PERRONE CONSULTING, INC., P.S.
Geotechnical & Underground Engineering

MEMORANDUM

Project No. 15135

August 18, 2016

To: Brian Scott (Herrera Environmental Consultants)

cc:

From: Vincent J. Perrone

Subject: Mashel River Restoration – Task 2 Landslide Risk Assessment

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Introduction

This memo summarizes the results of our landslide risk assessment for the Mashel River Restoration project. The project reach and proposed project elements are shown in Figure 1, "Site and Geophysical Exploration Plan" and the site topography is shown in Figure 2. The project consists of constructing engineered log jams (ELJ's) along the river (see Figure 1) to improve fish habitat conditions. However, the site includes an approximately 400 ft wide recent landslide on the right bank of the Mashel River that extends upslope (northward) from the river for about 220 ft.

The purpose of our work was to evaluate the risk of future landslide movement under current river conditions and the impacts of the proposed ELJ structures on the landslide risk level. Our scope of work included site reconnaissance, review of published geologic information, and preliminary engineering analyses of the landslide. These evaluations were based upon: (a) our site reconnaissance and observations of existing surficial features including topography, soil and rock exposures, vegetation, and groundwater seeps; (b) published geologic maps (Washington DNR, 2016); (c) a landslide geomorphic assessment (Herrera 2016); (d) a geophysical survey (Duoos 2016) and; (e) predicted stream flow velocities (Herrera 2016a). No exploratory borings or test pits were completed as part of this scope of work.

Site Description and Observations

The landslide topography is illustrated in Figures 2 and 3. The landslide area descends about 135 ft in elevation from the upland plateau at about elevation 850 ft to the Mashel River bottom at elevation 715 ft. The topography is irregular with a steep 50 to 80-degree slope in the headscarp area from elevation 850 ft. to elevation 805 ft. followed by two series of 30 degree slopes and level benches (upper and lower benches) down to elevation 735 ft and a final 36-degree slope down to the river at elevation 715 ft.

The topography upstream and downstream of the recent landslide area indicates older landslide activity which appears to have stabilized now that the river channel has meandered away from the toe of the steep slope.

The recent landslide area is generally underlain by landslide debris overlying Mashel Formation bedrock (see Figure 3). The headscarp at the top of the landslide consists of about 50 ft of soft sandstone and siltstone overlying claystone below about elevation 800 ft. The claystone outcrop observed at about elevation 780 ft was tan, moderately to highly plastic, fractured and appeared to be unstable and possibly a large intact block within the landslide mass. Red, highly plastic claystone with beds dipping 45 degrees south was observed at the river level.

We observed surface water runoff into the landslide complex from the upland plateau. The stormwater runoff was eroding drainage channels in the headscarp. The ground surface in the

level bench areas were soft, wet and vegetated with hydrophilic horsetails. The slope below the lower bench and down to the river was unstable and actively eroding with some cobble and boulder sized claystone having been transported downstream. We also observed parallel ground tension cracks on the lower bench.

Based on your review of historic aerial photos (Herrera 2016), it appears that the current landslide likely formed between 1941 and 1952 as a conical, shallow planar failure caused by concentrated seepage and/or surface water runoff flowing in a hollow that leads down from the ridge. The headscarp was located about 140 ft from the toe of the slope. Between 1979 and 1989 the landslide enlarged to a wider arcuate-scarp failure with the headscarp distance increasing to 240 ft. from the toe of the slope.

Analysis

Seismic Survey

The interpreted seismic velocity layers at survey line SL-6 are shown in Figure 4. The data (Duoos, 2016) indicated low compressional wave velocities (Layer L1) on the order of 1000 feet per second (fps) to a depth of about 20 ft. to 30 ft. These low velocities were interpreted to be landslide debris which sharply contrasted with the underlying Mashel claystone with velocities that exceeded 6200 fps (layers L2 and L2 High). A medium velocity layer (L2 Low) of unknown thickness with velocities of 3900 fps to 4200 fps was indicated near the toe of the landslide. It is unclear if this material is landslide debris, highly fractured and/or weathered bedrock or river alluvium.

Interpreted Subsurface Stratigraphy

Figure 3 illustrates our general interpretation of the subsurface stratigraphy at the recent landslide. In general, the landslide area is covered with up to 30 ft of landslide debris underlain by soft Mashel bedrock. However, the thickness of the landslide debris beneath the lower slope bench may be thicker and extend to an elevation well below current river bottom elevation. Alternatively, the landslide debris beneath the lower slope bench may be underlain by river alluvium or highly weathered/fractured bedrock.

Landslide Analysis

Preliminary slope stability analyses were performed on two postulated landslide slip surfaces to evaluate the reasonableness of the proposed failure surfaces and subsurface conditions. Case 1 defines the bottom of the landslide at the bottom of the L1 seismic layer. Case 2 assumes that river alluvium has infilled a deep channel below the lower bench.

The assumed soil properties used in the analyses are summarized in Table 1.

Table 1 – Engineering Material Properties

	Unit Weight (pcf)		Strength	
Material Description	**Moist**	**Saturated**	**Cohesion (psf)**	**Friction (degrees)**
Landslide debris/Colluvium	120	125	0	26
Alluvium	120	125	0	30
Mashel Formation:				
Intact claystone	130	135	6000	0
Sheared claystone	125	130	0	15

The material properties were estimated based on our experience with soils of similar type and geologic origin.

The claystone has low rock strength but in relation to soil strength it has relatively high intact strength. Claystone strength will decrease from maximum peak levels when it is submerged and over-stressed by loading from steep slopes (particularly near the toe of overly steep slopes). If large deformations occur in the claystone, its strength decreases even further to residual strength. Given the large deformations observed in the landslide mass, it is reasonable to assume that the strength of the claystone along the shear surface at the base of the landslide mass is currently at residual strength values.

In general terms, the calculated factor of safety is the ratio of available soil shear resistance to the existing gravitational forces tending to produce landsliding. When the soil strength is exactly equal to the slide producing forces, the factor of safety is 1.0 and the slope would be on the verge of movement. Uncertainties and inaccuracies are usually associated with the assumed subsurface conditions, soil strength, groundwater levels and location of the most critical failure surface. A factor of safety of 1.3 to 1.5 for static (non-seismic) conditions and 1.10 for seismic conditions is typically prescribed to account for uncertainties and inaccuracies with the assumed subsurface conditions and engineering soil properties.

Back analyses of the full landslide mass in Case 1 indicate a factor of safety (FS) of about 1.0 indicating that the landslide mass is unstable (see Figure 5). Back analyses of Case 2 with loose granular alluvium beneath the toe area indicate a FS = 1.4. If, instead of alluvium, the material beneath the toe was sheared/fractured claystone, the computed factor of safety was greater than 1.0 and increased with increasing depth of the sheared zone below the toe.

Conclusions

Our back analyses of the interpreted subsurface conditions indicate that, in its current condition, the whole landslide mass from the river to the headscarp at the upland plateau is marginally stable. Parametric analyses indicate that it is more probable that the base of the landslide does not extend much below river bottom elevation. In our opinion, if the river erodes the toe of the landslide, or if a significant earthquake occurred, the landslide mass could continue to move toward the river. While movement of the headscarp could result in an increased headscarp height, it is our opinion that northward retreat of the headscarp at the top of the landslide will depend more upon the intensity of surface water runoff from the upland plateau and groundwater seepage into the headscarp area.

The predominant cause of the original landsliding is uncertain but in our opinion several factors were possible contributors: (1) river erosion at the toe of the slope; (2) a pre-existing weak shear zone in the highly plastic clay that occurred during Mashel formation deposition, loading from prior glaciations, or from large seismic events and; (3) high groundwater levels in the Mashel formation. The presence of colluvium and/or alluvium under the toe of the landslide suggests that the river channel may have historically been located about 60 to 80 ft north of its current location, significantly reducing the stability of the slope and resulting in the large landslide. It is likely that the current topographic and geologic conditions immediately downstream of the landslide represent advanced stages of the natural on-going process of mass wasting.

In more recent times since 1941 your analyses (Herrera 2016) have indicated that the river has migrated northward into the toe of the landslide at an average rate of 4 feet per year until 2002 when it slowed to near zero up to the present time. You have concluded that colluvium was accumulating at the toe area faster than the river could erode it and, with the exception of the very upstream corner of the landslide that appears to be destabilized by past toe erosion, that toe erosion would likely occur only during very high, infrequent discharges like the 100-year flood event. Therefore, to the extent that toe erosion by the river has abated, the current risk of large scale landslide activity should not increase. Furthermore, we expect that since your analyses of the

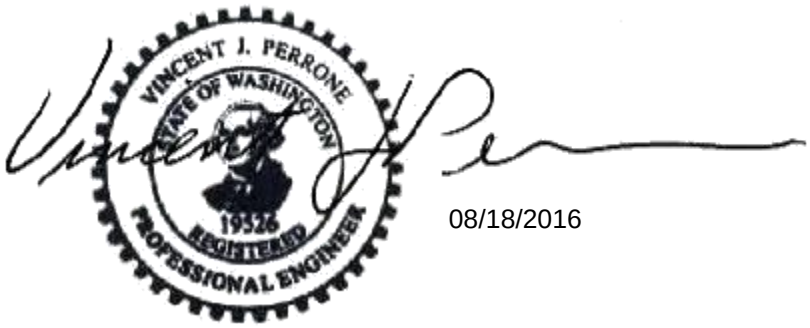
proposed project improvements indicate about a 3 to 4 fps decrease in flow velocities at the landslide toe during the 100-year flood event (Herrera 2016b), the amount of toe erosion and therefore, landsliding risk, should decrease compared to that of the pre-project levels.

Figure 6 illustrates our qualitative assessment of landslide risk in the project reach based on the current river location and conditions. This preliminary assessment is intended to assist in locating the proposed structures in areas of lower potential for damage from landsliding. The highest risk areas generally occur where the river is in close proximity to the toe of the existing steep slopes such as at the recent landslide area.

Limitations

This memo was prepared for your exclusive use for specific application to this project as it relates to the geotechnical aspects discussed herein. The purpose of this preliminary site assessment was to evaluate existing site conditions and assess the risk of slope instability and potential damage to the proposed in-river structures. Geotechnical borings and/or test pits were not completed for this phase of the work. As such, the conclusions contained in this memo are based on limited information and should be considered preliminary. More extensive geotechnical investigations of the landslide mass would be required to more reliably evaluate the landslide.

Within the limitations of scope, schedule and budget, the analyses, conclusions, and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical engineering principles and practice in this area at the time this report was prepared. We make no other warranty, either express or implied. These conclusions and recommendations were based on the site conditions as observed at the time of our site reconnaissance. Additional guidance about this geotechnical report can be found in the attachment to this report, “Important Information about Your Geotechnical Engineering Report.”



08/18/2016

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References

Duoos, P.H., 2016. "Seismic Refraction Survey Report, Mashel River Restoration Project, Pierce County, Washington Seismic Survey," technical memorandum, July 22, 2016.

Herrera Environmental Consultants, Inc., 2008. "Hazard and Risk Assessment, Mashel River Phase II Restoration Analysis and Design," final memorandum, November 6, 2008.

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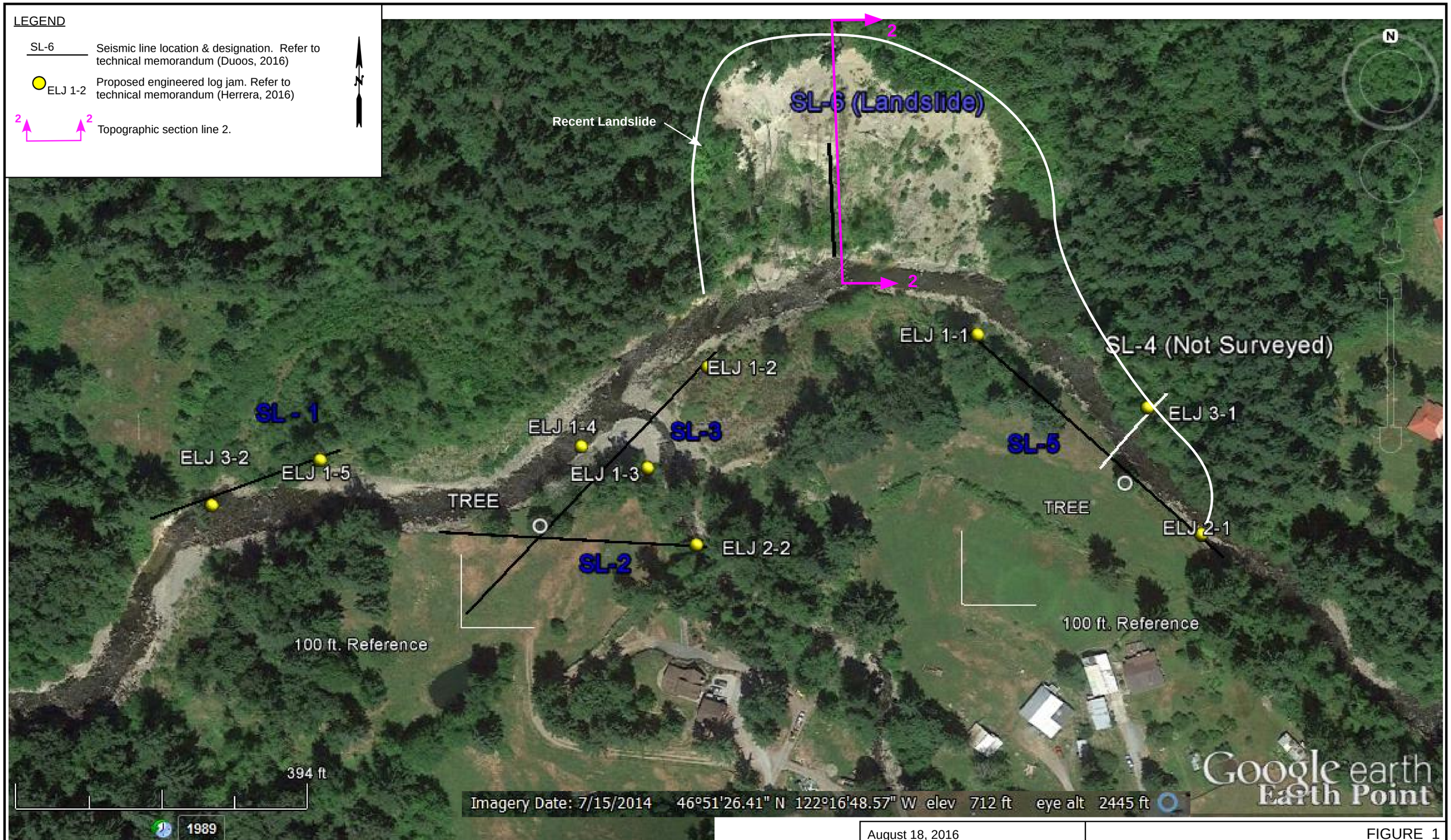
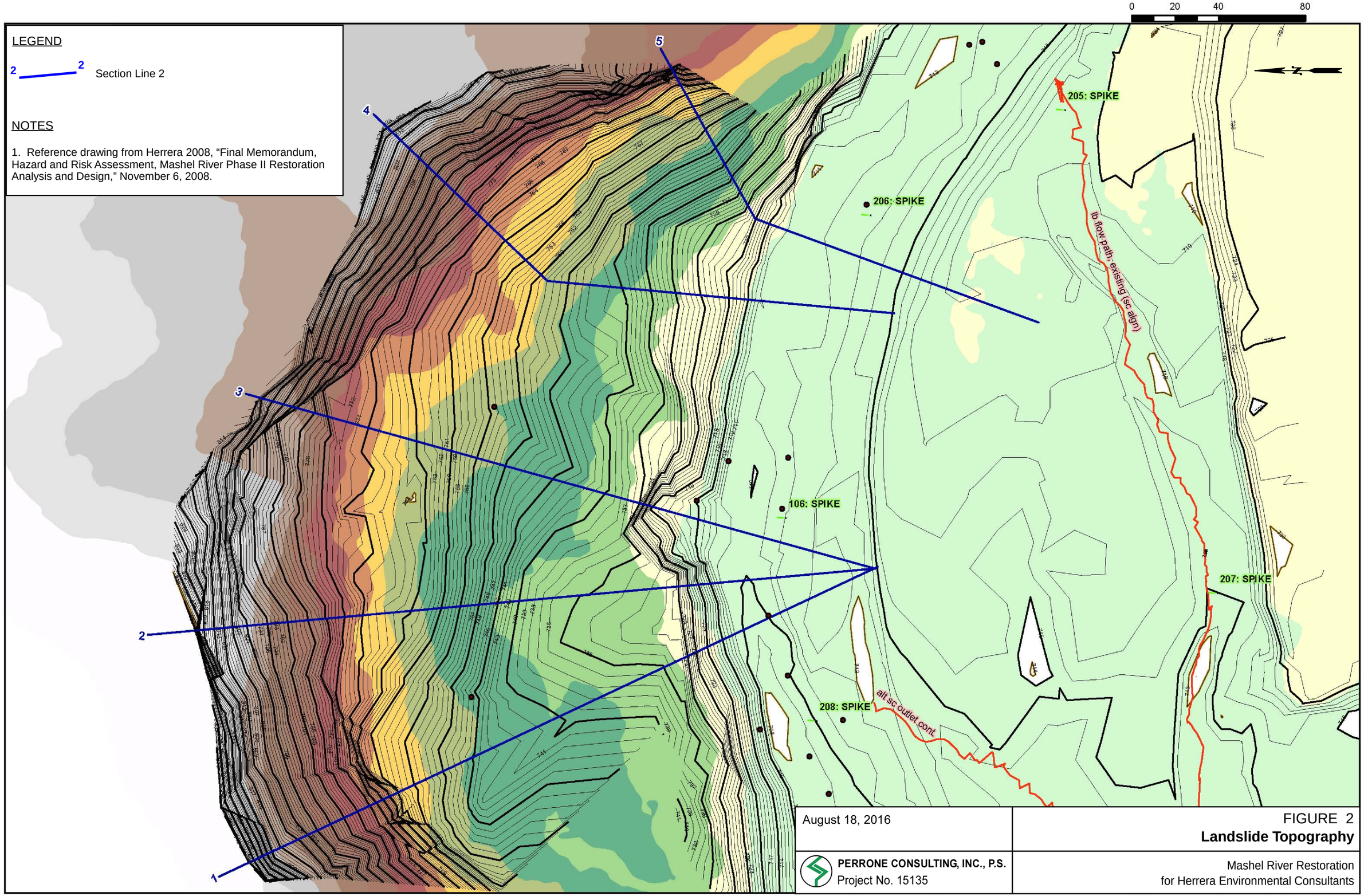
Herrera Environmental Consultants, Inc., 2016a. "Mashel River Reach 7 Alternative 2, Velocity Differences for 100-year Flood Event," drawing, February 23, 2016.

Washington Department of Natural Resources, 2016. "Washington Interactive Geologic Map," Division of Geology and Earth Resources – Washington's Geological Survey, website: https://fortress.wa.gov/dnr/protectiongis/geology/?Theme=wigm



REFERENCE: "Mashel River Seismic Survey," Phil Duoos, July 22, 2016.

August 18, 2016	FIGURE 1 **Site and Geophysical Exploration Plan**
PERRONE CONSULTING, INC., P.S. Project No. 15135	Mashel River Restoration for Herrera Environmental Consultants

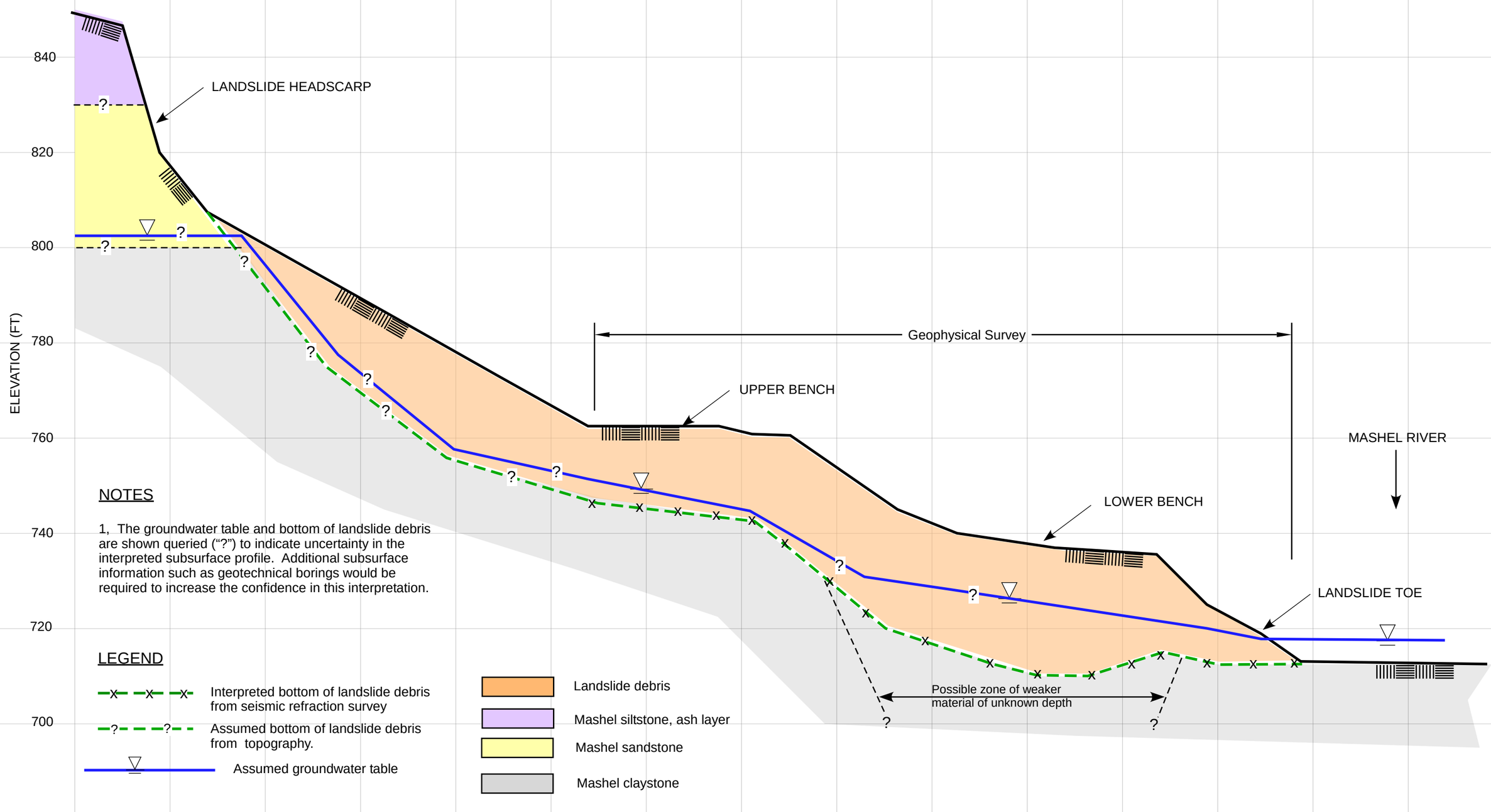


August 18, 2016

FIGURE 2
Landslide Topography

PERRONE CONSULTING, INC., P.S.
Project No. 15135

Mashel River Restoration
for Herrera Environmental Consultants

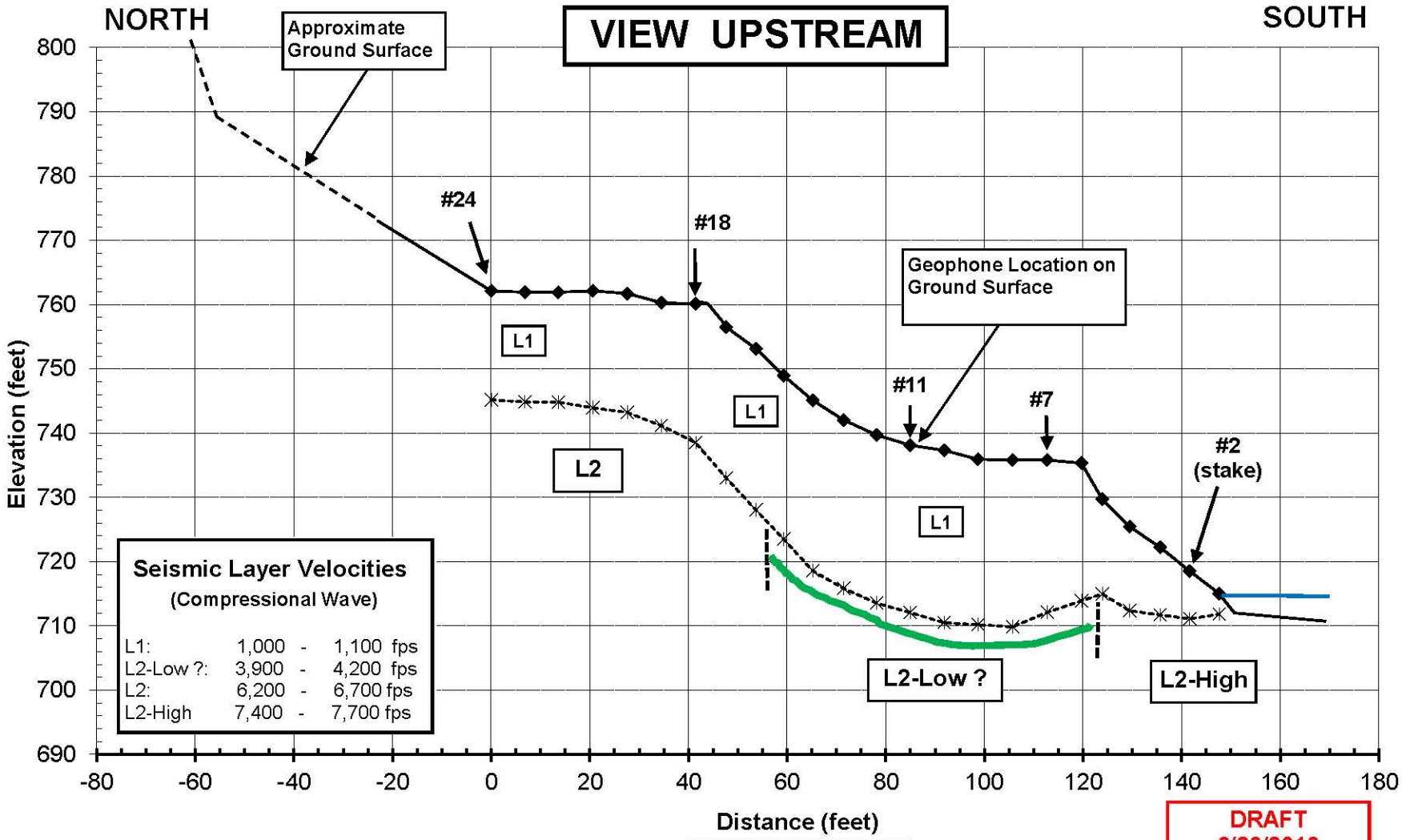


NOTES

1, The groundwater table and bottom of landslide debris are shown queried ("?") to indicate uncertainty in the interpreted subsurface profile. Additional subsurface information such as geotechnical borings would be required to increase the confidence in this interpretation.

LEGEND

August 18, 2016	FIGURE 3 **Interpreted Subsurface Profile at Section 2**
PERRONE CONSULTING, INC., P.S. Project No. 15135	Mashel River Restoration for Herrera Environmental Consultants



DRAFT
6/26/2016

Not to Scale

MASHEL RIVER SEISMIC INVESTIGATION
Philip H. Duoos, Geophysical Consultant
for Herrera Associates, Inc.

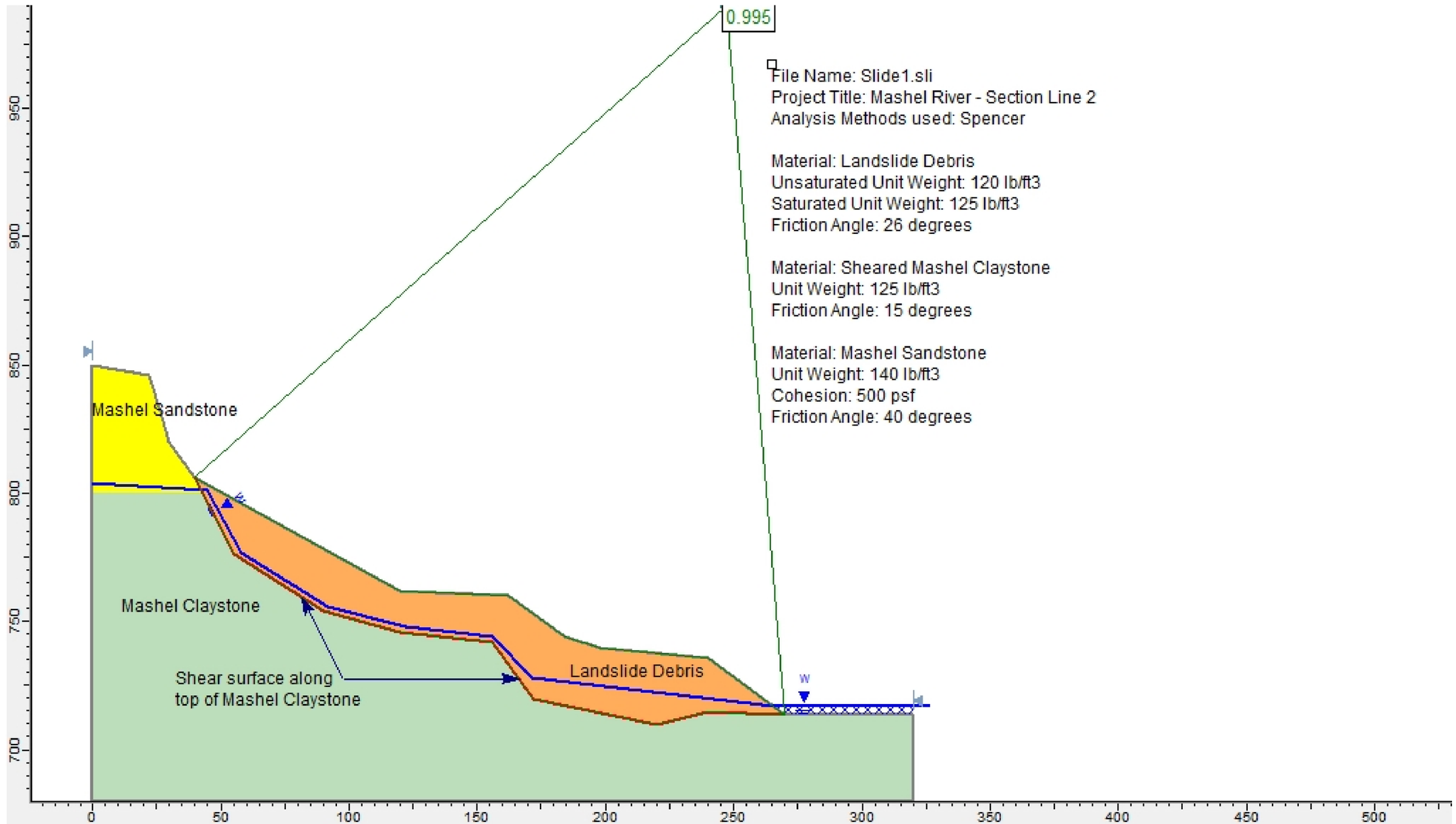
Job. 1185-16 June 17, 2016

Ground surface elevations are based on hand level measurements. Geophone #1 referenced to water level at about 715 feet based on Google Earth image.

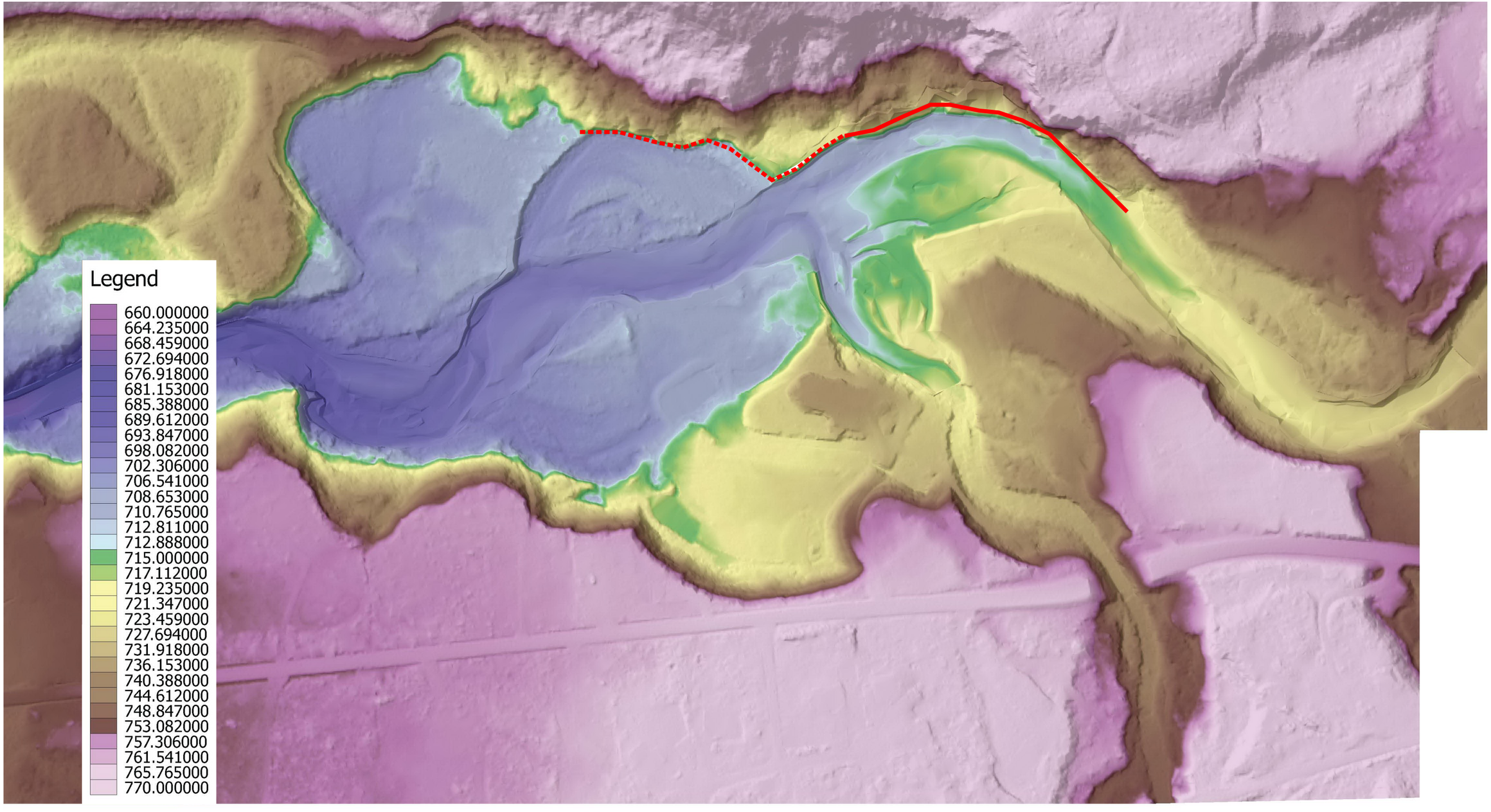
SEISMIC PROFILE, SL-6

Mashel River, Eatonville, WA

August 18, 2016	FIGURE 4 **Seismic Profile SL-6**
PERRONE CONSULTING, INC., P.S. Project No. 15135	Mashel River Restoration for Herrera Environmental Consultants



August 18, 2016	FIGURE 5 **Slope Stability Analysis Results**
PERRONE CONSULTING, INC., P.S. Project No. 15135	Mashel River Restoration for Herrera Environmental Consultants



LEGEND:

High risk of landslide damage to in-stream improvements

Moderate risk of landslide damage to in-stream improvements

NOTES

1. Qualitative risk assessment is for current conditions, prior to construction of project improvements.
2. Refer to text for more explanation of this figure.
3. Reference drawing: Herrera 2008.

August 18, 2016	FIGURE 6 **Current Landslide Damage Risk Locations**
PERRONE CONSULTING, INC., P.S. Project No. 15135	Mashel River Restoration for Herrera Environmental Consultants

Important Information about Your

Geotechnical Engineering Report

Subsurface problems are a principal cause of construction delays, cost overruns, claims, and disputes.

While you cannot eliminate all such risks, you can manage them. The following information is provided to help.

Geotechnical Services Are Performed for Specific Purposes, Persons, and Projects

Geotechnical engineers structure their services to meet the specific needs of their clients. A geotechnical engineering study conducted for a civil engineer may not fulfill the needs of a construction contractor or even another civil engineer. Because each geotechnical engineering study is unique, each geotechnical engineering report is unique, prepared *solely* for the client. No one except you should rely on your geotechnical engineering report without first conferring with the geotechnical engineer who prepared it. *And no one — not even you* — should apply the report for any purpose or project except the one originally contemplated.

Read the Full Report

Serious problems have occurred because those relying on a geotechnical engineering report did not read it all. Do not rely on an executive summary. Do not read selected elements only.

A Geotechnical Engineering Report Is Based on A Unique Set of Project-Specific Factors

Geotechnical engineers consider a number of unique, project-specific factors when establishing the scope of a study. Typical factors include: the client's goals, objectives, and risk management preferences; the general nature of the structure involved, its size, and configuration; the location of the structure on the site; and other planned or existing site improvements, such as access roads, parking lots, and underground utilities. Unless the geotechnical engineer who conducted the study specifically indicates otherwise, do not rely on a geotechnical engineering report that was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

Typical changes that can erode the reliability of an existing geotechnical engineering report include those that affect:

- the function of the proposed structure, as when it's changed from a parking garage to an office building, or from a light industrial plant to a refrigerated warehouse,
- elevation, configuration, location, orientation, or weight of the proposed structure,
- composition of the design team, or
- project ownership.

As a general rule, *always* inform your geotechnical engineer of project changes—even minor ones—and request an assessment of their impact. *Geotechnical engineers cannot accept responsibility or liability for problems that occur because their reports do not consider developments of which they were not informed.*

Subsurface Conditions Can Change

A geotechnical engineering report is based on conditions that existed at the time the study was performed. *Do not rely on a geotechnical engineering report* whose adequacy may have been affected by: the passage of time; by man-made events, such as construction on or adjacent to the site; or by natural events, such as floods, earthquakes, or groundwater fluctuations. *Always* contact the geotechnical engineer before applying the report to determine if it is still reliable. A minor amount of additional testing or analysis could prevent major problems.

Most Geotechnical Findings Are Professional Opinions

Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. Geotechnical engineers review field and laboratory data and then apply their professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ—sometimes significantly—from those indicated in your report. Retaining the geotechnical engineer who developed your report to provide construction observation is the most effective method of managing the risks associated with unanticipated conditions.

A Report's Recommendations Are *Not* Final

Do not overrely on the construction recommendations included in your report. *Those recommendations are not final,* because geotechnical engineers develop them principally from judgment and opinion. Geotechnical engineers can finalize their recommendations only by observing actual

subsurface conditions revealed during construction. *The geotechnical engineer who developed your report cannot assume responsibility or liability for the report's recommendations if that engineer does not perform construction observation.*

A Geotechnical Engineering Report Is Subject to Misinterpretation

Other design team members' misinterpretation of geotechnical engineering reports has resulted in costly problems. Lower that risk by having your geotechnical engineer confer with appropriate members of the design team after submitting the report. Also retain your geotechnical engineer to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering report. Reduce that risk by having your geotechnical engineer participate in prebid and preconstruction conferences, and by providing construction observation.

Do Not Redraw the Engineer's Logs

Geotechnical engineers prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering report should *never* be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, *but recognize that separating logs from the report can elevate risk.*

Give Contractors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering report, *but* preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with the geotechnical engineer who prepared the report (a modest fee may be required) and/or to conduct additional study to obtain the specific types of information they need or prefer. A prebid conference can also be valuable. *Be sure contractors have sufficient time* to perform additional study. Only then might you be in a position to give contractors the best information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions.

Read Responsibility Provisions Closely

Some clients, design professionals, and contractors do not recognize that geotechnical engineering is far less exact than other engineering disciplines. This lack of understanding has created unrealistic expectations that have led to disappointments, claims, and disputes. To help reduce the risk of such outcomes, geotechnical engineers commonly include a variety of explanatory provisions in their reports. Sometimes labeled "limitations" many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. *Read these provisions closely.* Ask questions. Your geotechnical engineer should respond fully and frankly.

Geoenvironmental Concerns Are Not Covered

The equipment, techniques, and personnel used to perform a *geoenvironmental* study differ significantly from those used to perform a *geotechnical* study. For that reason, a geotechnical engineering report does not usually relate any geoenvironmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. *Unanticipated environmental problems have led to numerous project failures.* If you have not yet obtained your own geoenvironmental information, ask your geotechnical consultant for risk management guidance. *Do not rely on an environmental report prepared for someone else.*

Obtain Professional Assistance To Deal with Mold

Diverse strategies can be applied during building design, construction, operation, and maintenance to prevent significant amounts of mold from growing on indoor surfaces. To be effective, all such strategies should be devised for the *express purpose* of mold prevention, integrated into a comprehensive plan, and executed with diligent oversight by a professional mold prevention consultant. Because just a small amount of water or moisture can lead to the development of severe mold infestations, a number of mold prevention strategies focus on keeping building surfaces dry. While groundwater, water infiltration, and similar issues may have been addressed as part of the geotechnical engineering study whose findings are conveyed in this report, the geotechnical engineer in charge of this project is not a mold prevention consultant; ***none of the services performed in connection with the geotechnical engineer's study were designed or conducted for the purpose of mold prevention. Proper implementation of the recommendations conveyed in this report will not of itself be sufficient to prevent mold from growing in or on the structure involved.***

Rely, on Your ASFE-Member Geotechncial Engineer for Additional Assistance

Membership in ASFE/The Best People on Earth exposes geotechnical engineers to a wide array of risk management techniques that can be of genuine benefit for everyone involved with a construction project. Confer with you ASFE-member geotechnical engineer for more information.

ASFE
THE BEST PEOPLE ON EARTH

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