APPENDIX F
TAILINGS PILE STABILITY ANALYSIS

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PURPOSE AND SCOPE

This appendix documents the results of Hart Crowser's geotechnical subsurface investigations and slope stability analyses, and provides preliminary geotechnical recommendations for the Upper and Lower Tailings Piles (AOI-2 and -3) of the Van Stone Mine. Hart Crowser is completing a Remedial Investigation (RI) for the mine, which includes analyzing the stability of the Upper and Lower Tailings Piles. The purpose of the analysis is to determine the current condition and stability of the tailings piles.

Our scope of work for this task included:

- Assessing subsurface conditions using subsurface explorations and laboratory tests, and reviewing previous geotechnical reports;
- Characterizing geotechnical properties affecting the stability of the tailings piles;
- Performing geotechnical analyses to assess tailings pile stability; and
- Completing this section for the RI.

BACKGROUND INFORMATION

Mill tailings from the Van Stone Mine were discharged at two separate sites: the Upper Tailings Pile and the Lower Tailings Pile. The Upper and Lower Tailings Piles are shown on Figures F-1 and F-2, respectively.

The Upper Tailings Pile covers approximately 9.5 acres, has a maximum height of approximately 35 feet, and contains about 780,000 tons of tailings. The Upper Tailings Pile was used between 1952 and 1961 and was discontinued when a section of the embankment failed.

The Lower Tailings Pile covers approximately 37 acres and contains about 1,820,000 tons of tailings. The Lower Tailings Pile was constructed in two lifts; the lower lift was constructed between 1961 and 1970 and the upper lift between 1991 and 1993. The maximum heights of the upper and lower lifts are approximately 60 and 25 feet respectively.

SITE CHARACTERIZATION

The site characterization included an evaluation of the surface geometry, subsurface stratigraphy, soil engineering properties, and groundwater conditions along the perimeter slope of the tailings piles. The results of the site characterization were used to develop slope stability analysis models.

Surface Geometry

During field work in October 2011, a limited slope stability reconnaissance was performed at the Van Stone Mine by a field geologist and geotechnical engineer. The purpose of the reconnaissance was to observe current conditions and select sections of the Upper and Lower Tailings Piles for slope stability analysis.

During this site visit, the tailings piles were divided into reaches about 500 feet long measured along the crest of the pile. The team examined the downstream slope and crest of each reach, looking for signs of instability including seepage, erosion, tension cracks, and over-steepened slopes. The height and gradient of the slopes was also taken into consideration. The team then selected the section within each reach that appeared to be the least stable, and surveyed a cross-section of the embankment.

After comparing the geometry of nine surveyed cross-sections, two sections from the lower pile and two from the upper pile were identified as potential critical sections where we expect the slopes to be the least stable. Subsurface explorations were completed at these cross-sections. The locations of the cross-sections from the Upper and Lower Tailings Piles are shown on Figures F-1 and F-2 respectively.

Subsurface Stratigraphy

The subsurface stratigraphy was based on field explorations advanced for this study, laboratory tests on selected soil samples, and information from the Tailings Disposal Design Report (DCN-1037). Approximate locations of the field explorations are shown on Figures F-1 and F-2 for the Upper and Lower Tailings Piles, respectively. Boring logs and results of the laboratory tests conducted for this study are included in Appendix A.

We understand that the Upper and Lower Tailings Piles were constructed using the upstream method of tailings deposition. Typically with this method of construction, a starter dike is constructed at the downstream toe using on-site soil. Tailings are discharged from the crest of the starter dike. The coarser sand-sized particles settle close to the dike, and become the foundation and a source of material for the next dike as the impoundment rises. The finer silt and clay-sized particles are transported toward the center of the impoundment. The material in the tailings piles is expected to be inter-layered with varying particle sizes and soil strength parameters.

The field explorations consisted of eleven Cone Penetration Tests (CPTs) and four mud rotary borings. As expected, inter-layering of the tailings deposits was visible in the CPT logs and was observed in the soil samples obtained from the borings. Pore pressure dissipation and shear wave velocity tests were completed in conjunction with the CPTs.

In general, the soil/material encountered in our field explorations can be grouped into four units. The following sections describe the generalized soil types/units from the ground surface downward.

Tailings. The tailings unit was identified in all four borings with an approximate thickness between 33 and 36 feet at the Upper Tailings Pile and between 42 and 68 feet at the Lower Tailings Pile. The unit contains of loose to medium dense, silty fine sand, interbedded with low plasticity silt and silty clay. The amount of fines (percent passing the US No. 200 sieve) ranged from 28 to 52 percent.

Medium Dense Native Soil. The medium dense native soil unit was encountered below the tailings unit at the Upper and Lower Tailings Piles with an approximate thickness of 5 feet. The unit contains medium dense gravelly sand at the Upper Tailings Pile and very stiff, slightly sandy low plasticity silt at the Lower Tailings Pile.

Very Dense Native Soil. The very dense native soil unit was encountered below the medium dense native soil unit at the Upper and Lower Tailings Piles. At the Upper Tailings Pile, the borings terminated in this unit, which contains dense gravelly sand. At the Lower Tailings Pile, this unit contains very dense, silty, gravelly sand to hard, sandy, gravelly silt with an approximate thickness between 11 and 44 feet.

Weathered Granite. The weathered granite unit was encountered below the very dense native soil unit at the Lower Tailings Pile. The unit contains very dense, fine to coarse sandy gravel with granitic rock fragments.

Figures F-3 through F-6 illustrate the generalized subsurface soil conditions at the critical cross-sections for the Upper and Lower Tailings Piles.

Soil Engineering Properties

The engineering properties for the soil units described above are based on exploration data, lab test results, correlations with blow counts from borings, and correlations with CPT data. The engineering properties are summarized in Table 1.

Groundwater Conditions

The groundwater conditions at the study cross-sections were evaluated and characterized based on water levels observed during drilling, measurements made with vibrating wire piezometers installed in two of the completed borings, and pore pressure dissipation tests completed in conjunction with the CPTs.

During drilling, groundwater was observed in UT-HC-1 within the tailings approximately 12 feet above the contact with native soil. Groundwater was observed in UT-HC-2 within the tailings approximately two feet above the contact with native soil. Perched groundwater was observed in LT-HC-3 within the tailings approximately 42 feet above the contact with native soil. Groundwater was observed in LT-HC-4 at the contact between tailings and native soil. Groundwater levels observed in the explorations are indicated on the logs in Appendix A and on the generalized subsurface profiles (Figures F-3 thru F-6).

The explorations advanced as part of this study are located along the perimeter of the tailings piles. The explorations indicate that the perimeter of the piles are generally dry to moist, with the groundwater level typically near the contact between the tailings and native soil. It is expected that the groundwater levels will be highest during or immediately after the spring snowmelt. Because the groundwater measurements were taken in the fall and early summer, they may not represent the worst-case scenario for slope stability. Therefore, several iterations of the slope stability analysis were performed, varying the groundwater level between the base and four feet above the base of the tailings piles.

SLOPE STABILITY ANALYSIS

To assess the stability of the tailings piles, slope stability analyses were conducted for two slope configurations, one from the Upper Tailings Pile (Cross Section 1) and one from the Lower Tailings Pile (Cross Section 3) using limit equilibrium software. The two slope sections were selected from the four potentially critical sections shown on Figures F-3 thru F-6. The subsurface explorations advanced at the four sections indicate that the engineering properties of the tailings and native soil do not vary significantly with location. Therefore, the two analyzed sections were selected based on slope geometry.

The analysis criteria, method of analysis, and loading conditions are discussed below.

Stability Analysis Criteria

Static and seismic slope stability analysis of the Upper and Lower Tailings Piles was conducted in general accordance with the Washington State Department of Ecology Dam Safety Guidelines Part IV: Dam Design (1993).

The guidelines recommend static analysis for the end of construction, sudden drawdown from maximum pool, sudden drawdown from spillway crest, and steady seepage with maximum storage pool (long-term) design conditions. Because the Upper and Lower Tailings Piles have been in place since 1961 and 1993, respectively, the end of construction condition is not applicable and was not evaluated. Additionally, because the embankments impound tailings, the sudden drawdown conditions are also not applicable and were not evaluated.

The guidelines recommend a two tracked seismic assessment including a deformation analysis and a liquefaction analysis (post-earthquake).

The minimum factor of safety against static slope failure recommended by the dam safety guidelines is 1.5 for the long-term condition. Minimum seismic factors of safety are not provided in the guidelines so a typical value of 1.1 was used to asses the post-earthquake stability.

Method of Analysis

Slope stability analysis was completed using SLOPE/W a limit equilibrium computer program developed by GEO-SLOPE International Ltd. The Morgenstern-Price method, which satisfies both moment and force equilibrium was selected for the analysis.

Circular slip surfaces were evaluated for all loading conditions. In addition, truncated circular slip surfaces were evaluated for the post-earthquake and yield acceleration conditions. Only significant slip surfaces, at least 5 feet thick, were considered in our analysis because surficial sloughing is not likely to affect the overall stability of the tailings piles. For the Upper Tailings Pile for each loading condition we completed three analyses considering slip surfaces at least: 5 feet thick, 10 feet thick, and 20 feet thick. For the Lower Tailings Pile for each loading condition we completed three analyses considering slip surfaces at least: 5 feet thick, 20 feet thick, and 30 feet thick.

Slope stability was evaluated for the long-term and post-earthquake loading conditions. The yield acceleration was also determined for each tailings pile to allow calculation of the seismic slope deformation. The yield acceleration was not calculated for some analysis cases because the factor of safety was less than 1.0 before applying a seismic acceleration.

Seismically induced horizontal slope deformation of the Upper and Lower Tailings Piles was estimated using two simplified methods developed by Makdisi and Seed (1977) and Bray and Travasarou (2007).

Loading Conditions

Static Long-Term

Drained (effective) shear strength parameters were assigned to all materials. As discussed above, several iterations of the analysis were performed varying the groundwater between the base of the tailings and 4 feet above the base in 2-foot increments.

Seismic

The Washington State Department of Ecology Dam Safety Office (DSO) performed a periodic inspection of the Lower Tailings Pile on August 16, 2006, which is documented in an Inspection Report (DCN 1005) dated January 18, 2008. As part of the inspection, the DSO classified the downstream hazard in accordance with the Dam Safety Guidelines as Significant, Hazard Class 2 based on the nature and quantity of the impounded tailings. A seismic event with a 2 percent probability of exceedance in 50 years (corresponding to a nominal return period of 2,475 years) is the typical basis of design for this level of risk. For the tailings piles, liquefaction potential and seismic slope deformation were estimated using an earthquake with a return period of 2,475 years.

Seismic hazard parameters were obtained from the United States Geological Survey Interactive Deaggregation web site using the latitude and longitude for the site. The deaggregation indicates that the “modal source” for earthquake shaking at the Upper and Lower Tailings Piles is a magnitude 5.2 event with an epicenter approximately 13 kilometers from the site producing a peak ground acceleration (PGA) of 0.13 g. The PGA obtained from the deaggregation represents the acceleration at bedrock beneath the site and does not account for ground motion amplification due to site-specific effects.

Site modified values were determined based on the site class using methods in the 2009 International Building Code (IBC). The 2009 IBC requires that the site soil be classified based on the upper 100 feet of soil. Because the explorations at the site were less than 100 feet deep, the last reasonable standard penetration value for each exploration was extrapolated to a depth of 100 feet. Based on the inferred properties of the upper 100 feet of soil and bedrock below the tailings piles, the Upper Tailings Pile is classified as site class D and the Lower Tailings Pile is classified as site class C. The appropriate site modified ground surface PGAs for the Upper and Lower Tailings Piles are 0.19 g and 0.15 g, respectively.

Post-Earthquake

For the post-earthquake condition, residual undrained (total) shear strength parameters were assigned for the tailings below the groundwater level. Residual shear strength values were determined using the Idriss and Boulanger (2008) empirical method based on SPT values from the site. Drained (effective) shear strength parameters with no strength reduction were assigned to all other materials. As discussed above, several iterations of the analysis were performed, varying the groundwater between the base of the tailings and four feet above the base in 2-foot increments.

Yield Acceleration

A yield acceleration analysis was performed to determine the horizontal seismic coefficient that results in a factor of safety of 1.0 for the critical slip surface. Undrained (total) shear strength parameters reduced by 20 percent were assigned for the tailings below the groundwater level. Drained (effective) shear strength parameters with no strength reduction were assigned to all other materials. As discussed above, several iterations of the analysis were performed, varying the groundwater between the base of the tailings and 4 feet above the base in 2-foot increments.

Slope Stability Results

Tables 2 and 3 summarize the static and seismic slope stability results in terms of factor of safety for the Upper and Lower Tailings Piles, respectively.

Seismic Slope Deformation Results

Tables F-4 and F-5 summarize the permanent seismically induced displacements calculated using both the Makdisi and Seed and Bray and Travasarou methods for the Upper and Lower Tailings Piles, respectively.

CONCLUSIONS

The results of the slope stability analysis of the Upper and Lower Tailings Piles indicate that varying the water table by up to 4 feet has minimal effect on factors of safety for static conditions, but a significant effect on post-earthquake factors of safety and seismically induced displacements. The effect of additional variability of groundwater levels should be assessed when additional data are available.

Upper Tailings Pile

The Upper Tailings Pile slopes are marginally stable for static long-term loading conditions with factors of safety generally greater than 1.0 and less than 1.5. Although stability factors of safety for failure surfaces at least 20 feet thick with groundwater at the base of the tailings pile meet Ecology's minimum requirements, factors of safety are below the minimum requirements for all other cases analyzed.

Factors of safety for post-earthquake conditions exceed minimum requirements for failure surfaces greater than 10 feet thick with groundwater at the base of the tailings piles. Factors of safety do not meet minimum requirements for failure surfaces less than 10 feet thick or failure surfaces of any thickness with groundwater above the base of the tailings piles.

As long as the groundwater table remains below the base of the pile, the estimated seismic displacements are unlikely to cause overall instability of the Upper Tailings Pile. However, if the groundwater rises 2 feet, the estimated displacements are likely to affect overall slope stability and could cause catastrophic failure. For failure surfaces 10 feet deep and greater with the groundwater at least 2 feet above the base of the tailings pile, displacements could not be calculated because the pseudostatic factor of safety was less than 1.0 before applying a seismic acceleration. For these cases, it is assumed that displacements will be significant.

Lower Tailings Pile

The results of the slope stability analyses indicate that the Lower Tailings Pile slopes are marginally stable for static long-term loading conditions with factors of safety generally greater than 1.0 and less than 1.5. None of the static cases analyzed met Ecology's minimum factor of safety requirements.

Factors of safety for post-earthquake conditions exceed the minimum requirements, for failure surfaces at least 20 feet thick and groundwater less than

2 feet above the base of the tailings piles, and for failure surfaces at least 30 feet thick and groundwater less than 4 feet above the base of the tailings pile.

If the groundwater table remains below the base of the pile, the estimated seismic displacements are unlikely to cause overall instability of the Lower Tailings Pile. However, if the groundwater rises two feet or more, the estimated displacements are likely to affect overall slope stability and could cause catastrophic failure. Displacements could not be calculated for some of the scenarios analyzed because the pseudo-static factor of safety was less than one prior to applying a seismic acceleration. For these cases, it is assumed that displacements will be significant.

REFERENCES

Bray, J.D. and T. Travasarou, 2007. Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 133:4

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Makdisi F.I. and H.B. Seed, 1977. A simplified procedure for estimating earthquake-induced deformations in dams and embankments. Earthquake Engineering Research Center Report No. UCB/EERC-77/19

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Table F-1 - Estimated Soil Strength Parameters

		Tailings	Saturated Tailings	Medium Dense Native Soil	Very Dense Native Soil
Drained	γ (pcf)	110	110	125	125
	ϕ' (deg)	36	36	32	38
	c' (psf)	0	0	0	0
Undrained	Su/p	-	0.26	-	-
Residual Undrained	Sr/σ'vo	-	0.2	-	-

Notes:

1. γ = Soil moist unit weight, ϕ' = soil effective angle of internal friction, c' = soil effective cohesion, Sr = residual shear strength, σ'vo = vertical effective stress for effective overburden, Su = undrained shear strength, p = confining pressure.

Table F-2 - Slope Statility Analysis Results - Upper Tailings Pile Cross Section 1

Analysis Case	**Static Long-Term (Steady State Seepage)**			**Post-Earthquake**			**Yield Acceleration Coefficient (k_y)**		
Groundwater Height Above Base	**0 Feet**	**2 Feet**	**4 Feet**	**0 Feet**	**2 Feet**	**4 Feet**	**0 Feet**	**2 Feet**	**4 Feet**
FS Criteria	**1.5**	**1.5**	**1.5**	**1.1**	**1.1**	**1.1**	**-**	**-**	**-**
A	**1.05**	**0.99**	**0.86**	**1.05**	**0.72**	**0.57**	0.02 g	-	-
B	**1.19**	**1.10**	**1.42**	1.19	**0.89**	**0.71**	0.08 g	-	-
C	1.48	**1.42**	**1.35**	1.48	**0.97**	**0.83**	0.19 g	-	-

Notes:

1. **Bold** factor of safety (FS) values are below minimum FS criteria. All FS values only valid to two significant digits, but reported to two decimal places for comparison purposes.

2. Analysis cases A, B, and C are identical, except the minimum failure surface thicknesses are 5 feet, 10 feet and 20 feet for cases A, B and C, respectively.

Table F-3 - Slope Statility Analysis Results - Lower Tailings Pile Cross Section 3

Analysis Case	**Static Long-Term (Steady State Seepage)**			**Post-Earthquake**			**Yield Acceleration Coefficient (k_y)**		
Groundwater Height Above Base	**0 Feet**	**2 Feet**	**4 Feet**	**0 Feet**	**2 Feet**	**4 Feet**	**0 Feet**	**2 Feet**	**4 Feet**
FS Criteria	**1.5**	**1.5**	**1.5**	**1.1**	**1.1**	**1.1**	**-**	**-**	**-**
A	**1.01**	**1.00**	**0.99**	**1.01**	**1.00**	**0.95**	0.01 g	-	-
B	**1.20**	**1.19**	**1.17**	1.20	**1.01**	**0.91**	0.10 g	0.004 g	-
C	**1.33**	**1.30**	**1.27**	1.33	**1.01**	**0.91**	0.16 g	0.004 g	-

Notes:

1. **Bold** factor of safety (FS) values are below minimum FS criteria. All FS values only valid to two significant digits, but reported to two decimal places for comparison purposes.

2. Analysis cases A, B, and C are identical, except the minimum failure surface thicknesses are 5 feet, 20 feet and 30 feet for cases A, B and C, respectively.

Table F-4 - Seismically-Induced Displacements - Upper Tailings Pile Cross Section 1

Analysis Case	Seismic Displacement in Inches (Makdisi and Seed)			Seismic Displacement in Inches (Bray and Travasarou)		
Groundwater Height Above Base	0 Feet	2 Feet	4 Feet	0 Feet	2 Feet	4 Feet
A	17	n/a	n/a	16	n/a	n/a
B	2	n/a	n/a	4	n/a	n/a
C	0	n/a	n/a	1	n/a	n/a

Notes:

1. "n/a" indicates scenarios for which the pseudostatic factor of safety is less than 1.0 and displacements could not be calculated.

2. Analysis cases A, B, and C are identical, except the minimum failure surface thicknesses are 5 feet, 10 feet, and 20 feet for cases A, B and C, respectively.

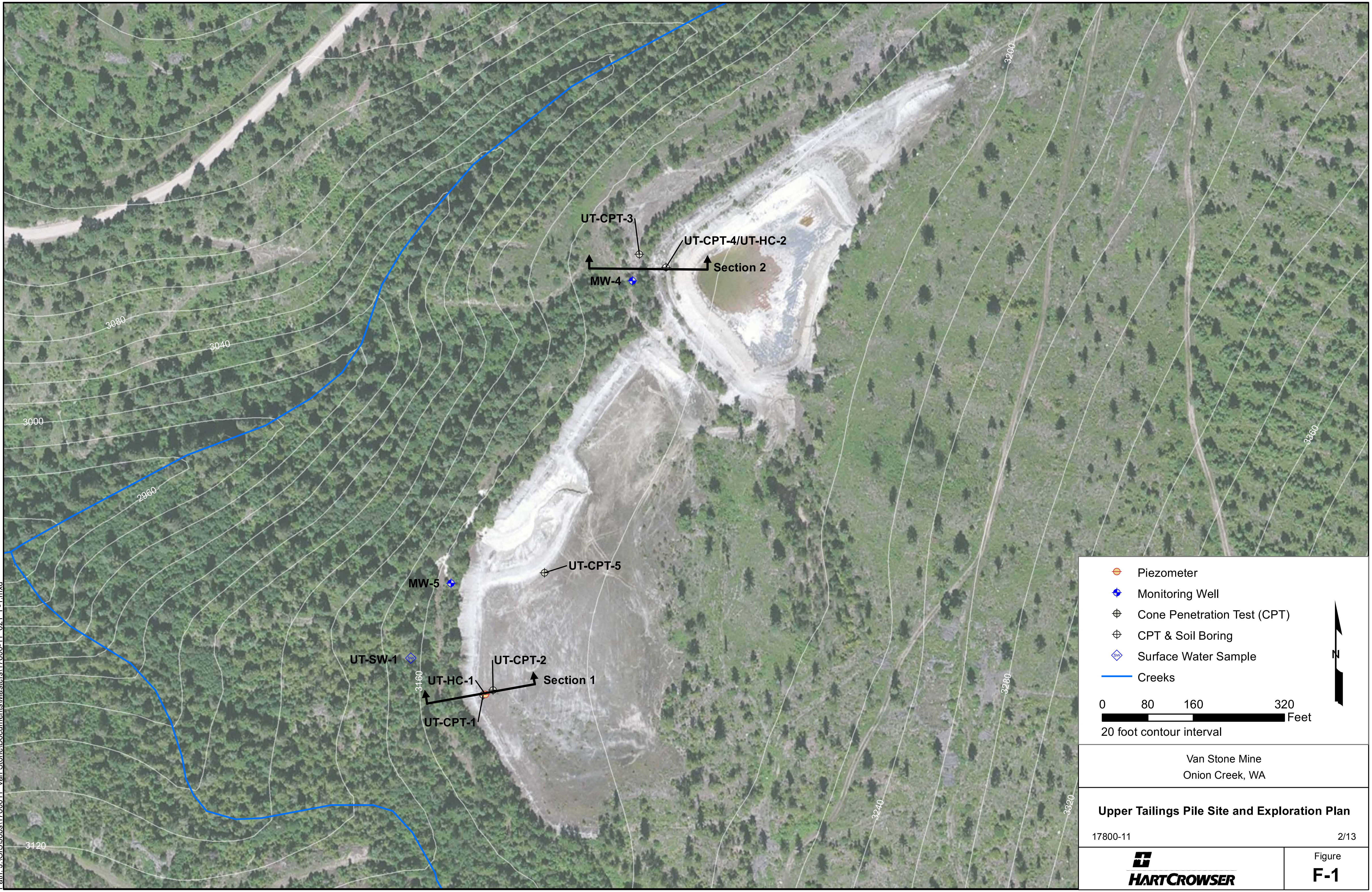
Table F-5 - Seismically-Induced Displacements - Lower Tailings Pile Cross Section 3

Analysis Case	Seismic Displacement in Inches (Makdisi and Seed)			Seismic Displacement in Inches (Bray and Travasarou)		
Groundwater Height Above Base	0 Feet	2 Feet	4 Feet	0 Feet	2 Feet	4 Feet
A	27	n/a	n/a	23	n/a	n/a
B	0	38	n/a	2	24	n/a
C	0	38	n/a	1	24	n/a

Notes:

1. "n/a" indicates scenarios for which the pseudostatic factor of safety is less than 1.0 and displacements could not be calculated.

2. Analysis cases A, B, and C are identical, except the minimum failure surface thicknesses are 5 feet, 20 feet, and 30 feet for cases A, B, and C, respectively.



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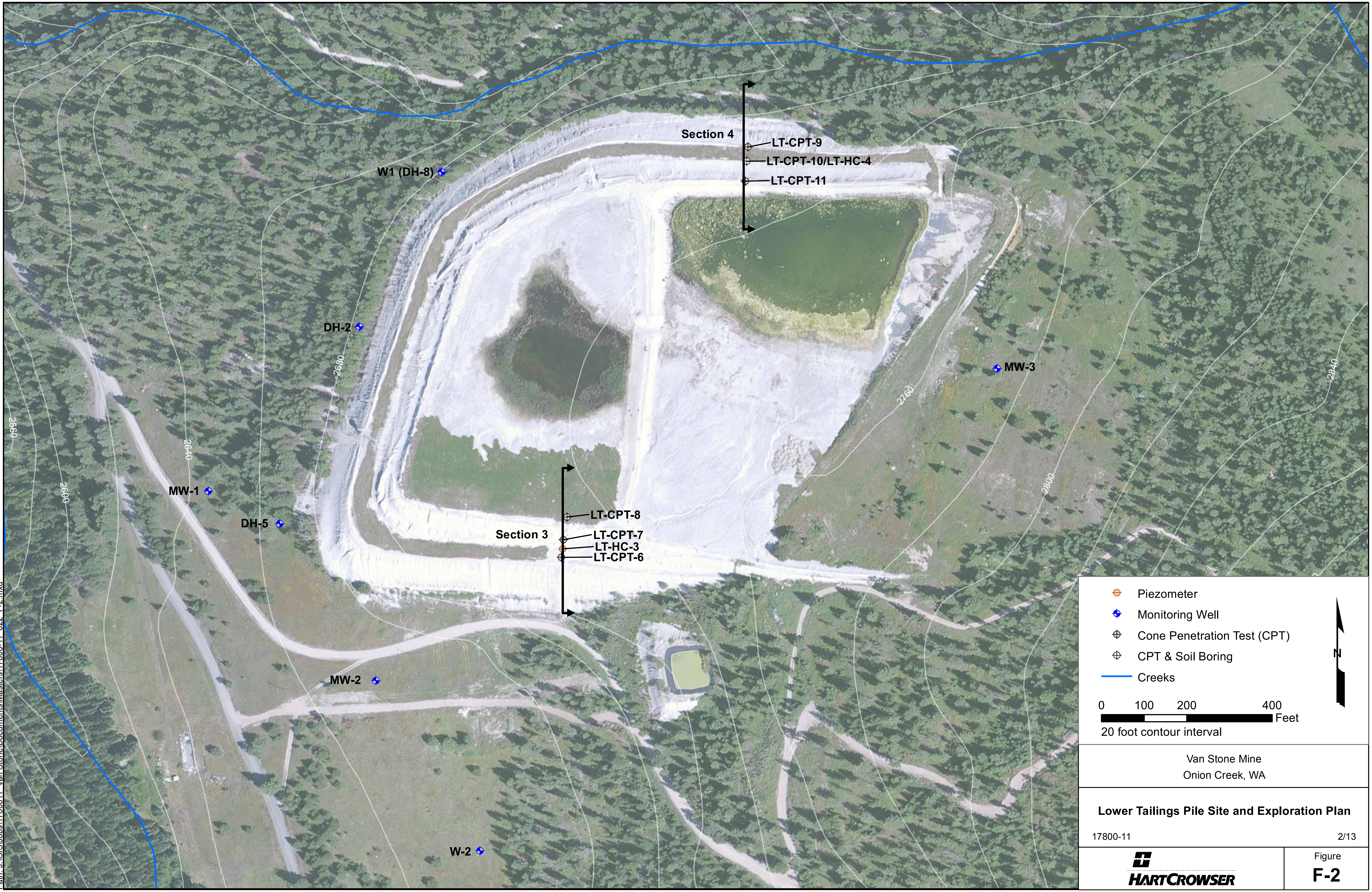

Van Stone Mine
Onion Creek, WA

Lower Tailings Pile Site and Exploration Plan

17800-11 2/13

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Figure F-2

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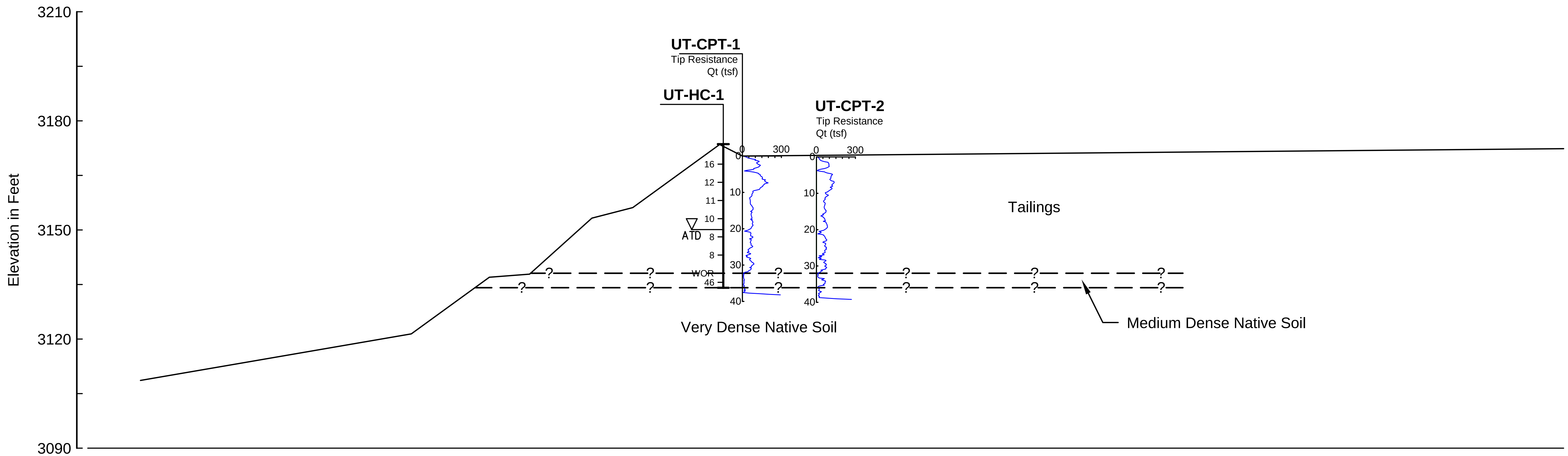
Generalized Subsurface Profile Along Upper Tailings Pile Cross Section 1
Van Stone Mine



UT-HC-1 Exploration Number

Exploration Location

Standard Penetration Resistance in Blows per Foot

Water Level (ATD)

UT-CPT-1 Cone Penetrometer Number

Cone Penetrometer Location (qt (tsf))

Note: Unless shown otherwise, explorations are located within 10 feet of the cross section.

0 30 60

Scale in Feet

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17800-11 ***2/13***

Figure F-3

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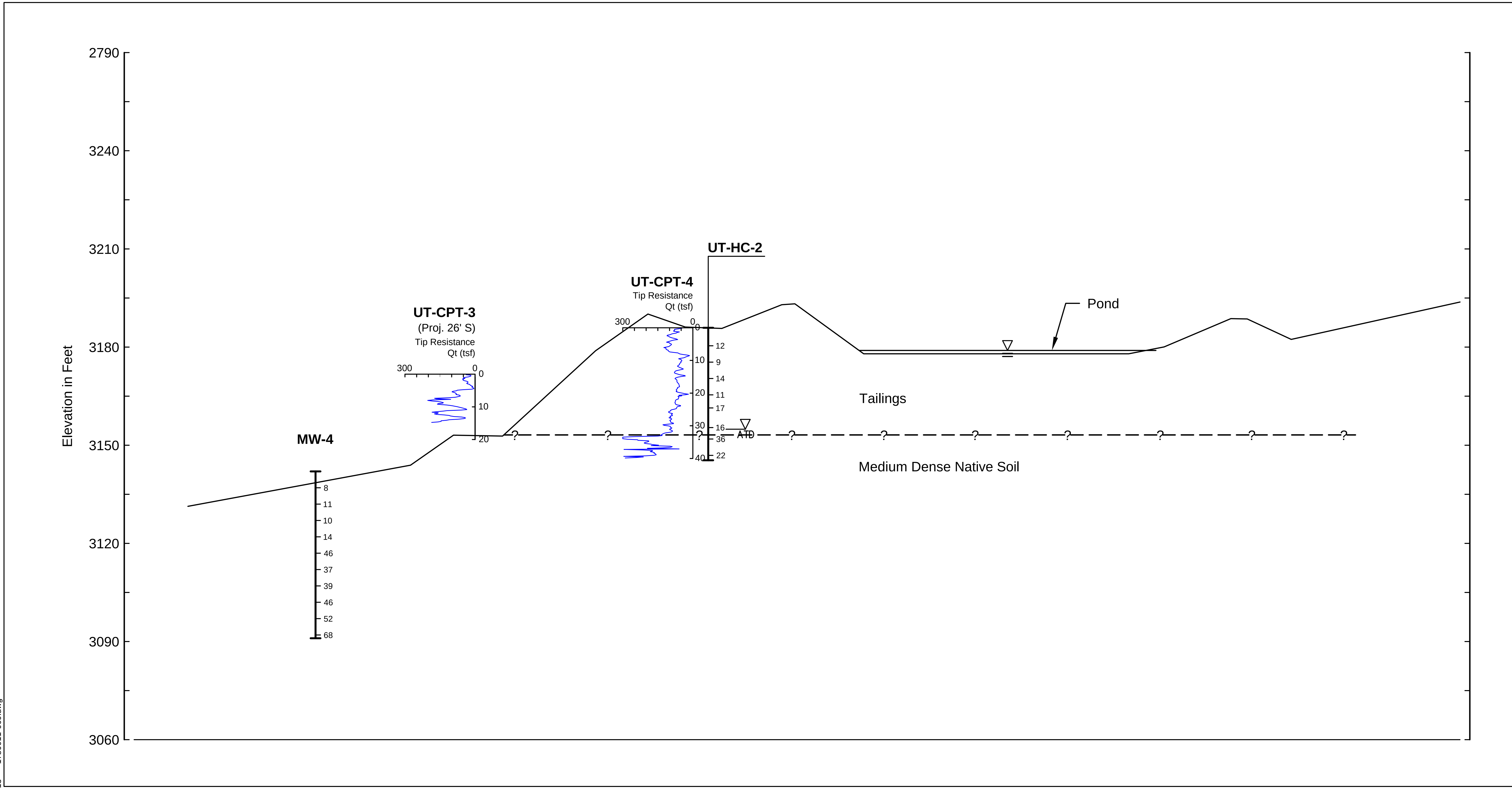
Generalized Subsurface Profile Along Upper Tailings Pile Cross Section 2
Van Stone Mine



UT-HC-2 Exploration Number

Exploration Location

Standard Penetration Resistance in Blows per Foot

Water Level

UT-CPT-3 Cone Penetrometer Number

Cone Penetrometer Location

Note: Unless shown otherwise, explorations are located within 10 feet of the cross section.

0 30 60

Scale in Feet

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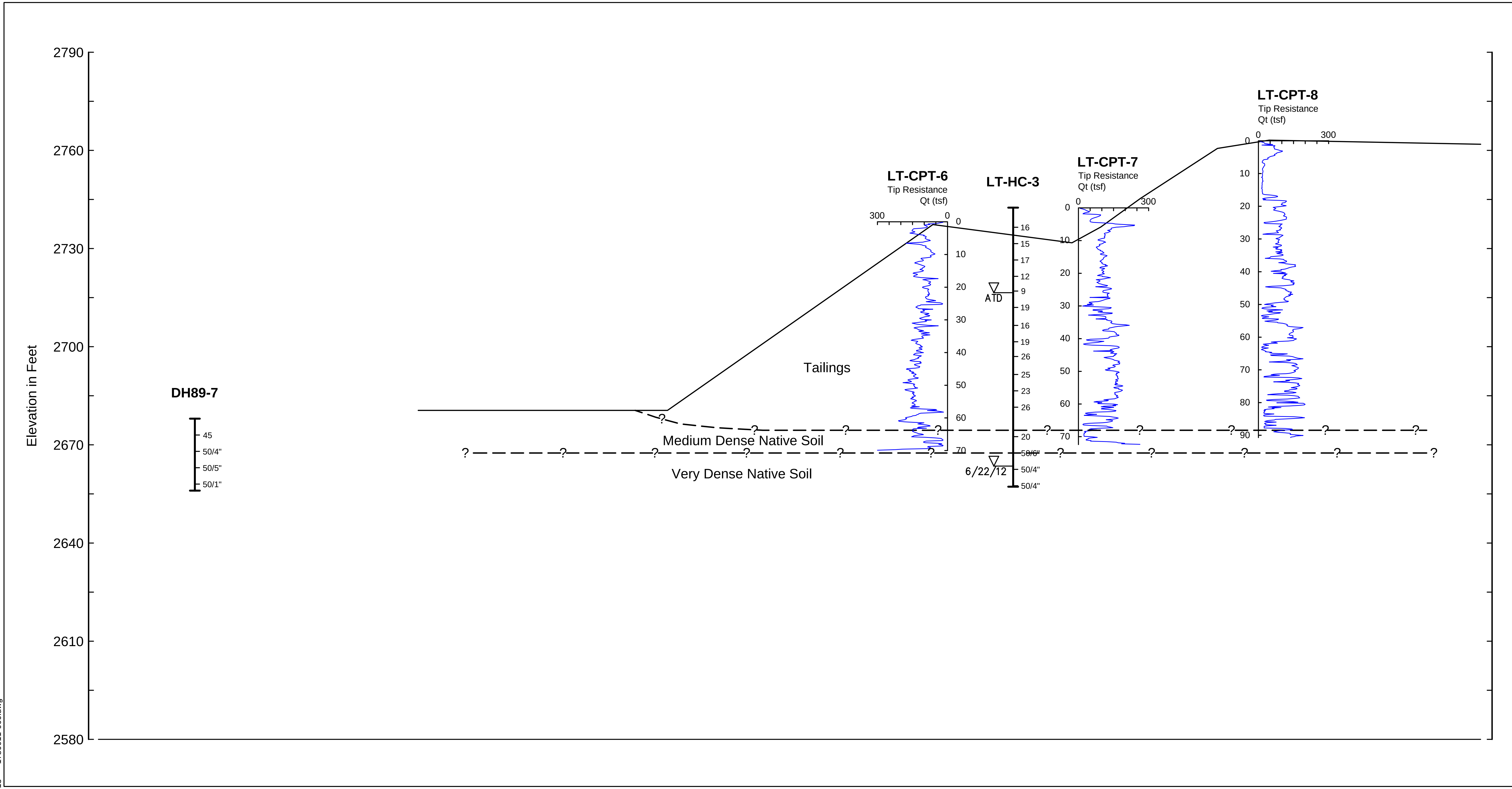
17800-11 ***2/13***

Figure F-4

Generalized Subsurface Profile Along Lower Tailings Pile Cross Section 3
Van Stone Mine



LT-HC-3 Exploration Number

Exploration Location

Standard Penetration Resistance in Blows per Foot

Water Level

LT-CPT-6 Cone Penetrometer Number

Cone Penetrometer Location

Note: Unless shown otherwise, explorations are located within 10 feet of the cross section.

0 30 60
Scale in Feet

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17800-11 ***2/13***

Figure F-5

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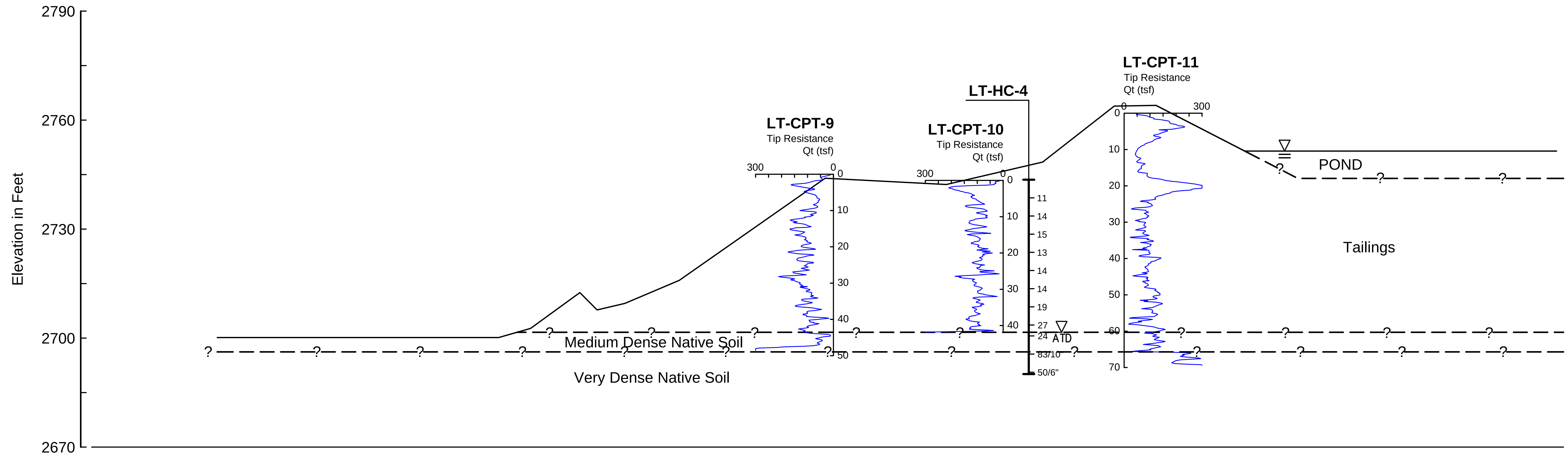
Generalized Subsurface Profile Along Lower Tailings Pile Cross Section 4
Van Stone Mine



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LT-HC-4 Exploration Number

Exploration Location

Standard Penetration Resistance in Blows per Foot

Water Level

LT-CPT-9 Cone Penetrometer Number

Cone Penetrometer Location

Note: Unless shown otherwise, explorations are located within 10 feet of the cross section.

0 30 60
Scale in Feet

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17800-11 ***2/13***

Figure F-6