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January 22, 2015 2381

Tom Boland, P.E.
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Geotechnical Engineering Services
Bolton Reservoir Seismic Landslide Evaluation
West Linn, Oregon

Dear Mr. Boland,

This letter summarizes our geologic reconnaissance and qualitative seismic stability evaluation of an ancient landslide surrounding the existing Bolton Reservoir. Recent geologic maps (Madin, 2009) have indicated the area including and surrounding the reservoir is an ancient landslide, but do not indicate if the landslide is currently active. Our evaluation was performed to identify any signs of landslide activity near the reservoir and to provide opinions on potential impacts of seismic landslide displacements on proposed improvements at the site.

Background Information

The Bolton Reservoir, shown on Figure 1, is located within a large ancient landslide mapped by the Oregon Department of Geology and Mineral Industries (DOGAMI). We understand that Murray, Smith & Associates, Inc. (MSA) has recently completed a Reservoir Siting Alternatives Analysis for the City of West Linn and has recommended that the City proceed with analyses to confirm the suitability of the existing reservoir site for new reservoir infrastructure. We also understand that MSA has been asked by the City to evaluate potential hazards posed by the landslide, including the potential for earthquake-induced movement.

Previous Landslide Studies in the Vicinity. In 1991 Landslide Technology (LT), a division of Cornforth Consultants, performed a geotechnical reconnaissance and design services for a landslide along Skyline Drive, approximately 600 feet southeast of the existing reservoir. The landslide affected two residential properties and a portion of Skyline Drive. In 1993, the landslide was mitigated with a rockfill buttress downslope of the two residences (LT, 1993). The buttress is keyed into basalt bedrock which underlies the landslide shear zone. In 2002, a waterline ruptured upslope of the landslide mitigation. LT performed a reconnaissance of the slide area to evaluate whether the water released by the pipe had an impact on the mitigation measures (LT, 2002). Surface cracking was observed near the centerline of Skyline Drive near where cracks were mapped in 1991. It was concluded that the rockfill buttress was performing adequately.

In 1998, LT performed a geotechnical investigation and developed mitigation measures for a shallow flow slide area near the northeast corner of the Bolton Reservoir site. The slide occurred in the 1970s, but additional ground cracks developed upslope of the slide in 1996 that suggested the slide was retrogressing (LT, 1998). The report indicated that the 1970s flow slide was likely due to a waterline break, and that the waterline had been relocated. As part of the 1998 study, one boring and several test pits were used to identify the limits of the flow slide.

In 2012 Geotechnical Resources Inc. (GRI) completed a geotechnical evaluation for the Bolton Reservoir conceptual siting analysis (GRI, 2012). As part of the study, GRI reviewed the landslide hazard maps prepared by DOGAMI and concluded that the Bolton Reservoir is located on a prehistoric (>150 years), deep-seated (>15 ft depth), translational landslide. GRI completed subsurface explorations to evaluate foundation conditions at the existing reservoir site. GRI's boring on the south side of the reservoir identified potential landslide debris to a depth of 60 feet. Readings collected on the inclinometer installed by LT in 1998 showed that 1/8 inch of shear displacement had occurred at a depth of 28 feet since installation.

Observations and Analysis

Reconnaissance. We visited the site on the November 10, 2014 to perform a reconnaissance of the ancient landslide and document any evidence of recent landslide activity. The general topography of the area is consistent with an ancient landslide, but surface expressions are muted or masked by development. General expressions of past movement include steepened slopes or scarps, translated slide blocks, and an offset creek channel. The landslide features shown on Figure 1 were mapped using a combination of field reconnaissance and interpretation from LiDAR maps prepared by DOGAMI. Figure 2 presents two schematic cross sections through the ancient landslide. The cross sections also show an interpreted potential shear zone that is consistent with surface expressions and limited subsurface data. The potential shear zone is shown for qualitative discussion, and does not represent known landslide conditions.

Walking reconnaissance was performed around the perimeter of the mapped landslide limits in an effort to locate signs and patterns consistent with recent landslide movement, including roadway cracking, buckling or separation of sidewalks, distorted driveway slabs, structural distress, and trees with curved trunks. Overall, the reconnaissance did not identify signs of distress consistent with active, on-going slide movement. Notably, sidewalks and pavement along Summit Street, Clark Street, and Linn Lane are in relatively good condition with little cracking or distortion. These streets cross the lateral limits of the mapped landslide where differential movements are generally most noticeable.

Several residences along Gloria Drive, near the headscarp of the landslide, show signs of structural distress to detached garages and raised decks. It appears that structures have experienced localized settlement and lateral displacement as evidenced by added bracing and leveling jacks supporting structural members. Detailed examination was not completed, but the type and location of the structural modifications are consistent with settlement or surficial slope movement.

Along Bridgeview Drive, approximately 500 feet from the intersection with Summit Street, a transverse crack was observed in the pavement. The crack appears to be an extension of cracks occurring in the sidewalk where there is separation between the sidewalk and a concrete retaining wall. The cracks do not exhibit signs of recent movement, and in our opinion, could be due to settlement or instability of localized cuts and fills.

Reconnaissance was also conducted along the northern limit of the mapped landslide, namely along Caufield Drive, West A Street, Hammerle Street, and Buck Street. Basalt outcrops were identified along Caufield Drive directly downslope of the existing reservoir. The outcrops were observed in the road cut as well as within the bed of the creek that runs just northeast of the existing reservoir. The basalt observed in these locations is consistent with basalt encountered in borings completed for the new reservoir and borings completed for landslide explorations.

Geology. The geology of the area is controlled by the following: (1) two members (Wanapum and Grande Ronde) of the Columbia River Basalt Group comprising the Tualatin Hills which are faulted by; (2) the Bolton Fault and associated splays forming the major northwest/southeast alignment of the Tualatin Hills; 3) an ancient terrace of the Willamette River covered with a mantle of Missoula Flood sediments; and 4) quaternary landslide features scattered along the front of the Tualatin Hills and the terrace above the Willamette River.

The Bolton Fault is mapped about 500 feet northeast of Bolton Reservoir, and extends in a northwest-southeast direction. The Oatfield and Portland Hills faults are mapped approximately 2.5 and 3 miles northeast of the site, respectively, and also trend in a northwest-southeast direction. These faults are included in the USGS Quaternary fault database (Personius, S.F., 2002) and are considered potentially active.

Also prominent in the vicinity of the site is the contact between the Wanapum and Grande Ronde members of the Columbia River Basalt Group. This contact is characterized by a well-developed, soil profile referred to as the Vantage Horizon. This feature formed during a long quiescent period that allowed soil to develop on top of the Grande Ronde basalt (17 to 15.6 million years old). The soil was subsequently covered by the Wanapum basalt (15.6 to 13 million years old). The Vantage Horizon is relatively weak compared to the surrounding rock and has acted as a landslide slip surface for multiple landslides in the Portland area.

Below the Bolton Reservoir site, there are a number of individual flow units of the Grande Ronde Basalt mapped (GMS-059, Beeson, 1989). These units were observed in the creek leading up from Caufield Street with some soil development apparent. Springs, with a combined estimated flow of 2 to 3 gallons per minute, were observed emanating from above basalt outcrops on Caufield Street.

Comments on Landslide Surrounding Bolton Reservoir. Based on our review of geologic maps and observations made during our site reconnaissance, we offer the following comments regarding the landslide surrounding the Bolton Reservoir site:

- In our opinion, the mapped landslide is a large, ancient, translational landslide mass consistent with other large landslides in the Portland area.

- Ancient translational landslides in the Pacific Northwest are typically marginally stable with factors-of-safety slightly above 1.0.
- The landslide surrounding the Bolton Reservoir has likely translated on a decomposed basaltic or tuffaceous, stiff clay layer. The borings indicate that the slide material is primarily stiff, clayey silt with SPT blow counts ranging between 10 and 20.
- As shown on the schematic cross sections, the basal shear zone is likely planar and dipping at a shallow angle to the northeast.
- We did not observe any signs of recent, deep-seated landslide movement during the site reconnaissance.
- There is a history of localized landslide movement at the reservoir site and the toe of the ancient slide, but the movements are likely related to a ruptured waterline and localized movements of steeper slopes at the toe of the ancient landslide.
- There have been no apparent operational difficulties at the existing reservoir due to deep-seated slide movements.

Seismic Behavior of Translational Landslides. Given the currently available data on the depth and extent of past landslide movement, it is not possible to perform a quantitative seismic stability evaluation at this time. To provide the City with information that would assist with Bolton Reservoir replacement project, the following paragraphs discuss on a qualitative basis the observed performance of large, translational landslides subjected to earthquake motions. Several case histories are cited that document seismically-induced landslide displacements in slide masses with characteristics similar to the landslide surrounding the Bolton Reservoir. The following section also discusses our experience regarding rate effects on shear strength of clayey soils at residual shear strength, and how strength gain could impact landslide displacements.

Seismic Deformation of Pre-Existing, Translational Landslides. During the past several decades, many active translational landslides have been subjected to earthquake-induced ground motions. Several case histories have been documented by earth scientists following large earthquake events. One of the more important observations gained from the post-seismic reconnaissance was that most pre-existing landslides have remained relatively stable with small to moderate displacements during the seismic event. Another observation is that translational landslides tend to move as coherent masses with small differential movements away from the slide margins. Several examples are listed below:

- The two largest historical earthquakes in the Pacific Northwest were the 1949 Olympia earthquake (M 7.1) and the 1965 earthquake near Seattle (M 6.5). During these earthquakes, it was observed that “seismic displacements associated with existing coherent slide blocks were typically less than 3 feet” (Chleborad, 1994).
- In 1976, a M 7.5 earthquake in Guatemala caused over 10,000 landslides. A USGS reconnaissance of the distribution and extent of landsliding indicated that, “despite strong

seismic shaking from the 1976 earthquake, pre-earthquake-landslide material mostly appeared to remain stable" (Harp, et al., 1981).

- In 1991, the M 7.0 Racha earthquake struck the Republic of Georgia triggering numerous landslides. Another USGS reconnaissance indicated that co-seismic displacements of active earth slides were generally less than 1 foot (Jibson, et al., 1994).
- The Loma Prieta earthquake was a M 7.1 event that struck the San Francisco Bay area on October 17, 1989. Shortly after the earthquake, engineers and earth scientists performed a reconnaissance of landslide and other geologic damage caused by the earthquake. These observations were summarized by the California Division of Mines and Geology (Manson, et al., 1992). Approximately 50 landslides were documented, and overall displacements were estimated based on fractures at the headscarp for each slide; 12 of these slides were active prior to the earthquake. The landslides had slope movements in the range of 1 to 12 inches at a distance of 10 kilometers from the epicenter.
- The 2010 Chile earthquake was a M 8.8 event that struck the central region and hilly coastal range. Earthquake reconnaissance by the Geo-Engineering Extreme Events Reconnaissance Association (GEER, 2010) documented that while scattered shallow slumps and rockfall were observed, deep-seated slides were relatively rare and in most cases the slides did not present a significant engineering issue. The report states that the most noteworthy aspect of deep-seated slides was their general absence. The scarcity of landslides is best illustrated by the fact that identifiable areas of prior extensive landslide activity had little or no evidence of seismically-triggered movement.

Dynamic Shear Strength. Many large, translational landslides involve movement along a relatively thin shear zone consisting of medium to highly plastic clayey soil. One of the key issues regarding the seismic behavior of ancient and active landslides is the response of clayey soils to earthquake loading conditions. There is limited data regarding the cyclic shear strength of stiff, clayey soils at residual strength. Several research studies on the shear properties of clays have focused on the effect of shearing velocity on shear strength (Lemos, Skempton and Vaughn, 1985: Kulhawy & Mayne, 1990, Meehan, et al., 2008). The trend of this data is that the undrained shear strength of clay increases approximately 5 to 10 percent per tenfold increase in the shearing velocity.

We have performed seismic stability evaluations for two landslides in the Portland area that have similar geology and geomorphology as the landslide mapped by DOGAMI at the Bolton Reservoir site. The landslides were both instrumented to determine the rate of movement occurring at the shear zone, and detailed studies were completed to quantify the strength gain that could be anticipated from the shear zone material during seismic shaking. Landslide instruments showed both slides moved at a rate on the order of 1/8 inch per year. By comparison, the average velocity induced by the various earthquake sources can reach up to 20 inches per second or more. Thus, the rate of shearing which could be generated by an earthquake is 8 to 9 orders of magnitude higher than the typical "creep" movement of reactivated ancient landslides. These

prior studies concluded that the dynamic shear strength of the shear zone material could be significantly higher than the residual shear strength measured at low shear rates.

Finite element and Newmark modeling has also been completed on the two landslides mentioned above. The models incorporated strength gain during strong shaking to estimate displacements at several key positions along the shear zone. The models showed that earthquake-induced movements were typically between 1 and 3 feet in the main body of the slide, but movements up to 10 feet were calculated in localized areas. Without including dynamic shear strength into the models, displacements on the order of tens of feet would have been predicted, which is inconsistent with the observed behavior of translational landslides comprised predominantly of stiff soils.

Conclusions

Geotechnical reconnaissance of the ancient landslide around the Bolton Reservoir did not identify signs of active movement, especially along the margins where differential movement would be greatest. Occasional areas of suspect deformation were observed within the landslide mass, but in our opinion these are attributable to settlement, localized instability of cuts and/or fills, and shallow sloughing of steep slopes.

It is our understanding that GRI has performed local static and seismic stability analyses for local slope stability in the vicinity of the new reservoir and to address observations of past slope movement. Based on their analyses, GRI has recommended ground improvement, a setback from the existing bluff as well as regrading of the upper portion of the bluff to improve the local stability in the vicinity of the slide.

It is our experience that visual, walking reconnaissance is a useful tool to identify surficial landslide features. However, it is not as effective as instrumenting landslides with slope inclinometers and piezometers. Slope inclinometers can measure very small ground movements that may not be manifested at the ground surface, and piezometers can provide important groundwater head data acting on the shear zone.

Recent borings completed by GRI reportedly encountered the Vantage Horizon, which has been shown to be a weak zone that contributes to slope instability. In addition, soil layers between individual flows of the Grande Ronde basalt observed in the creek near Caufield Street could possess strength properties similar to the Vantage Horizon.

Case histories of existing landslides subjected to strong shaking indicate that translational landslides with stiff, clayey shear zones have typically undergone small to moderate deformations during earthquakes. In our opinion, the dynamic shear strength of the landslide shear zone is probably significantly higher than the static shear strength, which limits earthquake-induced movements. Finite element modeling of large, translational landslides in the Portland area has generally confirmed this observation. Based on our review, the ancient landslide at the Bolton Reservoir site is likely to move feet rather than tens of feet during a large earthquake.

Structures and piping can typically be designed to accommodate some level of landslide movement. Structures situated in the middle of large, translational landslides tend to "raft" along with landslide movement. In this event, differential settlements can occur and cause some structural cracking. Structures or utilities located on the margins of the landslide will be subjected to larger differential displacements than those located in the central portion of the slide mass. Alternative Site No. 2 identified in MSA's reservoir siting analysis is located along the scarp flank and would be expected to be subjected to larger differential displacements than the currently proposed location. Due to the larger differential displacements at Alternative Site No. 2, it is our understanding that the civil/structural design team prefers Site No. 1 adjacent to the existing reservoir.

We recommend that site-specific, quantitative stability analyses be completed if the civil/structural design team determines the magnitude of seismically-induced landslide movement is needed for design of the new reservoir. Geotechnical investigations and analyses to further evaluate the geotechnical feasibility of the site should include deep exploratory borings and instrumentation to characterize the conditions and geometry of the ancient landslide mass and determine if active movement is occurring.

We trust that this letter is sufficient for your current needs. If you have questions regarding the information presented above, please call Chris Carpenter at 503-452-1100.

Very truly yours,

CORNFORTH CONSULTANTS, INC.

Darren L. Beckstrand
Senior Associate Geologist

Christopher I. Carpenter
Associate Engineer

Enclosures: Figure 1 – Site Plan
Figure 2 – Cross Sections

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REGISTERED PROFESSIONAL ENGINEER 65646PE

OREGON NOV. 13, 2012 CHRISTOPHER IAN CARPENTER

RENEWS: 12-31-2015

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Limitations in the Use and Interpretation of this Geotechnical Report

Our professional services were performed, our findings obtained, and our recommendations prepared in accordance with generally accepted engineering principles and practices. This warranty is in lieu of all other warranties, either expressed or implied.

The geotechnical report was prepared for the use of the Owner in the design of the subject facility and should be made available to potential contractors and/or the Contractor for information on factual data only. This report should not be used for contractual purposes as a warranty of interpreted subsurface conditions such as those indicated by the interpretive boring and test pit logs, cross-sections, or discussion of subsurface conditions contained herein.

The analyses, conclusions and recommendations contained in the report are based on site conditions as they presently exist and assume that the exploratory borings, test pits, and/or probes are representative of the subsurface conditions of the site. If, during construction, subsurface conditions are found which are significantly different from those observed in the exploratory borings and test pits, or assumed to exist in the excavations, we should be advised at once so that we can review these conditions and reconsider our recommendations where necessary. If there is a substantial lapse of time between the submission of this report and the start of work at the site, or if conditions have changed due to natural causes or construction operations at or adjacent to the site, this report should be reviewed to determine the applicability of the conclusions and recommendations considering the changed conditions and time lapse.

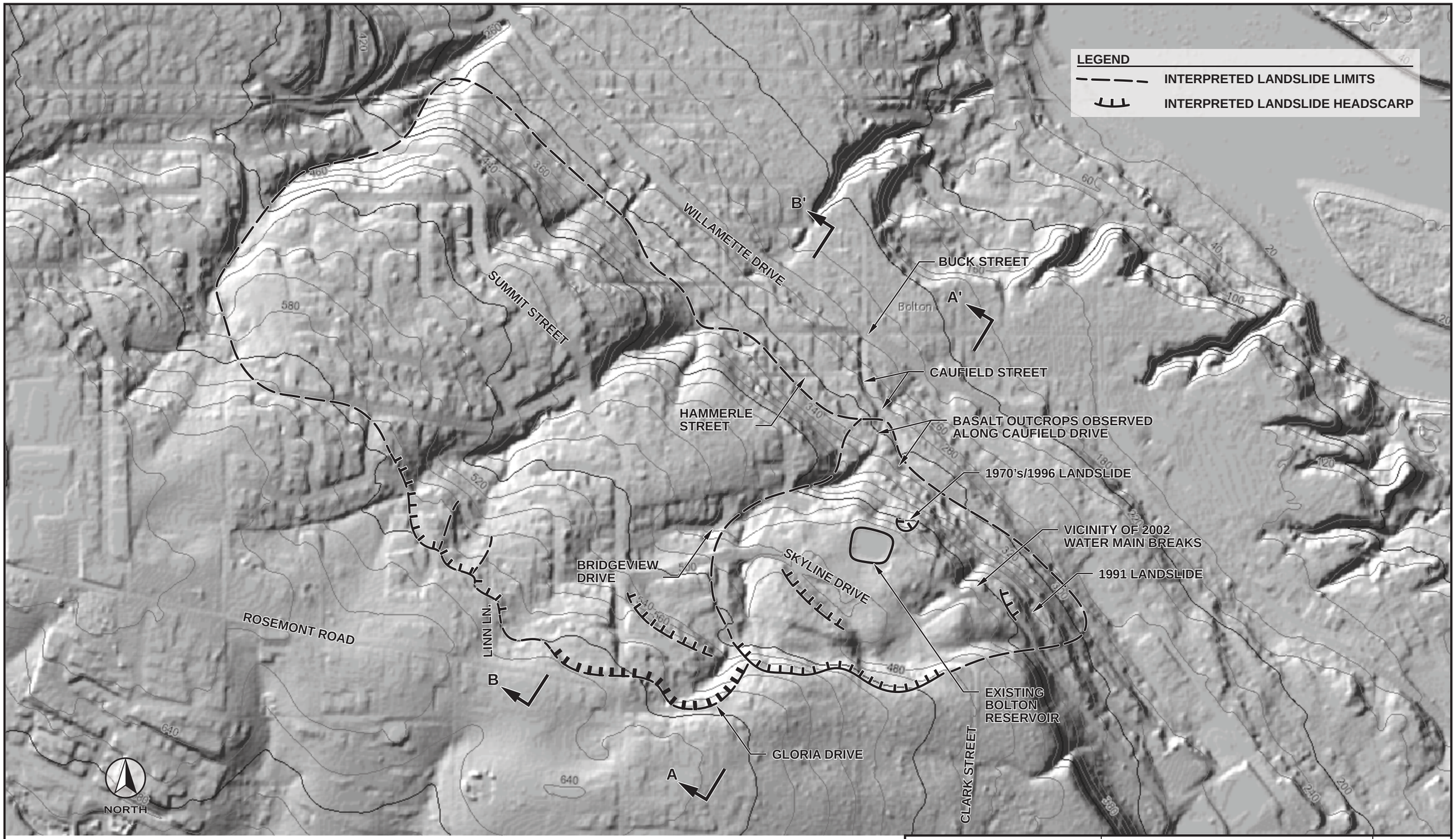
The Summary Boring Logs are our opinion of the subsurface conditions revealed by periodic sampling of the ground as the borings progressed. The soil descriptions and interfaces between strata are interpretive and actual changes may be gradual.

The boring logs and related information depict subsurface conditions only at these specific locations and at the particular time designated on the logs. Soil conditions at other locations may differ from conditions occurring at these boring locations. Also, the passage of time may result in a change in the soil conditions at these boring locations.

Groundwater levels often vary seasonally. Groundwater levels reported on the boring logs or in the body of the report are factual data only for the dates shown.

Unanticipated soil conditions are commonly encountered on construction sites and cannot be fully anticipated by merely taking soil samples, borings or test pits. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed project. It is recommended that the Owner consider providing a contingency fund to accommodate such potential extra costs.

This firm cannot be responsible for any deviation from the intent of this report including, but not restricted to, any changes to the scheduled time of construction, the nature of the project or the specific construction methods or means indicated in this report; nor can our firm be responsible for any construction activity on sites other than the specific site referred to in this report.



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SCALE IN FEET

NOTE: BASE MAP FROM OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES LIDAR DATA VIEWER AND STATEWIDE LANDSLIDE INFORMATION LAYER FOR OREGON (SLIDO) (WWW.OREGONGEOLOGY.ORG/DOGAMILIDARVIEWER) (WWW.OREGONGEOLOGY.ORG/SLIDE/INDEX.HTML)

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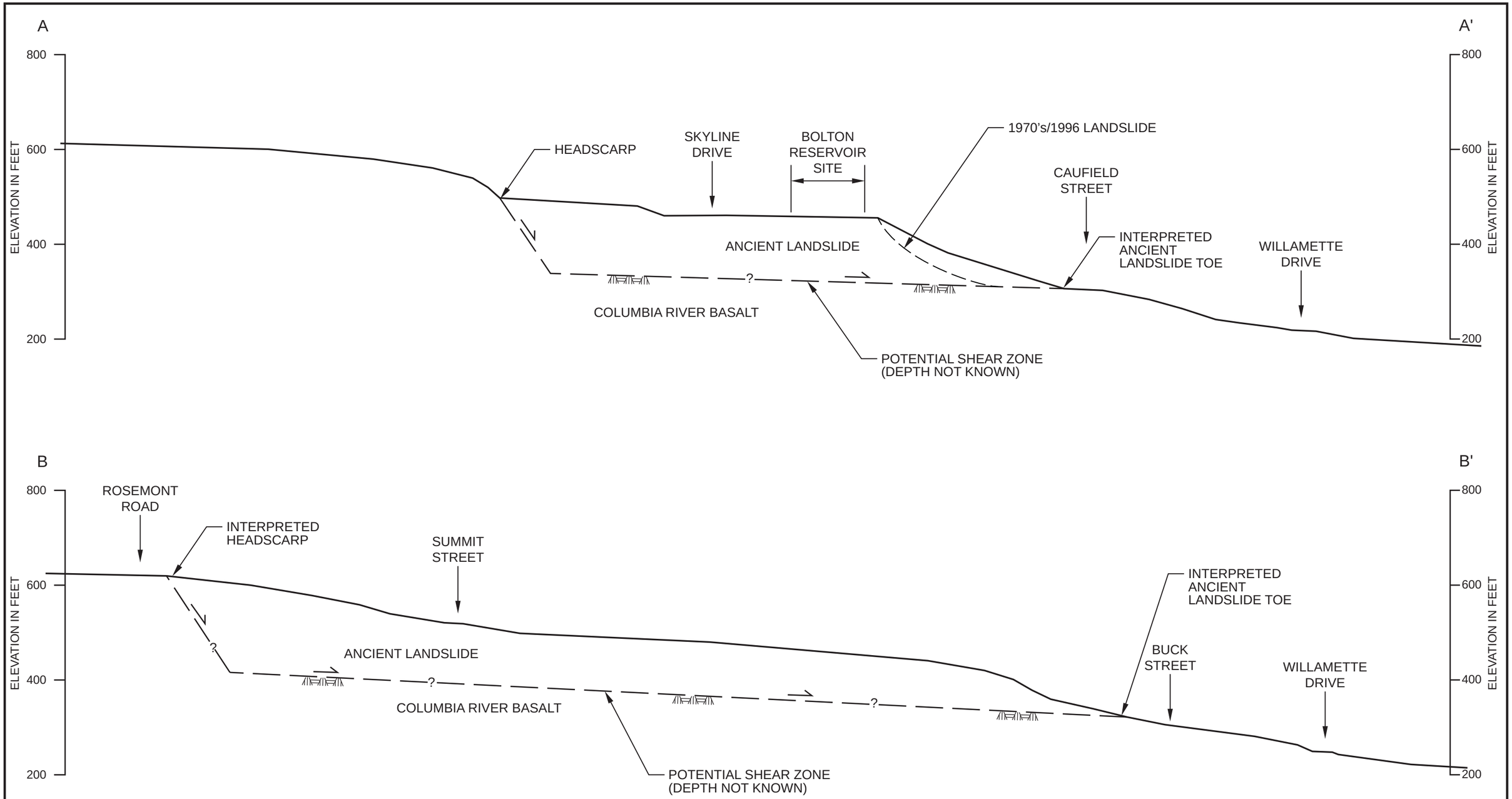
SITE PLAN

BOLTON RESERVOIR REPLACEMENT
WEST LINN, OREGON

JAN 2015

PROJ. 2381

FIG. 1



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SCHEMATIC CROSS SECTIONS

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FIG. 2