitored and calculated on a rolling 15-minute time-weighted average (TWA). Specific actions were to be taken when the total dust 15-minute TWA attained 75% of the Total Dust Action Level of 0.813 mg/m^3 which equals 0.610 mg/m^3, and when the 15-minute TWA Total Dust Action Level itself was exceeded. Total dust is normally visible at approximately 2 mg/m^3. Any time visible dust is present at the Site, dust suppression should be implemented via a water truck or hose to wet soil and roadways to remove any airborne dust caused by site operations. Upwind and downwind air monitoring for particulates will occur for the duration of excavation activities and at the discretion of the Site Safety Officer (SSO). EPA will recommend to residents in the vicinity of earth disturbance or excavation work to keep doors and windows closed to avoid nuisance dust entering their homes. These are the general requirements for the RA contractor to perform work or can be modified as appropriate.

In addition to dust monitoring, air silica monitoring should be conducted during demolition of structures being used by on-site businesses in the SIA (Section 4.2.2). The OSHA requires protection of construction workers from potential exposure to respirable crystalline silica that can be found in construction materials such as sand, stone, concrete, mortar, bricks, etc. The OSHA regulations sets an 8-hour permissible exposure limit (PEL) of 50 µg/m^3 and action level of 25 µg/m^3 as an 8-hour time-weighted average (29 CFR 1926). Table 1 of the regulation specifies exposure control methods when working with materials containing crystalline silica, including tool manufacturer's instructions, dust suppression, high efficiency particulate air (HEPA)-filtered vacuum, etc.

To demonstrate implementation of proper exposure control measures, the RA contractor should collect two samples and one field blank (as a minimum) during demolition, and analyze crystalline silica by laboratory in accordance with the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods (NMAM) 7500 or other methods specified in 29 CFR 1926. Air samples can be collected from a sampling pump fastened to the worker's belt within the demolition zone to collect air samples in the breathing zone, and/or on a post (5 feet high) outside the demolition zone.

4.15.8 Erosion and Sediment Control

The E&S control measures, standard notes, and details provided on the design drawings will serve as the ESCP. These control measures, along with any additional measures determined to be necessary on-site, will be used for the E&S control during construction activities. Temporary and permanent E&S and Best Management Practice (BMP) control measures will be in accordance with the PA Erosion and Sediment Pollution Control Program Manual, (PADEP, July 2012). The ESCP narrative, checklists, and computations are provided in conjunction with the SWM Report (Attachment P).

Temporary measures include standard features such as stabilized construction entrance, sediment basins, silt fence, compost socks (e.g., Filtrexx® products), temporary pipes, rip rap outlet protection, diversion berm, and coffer dams (creek bank restoration). Additional E&S control measures and BMPs will be developed for construction based on field conditions encountered. Permanent features include those associated with permanent SWM features, such as stormwater pipes, rip rap outlet protection, channel stabilization, and site restoration. The Contractor should clear areas within each phased cell to the extent that E&S controls can be properly maintained and achieve the necessary performance. All temporary E&S control measures will be removed and the area restored up at completion of the RA, or sooner if appropriate.

Prior to placement of E&S controls, the RA contractor will place fencing, flagging, or staking to delineate sensitive areas (undisturbed wetlands, tree preservation lines, and certain trees slated for preservation) as

part of the mobilization effort. Some minor clearing may be needed for this effort.

Dewatering operations (see Section 4.3.3) will most likely be needed prior to or during E&S control measure installations, and dewatering activities and monitoring are expected to last throughout the construction period. The RA contractor is required to provide a Dewatering Plan that is consistent with the E&S narrative and E&S sequence of construction prior to commencing any dewatering operations. Any cut material from E&S control measure installations shall be consolidated underneath the proposed landfill cover.

4.15.9 Hazardous and Toxic Waste Management

Hazardous wastes are defined in the RCRA and, in some instances, by state governments. Toxic wastes are defined in the Toxic Substances Control Act (TSCA).

Hazardous Wastes: Hazardous wastes include those that exhibit the characteristics of ignitability (waste posing a fire hazard under certain conditions and having a flashpoint less than 140°F), corrosivity (highly acidic or alkaline waste), reactivity (unstable waste under normal conditions), toxicity (waste capable of releasing specified substances to water in significant concentrations, as determined by the Toxicity Characteristic Leaching Procedure [TCLP] or other methods), or those that are listed by regulations.

No listed and/or characteristic hazardous wastes are anticipated to be uncovered during construction. However, since the contents of the landfill are largely unknown, it is prudent for the RA contractor to establish hazardous waste management procedures, as part of the WP.

Toxic Wastes: As previously described in Section 4.11, the PCB-bearing wastes remaining after a removal action in the SIA are considered toxic waste (a.k.a., PTWs), and will need to be excavated and disposed of off-site during the RA. The RA contractor must identify appropriate off-site facilities and develop the plan for this activity.

No radioactive wastes are known to exist at the Site. The RA contractor shall prepare the contingency plan to address any drums or cylinders uncovered during excavation.

4.15.10 Environmental Footprint Evaluation

The Environmental Footprint Evaluation was conducted as part of RD using the U.S. EPA Spreadsheets for Environmental Footprint Analysis (SEFA), August 2014 version. The purpose of the footprint

evaluation was to assess the environmental impacts of the various steps to complete the proposed remedial alternative using the metrics of greenhouse gas (GHG) and criteria pollutant emissions, energy use, water consumption, and materials and waste sources and endpoints.

The ET cover is the main component of the remedy. Therefore, it is a sustainable remedy with regard to its footprint compared to that of a conventional geomembrane cover system. Further reduction of the environmental footprint could be realized for all construction phases through the possible use of emission control measures such as alternate fuel sources (e.g., biodiesel), equipment exhaust controls, and equipment idle reduction. This evaluation will be provided to the RA contractor(s) as a supplement to inform steps that can be taken to reduce the environmental footprint throughout the life of the RA construction. The report is provided as Attachment T.

4.16 LONG-TERM MONITORING

This section discusses long-term monitoring of media of concern associated with the OU1 remedy as required by the ROD. A long-term monitoring is required to ensure that remedial components are meeting the criteria set forth in the performance standards. The O&M plan is provided as Attachment S.

4.16.1 Sampling and Analysis

To determine the effectiveness of the remedy with regard to containment or treatment of site-related contaminants, multimedia samples from groundwater monitoring wells, treatment wetlands, LFG vents, and creeks will be collected, and analyzed for regulated substances.

The specific locations and frequency of sampling are provided in the O&M plan, and will be updated as necessary based on monitoring results. Long-term monitoring results will also support the on-going OU3 investigation.

4.16.2 Operation and Maintenance (O&M)

The O&M plan was developed to provide details on activities for operating, inspecting and maintaining all components of the remedy. The plan describes routine inspection and maintenance activities required on a regular basis or an as-needed basis. This section briefly discusses performance monitoring required for the ET cover and treatment wetlands.

4.16.3 Cover Maintenance and Performance Monitoring

Long-term performance monitoring shall be conducted to evaluate the attainment of equivalent performance standards for the ET cover (Section 3.2) and to determine when the ET cover is operational and functional (O&F). The following parameters will be monitored as part of long-term performance monitoring. The O&F criteria for each parameter and select instruments are provided in the O&M plan.

- Percent (%) areal coverage with native and/or planted woody species will be used to evaluate performance of vegetation on the ET cover. Aerial photos such as Google aerials are updated annually or biannually. Random plots selected from aerials will be examined on the ground to verify species composition (e.g., native vs. non-native and planted vs. unplanted).

- Soil volumetric water content will be used to assess ET cover water storage change over time and to determine when the water storage capacity of the ET cover has been exceeded. Soil moisture profile probes such as a time domain reflectometry (TDR) probe can be used for continuous, long-term measurements of water content in the ET cover at multiple depths. The probes are installed at intervals in the cover profile at each monitoring station on the top deck, side slopes and in other variations within the ET cover. Pre-programmed data loggers with remote download of data over the internet are available.

- Leaf Area Index (LAI) is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. The water balance model (Attachment R) estimated drainage rates through the ET cover with various vegetation conditions (e.g., grassland, shrubs, meadowlands, or dense trees) represented by respective LAI values. Field measurement of LAI can confirm accuracy of the modeled LAI values. LAI is also used to estimate canopy structures of trees indirectly. For example, an instrument such as LI-COR® LAI-2200C Plant Canopy Analyzer measures LAI and provides canopy closure within a monitoring area.

Vegetation surveys will evaluate the survival rate and relative distribution of plant species on the cover as well as the percent coverage to ensure that a diverse and desirable plant community has been established and that succession toward a complex plant community is occurring. Such surveys will be conducted annually after the first phase of the cover installation is completed and one growing season is completed. The frequency of the surveys thereafter may be adjusted, depending on observations and trends.

The long-term monitoring of the ET cover should be carefully reviewed by a person knowledgeable and experienced in unsaturated soil moisture content and LAI measurement. Because there are uncertainties in the design assumptions, and methods and field performance data for ET cover system designs are limited, a conservative design approach was used. Therefore, field monitoring of these parameters should be conducted to verify that the design assumptions and methods are appropriate.

4.16.4 Treatment Wetland Maintenance and Performance Monitoring

Once a wetland is constructed and become operational, the system requires monitoring to ensure proper operation. Based on monitoring results, these systems may need minor modifications to maintain optimum performance. Several key operational monitoring and maintenance items are discussed herein.

Water level and flow control are usually the only operational variables that have a significant impact on performance of a constructed wetland. Significant changes in water levels should be investigated immediately, as they may be due to leaks, clogged outlets, breached berms, storm water drainage, or other causes. Seasonal water level adjustment helps to prevent freezing in the winter. In cold climates, the water levels should be raised close to the media surface in late fall until an ice sheet develops. Once the water surface is completely frozen, the water levels can be lowered to create an insulating air pocket under the ice and snow cover to maintain higher water temperatures in the wetland.

The inlet and outlet manifolds should be inspected routinely, and regularly adjusted and cleaned of debris that may clog the inlets and outlets. Submerged inlet and outlet manifolds should be flushed periodically. Additional cleaning with a high-pressure water spray or by mechanical means may also become necessary.

Wetland plant communities are self-maintaining, and will grow, die, and regrow each year. Plants will naturally spread to poorly vegetated areas. The primary objective in vegetation management is to maintain the desired plant communities (e.g., cattails) where they are intended to be within the wetland. Vegetation management activities to improve plant cover may include water level adjustment, reduced loadings, pesticide application, and replanting. However, the SSF wetland should not require routine harvesting.

Berms and dikes may require mowing, erosion control, and prevention of animal burrows and weed growth. If the trees are allowed to reach maturity, they may shade out the emergent vegetation.

Routine monitoring is essential in managing a wetland system. Operational conditions such as inflow and outflow rates, water quality, water levels, and percent cover of dominant plant species should be regularly

monitored and evaluated. Over time, these data help the operator predict potential problems and select appropriate corrective actions.

Microbial activity varies seasonally with less activity in cold months although the performance difference in warm versus cold climates is less in full-scale constructed wetlands than in small-scale controlled experiments because of the multiplicity of physical, chemical, and biological transformations taking place simultaneously over a larger contiguous area. Moreover, the insulating layer provided by ice cover would slow down the rate and degree of cooling in the water column, but would not affect physical processes such as settling, filtration, and flocculation. A constructed wetland requires more than one growing season, to achieve normal wetland plant densities and become fully functional and meet discharge requirements. Development of the microbial biomass in the media of a SSF wetland typically requires six month or longer.

The bulk of the solids accumulation occurs at the inlet of the system. Therefore, solids may need to be removed from only a portion of the system (10 to 25% of the surface area). Sediment accumulation is typically not a problem in a well-designed and properly operated constructed wetland. Gabions are used in the inlet zone of the wetland to easily remove and clean the media if it becomes clogged.

Water quality monitoring may be the most demanding task for the treatment wetlands. Several key water quality parameters are monitored with sensors. Water samples from wetlands and other process units will be collected routinely and analyzed by laboratories for regulated substances listed in the discharge permit. Weekly inspection and sampling are typically required for initial six months or until effluent quality meets discharge limits. Monthly inspection and sampling are recommended thereafter.

Although harvesting of plants is generally not required for the SSF wetlands, removal or thinning of vegetation or replanting of vegetation may be occasionally needed to maintain flow patterns and treatment functions. Mosquitoes or other vectors are not a problem in a properly designed SSF wetland system.

5.0 SUBSTANTIVE REGULATORY NOTIFICATION REQUIREMENTS

CERCLA response actions, including the OU1 RA, are generally exempt from administrative requirements of ARARs. This section identifies the regulatory entities or substantive requirements applicable to the OU1 RA:

- E&S/NPDES Notice of Intent (NOI): Although this project is exempt from pursuing the typical NPDES permit related to E&S controls from the local conservation district, the RA contractor (or EPA) should provide the NOI to the following entity prior to the start of earthmoving activities.

Delaware County Conservation District
1521 N Providence Rd.
Media, PA 19063
(610) 892-9484

- Stormwater Management Plan (SWMP): The SWMP, which includes the design of both temporary and permanent E&S controls will be submitted to PADEP for a substantive regulatory review, and to the Philadelphia Water Department (PWD) and the Delaware County Conservation District (DCCD) for informational purposes only.

- Section 404 Permitting (Wetlands/Subaqueous Permits): Wetlands and subaqueous permitting is typically passed through the USACE and delegated to PADEP as the authority in the Southeastern PA region. Wetlands mitigation will be delegated internally to the EPA Region 3 BTAG. Subaqueous work (the creek bank restoration) will be submitted to PADEP for a substantive review.

- Floodplain Management: Floodplain management will be routed through FEMA's National Flood Insurance Program (NFIP) via the LOMC process. A floodplain analysis with a hydraulic model focusing on the Site and surrounding flood-prone areas was conducted for both the existing and proposed RD conditions, to demonstrate the RD has no impacts on the floodplain.

- Construction Permit: This project is exempt from the construction permit requirement.

- Highway Access Permit and Hauling Permits: The main site entrance during construction will be at 84th Street (other entrance points may be considered.) A highway access permit is typically required during construction. Given the large volume of imported fill and the potential for hazardous materials to enter public roads, the RA contractor (or EPA) should contact PennDOT prior to starting the RA.

Pennsylvania Department of Transportation (PennDOT)
Keystone Building
400 North Street
Harrisburg, PA 17120
(610) 929-0766

- OSHA: The work site will be subject to OSHA inspections during all phases of construction and operation. Safety infractions and accidents must be reported to:

United States Occupational Safety and Health Administration
US Custom House, Room 242
2nd and Chestnut Street
Philadelphia, PA 19106-2902
(215) 597-4955

6.0 DRAWINGS AND SPECIFICATIONS

This BDR includes design drawings and specifications that have been developed to date. Additional drawings and specifications (e.g., electrical design) may be provided in the final BDR.

6.1 LIST OF DRAWINGS

The design drawings provided for the OU1 RD are listed below. These drawings are provided as Attachment A.

G00.01	Cover Sheet
G00.02	General Notes and Legend
C00.01	Existing Conditions Plan
C01.01	Sensitive Resources Map – Floodplain & Riparian Areas
C01.10	Wetlands Delineation Plan
C01.20	Wetlands Restoration Plan
C02.01	Construction Phasing Plan
C02.10	Survey Control Plan
C02.11	Demolition Plan
C02.12	Excavation Plan
C03.10 to 18D	Initial Erosion & Sediment Control Plan
C03.20 to 28D	Final Erosion & Sediment Control Plan
C03.51 to 55	Erosion & Sediment Control Details
C15.10 to 18D	Interim Grading Plan
C15.20 to 28D	Final Grading Plan
C15.40	Groundwater and Landfill Gas Monitoring Locations
C15.50 and 52	Landfill Cross-Sections

C15.60 to 66	Creek Restoration Feature Profiles
C15.67	Log Crib Wall Details
C15.68	Log Vane and Mud Sill Details
C15.70 to 85	Creek Restoration Sections
C17.10 to 14	Leachate Collection Trench Profile
C17.21 to 23	Storm Drain & Leachate Discharge Profiles
C17.30 to 34	Redi-Rock Wall Profile
C20.01	Overall Site Planting Map
C20.02	City Park Restoration Plan
C20.03	Seed and Plant List
C20.04	Site Planting Plan
C20.05	Planting Details
C20.06	Feature-Specific Planting Plan
C60.01 to 04	Site Details
C60.11 and 14	Leachate Collection and Treatment Wetlands Details
C60.15	Membrane Filtration System Details
C60.31 to 33	Drainage Structures Details
C60.41	Miscellaneous Details
L001 and 002	P&ID Mechanical Legend
D001 to 004	Leachate Treatment System P&ID
E001	Electrical Single Line Diagram
E002	Electrical Pole Riser & Split to 1 Pump Station and to Wetlands Area
E003	Electrical Pole Riser & Split to 2 Pump Stations
E004	Electrical Details
E005 to 013	Electrical Power & Grounding Plans
E014	Electrical Panel Elevation Details at Water Storage Tank Area
E15	Electrical Panel Elevation at Blower Area

6.2 LIST OF SPECIFICATIONS

Following is a list of technical specifications for the RD. The technical specifications are included in Attachment B. These specifications are subject to modification, addition, or consolidation based on review comment.

Division 1 - General Requirements

01010	Summary of Work
01025	Measurement and Payment
01030	Project Conditions
01035	Contractor's Health and Safety Plan
01051	Field Engineering
01200	Project Meetings
01300	Contractor Submittals
01370	Schedule of Values
01396	Contractor's Construction Operations Plan
01400	Construction Quality Control
01510	Temporary Facilities and Controls
01520	Photographic Documentation
01540	Site Security
01561	Environmental Protection
01700	Project Closeout/Final Cleanup
01720	Record Drawings
01740	Warranties

Division 2 - Site Work

02063	Monitoring Well Modifications and Installation
02110	Site Clearing
02150	Erosion, Sediment, and Pollution Controls
02210	Earthwork and Grading
02220	Site Excavation and Relocation
02225	Leachate Collection Trench
02240	Dewatering
02260	Excavation Support and Protection
02310	Foundation and Cover Layers
02320	Landfill Gas Vents
02535	Pump Station
02630	Storm Drainage
02820	Chain-Link Fence, Gate, and Sign
02900	Landscaping

02910	Precast Modular Block Retaining Wall
02920	Mud Sill
02930	Log Vane
02940	Log Crib Wall
02950	Non-MSW Living Wall
02960	Treatment Wetland

Division 26 – Electrical

255000	Integrated Automation and Facility Controls
260100	Basic Electrical Requirements
260511	Requirements for Electrical Installations
260519	Low Voltage Wires & Cables
260523	Control-Voltage Electrical Power Cables
260526	Grounding
260529	Hangers & Supports
260533	Raceway & Boxes
260543	Ug Ducts & Raceways
260553	Identification for Electrical Systems
262213	Low Voltage Transformers
262416	Panelboards
262726	Wiring Devices

7.0 COST ESTIMATE

A construction cost estimate has been developed for the OU1 remedy, based on generally available cost information (e.g., RACER® by AECOM), various vendor estimates, experience from similar projects constructed elsewhere, and engineering judgment. Details of capital and O&M costs are presented in Attachment C.

The cost estimate presented herein assumed the fill and cover materials would be purchased from local sources. However, a large amount of excess dredged materials from the USACE confined disposal facilities is likely available as a borrow source for the project, as discussed previously. In this case, only labor and equipment costs associated with excavation, transportation, and placement will be required.

Total estimated cost to construct the remedy is $36M, including 10% contingency. An annual O&M cost is estimated to be $156,720, and expected to be reduced over time. With a discount rate of 7% over 30 years for O&M, a present worth cost of the remedy is approximately $37M. The RA costs are summarized below:

Construction Cost	$24,830,860
Contingency (10%)	$2,483,086
Engineer of Record and Other Fees (7%)	$1,738,160
Total Construction Cost	**$29,052,106**
Other Costs* (independent estimate by EPA for borrow source sampling, residential yard excavation, and permanent business relocation)	$6,972,899
Total Estimated Cost of Remedy	**$36,025,005**
Total Estimated Present Worth Cost	**$36,955,910**

* Note that the activities (other than borrow source sampling) associated with this cost will not be performed by the RA contractor.

The greatest uncertainty to the construction cost estimate lies with the cost associated with borrow sources to construct the ET cover, which accounts for a large percentage of the estimated construction costs. The potential factors that would affect the cost of borrow sources include, but are not limited to:

- Availability of large quantity of borrow sources at time of construction that meet quality requirements and soil property requirements (Section 4.3.6)
- Transportation distance of available borrow sources (i.e., the longer the distance, the higher the costs)
- Availability of sufficient number of transport vehicles to deliver borrow sources at time of construction
- Cost of fuel at time of construction.

The EPA has been proactively investigating to locate potential borrow sources during the RD. If EPA is unable to secure borrow sources prior to the start of the RA, sufficient time must be allowed for RA bidding contractors to thoroughly investigate and locate potential borrow sources.

8.0 PROJECT EXECUTION AND CONSTRUCTION SCHEDULE

8.1 PROJECT DELIVERY

This project will be executed in accordance with the procedures described in Division 1 - General Requirements of the Technical Specifications. Contract Documents will be drafted to procure a single construction contract to implement the remedy. The RA contractor will be responsible for all the work identified in the Contract Documents, including addressing defective work and warranty issues following substantial completion.

Prior to construction, the RA contractor will be required to submit the following for approval by the EPA:

- Temporary Facilities Plan (including a facilities layout plan and phasing approach).
- Contractor's Construction Operations Plan (or Work Plan): This plan will identify personnel and equipment, detail the construction procedures to be used in carrying out the requirements of the RD documents, and include standard Contractor Forms or Templates (e.g., change order forms, field work logs, daily activity reports, etc.)
- Contractor Quality Control Plan: This plan will detail all the quality control measures that will be implemented by the RA contractor, as required by the Technical Specifications.
- Environmental Control Plan(s): This plan(s) will detail how the RA contractor will implement the RA in a manner to protect the environment (e.g. land and water resource protection, dust and odor control, trash and debris disposal, E&S controls, dewatering, etc.)
- RA Health and Safety Plan.
- RA Sampling and Analysis Plan
- Construction Schedule

In addition, the RA contractor will be required to submit specifications of products used (e.g., for E&S controls, bank stabilization, etc.) or testing results (e.g., for borrow sources) for approval by the Government as stated in the Technical Specifications. The RA contractor will also be required to submit QC documents (photos, field test reports, as-built documentation, land surveys, etc.) as work is completed, together with any revisions made on the plans developed during the RD.

8.2 CONSTRUCTION SCHEDULE

The projected construction schedule for the RA is summarized below.

Activity	Approximate Duration (Months)	Completion after Commencement of RA (Months)
Contractor Procurement	4	4
Notice to Proceed	-	4
Mobilization and Submission/Approval of Pre-construction Submittals	3	7
RA Construction	36	43
Substantial Completion	-	43
Final Completion (including final submittals)	2	45

Note that this schedule is subject to change pending on availability of RA funding. A final construction schedule will be submitted by the awarded RA contractor.

The RA contractor should consider the following factors when a final construction schedule is developed:

- Cutting or trimming of large existing trees within the project area is allowed only outside bird nesting seasons, starting from April 1 to September 31 (refer to Section 4.15.2).

- The recommended planting time is fall and winter to help maximize survival and root development prior to bud break and leafing out (refer to Section 4.7).

- Substantial completion of the RA is typically realized when construction of all remedial components has been essentially complete. However, the completion of the RA can be recognized only after it is demonstrated that all remedial components are fully operational and functional (refer to Sections 4.16.3 and 4.16.4). If the remedial components do not meet their operation and function criteria, the RA contractor should make additional effort to meet the criteria.

8.3 CONSTRUCTION PHASE

To optimize construction efficiency and E&S controls, a construction sequence (phase) was developed with five areas (see Attachment A). Depending on funding availability, construction can start in any of the following areas independently:

- Area A: Creek side of the landfill
- Area B: Eastwick side of the landfill, including the maintained portion of the southern City

Park

- Area C: North side of the landfill including northern City Park
- Area D: Southern wooded area of the City Park area (south of the landfill near the access road)
- Area E: Darby and Cobbs Creek banks.

Area A consists of the creek side of the landfill starting at the top of Darby and Cobbs Creek bank extending up to the top of the landfill. This portion of the landfill will contain several critical elements of the overall landfill remediation design, including the leachate collection trench and the modular block retaining wall (Redi-Rock®). Once operational, the leachate collection trench will intercept shallow leachate and transport to the treatment wetlands located in Area B. The retaining wall will allow the landfill cover to be placed on the landfill without filling in the floodplain. Currently this portion of the landfill contains moderate-to-steep slopes, and is primarily stabilized with trees and underbrush. Generally, construction of the ET cover in this area will begin at the creek and proceed uphill to the top of the landfill.

Area B is the largest area of the landfill that slopes down to the adjacent Eastwick neighborhood. This portion of the landfill will be covered as typical of elsewhere on the landfill. A portion of Area B is an existing wetland, likely resulting from settlement of the landfill or the installation of the access road. This wetland will be disturbed during construction and utilized as a sediment basin until the entire drainage area is stabilized, and converted to a “restoration wetland.” Currently this portion of the landfill contains moderate-to-shallow slopes and is primarily stabilized with trees and underbrush. This area also includes the maintained portion of the southern City Park. Construction of the ET cover in this area will begin at the toe of the existing slope with the installation of a temporary sediment basin in the location of the existing wetland. Area B also includes construction of the treatment wetlands (Section 4.4), and demolition and disposal activities in the SIA. Moreover, an on-site nursery is located in this area. All trees in the nursery should be harvested during the planting season (see Section 4.7) prior to repurposing of the nursery area.

Area C contains a relatively small portion of the landfill and an open field of the northern City Park. The City Park portion of Area C is relatively flat, and bounded east and west by the Eastwick neighborhood and Cobbs Creek, respectively. The landfill portion of Area C has moderate slopes and is stabilized with trees and underbrush. Area C also has an existing wetland, which will be used as a sediment basin during construction and converted to a restoration wetland after construction. In addition, the top 2 feet of contaminated soils in the area between the landfill cover boundary and the LOD will be excavated, replaced with clean fill to the final grade, and replanted per the landscaping plan.

Area D is the grassed area south of the landfill near the access road and adjoining the Eastwick

neighborhood. This portion of the Site is relatively flat and is primarily grass. The top 2 feet of contaminated soils in a portion of this area will be excavated, and replaced with clean soils to the grade.

Area E is the area within the Darby and Cobbs Creeks that will have restorative construction performed as part of the remedy. Work within the creeks includes removal of large pieces of debris (such as tires and white goods), and installation of stream restoration features (e.g., log vanes, mud sills, and crib walls) to stabilize the creek banks and cover exposed construction debris from the landfill along some portions of the creek.

The following sequence of construction in each area was developed during the RD for informational purposes. The final grade at the boundaries between the two areas next to each other can be significantly different among construction phases. Therefore, the side slopes of the cover constructed in each area must be graded temporarily to ensure adequate and stable slopes (e.g., <33%) with proper erosion control measures. Moreover, cutting or trimming large trees, or removing active nests within the project area is not allowed during the bird nesting season (from April 1 to August 31) per the MBTA. Furthermore, excavation should be performed incrementally and followed by backfilling as soon as practical. The Contractor should clear areas within each phased cell to the extent that E&S controls can be properly maintained and achieve the necessary performance. The RA contractor shall prepare its construction operations plan (or Work Plan) to detail the construction procedures to be used, conforming all these requirements, and approved by EPA.

Sequence of Construction (Area A)

1. Stake at the LOD and remove any large or loose debris.
2. Place E&S controls as shown on the plans at the edge of the creek, and conduct perimeter control inspection.
3. Clear and grub for perimeter access road construction between the creek and the Landfill.
4. Grade area for perimeter access road.
5. Install storm manholes and stormwater outlet pipes from the creek to the storm manholes.
6. Install stone access road around the perimeter of the Landfill.
7. Place temporary stabilization for any remaining disturbed areas.
8. Stake location of retaining walls and leachate collection trench.
9. Install reinforced silt fence at upstream edge of stone access road along the length of the retaining wall.
10. Install retaining walls. Excavation and temporary grading behind retaining walls may be required to allow for wall installation.

11. Install leachate collection trench, sump manholes, leachate forcemain, and electric conduits.
12. Place diversion berm at downstream side of a reverse slope bench (RSB) with a temporary slope pipe as indicated on the plans.
13. Grade to interim grades from back of retaining walls to diversion berm.
14. Install storm sewer from catch basins to storm manholes previously installed.
15. Install ET cover from retaining wall to RSB.
16. Place temporary seed (and other cover crop and native seeds per EPA's direction) and mulch to stabilize.
17. Grade to interim grade from RSB to top of the Landfill.
18. Install ET cover from RSB to top of landfill.
19. Place temporary seed and mulch to stabilize.
20. Remove erosion controls if the cover surface is fully stabilized.
21. Perform landscaping.

Sequence of Construction (Area B)

1. Stake at the LOD and remove any large or loose debris.
2. Install E&S controls as shown on the plans.
3. Clear the Landfill area to receive excavated soils from City Park.
4. Clear the park area subject to excavation.
5. Excavate the top 2 feet of surface soil in City Park, and place excavated soils in a designated area of the Landfill.
6. Place imported clean fill in the excavated park area to proposed finish grades, as excavation progresses incrementally.
7. Install outfall pipe from the creek to the existing wetland (W1), which will be used as a temporary sediment basin during construction.
8. Excavate a temporary sediment basin.
9. Place outlet structure and skimmer. Note that since this temporary basin is entirely within the 100-year floodplain, an emergency spillway for conveyance of the 100-year storm is not needed.
10. Install the swale at the toe of the landfill cover and stabilize swale with Turf Reinforcement Matting.
11. Install diversion berm below RSB.
12. Grade to interim grades from gravel access road to diversion berm.
13. Install RSB with underdrain and catch basin, and place inlet protection on inlets.
14. Install storm sewer from catch basins to swale, and place rock outlet protection at all storm sewer outlets.
15. Install the ET cover from swale to first RSB.

16. Repeat this process working up the slope of the Landfill to the top, installing diversion berms at the bottom of the next RSB as construction moves up the slope.
17. Place temporary seed (and other cover crop and native seeds per EPA's direction) and mulch to stabilize after grading and placement of the ET cover is complete.
18. Remove erosion control devices if the cover surface is fully stabilized.
19. Perform landscaping.

Sequence of Construction (Area C)

1. Stake at the LOD and remove any large or loose debris.
2. Place E&S controls around the LOD of the City Park.
3. Construct access road from City Park to the Landfill.
4. Clear the Landfill area to receive excavated soils from City Park.
5. Clear the park area subject to excavation.
6. Excavate the top 2 feet of surface soil in City Park, and place excavated soils in a designated area of the Landfill.
7. Place imported clean fill in the excavated park area to proposed finish grades, as excavation progresses incrementally.
8. Install storm sewer outfall pipes and a catch basin.
9. Set a catch basin to the final grade and install a catch basin inlet protection.
10. Install temporary seed and mulch over park area. Landscape/hardscape can be installed within the park area any time following.
11. Excavate for a sediment basin as shown on the E&S plans.
12. Place diversion berms on north and south sides of a sediment basin, which will also provide erosion control for the portion of Area B.
13. Place gravel access drive at the bottom of the Landfill.
14. Install a diversion berm above RSB.
15. Grade to interim grades from gravel access road to a diversion berm.
16. Install RSB with underdrain and catch basin and place inlet protection on inlets.
17. Install storm sewer from catch basins to storm manholes previously installed.
18. Install the ET cover from retaining wall (to be constructed as part of Area A) to RSB. If Area A has not been constructed, it is EPA's discretion to construct retaining wall as part of Area C.
19. Place temporary seed (and other cover crop and native seeds per EPA's direction) and mulch to stabilize.
20. Remove erosion control devices if the cover surface is fully stabilized.
21. Perform landscaping.

Sequence of Construction (Area D)

1. Install perimeter controls around the southern City Park area.
2. Install stabilized construction entrance, including E&S controls.
3. Excavate top 2 feet of contaminated soil within the delineated area.
4. Place imported clean fill within the excavated area to the final grade.
5. Place permanent seed and mulch.
6. Remove perimeter controls if the cover surface is fully stabilized.
7. Perform landscaping.

Sequence of Construction (Area E)

This area includes construction of the bank stabilization features within the stream banks of the Darby and Cobbs Creeks. The RA contractor shall be expected to perform the work from the bank as much as practical, or within the creeks during low tide. The RA contractor shall monitor water depth and instream water quality such as turbidity closely during this work.

1. Work to be staged from perimeter access road wherever possible.
2. Install a cofferdam (either the stacked sandbag or Jersey barrier) only as needed for installation of specific improvement.
3. Install turbidity curtain across downstream side of work area if erosion becomes problematic.
4. Dewater work area as required and discharge pumped water through a filter bag.
5. Install creek bank improvement once the work area has been dewatered.
6. After completion of improvement, allow water back into the dewatered area at a controlled rate to minimize erosion.
7. Remove and relocate a cofferdam to next work area and repeat the process.

9.0 EASEMENTS AND ACCESS AGREEMENTS

Temporary access easements will be required for construction of the remedy. In addition, it is anticipated that permanent access agreements will need to be in place to perform long-term O&M on the landfill property and in the City Park. If necessary, EPA will authorize the USACE to obtain all easements required to implement the remedy. A tax parcel composite map depicting the locations of proposed easements and the affected parcels is provided as Attachment O. Upon consultation with EPA or USACE, the tax parcel and individual property easement maps will be developed or refined to assist in obtaining all required easements.

Based on the pre-final design, a brief description of the activities that will occur on these properties follows.

Landfill Property (Tax Map ID No. 15-10-001-000)

EPA has court-ordered long-term *in rem* access to this parcel to perform all necessary environmental work to design, implement, operate, and maintain appropriate remedial actions at the Site. .

City Park (Tax Parcel ID No. 28-46-508-101)

Both a temporary construction access easement and a permanent maintenance access agreement will be required on a portion of this "public lands" parcel to construct the remedy and to perform long-term O&M.

Eastwick Parcels Adjacent to City Park

A temporary construction access easement will be required for about 40 residential properties in Angelo Place that adjoin the City Park. Although it is not anticipated that construction (e.g., major regrading) will actually be performed within these properties, equipment and personnel access to portions of these backyards may be required to construct perimeter berms or drainage swales. It is anticipated that approximately 15-foot temporary easement will be required for each of these residential properties. Note that the backyard fence line of many of these properties have encroached into City Park; therefore, these encroachments may need to be adjusted, relocated, or removed if necessary.

10.0 REFERENCES

Remedial Investigation Report for Lower Darby Creek Area Site, Clearview Landfill, Operable Unit 1 (OU-1). Tetra Tech NUS, Inc., May 2011, amended August 2012

Feasibility Study Report for Lower Darby Creek Area Site, Clearview Landfill, Operable Unit 1 (OU-1). Tetra Tech Inc., October 2012

Record of Decision, Lower Darby Creek Area Superfund Site Operable Unit 1 – Clearview Landfill Soils & Waste. EPA Region 3, September 2014

Sampling and Analysis Plan. Tetra Tech, August 2015

25 PA Code Chapter 273: Municipal Waste Landfills, Commonwealth of Pennsylvania.

Pennsylvania Erosion and Sediment Control Program Manual. PADEP, March 2012

Publication 408: Construction Specifications. Pennsylvania Department of Transportation (PennDOT), October 2015

Phase 1 Archaeological Survey Report. Tetra Tech, March 2011

Vicent Caldel and Timothy Stark, Aluminum Reactions and Problems in Municipal Solid Waste Landfills, Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, ASCE, October 2010.

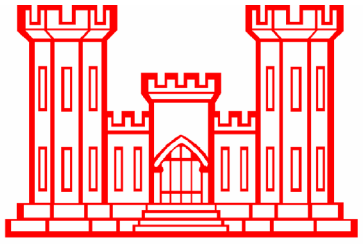
COST ENGINEERING DOCUMENTATION
SUB-APPENDIX V

EASTWICK
CAP SECTION 205
FLOOD RISK MANAGEMENT STUDY
CITY OF PHILADELPHIA
PENNSYLVANIA

FEASIBILITY PHASE

PHILADELPHIA, PENNSYLVANIA

DRAFT - AUGUST 2023



U.S. Army Corps of Engineers
Philadelphia District

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1 COST

1.1 Cost Estimates for Tentatively Selected Plan

1.1.1 Cost Estimate Development

The project cost estimate was developed in the MCACES MII cost estimating software and used the standard approaches for a feasibility estimate structure regarding labor, equipment, materials, crews, unit prices, quotes, sub-contractor markups and prime contractor markups. This philosophy was taken wherever practical within the time constraints. It was supplemented with estimating information from other sources where necessary such as from quotes, bid data, and Architect-Engineer (A-E) estimates. It is to be noted that after development of Abbreviated Risk Analysis (ARA), the costs withing the Tentatively Selected Plan were further refined so some minor inconsistencies between the Cost Appendix and the Engineering Appendix may be present.

Cost estimates for the Tentatively Selected Plan were developed at a Class 3 level of effort utilizing largely parametric unit prices from sources such as historical Government and Commercial bid data, A-E cost estimates available from design reports, the 2023 Gordian/RS Means Cost Data Books and other available historical cost data sources. For developing costs for the levee construction, the standard approaches for developing a feasibility cost regarding cost elements such as labor, equipment, materials, crews, unit prices, subcontractor and prime contractor markups were used.

The intent of the cost estimate was to provide or convey a “fair and reasonable” estimate and where cost detail was provided, it depicted the local market conditions. The construction work is common to the Philadelphia region. The construction site is only accessible via local and state roads, which are in close proximity to various interstate highways. The proposed staging area is also easily accessible through the same local and state roads in the Philadelphia area. No water access is available.

1.1.2 Estimate Structure

The estimate has been subdivided by feature and contains U.S. Army Corps of Engineers (USACE) feature Work Breakdown Structure (WBS) codes. Each WBS cost is subdivided into base cost, contingency and total cost.

1.1.3 Bid Competition

It is assumed there will not be an economically-saturated market, and that bidding competition will be present.

1.1.4 Contract Acquisition Strategy

There is no declared contract acquisition plan/type at this time. It is assumed that the contract acquisition strategy will be similar to past projects. The assumption is that there will be some negotiated contracts with a focus and preference for small business/8(a) along with some large, unrestricted design-bid-build contracts.

1.1.5 Labor Shortages

It is assumed there will be a normal labor market pulled from the Philadelphia area.

1.1.6 Labor Rates

Labor rates were developed comparing Region 1 labor market wages with the local Davis-Bacon Wage Determination, using whichever was determined greater. Regional wage information was formulated from data gathered from approximately 5 different USACE, Philadelphia District (CENAP) construction projects in the Greater Philadelphia region and is assumed to be a fair representation of wage rates for the Philadelphia area.

1.1.7 Materials

Detailed cost estimates were developed for the major construction items such as rip rap and geotextile material. Material quotes were obtained in the development of this estimate and are assumed to remain consistent throughout the project. It is assumed that materials will be purchased as part of the construction contract and prices include delivery of materials.

Cost quotes are used on major construction items when available Material price quotes were taken from previous jobs or from other historical data.

All riprap material is assumed to be contractor furnished. Specific sources for riprap material have been identified, yet are located a considerable distance away from the project site. Since the project location is in Philadelphia, quarries that carry the required quantity and riprap size were unavailable. As such, quarries in Pennsylvania and Maryland were considered and material quotes from suppliers were received. Truck delivery was the only method of material delivery that was quoted. The PDT assumed that truck delivery would be optimal due to site location and the material supplier quoted truck rental rates for delivery of materials to the staging area.

1.1.8 Quantities

Quantities for levee construction were provided by CENAP Civil Section.

The PDT decided that for the Tentatively Selected Plan a comprehensive quantity of the alignment would be provided. The levee crown elevation remains consistent throughout the project length, independent of location. The preliminary assumptions are that the levee has a 10 ft wide crown and side slopes of 1V:2H with riprap to be placed along the floodside. Since the typical levee design elevation for the TSP was fixed, the designer calculated the area per station and multiplied it by the length. Quantities for the levee construction were developed by the civil designer and are provided in the Engineering Appendix. Cost engineering completed a review and verified the provided quantities. The Project Delivery Team (PDT) also noted that the quantities within the TSP design have considerations for settlement of the compacted soils and global subsidence to comply with the latest design criteria. Additionally, a Staging area was scoped and provided along with potential access points. The design parameters and quantities for the levee were provided by the civil designer to meet

the required design elevations for the levee and costs were developed to represent each feature within the TSP.

1.1.9 Equipment

Rates used are based on the latest USACE EP-1110-1-8, Region I. Adjustments are made for fuel and facility capital cost of money (FCCM). Full FCCM/Cost of Money rate is the latest available. The MII program takes the EP-recommended discount, but no other adjustments have been made to the FCCM. Equipment was chosen based on historical knowledge of similar projects.

1.1.10 Rental Rates

Judicious use of owned verses rented rates was considered based on typical contractor usage and local equipment availability. Where rental of equipment is typical, rental rates were applied (i.e. for Tugboat, marine barges, etc.).

1.1.11 Fuels

Fuels (e.g., gasoline and diesel fuel) for rental equipment were based on local market averages for the Philadelphia area. The fuel rates were reviewed over a period of time and a composite, conservative cost was used. Due to the volatility of fuel and significant potential escalation of fuel rate, conservative costs were used in the estimates.

1.1.12 Crews

Major crew and productivity rates were developed and studied by senior USACE estimators familiar with the type of work. The work is typical to the Philadelphia area and is well understood by CENAP cost engineers. The crews and productivity rates were checked by local CENAP estimators and comparisons with historical cost data were referenced. Crews and productivity rates were adjusted as necessary based upon those findings to reflect reasonable crew sizes and production rates. Major crews are used for placement of riprap and geotextile in marine conditions.

A 10% markup on labor for weather delay was selectively applied to the labor in major levee and riprap placing detail items and associated items that would be affected by the weather. Creating unsafe or difficult conditions to operate (e.g., trying to place compacted in rainy weather) would be detrimental/non-compliant to the work being performed. The 10% markup was to cover the common practice of paying for labor “showing up” to the job site and then being sent home due to minor weather conditions, which is part of known average weather impacts as reflected within the standard contract specifications.

Most crew work hours are assumed to be 8 hours, 5 days/week, which is typical for the project area.

1.1.13 Unit Prices

The unit prices were kept to a minimum since further refining of the TSP, which allowed for development of cost items. Recent pricing data and cost estimate was reviewed and compared to historical data to ensure that all costs were within reason. Historical unit price variance versus the

fully developed costs are a result of differing haul distances, small or large business markups, subcontracted items, designs, and estimates by others.

1.1.14 Relocation Costs

Relocation costs are defined as the relocation of public roads, bridges, railroads and utilities required for project purposes. Relocation costs were discussed within the PDT and it was determined that the project does not anticipate any costs. Information from the Relocations Designer showed no relocations of public roads, bridges or railroads were required in the TSP. Further refinement of the TSP may provide additional data and information regarding utilities to be relocated. As such, a zero sum placeholder was placed in Work Breakdown Structure WBS-02 Relocations. As details emerge, costs will be developed using historical cost data and the 2023 Heavy Construction Gordian/RS Means Data Book.

1.1.15 Mobilization

Contractor mobilization and demobilization are based on the assumption that most of the contractors will be coming from within the Philadelphia area. Mobilization and Demobilization costs are based upon historical studies and detailed Government estimates with relevant historical cost pricing data, which are typically in the range of 5-10% of the construction costs. With undefined acquisition strategies and assumed individual project limits, the estimates developed detailed Mobilization and Demobilization costs, which is approximately 10.8% value of Cost to Prime for the Tentatively Selected Plan.

1.1.16 Field Office Overhead

The estimated percentages for Field Office Overhead were based upon estimating and negotiation experience, and consultation with local construction representatives. The estimates used a field office overhead rate based on the average of relevant jobs with a similar scope and magnitude. Different percentages are used when considering the scope of work for each feature. However, when reviewing historical cost pricing data, a range of 10 -25% is typically used. The field office overhead rate of 15% was used for the prime contractors, which was based on historical projects.

1.1.17 Overhead Assumptions

Overhead assumptions may include costs for the superintendent, the office manager, pickup trucks, periodic travel costs, communications, temporary offices (contractor and Government), office furniture, office supplies, computers and software, as-built drawings and minor designs, tool trailers, staging setup, camp/facility/kitchen maintenance and utilities, utility service, toilets, safety equipment, security and fencing, small hand and power tools, project signs, traffic control, surveys, temporary fuel tank station, generators, compressors, lighting and minor miscellaneous items.

1.1.18 Home Office Overhead

The estimated percentages vary based upon consideration of 8(a), small business and unrestricted prime contractors. The rates were based upon estimating and negotiating experience, and consultation with local construction representatives. Different percentages are used when considering the contract acquisition strategy regarding small business 8(a), competitive small business and large business, high to low, respectively. For Home Office Overhead a percentage of 10% was assumed for the prime contractor.

1.1.19 Taxes

Local taxes on supplies and materials needed for construction would be applied based on the county that contains the work. Reference the tax rate website for New Jersey: http://www.salestaxstates.com. The contracts are located in Philadelphia, Pennsylvania and the tax rate is 8.0%. As such, the tax rate used for this project is 8.0%.

1.1.20 Bond

The Bond interest rate was assumed to be 2.50%, applied against the prime contractor, assuming large contracts.

1.1.21 Real Estate Costs

Real Estate (RE) costs were developed and provided by the Realty Specialist and placed in WBS-01 Lands and Damages. The RE cost for each alternative includes land costs, acquisition costs, and 25% for contingencies.

1.1.22 Environmental Costs

Environmental mitigation costs were developed and provided by the Biologist and placed in WBS-06 Fish and Wildlife Facilities. The Environmental mitigation cost for the levee includes costs for impacts to forested wetlands, to EPA wetlands, and to restored habit. Additionally, environmental monitoring and adaptive management costs were included by the Biologist.

1.1.23 Cultural Resources Costs

Cultural Resources (CR) costs were discussed within the PDT and it was determined that the project does not anticipate any Cultural Resources costs. It is estimated that Phase I & II Cultural Surveys and mitigation of resources will not be required. The PDT anticipated that no known or identified cultural resource sites will be present around the project site in Eastwick, Philadelphia. At this time there is no reason to believe additional Cultural Resource sites will be found, therefore, the estimates do not include costs for any potential Culture Resources.

1.1.24 Pre-Construction Engineering and Design (PED)

The PED cost included such costs as USACE project management, engineering, planning, designs, investigations, studies, reviews, value engineering (VE) and engineering during construction.

Historically, a rate of approximately 12% for Engineering and Design (E&D) portion, plus small percentages for other support functions, is applied against the estimated construction costs. Other USACE civil works districts have reported values ranging from 10% to 20% for E&D. Additional support functions might include project management, engineering, planning, designs, investigations, studies, reviews and VE. The percentage was calculated using PDT input and costs provided from all disciplines using their respective historical costs for this phase. A PED rate of 25.0% was applied for this project.

1.1.25 Supervision and Administration (S&A)

Historically, a range from 5% to 15%, depending on project size and type, has been applied against the estimated construction costs. Other USACE civil works districts report values ranging from 7.5% to 10%. Consideration is given that a portion of the Supervision and Administration (S&A) effort could be performed by contractors. An S&A rate of 15.0% was applied for this project.

1.1.26 Contingencies

Contingencies for the Tentatively Selected Plan were developed using the USACE Abbreviated Cost Risk Analysis (ARA) program. An ARA is a qualitative approach used by the PDT to address key risk concerns for major features of work and their impact to cost and schedule drivers such as Project Scope Growth, Acquisition Strategy, Construction Elements, Quantities, Specialty Fabrication or Equipment, Cost Estimate Assumptions and External Project Risks. The development of the ARA resulted in a composite risk contingency of 43.2%, considering all factors of the project. It should be noted Real Estate, PED and S&A costs were not included in formulating the composite risk contingency; however, the overall total project contingency that was developed in the ARA by the PDT was applied to the PED and S&A costs.

1.1.27 Escalation

The escalation for the structural items taken from the historical cost pricing data were based upon the latest version of the USACE Engineering Manual (EM) 1110-2-1304, “Civil Works Construction Cost Index System (CWCCIS)”.

1.1.28 Hazardous, Toxic and Radioactive Waste (HTRW)

Phase 1 surveys have not been performed, but preliminary investigation by the Biologist indicates potential issues were found along the proposed final alignments. The risk of finding HTRW on the mostly landfill and surrounding residential areas that are along the alignment is high. At this time there is reason to believe HTRW will be found, however, no costs were initially captured due to a preliminary scope of work. A contingency was captured in the ARA for the HTRW and applied to the overall total project cost. The cost estimates do not include costs for any potential HTRW, but the ARA does.

1.1.29 Schedule

The project schedule for the Tentatively Selected Plan was developed based on the construction features of work. Plan Formulation/Project Management for the Eastwick Philadelphia Flood Risk Management study have directed that construction of the levee be assumed to begin in February of 2026 with a completed levee in place by August of 2027. The expected construction period is 8 months total. For the purposes of this study, the design is to begin in 2024 and is assumed to be complete in 2025. Table 1-1 below represents the anticipated construction schedule for Mordecai Island Ecosystem Restoration.

***Table 1-1: TSP – Construction Schedule**

Eastwick Flood Risk Management Construction Schedule

PHASE 1 PROJECT START:	2/1/2026
Display Week:	2

Phase 1

Task	Duration - Work Days	Start Date	End Date
Submittals and Site Prep	30 days	2/1/2026	3/3/2026
Mobilization	3 days	3/4/2026	3/8/2026
Development of Work Plan	5 days	3/9/2026	3/15/2026
Clearing and Grubbing	3 days	3/16/2026	3/20/2026
Silt Fence Placement	3 days	3/20/2026	3/23/2026
Drive Steel Sheetpile. PZ-22	55 days	3/23/2026	5/17/2026
Geotextile Placement	8 days	5/18/2026	5/30/2026
Place RCP Culvert	6 days	5/30/2026	6/9/2026
Place Embankment, Compacted Fill	16 days	6/9/2026	7/3/2026
Place Riprap, R5	12 days	7/3/2026	7/23/2026
Excavate Drainage Swale	2 days	7/23/2026	7/25/2026
Geotextile Placement, Drainage Swale	2 days	7/25/2026	7/27/2026
Place Riprap, R3, Drainage Swale	2 days	7/27/2026	7/29/2026
Fertilize, Seed, and Mulch	5 days	7/29/2026	8/3/2026
Demobilization	2 days	7/29/2026	7/31/2026
Weather Days and Holidays	6 days	7/31/2026	8/10/2026

Assumptions

*Assume that all work is to be completed sequentially and all tasks are finish to start

*Schedules above assume each crew is working 7 days a week, 8 hours per day (in reality, crew is working 5 days per week, 8 hours per day). Estimator had difficulty in adding weekends, holidays, and weather days off so it was counted. Anticipated duration is shown in tab 'Duration'

1.1.30 Cost Estimates

Tables 2-1 show the project first cost for the Tentatively Selected Plan. All costs are at June 2023 price levels.

***Table 2-1: TSP – Levee 2**

Feature	Cost	Contingency	Total
01 Lands and Damages	$129,000	$32,000	$161,000
02 Relocations	-	-	-
06 Fish and Wildlife Facilities	$183,000	$79,000	$262,000
11 Levees and Floodwalls	$6,055,000	$2,616,000	$8,671,000
ALL Composite Index Weighted Average	$330,000	$143,000	$473,000
30 Planning, Engineering & Design	$1,644,000	$710,000	$2,354,000
31 Construction Management	$985,000	$426,000	$1,411,000
TOTAL	$9,327,000	$4,005,000	**$13,332,000**

The total baseline project cost for the comprehensive Tentatively Selected Plan is $13,332,000.

1.1.31 Attachments

EASTWICK CAP 205
PHILADELPHIA, PENNSYLVANIA
FLOOD RISK MANAGEMENT
FEASIBILITY STUDY AND INTEGRATED ENVIRONMENTAL ASSESSMENT

Table 1 - Alternative 1: Levee 2

CIVIL WORKS BREAKDOWN STRUCTURE

Construction duration: 8 months

Price Level: June 2023

ACCOUNT NUMBER	DESCRIPTION OF ITEM	QTY	UOM	UNIT PRICE	ESTIMATED AMOUNT	CONTINGENCY	TOTAL ESTIMATED AMOUNT
01.	LANDS AND DAMAGES				$129,385	$31,826.12	$161,211
02.	RELOCATIONS				$0	$0.00	$0
06.	FISH AND WILDLIFE FACILITIES				$182,868	$78,999	$261,867
11.	LEVEES AND FLOODWALLS	1	Job	LS	$6,055,655	$2,616,043	$8,671,697
06.03.74	ADAPTIVE MANAGEMENT @ PROVIDED COSTS	1.00	Job	LS	$80,000	$34,560	$114,560
29.	ENVIRONMENTAL MONITORING @ PROVIDED COSTS	1.00	Job	LS	$250,000	$108,000	$358,000
30.	PLANNING, ENGINEERING, & DESIGN @ 25.00 %	1.00	Job	LS	$1,642,131	$709,400	$2,351,531
31.	CONSTRUCTION MANAGEMENT (S&A) @ 15.00 %	1.00	Job	LS	$985,278	$425,640	$1,410,919
		TOTAL PROJECT AMOUNT			$9,325,317	$4,004,469	$13,329,785
				ROUNDED	$9,325,000	$4,004,000	$13,330,000

Additional costs:

ADAPTIVE MANAGEMENT @ PROVIDED COSTS OF CONSTRUCTION (Year 1)	$114,560 includes contingency
ENVIRONMENTAL MONITORING @ PROVIDED COSTS OF CONSTRUCTION (Years 1 thru 10)	$35,800 per year includes contingency

Notes:

1. PED and S&A costs are approximate percentages using historical data.

2. Environmental costs are rough parametric costs provided by Valerie Whalon. Costs estimate that 10 years of environmental monitoring and 1 year of adaptive management are within reason. 10 years at approximately $25,000 per year (without contingency) for environmental monitoring and a 1 time cost of $80,000 for adaptive management (without contingency).
3. No anticipated Relocations cost for Levee alignment.
4. Lands and Damages costs are rough parametric costs provided by Janay Dixon. Lands and Damages assumes a 25% contingency that was applied to the Lands and Damages cost.

5. A 42% contingency was developed using the Abbreviated Risk Analysis for the following accounts: 06 Fish and Wildlife Facilities, 11 Levees and Floodwalls, 06.03.74 Adaptive Management, 29 Environmental Monitoring, 30 Planning, Engineering, and Design, and 31 Construction Management. Costs provided are parametric costs and the contingencies applied are subject to change pending further details.

DRAFT REPORT
15 JUNE-2023

Eastwick CAP Study
Eastwick Flood Risk Management CAP
Tentatively Selected Plan (TSP)
June 2023

DRAFT REPORT
15-JUNE-2023

Estimated by	Cost Engineering Section ECT-E
Designed by	ECT-E
Prepared by	Jeffrey Sklencar
Preparation Date	6/9/2023
Effective Date of Pricing	6/9/2023
Estimated Construction Time	230 Days

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Description	Quantity	UOM	ContractCost	Escalation	Contingency	SIOH	ProjectCost
Project Cost Summary Report			**6,055,356.03**	**0.00**	**0.00**	**0.00**	**6,055,356.03**
Eastwick Levee May 2023	**1.00**	**JOB**	**6,055,356.03**	**0.00**	**0.00**	**0.00**	**6,055,356.03**

DRAFT REPORT
15-JUNE-2023