APPENDIX D
PIT LAKE DAM STABILITY ANALYSIS

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PURPOSE AND SCOPE

This appendix documents the results of Hart Crowser's geotechnical subsurface investigations and slope stability analysis, and provides preliminary geotechnical recommendations for the Pit Lake Dam (AOI-1) at the Van Stone Mine. Hart Crowser is completing a Remedial Investigation (RI) for the mine, which includes analyzing the stability of the Pit Lake Dam. The purpose of the analysis is to determine the current condition and stability of the dam.

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 dam;
- Performing a geotechnical analysis to assess stability of the dam; and
- Completing this report.

BACKGROUND INFORMATION

The Pit Lake Dam is located at the west end of the West End Pit Lake. The pit lake covers approximately 4.5 acres and is approximately 100 feet deep, containing an estimated 146 million gallons (approximately 448 acre-feet) of water. The dam consists of a rock-fill berm, about 30 feet wide at the top, which was likely constructed as a temporary road embankment using a mixture of rock-blasting debris and local soil. The berm is about 25 feet high. Side slopes vary from about 3.5H:1V to 1H:1V.

As the West End Pit filled with groundwater and rain, the temporary road fill began to function as a dam. An unlined, open channel spillway about 2 feet deep at the west end of the dam discharges into an unnamed tributary to the Southeast Tributary of Onion Creek. During years of high snowfall, spring runoff may overflow the dam. No information is available about preparation of the subgrade or abutments before construction of the fill.

PIT LAKE DAM CHARACTERIZATION

The site characterization included evaluating the surface geometry, sub-surface stratigraphy, soil engineering properties, and groundwater conditions at the Pit Lake Dam. The results of the site characterization were used to develop a slope stability analysis model.

Surface Geometry

During field work in October 2011, a field geologist and geotechnical engineer performed a limited slope stability reconnaissance at the Van Stone Mine. The purpose of the reconnaissance was to observe conditions and select a critical section of the Pit Lake Dam for slope stability analysis.

During this site visit, the team examined the upstream and downstream slopes and the crest of the dam looking for signs of instability including seepage, erosion, tension cracks, and over-steepened slopes. The team selected the section of the dam that appeared to be the least stable, and surveyed a cross-section of the embankment. The location of the selected cross-section is shown on Figure D-1. This section was selected because of the height of the embankment, the steepness of the side slopes, and the presence of a seep near the base of the slope. A boring designated PL-HC-5 was completed near this critical cross-section during a later site visit.

Subsurface Stratigraphy

The subsurface stratigraphy was developed based on the hollow-stem auger and mud rotary boring advanced as part of this study, and laboratory tests on selected soil samples. The approximate location of the boring is shown on Figure D-1. A detailed boring log of the subsurface conditions at the exploration location and results of the laboratory tests conducted for this study are included in Appendix A.

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

Very Sandy Gravel. The unit is approximately 3 feet thick. The unit contains dense, very sandy gravel.

Gravelly, Sandy Silt. This unit was encountered below the very sandy gravel unit and is approximately 10 feet thick, and contains medium dense to very dense, gravelly, sandy silt.

Very Silty Sand. This unit, encountered below the gravelly, sandy silt unit is approximately 10 feet thick and contains dense, very silty, fine sand.

Silty, Gravelly Sand. This unit was encountered below the very silty sand unit, is approximately 8 feet thick, and contains very dense, slightly silty to silty, gravelly sand.

Sandy Gravel. This unit was encountered below the silty, gravelly sand unit and contains very dense, sandy gravel. The boring terminated in this unit, approximately 34 feet below ground surface.

The presence of gravel can have a significant influence on the penetration resistance observed during standard penetration testing. As a result, the blow counts and apparent density shown on the boring logs for soil units that contain gravel may be artificially high.

Figure D-2 illustrates the generalized subsurface soil conditions at the critical cross-section for the Pit Lake Dam.

Soil Engineering Properties

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

As part of the feasibility study, a sensitivity analysis will be completed to determine the effect that varying the soil engineering properties has on slope stability factors of safety. The sensitivity analysis will be used to optimize the design of remediation alternatives.

Groundwater Conditions

The groundwater conditions at the study cross-section were evaluated and characterized based on water levels observed during drilling and measured with two vibrating wire piezometers (VWP) installed in the completed boring.

During drilling, groundwater was observed in PL-HC-5 approximately 23 feet below ground surface. Groundwater levels observed in the exploration are indicated on the boring log in Appendix A and on the generalized subsurface cross section (Figure D-2).

SLOPE STABILITY ANALYSIS

To assess the stability of the Pit Lake Dam, a slope stability analysis was conducted using limit equilibrium software. The analysis criteria, method of analysis, and loading conditions are discussed below.

Stability Analysis Criteria

Static and seismic slope stability analysis of the Pit Lake Dam 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 Pit Lake Dam has been in place for a significant period of time, the end of construction condition is not applicable and was not evaluated. Additionally, the sudden drawdown conditions are not applicable because the spillway can only drop the pool approximately 2 feet unless the base of the spillway was to erode. In that case, the embankment could fail by sudden release and the effect of rapid drawdown on stability would be moot. Therefore, the sudden drawdown conditions 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 each loading condition. Only significant slip surfaces, at least 5 feet thick, were considered in our analysis because surficial sloughing is not likely to affect the overall function of the Pit Lake Dam. For each condition we completed three analyses considering slip surfaces at least 5 feet thick, 10 feet thick, and 20 feet thick.

Slope stability was evaluated for long-term and post-earthquake loading conditions. The yield acceleration was also determined 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 before applying a seismic acceleration.

Seismically induced horizontal slope deformation of the Pit Lake Dam 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. The groundwater level used in the analysis is based on the highest groundwater level measured with the VWPs.

Seismic

The Department of Ecology, Dam Safety Office (DSO) performed a periodic inspection of the Lower Tailings Pile on June 11, 2010, which is documented in a Notice of Correction Docket (DCN 1002) dated August 2, 2010. As part of the inspection, the DSO classified the downstream hazard in accordance with the Dam Safety Guidelines as Significant, Hazard Class 2, because there are two houses downstream that could flood if the dam fails. 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 Pit Lake Dam, 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 Geologic 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 Pit Lake Dam 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 100 feet deep. Based on the inferred properties of the upper 100 feet of soil and bedrock below the dam, the site is classified as site class C. The appropriate site-modified ground surface PGA for the Pit Lake Dam is 0.15 g.

Post-Earthquake

Residual shear strength values were determined using the Idriss and Boulanger (2008) empirical method based on SPT values from the site. The results indicate that there is no strength reduction due to liquefaction during the design seismic event. As a result, post-earthquake stability will be identical to the long-term stability and a separate analysis was not completed.

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. Drained (effective) shear strength parameters with no strength reduction were assigned to all materials. The groundwater level used in the analysis is based on the highest groundwater level measured with the VWPs.

Slope Stability Results

Table D-2 summarizes the static and seismic slope stability factors of safety for the Pit Lake Dam.

Seismic Slope Deformation Results

Table D-3 summarizes the permanent seismically induced displacement calculated using both the Makdisi and Seed and the Bray and Travasarou methods.

INTERNAL EROSION AND PIPING

The Pit Lake Dam is potentially susceptible to failure due to internal erosion or piping. Internal erosion and piping occur when water passing through the structure transports fine-grained soil from the interior of the dam, leaving voids and channels within the structure. Embankment dams typically include an impervious zone, a properly prepared foundation, and/or drains that are designed to minimize or control seepage. Because the Pit Lake Dam was constructed as a road embankment, it does not have these features and is, therefore, susceptible to internal erosion and piping.

The seep located near the base of the dam indicates that uncontrolled seepage is occurring, which increases the probability that piping or internal erosion is occurring. If piping or internal erosion continues unchecked, the structural integrity of the dam could be impaired.

CONCLUSIONS

The results of the slope stability analysis indicate that the Pit Lake Dam is below Ecology's target factor of safety for static long-term loading conditions with factors of safety (FS) less than 1.0 for shallow failure surfaces (5 feet or less); and between 1.0 and 1.5 for failure surfaces less than 10 feet thick. This supports the assumed strength criteria for the embankment are conservative, but the degree of conservatism is unknown. Although factors of safety for post-earthquake conditions exceed the minimum criteria for failure surfaces at least 20 feet thick, factors of safety are below the minimum criteria for potentially significant failures at least 10 feet thick.

For relatively shallow failure surfaces, with depths of approximately 5 feet, the seismically induced displacement is estimated to be up to 15 inches. For potentially significant failure surfaces at least ten feet thick, the displacement is approximately 12 inches. A displacement of 12 inches is a significant fraction of the approximately 3 feet of available freeboard at the Pit Lake Dam and could have a significant effect on dam function.

In addition, the Pit Lake Dam is susceptible to failure caused by internal erosion or piping.

Instability of the Pit Lake Dam could cause downstream flooding. These conditions do not satisfy Ecology's dam safety requirements for static or seismic stability. Improved stability or other hazard elimination should be addressed in the Feasibility Study for Van Stone Mine.

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.

Idriss, I.M. and R.W. Boulanger 2008. Soil Liquefaction during Earthquakes by Earthquake Engineering Research Institute MNO-12.

International Code Council (ICC) 2009. 2009 International Building Code (IBC).

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.

USGS 2010. National Seismic Hazard Mapping Project – Probabilistic Seismic Hazard Assessment Interactive Deaggregation website: https://geohazards.usgs.gove/deaggint/2002

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Table D-1 - Estimated Soil Strength Parameters

Van Stone Mine

		Very Sandy Gravel	Gravelly, Sandy Silt	Very Silty Sand	Silty, Gravelly Sand	Sandy Gravel
Drained	**γ (pcf)**	125	120	125	125	130
	ϕ' (deg)	39	35	35	38	40
	c' (psf)	0	0	0	0	0

Notes:

1. γ = Soil moist unit weight, ϕ' = soil effective angle of internal friction, c' = soil effective cohesion.

Table D-2 - Slope Statility Analysis Results - Pit Lake Dam

Van Stone Mine

Analysis Case	Static Long-Term (Steady State Seepage)	Post-Earthquake	Yield Acceleration Coefficient (k_y)
FS Criteria	**1.5**	**1.1**	**-**
A	**0.95**	**0.95**	-
B	**1.06**	**1.06**	0.03 g
C	**1.33**	1.33	0.14 g

Notes:

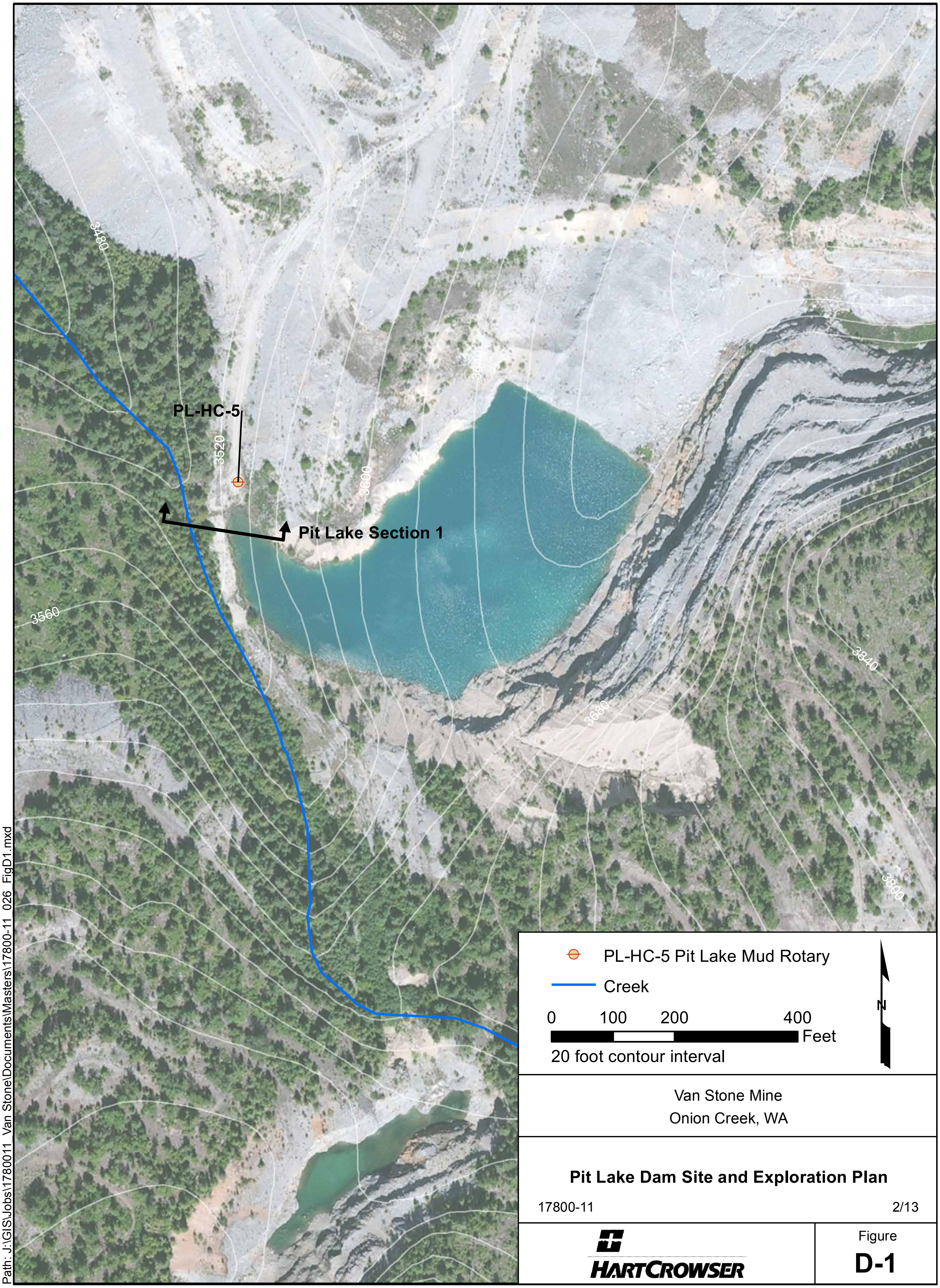
1. **Bold** factor of safety (FS) values are at or below minimum target FS criteria. All FS values are only valid to two significant digits, but are reported to two decimal places for comparison purposes.

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 D-3 - Seismically Induced Displacement - Pit Lake Dam
Van Stone Mine

Analysis Case	Seismic Displacement in Inches (Makdisi and Seed)	Seismic Displacement in Inches (Bray and Travasarou)
A	n/a	n/a
B	14	11
C	0	1

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



Van Stone Mine
Onion Creek, WA

Pit Lake Dam Site and Exploration Plan

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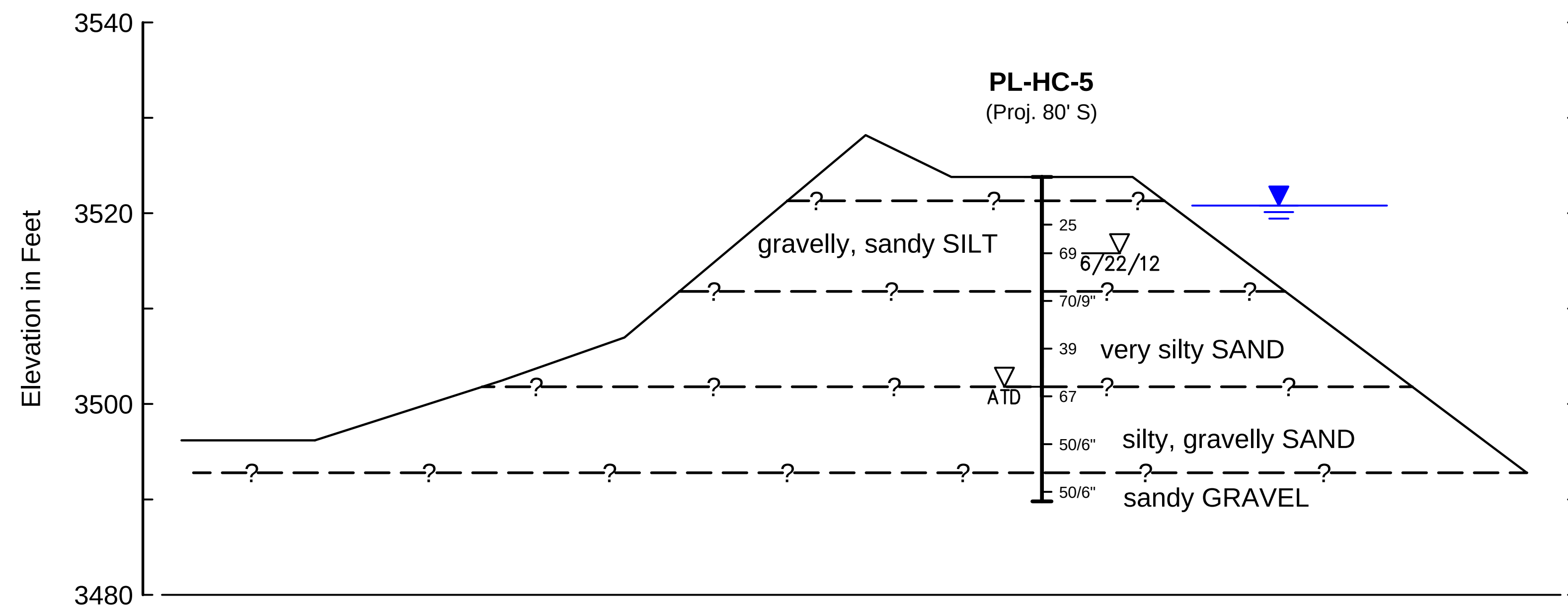
Figure
D-1

Path: J:\GIS\Jobs\1780011 Van Stone\Documents\Masters\17800-11 026 FigD1.mxd



PL-HC-5 Exploration Number

Exploration Location

9 Standard Penetration Resistance in Blows per Foot

ATD Water Level

0 20 40
Scale in Feet

Van Stone Mine
Onion Creek, WA

Generalized Subsurface Profile Along Pit Lake Dam

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Figure
D-2

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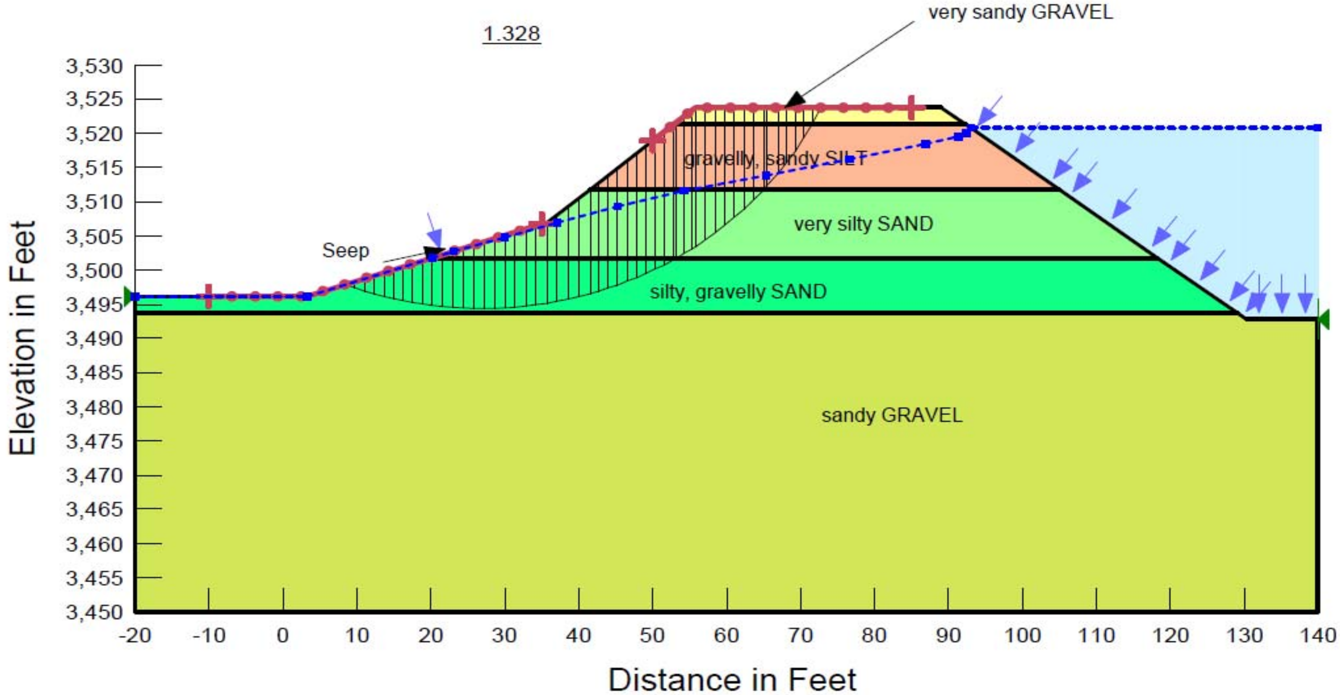
MKH 10/28/2012L:\Project Notebook\1780011_Van Stone Mine\REMEDIAL INVESTIGATION REPORT\Appendix D - Pit Lake Dam Stability\[Fig D-3.xlsx]Figure 6

Pit Lake Dam
Long Term (b)2
Minimum Slip Surface Depth: 20 ft
Entry and Exit



Name: very sandy GRAVEL Model: Mohr-Coulomb Unit Weight: 125 pcf Cohesion': 0 psf Phi': 39 °
Name: gravelly, sandy SILT Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 0 psf Phi': 35 °
Name: very silty SAND Model: Mohr-Coulomb Unit Weight: 125 pcf Cohesion': 0 psf Phi': 35 °
Name: silty, gravelly SAND Model: Mohr-Coulomb Unit Weight: 125 pcf Cohesion': 0 psf Phi': 38 °
Name: sandy GRAVEL Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 40 °

Van Stone Mine
Onion Creek, WA

Static Slope Stability Section - Pit Lake Dam

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Figure
D-3