Greater West Bench Geotechnical Review

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Executive Summary

Background

Ecora Engineering & Resource Group Ltd. (Ecora) in conjunction with Clarke Geoscience Ltd. (CGL) were retained by the Regional District of Okanagan-Similkameen (RDOS) to undertake a Geotechnical Review for the Greater West Bench (GWB) located within RDOS Electoral Area “F”, which is situated northwest of the City of Penticton (CoP).

In the RDOS Electoral Area “F” Official Community Plan (OCP) Bylaw No. 2790 (Bylaw 2790), (2018), the policy for hazard lands recommended an updated technical assessment of geotechnical hazards in the Greater West Bench Study Area (GWB Study Area), which includes the neighbourhoods of Sage Mesa, West Bench, Husula Highlands and Westwood.

This Geotechnical Review report builds on the work completed by Klohn Leonoff (1992) and provides an assessment of geotechnical conditions utilizing more recent data and modern approaches, technical rationale for the creation of land use policies specific to the GWB Study Area and, will inform and guide GWB residents of the geotechnical conditions and appropriate use of lands.

The scope of work for the assessment is completed at a resolution suitable for electoral area planning. Results are not intended to be site-specific and may need to be confirmed by further geotechnical assessment when applied at a site level.

Unique Geotechnical Character of the Greater West Bench Study Area

The GWB Study Area has unique geotechnical characteristics and is distinguished by a relatively flat terrace that is deeply dissected by gullies and bounded on the east by dramatic silt bluffs adjacent to Okanagan Lake.

The thick deposits of silt soils, derived from Glacial Lake Penticton, have unique Engineering Material Properties that control the geotechnical character of the area. Research and experience indicate that, in a dry state, the undisturbed silt soils are very stable and can maintain near-vertical slopes. When wetted or disturbed, however these silt soils are prone to rapid erosion, collapse/compression, and slumping. The combination of unique soils, combined with historical land use, influences the nature and frequency of geotechnical hazards in the subject area, such as landslides and the development of sinkholes.

Historical Geohazard Events within the Study Area

The first documented geohazard within the GWB Study Area is a landslide that occurred in 1913 during construction of the Summerland to Penticton Lakeshore Road, killing three workers (Section 3.2.4). Further awareness of the geohazards in the GWB area became apparent soon after the area was settled in the 1950s and continues to this day. In a public survey to residents of RDOS Electoral Area “F” completed as part of this study, approximately one third of respondents’ report experiencing issues with sinkholes (Section 3.3).

Documented occurrences of geohazards, including sinkhole development, gully erosion and soil collapse, are observed to have resulted from domestic water leaks or irrigation, septic fields, or where roof and road drainage have been diverted onto the silt soils. These events have caused property damage but have rarely resulted in injury or death.

Historical Land Development and Current Servicing

The GWB Study Area is comprised of residential neighbourhoods, consisting primarily of single detached homes on medium and small-sized lots (Section 4.2). Lots in the West Bench - Sage Mesa neighbourhoods were originally developed in the early 1950s. In the 1960s and 1970s the area was partially subdivided and infilled with residential development and, in the 1970s to 1980s the Husula Highlands subdivision was developed. There is an elementary school on West Bench Road, two private golf courses, and a commercial gravel quarry operating south of Madeline (Max) Lake. Since 1992, further land densification and/or large-scale subdivision has not occurred, due to the concerns for geotechnical hazards. As per recommendations in the Klohn Leonoff (1992) report, further development was contingent on the installation of community sewer and stormwater systems.

The current supply of potable water to the West Bench area is from the CoP. The remainder of the GWB Study Area, servicing the Sage Mesa, Husula Highlands, and Westwood Properties residential areas, and two commercial golf courses, is from Okanagan Lake. In the 1990s, due to an increase in water pipe failures, the West Bench Irrigation District (WBID) initiated a major pipe replacement project. By 2010, over 60% of the water mains in the system had been upgraded. The RDOS have a National Award-Winning leak detection program operating on the West Bench that is an incredibly important tool in the management of potentially unstable ground in an area with soils sensitive to the introduction of water.

To this day, there is no municipal wastewater collection system servicing the GWB Study Area (Section 4.3). All residential dwellings in the have individual septic tanks and tile field wastewater treatment systems. Stormwater management is inconsistent and not well documented. Stormwater runoff at the property site level is unmanaged and largely unknown. It is assumed that roof and driveway runoff is directed to ground, or possibly into rock pits situated on individual properties.

Geohazards Occurring in the Greater West Bench Study Area

Key geohazards observed in the Glaciolacustrine Silts occurring in the GWB Study Area include the following:

- Shallow planar landslides;
- Deep-seated rotational landslides;
- Silt block falls or ravelling;
- Piping and sinkhole development; and
- Soil collapse.

These processes are often driven by the material’s sensitivity to increasing water content from natural hydrologic processes and/or artificial water sources.

Increases in precipitation, and more specifically, the projected increase in the frequency and intensity of rainstorms associated with predicted changes in climate, has potential to affect the likelihood for geotechnical hazards in the GWB Study Area.

Land use activities may also potentially have a negative effect on the geological stability of lands. Activities that potential impact stability may include land densification, increased concentrated water discharge to the ground, changing slope geometry, and soil loading (see Figure 4.3.a in report). For practical purposes, understanding the land use activity implications on geomorphological process and geohazards such as landslide initiation, sinkhole development, or soil collapse/compression, helps in the development of policies and guidelines for the management and/or mitigation of the hazards.

Geohazard and Risk Assessment

The process of assessing geohazards and risk involves identifying the trigger mechanisms, characterizing the event, estimating the potential likelihood of occurrence, and estimating areas potentially impacted. Hazard maps were produced as part of the assessment and are included in Appendix B (Maps 3.0-5.0).

The landslide hazard assessment results indicate that landslides persist within the vicinity of the steep silt bluff slopes that occur along the eastern boundary of the study area. Landslide hazards are greatest within approximately 50 metres of the slope or gully crest and extend beyond the toe of the slope towards Highway 97 and Okanagan Lake.

Sinkhole hazard levels within the GWB Study Area are greatest within 50 metres of the silt bluff slope crest and are observed exclusively within the Glaciolacustrine Silts (Section 5.3). Sinkhole hazard levels are greatest within the eastern portion of the study area and predominantly over the northern half of the GWB area.

Collapsible / compressible soils hazard occurs in conjunction with the silt bluffs and associated gullies (Section 5.4). It is unlikely that any area mapped as having a collapsible / compressible soils hazard is not also mapped as having a landslide and/or sinkhole hazard. However, this hazard class emphasizes the importance of recognizing the soil material properties susceptible to collapse / compression.

Geotechnical Constraints Mapping

The hazard maps presented in Appendix B (Maps 3.0-5.0) were combined to identify Geotechnical Constraint Zones, which are equivalent to “partial risk”. For this study, partial risk is the probability of a hazardous event (i.e., landslide, sinkhole, and/or collapsible / compressible soils) reaching or otherwise affecting a legal parcel.

The Geotechnical Constraints Zones map is presented as Map 6.0 in Appendix B, and can be interpreted as follows:

Geotechnical Constraints Zone	Criteria	Likelihood of a Damaging Geohazard Event Affecting a Parcel
Zone A	All three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated low.	Low
Zone B	Any one of the three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated moderate.	Moderate
Zone C	Any one of the three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated high.	High

Application of the Results to Land Use Management Planning

The type and level of regulatory response to land use corresponds with the relative likelihood that a particular type of land use activity will affect the likelihood of a damaging geohazard event. For example, although minor changes in land use (i.e., repairs and rebuilds) are unlikely to alter the geohazard condition, even these smaller-scale development applications require more scrutiny when proposed in high-risk areas. With larger-scale development applications, where proposed land use activities include expansion, densification, new building, and rezoning, there is a higher likelihood of adverse impact within all three Geotechnical Constraints Zones. Larger-scale development applications, when proposed within the moderate and high-risk zones, should be subject to rigorous review and certain types of development may be considered unsuitable for the high-risk zones.

Recommendations

Recommendations, presented for consideration by RDOS with the overall objective of reducing geotechnical risk within the GWB study area, include:

- Develop Land Use Management Policies for Hazard Lands, such as:
  - Incorporate results of this study into current RDOS bylaws;
  - Develop Geotechnical Report requirements;
  - Introduce a Soil Removal and Deposition Bylaw;
  - Develop specific land use activity Best Management Practices; and,
  - Implement a public education and outreach program specific to geohazards.

- Address Data Gaps, as needed, such as:
  - Conduct incidence tracking and data management;
  - Conduct additional subsurface soils investigation in conjunction with future geotechnical studies;
  - Conduct additional groundwater investigation and monitoring if resources are made available;
  - Update the 1994 Wastewater Management Plan when time is appropriate and when funding is available;
  - Advocate development of a Stormwater Management Plan by MOTI; and,
  - Conduct periodic review of geohazard conditions.

Acknowledgements

We would like to acknowledge the guidance and assistance of the RDOS staff throughout various stages of report preparation.

Background information was provided from the BC Ministry of Transportation and Infrastructure (MoTI) by Mr. Tom Kneale, P.Eng., Manager, Geotechnical and Materials Engineering for the Southern Interior Region.

Responsibilities

The Geotechnical Review report required collaboration amongst team members practicing in different technical disciplines. Although presented as a whole, we have assigned the following responsibilities for different technical components of the report, as per EGBC Practice Guidelines:

Personnel/Role	Technical Subject Area	Corresponding Report Sections
Michael J. Laws, P.Eng. Senior Geotechnical Engineer Ecora Engineering & Resource Group Ltd.	Overall administrative project manager and technical reviewer	All
Jennifer Clarke, P.Geo. Geomorphologist Clarke Geoscience Ltd.	Overall technical project manager. Geomorphology, terrain analysis, hazard assessment, regulatory response	All, Specifically Sections 1.0, 2.0, 3.0 (except, where indicated by others), 4.0, 5.0, 6.0, 8.0, 9.0
Naomi Mason-Herrtage, M.Sc., P.Geo. Engineering Geologist Ecora Engineering & Resource Group Ltd.	Engineering material properties of soils, gINT borehole log creation and geologic-cross-section, geomorphological processes	Sections 3.2.2, 3.4, 5.0
Donna Butler, MCIP Senior Planner Ecora Engineering & Resource Group Ltd.	Land use planning components, existing policies, and input to recommended policies	Sections 7.0, 9.0
Chelsea Evans, B.E (Hons) Civil Geotechnical Consultant Ecora Engineering & Resource Group Ltd.	Seismicity background, info on collapsible/compressible soils, slope stability analysis for silt bluff slopes	Sections 3.6, 5.4, 6.4, 6.7
Christopher Homes, P.Geo. Hydrogeologist Western Water Associates Ltd.	Characterize groundwater regime based on review of information and existing well logs. Comments on conclusions and recommendations of previous work.	Section 3.7, 5.5

Limitations of Report

This report and its contents are intended for the sole use of the Regional District of Okanagan-Similkameen (RDOS), their agents and the applicable regulatory authorities. Ecora Engineering & Resource Group Ltd. (Ecora) and Clarke Geoscience Ltd. (CGL) does not accept any responsibility for the accuracy of any data, analyses, or recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the RDOS, their agents, the applicable regulatory authorities or for any Project other than that described in this report. Any such unauthorized use of this report is at the sole risk of the user.

Where Ecora & CGL submits both electronic file and hard copy versions of reports, drawings, and other project-related documents, only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Ecora and CGL shall be deemed to be the original for the Project. Both electronic file and hard copy versions of Ecora and CGL's deliverables shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Ecora and CGL.

Ecora's General Conditions are provided in Appendix A of this report.

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Acronyms and Abbreviations

AIM	Acciona Infrastructure Maintenance
BC	British Columbia (Province of)
BCBC	British Columbia Building Code (2018)
BMP	Best Management Practice
BP	Building Permit
CGL	Clarke Geoscience Ltd.
CL	Low plastic clay (Atterberg Limits Test)
CoP	City of Penticton
CPCN	Certificate of Public Convenience and Necessity
CSA	Canadian Standards Association
DP	Development Permit
EGBC	Engineers and Geoscientists of British Columbia (formerly APEGBC)
ESDP	Environmentally Sensitive Development Permit
FCL	Flood Construction Level
FoS	Factor of Safety
GIS	Geographic Information System
GSA	Grain Size Analysis
GSC	Geological Survey of Canada
GWB	Greater West Bench
IH	Interior Health
ISWMP	Integrated Stormwater Management Plan
kPa	Kilopascal
KVR	Kettle Valley Rail (Trail)
LAS	Local Area Specifications
LIDAR	Light Detection and Ranging
LL	Liquid Limit (Atterberg Limits Test)
LSE	Limit State Equilibrium
m asl	meter(s) above sea level
ML	Low plastic silt (Atterberg Limits Test)
MoTI	(BC) Ministry of Transportation and Infrastructure
NBCC	National Building Code of Canada (2015)
OCP	Official Community Plan
PGA	Peak Ground Acceleration

PI	Plasticity Index (Atterberg Limits Test)
PIB	Penticton Indian Band
PL	Plastic Limit (Atterberg Limits Test)
QP	Qualified Professional
RAPR	(Provincial) Riparian Areas Protection Regulation (2019)
RDNO	Regional District of North Okanagan
RDCO	Regional District of Central Okanagan
RFP	Request for Proposal
RGS	Regional Growth Strategy
RDOS	Regional District of Okanagan-Similkameen
ROW	Right-of-way
Sa(T)	Spectral Acceleration
SH	Small Holdings
SWMP	Stormwater Management Plan
TRIM	Terrain Resource Information Management
WBID	West Bench Irrigation District
WDP	Watercourse Development Permit
WQA	Water Quality Advisory
WWMP	Wastewater Management Plan

1. Introduction

1.1 General

Ecora Engineering & Resource Group Ltd. (Ecora) in conjunction with Clarke Geoscience Ltd. (CGL) were retained by the Regional District of Okanagan-Similkameen (RDOS) to undertake a Geotechnical Review for the Greater West Bench Study Area (the GWB Study Area).

Geohazard issues in the GWB Study Area date back to 1913 when a landslide occurred during construction of the Summerland to Penticton Lakeshore Road, killing three workers (Vernon Morning Star, Jan 5, 2020). In 1958; a large sinkhole appeared in the area (Wright and Kelley, 1959), as a result, investigation, and mapping of the glaciolacustrine soils was completed, leading to early recommendations regarding land use activities to reduce the likelihood of accelerated erosion (Nyland and Miller, 1977).

Detailed geohazard mapping was completed for a portion of the GWB Study Area by Klohn Leonoff (1992). The map work identified potential areas affected by landslide, sinkhole, and silt bluff hazards, and was relied upon by RDOS for many years to direct land development away from hazardous areas.

In the RDOS Electoral Area “F” Official Community Plan (OCP) Bylaw No. 2790 (Bylaw 2790), (2018), the policy for hazard lands encouraged an updated technical assessment of geotechnical hazards in the West Bench / Sage Mesa area to current technical standards. With respect to hazard lands, the current Bylaw 2790 (2018) provides objectives and policies to minimize damages due to natural hazards, and to ensure that development avoids areas subject to hazardous conditions.

The intent of this study is to address the recommendations of Bylaw 2790 (2018) to develop a current technical assessment of hazard conditions within the designated GWB Study Area. The results from this Geotechnical Review report will provide a starting point from which RDOS may develop future policies for regulating various land use activities.

1.2 Study Area Location

The GWB Study Area, shown in Figure 1.2.a, is located within RDOS Electoral Area “F”, and is situated to the northwest of Penticton, British Columbia (BC). The GWB Study Area has a total area of 520 ha, and is comprised of the following residential neighbourhoods:

- Sage Mesa;
- West Bench;
- Husula Highlands; and
- Westwood Properties.

The GWB Study Area is bounded by First Nation Reserve Lands administered by the Penticton Indian Band (PIB). The Red Wing residential subdivision (indicated in Appendix B, Map 1.0) is situated along the east side of the West Bench. PIB are based in Syilx traditional territory and are one of eight communities in the Okanagan Nation (RDOS Electoral Area “F” OCP, 2018).

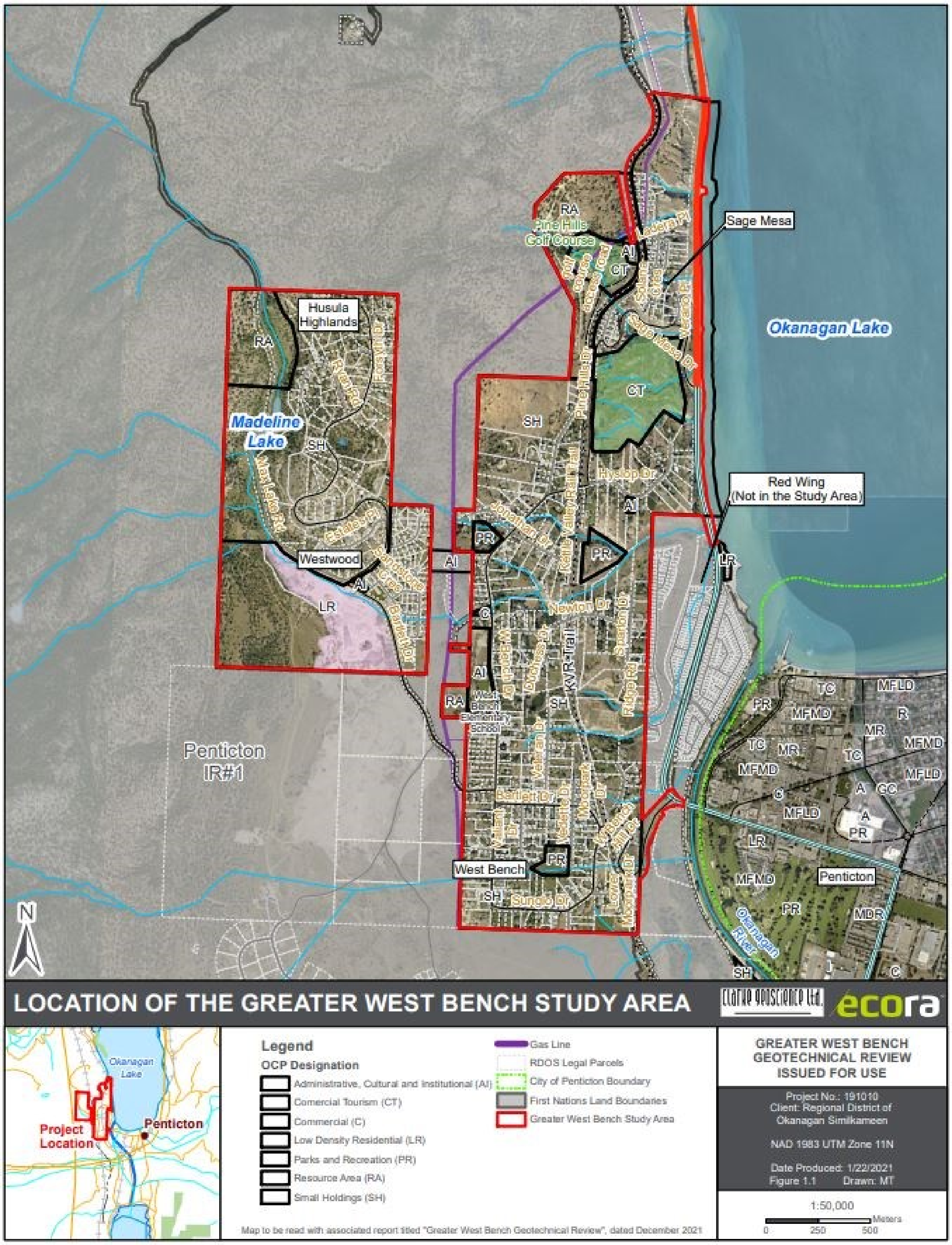


Figure 1.2.a Location of the Greater West Bench Project Study Area.

1.3 Project Objectives and Scope of Work

Based on the RDOS Request for Proposals (RFP No. 2019-DE-01), the project objectives and scope of work was to:

1. Conduct a review of previous and relevant geotechnical studies relating to the Greater West Bench (GWB) area and soil conditions.
2. Expand the Study Area to include all lands that are within RDOS Electoral Area ”F” and have zoning designations in the “Regional District Okanagan-Similkameen, Electoral Area “F” Zoning Bylaw No. 2461, 2008”; generally, within the West Bench, Sage Mesa and Husula Highlands area (GWB).
3. Determine any changes since 1992 to topography, sinkhole patterns, roads and other infrastructure, and land use development using any available data such as air photo interpretation, site visits, survey of the Study Area residents, contact with provincial agencies, such as Ministry of Transportation and Infrastructure, etc. Identify and show changes on a base map of the Study Area utilizing existing LiDAR and RDOS data.
4. Field reconnaissance will be necessary to assess the nature, extent, and potential effect of natural hazards within the GWB Study Area.
5. A drilling program may not be necessary a part of the investigation program but utilization of available drill holes and well logs is the expectation for this study.
6. Provide discussions on the benefits and detriments of adding community servicing infrastructure, such as sanitary and storm sewers, and road curb and gutter to the Study Area. Some specifics to consider include:
    a. How the infrastructure could impact the risk and influence area of existing geological hazards.
    b. How staging of community servicing systems could be utilized to gain a maximum benefit with limited expenditures.
    c. Provide recommendations regarding servicing, design and, installation procedures with a view to limiting or preventing adverse influences from servicing work on the prevailing subsurface conditions.
    d. Discuss ongoing monitoring programs that should be implemented.
7. Assess the levels of risk of existing land use and individual lots in the hazard areas to determine appropriate use, for example, hard surface coverages, pools, and irrigation.
8. Explore opportunities, risks, and mitigation on existing parcels and zoning designations, taking into account existing subsurface prevailing conditions, that have the possibility of densification or alternate land uses, for example, secondary suites and carriage houses within existing zoned areas. Consideration should also be given to land areas where combinations of mitigative measures and ongoing geotechnical monitoring programs could facilitate future residential development and alternate land use possibilities.
9. Provide an interpretation of the potential hydrologic impacts to the Study Area of increased residential development in the higher elevation gravel/bedrock areas located immediately above and west of the silt bluffs in the West Bench/ Sage Mesa area.
10. Additionally, provide a discussion as to the character of the groundwater regime in these higher elevation areas and potential influences from climate change and increased development.

11. Consider the influence that groundwater levels have on defined hazard areas in the silt bluffs. Provide a framework for a groundwater monitoring program to track fluctuations within the Study Area. Include considerations for a mitigative program to control fluctuations if climate change and/or residential development causes unacceptably high groundwater levels.
12. Consideration of future climate change impacts for hazard conditions, mitigative methods, infrastructure design and land use planning.
13. Review benchmarks for risk provided in the Klohn Leonoff (1992) report and provide an up-date to current practice to allow administrators to decide on acceptable risk levels when adopting policies and bylaws controlling the type and location of land use in the Study Area.
14. Re-visit and assess established hazard zone boundaries set out in the Klohn Leonoff (1992) report and confirm or modify these boundaries. Prepare updated geotechnical hazard mapping that summarizes the results of the findings. Mapping should include but not limited to hazard and buffer zones, and risk assessment, mitigation method areas and land use alternatives. Slope stability assessments should follow EGBC (2010) Guidelines.

In response to the RFP, Ecora and CGL developed a work plan tailored to address the above-listed tasks. It is noted that the report organization deviates from this list to provide a logical flow. This Geotechnical Review report builds on the Klohn Leonoff (1992) report, comprising an assessment of geotechnical conditions utilizing historical and recent data, and applies modern technology and methods.

The final Geotechnical Review report and map work will inform the RDOS of the geotechnical conditions and appropriate use of lands within the GWB Study Area and provides a technical rationale for the development of land use policies specific to the area.

2. Approach and Methods

2.1 General

The Geotechnical Review approach, detailed in the following sections, draws upon a combination of Provincially and Nationally recognized techniques and approaches, and incorporates these different approaches to form one that is unique to the study.

This Geotechnical Review report relies on previous geohazard studies, reports, and borehole/well logs, completed by others, to provide subsurface soils and groundwater characterization. No additional subsurface investigations were carried out as part of this study. The current review includes interpretation and evaluation of recent air photo imagery to document terrain conditions, as well as landslide and sinkhole occurrences. Additional information on geohazard occurrences in the GWB Study Area was obtained through agency consultation and a public survey. A three-day field program was conducted to review site conditions, to confirm image interpretation, and to follow up on reported geohazard occurrences.

Relevant documents providing overall guidance to the technical approach include:

- Engineers & Geoscientists British Columbia (EGBC, 2010), *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC*.
  - This document provides professional practice guidelines for landslide analysis and guidance as to how to compare assessment results to levels of landslide safety.
- Wise, et al. (2004), *Landslide Risk Case Studies in Forest Development Planning and Operations*.
  - This document defines the framework, terminology, and procedures for conducting natural hazard and risk assessments.
- Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction (2010-2016).
  - Canada's Landslide Guidelines include a collection of reports assembled by the Geological Survey of Canada (GSC). The documents provide a review and comprehensive summary of national approaches for landslide hazard assessment and risk assessment.
- Porter and Morgenstern (2013), *Landslide Risk Evaluation*. Open File 7312.

2.2 Previous Geohazard Studies and Relevant Reports

The primary document of relevance to this Geotechnical Review is the *West Bench / Sage Mesa Geological Hazards Review*, submitted to the RDOS by Klohn Leonoff in 1992. The Klohn Leonoff (1992) report forms the basis for this updated Geotechnical Review report. Other than this primary document, other key geotechnical documents providing background information and reference material for the assessment include the following:

Geohazard Studies

- Nyland and Miller (1977), *Geological Hazards and Urban Development of Silt Deposits in the Penticton Area*. BC Ministry of Highways and Public Works, Geotechnical and Materials Branch. Kamloops, BC.

Engineering Properties of Soils Reports

- Wright, A.C.S. and C.C. Kelley (1959), *Soil Erosion in the Penticton Series, West Bench Irrigation District, Penticton, BC*. Soil Survey Branch, Department of Agriculture, Kelowna, BC.

- Lum, K.K.Y. (1979), *Stability of the Kamloops Silt Bluffs*. M.A.Sc. Thesis, Department of Civil Engineering, University of British Columbia. Vancouver, BC.
- Iravani, S. (1999), *Geotechnical Characteristics of Penticton Silt*. PhD Thesis, Department of Civil and Environmental Engineering. University of Alberta. Edmonton, AB.
- Thurber (2007), *Highway 97 Bentley Road to Okanagan Lake Park, Detailed Geotechnical Design Report, Victoria, BC*.
- Bigdeli, A. (2018), *Evaluation and Control of Collapsible Soils in Okanagan-Thompson Region*. Ph.D. Thesis, Department of City Engineering. University of British Columbia – Okanagan. Kelowna, BC.

Hydrogeological / Groundwater Reports

- Piteau Gadsby Macleod Ltd. (1976), *Preliminary Report Hydrological Aspects, Husula Developments Ltd.* A hydrogeological investigation report completed for the Husula Highlands neighbourhood.
- Pacific Hydrology and Piteau Associates (1993), *Evaluation of the Groundwater Regime in the Area of Max Lake Road and Forsythe Drive on the West Bench at Penticton, BC*. Prepared for Inland Contracting Ltd. Vancouver, BC.

Several site-specific geotechnical investigations were provided for information purposes. However, there is no complete repository of reports that is readily available for review. Reports prepared for the subdivision approving authority are retained on file with the Ministry of Transportation and Infrastructure (MoTI) and were not available for review. Reports prepared for Building Permit (BP) requirements are retained on file with the RDOS and were also not available for review for this project.

The background information review found that few regional-scale geotechnical or hydrogeological investigations have been completed since the Klohn Leonoff (1992) review. To date, it is the results of the Klohn Leonoff (1992) study that have been incorporated into RDOS development planning policy.

2.3 Terrain Classification

Throughout the GWB Study Area the terrain was classified and mapped according to the BC Terrain Classification System (Howes and Kenk, 1997), and followed the BC Province (the Province) methods for terrain mapping (Resources Inventory Standards Committee, 1996). These methods represent current standards of practice for terrain mapping in BC and provide a consistent and standardized approach.

2.3.1 Historical Air Photo and Imagery Review

A review of available historical air photos and Google Earth(TM) imagery was undertaken to determine changes in land development and terrain response since the Klohn Leonoff (1992) report, which was based on air photos from1990. The overall historical air photo record of the GWB Study Area spans across 80 years and includes 15 years of photographic coverage during this period. Since the Klohn Leonoff (1992) study, there have been seven years of air photo and orthophoto coverage, including high resolution digital orthoimagery and LiDAR data acquisition. Table 2.3.a provides a list of historic imagery reviewed for this assessment. It is noted that identification of features was limited to the resolution, elevation, and scale at which the aerial photography was taken.

Table 2.3.a List of Historical Imagery Reviewed for this Geotechnical Review

Year	Flight Line and Photo Number	Scale
1938	BC105 No. 41-42	Not available
1951	BC1244 No. 38-39	Not available

Year	Flight Line and Photo Number	Scale
1963	BC4171 No. 189-190	1:15,840
1974	BC7572 No. 23-24	1:16,000
1979	BC5329 No. 228-229	1:32,000
1980	BC80054 No. 100-101	1:20,000
1985	30BCC371 No. 65-66	1:15,000
1990	30BCB90004 No. 27-29	1:10,000
1996	30BCC96046 No. 25-26	1:15,000
2001	15BCC01032 No. 216-217	Not available
2007	BCD07035 No. 133-135	1:27,000
2003, 2010, 2016, 2018	Google Earth	
2018	RDOS GIS (LiDAR)	

2018 LiDAR[1] data (hillshade and orthophoto imagery) was interpreted for the terrain mapping, sinkhole inventory, and landslide inventory. The 2018 Bare-Earth model developed from the LiDAR data was used to create a base for the Terrain Map (see Appendix B, Map 2.0). Figure 2.3.a shows a clipped example of the Bare-Earth model. Terrain polygon linework, interpreted sinkholes, and landslides were transferred to the base map as a shapefile (.shp) file. An associated terrain ArcInfo GIS database was also transferred.

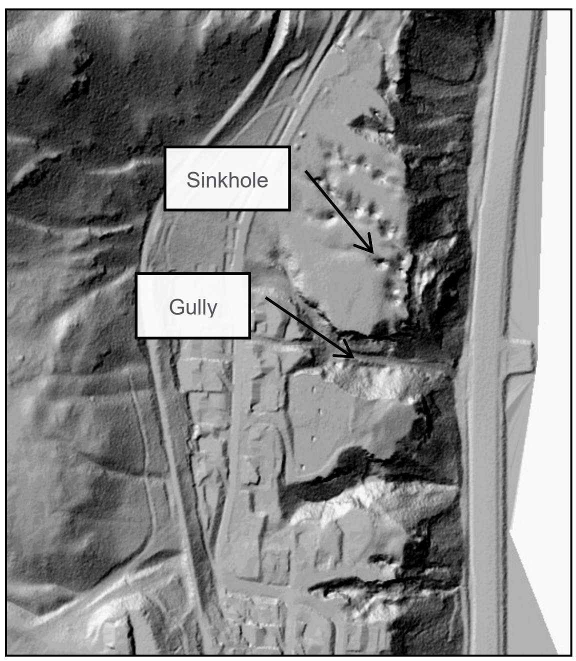


Figure 2.3.a A clipped example of 2018 Bare-Earth LiDAR data, showing gullies and sinkholes at the north end of the GWB Study Area.

The 2018 LiDAR data was supplemented with field observations, available information on historical events from RDOS and MoTI, background review information, and information from local residents.

1 LiDAR stands for *Light Detection and Ranging*. It is an airborne remote sensing method that uses a pulsed laser to measure distances to the earth surface. Processed LiDAR data used to create a bare-earth image eliminates vegetative cover such that precise information on the earth surface and its character may be obtained using this technique.

2.3.2 Borehole and Well Log Data Compilation

The Government of British Columbia Groundwater Wells and Aquifers database (https://apps.nrs.gov.bc.ca/gwells/) was reviewed for all groundwater well records within the GWB Study Area. The information provided by the records included subsurface soils and groundwater conditions. Select well records were used to develop two geologic cross-sections through the Study Area (see Section 2.3.2 above).

2.3.3 Field Review

Fieldwork was completed between November 27 and 29, 2019. The entire portion of the GWB Study Area covered by residential development was traversed by vehicle. Targeted groundwork was completed with an intent to confirm surficial materials (for the terrain mapping), to confirm areas of instability, sinkhole activity, and to observe surface water storm runoff conditions.

No soil sampling or subsurface investigation was conducted during the field review. Select photographs taken during the fieldwork are provided in Appendix C.

2.4 Agency Consultation, Interviews and Public Survey

Past geotechnical hazard events and current site conditions was gathered through agency consultation, interviews, and a web-based public information survey.

RDOS staff coordinated the provision of background information and consultation however, due to data storage and retrieval limitations, only a few recent examples of documented geohazard occurrences were provided. The recent examples were addressed by the Public Works - Operations Department. One example included development of a sinkhole near a broken water main in Sage Mesa (Tetra-Tech EBA, 2014).

Mr. Tom Kneale, P.Eng., the MoTI manager for Geotechnical and Materials Engineering for the Southern Interior Region provided previous geotechnical investigation reports and data for three bridges over the Kettle Valley Rail (KVR) Trail. No information was provided by MoTI District staff, nor from Acciona Infrastructure Maintenance Inc. (AIM), the current Roads Maintenance Contractor

Local resident, John Chapman, provided historical geotechnical investigation documentation for a proposed residential subdivision development in the late 1990s, at the north end of the study area. Interviews with long-time residents and an electronic public participation survey arranged by the RDOS communications department garnered anecdotal information on previous landslides, sinkholes, and other geotechnical issues. A copy of the RDOS survey is included in Appendix D and results are presented for discussion in Section 3.3 below.

3. Geotechnical Character of Study Area

3.1 General

The following sections describe the geotechnical character of the GWB Study Area, including surface and subsurface conditions that support the subsequent interpretations and hazard analysis.

The GWB Study Area is characterized as a relatively flat silt terrace, dissected by gullies, and bounded to the east by dramatically steep bluffs adjacent to Okanagan Lake. The western side of the study area is characterized with several levels of terraces, comprised of sands and gravels. The mid-slope area between the silt terrace and the gravel terraces has a kettle topography identified by an irregular pattern of hills, ridges, and enclosed depressions. The mid-slope area is bisected by the Madeline (Max) Lake Valley. Upland areas within and adjacent to the GWB Study Area are described as moderate to steep bedrock-controlled slopes.

Post-glacial landform development combined with the stratigraphic sequence of the GWB soils and the Engineering Material Properties of the soil (see Section 3.4), control the geotechnical character of the GWB Study Area. The combination of unique soil characteristics, combined with land use practices, dictates the nature and frequency of geomorphological processes, and associated geotechnical hazards.

3.2 Surficial Geology

3.2.1 Landform Development

Landforms and surficial materials in the GWB Study Area reflect the post-glacial history and are relevant to this Geotechnical Review because it has led to the formation of the silt bluffs, and juxtaposition with the sand and gravel terraces. Post-glacial landform development in the South Okanagan is detailed by Nasmith (1962), Roed and Fulton (2011), and is also interpreted by Nyland and Miller (1977), and Klohn Leonoff (1992).

At the end of the last glaciation, glaciers in the Southern Interior of BC melted, not by retreating, but rather by down-wasting (melting in place). Ice melted first from the upland plateau, while ice remained in the valley bottom.

At the end of the most recent glacial episode, the Faulder-Meadow Valley Area west of Summerland, BC, was impounded behind a glacial ice dam (Nasmith, 1962). As a result, Trout Creek was diverted southward down a valley located east of Blue Mountain and west of Mount Nkwala (referred to as “Madeline Canyon” by Roed and Fulton (2011)) and discharged onto a periglacial fan. Much of the sandy gravel deposits may have been deposited on top of, or around stagnant ice in that area at the time of glacial retreat and are therefore described as ice-contact deposits (Pacific Hydrology and Piteau Associates, 1993). Once the ice began to retreat, Trout Creek re-routed to its present-day alignment, creating the Trout Creek Fan just south of Summerland.

During the period of meltwater flow through the Madeline Canyon, coarse glaciofluvial outwash deposits were deposited at the outlet of the canyon, which now contains a small lake called Madeline Lake (also referred to as “Max Lake”). The deposits in the area extend south along the lower valley slopes and currently support several sand and gravel quarry operations, one of which is located within the GWB Study Area.

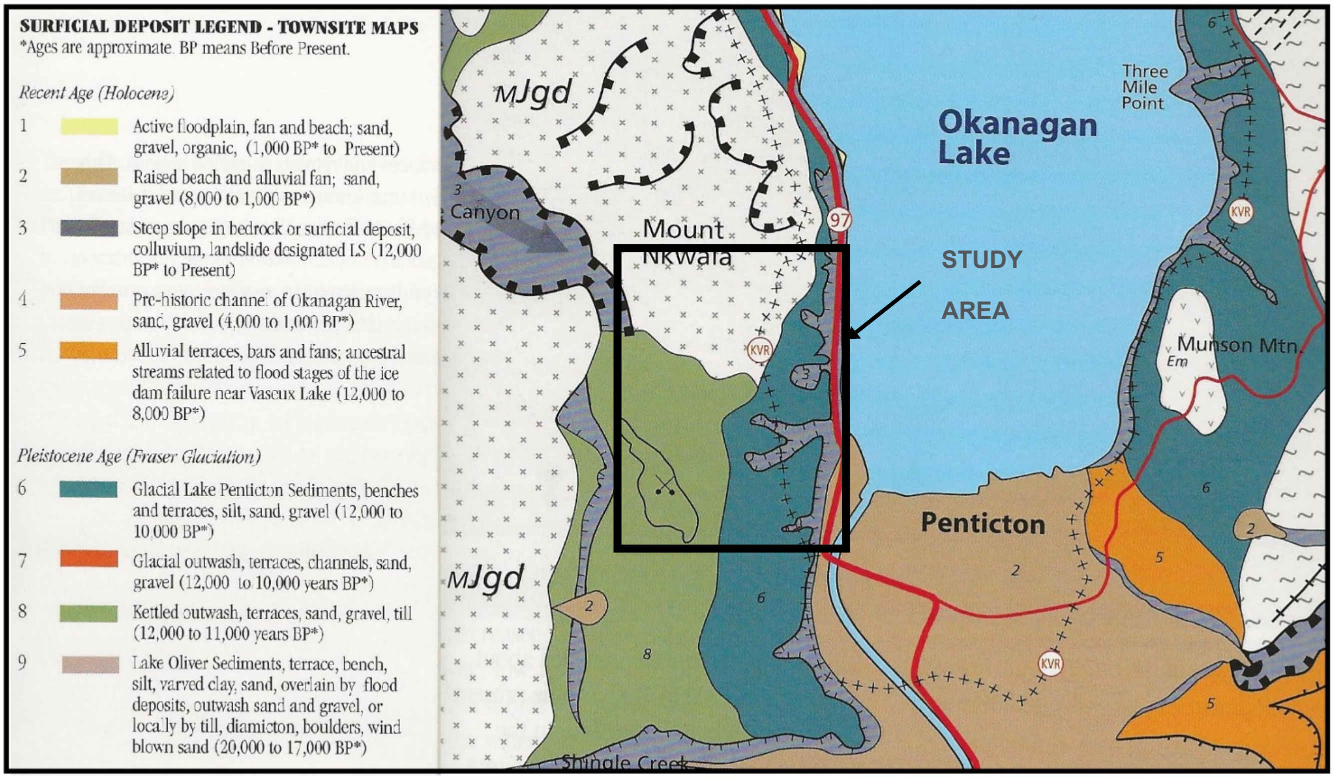


Figure 3.2.a Glacial Deposits in the Penticton Area (from Roed and Fulton, 2011)

During the late stages of deglaciation, the Okanagan Valley was occupied by a large lake, referred to as Glacial Lake Penticton. At one time the valley lake stretched from Osoyoos to as far north as Enderby, draining into the Shuswap / North Thompson River and Fraser River system. This was later bisected, with the predominant flow trending southwards through the South Okanagan and into the Columbia River system. During the period that Glacial Lake Penticton occupied the Okanagan Valley, very fine silty material (i.e., glaciolacustrine deposits) were deposited and accumulated on the lake bottom. The silt was deposited in rhythmic successions due to seasonal variations in runoff (i.e., varves). Thicker layers were deposited during the higher runoff periods through spring and summer, while thin layers were deposited during the low runoff winter months. As a result, a layered stratigraphic sequence of silt, sometimes interbedded with fine sands, deposited during periods of extreme inflow, accumulated over time.

Glaciolacustrine deposition is responsible for development of the silt terrace that forms the majority of the GWB Study Area to the east. The silt deposits, up to 100 m thick, were deposited up to approximate elevations between 400 m above sea level (m asl) and 420 m asl.

During retreat of the last phase of glaciation, as the lake lowered to the current elevation of present-day Okanagan Lake, extensive excision and erosion of the bluffs likely occurred, from surface rilling and gully formation to mass wasting and large landslides. Erosional processes such as piping, caving, and collapse / compression are associated with the evolution of the gullies. Saturated formations west of the silts also drained with the lowering of the lake, contributing to further erosion of the bluffs.

It is relevant to note that for several thousand years immediately following glaciation (also known as the paraglacial period) the climate transitioned from a cool, wet period associated with a very high sediment yield, and characterized by large-scale mass wasting and high rates of landscape evolution (Church and Ryder, 1972). The climate then transitioned to a warm, dry period punctuated by short periods of neoglacial advances and, for the most recent (few thousand) years, rates of sediment yield and mass movement remain low. More recently, landscape evolution is more likely to be associated with degradation, valley downcutting, and erosion.

Glacial deposits in the vicinity of the GWB Study Area are shown in Figure 3.2.a. The distribution of sediments shows that the outwash sands and gravels are peripheral to the Glaciolacustrine Silts. However, the contact zone between the sands and gravels and the silts is not well defined. Previous studies indicate that there is some discontinuous interbedding on the periphery (Nyland and Miller, 1977). Further north in the Sage Mesa area, the silt deposits are less influenced by the meltwater sands and gravels of the Madeline (Max) Lake Valley area.

Previous work speculated that deposition of the Glaciolacustrine Silts and the ice-contact sands and gravels was at least partly simultaneous, although the time required for deposition of the silt would have been longer, and that the deposits were subsequently eroded with lowering glacial lake levels (Pacific Hydrology and Piteau Associates, 1993). The complex interrelationships between the Glaciolacustrine Silts and the sands and gravels influence the movement of groundwater through the GWB Study Area and subsequently influences slope stability.

3.2.2 Geologic Cross-Section

As discussed in Section 2.3.2 , two geologic cross-sections were developed based on available borehole and water well records. The borehole and water well data was entered into gINT software[2] to create the cross-sections. The cross-sections are aligned east to west through the study area, illustrating the general topography of the bedrock surface, and the relationship between the outwash sands and gravels and the Glaciolacustrine Silt. Simplified versions of the two cross-sections are shown in Figure 3.2.b and Figure 3.2.c. Detailed cross-sections as well as a plan view map showing the cross-section locations, are provided in Appendix E1 and E2.

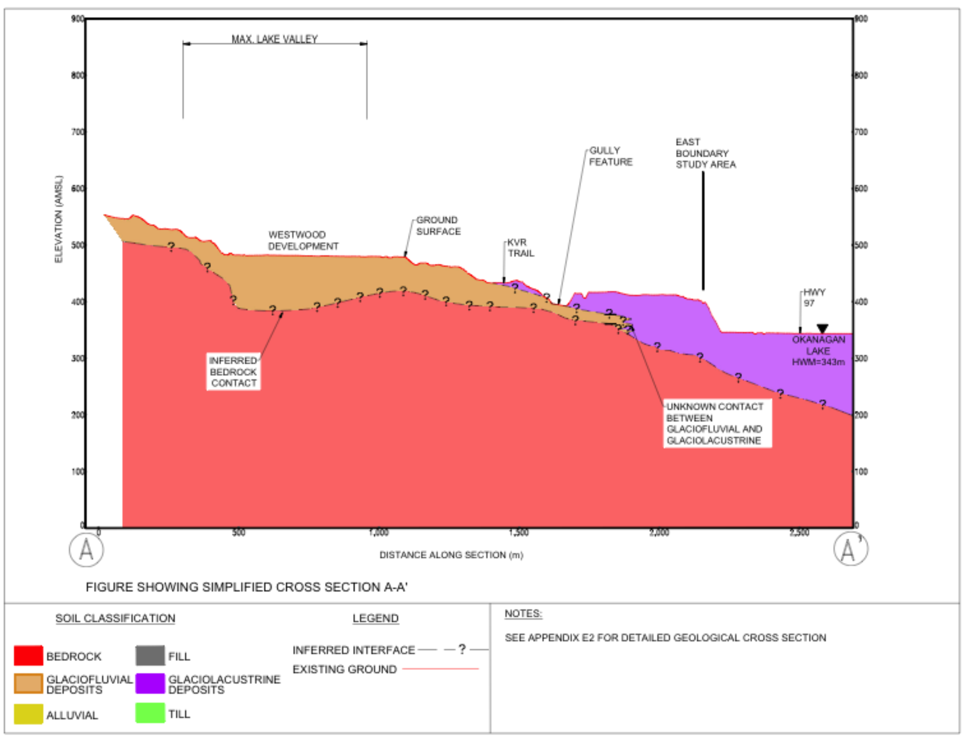


Figure 3.2.b Simplified Geologic Cross-Section A-A'

2 gINT is a subsurface data management and reporting software product that logs subsurface data from boreholes or wells for consistent visualization.

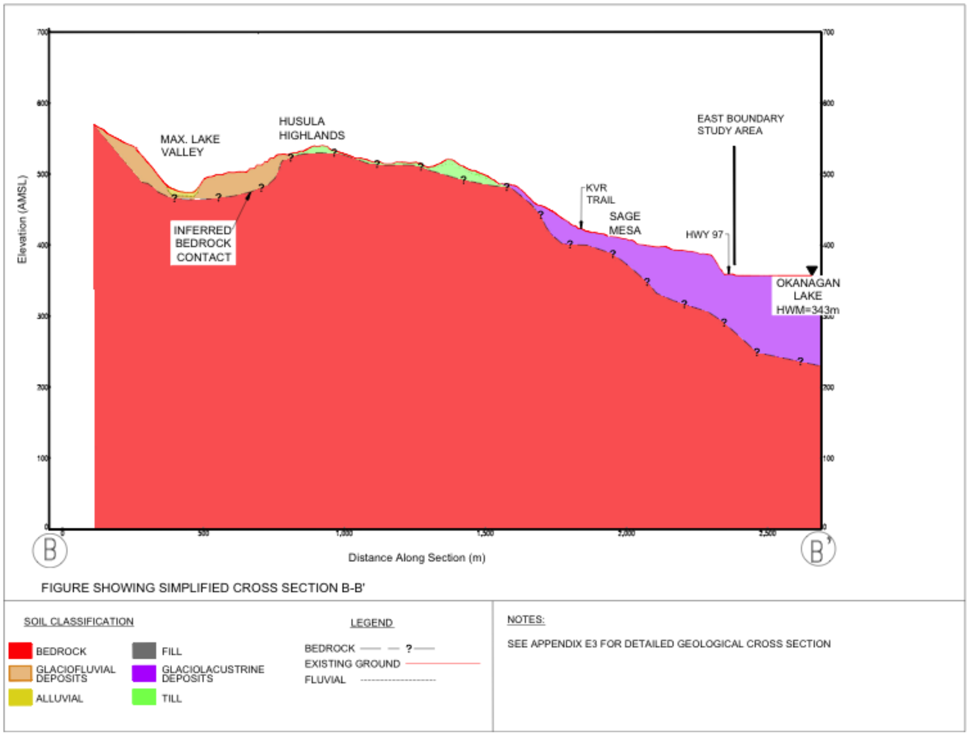


Figure 3.2.c Simplified Geologic Cross-Section B-B'

The following stratigraphic interpretations are made from the cross-sections:

- As described in the Pacific Hydrology and Piteau Associates (1993) report and confirmed in this report, the cross-sections suggest that there is a buried bedrock trough (either a glacially scoured trough, or a bedrock graben defined by a regional scale fault (see Section 3.5, Figure 3.5.a)) trending north-south through the Madeline (Max) Lake Valley. The eastern edge of the trough forms a buried bedrock ridge, which serves to direct the predominant flow of groundwater southwards.
- There are few available boreholes to characterize the interfingering contact between the outwash sands and gravels, and the Glaciolacustrine Silts. Along the western edge of the Glaciolacustrine Silt terrace, available boreholes suggest that the silts are sometimes interbedded with sands, and generally overlie the outwash sands and gravels.
- Gullies dissecting the Glaciolacustrine Silts intercept the sands and gravels. As reported by Klohn Leonoff (1992) and confirmed here, all gullies within the GWB Study Area terminate at the outwash contact, or at a bedrock outcrop. This suggests that these features slowed or stopped the headward progression of the gully and that groundwater flow from the gravels or along the bedrock contact may have influenced the formation of the gully.
- Approaching the east side of the study area towards Okanagan Lake, the Glaciolacustrine Silts are very thick (approaching 100 m) and the depth to bedrock is very deep (est. 100+ m).

3.2.3 Terrain Classification

Terrain classification was undertaken for the GWB Study Area and is presented in Appendix B, Map 2.0. The analysis (described in Section 2.3) essentially confirms the Klohn Leonoff (1992) geological map. Updated imagery since publication of the Klohn Leonoff (1992) geological map enabled this Geotechnical Review to refine and make minor adjustments in terrain boundaries. In addition, digital imagery and the use of GIS software allowed for more precise presentation and mapping of the results.

Interpretation of the terrain confirms that the lower slopes, representing just over half of the GWB Study Area (53%), consist of a silty glaciolacustrine terrace and associated steep silt bluff slopes. Traditional terrain mapping methods would have resulted in combining the terrace and bluff units however, it was decided that these units should be separated due to the different land management implications of these areas. A summary of the terrain classification is provided in Table 3.2.a below.

West of the glaciolacustrine terrace is a sand and gravel outwash fan with associated terrace deposits, derived from the post-glacial meltwaters flowing from the Trout Creek catchment to the north. For the purposes of the terrain mapping, ice-contact sand and gravel deposits are not distinguished from the outwash deposits; both are classified as glaciofluvial deposits. The glaciofluvial sandy gravel and more recently deposited fluvial deposits represent 41% of the GWB Study Area.

Small upland portions of the GWB Study Area are classified as moderate to moderately steep bedrock-controlled slopes, mantled with silty Till and/or silty-gravelly colluvium (4%). The remaining 2% is made up of the developed Highway 97 corridor.

Appendix B, Map 2.0 provides an updated terrain map illustrating the distribution of soils within the GWB Study Area and forms the basis for subsequent hazard interpretations and analysis.

Table 3.2.a Terrain Classification within Study Area

Terrain Unit	Description	Area (ha) (% of study area)
zLG	Silty Glaciolacustrine Sediments	274 ha (53%)
sgFG	Sandy Gravel Glaciofluvial Sediments	187 ha (36%)
sgF	Sandy Gravel Fluvial Sediments	24 ha (5%)
zsM	Silty Sand Morainal (Till) Sediments	21 ha (4%)
Highway	Developed Highway 97 corridor	13 ha (2%)
	Total	**520 ha**

3.2.4 Geohazard Events Since 1992

The sources of information for documented geohazard events or encounters with geotechnical issues since 1992 are from agency consultation, interviews, or public survey (as described in Section 2.4). Some events were also documented by local online news sources. The documented events (since 1992) have been attributed to geotechnical issues (associated with water leaks, sinkhole development, or landslides) or to safety issues (where people (or animals) had encountered and suffered injuries from the geotechnical hazard(s) such as a sinkhole).

Previous reports by Nyland and Miller (1977) and Iravani (1999) noted the occurrence of geohazard events within the GWB Study Area around the time of initial land development. These include documented historical occurrences of sinkhole development, gully erosion and soil settlement. Most events, observed to have resulted from domestic water leaks or irrigation, septic fields, or where roof and road drainage have been diverted onto the silt soils, caused minor property damage, but rarely injury or death. Some exceptions to this include:

- The death of three workers during construction of the Summerland to Penticton Lakeshore Road (Highway 97) in 1913 by a collapsing silt bluff slope (Vernon Morning Star, Jan 5, 2020); and
- The death of one person and destruction of three homes along Lakeshore Drive in Summerland (north of Study Area) in September 1970 by a silt block fall (reported in Nyland and Miller, 1977).

Sinkhole occurrences (since 1992) are not uncommon within the GWB Study Area, however, are relatively small in size and have little consequence in terms of damages and/or injuries. Development of a notable sinkhole occurred in the Sage Mesa area in 2014, along the water main distribution right-of-way (ROW). A subsequent geotechnical investigation did not identify the cause of the sinkhole but did provide comments for remediation (Tetra Tech EBA, 2014). Approximately two truckloads (20 m^3) of granular material was backfilled into the sinkhole.

Numerous silt block falls have impacted Highway 97 between Summerland and Penticton, resulting in debris covering the road, however no fatalities have been recorded. Table 3.2.b below provides a summary of the documented geohazard events within the study area since 1992.

Table 3.2.b Documented Geohazard Events within the Study Area since 1992

Date	Location	Description of Event (information source)
August 24, 2004	Sage Mesa	Deer rescued from sinkhole (www.castanet.net)
Not Specified	Sage Mesa	Uneven settlement of soils under a recently completed pool caused damage to pool and to road below the silt bluff (public survey)
Not Specified	Sage Mesa	Collapse of a carport foundation into a sinkhole
Not Specified	Sage Mesa	Major soil cavity formed under a house
Not Specified	Sage Mesa Road (during construction)	Large sinkhole formed during construction. When filling the hole, reported seeing material bubbling up just offshore in Okanagan Lake
Not Specified	At old hotel on Highway 97	Crawling up pipe starting at Highway and exiting at railroad tracks (unknown source)
April 10, 2014	Between 4655 and 4675 Sage Mesa Drive (Waypoint A)	Sinkhole formed along water main right of way and backfilled (Tetra Tech EBA, 2014)
October 2015	4200 Highway 97, Summerland, BC (outside of the study area)	Buried water pipe broke and resulted in creation of large erosion gully feature and sinkhole (Keystone Environmental, 2017)
April 12, 2018	West Bench Hill Road, Penticton, BC (Waypoint B)	Landslide on silt slope above road (GlobalNews.ca)
August 19, 2018	604 West Bench Hill Rd. (Waypoint C)	Damage to property due to broken irrigation line (investigated by Ecora).
Nov. 6, 2018	KVR Trail, West Bench (Waypoint D)	Penticton firefighters retrieve cyclists who fell into sinkhole on KVR Trail (www.pentictonwesternnews.ca)
Feb. 22, 2019	Highway 97, just south of Summerland, BC (outside GWB Study Area)	Landslide from silt bluffs onto Highway 97
May 15, 2019	KVR Trail, north of West Bench Hill Rd., West Bench (Waypoint E)	UTV driver hit a sinkhole and was injured when thrown down embankment (KelownaNow.ca)

Despite mapped landslide and sinkhole occurrences based on 2018 LiDAR data, orthophotos, and supplemented by fieldwork, the occurrences may have existed prior to 1992. The interpretation is impacted due to a lack of consistent landslide and sinkhole monitoring and incident reporting within the RDOS.

Based on data gathered from public media and anecdotal sources, the landslide and sinkhole inventory is summarized as follows:

- 12 landslides were identified along the Glaciolacustrine Silt bluffs and four landslides were identified on steep glaciofluvial side slopes of the Madeline (Max) Lake Valley, for a total of 16 landslides within the Study Area (see Appendix B, Map 3.0). Landslides were not identified in the Klohn Leonoff (1992) mapping. Only one of the slides, located at the junction of Sage Mesa Road and Highway 97, is characterized as an ancient large-scale rotational landslide.

- 97 sinkholes were identified within the GWB Study Area (several lie just outside the GWB Study Area boundaries but were counted regardless) (see Appendix B, Map 4.0). By comparison, Klohn Leonoff (1992) identified 301 sinkholes using air photos, field work and anecdotal information.

  The reason for the difference is somewhat unclear but it is possible that both the image resolution and image interpretation were factors. It is also quite likely that a significant number of sinkholes have been infilled with soil during land development or are obscured by soils and/or vegetation.

Similarly, to RDOS' landslide and sinkhole monitoring and incident reporting, the MoTI Road Maintenance Contractor(s) lacks consistent reporting of geotechnical or water management issues. Historically, the road maintenance Contractor for the MoTI Area 8 South Okanagan was Argo Road Maintenance Inc. (Argo), however in 2019, road maintenance activities were taken over by AIM. It is unclear whether Local Area Specifications (LAS) are in place and whether maintenance measures address the sensitive soil conditions. More information on road maintenance record-keeping and communication protocol with RDOS is required.

Correspondingly, RDOS reporting of geotechnical issues associated with water line leaks or breaks, or instances where residents have documented issues with groundwater seepage, instability or erosion is inconsistent.

3.3 Public Survey Results

In an effort to obtain information regarding historical landslides, sinkholes and other geotechnical issues, a public survey of area residents was conducted. The survey was distributed to RDOS Electoral Area "F" residents and posted on the RDOS website between February 14 and March 13, 2020.

A total of 41 responses were received from residents, with an average timeframe of occupation within the GWB Study Area (where indicated) of 17 years. Several respondents highlighted smaller-scale issues that would not have been observed by the historic air photo review or fieldwork assessment due to size and/or location (i.e., on private property). A detailed response table is provided in Appendix D. A summary of responses indicates that:

- Approximately one third (33%) of the 41 respondents reported experiencing issues with sinkholes;
- Approximately 15% of respondents reported issues with land subsidence, landslides, erosion, or other land disturbance; and,
- Few respondents (5%) reported issues with groundwater seepage.

3.4 Engineering Material Properties of the Glaciolacustrine Silts

The Glaciolacustrine Silts encountered in the Study Area, also commonly known as Penticton Silt (used interchangeably in the following section), can present significant geotechnical challenges, and have historically performed poorly when their unique behaviour has not been taken into consideration during site development.

The Klohn Leonoff (1992) report derived engineering material property information and data for the Glaciolacustrine Silts from Quigley (1976), and Nyland and Miller (1977). This Geotechnical Review derives additional engineering material property data from Iravani (1999) and Thurber (2007). The background reference studies include in-situ and laboratory testing of the silt at various moisture contents, including seismic cone penetration testing, classification, mineralogy and chemical testing, consolidation testing and triaxial testing. It should be noted that the engineering material properties in some studies include both undisturbed glaciolacustrine soils and colluvial soils, derived from the glaciolacustrine deposits.

The Glaciolacustrine Silts are generally described as varved (Jones, 1973; Shaw, 1975; Evans, 1982; Thurber, 2007), a few cm to ~1 m thick (Thurber, 2007), with small pockets of granular material and erratics. Soft sediment deformation structures have also been noted. Comparatively, Colluvial Silt has been characterised as being derived from Glaciolacustrine Silts (Iravani, 1999), homogeneous, and occur on slopes and infilling gully bottoms (Buchanan, 1977; Nyland and Miller, 1977; Wilson, 1985; Klohn Leonoff, 1992; Thurber 2007).

Contrary to other studies, the Iravani (1999) study indicated that soil suction, as a result of negative pore pressure in unsaturated soils above the groundwater table, is not a key factor in the behaviour of the Penticton Silt. Rather, the study implies that the Penticton Silt is structurally bonded by a number of chemical bonding agents (mainly silica acid gel), and the strength of the inter-particle bonding is highly sensitive to changes in water content.

The Engineering Material Properties of the Glaciolacustrine Silt and Colluvial Silt (where identified), which have been used for the current assessment, are discussed in the following sections. Table 3.4.a is a summary table showing those properties, which have been used for the current assessment. Significant differences are noted between properties identified by Klohn Leonoff (1992) and those identified for this assessment using more recent studies. Further detailed descriptions of the Engineering Material Properties of the Glaciolacustrine Silts is provided in Appendix F.

Table 3.4.a Summary of Engineering Material Properties of the Glaciolacustrine Silts, as summarized by Iravani (1999) and Thurber (2007)

Material Property Type	Parameter Values	Comments
Grain Size Analysis	Sand: 0% - 5% Silt: 70% - 100% Clay: <1% - <20% Natural Moisture Content: 9% - 30%	Generally, no major difference identified between glaciolacustrine and colluvial stilts by the author. Sand: up to 20% reported in one study Silt: dominant material Clay: up to 91% reported in one study Natural Moisture Content: 9% - 30% Limited Natural Moisture Content data available
Atterberg Limits	Liquid Limit: 21% - 40% Plastic Limit: 20% - 33% Plasticity Index: 1% - 14% In-situ Water Content: 1% - 43%	Liquid Limit: between 50% and 68% reported in three studies Plastic Limit: as low as 13% reported in one study Plasticity Index: up to 43% reported four studies Only one study provided properties for Colluvial silt, which appear similar to the other studies
Shear Strength	Drained: 30 kPa – 35 kPa (peak) 10 kPa (residual)	MoTI reported lower drained shear strengths in their study
Friction Angle	30°–35°	Generally, for silt with moisture content at/near, or significantly below the Plastic Limit Soils with higher cohesion (peak strength) reported lower friction angles in one study
Consolidation	Volumetric strain decrease in Glaciolacustrine Silts: 2% - 11% Volumetric strain decrease in Colluvial Silts: 25% - 31%	
Specific Gravity	2.6 - 2.88	
Density	1152 kg/m^3 – 1734 kg/m^3 (dry density)	
In-situ Void Ratio	0.68 - 1.56	

Material Property Type	Parameter Values	Comments
Fabric and Scanning Electron Microscopy (SEM)	Horizontally oriented platy particles Anisotropic fabric Micaceous	

3.4.1 Grain Size Analysis

Grain size analysis (GSA) indicates the glaciolacustrine soils typically comprise 0% to 5% sand (but can be up to 10%), 70%+ silts (generally 80%-90%), and the remaining percentage is clay (generally 8% to 18% based on Iravani,1999, and Thurber, 2007).

Evans and Buchanan (1976) and Wilson (1985) noted there was no major difference in grain size between the glaciolacustrine soils and the colluvial silt. However, there is very little data on colluvial silt to confirm this. Natural moisture contents in the glaciolacustrine soils generally range between 10% to 30%. No natural moisture contents were reported for testing carried out on the colluvial silt.

Ecora has carried out limited soils testing on the Glaciolacustrine Silts for a number of projects in the area. Results of the GSA and natural moisture content tests concur with the previous studies, with fines contents of 94% to 100% and moisture contents in the range of 9% to 20% (average of 16%).

3.4.2 Natural Moisture Content & Atterberg Limits

Iravani (1999) indicated that the in-situ water content of the Penticton Silt is typically around 15-25% depending on seasonal changes and depth, and that water content increases rapidly with distance from the exposed bluff faces. Iravani (1999) also indicated that the water content at saturation is 43%, which is higher than the liquid limit (LL) of the silt.

Previous Atterberg Limits testing in the glaciolacustrine soils indicated the material primarily consisted of low plastic silt (ML) and low plastic silt and clay (ML-CL). Laboratory test results indicated the soils ranged between 21%-40% for LL, 13%-33% for plastic limits (PL), and 1%-<20% plasticity indices (PI).

Based on the summary reports by Iravani (1999) and Thurber (2007) LL, PL, and PI generally ranged between 35%–40%, 25%–33%, and 0%-10% respectively. There is limited data on the plasticity of the colluvial soils. Undisturbed samples tested by Iravani (1999) from the Okanagan Lake Park Slide and Koosi Creek slide were noted to have shown swelling up to 45% volume, with slurry samples showing signs of shrinkage and volume decrease upon exposure to drying.

Results of Ecora's Atterberg Limits testing in the Glaciolacustrine Silts indicates the LL, PL, and PI were generally within the ranges tested by others.

3.4.3 Shear Strength

Iravani (1999) stated that the Penticton Silt are strongly structured, with undrained stress paths controlled by soil structure, which in turn are moisture sensitive. Some signs of stress paths caused by pore pressure was noted by Iravani (1999), however the pore pressure generated in test results did not have a significant influence on the undrained response of structured Penticton Silt. Soil structure is a controlling factor of undrained stress paths rather than generation of pore pressures. Increase in structural bonding within the soil increases as the soil water content decreases. Under confined conditions, the behaviour of the Penticton Silt is attributed to the soil structure (cohesion rather than friction).

Unconfined compression tests performed by Lum (1977) indicated the average compressive strength was 180 kPa for uniaxial loading parallel to bedding, and 201 kPa for uniaxial loading perpendicular to bedding. The consolidated triaxial tests indicated samples with higher effective confining stresses (>100 kPa) presented an average shear strength between 130 kPa to 204 kPa and did not strain soften. Samples with lower effective confining stresses (<100 kPa) averaged 60 kPa and were found to show strain softening. The average water contents of the samples were 7%.

Triaxial testing by Lum (1977) and Iravani (1999) indicated shear strength increased with a decrease in water content. Low effective confining stresses were found by Lum (1977) to have cohesion of 60 kPa with a drained friction angle of 17.8°. Wilson (1985) carried out direct shear tests on unsaturated reconstituted specimens, resulting in a friction angle of 38° and 2° cohesion. Testing by Sobkowicz and Coulter (1992) found a 5% increase in friction angle on specimens with water contents significantly lower than the PL, compared to specimens with water contents at/near the PL. The cohesion intercept was the same (30 kPa) for both sample types.

3.4.4 Internal Angle of Friction

Based on the summary reports from Iravani (1999) and Thurber (2007), the internal angle of friction of the Penticton Silt range between 30° and 35°, with an approximate average of 32°. Klohn Leonoff (1992) summary report indicated friction angles of 17° to 35° in the clay fraction. The studies did not distinguish between glaciolacustrine and colluvial silt.

3.4.5 Consolidation

Limited 1-D consolidation testing in the glaciolacustrine soils indicated a general volumetric strain decrease between 2% and 4%. Results by Nyland and Miller (1977) showed a range of between 3% and 11%, however they noted “the magnitude of collapse increases as vertical effective stress corresponding to the flooding stage increases”.

Lum (1977) noted remolded dry specimens were more compressible than dry undisturbed specimens, and “glaciolacustrine soils are sensitive to water content and exposure to moisture, especially at small values of water content”. MoTI results of 1-D consolidation testing reported by Thurber (2007) indicate a volumetric strain decrease of between 25% and 31% in the colluvial soils.

3.4.6 Specific Gravity, Density, and In-Situ Void Ratio

Laboratory testing of specific gravity, density, and in-situ void ratio is poorly documented in Penticton Silt and studies do not distinguish between glaciolacustrine and colluvial silt. Based on the available data, specific gravity is reported to range between 2.6 to 2.88; maximum dry density is between 1152 kg/m^3 to 1734 kg/m^3; and in-situ void ratio ranges between 0.68 and 1.56.

3.4.7 Fabric and Scanning Electron Microscopy (SEM)

Previous studies on the fabric of the Glaciolacustrine Silts generally found the material to be horizontally oriented with anisotropic fabric. Iravani (1999) noted that one cycle of environmental loading resulted in changes in soil fabric and generation of meta-stable voids. His analysis using damping resulted in the formation of micro-cracks and showed evidence of de-structuring on a grain-to-grain level.

3.5 Bedrock Geology

The GWB Study Area is located on the east-facing slopes on the west side of the Okanagan Valley, with a regional north-south trending trench corresponding to the Okanagan Fault. The GWB Study Area is underlain by intrusive igneous rocks of the Bromley Batholith, while at depth a fault boundary with the much older Okanagan

Gneiss is assumed, with minor transverse faults intersecting the south side of Mount Nkwala (Okulitch, 2013) (Figure 3.5.a).

Intrusive igneous rocks are formed under the earth surface by the cooling of magma and are composed of mostly durable minerals in the form of large interlocking crystals and wide-spaced joint planes. Bedrock underlying the GWB Study Area is characterized as medium to coarse-grained granodiorite, quartz diorite and granite.

Normally, these rocks are quite stable and can support steep slopes. However, the presence of feldspar minerals, as indicated by a pinkish rock colour, indicates a less resistant rock type that is subject to granular disintegration due to chemical and mechanical weathering.

Within the GWB Study Area, bedrock is only exposed on the steep upper elevation slopes, such as the side slopes of Mount Nkwala, with minor outcrops at the incised gully headwalls. Available borehole records in the West Bench and Sage Mesa areas indicate that bedrock is quite deep (greater than 80-100 m deep), except for a buried bedrock ridge situated mid-slope, where bedrock is approximately 20 m deep. The orientation of the buried bedrock ridge and the adjacent Madeline (Max) Lake Valley generally coincides with the minor transverse fault, west of Mount Nkwala.

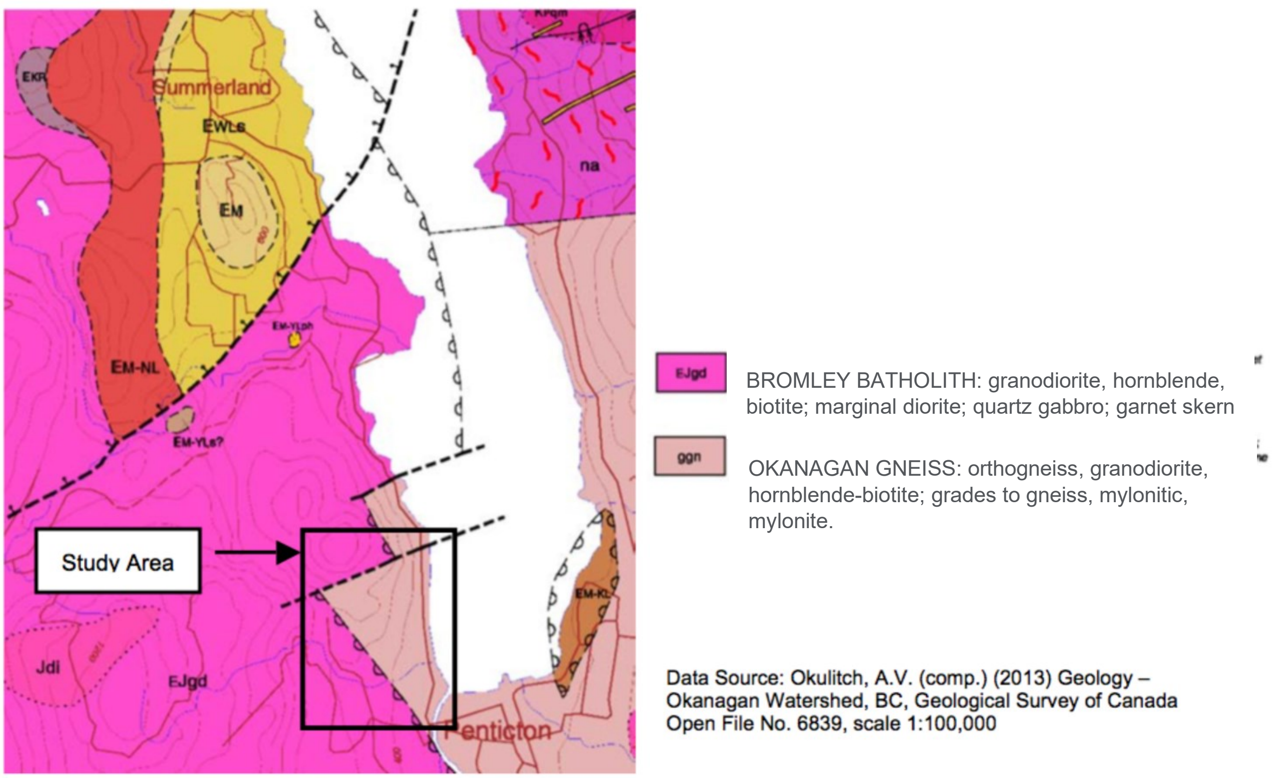


Figure 3.5.a Bedrock Geology within the Study Area (from Okulitch, 2013)

3.6 Seismicity

The GSC has developed a probabilistic (5th Generation) seismic hazard model (Halchuk et. al, 2015) that forms the basis of the seismic design provisions of the 2015 National Building Code of Canada (NBCC, 2015).

Peak Ground Accelerations[3] (PGA) and Spectral Accelerations (Sa(T)) for a reference "Class C" (very dense soil and soft rock) can be obtained from the Earthquakes Canada website (http://earthquakescanada.nrcan.gc.ca) for various return periods. The values for the GWB Study Area are summarized in Table 3.6.a below.

Table 3.6.a Reference (Class C) Design Peak Ground Acceleration (PGA) and Spectral Accelerations (Sa(T)) for the Greater West Bench Study Area

Return Period	PGA (g)	Sa(0.2) (g)	Sa(0.5) (g)	Sa(1.0) (g)	Sa(2.0) (g)
475 years	0.031	0.069	0.068	0.049	0.031
1,000 years	0.047	0.102	0.095	0.070	0.045
2,475 years	0.074	0.160	0.139	0.102	0.071

3.7 Hydrogeology and Groundwater Regime

Background information on the hydrogeology and groundwater regime within the GWB Study Area is provided in the Pacific Hydrology and Piteau Associates (1993) report. The report, which was commissioned for Inland Contracting Ltd. (Inland), evaluated groundwater conditions in the vicinity of a proposed residential development at the south end of Madeline (Max) Lake Valley, located on the west side of the study area.

Pacific Hydrology and Piteau Associates (1993) carried out an investigation which included drilling five cased boreholes, completed as screened pumping wells or water level monitoring piezometer sites. Well logs, pump testing, and a field reconnaissance program provided the information required to characterize groundwater conditions and to determine possible negative impacts from the proposed development. This study by Pacific Hydrology and Piteau Associates (1993) remains the only comprehensive groundwater investigation completed for the GWB Study Area. No new groundwater wells have been completed since.

The Pacific Hydrology and Piteau Associates (1993) report concluded that the depth and morphology of the bedrock surface under the glacial outwash sands and gravels west of the West Bench imparts a strong influence on the groundwater hydrology of the area. A buried bedrock trough is purported to extend southward from the mouth of Madeline (Max) Lake Valley and turns southeast at Bartlett Drive. A buried bedrock ridge extending south from Mount Nkwala separates this bedrock trough from the thick silts underlying the West Bench. The buried bedrock ridge inhibits direct easterly flow from the bedrock valley into the silts. Consequently, groundwater flows in a south-southeasterly direction through the glacial outwash sediments, until the southern extent of the bedrock ridge is reached. The groundwater flow direction then turns eastward, toward Penticton, through southern portions of the West Bench. This suggests that the groundwater regime differs between the north (i.e., Sage Mesa) and south (i.e., West Bench).

Once the groundwater turns toward Okanagan Lake and encounters the thick (over 100 m) saturated silt and sandy silt horizons, the regional groundwater gradient and velocity are both very low and are deemed incapable of causing structural changes (internal subsurface erosion) to the soil deposits under natural loading conditions.

From a regional perspective, the groundwater regime is important where more permeable stratigraphic units encounter a less permeable unit. For example, while groundwater flow through the Madeline (Max) Lake buried valley can permeate the Glaciolacustrine Silts underlying the West Bench area, groundwater flow on the eastern side of the buried rock ridge encounters the Glaciolacustrine Silts at a shallower depth. Gully headwalls in the GWB Study Area terminate at the bedrock interface, or the interface with the sand and gravel unit, suggesting that groundwater contributes to the development of the erosional landform.

In the Sage Mesa area, at the north end of the GWB Study Area, the groundwater regime within the Glaciolacustrine Silts may also be affected by changing water levels on Okanagan Lake. At low lake levels, the

[3] Peak ground acceleration (PGA) is equal to the maximum ground acceleration that occurs during earthquake shaking at a location. PGA is equal to the amplitude of the largest absolute acceleration recorded on an accelerogram at a site during a particular earthquake.

hydraulic gradient through the silts would be higher, increasing the potential for piping and internal erosion through the silts (see Section 5.3). Conversely, during high water levels, the hydraulic gradient may be lower. However, the internal soil strength may be reduced due to increased pore pressures at a higher water table. This may affect the potential for future larger-scale landslides and is a factor to be considered in further investigations.

3.8 Surface Water Hydrology

The most significant surface water feature in the GWB Study Area is Madeline (Max) Lake, which is a shallow pond located in the valley on the west side. The Madeline (Max) Lake is a wetland identified as part of the Okanagan Wetlands Strategy (http://okanaganwetlands.ca/). The pond is mostly full of cattails, with only a small amount of open water remaining. The outlet of the lake drains into the Peter Bros. Gravel Pit area and there is no visible outflow. It is judged that all flows downstream of Madeline (Max) Lake are subsurface.

Madeline (Max) Lake and its associated riparian habitat is one of the last remaining wetland habitats in the Penticton Area and is home to a number of rare and endangered species (http://okanaganwetlands.ca/wetlands/max-lake/). The Madeline (Max) Lake Conservation Covenant is The Land Conservancy's first covenant in the Okanagan-Similkameen area (http://conservancy.bc.ca/max-lake/). This covenant, which protects 5.72 hectares of wetland habitat around the lake, is co-held with the RDOS and is the first of its kind for the Regional District.

There are no gazetted streams within the GWB Study Area. The "blue line work" shown on the enclosed maps represents water courses and is sourced from the BC Freshwater Atlas. Line work for the Freshwater Atlas is derived from provincial 1:20,000 scale Terrain Resource Information Management (TRIM) maps that are interpreted from topographic information and aerial image interpretation. Therefore, the blue lines on the map do not necessarily reflect the true hydrologic nature of the water course, such as whether the stream flows on the surface or sub-surface. Based on experience in the South Okanagan, it is not uncommon for mapped streams to flow subsurface.

On the slopes above the Glaciolacustrine Silt terraces, surface water catchment areas were defined by topography and delineated for further characterization. These upslope catchments would typically have seasonal flow, during spring snow melt, and storm flows during and after rainstorm events. The largest catchment in the GWB Study Area is associated with the area draining into Madeline (Max) Lake (28 km^2). Other identified catchments are associated with the headwater reaches on the bedrock-controlled slopes on the south side of Mount Nkwala above the larger gully systems on Sage Mesa / West Bench, or are headwater reaches on slopes above the gravel terraces above West Bench.

In summary, the surface water hydrology of the GWB Study Area is characterized by:

- A lack of perennially flowing streams within the study area;
- Predominantly seasonal surface water flow from relatively small bedrock-controlled catchments above the study area;
- Rapid infiltration of surface water to the ground, reflected in the relative lack of incised stream channels; and
- Localized scour along road ditches and through culverts that reflects periodic flow attributed to rainstorm events.

3.9 Climate

Geotechnical processes in the GWB Study Area are driven by various climate parameters, such as temperature and precipitation. The GWB Study Area has a semi-arid mid-latitude climate, characterized by hot dry summers and cool dry winters. Very low precipitation in the summer and winter creates a more stable geotechnical condition

The closest climate station with long-term records to the GWB Study Area is located at the Penticton Airport, approximately 4.5 km to the south (Environment Canada Stn. 1126150). Previously completed geotechnical hazard studies reviewed climate data for the periods 1964-1973 (Nyland and Miller, 1977), 1945-1985 (Klohn-Leonoff, 1992) and 1941-1990 (Iravani, 1999). For the current study, the most recent “Climate Normals”, for the period 1981-2010, are reviewed and summarized in Figure 3.9.a.

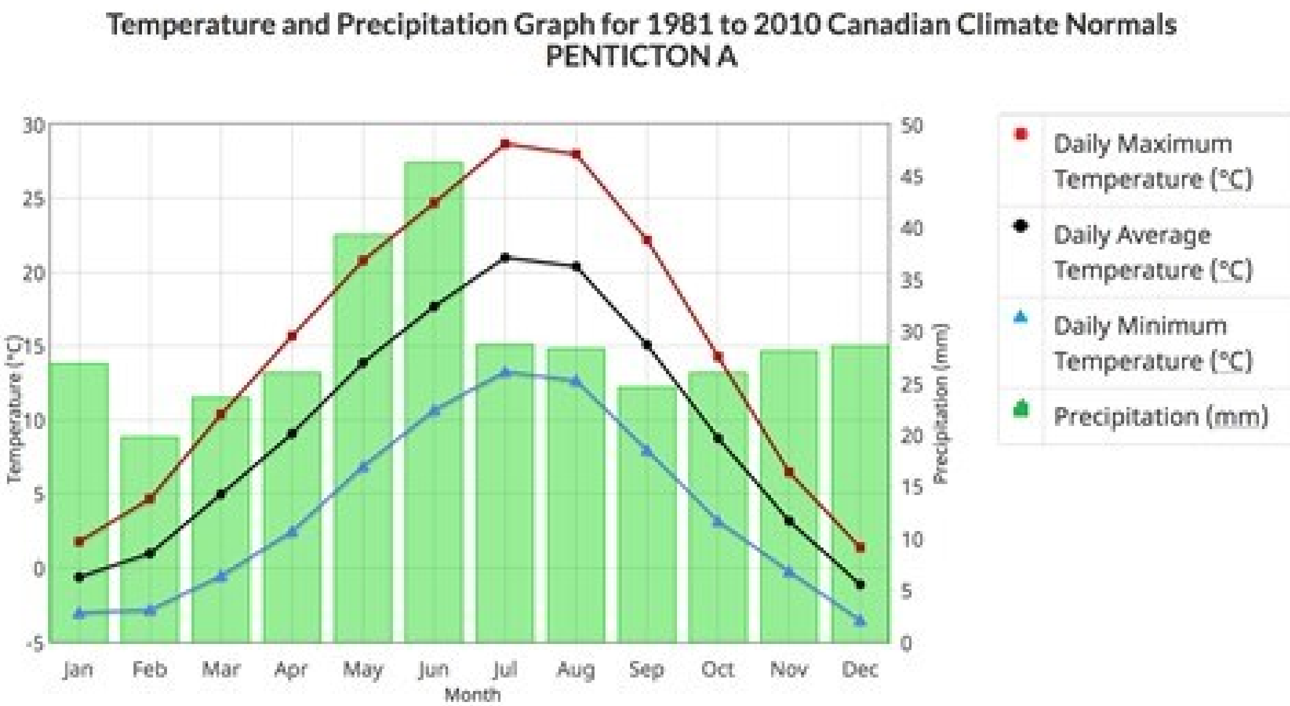


Figure 3.9.a 1981 to 2010 Climate Normals for Penticton A (Env Can Station 1126150)

For the period 1981-2010, the GWB Study Area had a mean monthly temperature of 9.5^{o}C and a mean annual precipitation of 346 mm, of which 58.7 mm fell as snow. On average, the greatest amount of precipitation fell during the month of June (46.3 mm). Extreme daily rainfall events tended to occur in the summer months, with the highest daily rainfall event was recorded on Aug. 9, 2008 (45.6mm).

Climate trends recorded at Penticton Airport (Table 3.9.a) indicate that mean annual precipitation is increasing (22% increase in 25 years), while the proportion of precipitation falling as snow is decreasing (29% decrease in 25 years). Further commentary on future changes in climate, and potential effects on geotechnical stability, are provided in Section 6.10.

Table 3.9.a Climate Trends at Penticton Airport (Stn. 1126150)

	Mean annual precipitation	Mean annual snowfall
Period 1945-1985 (Hogg and Carr, 1985)	282.9 mm	76.0 mm
Climate Normals 1961-1990	308.5 mm	73.0 mm
Climate Normals 1971-2000	332.7 mm	67.2 mm
Climate Normals 1981-2010	346.0 mm	58.7 mm

3.9.1 Regional Water Balance Character

Previous reports that calculate the regional water balance indicate that, due to evapotranspiration during the spring and summer months, there is a net water deficit in the GWB Study Area (Nyland and Miller, 1977). Nyland and Miller (1977) calculate a pre-development moisture deficit of 365.8 mm and concluded that proper irrigation practices (i.e., use of sprinklers), would balance evapotranspiration, and would not cause any rise of groundwater table. Klohn Leonoff (1992) calculated an annual moisture deficit of 194 mm. Further differences in the local water balance may occur due to changing precipitation and land use practices.

Changes in mean annual precipitation and future changes in climate may affect the regional water balance. Projected increases in mean annual precipitation may alter the overall regional water balance. At a local site level, increases in mean annual precipitation and increased frequency of high intensity rain events, will increase reliance on a robust stormwater management system. Groundwater levels may increase, which could increase the frequency of landslide events and accelerate the development of sinkholes.

Further investigation is required to determine whether larger-scale impacts on the regional groundwater table are being affected by changes in climate. Investigation work should include monitoring groundwater levels in existing wells and expanding work to include the development of new monitoring wells.

4. Land Development in the Study Area

4.1 General

The following section provides background information on historical land development and community infrastructure and site servicing.

4.2 Land Development History

The GWB Study Area is comprised of residential neighbourhoods, consisting primarily of single detached homes on medium and small-sized lots. Lots in the West Bench - Sage Mesa neighbourhoods were originally developed as part of the *Veteran's Land Act* after World War II (RDOS Electoral Area "F", OCP, 2018). In the early 1950s, original lots up to 2 Acres in size, were intended for small scale agricultural production (e.g., orchards and gardens). In the 1960s and 1970s the area was partially subdivided and infilled with residential development. On a sloping upland area to the west of the West Bench area, the Husula Highlands subdivision was developed in the 1970s and 1980s. An elementary school is situated on West Bench Road. Within the GWB Study Area, there are two private golf courses, and a commercial gravel quarry operating south of Madeline (Max) Lake on the west side.

Land development that has occurred since the completion of the Klohn Leonoff (1992) report include:

- Subdivision and development of Westwood Properties, and further infill within the Husula Highlands subdivision, comprised of approximately 108 single-family residential lots;
- Subdivision and development of the Red Wing Properties, located on PIB reserve land east of the study area;
- Scattered infrequent infill and single-lot subdivision within the West Bench and Sage Mesa areas; and,
- Development improvements at two private golf courses in the Sage Mesa area, including adding a large, paved parking lot at the WOW Golf Course.

Associated with new development within the GWB Study Area, is approximately 1.4 km of new (paved) road plus driveways and associated paved surfaces.

4.3 Community Infrastructure and Servicing

Previous research has indicated that water introduced from non-natural sources is a contributing factor to landslides, the development of sinkholes, and other soil instability (Nyland and Miller, 1977; Klohn Leonoff, 1992). Therefore, infrastructure and servicing components such as domestic/irrigation water, wastewater (sewerage systems), and stormwater are considered relevant to this Geotechnical Review. A community infrastructure overview was completed by Associated Environmental (2017) during updates to the RDOS Electoral Area "F" OCP (2017).

Water distribution and management requires water lines, which may potentially leak or break. Sewerage systems, comprised of individual septic drain fields, are not connected to a community system, and introduce water to the ground. Where there is no formal stormwater management plan, unmanaged stormwater runoff from hard surfaces such as pavement, concrete, and roofs, may contribute to instability. The following sections summarize the existing community infrastructure and servicing within the GWB Study Area.

4.3.1 Domestic/Irrigation Water Supply

Currently there are two separate water providers: 1) RDOS West Bench Water System (formerly West Bench Irrigation District (WBID)) and 2) the Sage Mesa Water & Public Service Co. Ltd.

RDOS West Bench Water System

The WBID water system was built in the early 1950s to supply water for a Veterans Land Act development. The original lots consisted of larger acreages that in the early days were planted into fruit trees such as cherry, apple, peach, pear and plum. As time went on, some of those lots were subdivided until soil studies identified trends for sinkhole activity in certain areas. In the early days, water was pumped from the river channel and later the intake was extended into Okanagan Lake in an effort to improve water quality. As drinking water requirements increased over the years, and the old steel pipe began to deteriorate, the Irrigation District began a water system infrastructure replacement project and started investigating options to move the system to the RDOS or the City of Penticton (CoP) where they would be eligible for professional management and grant funding. As of 2010, over 60% of the water mains in the system had been upgraded.

In 2011, the WBID's Letters Patent were dissolved through a Provincial "Order in Council", that moved ownership of the water system and its assets to RDOS. As part of that move the Provincial and Federal Governments provided grant funding to finish rebuilding the water system, add water meters, a booster station, back-up power, and supported an "extra territorial" Bulk Water Servicing Agreement between the CoP and RDOS.

The Bulk Water Servicing Agreement provided access to fully treated, filtered water from the CoP's water treatment plant that enabled the West Bench residents to finally meet the Interior Health (IH) Authority's Permit to Operate conditions. Once the work was completed, the long-lasting Boil Water Notice was rescinded.

In 2013, water in the West Bench area was reported to be distributed to the following sectors (WSP, 2016):

- Rural residential (0.5-0.75 acres): 80%;
- Other rural residential: 14%;
- Agricultural: 5%; and,
- Institutional: 1%

The RDOS have a National Award-Winning leak detection system operating on the West Bench water system. Water meters are installed for 351 residential connections and 18 agricultural connections on the West Bench system and monthly readings have been obtained since 2015. Water meters measure the volume of water used at a property and are a valuable tool in assisting the RDOS with water conservation efforts and improving water infrastructure life span.

Using Neptune R900i water meters, RDOS can identify water leaks within the property and relays that information to the homeowner for repair. The metering system alerted RDOS that 66 of the 351 meters had continuous leaks of 35+ days and another 35 meters detected intermittent leaks, totalling over 500 litres per hour (Z. Kirk, personal communication, 2020).

In one example, provided by RDOS, the leak detection system alerted a homeowner situated in a high hazard zone of a 30 litre/hour leak that was not visible. Leaks are documented and reported in a systematic manner, ensuring that the issue is eventually addressed. Overall, the program is an incredibly important tool in the management of potentially unstable ground in an area soils sensitive to introduced water.

Sage Mesa Water & Public Service Co. Ltd. System

Sage Mesa Water & Public Service Co. Ltd. was built as a private system and was regulated under a Certificate of Public Convenience and Necessity (CPCN) to supply water to a development in the "lower zone" of the current water system in the 1970s. In the early 1990s the Province seized the operation for various reasons and the system has been managed through the provincial water controllers ever since. An expansion to the supply water to new subdivisions (referred to as the “upper zone”) that included Westwood Estates and Husula Highlands also happened in the early 1990s.

In 2010, the Province contracted the RDOS to operate the system and this agreement is still in place.

The system, which includes two golf courses is partially metered and is on a permanent Boil Water Notice in the lower zone and seasonal Water Quality Advisory (WQA) for turbidity in the upper zone. Their current water source is Okanagan Lake.

The Bulk Water Agreement between the RDOS and the CoP included future provisions to supply the Sage Mesa water system if a decision is made to go in that direction.

4.3.2 Wastewater System

To this day, there is no community sanitary sewer or wastewater collection system servicing the GWB Study Area. All residential dwellings have individual septic tanks and tile field wastewater treatment systems.

A Wastewater Management Plan (WWMP), developed for RDOS Electoral Area “F” in 1994, identified the West Bench / Sage Mesa area as a priority for alternate wastewater management options due to geological concerns (Stanley Associates, 1994). The alternatives were identified as:

1. A regional sewerage collection system for the GWB area to connect to the CoP wastewater system;
2. A localized facility in the West Bench to collect and treat wastewater, discharging treated effluent to the Okanagan River; or
3. Maintain existing treatment and restrict future development due to geological concerns.

At the time of completion, Option 3 (maintain existing (individual, on-site) wastewater treatment systems) at the property level was chosen. The WWMP was completed in 1994, therefore the OCP update recommended a review to ensure that the WWMP was still valid and that an updated geotechnical hazard assessment was taken into consideration (Associated Environmental, 2017).

A feasibility assessment and preliminary costing for a wastewater collection system was completed in 2005 (by Stantec) to examine the feasibility of a primarily gravity system that connects to the CoP for wastewater treatment and disposal.

4.3.3 Stormwater Management System

Stormwater management within the GWB Study Area is inconsistent and not well documented.

Stormwater runoff along public roads is inconsistent and non-integrated. Roads are maintained at a rural level under contract on behalf of the MoTI. Public roads in the GWB Study Area generally lack curb, gutter, and storm drains. However, there are areas within the Sage Bench and West Bench area that do have storm drains, and it appears that runoff is directed by pipe into nearby gully systems. Little stormwater management information was provided by MoTI or the roads Contractor.

Stormwater drainage for new single family dwelling development requires professional engineering sign off as per current BP requirements. Stormwater runoff at the property site level is unmanaged and largely unknown. It is assumed that roof and driveway runoff is generally managed within the individual properties and is directed to ground, or possibly into rock pits situated on the property, which is the Provincial standard practice for rural storm drainage systems.

There is no provision in the BCBC (2018) to account for sensitive soil conditions, or downslope slope instability. Due to the sensitive nature of soils in the West Bench area with respect to the disposal of water, particular care shall be taken to ensure that any stormwater disposal does not negatively impact downslope adjacent properties.

Generally, the Glaciolacustrine Silts are not considered suitable for on-site disposal (dry wells) and require alternative measures such as the use of rigid stormwater lines to convey stormwater to a sewer, drainage ditch or a natural water course. As an example, properties with no direct access to an existing sewer, open drainage ditch, or natural watercourse may need to negotiate easements to accommodate conveyance of their stormwater to a suitable stormwater disposal system.

During the field review, several instances of soil erosion (i.e., piping) were observed and considered to be associated with storm drainage. Figure 4.3.a shows photographs of several examples of sinkhole development and erosion.

 **Sinkhole development near catch basin below Sage Mesa Dr.**	 **Erosion at culvert inlet at Sage Mesa Dr., near WOW Golf Course**
 **Sinkhole next to catch basin below Sage Mesa Dr.**	 **Sinkhole development below culvert below Crescent Dr**

Figure 4.3.a Photographs of Example Sinkholes and Erosion Features Associated with Stormwater Management in the GWB Study Area

There is a clear connection between concentrated stormwater runoff and soil stability issues. As a result, further investigation of existing erosion issues is required, and development of an integrated Stormwater Management Plan (SWMP) for the area is recommended.

A hydrogeological and geotechnical assessment completed for the City of Kelowna (CoK), determined the suitability of in-ground stormwater disposal for different soil types, slope, and depth to groundwater conditions (EBA Engineering Consultants Ltd., 1997). The investigation concluded that dry wells do not perform well in glaciolacustrine soils due to their low hydraulic conductivity, and that plugging of the drain rock surrounding the dry well by fine sediment transported in the stormwater limits the lifespan of the dry well. Mapping of in-ground stormwater disposal suitability was completed and, for areas mapped as poorly suited, the use of hard-piped systems was recommended. A similar study, completed as part of an integrated SWMP, may prove to be useful for RDOS and MoTI.

It is recommended that stormwater lines installed in the sensitive glaciolacustrine soils within the GWB Study Area are directionally drilled, inclined no steeper than 2H:1V, and with minimal vegetation disturbance. Installed stormwater lines should consist of a single continuous length with no joints and should have a secondary sleeve, in case of leakage, along its entire length to be connected directly to an existing stormwater disposal system.

4.3.4 Foundation Drainage – BC Building Code

Foundation drainage for houses and small buildings is dictated by the BC Building Code (BCBC 2018). Section 9.14.2 of the BCBC (2018) specifies that, unless it can be shown to be unnecessary, the bottom of every exterior foundation wall shall be drained by drainage tile or pipe laid around the exterior of the foundation by a layer of gravel or crushed rock. The BCBC (2018) indicates that exterior drains are to drain to a sewer, drainage ditch or dry well.

5. Geomorphological Processes

5.1 General

The following section discusses the character and trigger mechanisms of the identified geomorphological processes in the GWB Study Area. For each process identified, we describe the nature of the process (types of processes occurring), the mechanisms of failure and the factors affecting the process.

Later in this report, the interrelation between the geomorphological process and the surrounding environment is considered for the geohazard and risk assessment (Section 6). To clarify, a “geohazard” is a geomorphological process with the potential to cause harm, while events with no harmful potential are simply natural geomorphological processes, or features.

Key geomorphological processes/geotechnical processes observed in the GWB Study Area are shown in Figure 5.1.a and include the following:

- Shallow planar landslides;
- Deep-seated rotational landslides;
- Silt block falls or ravelling;
- Piping and sinkhole development; and
- Collapse/compression.

Other processes, such as rockfall and debris flow/debris flood, were considered. However, the potential for these two processes to occur within the GWB Study Area is considered to be low. The potential for rockfall is only present on steep bedrock-controlled slopes above the north end of the Sage Mesa area. Potential for debris flow/debris flood is considered for some of the small steep catchment areas above the Madeline (Max) Lake Valley. Both areas are considered to be outside the areas of potential future development, so these processes are not discussed further.

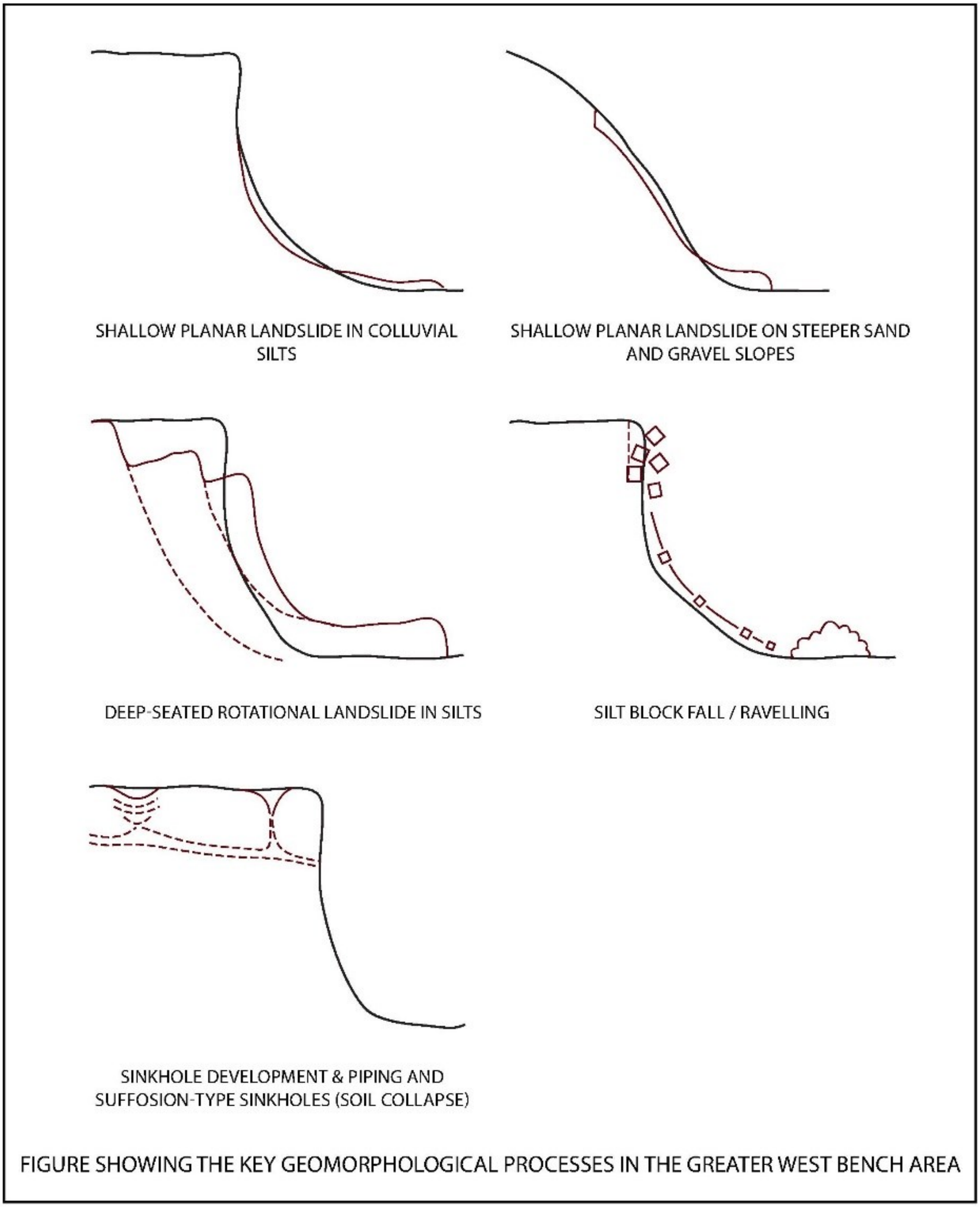


Figure 5.1.a Key Geomorphological Processes in the Greater West Bench Study Area

5.2 Landslides

5.2.1 Shallow Planar Landslides

Shallow planar landslides typically occur on colluvial slopes located at the base of a silt bluff, or on steep glaciofluvial and till slopes. Landslide depth is limited to the upper layer of weathered material and slides roughly parallel (planar) to the original ground surface. Depth may be limited by bedrock in some areas. A recent example of this type of landslide occurring in the silt soils occurred on West Bench Hill Drive in 2018. Other examples of landslides on steep unconsolidated sands and gravel slopes are visible on steep (>50%) slopes at the upper end of the Madeline (Max) Lake Valley.

Shallow planar sides can be triggered by the same failure mechanisms for deep-seated rotational landslides as discussed in Section 5.2.2 below, however, generally occur because of an increase in water content. In silt soils, subsequent swelling of the soil particle surface also contributes to the failure mechanism. The key swelling mechanism according to Iravani (1999) is the expansion of the silica acid gel inter-particle bonding under low confining pressures which causes the loss of integrity of the soil structure. Upon exposure to excess water and swelling, breakage of water sensitive bonds, elimination of soil suction and a change in fabric occurs, causing the silt to strain soften and flow.

5.2.2 Deep-Seated Rotational Landslides

Deep-seated (rotational) landslides are complex events and represent the greatest hazard due to size and extent of runout zone of debris, and often sudden occurrence. These types of slides are relatively uncommon in the GWB Study Area. However, there have been a number documented in the silt soils, including those reported in studies by Nasmith (1962), Nyland & Miller (1977), Lum (1977), and Klohn Leonoff (1992).

The following potential deep-seated landslide triggering mechanisms have been identified:

- **Loss of toe support (undercutting)** – prior to construction of Highway 97 along the toe of the silt bluffs there may have been some loss of material from the toe of the silt bluff slopes, leading to landslide activity. Currently, the toe of the slope along Highway 97 is buttressed by colluvial material, constructed protection berms, and Highway 97 itself. Continued ravelling and shallow landslides along the slope gradually result in a more stable slope condition.
- **Introduction of water** – due to precipitation, snowmelt, groundwater flow from the gravels west of the silt bluffs migrating into the gullies and silts and/or natural groundwater flow in the bedrock underlying the silt, or artificially through septic fields, storm water, leaking irrigation, water lines, or swimming pools. In addition, concentration of surface runoff from impervious surfaces such as roadways, driveways, roof drains, or compacted fill surfaces may increase the amount of water being introduced to a sensitive area. Introduction of water is believed to have been the trigger mechanism for most of the documented slides in the silt bluffs (Nyland and Miller, 1977). Additionally, most documented slides in the silt bluffs were triggered by open ditch irrigation (Klohn Leonoff, 1992).

  Development increases the amount of water being introduced to the ground and increased infiltration can raise the groundwater level, such that smaller events such as rainstorms have the potential to trigger slides. Klohn Leonoff (1992) indicate that water introduced to, and infiltrating, the silt will raise the water table more than water added to the gravel layers on the west side of the study area.

  Compared to pre-development conditions, there has been an overall increase in average annual precipitation, but also increases in irrigation and household water application associated with development. With further development and densification, there would be further increases of water infiltration to the ground.

- **Soil structure** – the Glaciolacustrine Silts have a structured fabric comprising varves and platy particles preferentially aligned in a horizontal orientation making the silt highly anisotropic and likely to have weaker sliding planes. Stress release joints form perpendicular to the face of silt bluffs also resulting in a weak plane which may lead to the initiation of a landslide.
- **Seismicity** – earthquake-induced ground motion could induce soil displacement, and result in a landslide. The size of landslide would be dependant on the vicinity and magnitude of the earthquake and the groundwater conditions at the time of the event. However, as there are no known active faults near the GWB Study Area, earthquake-induced design ground motion is considered relatively low and would be more likely to cause a silt block fall or shallow slide of existing marginally stable bluffs and slopes rather than a deep-seated rotational landslide.

5.2.3 Silt Block Falls or Ravelling

Silt block falls or ravelling are small-scale failures attributed to toppling of blocks of material within the upper near vertical (71° – 82°) silt bluff face. Blocks commonly break up upon impact and debris flows down the slope as a dry, or moist avalanche of silty soil. A slide of this type occurred in 1970 on Lakeshore Road in Summerland, killing one person and damaging three homes. An example of smaller-scale silt falls occurs along the Highway 97, sometimes affecting traffic.

Silt block falls or ravelling are often caused by softening or erosion of a supporting layer, or by cleft water pressures developing in the perpendicular stress release joints behind the bluff face. Ice jacking (freeze/thaw) action within the silt joints (typical of rock fall initiation) may also lead to the smaller-scale silt block falls, typically along the crest or top of slope where silt is not yet mantled by a colluvial talus.

5.3 Piping and Sinkhole Development

5.3.1 General

Sinkholes have been commonly been observed in the Glaciolacustrine Silt deposits within the GWB Study Area (as shown in Appendix B, Map 4.0). The development of sinkholes is associated with the geomorphological process of subsurface internal erosion (piping), predominantly by water but may also be gravity based (not discussed in this report).

Sinkholes are normally initiated by the collection of water in surface depressions, or via penetration of water into zones of structural weakness such as vertical joints, fissures, etc. The water penetrates downwards through joints, fissures, and higher permeable zones until reaching a permeable horizontal layer with an egress such as close to the crest of a gully. Transportation of water and sediment within the permeable horizontal layer over time forms pipes (vertical or horizontal rounded tunnels). Where caving and collapse of material around the edge or roof of the tunnel occurs, a sinkhole is formed. The presence of a linear pattern of sinkholes can indicate there is a horizontal pipe at depth. Collapse of the linear series of sinkholes can result in the formation of a gully. This process is illustrated the schematic diagram sourced from Nyland and Miller (1977) (see Figure 5.3.a). In the GWB Study Area all large, incised gullies terminate at the glaciofluvial gravel layer, or at bedrock (Klohn Leonoff, 1992).

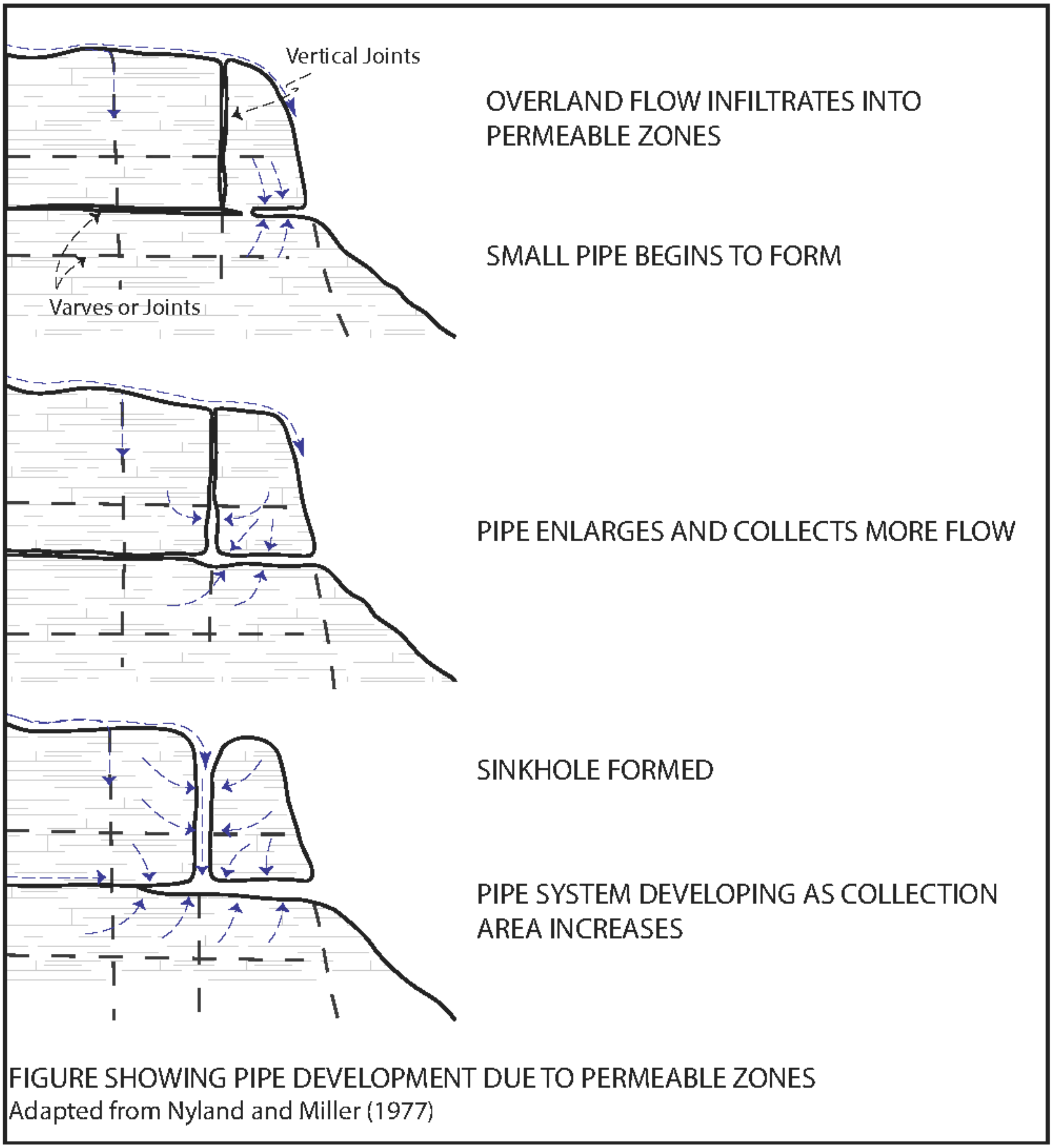
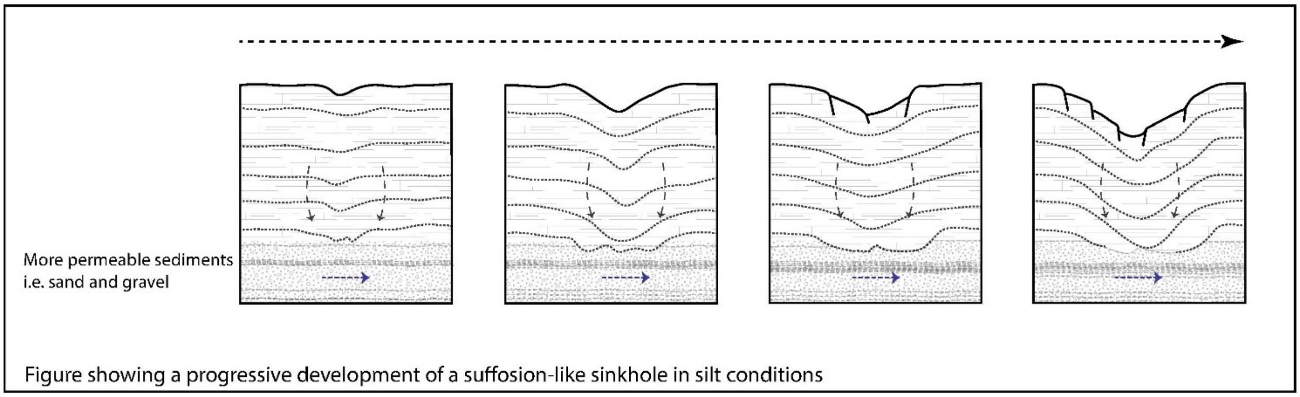


Figure 5.3.a Schematic diagram sourced from Nyland and Miller (1977)

Sinkholes can also be formed by the process of suffosion. Waltham, Bell, and Culshaw (2005) define suffosion as *"the transport of disaggregated soil or sediment into fissures in the underlying bedrock",* or mobilization of soil and particles into an underlying pipe, joint, or higher permeability sand/gravel seam. (see Figure 5.3.b below). A clay bearing or indurated cohesive soil can bridge a void for a period of time before collapse (Waltham, Bell, and Culshaw, 2005).



Source: adapted from Waltham, Bell and Culshaw (2005)

Figure 5.3.b Progressive Development of a Suffosion-like Sinkhole in Silt Conditions

5.3.2 Factors Affecting Sinkhole Development and Distribution

The following factors affect the location and rate of sinkhole development:

- **Internal stability of soils** –low plasticity soils that are poorly graded may be susceptible to internal erosion and do not self-filter. Soils that self-filter have coarse particles that prevent internal erosion of the medium size particles that in turn prevent internal erosion of fine particles. Soils which potentially do not self-filter include those which are susceptible to internal instability (suffusion) and very broadly graded soils. Plasticity, or PI, influences the progression of erosion, and is a soil parameter that indicates susceptibility to internal erosion, or piping (Table 5.3.a).

Table 5.3.a Influence of Plasticity on the Likelihood of Sinkhole Development

	More Likely	Neutral	Less Likely
Plasticity Index (PI) Value	PI < 6	6 < PI < 15	PI > 15

Source: Geotechnical Engineering of Dams (2018)

- **Hydraulic gradients** – loss of material through piping may occur if the drag force created by water seepage passing through the material (seepage force) overcomes the weight of the material.

  Hydraulic gradients increase along preferential flow paths such as pipes, fissures, varve boundaries, root holes and/or higher permeability sand/gravel layers. With increased hydraulic gradients, the erosion occurs more intensely and the pipe advances at an increasing rate towards the water source. Once the pipe has reached the source of water, much higher flow rates are possible, so that the flow of water along the pipe can mobilize silts along the pathway, enlarging the size of the pipe.

  It is said that the piping process is not a continuous phenomenon but a sudden process that can occur during a short period of increased pore water pressures.

  Water may be introduced to the ground naturally, through precipitation, snowmelt, ground water flow from the gravels west of the silt bluffs migrating into the gullies and silts and/or natural groundwater flow in the bedrock underlying the silt, or artificially through septic fields, storm water, leaking irrigation, water lines, or swimming pools. In addition, concentration of surface runoff from impervious surfaces such as roadways, driveways, roof drains, or compacted fill surfaces may increase the amount of water being introduced to a sensitive area. Any event that promotes subsurface erosion process has the potential to trigger the development of a sinkhole.

- **Proximity to slope crest or next closest sinkhole** – the current distribution of sinkholes in the GWB Study Area was identified using 2018 orthoimagery and LiDAR data (as discussed in Section 2.3.1). The distance from the slope, or gully, crest and the distance between sinkholes was measured using GIS.

  The inventory, tabulated in Table 5.3.b and shown in Appendix B, Map 4.0, identified 99 sinkholes and found that 85% of all sinkholes identified were located within 30 m of a slope crest, or the next closest sinkhole. For comparison, Klohn Leonoff (1992) identified more than 300 sinkholes. Their study determined that all sinkholes were located within 40 m of a gully slope crest. The difference in the number of identified sinkholes may be attributed to air photo interpretation and possibly changes in land surface (such as infilling and site grading) since 1992.

  The remaining 15% of the sinkholes that lie beyond 30 m of the slope crest or another sinkhole are thought to be outliers that are likely associated with compromised soil conditions attributed to the introduction of water to the ground (i.e., such as a broken or leaking water line, or a concentration of surface runoff).

  This spatial relationship forms the basis of the sinkhole hazard classification, presented in Section 6.6.

Table 5.3.b Sinkhole Inventory and Distance to Slope Crest or Next Closest Sinkhole

Distance to Crest or Sinkhole (m)	No. of Sinkholes	Cumulative Percentage (%)
0	25	26
5	6	32
10	13	45
15	8	53
20	13	66
25	11	78
30	7	85
35	5	90
40	2	92
45	1	93
50	2	95
55	1	96
60	1	97
65	2	99
70	0	99
75	1	100
TOTAL	**99**	

5.4 Soil Collapse/Compression

5.4.1 General

Soil collapse is a change in volume (strain) of soil structure due to an increase in moisture content whereas soil compression is considered to be a change in volume (strain) due to an increase in load (stress) acting on the soil structure. The Glaciolacustrine Silt within the GWB Study Area are susceptible to both mechanisms which both result in vertical deformation of the soil. Therefore, for the purpose of establishing hazard criteria, these two mechanisms have been combined.

Collapse / compression of soil structure is analogous to that of a house of cards (Nyland and Miller, 1977): no material is lost but its bulk volume decreases. It was observed that Colluvial Silt (non-stratified depositional material in gullies and along the base of slopes) is highly susceptible to collapse/compression with the introduction of water, particularly under loaded conditions.

Areas of historic infill inferred as where collapse/compression of the Glaciolacustrine Silt deposits have occurred are identified within the GWB Study Area through comparison of historical air photos and from interpretation of the 2018 LiDAR data (shown in Appendix B, Map 5.0). The delineation of filled areas is approximate and completed on a larger scale. For specific sites, assessing the potential for collapsible/compressible soils must be determined through a more detailed investigation.

The historic KVR Trail is located through the GWB Study Area, crossing high embankments that pass through large gullies. Archival photos show that gully infill occurred by side-dumping material, most likely silt material derived from local slope through cuts (see Figure 5.4.a). Material would be loosely packed around a wooden trestle, with the wooden structure providing some additional support to the soil mass.

It was likely that some means of cross-drainage through the infill drainage was provided. However, these cross-drains are now obscured by colluvium and vegetation.

Figure 5.4.a Side dumping on KVR Trestle, at Mile 2.2 (Vancouver Archives: Item CVA 289-002.426, circa 1923) (likely located at the big gully north of Newton Drive)

5.4.2 Factors Affecting the Susceptibility to Collapse/Compression

The following factors affect the soil susceptibility to collapse/compression:

- **Soil structure** – Iravani (1999) states the silt is structurally-bonded by a number of chemical bonding agents (mainly silica acid gel), and the strength of the inter-particle bonding is highly sensitive to water content. The addition of water results in an increase in water content, subsequent swelling and a loss of integrity of the soil structure. Upon exposure to excess water and swelling, breakage of water sensitive bonds, elimination of soil suction and a change in fabric occurs resulting in a rapid reduction of air voids (collapse).
- **Soil depositional environment** – the depositional environment of the uniform Glaciolacustrine Silt particles resulted in a relatively high void ratio making it more susceptible to volume changes (collapse/compression) when subject to the mechanisms described above. Colluvial Silts are formed by erosion of silt bluffs and the infill of gullies and sinkholes and are deposited in a looser state than the Glaciolacustrine Silts themselves resulting in significantly higher potential for volume change (collapse/compression). MoTI (1991) indicated that Glaciolacustrine and Colluvial Silts experienced 2-4% and 28-31% vertical deformation upon flooding under the same applied field load.

5.5 Groundwater Influence on Geohazards

Previous investigations report a strong correlation between groundwater patterns and geotechnical hazards in the Study Area (Nyland and Miller, 1977; Klohn Leonoff, 1992). Under natural conditions, landslides are relatively infrequent in the GWB Study Area. Over the past century, however, there is increasing correlation between groundwater and the frequency of geotechnical hazard events, where groundwater is attributed to land use practices.

Of the twelve major landslides that have been reported in the region, the majority occurred after more extensive agricultural irrigation began, but before the use of sprinklers (Klohn Leonoff, 1992). Consequently, the cause of many of these slides is attributed to high groundwater pressures (Nyland and Miller, 1977).

Previous studies indicate that the use of septic fields for residential wastewater disposal significantly increases the groundwater levels within the silt bluffs, which can increase the probability of a landslide or other slope failure (Klohn Leonoff, 1992). Development-induced trigger mechanisms such as broken pipes, leaking swimming pools and ornamental ponds, and uncontrolled concentration of precipitation runoff are also known to increase the likelihood of subsurface erosion and sinkhole development. Measures to detect and monitor water leaks are very important in mitigating these hazards.

6. Geohazard and Risk Assessment

6.1 General

The basis for the geohazard and risk assessment approach is adapted from that which is presented in Wise et al. (2004) and in Porter and Morgenstern (2013). These source documents reference the generic risk management approach of the Canadian Standards Association (CSA), (CSA, 1997).

Terms commonly used for geotechnical hazard and risk assessment, and employed in this report include:

Hazard (P_H) - a source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment, and other things of value; or some combination of these (CSA, 1997). With respect to geohazards, it is the process (i.e., landslide, sinkhole, soil collapse/compression) that is the source of potential damage or harm.

> Probability (or likelihood) of occurrence of a geohazard event describes the potential for that landslide to occur. It is a number between zero (event will not occur) and one (event will occur) expressed over a specified period of time, such as an annual probability of occurrence. When expressed qualitatively, the probability of occurrence is defined in terms such as unlikely, likely, and very likely.

Consequence ($P_{S:H}$ x $P_{T:S}$) - the effect on human well-being, property, the environment, or other things of value; or a combination of these (adapted from CSA,1997). This may be described as the change, loss, or damage caused by the geohazard.

Risk - the chance of injury or loss as defined as a measure of the probability and the consequence of an adverse effect to health, property, the environment, or other things of value (adapted from CSA, 1997).

> Specific Risk (R) – the probability of loss or damage to a specific element, resulting from a specific hazardous event. Information regarding vulnerability, which is a measure of robustness and exposure of the occupied site to the hazardous event, is required and considered outside the scope of this assignment.

> Partial Risk (PHA) – the probability of a specific hazardous event. It includes an assessment of probability of the event reaching or otherwise affecting the occupied site. Partial risk does not consider the vulnerability.

For this assignment estimating geohazard partial risk is a process that involves identifying the trigger mechanisms, estimating the characteristics of an event, estimating the potential likelihood of an event and the area potentially affected by the event. The assessment process and approach are described further in the following Sections.

6.2 Assessment Process

The following section describes the partial risk assessment process employed for this study. The partial risk assessment process, shown in Figure 6.2.a, begins with an “inventory and characterization of hazardous processes” in the GWB Study Area. This resulted in the development of a Terrain Map (Appendix B, Map 2.0). Areas within the GWB Study Area are then delineated based on an associated level of partial risk, using criteria developed for each different geotechnical hazard being investigated. The partial risk maps are presented as Hazard Maps for landslide, sinkhole, and for soil collapse/compression (see Appendix B, Maps 3.0-5.0). A derivative map is produced that combines the three hazard maps into a single combined partial risk map, referred to as a Geotechnical Constraints Map (Appendix B, Map 6.0). This derivative map can be used to assist in the management of existing and future development.

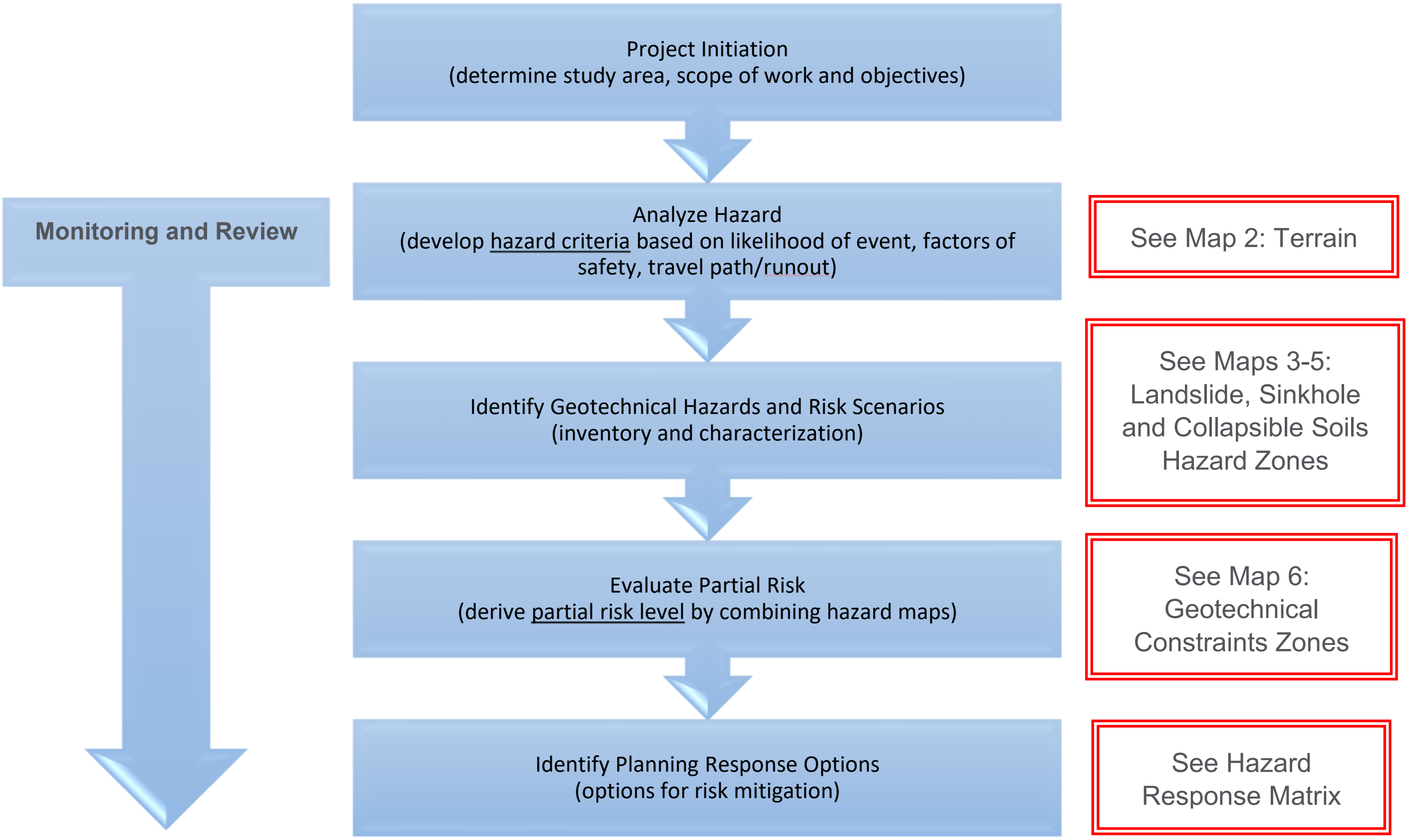


Figure 6.2.a Partial Risk Assessment Process

6.3 Qualitative Partial Risk Assessment Approach Used for this Study

For the purposes of this assessment, we have developed a hybrid qualitative partial risk assessment, using traditional approaches presented by Wise et al. (2004) and Porter and Morgenstern (2013) but also incorporating a Factor of Safety (FoS) approach. By combining the two approaches we present one that is unique and tailored to fit the conditions present in the GWB Study Area, and the information available.

The traditional partial risk (also known as encounter probability) assessment approach is expressed as follows:

PARTIAL RISK (P_{HA}) = HAZARD (P_H) x CONSEQUENCE ($P_{S:H}$)

Where:

P_H = hazard, or probability of a damaging geohazard event; and

$P_{S:H}$ = consequence, or probability that the geohazard will reach the site.

The partial risk assessment assumes that sites that are permanent, or fixed, and does not consider vulnerability, or the probability of loss of life or damage.

The partial risk evaluation matrix used for this study is shown in Table 6.3.a and Table 6.3.b, where the risk level is based on the HAZARD, or relative probability of a damaging geohazard event, combined with the CONSEQUENCE, or probability that the event will reach or otherwise affect the site.

To estimate HAZARD the traditional approach is to determine a frequency-magnitude relationship. Generally, smaller events occur more frequently, and larger events tend to be less frequent. For this study, this relationship may only be based on the period of documented history, which represents a period approaching 100 years. It is known that small surficial landslides and sinkhole development occur frequently over this period and this is documented. Large-scale events, such as the deep-seated rotational landslide, are relatively rare but there is at least one occurrence, judged to have occurred within the post-glacial period. Due to the short period of record and lack of documented large-scale events, it is difficult to develop a meaningful relationship for geohazard frequency and magnitude.

With no other data upon which to base the relations, we have chosen to use a terrain-based approach for all processes, except for the large-scale rotational landslides in the Glaciolacustrine Silts where there have been many studies undertaken on the material parameters. The terrain-based approach, which estimated event likelihood based on geological (soils) character, and terrain character is applied to landslides on sand and gravel sediments, sinkhole formation, and collapsible/compressible soils.

For large-scale rotational landslides in the Glaciolacustrine Silts, a FoS approach has been used based on the results of Limit State Equilibrium (LSE) stability analyses to establish setback criteria for the silt bluffs. This is discussed further in Section 6.4.

Table 6.3.a Qualitative Partial Risk Evaluation Matrix Used for this Study

Hazard - Probability of damaging geohazard event (P_H)	Consequence - Probability that the geohazard will reach the site ($P_{S:H}$)		
	Low (event will not reach the site)	Moderate (event may reach the site)	High (event is likely to reach the site)
Unlikely (i.e., event is possible but expected to occur every 1,000 to 10,000 years)	L	L	M
Likely (i.e., event is expected to occur every 100 to 1,000 years)	L	M	H
Very Likely (i.e., event is expected to occur more than once every 100 years)	M	H	H

Table 6.3.b Qualitative Partial Risk Levels Defined

Partial Risk Level P_{HA} (probability of a geohazard event and affecting the parcel)		Description
High	H	High Risk – damaging event is very likely
Moderate	M	Moderate Risk – damaging event is likely
Low	L	Low Risk – damaging event is unlikely to occur

The assessment process recognizes that in moderate and low risk areas, there is still some probability of a damaging geohazard and, therefore, a residual level of risk that may still require some further assessment, or some conditions placed on development. Conditions or mitigative actions may be placed on development to reduce the residual risk. The degree of effort required to reduce the risk are based on practicality.

6.4 Landslide Hazard Criteria for Silt Bluff and Gully Side Slope Areas

6.4.1 General

Slope stability analyses were carried out to assess the potential for deep-seated landslides, and to determine setback distances from the slope crest (escarpment) for the purposes of establishing landslide hazard zones within the silt bluff and gully side slope areas.

The stability of a slope is controlled by the ratio between forces acting on the slope (shear stress) and the forces resisting failure (shear resistance). This ratio is expressed as a FoS. A slope with a FoS less than 1.0 is unstable, greater than 1.0 is stable, at 1.0 the slope is at equilibrium and is considered marginally stable.

The stability analysis adopted for this study uses the following landslide hazard criteria for static conditions:

- FoS < 1.0 – High Hazard
- 1.0 < FoS < 1.5 – Moderate Hazard
- FoS > 1.5 – Low Hazard

The stability analysis was also undertaken for pseudo-static conditions assuming horizontal acceleration (k_h) equal to the PGA corresponding to a return period of 2,475 years (Table 3.6.a) and amplified by F(PGA) for Site Class D in accordance with Section 4.1.8.4 of the BCBC (2018). The stability assumes hazard criteria for seismic conditions of FoS > 1.1 – Low Hazard.

Global factors of safety were calculated using the two-dimensional LSE software program called Slide2 v9.008 by RocScience utilizing the Morgenstern-Price method with a half sine interslice force adopted.

Slope stability analyses were undertaken for five cross-sections within the silt bluffs in the GWB Study Area (see Appendix G, section line 1-5). The cross-section locations were selected to be representative of the worst case (steepest) topography of the silt bluffs within the GWB Study Area. Geometry of the cross-sections were taken from the 2018 LiDAR data. Each section was analyzed for two groundwater levels, 343.66 m asl, and 347.26 m asl, corresponding to the Flood Construction Level (FCL) of Okanagan Lake under current conditions and for potential future conditions considering climate change, respectively[4].

With regards to the landslide runout hazard criteria, we have adopted the same criteria employed by Klohn Leonoff (1992), which appears to be consistent with geometric observations from historical slides within the Glaciolacustrine Silt.

Upon reviewing historical case studies from gully erosion events resulting in liquefied soils, it is our opinion that the impact to people and infrastructure downslope from events of this nature appears to be minimal (i.e., maintenance and cosmetic damage only) in comparison to runout from mass slope movements. In addition, the majority of the areas downslope of the slit bluffs fall outside of the study area, along the highway. Therefore, gully erosion and earthflow events have not been considered in the landslide runout hazard criteria.

6.4.2 Material Parameters and Water Level Assumptions

Geotechnical parameters used in the analysis are given in Table 6.4.a based on existing site conditions and published correlations (as discussed in Section 3.4).

[4] Okanagan Lake Shoreline FCL including wave runup including mid-century climate change is presented by the Okanagan Basin Water Board – Okanagan Flood Story (https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/app/c6ad2e783be1432bad51e23f42187288)

The analysis assumes that the soil shear strength is based on the Mohr-Coulomb failure criterion where the soil shear strength is dependent on effective cohesion (c') and the effective angle of internal friction (ø'). Cohesion is the component of shear strength that is independent of interparticle friction. True cohesion is caused by either electrostatic forces in stiff, over-consolidated fine-grained soils or chemical cementation between soil particles. Apparent cohesion can exist in soils as a result of negative pore pressure (suction) above the water table which is lost upon wetting. The angle of internal friction represents the soil's internal resistance to movement and is based on a number of physical properties of the soil such as grain size distribution, angularity, and particle interlocking.

Effective cohesion (c') of the Glaciolacustrine Silt is highly sensitive to moisture content. For "in-situ" and "air-dried" states, effective cohesion values are approximately 60 kPa and 800 kPa, respectively, as suggested by Iravani (1999). Cohesion reduces to 0 kPa under saturated conditions. A sensitivity analysis of the effect of cohesion on the FoS was completed for the critical slope stability (see Appendix G, section line 2, Figure G6). The relationship indicates that for 0 kPa cohesion, the critical FoS is significantly less than 1.0 (unstable). When cohesion is increased to 60 kPa for the "in-situ" state as recommended by Iravani (1999), the critical FoS is approximately 1.6 (stable).

For the purposes of this study, due to the inherent uncertainty and limited site-specific subsurface geotechnical data with no site-specific strength data in the GWB area, the analysis conservatively assumes 0 kPa cohesion.

The effective angle of internal friction (ø') values for the Glaciolacustrine Silt and colluvium is conservatively based on the lower bound values provided by Iravani (1999). ***For the purposes of this study, the effective angle of internal friction is 32° for undisturbed silt and 24° for Colluvial Silt.***

Table 6.4.a Summary of Geotechnical Parameters used in the Stability Analysis

Material Name	Strength Type	Unit Weight, γ' (kN/m^3)	Effective Cohesion c' (kPa)	Effective Angle of Internal Friction, ϕ' (°)
Glaciolacustrine Silt	Mohr Coulomb	19	0	32
Colluvium	Mohr Coulomb	14	0	24
Fill	Mohr Coulomb	21	0	34

The stability analysis was also completed for varying lake elevations and found that, except for one section (section line 5), the resultant FoS did not change. The overall effect of Okanagan Lake is considered negligible for the global stability condition due to the distance from the silt bluff area. As it is recognized that the Glaciolacustrine Silts are sensitive to groundwater inputs (from upslope sources for example), using a 0 kPa cohesion is considered to account for this sensitivity. A 0 kPa cohesion essentially models the strength of a soil in a saturated condition. The phreatic surface behind the silt bluff was elevated by 10 m for the critical slope stability section (Appendix G, section line 3) and was found to have little impact on the FoS and resulting setback distance.

By using conservative material parameters, we recognize that the results are likely to be conservative. However, the use of less conservative parameters would require verification through site-specific geotechnical data including advanced soil laboratory testing.

6.4.3 Stability Analysis Results and Setback Criteria

The results of the stability analysis are expressed as setback distances, as a function of slope height (H). Results are summarized in Table 6.4.b below and are presented in Appendix G, Figures G1-G5.

Table 6.4.b Results of the Slope Stability Analysis

Section	Setback Distance for FoS < 1.0 *	Setback Distance for FoS < 1.5 *	Figure #

Section Line 1	0.3H	1.2H	G1
Section Line 2	0.7H	1.8H	G2
Section Line 3	0.9H	1.9H	G3
Section Line 4	0.6H	1.4H	G4
Section Line 5	0.4H	0.7H	G5
Section 5a (elevated lake level)	0.4H	0.9H	G5a

* Expressed as a function of the slope height (H).

Based on the results of the stability analyses, section line 3 represents the section with the largest setback distances required to achieve the corresponding FoS value (i.e., the critical section). These values are used in the development of silt bluff and gully side slope setback criteria.

The results under pseudo-static conditions indicated that slip surfaces with a FoS of 1.1 or less (outside of the Low Hazard zone) fall within the High Hazard and Moderate Hazard zones under static conditions for each section analyzed and potential development would require further site-specific investigation. In other words, the hazard criteria under static conditions are more critical where there are no geotechnical constraints in place for potential development. The result of the critical section (section line 3) under pseudo-static conditions is presented in Appendix G, Figure G3a).

The landslide setback hazard criteria for the silt bluffs and gully side slopes are summarized in Table 6.4.c, are graphically displayed on Figure 6.4.a, and are shown in Appendix B, Map 3.0. The setback criteria are based on the slope stability results for the critical section (section line 3) with a 10 m buffer added to account for future erosion and regression of the slope crest (escarpment).

Table 6.4.c Landslide Setback Hazard Criteria – Silt Bluffs

Hazard Zone	Setback Criteria *
High Hazard	D < 1.0H + 10 m
Moderate Hazard	1.0H + 10 m < D < 2.0H + 10 m
Low Hazard	D > 2.0H + 10 m

* Expressed as a function of the setback distance (D) and slope height (H).

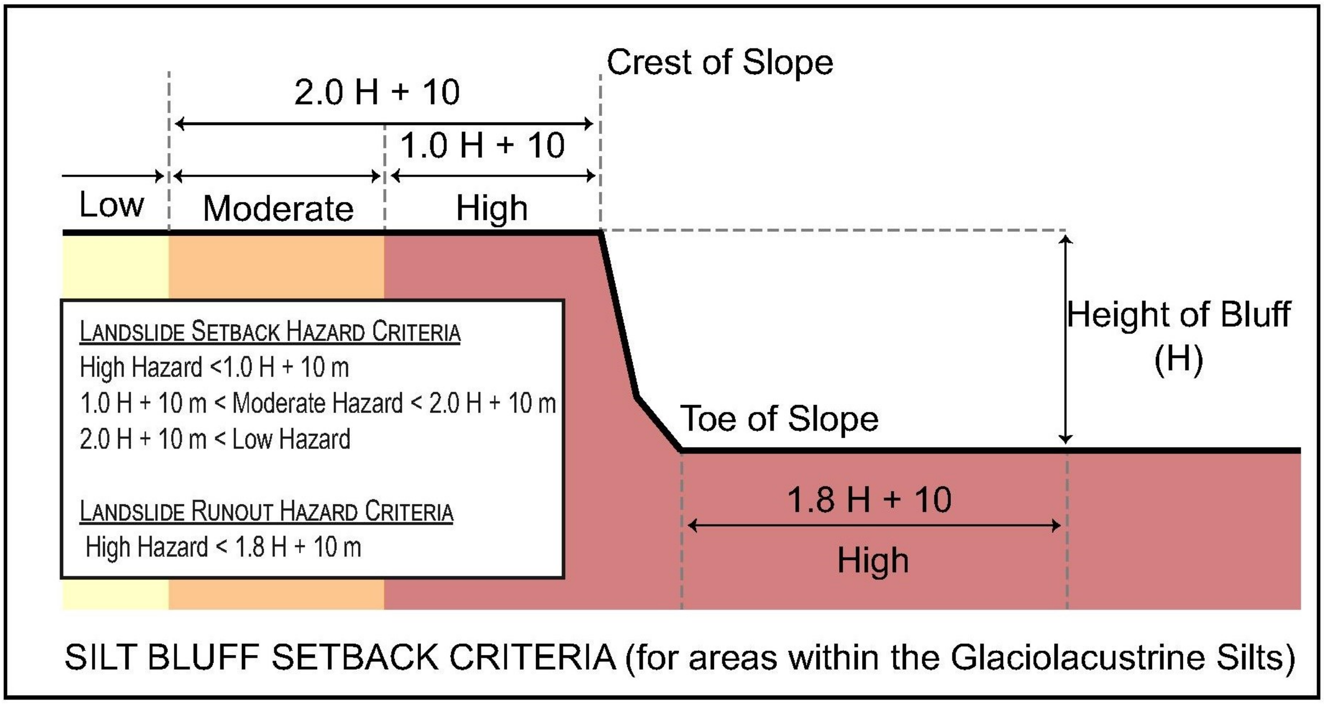


Figure 6.4.a Landslide Hazard Criteria and Setback Zones (also shown in Appendix B, Map 3.0)

6.5 Landslide Hazard Criteria for Areas Outside of Silt Bluffs

Areas outside of the silt bluffs, specifically the slopes in vicinity of Madeline (Max) Lake and the steeper slopes above West Bench Road at the north end of the study area are subject to a different type of landslide hazard. Landslides within areas underlain by unconsolidated sand and gravel glaciofluvial deposits are subject to shallow planar landslides on steeper slopes. These areas are, generally, much less prone to deep-seated landslides than areas underlain by the Glaciolacustrine Silts.

The landslide hazard criteria for areas outside of the silt bluffs is based on terrain conditions, slope, and whether there were historical landslides observed in the 2018 orthoimagery and LiDAR. Likelihood for a damaging landslide event within these areas was based on an approach that utilized information known about existing site conditions and geology in this area, and our previous local experience.

It should be noted that potential signs of slope instability were observed in several instances on slopes less than 50% (>2H:1V) corresponding to the Low Hazard zone. However, this is considered likely to be because of surficial erosion and not a result of global instability.

The landslide hazard criteria for areas outside of the silt bluffs are summarized in Table 6.5.a and in Appendix B, Map 3.0.

Table 6.5.a Landslide Hazard Criteria – Areas Outside of Silt Bluffs

Hazard Zone	Criteria
High Hazard	Greater than 50% slope (<2H:1V) and signs of historical slope instability
Moderate Hazard	Greater than 50% slope (<2H:1V) and no signs of historical slope instability
Low Hazard	Less than 50% slope (>2H:1V)

6.6 Sinkhole Hazard Criteria

Sinkholes continue to develop with the GWB Study Area. While none have been catastrophic in terms of property loss, many have caused damages to property or have resulted in injuries (see Section 3.2.4). The occurrence of sinkholes is almost exclusively within the area mapped as Glaciolacustrine Silt deposits. However, there is a predominance of sinkholes in the northern part of the Study Area (i.e., Sage Mesa). It is hypothesized that variations in the engineering material properties of the silt, such as the PI, for example, influence the preferential spatial development of sinkholes. Further investigation to refine this interpretation may be warranted for site specific investigations.

For this study, in the absence of detailed soil property data, the sinkhole hazard criteria are based on the theoretical evolution of sinkholes in association with the development of gullies (see Section 5.3). The spatial relationship, combined with the predominant underlying soil type, were used in the development of sinkhole hazard criteria.

Sinkhole hazard criteria are listed and described in Table 6.6.a. A schematic diagram showing the hazard criteria developed based on a spatial relationship is shown in Figure 6.6.a.

Table 6.6.a Sinkhole Hazard Criteria

Sinkhole Hazard	Criteria	Definition
High Hazard	▪ Located within 30 m of slope crest; ▪ Located within 30 m of an existing mapped sinkhole; and, ▪ Located within 10 m of an area identified as previous infill.	▪ A damaging sinkhole event is very likely to occur within this area
Moderate Hazard	▪ Located greater than 30 m of slope crest, greater than 30 m of existing sinkhole; and greater than 10 m from historic infill; and, ▪ Located within area underlain by Glaciolacustrine Silt sediments	▪ A damaging sinkhole event is likely to occur
Low Hazard	▪ Located within area underlain by glaciofluvial sand and gravel sediments or till	▪ A damaging sinkhole event is less likely to occur within this area

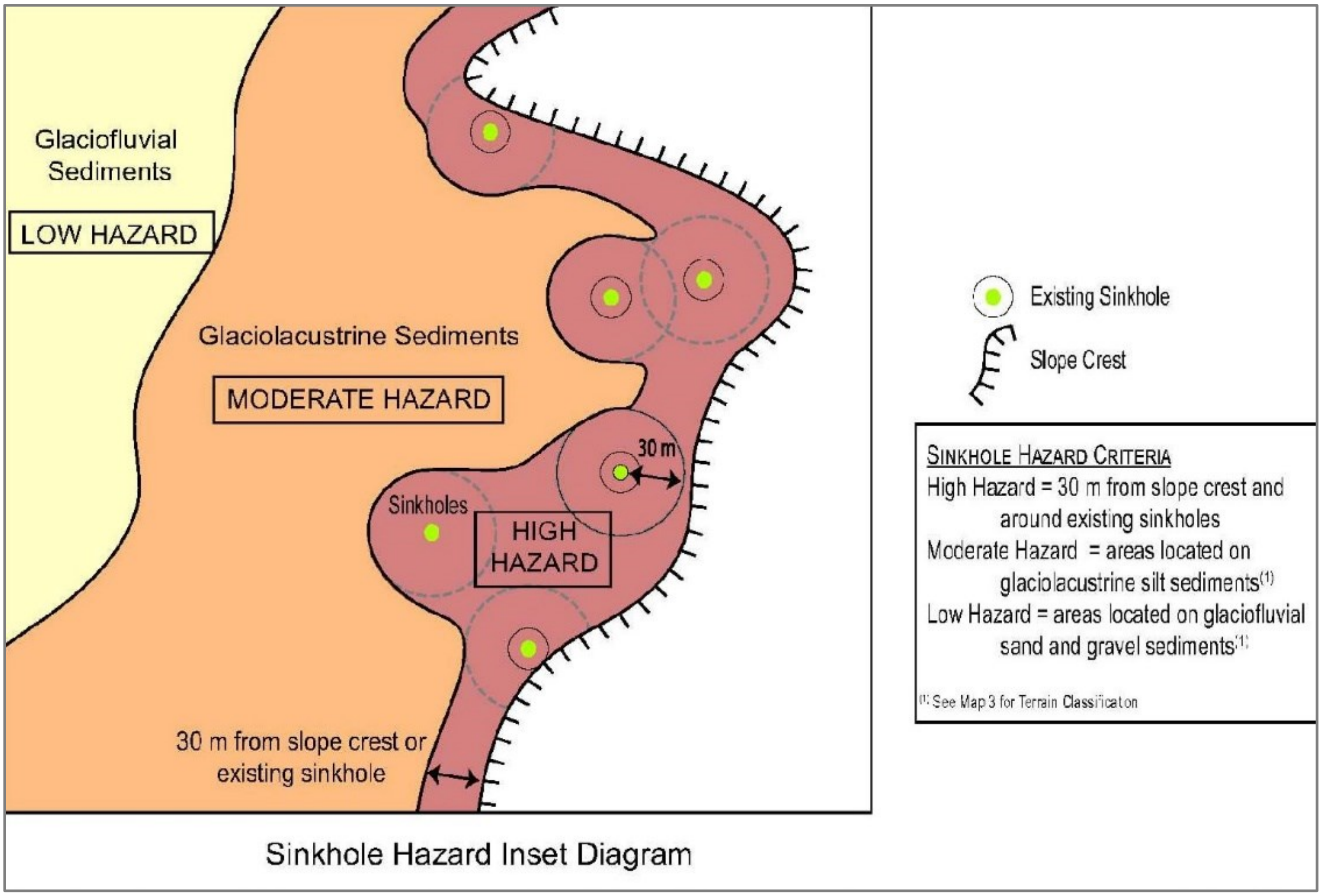


Figure 6.6.a Sinkhole Hazard Zone Diagram (also shown on Appendix B, Map 4.0)

6.7 Collapsible/Compressible Soils Hazard Criteria

The depositional environment of the uniform Glaciolacustrine Silt particles resulted in a relatively high void ratio, making it more susceptible to volume changes (collapse / compression) with the introduction of water, particularly under loaded conditions. This may result in a potentially damaging process associated with collapse or compression and can damage infrastructure and/or property.

Colluvial Silts that are formed by erosion of silt bluffs or infill of gullies or sinkholes have a higher potential for collapse / compression. These soils are deposited in a looser state and are often a conduit for preferential groundwater flow.

Collapsible/compressible soils hazard is based on the underlying soil type, and the terrain condition (intact soils vs. colluvial soils or infill). The hazard criteria are listed and described in Table 6.7.a.

Table 6.7.a Collapsible Soils Hazard Criteria

Collapsible Soils Hazard	Criteria	Definition
High Hazard	▪ Areas underlain by colluvial silt (non-stratified depositional material in gullies and along the base of silt bluff slopes) ▪ Areas of historic infill, such as gullies or sinkholes.	▪ A damaging soil collapse event or significant soil compression is very likely to occur within this area
Moderate Hazard	▪ Located within area mapped as Glaciolacustrine Silt sediments.	▪ A damaging soil collapse event or significant soil compression is more likely to occur
Low Hazard	▪ Located within area mapped as glaciofluvial sand and gravel sediments.	▪ A damaging soil collapse event or significant soil compression is unlikely to occur within this area

6.8 Hazard Mapping Results

The geohazard assessment results for landslide, sinkhole, and collapsible/compressible soils are presented in Appendix B (Maps 3.0– 5.0) .

The results indicate that landslide hazards persist within the vicinity of the steep silt bluff slopes that occur along the eastern boundary of the GWB Study Area. The landslide hazards are greatest within approximately 50 m of the slope crest and extend beyond the toe of the slope towards Highway 97 and Okanagan Lake.

Sinkhole hazards within the GWB Study Area are highest within 30 m to 50 m of the silt bluff or gully slope crest and are observed exclusively within the Glaciolacustrine Silts. The sinkhole hazard predominately occurs over the eastern and northern half of the West Bench area.

Collapsible/compressible soils occur in conjunction with the silt bluffs and associated gullies. It is unlikely that any area mapped as having a collapsible/compressible soils hazard is not also mapped as having a landslide and/or sinkhole hazard. However, this hazard class emphasizes the importance of potentially damaging soil material properties and therefore site-specific considerations.

The results indicate that, overall, the geotechnical hazard zones are more refined than the original Klohn Leonoff (1992) mapping of landslide and sinkhole hazards. The current Geotechnical Review provides additional refinement with the use of updated aerial imagery and 2018 LiDAR data. Additional landslide analysis using region-specific soil materials data and using slope sections from the GWB Study Area provides further refinement of the landslide hazard. The resultant mapping also interprets a varying degree of hazard (from Low, to Moderate, to High), whereas the Klohn Leonoff (1992) mapping did not. This refinement in hazard mapping allows different hazard areas to be better distinguished to inform future land use management decisions.

6.9 Development of a Geotechnical Constraints Zone Map

Upon completion of the landslide, sinkhole and collapsible / compressible soil hazard maps, the combined partial risk is evaluated following the process introduced in Section 6.2 (Figure 6.2.a). As discussed, partial risk is the probability of a hazardous event reaching or otherwise affecting the legal parcel. For this study, the partial risk is expressed as the combined likelihood of the key identified hazards (i.e., landslide, sinkhole, and collapsible / compressible soils).

Geotechnical constraints zones, defined as the combined potential hazard affecting an area are defined in Table 6.9.a. Zones A, B and C are equivalent to Low, Moderate, and High Risk, respectfully. Criteria for each zone are based on the assessed hazard levels:

- If the area is rated no greater than low hazard in any of the three hazard types, then the area is rated Low Risk (i.e., Zone A).
- If the area is rated moderate hazard in any of the three hazard types, the area is rated Moderate Risk (i.e., Zone B).
- If any area is rated high hazard for any of the three hazard types, the area is rated High Risk (i.e., Zone C).

The mapped Geotechnical Constraints Zones are shown in Appendix B, Map 6.0.

Table 6.9.a Geotechnical Constraints Zones

Geotechnical Constraints Zone	Criteria	Likelihood of a Damaging Geohazard Event Affecting a Parcel
Zone A	▪ All three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated low	Low
Zone B	▪ Any one of the three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated moderate.	Moderate
Zone C	▪ Any one of the three hazard types (i.e., landslide, sinkhole, and collapsible/compressible soils) are rated high	High

A Geotechnical Constraints Map was created on this basis by combining the three geohazard maps into one and is presented in Appendix B, Map 6.0. The zones, interpreted in the following section, form the basis for guiding development decisions.

6.9.1 Geotechnical Constraints Zone A – Low Risk

Geotechnical Constraints Zone A is designated to areas with a low geologic hazard level. Areas within Zone A have a low hazard rating for all mapped geologic processes and includes the following lands:

- Gentle to moderate (<50%) inclined sand and gravel slopes, with no signs of historic instability.
- Areas (broadly) not underlain by Glaciolacustrine Silts.

With respect to guiding development decisions, areas within Geotechnical Constraints Zone A, while rated Low Risk and not subject to hazards, are not necessarily free from influencing hazards elsewhere. For example, surface water runoff and groundwater runoff from Zone A lands may potentially impact more hazardous areas that lie adjacent, or downslope, from these lands.

6.9.2 Geotechnical Constraints Zone B – Moderate Risk

Geotechnical Constraints Zone B is designated to areas that are potentially subject to geologic hazard and where further assessment may be required to further define the hazard. Development within this Zone may require remedial measures, such as deep foundations, in-ground barrier pile walls, and/or specially designed on-site water management. Geotechnical Constraints Zone B includes the following lands:

- Moderate to steep (>50%) sand and gravel slopes, with no signs of historic instability.
- Presence of Glaciolacustrine Silt and/or unknown fill.
- Areas located within “moderate” landslide hazard, “moderate” sinkhole hazard, and/or “moderate” collapsible/compressible soils hazard.

Within Geotechnical Constraints Zone B, some limitations to development may include:

- Erosion, slope retreat, and instability (landslide hazard);
- Potential for sinkhole development (sinkhole hazard) limiting potential for on-site stormwater and effluent disposal;
- Soil conditions that require special geotechnical engineering controls; and,
- Development potential will require further site-specific investigations.

6.9.3 Geotechnical Constraints Zone C – High Risk

Geotechnical Constraints Zone C is designated to areas that are subject to a high level of geologic hazard. Within this zone, there may be evidence of past slope failures and/or sinkhole formation. Further instability and/or sinkhole development is considered very likely. Development within this zone will likely require more detailed site-specific investigation and may require special remedial measures to safely use the land. Geotechnical Constraints Zone C includes the following:

- Steep to very steep (>50%) sand and gravel slopes, that show signs of historic instability;
- Steep to very steep glaciolacustrine (silt bluff) slopes and areas beyond the crest of the slope that lie within the high landslide hazard setback zone or the high sinkhole hazard zone;
- Areas beyond the toe of the steep silt bluff slope that are subject to high hazard landslide runout;
- Areas of historic landslide activity and/or sinkhole formation; and,
- Presence of colluvium derived from Glaciolacustrine Silt and areas of historic infill.

Within Geotechnical Constraints Zone C, limitations to development are similar to those identified in Zone B, except that there is more certainty that controls will be required. These limitations may include:

- Erosion, slope retreat, and instability (landslide hazard);
- Potential for sinkhole development (sinkhole hazard) limiting potential for on-site stormwater and effluent disposal;
- Soil conditions that require special geotechnical engineering controls; and,
- Development potential will require further site-specific investigations.

6.9.4 How to Use the Geotechnical Constraints Zone Map

The following steps provide a conceptual idea as to how the Geotechnical Constraints Zone Map (Appendix B, Map 6.0) may be used to evaluate proposed development applications within the GWB Study Area. These are:

- **Step 1**: Development (or BP) Application received by RDOS;
- **Step 2**: Determine whether the subject property lies within Geotechnical Constraints Zone A, B, or C, using Appendix B, Map 6.0;
- **Step 3**: Request supporting documentation, including a Geohazard (Geotechnical Engineering) Report, as appropriate to the applicable Zone. Terms of Reference for the report, to be prepared by a Qualified Professional (QP), are provided; and,
- **Step 4**: Evaluate and receive the Geohazard (Geotechnical Engineering) Report that provides conclusions regarding site suitability for development and assures a low likelihood of offsite impacts.

6.10 Future Considerations

6.10.1 Monitoring and Review

Geohazard conditions may change over time and the landslide risk management process, presented in Section 6.3, includes a monitoring and review component that spans the entire process (Porter and Morgenstern, 2013). Monitoring and review represent an ongoing process that includes monitoring the incidence of landslides, sinkholes, or other geohazard events. It also includes periodic review of risk management methods, recognizing that different approaches and new technologies may develop over time. As development takes place, different risk scenarios may arise, where the potential exposure to geohazard events changes over time.

Temporal changes to geomorphological processes and/or geohazard conditions in the GWB Study Area may be expected with the effects of a changing climate, or with the effects of land development. Efforts were made to incorporate considerations for a changing climate and/or land development effects into the hazard criteria. These include the following:

- For the silt bluff and gully side slope landslide hazard setback criteria, a 10 m buffer is added to account for future erosion and regression of the slope crest.
- For the landslide hazard criteria, conservative values for material properties were chosen to account for a high degree of soil saturation (attributed to natural or artificial sources).
- For the sinkhole hazard criteria, ratings for potential sinkhole development are at least moderate for areas underlain by Glaciolacustrine Silts. This accounts for potential sinkhole hazard regardless of proximity to the slope/gully crest or other adjacent sinkholes.

6.10.2 Effects of Climate Change

A recent report titled *Climate Projections for the Okanagan Region* (RDNO, RDCO, RDOS and Pinna Sustainability, 2020) provides the most recent summary of projected climate change. This information was reviewed in the context of prevailing geomorphologic processes in the GWB Study Area.

Increases in precipitation, and more specifically, the projected increase in the frequency and intensity of rainstorms has potential to affect the likelihood for geotechnical hazards in the GWB Study Area. In Table 6.10.a below, changes in precipitation on wet and very wet days is an indicator of extreme precipitation. In the RDOS valley bottom, precipitation on very wet days areas is expected to increase by an average of 19% by 2050 and 52% by 2080 – these projections indicate a significant change in the volume and intensity of precipitation falling on very wet days.

Table 6.10.a Projected Climate Change Effects and Potential Impacts

Projected Climate Change Effect (on RDOS valley bottom for 2050 and 2080 projections)	Potential Impacts
Increases (10-20%) in total annual precipitation, except in summer months Increases in frequency and intensity of rainstorms. Increased precipitation on the wettest day (5-12% increase), wettest 5-day period (2-10%), and 1-in-20 wettest day (10-16%). Increased precipitation on wet (12-27% increase) and very wet (19-52%) days	Increased pressure on stormwater management and drainage systems. Potential to overwhelm drainage systems and streams leading to saturation of soils, increasing likelihood of landslides.
Warmer summer temperatures, with hottest days getting hotter (4 to 7 degrees warmer on average), more days over 30°C (30-54% increase), and a longer growing season (44 to 73 days longer).	Increased potential for agricultural drought, which increases pressure to irrigate.

7. Review of Current RDOS Land Use Management Planning Policies

7.1 General

The following summarizes current RDOS Land Use Management Planning and Development Policies that currently exist within the GWB area. Current tools and planning mechanisms are the same as municipal governments but are limited because the Regional District does not have subdivision approval authority. The RDOS can manage growth and density through land use and building bylaws and policies.

This report reviews the current state of the geotechnical hazards and land use management and offers recommendations and options to further explore land use for the GWB community. By linking geologic processes with land use activities, the Geotechnical Review provides the rationale for the application and use of various policy mechanisms for the management and mitigation of geohazards.

The policies range from a higher-level growth strategy to site-specific BPs, as per the hierarchy indicated as follows:

1. Regional Growth Strategy (RGS)
2. Official Community Plan (OCP)
3. Zoning Bylaw
4. Subdivision and Development Servicing Bylaw
5. Building Bylaw
6. Board Policies
7. Geological Studies

7.2 South Okanagan Regional Growth Strategy (RGS) Bylaw No. 2770, (2017)

The South Okanagan RGS Bylaw No. 2770 (Bylaw 2770), (2017), provides goals and policies regarding growth throughout the region. The West Bench is located within RDOS Electoral Area “F” and is identified as an existing “Settlement Area” but is not designated as either a “Primary Growth Area” or a “Rural Growth Area.”

The RGS does provide policies for non-designated growth areas, such as the GWB, in the following:

> *1C-4 Limit consideration for rezoning of large rural land parcels to smaller parcels outside of Primary Growth Area and Rural Growth Areas only where such growth is infill, does not significantly increase the number of units or the established density, and respects the character of its surroundings.*

Within Goal 3: “to support efficient, effective and affordable infrastructure services and an accessible multi-model transportation network”, objectives and supporting policies that are relevant to the current Geotechnical Review include:

- Goal 3-A Direct development to areas with publicly operated services and infrastructure.
- Goal 3-C Minimize environmental impacts of infrastructure and services by considering guidelines and alternative development standards to reduce environmental impacts of hillside

development; and minimize infrastructure development impacts by avoiding hazard areas and environmentally sensitive areas.

The RDOS has initiated a review of the RGS Bylaw 2770 (2017) in 2020. As noted in the RDOS OCP for Electoral Area “F” (2018), future development of the identified growth areas, may require an amendment to the RGS to re-designate the GWB as a “Rural Growth Area”.

7.3 RDOS Electoral Area “F” Official Community Plan Bylaw No. 2790, (2018)

The RDOS Electoral Area “F” OCP Bylaw No. 2790, (2018) was recently adopted (designated OCP zones are shown in Appendix B, Map 1.0). The goals and policies of the Bylaw 2790 (2018) as they relate to growth and development of the GWB Area are summarized below. A goal of Bylaw 2790 (2018) is to provide opportunities for limited growth and housing options and maintain rural residential and agricultural character.

Bylaw 2790 (2018) policies relevant to this Geotechnical Review include:

Local Area Policies

- Support for an updated geotechnical hazard assessment in the West Bench / Sage Mesa area with new technologies (e.g., LiDAR) that were not available when the area was last assessed;
- Support for an assessment and feasibility to provide community sewer and storm water services to part (Sage Mesa) or all of the GWB;
- Subject to an updated geohazard assessment in the GWB area may consider permitting secondary suites or accessory dwellings; and,
- May consider residential development of Low Density Residential or Multiple Family Residential on three development sites – North of Sage Mesa, Pine Hills golf course and west of Westwood Properties (gravel extraction, asphalt plan area) predicated on full sewer, storm water and community water infrastructure, geohazard risks being addressed and amendment of the RGS Bylaw 2770 (2017) to designate the development site(s) as a “Rural Growth Area.”

Small Holdings Policies

Much of the GWB area is designated as SH, Small Holdings (SH) in the RDOS Bylaw 2790 (2018), except for the Westwood and adjacent future development area that is designated Low Density Residential. Relevant policies to this review and GWB include:

- Supports a minimum parcel size of one hectare for lands without community sewer within the SH designation.
- Supports secondary suites and accessory dwellings, subject to accessory dwellings on parcels less than 1.0 ha in area being connected to a community sewer system.
- Subject to an updated technical assessment of geotechnical hazards in the GWB / Sage Mesa area, may consider permitting secondary suites or accessory dwellings in the zone(s) applied to this area(the technical assessment is meant as the current Geotechnical Review).

These policies show a willingness to investigate the possibilities of development by way of the potential of secondary suites and accessory dwellings after completing a geotechnical hazards review.

Infrastructure and Servicing

Policies associated with infrastructure and servicing include:

- Board may require adequate infrastructure, including water, sewer, roads, and storm water management for new developments at no cost to the public;
- Requires that all new parcels of 1 ha or less be connected to a community sewer system;
- Supports working with the CoP to conduct a feasibility study for the extension of a sanitary sewer system (and stormwater) from the CoP to service part or all the GWB; and,
- Encourages use of permeable surfaces on driveways, parking lots and access roads, as well as other measures such a xeriscaping, infiltration basins, swales, and other sustainable design features to reduce overland runoff.

Development Permit (DP) Areas

RDOS Electoral Area "F" has designated two DP areas that apply to the GWB area: Environmentally Sensitive Development Permit (ESDP) Area and the Watercourse Development Permit (WDP) Area.

ESDP Areas have been designated to protect the natural ecosystem. Areas designated include gullies, silt bluffs and larger undeveloped sites – many of the areas identified as having geotechnical hazards.

WDP Areas have been designated to protect fish and fish habitat along water courses and are applied to areas adjacent to fish-bearing watercourses or connected to fish-bearing water courses with fish. Watercourse DP Areas may also apply to isolated wetlands that may be environmentally sensitive or function as groundwater recharge areas. Watercourse DP Areas are assessed based on the *Provincial Riparian Areas Protection Regulation* (RAPR).

7.4 RDOS Electoral Area "F" Zoning Bylaw No. 2461, (2008)

As per the RDOS Electoral Area "F" Zoning Bylaw No. 2461 (Bylaw 2461) (2008), the majority of the GWB is zoned as West Bench Small Holdings (SH6). The principal use permitted is "single detached dwellings" and accessory uses include agriculture, bed and breakfast operations, home occupations and accessory buildings and structures. The minimum lot size in this zone is 0.25 ha when connected to a community sewer and water system; 0.5 ha when connected to a community sewer system and serviced by a well; or 1.0 ha when serviced by well and approved septic system.

Sage Mesa (and Westwood / Husula Highlands) are zoned West Bench Low Density Residential (RS6). The principal use permitted is single detached dwelling with accessory uses of bed and breakfast, home occupation and accessory buildings and structures. The minimum lot size is 500 m^2 when connected to a community sewer and water system; 0.5 ha when connected to a community sewer system and serviced by well; or 1.0 ha when serviced by well and approved septic system. This zone reflects the small lot character of Sage Mesa when compared to the more rural character of West Bench.

In RDOS Electoral Areas "A", "C", "D", "E" and "I" secondary suites are permitted in single family dwelling in Agricultural, Rural Holdings and Low-Density Residential Zones, with carriage houses allowed in limited areas. Carriage houses are not currently permitted in the GWB area based on recommendations by Klohn Leonoff (1992).

7.5 RDOS Subdivision Servicing Bylaw No. 2000, (2002)

The levels of infrastructure works, and services required for development are outlined in the RDOS Subdivision Servicing Bylaw No. 2000 (Bylaw 2000), (2002). If subdivision was to be approved and an additional parcel is created, the parcel must be a minimum of 1 hectare in size to be serviced by an on-site septic field or a connection to a community sanitary sewer system if the parcel is less than 1.0 hectare. The minimum level of service in Bylaw 2000 (2002) for a rural lot one-hectare and larger in size includes a groundwater well and on-site septic system, and on-site drainage.

The GWB area is serviced by two water systems but does not have a community sanitary sewer or community stormwater drainage systems. The MoTI is responsible for public drainage within road right of ways. There is little opportunity for subdivision as most lots in GWB are less than 1.0 hectare in size, and due to the requirement of a community sanitary sewer.

The approving authority for subdivisions in the RDOS is through MoTI. Applications for subdivision are referred from MoTI to the RDOS and are reviewed for compliance to Bylaw 2000 (2002) requirements. The MoTI Approving Officer has many requirements for subdivision applications, including the requirement for a geotechnical report. Since the Klohn Leonoff (1992) report, there has been little to no subdivision activity in the Sage Mesa and West Bench areas.

7.6 RDOS Building Bylaw No. 2805, (2018)

The RDOS offers building inspection services to GWB by way of the Building Bylaw No. 2805 (Bylaw 2805), 2018 and applies to the geographical areas such as land, the surface of water, air space, buildings, or structures; specifically:

> “This bylaw applies to the design, construction or occupancy of new buildings or structures, (including on site preparations, interconnection of modules, connection to services and installation of appliances for mobile homes and factory built houses) and the alteration¸ reconstruction, demolition, removal, relocation or occupancy or change of use or occupancy of existing buildings and structures (including on site preparations, interconnection of modules, connection to services and installation of appliances for mobile homes and factory built houses).”

The Bylaw 2805 (2018) does not:

- protect of owners, designers, or constructors from economic loss;
- give the assumption by the Regional District or any Building Official of any responsibility for ensuring the compliance by any owner, his or her representatives or any employees, constructors or designers retained by the owner, with the Building Code, the requirements of this bylaw, or other applicable enactments, codes, or standards;
- provide any person a warranty of design or workmanship with respect to any building or structure for which a BP or occupancy permit is issued under this Bylaw;
- provide any person a warranty or assurance that construction undertaken under BPs issued by the Regional District is free from latent, or any, defects; or
- provide protection of adjacent real property from incidental damage or nuisance.

For context and perspective, the RDOS has stated that 158 BPs have been issued between January 1992 to June 2020. The RDOS does not track the number BP issued with a geotechnical review completed under the Board Policy No. 3740-00.02, see Section 7.7 for the description of the policy.

7.7 RDOS Board Policies

A Board Policy gives reasoning and direction to the RDOS on how to conduct local government business. In 1992, the Regional Board adopted a policy on BP Issuance for the West Bench, Sage Mesa, Husula Highlands, West Bench Estates Area (Policy No. P3740-00.02) after receiving the report prepared by Klohn Leonoff (1992) (see Section 7.6). This policy was in response to the Klohn Leonoff (1992) report recommendations that focused on subdivision activity and includes excerpts from the report. This policy is applicable to the entire GWB area and applies a Zone designation 1,2,3,4 and 5 based on the soil conditions (hazards) review by the Klohn Leonoff (1992) report and requires:

- Upon receipt of a BP application for construction in the GWB area, the Building Inspector will provide the applicant access to the Klohn Leonoff (1992) report and advise that a detailed report by a certified professional engineer with experience in geotechnical engineering is required for the proposed development. This report is to certify that the land may be used safely for the use intended and to assess the impacts of the proposed development on adjacent and downstream lands.
- If the above conditions are met, the Building Inspector may issue a BP with the condition that the landowner registers a covenant with the Regional District to use the land only in the manner determined and certified by the engineer.
- If the geotechnical engineer determines that the land cannot be used safely for the use intended or that adjacent or downstream lands may be rendered unsafe, the Building Inspector shall refuse to issue the permit and provide the reasons for the denial.
- The Policy then provides for an appeal directly to the Regional Board who may approve or deny the issuance of the BP and require a covenant.
- The Policy also gives a definition of “construction” for the purposes of this policy:
“new construction of a building or the structural alteration or addition to an existing building but does not include the repair or reconstruction of an existing building or structure or the construction of a deck, balcony, shed, carport or garage that does not contain any plumbing fixtures.”

Section 56 of the *Community Charter* is also an available mechanism that local government building inspectors can utilize to require a geotechnical engineering report when a building or structure is proposed on hazardous lands, such as flooding or landslide. This report is to determine the suitability of the lands for the proposed building or structure and to obtain professional recommendations for conditions necessary to assure safe use of the land.

7.8 Geological Studies

In October 1991, the RDOS issued a “Proposal Call” to “determine criteria for development, taking into account identified geological conditions and associated risks.” The RDOS drafted a similar scope as what was given for this Geotechnical Review report: to review the *Geological Hazards and Urban Development of the Silt and Deposits in the Penticton Area*, (Nyland and Miller, 1977), analyse any other existing data and past reports, conduct field research, consult with the GWB residents, and develop conclusions and recommendations to assist with the land use matters in GWB. The Klohn Leonoff (1992) report. was the product of the “Proposal Call”.

The Klohn Leonoff (1992) report provided the following recommendations regarding land use management planning and regulatory hazard response:

- The study results led to the development of five risk categories, with Zone 1, being the highest risk. Most of the West Bench (below West Bench Drive) and all of Sage Mesa was designated to be Zones 1-3. Within Zones 1 and 2 new communities and subdivision of lands are not recommended. In Zone 3, subdivision is only recommended with installation of sanitary and storm sewers. Subdivision in Zones 4 and 5 is also restricted to areas with installed sewers or where water is drawn from groundwater.
- Development in the hazard zones is recommended only with implementation of mitigative measures that are practical, enforceable at time of construction and do not require ongoing policing by the RDOS. Recommended measures include:
  - Restrict development in the GWB area and catchment area to limit the quantity of water entering the silts and gullies;
  - Install septic sewers, storm sewers, road curbs and roof and driveway runoff collection to carry water to Okanagan Lake;

- Improve the community water system;
- Collect groundwater downstream of Madeline (Max) Lake and use as irrigation or transport to Okanagan Lake; and,
- Restrict construction of swimming and ornamental pools.

The Klohn Leonoff (1992) report states: “The obvious approach to reducing risk due to hazard is simply to avoid the risk. This can be achieved by building in areas where the risk is reduced”. The authors also recognize that “where development has already occurred, hazard avoidance would not be a possibility” and “if the risk of hazard can be reduced to acceptable limits of hazard reduction may be chosen an alternative to not developing”.

The Klohn Leonoff (1992) report has provided recommendations with respect to subdivision activity within the GWB Study Area and recommends no subdivisions in Zones 1-3. The message for future building activity in high hazard areas, Zones 1 – 3, is not as clear but seems to suggest that this should not occur until mitigative measures have taken place. Overall, the message is that there should be no further development in the GWB area without implementation of the mitigative measures outlined above. With an abundance of caution, these recommendations led to the RDOS drafting and adopting the policy “Building Permit Issuance West Bench, Sage Mesa, Husula Highlands, West Bench Estates Area” (detailed in Section 7.6) and may have influenced decisions of land use through the RDOS Bylaws.

7.8.1 Klohn Leonoff 1992 Decision Matrix

A “decision matrix” or regulatory hazard response model was created in the Klohn Leonoff (1992) report to assist the RDOS in land management decisions. Five zones were defined in the matrix (presented in Table 7.8.a) and indicate the soil conditions as follows:

Zone 1. Landslide Hazard

Zone 2. Sinkhole Hazard

Zone 3. Silt Bluff

Zone 4. Gravel or Bedrock in study area

Zone 5. Gravel or Bedrock outside study area

Zone 5 was included in the GWB Study Area for the current Geotechnical Review report.

The “decision matrix” also used a development type and only focused on applications for subdivision. Specifically, the subdivision of existing lots into larger (> 1 Acre (4,040 m^2)) parcels, or subdivision into smaller (< 1 Acre (4,040 m^2)) parcels; or the creation of a “new community”. The “new community” is suspected to be a reference to the development of Red Wing Subdivision on the PIB lands and outside the study area of this report.

In response to these types of soil conditions and subdivisions, the administrative direction presented at the time included:

- (a) “approved without conditions”
- (b) “approved only with a covenant registered on the property title clearly defining the hazards present”
- (c) “approved only with the installation of septic sewer and storm sewers”
- (d) “approved only with irrigation or domestic water drawn from groundwater”
- (e) “not approved”

Table 7.8.a Decision Matrix from the Klohn Leonoff Report (to be used with Drawing D-1007)

Zone	New Community	Subdivision of Existing Lot to >0.5 Acre	Subdivision of Existing Lot to >1.0 Acre
1. Landslide Hazard	e	e	e
2. Sinkhole Hazard	e	e	e
3. Silt Bluff	e	c	c
4. Gravel or Bedrock in Study Area	c	c	d
5. Gravel or Bedrock outside Study Area	c	c	d

As a result of the final Klohn Leonoff (1992) Report a RDOS Board Policy was adopted for GWB area BP processes. This policy is described in Section 7.7.

The RDOS has had challenges with interpreting the matrix and recommendations contained in the Klohn Leonoff (1992) report over the years, which include:

- The decision matrix only focused on subdivision and not the overall land use of GWB.
- Subdivision approvals lie outside the RDOS authority.
- Future subdivision in the GWB Study Area is mainly premised on the installation of community sanitary and storm systems. Public storm drainage is generally outside of the RDOS authority.
- The matrix does not consider any increase of land use to single-lot residential development such as additions to existing homes, existing dwelling being replaced by larger dwellings and accessory dwellings.
- The discussion of the additional development of “hard surfaces” by land use is not fully realized.
- The lack of guidance to future review of the geotechnical hazards in the GWB area.
- How to interpret the evolution of land use in the GWB with the constants of the existing hazards.

The general intent of this current GWB Geotechnical Review report is to review the geotechnical hazards and the land use mechanisms in place and suggest administrative guidance to development approval decisions.

8. Land Use Effects and Regulatory Tools for Hazard Land Management

8.1 Land Use Effects on Geohazards

For practical purposes, understanding the land use activity implications on geomorphological process and geohazards such as landslide initiation, sinkhole development, or soil collapse / compression, helps in the development of policies and guidelines for the management and/or mitigation of the hazards.

Land use activities that may potentially have a geotechnical issue, or that may have a negative effect on the geological stability of lands, include land densification, increased water inputs to the ground, changing slope geometry, and soil loading. Table 8.1.a, below, lists a variety of example land use activities and the associated implications on geomorphological process, or geohazard.

Table 8.1.a Effects of Example Land Use Activity on Geohazards

Example Land Use Activity	Effects on Geomorphologic Process or Geohazards
Area Densification (i.e., rezoning or subdivision)	▪ Increased impervious (hard) surfaces will increase surface water runoff (i.e., roofs and concrete or asphalt surfaces) ▪ Altered slope geometry and soil disturbance through fill placement and/or grading ▪ Increased water input to soils through sanitary and/or stormwater contributions
Parcel Densification (i.e., accessory dwelling or secondary suite)	▪ Increase surface water runoff from impervious surfaces ▪ Altered slope geometry and soil disturbance through fill placement and/or grading ▪ Increased water input to soils through sanitary and/or stormwater contributions. Difficult to manage occupancy limits for a specific lot. ▪ Geohazards are not necessarily related to parcel size but the effects of parcel densification are more apparent on smaller lots than on larger lots.
Swimming pool construction	▪ Potential impact on slope stability and sinkhole development due to introduction of water to soils by leaks and/or overland draining. ▪ Potential impact on slope stability by soil loading (above-ground pools)
Irrigation (residential use or agricultural use)	▪ Potential impact on slope stability and sinkhole development due to introduction of water to ground (excessive use or leaks)
On-site sewage systems	▪ Potential impact on slope stability and sinkhole development due to introduction of water to ground (excessive use or leaks)
Stormwater	▪ Potential impact on slope stability and sinkhole development due to introduction of water to ground associated with the concentration and diversion of surface water runoff.
Impervious surfaces (i.e., roads, driveways, parking lots, roof tops)	▪ Impervious surfaces can result in the concentration and diversion of surface water runoff which can impact slope stability and sinkhole development.
Excavation and fill placement, including soil and/or landscape waste disposal	▪ Changing slope geometry through excavation and fill placement can impact slope stability. For example, removal of toe support along base of a steep slope. ▪ Placement of fill in sinkholes and/or gullies may lead to future instability. ▪ Spoiling soil and/or landscape waste into gullies, or onto a steep slope can impact slope stability.

8.2 Regulatory Tools for Hazard Land Management

Table 8.2.a, below, lists a variety of land use activities and the possible regulatory tools available for hazard land management.

Alternate regulations may include adopting a Hazard Land Development Permit Area, establishing minimum reporting requirements for geotechnical investigations, and restricting development from high hazard zones. Considerations for new regulatory approaches are explored further in Section 9.

Table 8.2.a Possible Regulatory Tools for Hazard Land Management

Example Land Use Activity	Possible Regulatory Tools for Hazard Land Management
Area Densification (i.e., rezoning or subdivision)	▪ RDOS manages subdivision through Land Use and Works and Services bylaws in the subdivision application review process. ▪ Require geotechnical report that comments on soil stability, including on site and off-site effects.
Parcel Densification (i.e., accessory dwelling or secondary suites)	▪ Use zoning bylaws to manage development density (e.g., prohibit secondary suites and accessory dwellings) and land use (e.g., community sanitary sewer and storm drainage). ▪ Limit infill development to larger (>1 ha) lots.
Swimming pool construction	▪ Use zoning and/or Development Permit Areas to specify conditions for developing pools. ▪ Require a geotechnical report that comments on soil stability, operation of pool (including where to drain for maintenance and servicing) and risk of occurrence.
Irrigation (residential use or agricultural use)	▪ Develop land use policies specific for hazard lands. ▪ Continue to use water meters and leak detection program to detect excessive water use and/or leaks. ▪ Use Water Conservation Plan and Water Use bylaws to limit water use. ▪ Develop Best Management Practices (BMPs) to encourage use of low water use landscaping.
On-site sewage systems	▪ Use land use bylaws to establish minimum servicing levels for land development (e.g., subdivision and multi-unit forms of development).
Stormwater	▪ Advocate that the MOTI develop a stormwater management plan for the GWB Study Area to facilitate management of runoff. ▪ For land development, develop policies or DP area guidelines, to direct use of in-ground stormwater disposal (i.e., dry wells) to safe areas. ▪ Establish reporting requirements for geotechnical investigations that includes stormwater runoff be addressed.
Impervious surfaces (i.e., roads, driveways, parking lots, roof tops)	▪ Continue to use zoning bylaws to limit percentage of lot covered by impervious surfaces, including roofs, decks, and paved surfaces. ▪ Develop Best Management Practices to encourage use of pervious surfaces and vegetation for site coverage.
Excavation and fill placement (including soil and/or landscape waste disposal)	▪ Use Development Permits and/or Building Permits to require plans that show limits of excavation and fill placement. ▪ Implement a soil deposition and removal bylaw to require relocation permits to track volumes being removed or placed. ▪ Use BMPs to prohibit filling in sinkholes and/or spoiling material down steep gully slopes.

9. Recommendations

9.1 General

The following recommendations are presented for consideration by RDOS with the overall objective of reducing geotechnical risk in the GWB Area.

9.2 Develop Land Use Management Policies for Hazard Lands

9.2.1 Incorporate Results of this Study into Current RDOS Bylaws

It is recommended that the results of this study be taken into consideration in the development and update of current RDOS bylaws for land use management. Specifically, the Geotechnical Constraints Zone Map (Appendix B; Map 6.0) should be incorporated into a land use bylaw.

9.2.2 Develop Geotechnical Report Requirements

It is recommended that minimum report requirements for geotechnical studies conducted for properties in the Study Area be prepared and adopted by bylaw (e.g., through the Regional District's Building Bylaw 2805 (2018) or the Development Procedures Bylaw as formal application requirements).

Although a Building Inspector can require a geotechnical report be provided to the Regional District as part of a BP application, there is limited ability to review the report and to enforce the recommendations provided in the report. By developing specific Geotechnical Terms of Reference, some of the uncertainty associated with interpreting reports could be reduced and will help ensure that all geohazards of concern are addressed in a consistent manner.

It is recommended that geotechnical reports include a signed Assurance Statement accompanied by a checklist of technical report content requirements with a signed and sealed document summarizing the assessed hazards in relation to the Geotechnical Constraints Zones. It is recommended that RDOS consider an approach similar to what has been developed by the Fraser Valley Regional District[5].

9.2.3 Soil Removal and Deposition Bylaw

It is recommended that RDOS introduce a Soil Removal and Deposition Bylaw to regulate, monitor, and limit the removal and deposition of soil through permitting. Combined with the hazard mapping, soil removal and deposition activities can be reduced in high hazard areas and documented within the GWB area.

9.2.4 Develop Specific Land Use Activity Best Management Practices

The RDOS may develop policies and/or Best Management Practices (BMPs) for specific land use activities that are associated with geohazards in the GWB area. Example high risk land use activities include irrigation, landscape practices, and swimming pool use. BMPs provide a means to manage those activities to reduce geotechnical risk.

[5] https://www.fvrd.ca/assets/Services/Documents/Planning~and~Development/Application~Forms~and~Resources/APEG%20Form.pdf

9.2.5 Public Education and Outreach

It is recommended that the RDOS expand educational resources for GWB residents through public outreach and publication of educational materials. The District can disseminate important information regarding geohazards, the land use implications on geohazards, and provide educational information informing residents of the geotechnical sensitivity and potential trigger factors leading to issues.

Example educational materials to be developed and published may include BMPs for water use, irrigation practices, soil or yard waste debris placement, and incident reporting.

9.3 Address Data Gaps

9.3.1 Incidence Tracking and Data Management

It is recommended that RDOS develop a web-based reporting tool that could be accessed by staff and potentially residents to record geohazard events so that they may be responded to appropriately. Operations and maintenance activities can be recorded and potentially integrated with the already existing water leak detection program that tracks the location of continuous water leaks. The tool could also be used to track and record activities where leaks have been addressed and where repairs to public infrastructure has been completed.

One of the challenges encountered during this Geotechnical Review was that there is a lack of tracking geohazard incidences by the RDOS and other government and local authorities. Incidences may include landslide response, sinkhole development, road / sidewalk repairs attributed to erosion, soil collapse / compression, or piping.

It is also recommended that a publicly accessible database of previously completed geohazard and geotechnical reports, including this one, be made available. Access to geohazard reports would assist all other professionals working in the area to provide consistent results and would ensure that relevant information upon which judgements are made regarding hazard and risk are made available.

Incidence tracking and data management would reduce the number of information requests directed to RDOS staff and would provide a living repository that would ensure the future Geotechnical Review updates incorporate relevant historical geohazard data.

9.3.2 Additional Subsurface Soils Investigation

It is recommended that additional surface soils investigations be undertaken in conjunction with future geotechnical studies of the West Bench area to address data gaps identified in this Geotechnical Review report. This report utilized existing borehole and water well records, and no additional subsurface investigation work was completed due to the scope of budget of the project.

While completing this Geotechnical Review it was found that there was limited historic subsurface available upon which to characterize the underlying soils throughout the GWB area. There was insufficient data to fully characterize the interface between the outwash sands and gravels and the Glaciolacustrine Silt. This information would allow for further refinement of the terrain map and the corresponding sinkhole and collapsible / compressible soils hazard maps.

The study also identified that there is spatial variability of the plasticity of Glaciolacustrine Silt throughout the GWB Study Area. Soil plasticity is a key parameter in determining susceptibility to sinkhole formation. Thus, further information on the material properties of the silts would allow for further refinement of the sinkhole and collapsible / compressible soils hazard maps.

Further information may be gained by undertaking additional subsurface soils investigation or drilling boreholes. The boreholes should be strategically placed to further define the interface between the outwash sands and gravels and the Glaciolacustrine Silt, with soil characterization laboratory testing undertaken on retrieved samples of the Glaciolacustrine Silts to further investigate the correlation between low plasticity and sinkhole susceptibility.

9.3.3 Additional Groundwater Investigation and Monitoring

Additional groundwater investigation and monitoring is warranted to better understand the hydrogeologic regime within the GWB Study Area. If resources are made available, further work could include monitoring groundwater levels in existing wells and expanding work to include the development of new monitoring wells.

Additional work could also include an update and further development of a detailed water balance for the GWB Study Area to account for different land use activities, different water use character, additional development, differing climate conditions, and predictions for climate change.

This Geotechnical Review report provides little additional information on the assessment of groundwater conditions within the GWB Study Area, as there was no additional data to review. Previous investigations of groundwater and the potential effects of development on groundwater were relied upon.

The groundwater investigation by Pacific Hydrology and Piteau Associates (1993) concluded there would be no significant adverse effects on the silt soils on the West Bench because water volumes would be low, that the area was hydraulically isolated from the West Bench by a buried bedrock ridge, and that groundwater is transmitted through the silt at a low gradient and low velocity. Their work included the installation of several groundwater wells and ultimately recommended that a systematic monitoring program be completed to ensure no adverse impacts associated with development of the Inland Property, located within the sand and gravel sediments near Madeline (Max) Lake. Several groundwater monitoring wells are understood to still be functioning and could be monitored to support future development. It is presumed that since the development of Inland Properties never occurred, no further investigation or monitoring of groundwater conditions was conducted.

9.3.4 Update the 1994 Wastewater Management Plan

There are no immediate plans to connect properties within the GWB to a community sanitary system or the CoP wastewater collection system. RDOS, therefore, relies upon the Wastewater Management Plan developed for Electoral Areas “E” and “F” in 1994. Currently, updates to the plan are considered cost prohibitive. When the time is appropriate and funding is available, the Wastewater Management Plan should be updated and expanded to include an assessment of groundwater and geotechnical impacts. For maximum benefit, updates to the plan should coincide with the development of a stormwater management plan.

9.3.5 Advocate Development of a Stormwater Management Plan

It is recommended that a Stormwater Management Plan (SMP) be developed for the GWB area, considering the linkages between drainage servicing, land use planning and the unique geohazards.

As the Regional District has no authority in relation to stormwater management from road surfaces, RDOS should advocate for a stormwater management plan to be undertaken and implemented by the MOTI. To be complete, the plan should consider discharge from both residential (private) and road (public) sources. In addition, the stormwater management plan (or stormwater master plan) promotes the collection of stormwater from residents, roads, and the environment to areas of lower geotechnical hazard. The plan should develop recommendations for approved drainage solutions and irrigation practices based on soil characterization, land use, and proximity to known geohazards. The potential benefits of undertaking this plan include an improved functioning road network and reduced geotechnical risk.

9.3.6 Conduct Periodic Review of Geohazard Conditions

It is recommended that the geohazard conditions within the GWB area be periodically reviewed. The current Geotechnical Review should be revisited in the event of changed conditions, and at a frequency of no more than every ten years. Ten years is a time interval within which there is the potential to detect, and adapt to, geotechnical changes (i.e., landslides, sinkhole development, other recorded incidences). In addition, a ten-year interval roughly corresponds to the frequency of Official Community Plan updates.

10. Study Limitations and Closure

This Geotechnical Review report of the GWB Study Area is intended as a high-level regional assessment of geohazards. The review is completed for the GWB area as a whole and is not necessarily refined enough to be interpreted at a site level. For this reason, it is suggested that, where hazard boundaries intercept property boundaries, the more conservative rating should be applied to the entire property. For example, if a specific lot has areas rated both “moderate” and “high” then it is recommended that the higher of the ratings be applied when determining the appropriate level of response to a development application.

The Geotechnical Review relied upon information that was available at the time of the assessment. This includes limited and dated geotechnical borehole data, limited, and dated groundwater well data, and no additional subsurface investigation. The reliability and accuracy of the mapping and analysis would be improved with additional investigation, well monitoring, and material testing of the Glaciolacustrine Silts.

This Geotechnical Review report provides a snapshot of terrain conditions at the current time. It is anticipated that terrain conditions will change with changes to environmental and/or development conditions. It is expected that a Geotechnical Review should be revisited should conditions change and at a frequency of no more than every ten years. By implementing the recommendation for incidence tracking and development of a geohazard report repository, updates to the Geotechnical Review will be easier.

Due to the inherent uncertainty in the soil material properties and the assumed (and conservative) parameter values used in the slope stability analysis, the landslide setback criteria are also conservative. Further refinement of the model, based on updated material testing, should be undertaken when considering development on specific sites.

We trust this report meets your requirements. Please contact us if you have any questions or comments concerning this report.

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Appendix A

Statement of General Conditions – Geotechnical

1. Standard of Care

Ecora Engineering and Resource Group Ltd. (Ecora) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

2. Basis and Use of the Report

This report and the recommendations contained in it are intended for the sole use of Ecora's Client. Ecora does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Ecora's Client unless otherwise authorized in writing by Ecora. Any unauthorized use of the report is at the sole risk of the user. In order to properly understand the suggestions, recommendations and opinions expressed herein, reference must be made to the whole of the report. We cannot be responsible for use by any party of portions of the report without reference to the whole report.

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3. Alternate Report Format

Where Ecora submits both electronic file and hard copy versions of reports, drawings and other project-related documents, only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Ecora shall be deemed to be the original for the Project. Both electronic file and hard copy versions of Ecora's deliverables shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Ecora.

4. Soil, Rock and Groundwater Conditions

Classification and identification of soils, rocks and geological units have been based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Ecora does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities such as traffic, excavation, groundwater level lowering, pile driving, blasting on the site or on adjacent sites. Excavation may expose the soils to climatic elements such as freeze/thaw and wet /dry cycles and/or mechanical disturbance which can cause severe deterioration. Unless otherwise indicated the soil must be protected from these changes during construction.

5. Environmental and Regulatory Issues

The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report. The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

6. Sample Disposal

Ecora will dispose all soil and rock samples for 30 days following issue of this report. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

7. Construction Services

During construction, Ecora should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Ecora's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Ecora's report. Adequate field review, observation and testing during construction are necessary for Ecora to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Ecora's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

8. Job Site Safety

Ecora is responsible only for the activities of our employees on the jobsite. The presence of Ecora's personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that Ecora never occupy a position of control of the site. The Client undertakes to inform Ecora of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions or materials and that such a discovery may result in the necessity to undertake emergency procedures to protect our employees as well as the public at large and the environment in general.

9. Changed Conditions and Drainage

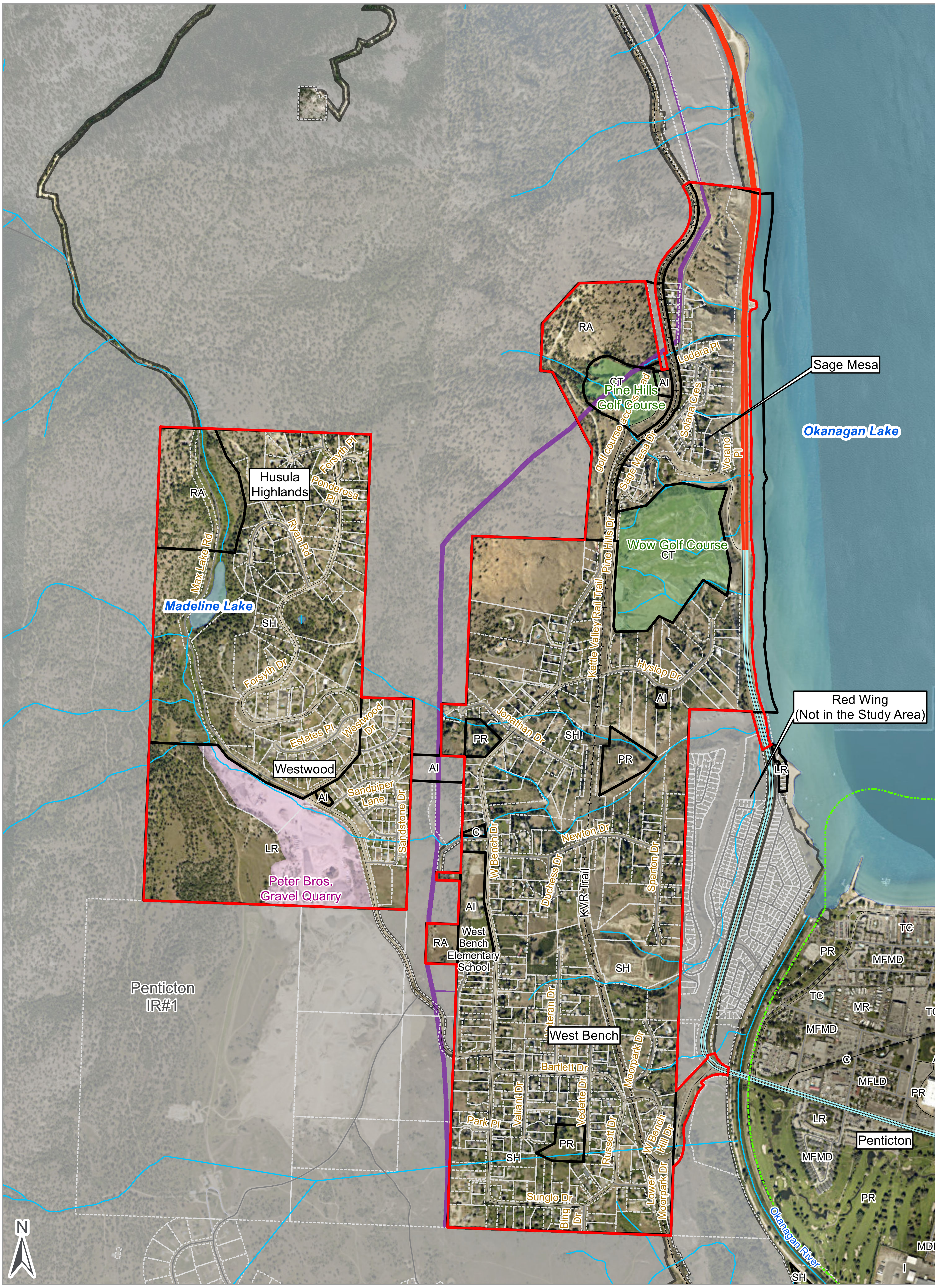
Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Ecora be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Ecora be employed to visit the site with sufficient frequency to detect if conditions have changed significantly. Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Ecora takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

10. Services of Sub consultants and Contractors

The conduct of engineering and environmental studies frequently requires hiring the services of individuals and companies with special expertise and/or services which we do not provide. Ecora may arrange the hiring of these services as a convenience to our Clients. As these services are for the Client's benefit, the Client agrees to hold the Company harmless and to indemnify and defend Ecora from and against all claims arising through such hiring's to the extent that the Client would incur had he hired those services directly. This includes responsibility for payment for services rendered and pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. In particular, these conditions apply to the use of drilling, excavation and laboratory testing services.

Appendix B

Maps (1.0-6.0)



GREATER WEST BENCH STUDY AREA

Clarke Geoscience Ltd.

ecora

GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

OCP Designation

- Administrative, Cultural and Institutional (AI)
- Comercial Tourism (CT)
- Commercial (C)
- Low Density Residential (LR)
- Parks and Recreation (PR)
- Resource Area (RA)
- Small Holdings (SH)
- Gas Line
- RDOS Legal Parcels
- City of Penticton Boundary
- First Nations Land Boundaries
- Greater West Bench Study Area

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

0 250 500 Meters

Project No.: 191010

Client: Regional District of Okanagan Similkameen

NAD 1983 UTM Zone 11N

Date: 2021/12/07

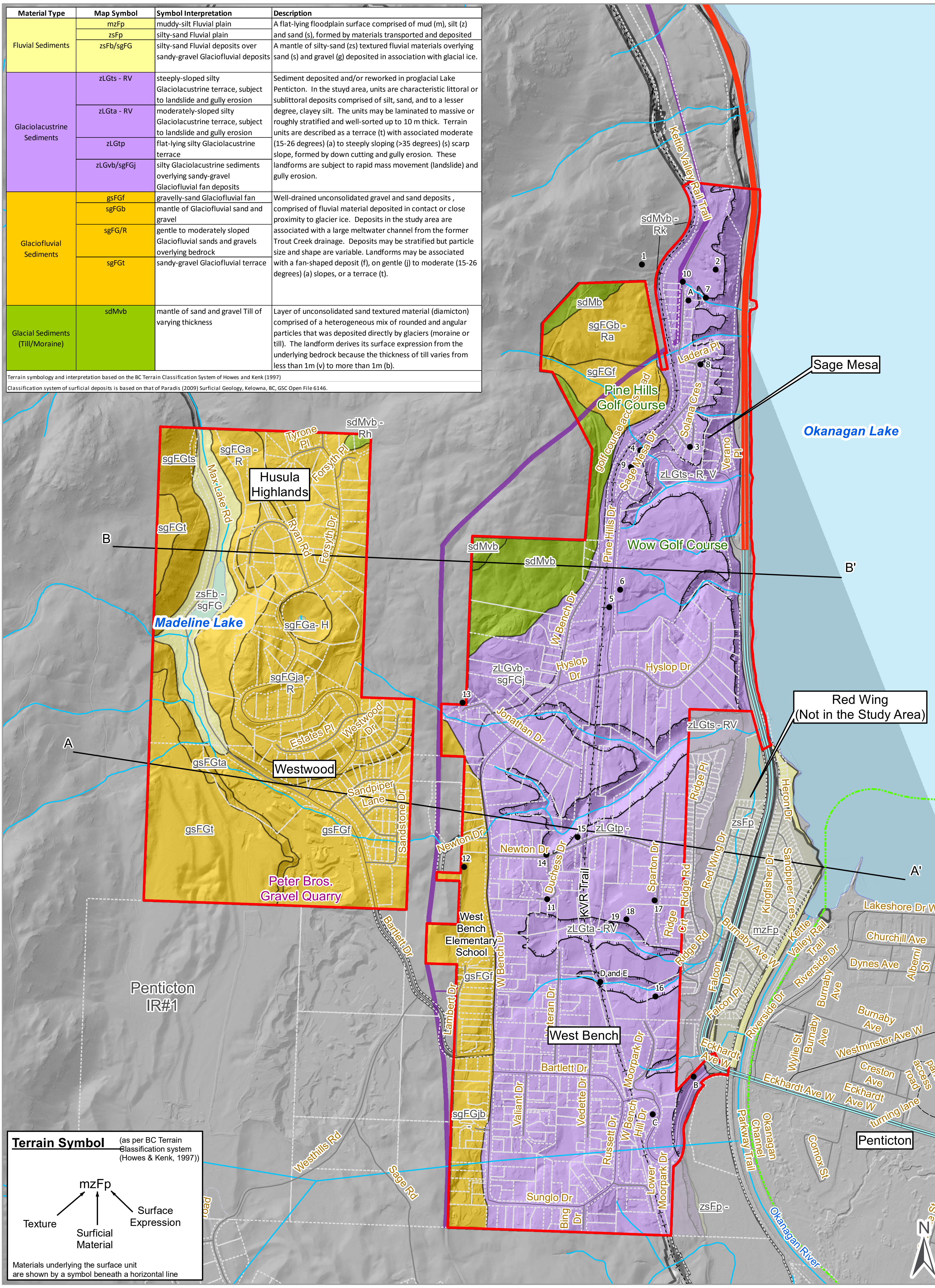
Drawn: MT Check: JC

Map 4.0

Material Type	Map Symbol	Symbol Interpretation	Description
Fluvial Sediments	mzFp	muddy-silt Fluvial plain	A flat-lying floodplain surface comprised of mud (m), silt (z) and sand (s), formed by materials transported and deposited
	zsFp	silty-sand Fluvial plain	
	zsFb/sgFG	silty-sand Fluvial deposits over sandy-gravel Glaciofluvial deposits	A mantle of silty-sand (zs) textured fluvial materials overlying sand (s) and gravel (g) deposited in association with glacial ice.
Glaciolacustrine Sediments	zLGts - RV	steeply-sloped silty Glaciolacustrine terrace, subject to landslide and gully erosion	Sediment deposited and/or reworked in proglacial Lake Penticton. In the stuyd area, units are characteristic littoral or sublittoral deposits comprised of silt, sand, and to a lesser degree, clayey silt. The units may be laminated to massive or roughly stratified and well-sorted up to 10 m thick. Terrain units are described as a terrace (t) with associated moderate (15-26 degrees) (a) to steeply sloping (>35 degrees) (s) scarp slope, formed by down cutting and gully erosion. These landforms are subject to rapid mass movement (landslide) and gully erosion.
	zLGta - RV	moderately-sloped silty Glaciolacustrine terrace, subject to landslide and gully erosion	
	zLGtp	flat-lying silty Glaciolacustrine terrace	
	zLGvb/sgFGj	silty Glaciolacustrine sediments overlying sandy-gravel Glaciofluvial fan deposits	
Glaciofluvial Sediments	gsFGf	gravelly-sand Glaciofluvial fan	Well-drained unconsolidated gravel and sand deposits , comprised of fluvial material deposited in contact or close proximity to glacier ice. Deposits in the study area are associated with a large meltwater channel from the former Trout Creek drainage. Deposits may be stratified but particle size and shape are variable. Landforms may be associated with a fan-shaped deposit (f), on gentle (j) to moderate (15-26 degrees) (a) slopes, or a terrace (t).
	sgFGb	mantle of Glaciofluvial sand and gravel	
	sgFG/R	gentle to moderately sloped Glaciofluvial sands and gravels overlying bedrock	
	sgFGt	sandy-gravel Glaciofluvial terrace	
Glacial Sediments (Till/Moraine)	sdMvb	mantle of sand and gravel Till of varying thickness	Layer of unconsolidated sand textured material (diamicton) comprised of a heterogeneous mix of rounded and angular particles that was deposited directly by glaciers (moraine or till). The landform derives its surface expression from the underlying bedrock because the thickness of till varies from less than 1m (v) to more than 1m (b).

Terrain symbology and interpretation based on the BC Terrain Classification System of Howes and Kenk (1997)

Classification system of surficial deposits is based on that of Paradis (2009) Surficial Geology, Kelowna, BC, GSC Open File 6146.



TERRAIN MAP

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GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

- Field Obs. Locations (See table in report)
- Cross Sections
- Crest of Slope
- Terrain Unit Boundary
- Gas Line
- RDOS Legal Parcels
- First Nations Land Boundaries
- City of Penticton Boundary
- Greater West Bench Study Area

Material Class

- Fluvial Sediments
- Glaciolacustrine Sediments
- Glaciofluvial Sediments
- Glacial Sediments (Till/Moraine)

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

0 250 500 Meters

Project No.: 191010

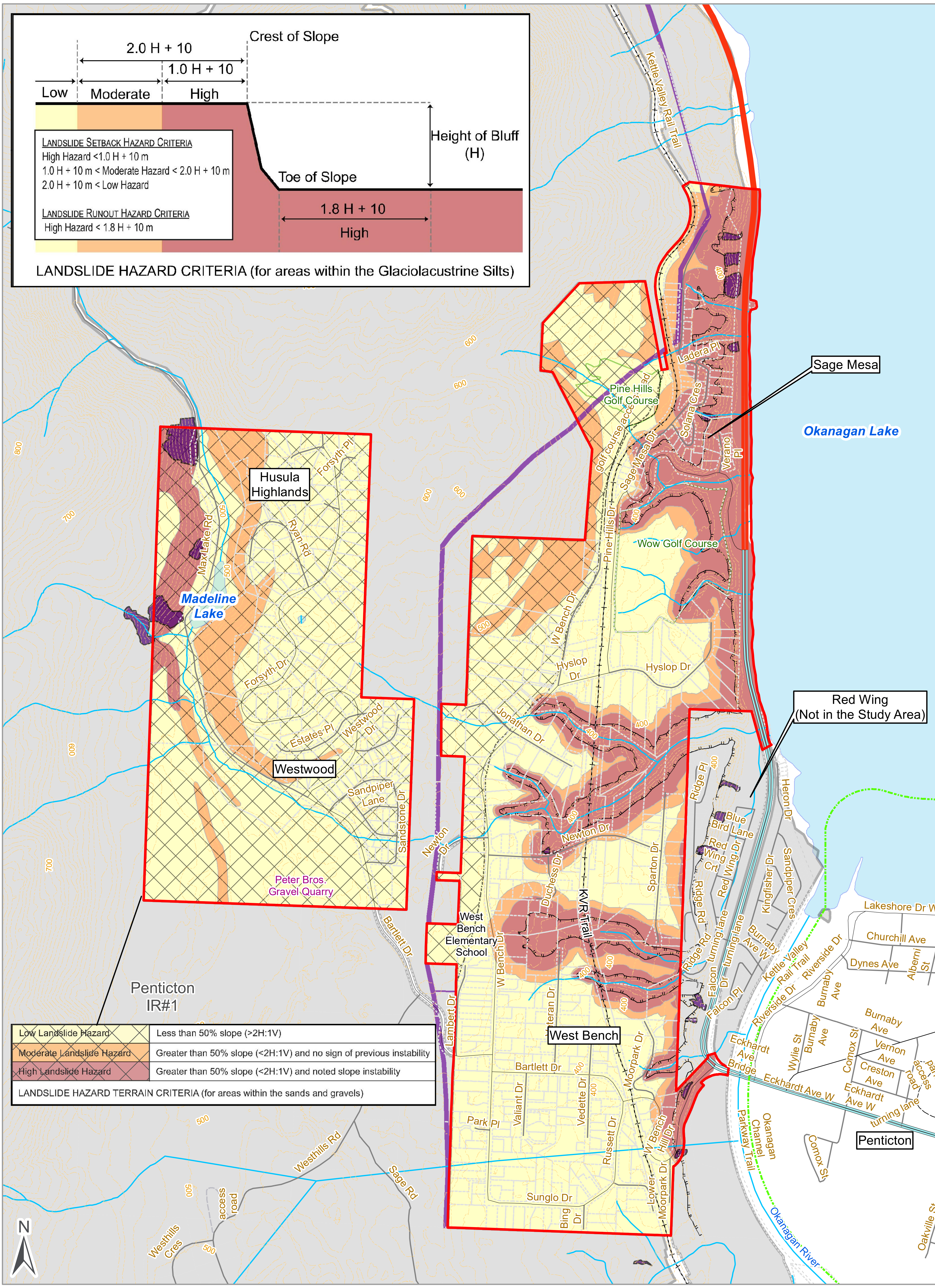
Date: 2021/12/07

Client: Regional District of Okanagan Similkameen

Drawn: MT Check: JC

NAD 1983 UTM Zone 11N

Map 2.0



LANDSLIDE HAZARD ZONES

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GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

- Crest of Slope
- Landslides (all identified)
- Low Landslide Hazard Zone
- Moderate Landslide Hazard Zone
- High Landslide Hazard Zone
- Landslide Hazard Within Sands and Gravel
- Gas Line
- RDOS Legal Parcels
- First Nations Land Boundaries
- City of Penticton Boundary
- Greater West Bench Study Area

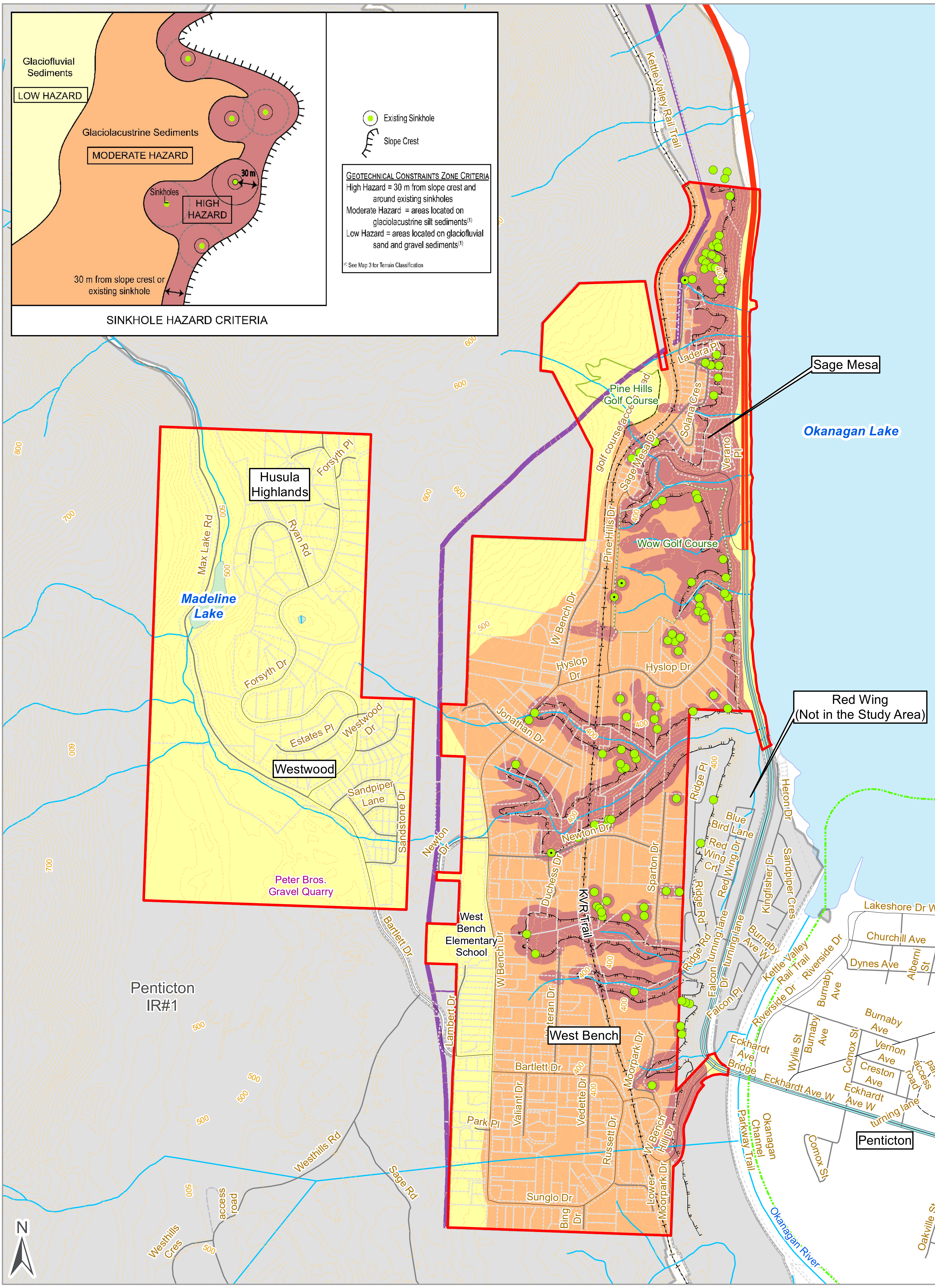
Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

0 250 500 Meters

Project No.: 191010
Date: 2021/12/07
Client: Regional District of Okanagan Similkameen
Drawn: MT Check: JC
NAD 1983 UTM Zone 11N

Map 3.0



SINKHOLE HAZARD ZONES

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GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend
- Sinkholes (Interpreted from 2018 LiDAR)
- Sinkholes (Identified in Field)
- Crest of Slope
- High Sinkhole Hazard Zone
- Moderate Sinkhole Hazard Zone
- Low Sinkhole Hazard Zone
- Gas Line
- RDOS Legal Parcels
- First Nations Land Boundaries
- City of Penticton Boundary
- Greater West Bench Study Area

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

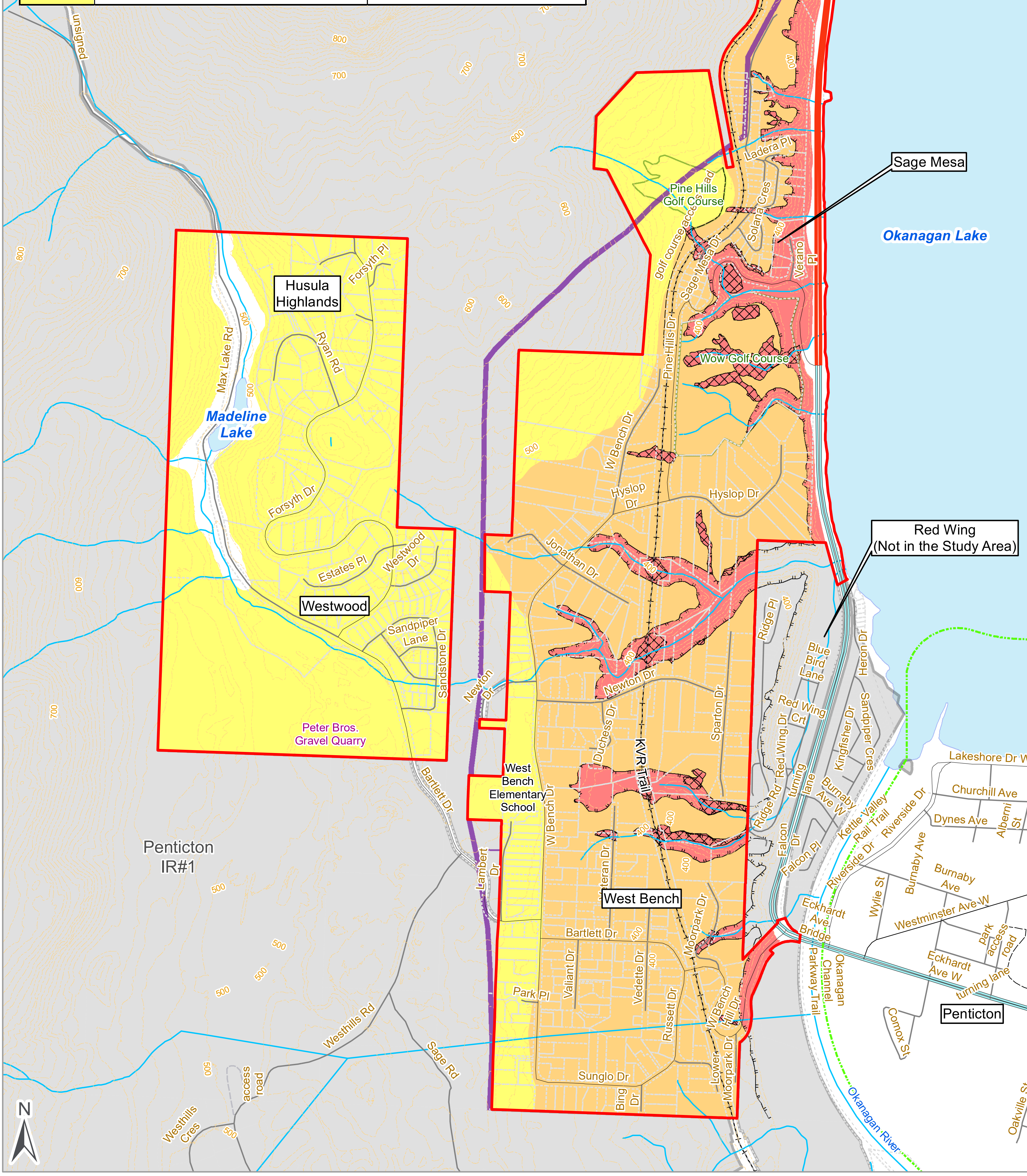
0 250 500 Meters

Project No.: 191010
Client: Regional District of Okanagan Similkameen
NAD 1983 UTM Zone 11N

Date: 2021/12/07
Drawn: MT Check: JC

Map 4.0

Collapsible Soils Hazard	Criteria	Definition
High Hazard	• Areas underlain by colluvial silt (non-stratified depositional material in gullies and along the base of silt bluff slopes). • Areas of historic infill, such as gullies or sinkholes.	• A damaging soil collapse event or significant soil compression is very likely to occur within this area.
Moderate Hazard	• Located within area mapped as Glaciolacustrine Silt sediments.	• A damaging soil collaps event or significant soil compression is more likely to occur.
Low Hazard	• Located within area mapped as Glaciofluvial Sand and Gravel sediments or Till (moraine).	• A damaging soil collaps event or significant soil compression is unlikely to occur within this area.



COMPRESSIBLE SOILS HAZARD ZONES

Clarke Geoscience Ltd.

ecora

GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

- Crest of Slope
- Gas Line
- RDOS Legal Parcels
- City of Penticton Boundary
- First Nations Land Boundaries
- Greater West Bench Study Area
- High Collapsible Soils Hazard
- Moderate Collapsible Soils Hazard
- Low Collapsible Soils Hazard
- Areas of Historic Infill

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

0 250 500 Meters

Project No.: 191010

Client: Regional District of Okanagan Similkameen

NAD 1983 UTM Zone 11N

Date: 2021/12/07

Drawn: BM Check: JC

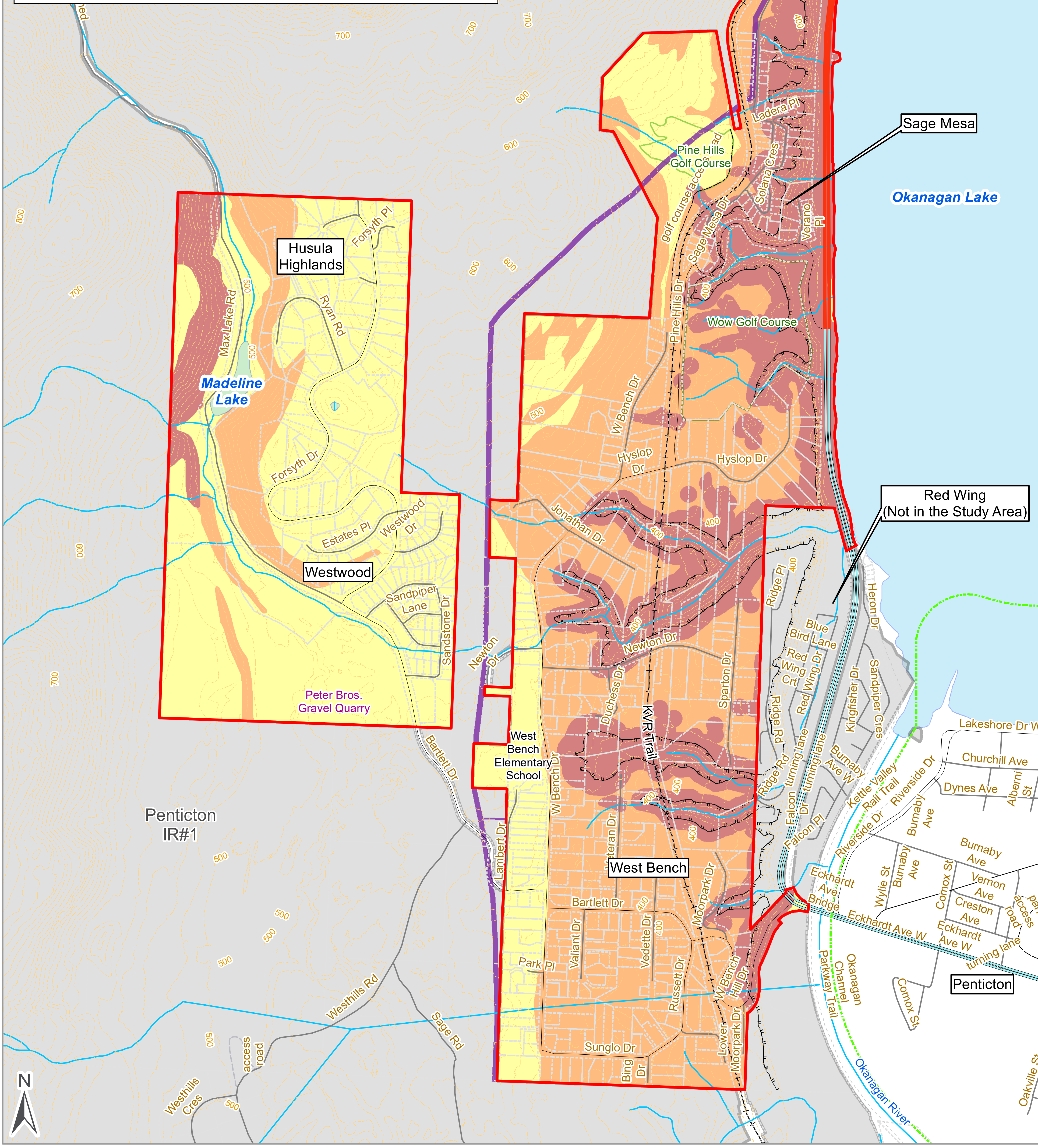
Map 5.0

Geotechnical Constraints Zones Defined			
Geotechnical Constraints Zone	Partial Risk Level P_{HA} (probability of a geohazard event and potential to affect the site)		Description
A	Low	L	Low Risk – damaging event is unlikely to occur at this location (i.e., event is possible but expected to occur every 1,000 to 10,000 years)
B	Moderate	M	Moderate Risk – damaging event is likely to occur at this location (i.e., event is expected to occur every 100 to 1,000 years)
C	High	H	High Risk – damaging event is very likely to occur at this location (i.e., event is expected to occur more than once every 100 years)

Partial risk levels are derived from combined landslide (Map 3), sinkhole (Map 4), and compressible soils (Map 5) hazards and do not distinguish the type of geohazard occurring at the site.

Hazard levels require field confirmation at the site level.

Mapping should be read in association with the Greater West Bench Geotechnical Review report (dated January 2021)



GEOTECHNICAL CONSTRAINTS ZONES

Clarke Geoscience Ltd.

ecora

GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

- Crest of Slope
- Geotechnical Constraints Zone A
- Geotechnical Constraints Zone B
- Geotechnical Constraints Zone C
- Gas Line
- RDOS Legal Parcels
- City of Penticton Boundary
- First Nations Land Boundaries
- Greater West Bench Study Area

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated December 2021

1:14,000

0 250 500 Meters

Project No.: 191010

Client: Regional District of Okanagan Similkameen

NAD 1983 UTM Zone 11N

Date: 2021/12/07

Drawn: MT Check: JC

Map 6.0

Appendix C

Select Fieldwork Photographs

Photo 1	View of rocky slopes at north end of study area (Sage Mesa)
Photo 2	Large (pre-existing) sinkhole in Sage Mesa area
Photo 3	Damaged culvert inlet (Sage Mesa)
Photo 4	Catch basin above Sage Mesa Road at top of steep embankment (showing signs of instability)
Photo 5	Sinkhole and tension crack near catch basin (see Photo 4)
Photo 6	Ditch line maintenance measures in disrepair, on Sage Mesa Rd above WOW Golf Course
Photo 7	Erosion at Culvert Inlet at Sage Mesa Rd crossing (near WOW GC)
Photo 8	Erosion at culvert outlet at Sage Mesa Rd crossing (near WOW GC)
Photo 9	Large sinkhole forming in parking lot (WOW GC)
Photo 10	Pavement cracking at WOW GC
Photo 11	Silt Bluff at north end of study area – showing “wax like” flow of saturated silt
Photo 12	Vertical jointing in silt bluffs and high degree of stability when dry
Photo 13	Tension crack at gully edge (Sage Mesa)
Photo 14	Massive sinkhole at culvert outlet (adj to Photo 13 Sage Mesa)
Photo 15	Small sinkhole in driveway (Sage Mesa)
Photo 16	Sinkhole next to catch basin, with sandbags blocking runoff
Photo 17	Depressions in road (end of Duchess Dr)
Photo 18	Glaciofluvial sands and gravels, exposure near school (West Bench Dr.)
Photo 19	Colluvial silt and sand and gravel contact (end of Jonathan Dr.)
Photo 20	Tension cracks and landslide activity along crest of gully (Newton Dr and Duchess Dr.)
Photo 21	Sinkholes at gully crest (Newton Dr and Duchess Dr)
Photo 22	Subsurface erosion and deep cavity on access to KVR at Newton Road
Photo 23	Fill dumping and shallow instability along gully slope (end of Moorpark Dr.)
Photo 24	Recent (2019) sinkhole repair due to leaking water valve (Sparton Road)
Photo 25	Partly infilled sinkhole on private property (off Sparton Road)
Photo 26	Sinkhole visible within gully (off Sparton Road)

	
Photo 1 **View of rocky slopes at north end of study area (Sage Mesa)**	**Photo 2** **Large (pre-existing) sinkhole in Sage Mesa area**
	
Photo 3 **Damaged culvert inlet (Sage Mesa)**	**Photo 4** **Catch basin above Sage Mesa Road at top of steep embankment (showing signs of instability)**

 **Photo 5** **Sinkhole and tension crack near catch basin (see Photo 4)**	 **Photo 6** **Ditch line maintenance measures in disrepair, on Sage Mesa Rd above WOW Golf Course**
 **Photo 7** **Erosion at Culvert Inlet at Sage Mesa Rd crossing (near WOW GC)**	 **Photo 8** **Erosion at culvert outlet at Sage Mesa Rd crossing (near WOW GC)**

Photo 9 **Large sinkhole forming in parking lot (WOW GC)**

Photo 10 **Pavement cracking at WOW GC**

Photo 11 **Silt Bluff at north end of study area – showing "wax like" flow of saturated silt**

Photo 12 **Vertical jointing in silt bluffs and high degree of stability when dry**

Photo 13 **Tension crack at gully edge (Sage Mesa)**

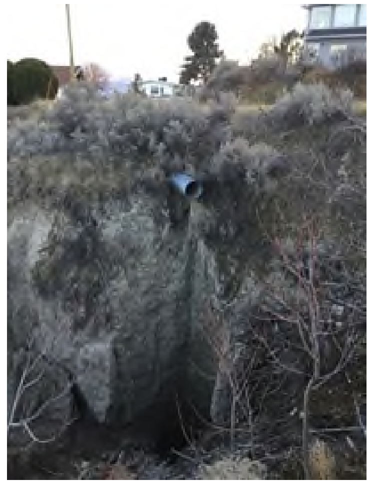


Photo 14 **Massive sinkhole at culvert outlet (adj to Photo 13 Sage Mesa)**

Photo 15 **Small sinkhole in driveway (Sage Mesa)**

Photo 16 **Sinkhole next to catch basin, with sandbags blocking runoff**

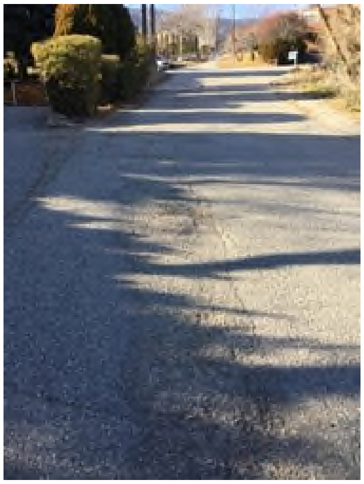


Photo 17 Depressions in road (end of Duchess Dr)

Photo 18 Glaciofluvial sands and gravels, exposure near school (West Bench Dr.)

Photo 19 Colluvial silt and sand and gravel contact (end of Jonathan Dr.)

Photo 20 Tension cracks and landslide activity along crest of gully (Newton Dr and Duchess Dr.)

Photo 21 **Sinkholes at gully crest (Newton Dr and Duchess Dr)**

Photo 22 **Subsurface erosion and deep cavity on access to KVR at Newton Road**

Photo 23 **Fill dumping and shallow instability along gully slope (end of Moorpark Dr.)**

Photo 24 **Recent (2019) sinkhole repair due to leaking water valve (Sparton Road)**

Photo 25 **Partly infilled sinkhole on private property (off Sparton Road)**

Photo 26 **Sinkhole visible within gully (off Sparton Road)**

Appendix D

RDOS Public Survey Results

REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN

INFORMATION RELEASE

February 14, 2020

RDOS Conducting Geotechnical Review for Greater West Bench Area

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The Regional District of Okanagan-Similkameen (RDOS) is conducting a geotechnical review of the Greater West Bench area. The purpose of the review is to create a more current and accurate snapshot of the area. It is expected that the review will help better define existing geotechnical hazard conditions and areas, and assist in determining appropriate planning land uses.

This review is to help expand the area of historical study to include all lands in the Greater West Bench area including Sage Mesa and Husula Highlands. Part of the geotechnical review is being conducted through in-person interviews and discussions, as well as an online survey.

The completed review is expected to produce a report and assessment of the Greater West Bench area geotechnical conditions using historical and current data while applying modern technology and methods.

The final report which will include updated mapping, will help the RDOS develop land use policies specific to the Greater West Bench area. In addition, the report will help inform and guide residents about appropriate uses of the lands in the area given the existing geotechnical conditions.

Please visit the RDOS website to take the survey: www.rdos.bc.ca

####

For further information, please contact Stephen Juch at (250) 492-0237 or info@rdos.bc.ca

Karla Kozakevich

Karla Kozakevich, Chair
Regional District of Okanagan-Similkameen

Public Engagement Survey (survey period Feb. 14- Mar. 13, 2020)

1. Which neighborhood do you live in, within Greater West Bench?

2. What is your home address and street name?

3. How many years have you lived at this address?

4. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [sinkholes]

Please describe [Sinkholes]

5. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Depressions in land surface]

Please describe [Depressions in land surface]

6. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Landslides, or loss of property adjacent to slope crest]

Please describe [Landslides, or loss of property adjacent to slope crest]

7. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Groundwater discharge or seepage]

Please describe [Groundwater discharge or seepage]

8. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Erosion due to surface water runoff]

Please describe [Erosion due to surface water runoff]

9. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Known fill sites, holes or gullies have been filled]

Please describe [Known fill sites, holes or gullies have been filled]

10. Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Any other land disturbance]

Please describe [Any other land disturbance [Please describe]

11. Have you completed or received any geotechnical investigations pertaining to the subsurface (soil) conditions on your property, for building permits, subdivision, or other land use applications? [Y /N]

[If yes, please describe]

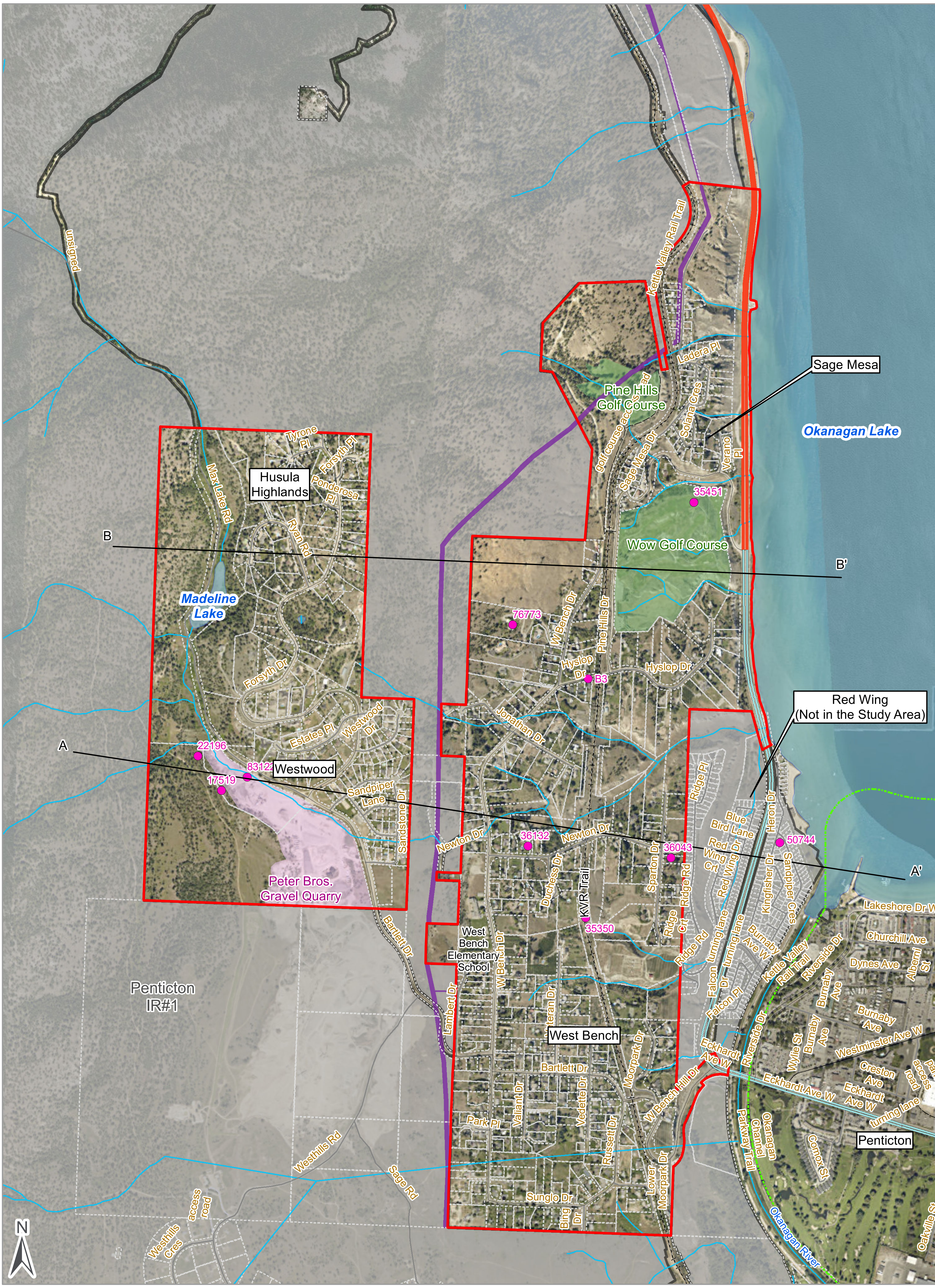
12. Do you consent to receiving a follow-up telephone call, and/or a personal visit from a representative of the study group to discuss this further? [Y / N] [If yes, please provide a contact telephone number and email address.]

Detailed Public Engagement Survey Response Data (collected on-line by RDOS during survey period Feb. 14- Mar. 13, 2020) (note: identifying personal information is not shown)

Response ID	1. Which neighborhood do you live in, within Greater West Bench?	3. How many years have you lived at this address?	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [sinkholes]	Please describe [Sinkholes]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Depressions in land surface]	Please describe [Depressions in land surface]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Landslides, or loss of property adjacent	Please describe [Landslides, or loss of property adjacent to slope crest]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Groundwater discharge or seepage]	Please describe [Groundwater discharge or seepage]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Erosion due to surface water runoff]	Please describe [Erosion due to surface water runoff]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Known fill sites, holes or gullies have been filled]	Please describe [Known fill sites, holes or gullies have been filled]	Have you experienced any of the following issues on your property, or do you know of other locations on private or public lands where the following issues have occurred? [Any other land disturbance]	Please describe [Any other land disturbance [Please describe]	Have you completed or received any geotechnical investigations pertaining to the subsurface (soil) conditions on your property, for building permits, subdivision, or other land use applications? [Y /N]
59	Husula Highlands		No		No		No		No		No		No		No		
25	West Bench	4	No		No		No		No		No		No		No		No
48	West Bench	1	No		No		No		No		No		No		No		
67	Sage Mesa	8	No		No		No		No		No		No		No		No
2	West Bench	55	Yes	Hyslop Drive near the east end and Newton Drive near KVR bridge and the KVR Trail	Yes	Hyslop, Sparton, Newton and the KVR Trail	Yes	Land above the entrance to West Bench - coming up the hill slide in 2019 - Hyslop Drive slope on highway side slide 1990's	No		No		Yes	West Bench Hill Rd - vineyard on corner was a cherry orcharg in a gully that has been filled. Some lots on the north end of West Bench Drive have been filled	No		Yes
3	West Bench	13	No		No		No		No		No		No		No		No
8	Sage Mesa	10	No		No		No		No		No		No		No		No
17	Sage Mesa	12	No		No		No		No		No		No		No		No
18	West Bench	9	Yes	KVR especially south of Newton drive and the path leading from the kvr up to Newton drive by the bridge.	No		Yes	The bank when entering West Bench on West Bench Hill drive.	No		No		Yes	The gully is partially filled where a new house sits on my street, so across the road and and 3 houses north.	No		No
20	West Bench	27	Yes	from irrigation leaks	Yes	suspect irrigation	No		No		No		No		No		No
21	West Bench	8	No		No		No		No		No		No		No		No
28	West Bench	17	No		No		No		No		No		No		No		No
29	West Bench	2	Yes	On KVR access trail off of Newton Drive	No		No		No		Yes	On KVR access trail off of Newton Drive	Yes	Off of Duchess Drive. Active filling of gully	Yes	slow slumping of slope on property	No
30	Sage Mesa	19	Yes	sink holes in yard and sink holes on road allowance and on the hill slope within my property line	No		Yes	the slope within my property line has increased to the point that it is unusable	Yes	some seepage from property across the road and uphill from my property	No		Yes	several by road maintenance company; from Goulder and Ass. as well as work I have done myself	Yes	my neighbour to the south of my property also experiences the same problems	Yes
32	West Bench	32	Yes	many along KVR and on the land north and east of KVR	No		No		No		Yes	upper Moorpark Drive paved curve immediately east of Bentham property; middle of upper Moorpark Drive in the lowest dip	Yes	gully filled 30 years ago on southern part of our land	No		Yes
34	West Bench	33	No		Yes		No		No		No		Yes	gully area above mariposa park	No		Yes
35	West Bench	3.5	No		No		No		No		No		No		No		No
36	Westwood Properties	17	No		No		No		No		No		No		No		Yes
37	Husula Highlands	29	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	No
38	Sage Mesa	41	No		No		No		No		No		No		No		No
40	Sage Mesa	11	No		No		No		No		No		No		No		No
41	West Bench	5	No		No		No		No		No		No		No		No
42	West Bench	12	No		Yes	yes	No		No		No		No		No		No
45	Husula Highlands	16	No		No		No		No		No		No		No		No
46	West Bench	10	Yes	along the KVR there are several dangerous sink-holes. Although this is not within RDOS property the area is used by many residents.	No		No		No		No		No		No		No
49	West Bench	30	Yes	sage mesa and rail tracks	Yes		Yes	west bench hill	No		Yes	bartlett drive	Yes	behind my home	Yes	road sinking bartlett and west bench hill	No
50	West Bench	24	Yes	On the KVR trail	No		Yes	Slides on slope of West Bench Hill	No		No		Yes	Fill site on private property located on NE corner of Sunglo Dr and Russet Dr,	No		No
51	West Bench	5	No		No		No		No		No		No		No		No
52	West Bench	30	No		No		No		No		No		No		No		No
55	Sage Mesa	11	No		No		No		No		No		No		No		No
58	West Bench	2	No		No		No		No		No		No		No		No
61	Sage Mesa	3	Yes	Due to buried irrigation line	No		No		No		No		No		Yes	Minor erosion of recently completed landscaping after very heavy rainfall	Yes
62	West Bench	6	No		No		No		No		Yes	KVR Entrance at Newton Drive	Yes	Several yards having gullies filled.	No		No
63	West Bench	8	Yes	On the KVR trail heading north	No		No		No		No		No		No		No
70	West Bench	16	No		No		No		No		No		No		No		No
71	Sage Mesa	2	No		No		No		No		No		No		No		No
72	West Bench	18	Yes	Two small ones on driveway over 18 years	No		No		No		No		No		No		No
75	Sage Mesa		No		No		No		No		Yes	Ground erosion from road drainage	Yes		No		Yes
76	Sage Mesa		Yes		No		Yes		No		Yes	Erosion due to road drainage	No		No		No
77	Sage Mesa	46	No		No		No		No		No		No		Yes	surface erosion from water utility system leak	No
78	Sage Mesa	50	No		No		No		No		No		No		Yes	Erosion due to road drainage	No

Appendix E

Detailed Geologic Cross-Sections



SITE PLAN

Clarke Geoscience Ltd.

ecora

GREATER WEST BENCH GEOTECHNICAL REVIEW

ISSUED FOR USE

Legend

- Boreholes Used For Geologic Cross Sections (E2 & E3)
- Cross Sections
- Gas Line
- RDOS Legal Parcels
- City of Penticton Boundary
- First Nations Land Boundaries
- Greater West Bench Study Area

Map to be read with associated report titled "Greater West Bench Geotechnical Review", dated January 2021

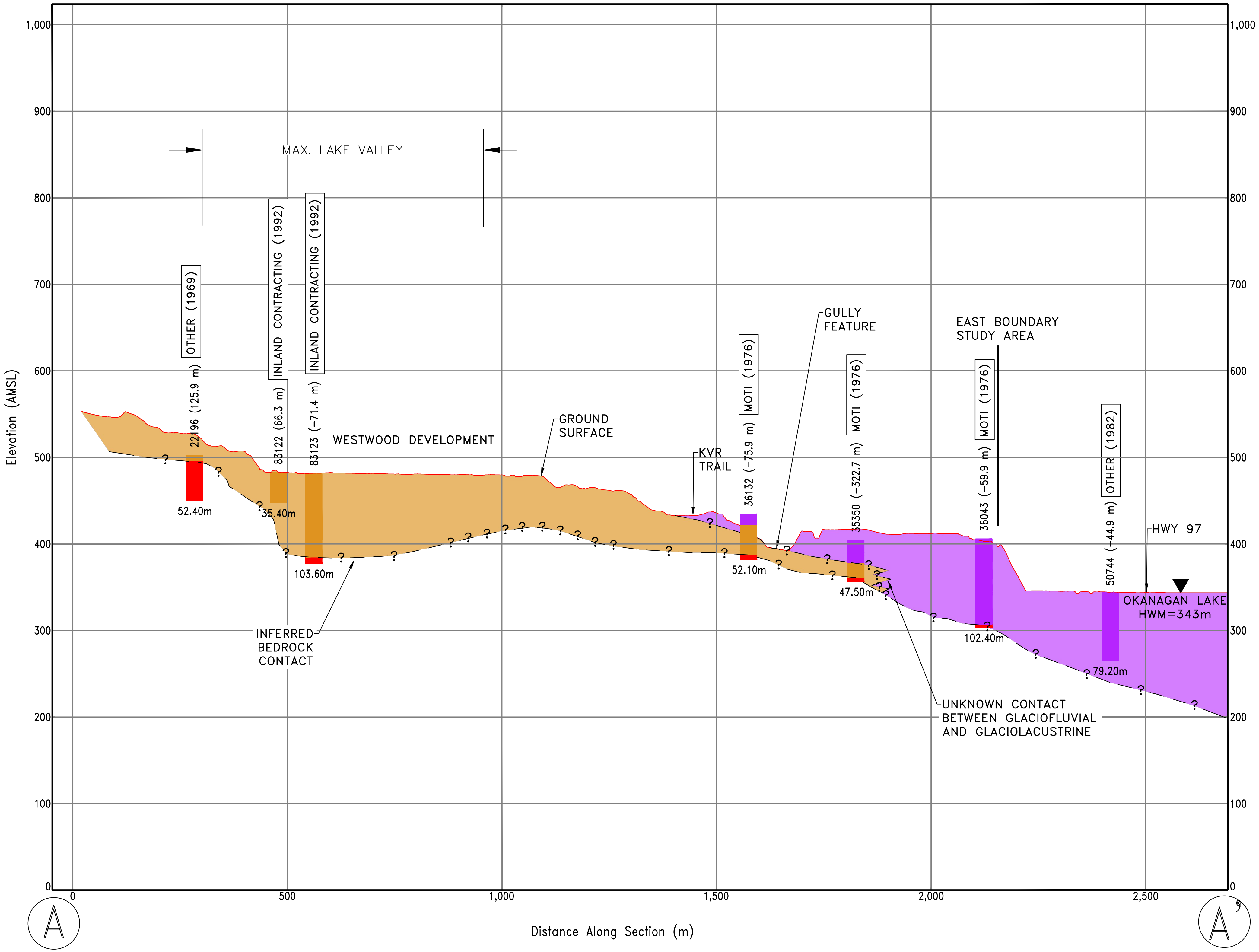
1:14,000

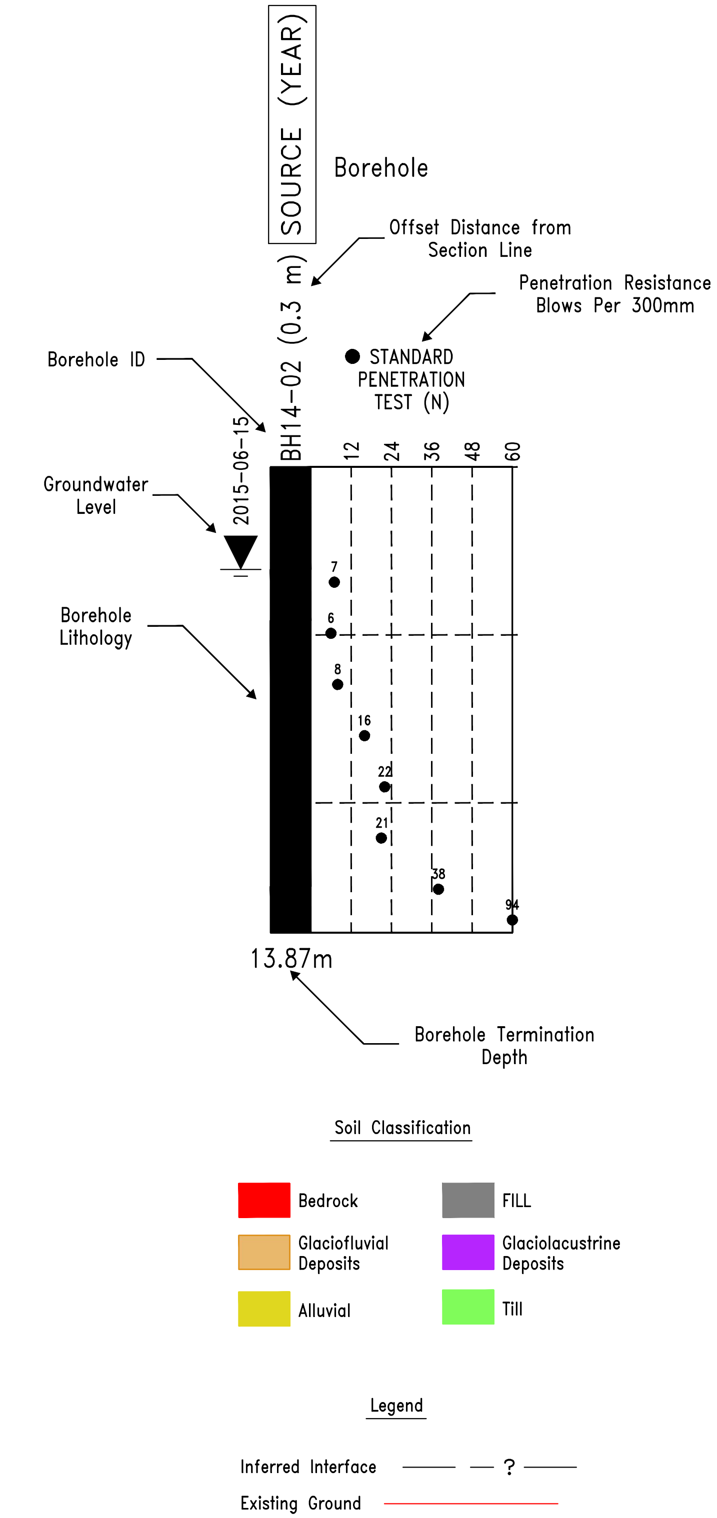
0 250 500 Meters

Project No.: 191010
Client: Regional District of Okanagan Similkameen
NAD 1983 UTM Zone 11N

Date: 2021/01/13
Drawn: MT Check: JC

Appendix E1





Notes:

GREATER WEST BENCH GEOTECHNICAL REVIEW

DETAILED GEOLOGIC CROSS SECTION A-A'

Project No.: 191010
Client: RDOS
Office: KELOWNA
Scale: NTS
Date: SEPT 2, 2020
DWN: NLS CHK: NM

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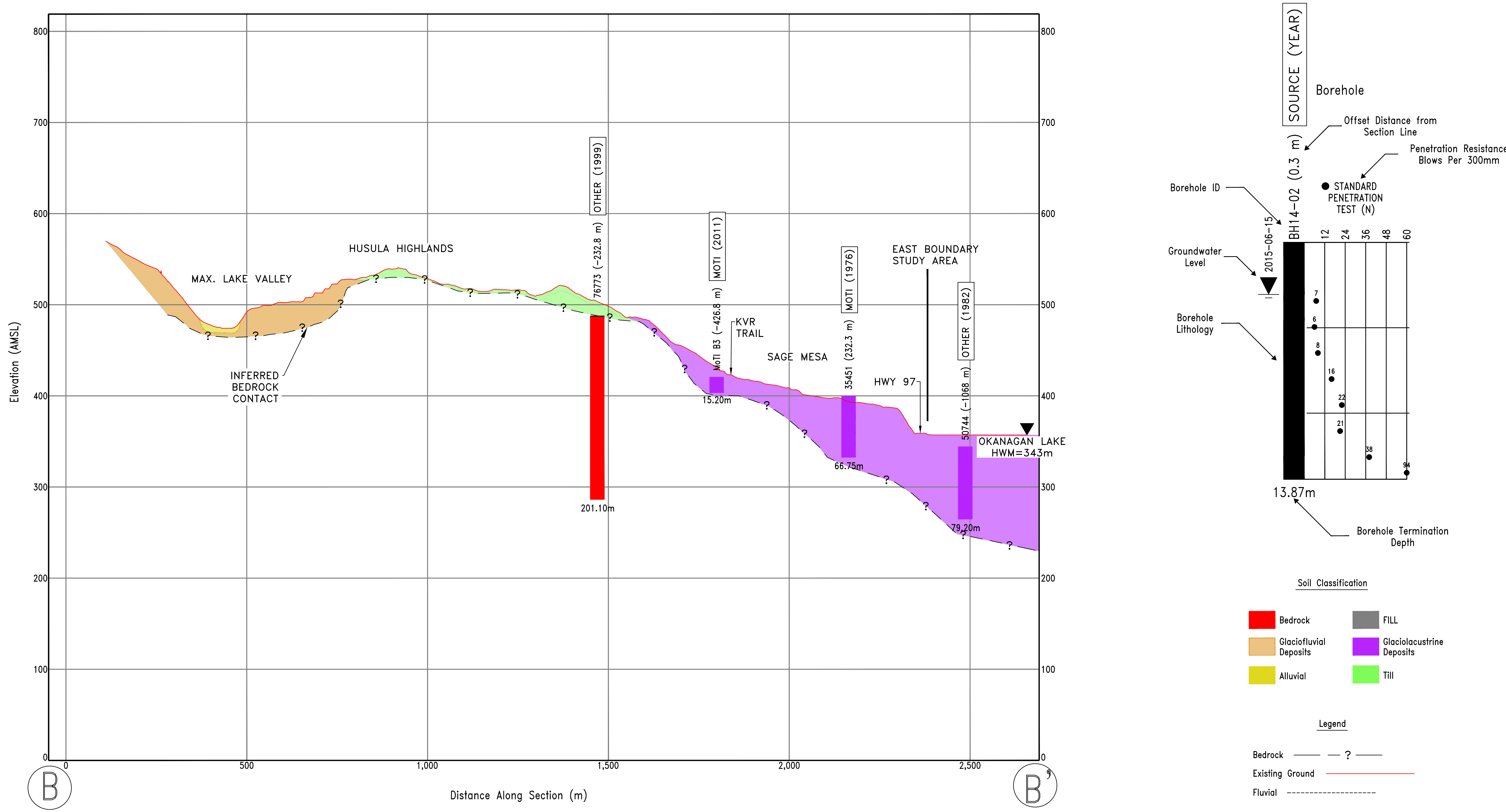
Appendix E2



Notes:

GREATER WEST BENCH GEOTECHNICAL REVIEW

DETAILED GEOLOGIC CROSS SECTION B-B'

Project No.:	191010
Client:	RDOS
Office:	KELOWNA
Scale:	NTS
Date:	SEPT 02, 2020
DWN:	NLS CHK: NM

Appendix E3

Appendix F

Engineering Material Properties of the Glaciolacustrine (Penticton) Silts

Engineering Material Properties of the Glaciolacustrine Silts

Summary Table of Grain Size Analysis - Laboratory Testing of the Glaciolacustrine Silts, adapted from Iravani (1999) Table 5.2

Original Source	Natural Moisture Content (%)	Sand (%)	Fines (%)		Comments
			Silt	Clay	
Meyer & Yenne (1940)	-	-	>99	<1	Samples from Okanagan Lake, Skaha Lake, Mission Creek Valley 4 samples tested
Fulton (1965)	-	<10	dominant	<20	Samples from South Thompson Valley 24 samples tested from individual varves
Quigley (1976)	-	-	-	7 - 10	Samples taken from Okanagan Valley, South Thompson Valley
Evans & Buchanan (1976)	-	<3	dominant	2 - 12	Samples taken from South Thompson Valley No major difference between glaciolacustrine and colluvial silts noted by authors
Lum (1977)	-	4	89	7	Samples taken from South Thompson Valley 5 samples tested
Evans (1982)	-	-	-	Up to 91	Samples collected from Northern Interior (Prince George and Quesnel)
Wilson (1985)	-	15 - 20	70 - 80	<3	Samples collected from South Thompson Valley No major difference between glaciolacustrine and colluvial silts noted by author
Klohn Leonoff (1992)	-	0 - 2	80 - 87	8 - 17	Samples taken from West Bench/Sege Mesa
Nyland & Miller (1977)	15 - 25[1]	0 - 2	80 - 87	8 - 17	
Iravani (1999)	-	0 - 5	85 - 90	8 - 18	
Thurber (2007)	10 - 30[2]	0 - 5	-	14 - 18	Tested from 9 Shelby tube samples Clay fraction reported from Direct Shear Testing Silt (ML)
Ecora[3]	9 - 20		94-100		

Notes:

[1] Seasonal variation and depth

[2] As summarized by Thurber (2007) for the majority of the tested material

[3] Based on a number of local projects

Summary Table of Grain Size Analysis Laboratory Testing of the Colluvial Silts, adapted from Iravani (1999) Table 5.2

Original Source	Natural Moisture Content (%)	Sand (%)	Fines (%)		Comments
			Silt	Clay	
Nyland & Miller (1977)	-			7 - 16.2	
Quigley (1976)	-	-	-	12 - 19	Samples taken from Okanagan Valley, South Thompson Valley
Evans & Buchanan (1976)	-	<3	dominant	2 - 12	Samples taken from South Thompson Valley No major difference between glaciolacustrine and colluvial silts noted by authors
Wilson (1985)	-	15 - 20	70 - 80	<3	Samples collected from South Thompson Valley No major difference between glaciolacustrine and colluvial silts noted by author

Summary Table of In-situ Water Content and Atterberg Limits Laboratory Testing of the Glaciolacustrine Silts, adapted from Iravani (1999) Table 5.4

Original Source	In-situ Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Comments
Evans & Buchanan (1976)	2 - 35	27 - 37	-	2 - 12	Samples taken from South Thompson Valley Clayey Silt (ML) 4/6 samples in-situ water content >LL
Nyland & Miller (1977)	1 – 8[(1)]	21 - 39	13 - 31	1 - 14	Samples collected from Okanagan Valley
Lum (1977)	7 - 8	-	-	-	Samples taken from South Okanagan Valley Measurements taken in June at 1.5 m bgl
Evans (1982)	-	>50	-	>20	Samples taken from Northern Interior
Wilson (1985)	6	-	-	-	Sample taken from South Thompson Valley Measurement taken at 5 m bgl
Thurber (1989)	-	28 - 52	-	7 - 37	Described in Thurber (2007) report
Thurber (1991)	-	31 - 68	-	6 - 43	Described in Thurber (2007) report
Iravani (1999)	-	35 - 40	25 - 33	0 - 10	Summary values
	15 - 43	35 – 39	30 – 33	29 - 31	Samples taken from Okanagan Park Slide and Koosi Creek Slide
Thurber (2007)		35 - 40[(2)]	25 - 30[(2)]	0 - 10[(2)]	Tested from 9 Shelby tube samples Silt (ML)
Ecora[(3)]	9 - 20	28 - 35	20 - 26	7 - 11	

Notes:

(1) Seasonal variation and depth

(2) As summarized by Thurber (2007) for much of the tested material

(3) Based on a number of local projects

Summary Table of In-siitu Water Content and Atterberg Limits Laboratory Testing of the Colluvial Silts, adapted from Iravani (1999) Table 5.4

Original Source	In-situ Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Comments
Evans & Buchanan (1976)	2-48	25-39	-	4-15	Samples collected from South Thompson Valley Clayey Silt (ML) In-situ water content >LL

Summary Table of Shear Strength Laboratory Testing, adapted from Iravani (1999)

Original Source	Average Shear Strength (kPa)	Comments
Lum, (1977)(1)	130 - 240	Higher effective confining stresses (greater than 100 kPa did not strain soften)
	60	Low effective confining stresses (less than 100 kPa were strain softened)
Wilson (1985)	38	Unsaturated, reconstituted specimen with a water content of 4.4%
MoTI (1989)	2 - 8	Samples with moisture content significantly below the PL (peak strength)
	8 - 20	Samples with moisture content at or near the PL (peak strength)
Sobkowicz & Coulter, (1992) (2)	30	Samples with moisture content significantly below the PL
	30	Samples with moisture content at or near the PL
	10	Residual soil
Thurber (2007)	30	Samples with moisture content significantly below the PL (peak strength)
	30	Samples with moisture content at or near the PL (peak strength)
	35	Clayey silt (peak strength)
	35	Silty clay
	10	Silty clay (residual strength)

Notes:

(1) Initial average specimen water contents of 7%

(2) Referenced in Klohn Leonoff (1992)

Summary Table of Friction Angle of the Penticton Silt, adapted from Iravani (1999)

Original Source	Friction Angle (°)	Comments
Evans & Buchanan (1976)	24° - 30.5°	Residual drained friction angle from direct shear testing
Lum, (1977)	34°	
Wilson, (1985)	34° - 42°	
Sobkowicz & Coulter, (1992)(1)	35°	Silt samples with moisture content significantly below the PL
	30°	Silt samples with moisture content at or near the PL
	22°	Clayey silt with 35 kPa cohesion (peak strength)
	17°	Silty Clay with 35 kPa cohesion (peak strength)
Iravani, (1999)(2)	32°	

Original Source	Friction Angle (°)	Comments
Thurber (2007)	35°	Samples with moisture content significantly below the PL 30 kPa cohesion (peak strength)
	30°	Samples with moisture content at or near the PL 30 kPa cohesion (peak strength)

Notes:

(1) Referenced in Klohn Leonoff (1992)

(2) Based on equation by Robertson & Campanella (1983)

Summary Table of 1-D Consolidation Laboratory Testing of the Glaciolacustrine Silts in the GWB Study Area, conducted by others

Original Source	Water Content (%)	Load (kPa)	Volumetric Strain Decrease (%)	Comments
Lum (1977)	7.2	1,400	3.2	Samples from north shore of the South Thompson River
Nyland & Miller (1977)	-	-	3 - 11	Magnitude of collapse increases as vertical effective stress corresponding to flooding stage increases
MoTI (date unknown)[1]	-	-	2	Compression index of 0.19
	-	-	3	Compression index of 0.09
	-	-	3	Compression index of 0.15
	-	-	4	Compression index of 0.26

Notes:

(1) Based on tested samples collected in 1978 and 1982. Reported by Thurber (2007)

Summary Table of 1-D Consolidation Laboratory Testing of the Colluvial Silts in the GWB Study Area, conducted by others

Publication	Water Content (%)	Load (kPa)	Volumetric Strain Decrease (%)	Comments
MoTI (date unknown)[1]	-	-	25	Compression index of 0.32
	-	-	31	Compression index of 0.70

Notes:

(1) Based on tested samples collected in 1978 and 1982. Reported by Thurber (2007)

Summary Table of Laboratory Testing of the Penticton Silt, adapted from Iravani (1999) Table 5.3

Original Source	Specific Gravity	Density (kg/m^3)	In-situ Void Ratio	Comments
Meyer & Yenne (1940)	2.88	-	-	Samples taken from Okanagan Valley
Quigley (1976)	-	-	1.02 - 1.20	Samples taken from Okanagan Valley and South Thompson Valley
Lum (1977)	2.60 - 2.80	-	-	Samples taken from South Thompson Valley 9 samples tested with an average Specific Gravity of 2.77
Nyland and Miller (1977)	-	1557 - 1734 (max. dry)	-	Samples taken from Okanagan Valley Optimum moisture content between 0.7% – 7.9%
Wilson, (1985)	2.65 (assumed)	1390 - 1680 (in-situ bulk)	0.68 - 1.02	Samples taken from South Thompson Valley
Thurber (2007)(1)	2.8	1152 - 1631	1.14 - 1.56	Testing from 1991 investigation program Four measurements from several samples Dry Density

Note:

(1) Thurber (2007) did not distinguish between testing of glaciolacustrine silt or colluvial silt

Mineralogy

Based on the bulk mineralogy analysis carried out by Iravani (1999) using x-ray diffraction, Chlorite and Muscovite were found to be the dominant materials within his study areas. Earlier mineralogy studies, summarized by Iravani (1999), and presented in the summary table below indicates quartz, K-feldspar, and plagioclase were also found to be major mineral components. Within the clay fraction, Illite and smectite were found to be dominant, with kaolinite and mica generally moderate to minor. Expanding clay not found to be significant enough to cause de-structuring. Magnetite and calcite are present in small amounts. There was no major crystalline bonding agent found.

Summary of Mineralogy Studies, adapted from Iravani (1999) Table 5.6-A (a & b)

Original Source	Methodology	Comments
Daly (1915)	Chemical analysis applicable only to igneous rocks	49% albite 18% quartz 15% orthoclase 8.5% anorthite
Flint (1935)	unknown	Fresh feldspathic rock flour Interbedded silt with very thin layers of clay at low elevations
Meyer & Yenne (1940)	Microscope	90% equal amounts feldspar and quarts ▪ 2/3 k-feldspar; 1/3 plagioclase 10% unidentified particles

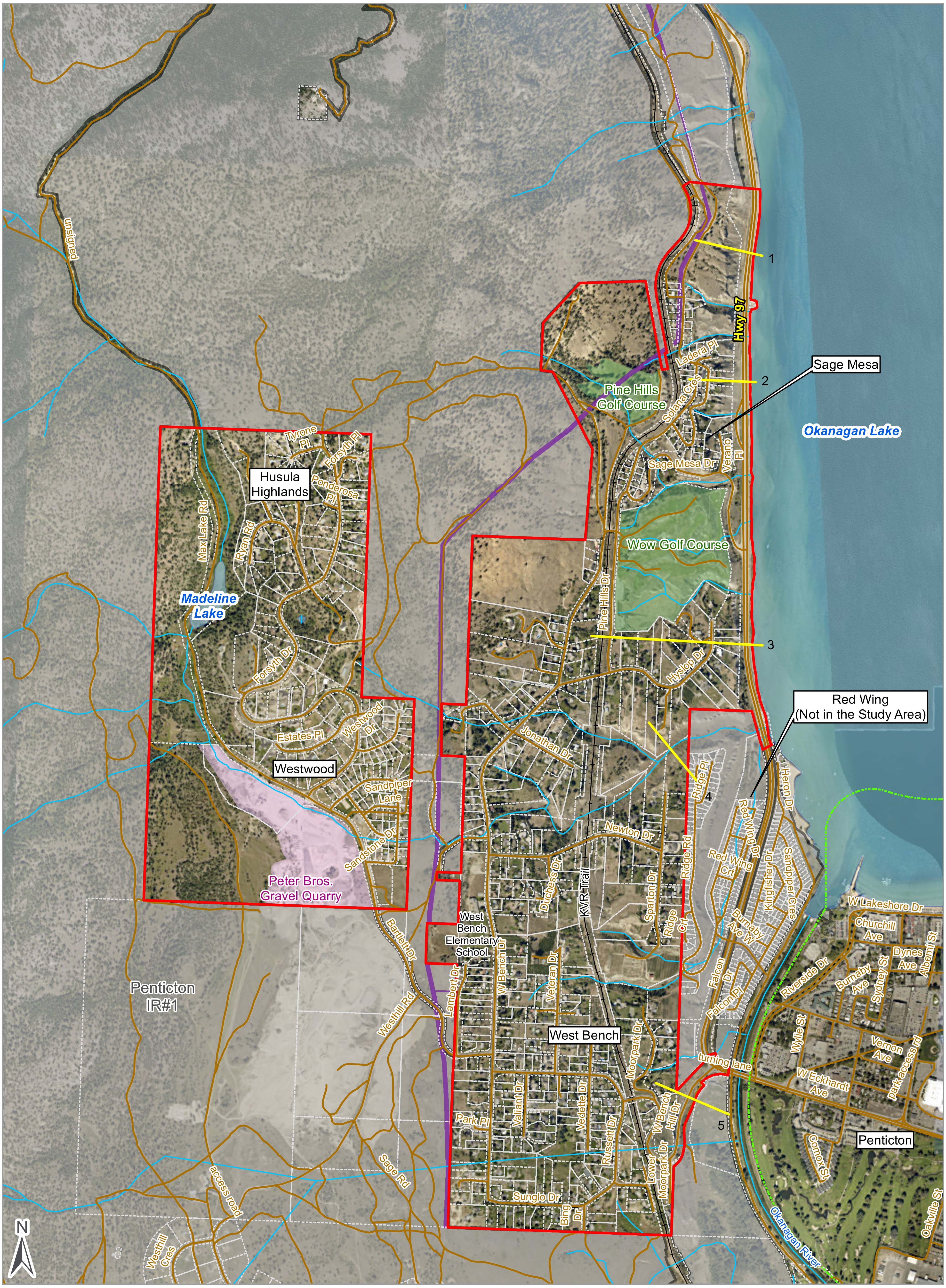
<table>
<tr><th>Original Source</th><th>Methodology</th><th>Comments</th></tr>
<tr><td>Fulton (1965)</td><td>Mineralogical Bulk Sample Analysis</td><td>Quartz (main)
Mica (major)
Feldspar (major)
Ferromagnesian Minerals (minor)
Clay Minerals (minor)
▪ 35%-40% Smectite
▪ 28%-35% Illite/Mica
▪ 27%-36% Chlorite</td></tr>
<tr><td>Quigley (1976)</td><td>X-ray diffraction-</td><td>Quartz (abundant)
Mica (minor)
Feldspar (moderate)
Carbonate (minor)
Amphibole (minor)
Ferromagnesian Minerals (minor)
Clay Minerals (minor)
▪ Smectite (abundant)
▪ Illite/Mica (moderate)
▪ Chlorite (minor)
▪ Kaolinite (minor)</td></tr>
<tr><td>Iravani (1999)</td><td>X-ra diffraction</td><td>Chlorite
Mica (Muscovite)
Quartz
K-Feldspar
Plagioclase (Ca-Feldspar)
Magnetite
Calcite
Clay Fraction
▪ Illite
▪ Smectite
▪ Chlorite
▪ Vermiculite
▪ Kaolinite
▪ Mica (Muscovite)
▪ Mica (Biotite)</td></tr>
</table>

Summary Table of Fabric and Scanning Electron Microscopy (SEM) of the Penticton Silt in the GWB Study Area, conducted by others

Original Source	Sample Type	Comments
Meyer & Yenne (1940)	Glaciolacustrine Silt	Predominantly angular and lath-shaped with elongation indices >10 Some reworked rounded particles noted
Quigley (1976)	Glaciolacustrine and Colluvial Silt	Silt-sized grains of quartz, feldspar, and oriented mica in an open porous structure 5-40 micron mica, horizontally oriented Soil structure appeared stabilized by agglomerated clusters (cementation)
Lum (1977)	Glaciolacustrine Silt (undisturbed and remolded)	Horizontal oriented platy particles Anisotropic fabric observed Similar fabric observations for undisturbed and remolded samples
Iravani (1999)	Glaciolacustrine Silt (undisturbed and remolded)	Anisotropic fabric Horizontally oriented platy particles One wetting and drying cycle was observed to have resulted in soil fabric changes and formation of up to 20 micron voids Gradual flooding under unconfined conditions resulted in micro-cracks less than 30 microns wide

Appendix G

Slope Stability Analysis (G, G1-G6)



GLOBAL STABILITY SECTIONS

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GREATER WEST BENCH GEOTECHNICAL REVIEW

Legend

- Slope Stability Sections
- Gas Line
- RDOS Legal Parcels
- City of Penticton Boundary
- First Nations Land Boundaries
- Greater West Bench Study Area

*Not verified in field

1:14,000

0 250 500 Meters

Project No.: 191010

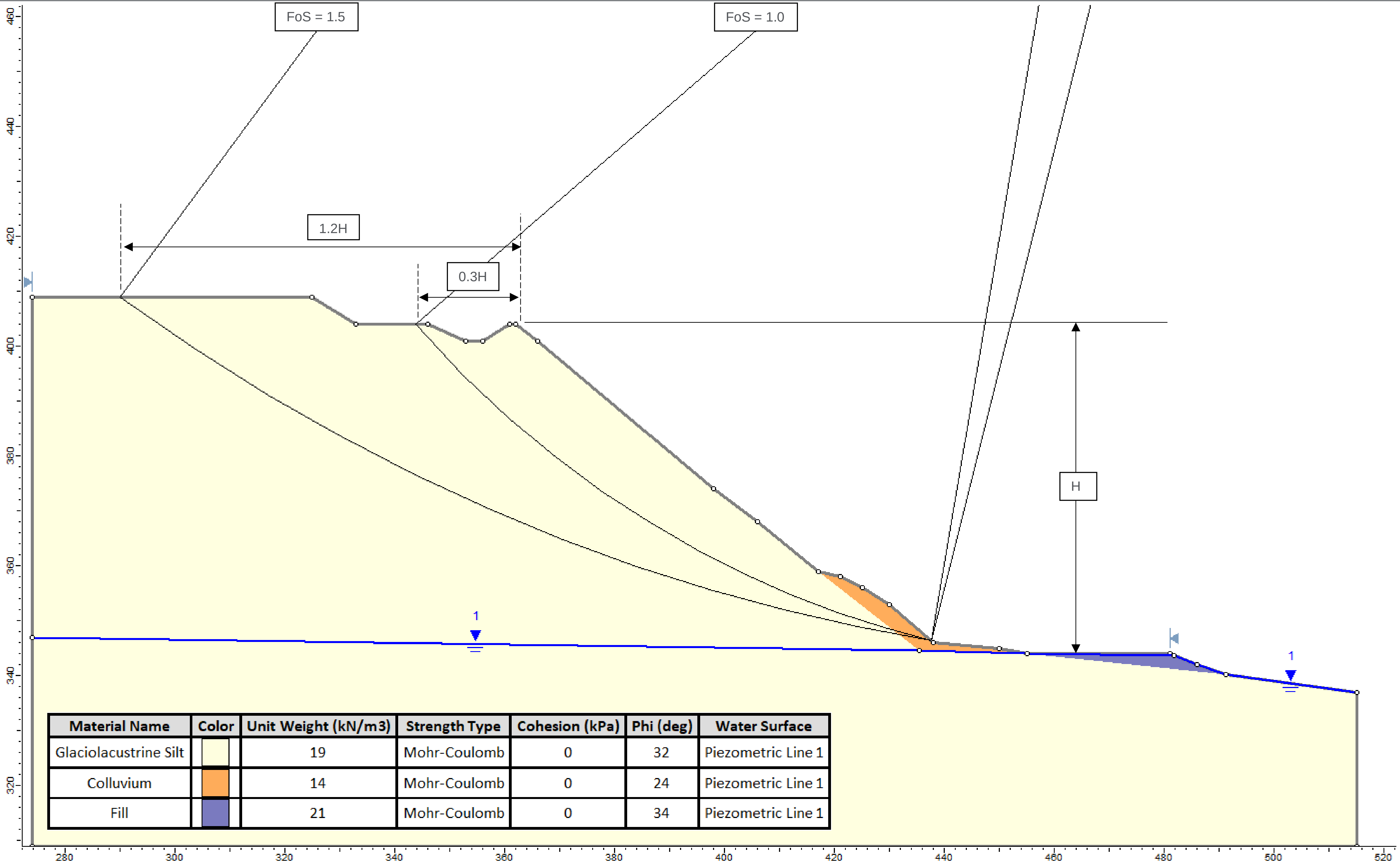
Client: Regional District of Okanagan Similkameen

NAD 1983 UTM Zone 11N

Date: 2020/09/01

Drawn: MT Check: CE

Appendix G



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

Results the same for the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 1

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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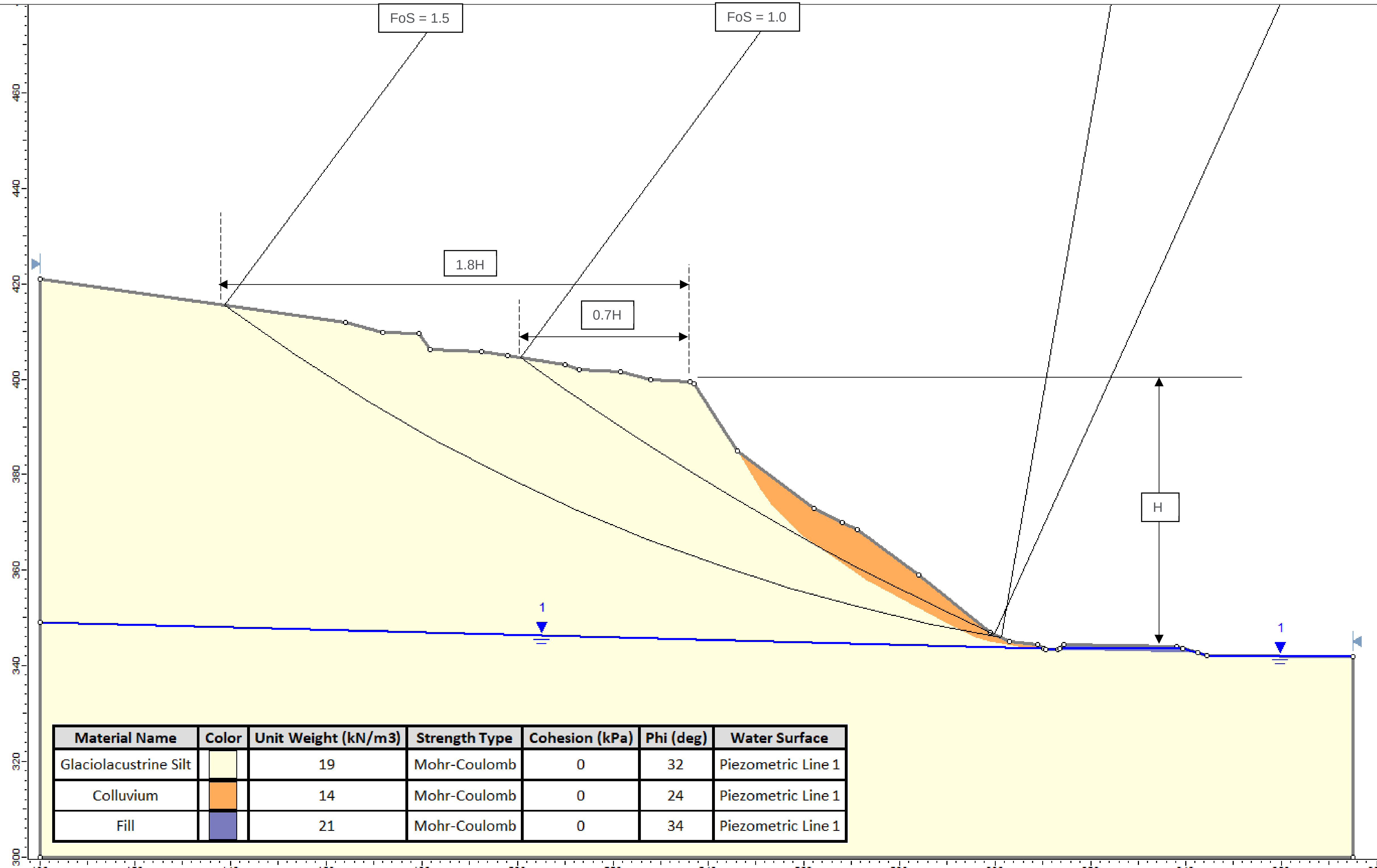
Appendix G1



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

Results the same for the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 2

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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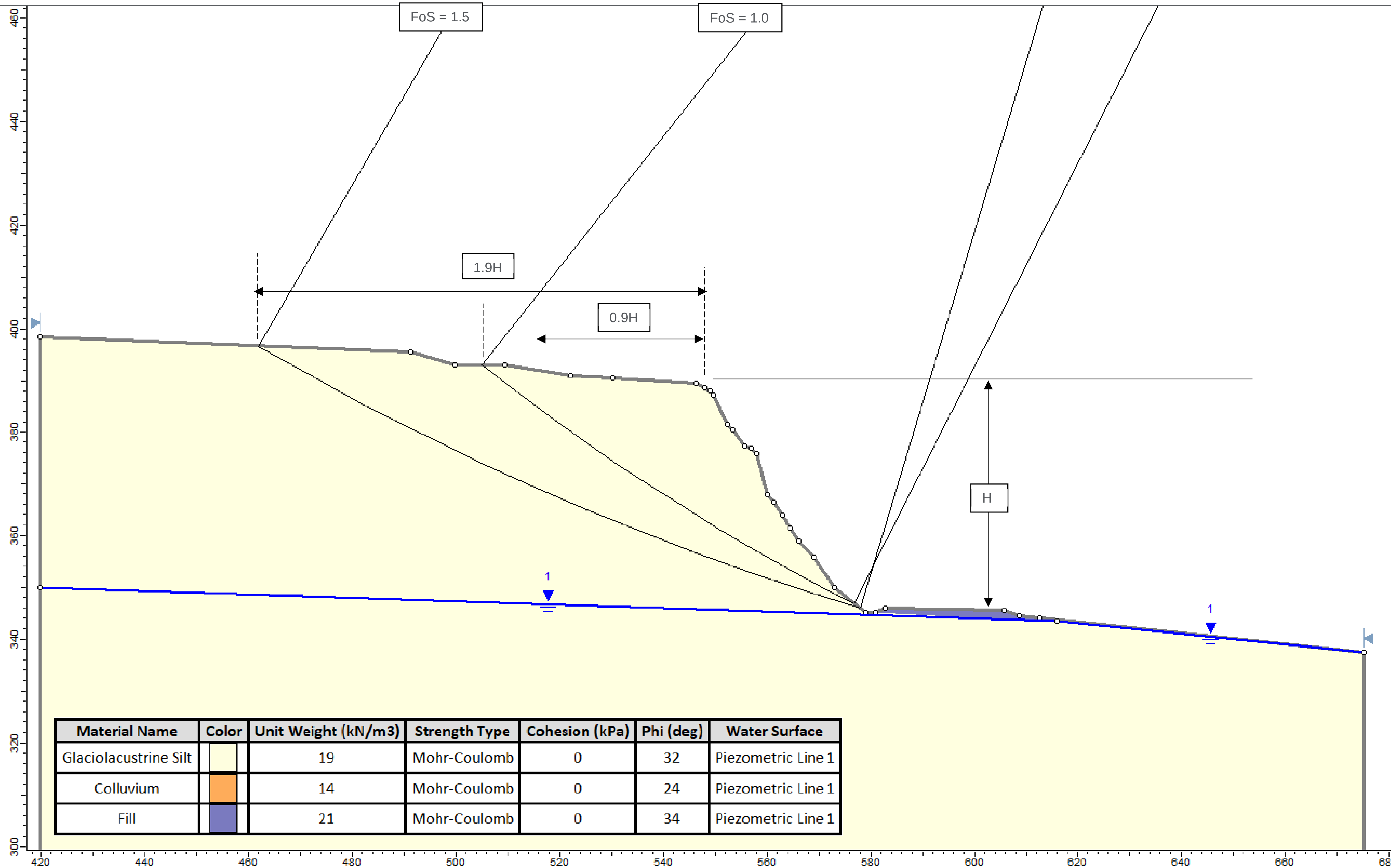
Appendix G2



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

Results the same for the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 3

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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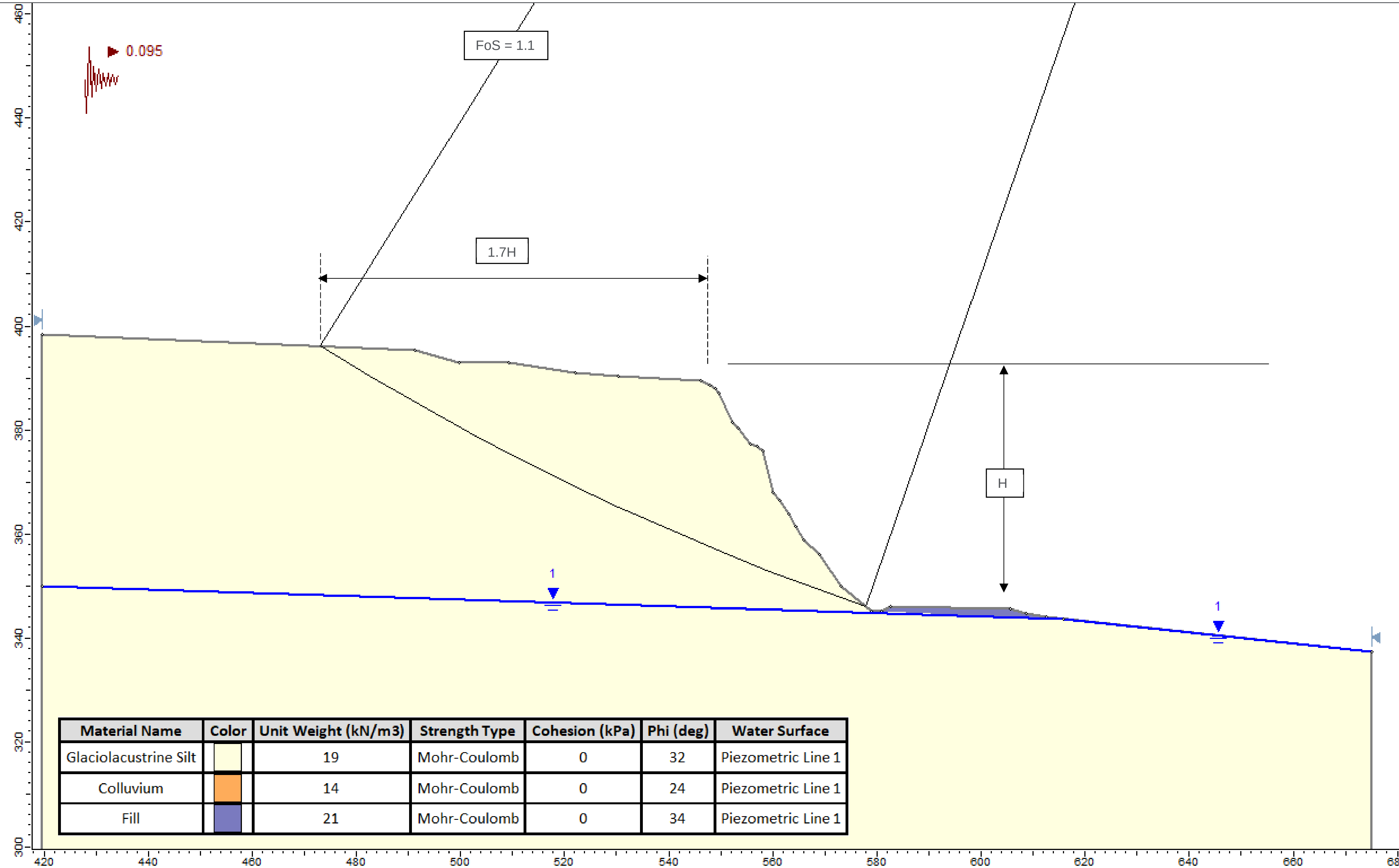
Appendix G3



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

Results the same for the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Pseudo-Static Stability Analysis – Section 3

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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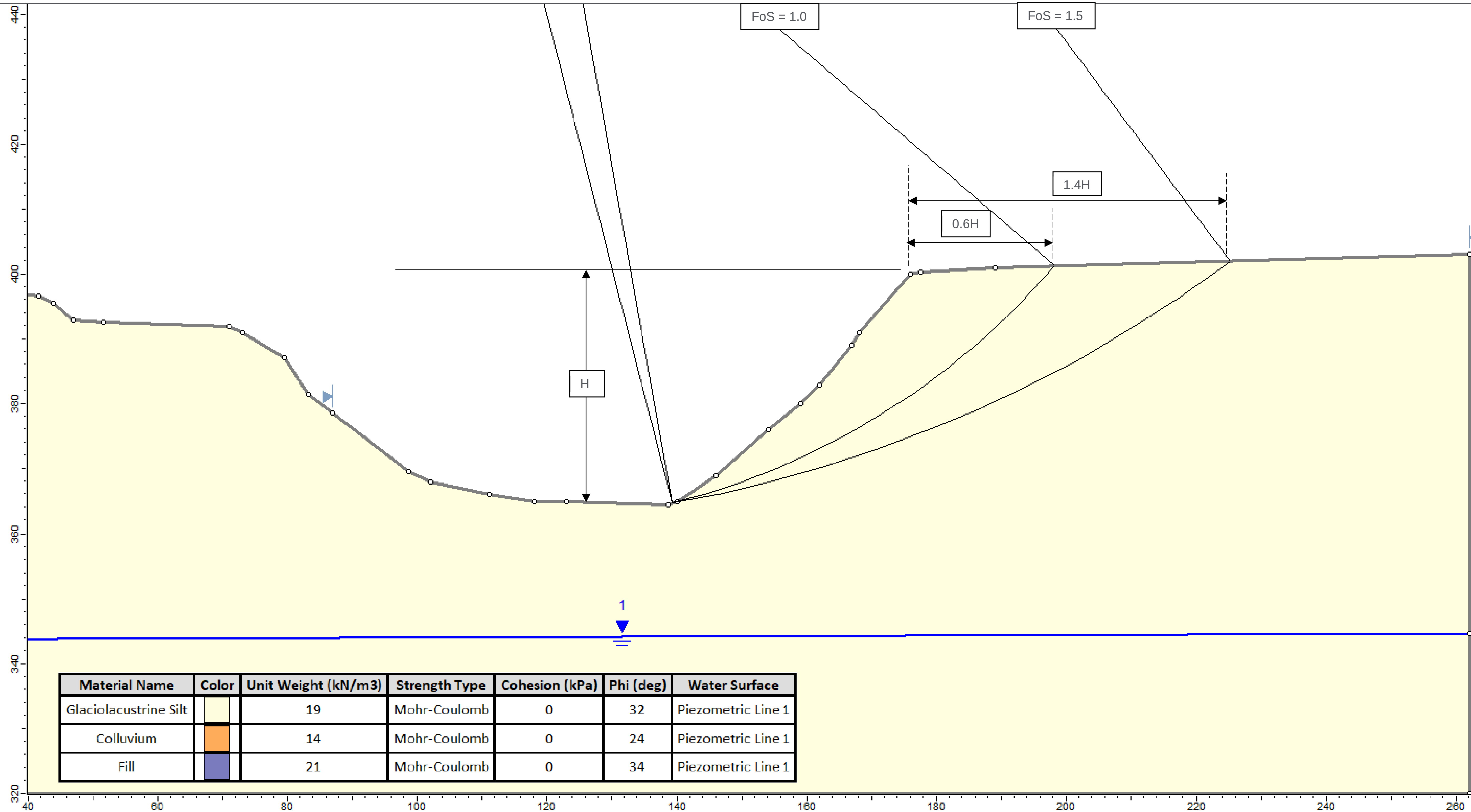
Appendix G3a



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

Results the same for the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 4

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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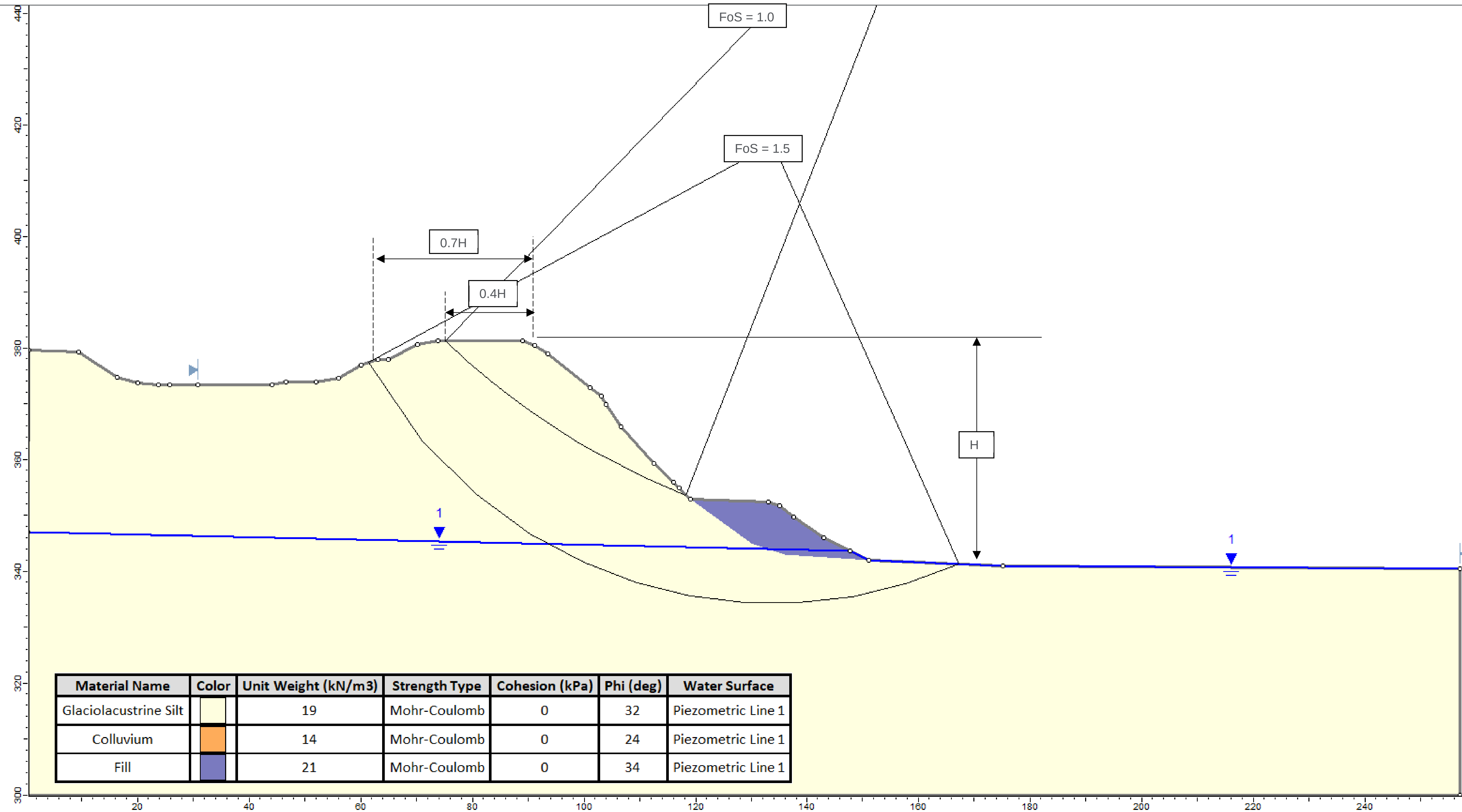
Appendix G4



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on HWM of 343.66 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 5

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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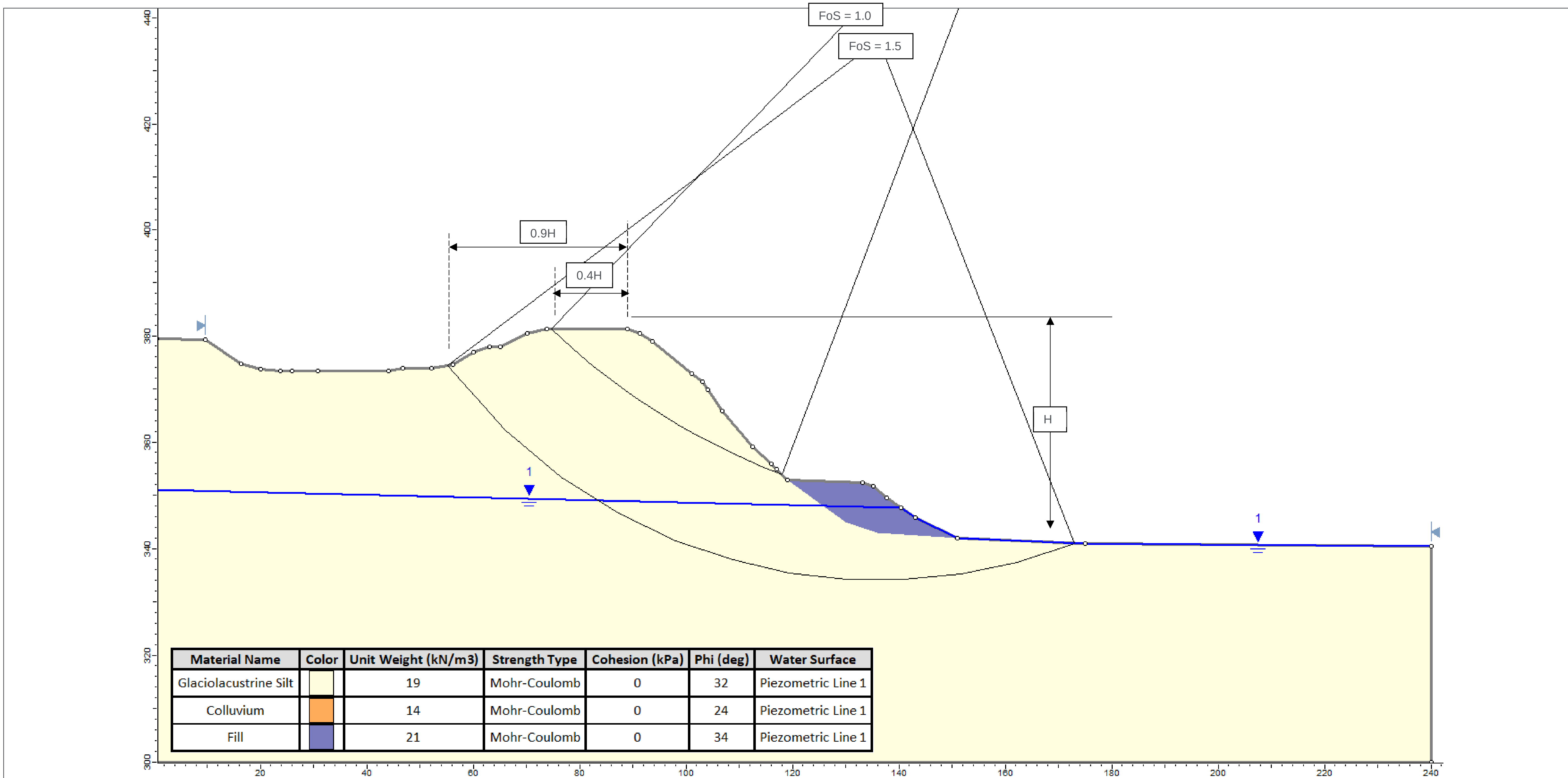
Appendix G5



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Glaciolacustrine Silt		19	Mohr-Coulomb	0	32	Piezometric Line 1
Colluvium		14	Mohr-Coulomb	0	24	Piezometric Line 1
Fill		21	Mohr-Coulomb	0	34	Piezometric Line 1

Notes:

Groundwater table based on the projected HWM considering climate change of 347.26 m for Okanagan Lake

GREATER WEST BENCH GEOTECHNICAL REVIEW

Static Stability Analysis – Section 5 (Climate Change)

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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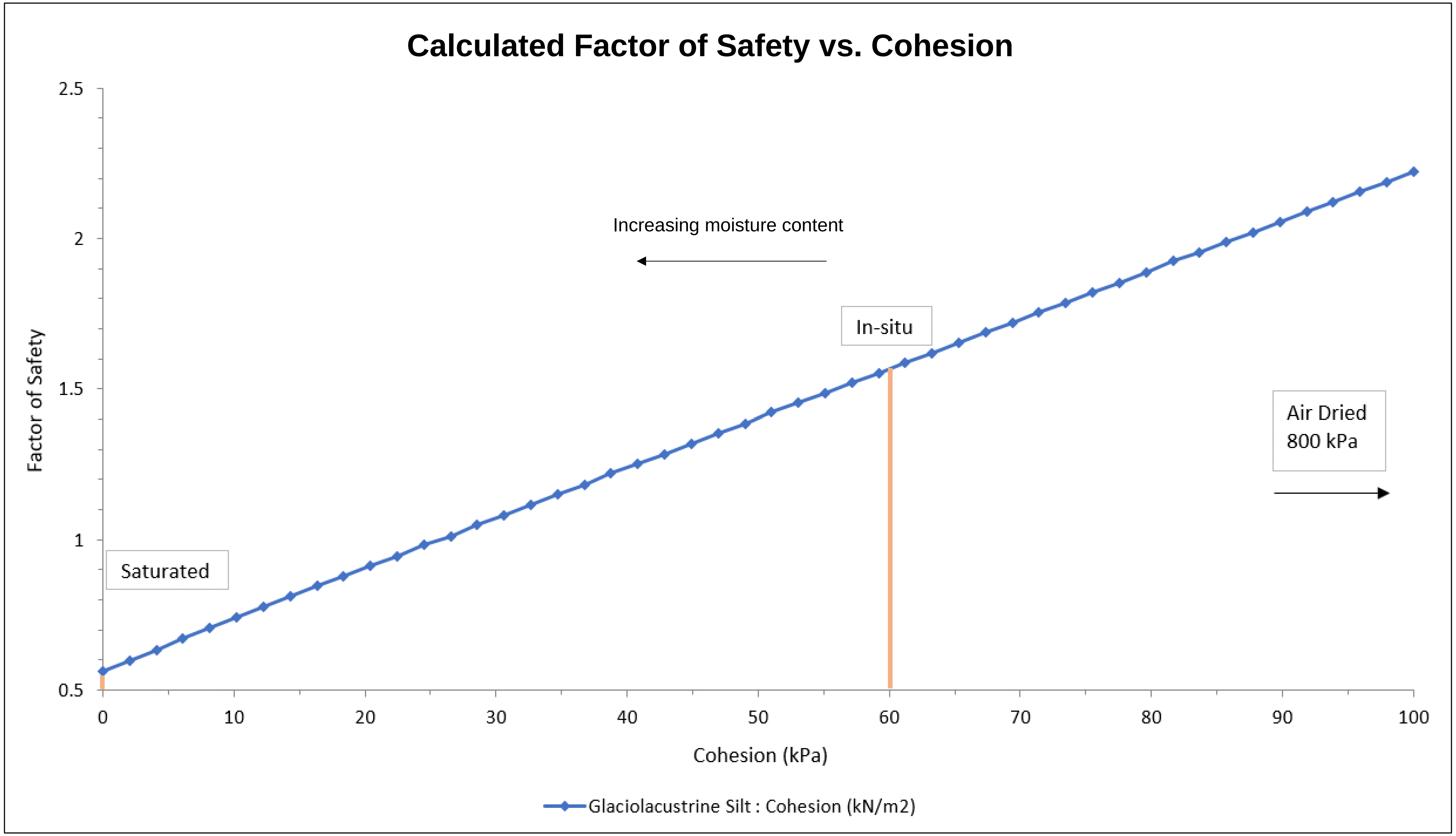
Appendix G5a



Notes:

Graph based on the results of the global stability analysis results for Section 3.

Saturated, "in-situ" and "air dried" cohesion values as recommended by Iravani (1999).

GREATER WEST BENCH GEOTECHNICAL REVIEW

Stability Analysis – Cohesion Sensitivity Plot

Project No. 191010
Client: Regional District of Okanagan Similkameen
Office: Kelowna
Scale: NTS
Date: January 28, 2021
DWN: CE CHK: MJL

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Appendix G6