GEOTECHNICAL GAP ANALYSIS SUMMARY

Fraser River Escarpment Area
Maple Ridge, BC

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EXECUTIVE SUMMARY

The City of Maple Ridge (CMR) retained Braun Geotechnical Ltd. (Braun) to carry out a geotechnical gap analysis for the Fraser River Escarpment (FRE) area of Maple Ridge. The purpose of the study was to provide a background and summary of current understanding of geological conditions and geotechnical hazards of the FRE area, to identify additional study requirements to improve understanding of the identified hazards, and to provide input on workable hazard management measures that could be implemented by CMR to guide land use.

A brief background and summary of geological and geotechnical conditions is provided in the report with more detailed information attached as Appendix I for reference.

Risk, Hazard, and Consequence concepts are discussed.

In addition to the above, a work plan with budget level costing is provided to assist CMR in addressing the following key issues identified:

a. Means and measures to close geological and geotechnical data gaps and to update existing analyses and findings,

b. Evaluation of the effectiveness of FRE area stormwater management measures currently being implemented to reduce water infiltration,

c. Modification, adoption, and/or development of municipal policies and procedures concerning dissemination of critical geotechnical information to FRE stakeholders,

d. Modification, adoption, and/or development of municipal policies and procedures concerning expertise and work scope requirements for geological and geotechnical professionals working in the FRE area,

e. Municipal role and responsibilities in updating and advancing procedures and policies to improve management of FRE area hazards,

f. Some additional risk to the city beyond those elements identified in existing practices and policies.

A work plan summary is provided in the form of a table that prioritizes tasks, identifies roles and responsibilities and provides anticipated budgets to complete task items.

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1.0 INTRODUCTION

The Fraser River Escarpment (FRE) area is currently defined by the City of Maple Ridge (CMR) as the development area described by the area in Figure 1 below confined by:

- South of 124th Avenue;
- Fraser River Escarpment crest of slope (variably located north of the CP Rail property alignment flanking the right bank of the Fraser River or private property);
- East of 207th Street (including the Maple Ridge Golf Course);
- West of 224th Street.

The above boundaries of the FRE demarcate an area for consideration of surficial or groundwater discharge that may potentially influence semi-static water levels at or near the Fraser River Escarpment slopes.

Figure 1 – Google Earth Imagery of Fraser River Escarpment Area

Historically, the FRE area within approximately 300m of the escarpment slope crests has been subjected to large (multi-hectare) scale retrogressive flow slides that fail back from the river cut escarpment crest and smaller sloughs and shallow slides from the escarpment slope (i.e. Port Hammond Slide, Minor Port Hammond Slide, and Fir Street Slide).

Ongoing surficial sloughing and shallow slides on the escarpment slope have occurred along the length of the FRE resulting in private and public property loss and on-going maintenance issues for the active rail line (CP Rail) located at the toe of the escarpment.

FRE surficial geological conditions have been identified in regional studies as possessing moderate to high risk of failure during strong earthquake shaking. Retrogressive impact to ground surfaces located well back from the escarpment crest could also occur.

Extensive CMR efforts to study and manage FRE hazards carried out from 1979 to date have included the following:

- Geotechnical and hydrological studies on the stability of FRE escarpment slopes and Fraser River erosion rates were commissioned in 1979, 1983 and 1986;
- Development and implementation of municipal policies in 1993 to manage and control development within escarpment slope crest setback areas identified as zones of potential geotechnical concern (Policy 6.03/ 6.04);
- In accordance with 1986 study findings, development and implementation of a stormwater plan to reduce water infiltration into the FRE area was initiated in 1993;
- A preliminary seismic vulnerability study of the FRE escarpment and slope crest areas was commissioned out in 2004 to update earlier geotechnical studies;
- Municipal policies 6.03 & 6.04 were superseded by municipal policies 6.23 & 6.24 in 2004 in response to the seismic vulnerability study findings;
- Collection of factual geological and geotechnical information, including insitu testing using state of practice Cone Penetration Test (CPT) methods was commissioned in 2007;

The Maple Ridge area is currently experiencing a stage of rapid growth. CMR is under considerable pressure to identify locations suitable for population densification (large lot subdivision, secondary dwellings, multi-family development, etc.) within existing residential subdivision development areas, including the FRE area. In view of identified geotechnical hazards, completion of a Comprehensive Risk Assessment to quantify probabilities of damage to public infrastructure, private property as well as loss of life within the FRE area is considered warranted. Key elements of risk assessment and basic definitions are presented below in Section 8.0.

In response, CMR requested a geotechnical gap analysis in 2016 to provide recommendations for updating current geological and geotechnical understanding of the FRE area and to provide input into development of a work plan for use by CMR in addressing key land use planning issues.

The objectives of this FRE geotechnical gap analysis included the following:

1. Provide a summary of geological and geotechnical processes that are important in describing the morphology of the FRE area and the level of understanding at present.
2. Identify existing geotechnical and geological information and understanding.
3. Identify CMR efforts to manage development in the FRE area.
4. Identify requirements for improved understanding of FRE morphological processes, hydrogeology and assessment of escarpment hazards, including conceptual work plans and budgets to close information gaps.
5. Suggest appropriate monitoring mechanisms for the collection and control of new data for management of areas considered to be impacted by FRE slope hazards. This would include;
    - Data and information required for collection.
    - Modification, adoption, and/or development of municipal policies and procedures for dissemination of geo-hazard information to FRE stakeholders.

- Modification, adoption, and/or development of municipal policies and procedures concerning expertise and work scope requirements for geological and geotechnical professionals working in the FRE area.

In addition to the above, input was requested to address additional issues of concern to CMR:

6. Identification of some additional risks not explicitly identified in current FRE development policies,
7. Municipal role and responsibilities in updating and advancing procedures and policies to improve management of FRE area hazards,

This gap analysis report was prepared specifically and solely for the FRE area as described previously. Further, this report should be interpreted as a geotechnical information gap analysis only, and not an external peer review of geotechnical information provided and/ or made available to Braun.

2.0 SURFICIAL GEOLOGY

Maple Ridge and the FRE area are underlain by a succession of Quaternary deposits extending from the last interglacial period (Olympia Interglacial) to present. The glacial and post glacial part of the succession comprises Vashon Drift comprised of lodgement till with lenses and interbeds of glaciolacustrine laminated stoney silt (Armstrong and Hicock, 1976). In the Maple Ridge area, the Vashon Drift is overlain by Fort Langley Formation comprising glacio-marine silty clay to fine sand with substantial sequences of silty clay (locally identified as blue Haney Clay) deposited by marine waters that inundated the iso-statically depressed Fraser Lowland upon retreat of the Vashon Ice lobe. To the north and west of the FRE area, Fort Langley Formation is overlain by Sumas Drift deposits comprising raised proglacial deltaic gravel and sand. These sediments inter-finger with Fort Langley formation in complex ways, and the depositional sequence can be disturbed by syndepositional land sliding and loading features making it difficult to extend a detailed geologic model across the study area.

Further details pertaining to the surficial geology in the FRE area is provided in Appendix I.

3.0 IDENTIFIED FRE LANDSLIDE TYPES

3.1 General

Current understanding of the FRE suggests that there may be at least three kinematically distinct types of slope movements that have occurred historically or that are ongoing in this area. These can be described as slides, spreads, and flows. The movement types briefly summarized below are discussed in further detail in Appendix I.

3.2 Slides

Slides refer to downslope movement of soil on relatively discrete rupture surfaces or thin zones of intense shear strain. Deeper seated slides tend to occur in homogenous fine-grained soils (exhibit cohesive behavior) occurring as rotational failures that move along a discrete rupture surface that is curved and concave (upward). Translational slides tend to occur in coarse-grained (non-cohesive) soils occurring as shallow seated downslope movements along a planar or undulating rupture surface.

It is speculated that FRE areas considered susceptible to slide hazard include the escarpment railway cut slopes, steep natural ravine slopes, steep backscarp slopes in the Fir Street slide area, and possibly the minor Port Hammond slide that does not appear to have undergone substantial retrogression.

3.3 Spreads

Spreads refer to subsidence and/or lateral displacement of overlying non-liquefiable soils into and along underlying zones of weak (or weakened) soils that have liquefied or that are exhibiting strain-softening behavior. Translational and retrogressive movements are typical for conditions that are favourable for spreading type failure.

It is speculated that the FRE areas that may be susceptible to spread type failure include the major Port Hammond slide, and possibly the minor Port Hammond (without retrogression) and Haney slides, and areas in between, extending landside from the escarpment several hundred meters to the north.

3.4 Flows

Flows can be described as spatially continuous soil movement such that shear surfaces that may develop are short-lived, closely spaced and typically not preserved. Retrogressive flowslide (or earth flow) type of soil movements can occur in marine and glacio-marine sediments comprising soft to firm sensitive silts and clays.

At the current level of understanding, it is speculated that areas within 300m of FRE slope crest or greater may also be susceptible to retrogressive flow slide. The major Port Hammond slide feature is believed to represent a liquefaction flow slide or slides.

4.0 CURRENT GEOTECHNICAL UNDERSTANDING OF FRE

4.1 General Soil Stratigraphy

The FRE stratigraphy encountered at testhole locations advanced during previous studies is summarized below.

Mainly firm to stiff fine-grained soil (typically silty clay but including lower plasticity clayey silt and higher plasticity clay) interlayered in places with seams of fine to medium sand to silty fine sand with highly variable thickness and strength. The thickness of the interbedded sandy layers varies from lenses that are 1 to 5 mm thick, to layers that are several metres in thickness. It was noted that the degree of interlayering varies with depth and from east to west along the bluffs, and the greatest amount of sand appears to occur within the upper 17 to 19 m, particularly at the east end of the bluffs near the Haney Slide and at the west end of the bluffs near the Port Hammond slide. At the Haney Slide escarpment, very dense silty sand and gravel was encountered at a depth of approximately 82m below ground surface.

4.2 Groundwater Conditions

Previous groundwater monitoring efforts noted semi-static water level fluctuations in the range of 0.2 to 1.1 m recorded in standpipe piezometers installed to depths ranging approximately 8 to 12 m deep. Semi-static water level fluctuations within piezometers installed to a depth of approximately 45 m ranged approximately 0.1 m to 0.3 m.

Water pressures were noted to increase with depth at nested piezometers in upland areas of the FRE at an average 50 percent of hydrostatic (ranging 30 to 70 percent) , and approximately 80 to 90 percent of hydrostatic near the toe of the FRE slopes along the CP Rail alignment.

CPT dissipation data collected during 2007 was noted to be consistent with standpipe piezometer information.

These data suggest that the effects of stormwater infiltration may only impact granular soils at relatively shallow depths, and that influence of stormwater infiltration on deeper granular soil layers may be insignificant due to confinement by overlying fine-grained low-permeability soil layers.

4.3 Fraser River Erosion

Over a 20 year study period, substantial erosion of the submerged Fraser River right bank below the FRE area has not been observed. Current understanding is that localized failures of the river bank below the CP Rail line would likely be reported and repaired before additional grade loss is allowed to occur sufficient in extent to trigger deep-seated movement of the escarpment slopes.

4.4 Geomorphological Features

4.4.1 Port Hammond Landslide Feature (Maple Ridge Golf Course)

Current understanding suggests that the ground surface morphology of the Port Hammond feature reflects a retrogressive flow slide of uncertain age that failed laterally into a steep ravine eroded by meltwater streams during de-glaciation.

4.4.2 Haney Landslide Feature (West of Haney Bypass)

The Haney Slide that occurred on January 30, 1880, was documented in newspaper articles due to the size of the slide, and the destruction of riverside property from the flood wave on both sides of the Fraser River (including one fatality in the Fort Langley area).

A proposed triggering mechanism for the Haney Slide is considered to be a rapid increase in groundwater pressures due to infiltration of rain and snow melt from the relatively thick snow cover at the time of the slide. The ability for the granular soils to adequately drain to the face of the bluffs or to nearby ravine slopes id speculated to have been impeded by frozen soil slopes and allowed water levels within permeable soil layers to rise rapidly.

4.4.3 Fir Street Landslide Feature (South End of Fir Street)

The Fir Street landslide features is thought to represent a single slump event with sufficient debris buttress of the back scarp such that retrogressive failures did not occur. Similar to the minor Port Hammond slide, early work by Golder (1979) assigned an age of the Fir Street slide to be at least 50 to 75 years old without supporting discussion. A testhole (BH-104) advanced near the Fir Street slide back scarp identified soft to firm sensitive clays to a depth of approximately 13.5m

4.4.4 FRE Ravines

Ravine features cut by surface runoff from the emergent surface are located near River Wynd, Wood Street, and to the south of River Road (approximate 217 Street alignments). These features are believed to reflect surface erosion and gullying processes that occurred during the last period of de-glaciation and uplift (Turner and Clague, undated).

4.5 Anthropomorphic Features

4.5.1 CP Rail Cut Slope

The predominant man-made escarpment feature is the CP Rail cut slope advanced along the escarpment toe area during the 1800's. It is understood that various geotechnical consultants have carried out site assessments, exploration and geotechnical consulting services to CP Rail in the FRE area. As part of additional detailed study it is anticipated this information would be obtained from CP Rail for review.

4.5.2 Lot Development

A review of historical air photos noted ongoing residential development of the upland area, including filling activities at the crest of escarpment slopes.

5.0 CURRENT UNDERSTANDING OF SEISMIC VULNERABILITY

5.1 General

Stability analysis of slopes under seismic conditions (i.e. additional pseudo-dynamic load condition) was considered in the most 2004 escarpment area study. State of practice stability analysis at that time (based on available FRE geotechnical information) assumed the following:

- Firm ground motions based on NBCC1985 3rd generation seismic hazard calculations,
- Peak Ground Acceleration (PGA) calculated for a design earthquake event with a probability of exceedance of 10% in 50 years (1:475yr return),
- Slope stability including seismic forces and assuming no liquefaction of FRE soils,
- Liquefaction potential was discussed in general terms only due to limited available data at the time of the study.

5.2 Design Seismic Event in 2004

The Geological Survey of Canada (GSC) produced 3rd generation model semi probabilistic seismic hazard maps in 1985 that presented the peak ground acceleration (PGA) spectrum for firm ground (Site Class C) sites and for a rare design earthquake with a probability of exceedance of 10% in 50 years (1:475 return period). These seismic hazard calculations were the state of the art at the time of the 2004 seismic vulnerability study.

Seismic hazard models continue to evolve as more and higher quality data is recorded from earthquake events around the globe.

Currently, the 2015 GSC 5th generation model (fully probabilistic seismic hazard calculations) is state of the art that supersede earlier models and for the very rare design earthquake with a probability of exceedance of 2% in 50 years (1:2,475yr return) adopted by the current BC Building Code (BCBC2018).

5.3 Potential Geotechnical Seismic Hazards

Potential geotechnical seismic hazards are summarized below:

- direct impact of earthquake ground motions on structures and services (i.e. non-permanent displacements),permanent vertical and horizontal ground displacements due to ground deformations (earthquake-induced differential lateral movements, settlement and/ or deviatoric deformations assuming no liquefaction);
- liquefaction of saturated granular soils with potential to cause lateral spreading, post-liquefaction subsidence, uplift of buried structures, loss of soil resistance sufficient to cause bearing failure, and/ or flow slides;
- slope failures including large deformations in fine-grained soils (in particular low plastic silts and sensitive clays) caused by reduction of soil strength to residual values due to generation of excess pore water pressure and strain-softening, and;
- landslide-induced flood waves.

5.4 Potential Consequences of Seismic Hazards

Potential consequences of geotechnical seismic hazards resulting in building and infrastructure failure:

- damage to, or destruction of roads,
- damage to, or destruction of surface or buried services,
- damage to, or destruction of houses,
- property loss,
- damage to, or destruction of the CP Rail line,
- impact to Fraser River flows and traffic,
- injury or loss of life.

6.0 RISK DISCUSSION

Everything is exposed to risk. The concept of safety involves acceptance or tolerance of a certain level of risk. Risk tolerance is a social phenomenon, and although risk tolerance thresholds should be defined by policy makers, they are often defined by the courts.

The product of the factors Hazard and Consequence discussed above determines Risk. Consequence itself is a product of factors, including but not necessarily limited to the factors below:

- probability that an event will reach a site location;
- probability that an element at risk will be present when the site is affected by the hazard;
- probability that the elements at risk will be vulnerable to the hazard affecting the site, and;
- estimation of the value of the elements at risk, or the number of persons exposed.

In BC there is no legislated guidance for risk tolerance to landslides and associated phenomenon, and the term "safe" has not been legally defined. In considering risk tolerance, an important concept is that risk of loss of life from natural hazards should not add substantially to that from all life's usual factors (driving, health, recreation, etc) combined. For reference, the risk of death and injury from driving in Canada is approximately 1/10,000 and 1/1000 per annum, respectively (Transport Canada 2011).

In general, tolerable risk from natural hazards is considered to describe the level of risk society is prepared to live with as long as the natural hazard is monitored and risk management options have been implemented (residual risk).

Acceptable risk from natural hazards is considered to describe the level of risk that society is willing to live with without implementation of risk management measures specific to the identified hazard (i.e. inherent risk). These are typically defined by technical approach with a view to quantify findings and develop risk criteria based on mathematical expressions of general public (societal) opinion.

Actual risk tolerance or risk acceptance for the same hazard can be expected to vary widely and can change over time. The following examples are provided below for clarification:

- ***Individual:*** Acceptance/ tolerance of a specific person determined by non-aggregated quantitative or qualitative methods;

- ***Aggregated-individuals***: Mean value of acceptance/ tolerance of multiple persons not necessarily internal to the identified hazard(s);
- ***System-internal***: communicated acceptance/ tolerance of a specific social network (i.e. stakeholders, expert community specific to the identified hazard(s), or impacted persons);
- ***Societal***: acceptance/ tolerance of society as a whole. Often defined by the courts;
- ***Expert***: Expert perceived by society (and peers) as a field leader defines acceptable/ tolerable risk levels.

7.0 CURRENT HAZARD MANAGEMENT MEASURES

7.1 General

CMR provided information on staff issues and concerns (August, 2016) with respect to assessment, monitoring and hazard mitigation efforts historically or currently implemented in the FRE area. The key efforts are summarized below.

7.2 Geotechnical/ Hydrological Studies

A review of available information noted that geotechnical and hydrological studies in the FRE area were carried out for the CMR in 1979, 1983, 1986, and 2004. Geotechnical data collection was carried out for CMR in 2007, and a factual report presenting the data was submitted in early 2008. Further discussion on the findings of these studies is presented in the attachment (Appendix I).

7.3 Groundwater Monitoring Program

Historically, periodic monitoring of standpipe piezometers that was carried out over a 20 year period gave representative seasonal water levels that correlated with annual precipitation. The 2008 CPT dissipation tests (to estimate equilibrium water pressure) were consistent with standpipe piezometer measurements with respect to shallow (less than ~20m) and deep piezometric levels in the FRE area.

It is understood that monitoring of the FRE area was limited to periodic water level measurement of standpipe piezometers discussed above. Monitoring of standpipe piezometers was discontinued in approximately 2004 and the remaining number of functional piezometers is not known.

A site walkover review of the escarpment toe of slope area noted CP Rail wireline installed along the railway alignment to provide warning of slides sufficient in magnitude to reach and break the wireline.

7.4 Fraser River Escarpment Development Area Policies

Based on recommendations provided in the geotechnical studies, policies were developed to govern the potential subdivision of, or building on, land within 300 meters of the crest of the Fraser River Escarpment (FRE) and surficial or groundwater discharge within the area bounded by 207 Street, 124 Avenue, and 224 Street.

In response to early escarpment studies, Maple Ridge adopted the Fraser River Escarpment Development Area Policies No. 6.04 and 6.05 in 1993 that included the following restrictions:

- A nominal minimum 10 m setback of all improvements (inferred to mean buildings, structures, and hard/soft landscaping) from the crest of slope,
- A restriction to control removal of trees and vegetation from the escarpment slopes,

- A restriction to control discharge of runoff, seepage, or other water onto the escarpment slopes,
- A restriction to control fill placement onto escarpment slopes, in ravines, or at the crest of escarpment slopes.
- Effective prohibition of development or subdivision of land within 100 m of the escarpment unless river erosion control measures are implemented.

The seismic vulnerability study carried out in 2004 provided the following additional recommendations:

- All development should require input from a qualified geotechnical engineer (based on site exploration and stability analysis) to assess potential retrogressive impacts within approximately 100 m from the backscarp of the major landslide features and ii) within approximately 300 m from the existing escarpment crest.
- Subdivision within 100 m of the escarpment located between the major landslide features increases density and thereby risk to human life and as such, should not be permitted without site exploration and analysis sufficient to quantify risks.
- Site development involving replacement of an existing building should be considered a financial risk but there is no greater risk to human life than already existed.

The existing CMR Fraser River Escarpment Development Area policies were updated to reflect the 2004 findings and re-issued as Policies 6.23 and 6.24.

7.5 Stormwater Management

Based on recommendations provided in the geotechnical studies, construction of new and upgraded municipal stormwater drainage is being carried out in the FRE area. The stormwater control measures are anticipated to reduce potential for water infiltration into the escarpment slopes and slope crest areas. The benefits of lowering semi-static water levels were considered two-fold; firstly, liquefaction is considered unlikely for drained (non-saturated) soil conditions, and secondly, potential for build-up of de-stabilizing seepage forces at escarpment slopes is reduced.

It is understood that mandatory connection to installed municipal storm sewers in the FRE area is required within a period of 5 years following installation. It is also understood that to date, approximately 30% of properties have connected to the storm system. Impacts to shallow water level fluctuations are not currently known.

Previous study recommendations (Golder) included active permanent dewatering measures comprising vertical wells to permanently lower water where deemed necessary by additional detailed study. A drainage gallery or inclined slope drains driven into the escarpment at the CP Rail track elevation were also considered in the Golder study.

7.6 Fraser River Erosion Protection

Active measures to address erosion or shallow sliding below the rail tracks are currently carried out by CP Rail in response to ongoing shallow bank sliding. It is considered that a substantial erosion event would initially express as localized failures of the bank below the CP Rail track alignment to provide early warning of substantial slope toe loss that if allowed to continue, could trigger escarpment slope movements.

In view of ongoing CP Rail efforts, later study findings by Golder deemed that erosion of the FRE escarpment slope toe areas to be a low concern.

8.0 GEOTECHNICAL GAP ANALYSIS

8.1 Study Tasks

8.1.1 General

The following sections discuss data/ analysis gaps in the existing geological, geotechnical,and seismic information that should be updated to assist in quantifying FRE area hazards. Estimated costs and priority for additional study tasks identified in this gap analysis are provided below in Section 10.

8.1.2 Soil Conditions

Analysis of factual geotechnical information (2008) should be carried out and possibly additional site exploration and mapping. These efforts are recommended with a view to;

- Update current geologic model(s),
- Collect high quality soil samples for further classification and detailed laboratory testing and,
- Obtain (by available literature research or exploration) subsurface information to a sufficient depth for dynamic response analysis of the soils overlying 'firm ground' at depth (i.e. Site Response Analysis).

8.1.3 Groundwater

A comprehensive hydrogeological study is considered warranted in order to develop a sound hydrogeological model for the FRE area. The study should be carried out with a view to:

- inventory existing piezometers;
- evaluate current stormwater management strategies and climate change impacts;
- evaluate effectiveness of existing active slope drainage systems (CP Rail);
- provide recommendations for additional monitoring measures, and;
- assess potential for installation of deep seated active or passive drainage measures.

8.1.4 Haney, Major/ Minor Port Hammond, and Fir Street Landslides

These preserved landslide features represent a record of ground response to historical de-stabilizing events (i.e. strong earthquake shaking, unusual climate conditions, Fraser River erosion, and natural slope degradation processes). A good geological understanding of these features is an important component in determining potential for occurrence of similar ground response along remaining intact escarpment crest/slope areas in future.

Additional geological and geotechnical study of these key escarpment features is considered warranted and may include, but may not be limited to the following:

- Geological mapping and intrusive exploration/ soil testing and carbon dating,
- Update static and seismic stability analysis work to reflect current design earthquake (GSC 5th generation seismic hazard model and for an earthquake that has a 2% probability of exceedance in 50 years) and state of geotechnical practice, including re-assessment of factor of safety against liquefaction (and lateral displacements by Youd, 2002) using magnitude deaggregation or mean magnitude-acceleration method.

- Limit Equilibrium (LE) analysis and Finite Element/Finite Difference Numerical Modelling (FEM/FDM) of flow and retrogressive sliding (both static and seismic) should be considered.

8.1.5 FRE Ravines and CPR Cut Slopes

Stability analysis efforts should be updated using state of practice methods, 2008 factual data, and the current design earthquake event (state of the art GSC 5th generation seismic hazard model and for an earthquake that has a 2% probability of exceedance in 50 years).

8.1.6 Seismic Considerations

The 2004 FRE seismic vulnerability assessment is based on superseded seismic hazard calculations (GSC 3rd generation ground motion). The current 5th generation model (NBCC2015) is based on a substantial quantity of new earthquake data and fully probabilistic treatment of all sources (crustal, in-slab and interface).

Analysis of the 2008 factual data should allow completion of a comprehensive liquefaction assessment of the FRE area involving state of practice liquefaction assessment methodologies, (5th generation model and site specific dynamic response (SSDR) analysis). The liquefaction assessment should include the findings of detailed laboratory testing on selected fine-grained soils (i.e. cyclic direct simple shear) to estimate cyclic response of these soils during earthquake shaking.

These efforts would be used to update the 2004 seismic vulnerability assessment of the FRE area (buried services, roads, buildings, other structures).

8.2 Management Tasks

8.2.1 General

The following summarizes tasks to evaluate effectiveness of currently implemented hazard management measures. It is anticipated that review and update of existing FRE geological, hydrogeological and geotechnical information will result in additional revision to the existing and recommended mitigation/ monitoring measures.

Estimated costs and priority for additional management tasks identified in this gap analysis are provided below in Section 10.

8.2.2 Monitoring

As discussed previously, it is anticipated that a hydrogeology study would include tasks to inventory existing functional piezometers, decommission abandoned piezometers in accordance with current BC Groundwater regulations, and install new piezometers at selected locations based on the findings of the study.

CP Rail should be approached for signal access to the slide warning system installed along their railway alignment at the toe of the escarpment.

8.2.3 Stormwater Management

A detailed review of the recommended and implemented storm drainage control measures should be carried out to assess effectiveness in lowering shallow semi-static water levels. It is expected that prior to construction of additional municipal storm water drainage, completion of a comprehensive hydrogeology assessment to model groundwater conditions (as discussed previously) would be completed in order to assess effectiveness of existing and future drainage improvement measures.

8.2.4 Avoidance, Acceptance and Resilient Design

Avoidance

Review and revision of the preliminary 100 m and 300 m escarpment zones of potential geotechnical concern is expected to result from analysis of FRE geotechnical data that has been collected since 2004, and updates to state of practice geotechnical analyses.

Acceptance

Based on the findings of a seismic vulnerability assessment discussed above, damage to, or destruction of selected infrastructure elements may be acceptable based on importance and cost/ downtime analysis. A failure modes and effects analysis (FMEA) is a proven qualitative technique for understanding the behavior of elements (and failure influence between elements) within a larger engineered system.

Resilient Design

Consideration should be given to developing 'resilient' design concepts for structures or elements within selected geotechnical hazard zones that have been advanced to a suitable level of understanding. Examples of resilient design measures include, but are not limited to flexible service connections, critical service re-routing, and deformation tolerant structures.

8.2.5 Fraser River Erosion Protection

CPR erosion/scour protection measures that have been implemented in the FRE area should be inventoried. A review of design details (if possible) and/ or constructed works should be reviewed by a hydrotechnical consultant.

As mentioned previously, researchers considered Fraser River erosion to be a low priority de-stabilizing concern to the stability of the FRE escarpment slopes.

8.3 Collection and Management of Geological/ Geotechnical Information

The following general suggestions for management of geotechnical hazard information are provided for reference;

- Collect and categorize all available geological, geotechnical and hazard reports specific to the FRE area (including in-house private reports and available published information). General categories could be used (i.e. sedimentary facies (distinct depositional sequences), geotechnical hazard assessment, slope stability assessment, peer review report, etc) and the reports recorded on a tracking sheet for digital inventory in a GIS-based (geographic information system) report management system.
- Archive reported and published instability events in the FRE area (newspapers, etc).
- Collect and compile a digital inventory of published (or by outside agency) hydrological/ geological information (regional provincial studies, university theses, CP Rail reports, etc).
- Compile a collection of submitted and released reports for mandatory review by consultants carrying out geotechnical assessments in the FRE area. http://www.fvrd.ca/EN/main/services/planning-development/application_forms.html
- Develop external access measures for dissemination of FRE hazard-related information. http://www.geoweb.dnv.org/applications/hazardsapp/
- Develop or adopt geohazard/risk acceptability criteria for existing and new development. https://www.dnv.org/programs-and-services/risk-tolerance

- Develop geotechnical reporting and peer review requirements specific to hazard assessment reporting in the FRE Area.
  http://www.delta.ca/docs/default-source/steep-slope-geotechnical-requirements/geotechnical-requirements-steep-slope-guide.pdf?sfvrsn=2

9.0 HAZARD ASSESSMENT

9.1 Maple Ridge Roles and Responsibilities as Approving Authority

The APEGBC Landslide Assessment guidelines (May, 2010) and the Municipal Insurance Association of BC guidelines (2002) provide guidance on the roles and responsibilities of municipalities as an Approving Authority.

As discussed in the guidelines, the Approving Authority is responsible for initiating the requirement for hazard assessment and should:

• inform as to why a landslide assessment is required;

• confirm the adopted level of safety against identified hazards to development in the FRE Area once specific criteria have been developed or adopted, and

• provide or provide reference to guidelines for carrying out a hazard assessment and/or preparing a hazard assessment report

• review and update hazard assessment requirements and acceptability criteria at least annually to maintain relevance of requirements with respect to advancements in geological, hydrogeological and geotechnical knowledge and new geotechnical data and information that may become available over time.

• during development (and post-development) phases, Maple Ridge has the responsibility to enact and enforce regulations pertaining to adopted hazard management measures.

Following the submission of a landslide assessment the Approving Authority should:

• review the Landslide Assessment Assurance Statement and the landslide assessment report findings, or forward the report to a technical expert(s) for Peer Review, and

• if necessary, discuss the assessment report with the Qualified Professional and/ or Peer Review Professional for any questions and/or clarifications of the findings.

The Approving Authority may be further guided by the Municipal Insurance Association of British Columbia's document "Guidelines for Planners, Approving Officers and Building Inspectors for Landslide-Prone Areas in British Columbia" (Skermer 2002).

The following suggestions for management of geotechnical hazard reporting in the FRE area are provided with reference to the EGBC (formerly APEGBC) Guidelines for Legislated Landslide Assessment for Proposed Residential Development in BC (May, 2010).

https://www.egbc.ca/getmedia/5d8f3362-7ba7-4cf4-a5b6-e8252b2ed76c/APEGBC-Guidelines-for-Legislated-Landslide-Assessments.pdf.aspx

- Screening of geological and geotechnical consultants could include requirements for consultants to provide a professional resume (or curriculum vitae) that demonstrate qualifications and suitable experience in geotechnical hazard assessment, static and seismic slope stability analysis, and assessment of liquefaction potential (See Section 6 of the Landslide Assessment Guidelines). For example, during 2008 City of New Westminster was requiring geotechnical consultants new to the Queensborough Development Area (underlain by deep Peat) to submit a resume with demonstrated geotechnical design experience in Peat soils and to attend a pre-design meeting with the technical staff in their Building Department to review geotechnical challenges encountered by others in the Queensborough area.

- Geotechnical assessment reports in the FRE area and within current (or developed) geotechnical setback areas should be automatically required to undergo independent peer review. (See Section 2 of the Landslide Assessment Guidelines). For example, City of Surrey has established Steep Slope Development Areas within the city. Geotechnical reports for building permits in these areas are automatically required to be subjected to independent peer review to confirm the report meets the requirements to be considered a Landslide Hazard Assessment Report per EGBC Guidelines.

9.2 Additional Considerations for FRE Policies and Practices

9.2.1 Private Land Use Activities

The current FRE policies include requirements for new private property development but not land use activities on private property. Consideration should be given to improving precision by identifying permissible, conditional, and impermissible land use activities within the FRE area. Mechanisms should be established to guarantee the ongoing maintenance of slope stability over time once a building is complete and occupied. It may be possible to stipulate requirements for ongoing maintenance in the form of a covenant to cover such concerns as water use, drainage, and soft and hard landscaping.

The policies do not address land use restrictions for developed properties. Enforcement of private land use restrictions presented in the policies is not known. It is considered likely that ongoing alterations by unknowledgeable property owners are being carried out without Maple Ridge oversight.

As part of risk management strategies for the FRE area, consideration should be given to provision of informational public meetings for FRE property owners and stakeholders:

- to make them aware of identified hazards;
- to outline CMR efforts to date (including proposed future work) that have been carried out to manage risk, and;
- to provide some education to property owners located near FRE slope crests on land use activities that may promote instability of these slopes.

Informational meetings could also be supplemented by online information on the City website and by expansion of Ridgeview mapping to include geo-hazards.

9.2.2 Technical Advancements

As discussed previously, geotechnical understanding of earthquakes has advanced rapidly over the last 20 years largely due to exponential growth in earthquake databases, technological advancements in seismic recording equipment, substantial improvements in computer processing power and speed, improved understanding of liquefaction triggering processes and outcomes, and the development of increasingly robust earthquake attenuation models for seismic hazard calculations.

Based on current level of technical understanding earthquake shaking and ground response, the geotechnical setback zones identified in the policies should be considered preliminary based on, but not limited to the following:

- Current zones are based on an overview level of study in 2004 (i.e. the report clearly indicates that there was not sufficient data at the time to carry out a rigorous assessment of liquefaction susceptibility);
- Seismic hazards were calculated for superseded ground motion models that are no longer considered state of practice;
- The rare design earthquake return period (10% probability of exceedance in 50 years) adopted by Building Codes at the time of study has been superseded by the very rare design earthquake return period (2% probability of exceedance in 50 years).
- In the absence of detailed laboratory testing, displacement triggers for headscarp retrogression should be considered approximate estimates only.

In view of the above, geotechnical setback zones in the current policies can be expected to be refined by additional detailed study.

9.2.3 Land Value Impact

Fire, flood and earthquake hazards are short-lived and definite. Landslides hazards can occur rapidly in response to a critical trigger. However, unlike other hazards, landslide-damaged ground is preserved as a visible record of the event over an extended period of time. As such, at a minimum, public perception of adjacent intact areas tend to be negatively impacted. In addition, geotechnical damage to intact slopes adjacent to the landslide may result in additional sliding or displacements of these areas over time such that post-slide cumulative damage could also grow.

In the event that that Maple Ridge implements land use restrictions specific to the FRE, there is a potential for land values of properties identified for land use restrictions to be negatively impacted.

Note that these is also some potential that additional detailed study may identify properties within the FRE that require substantial remedial measures to safely occupy the property, or may identify properties that are not feasible to remediate and that are not suitably safe for occupation.

9.2.4 Interpretation of Policies 6.23 and 6.24

As mentioned previously, the last technical analysis of the FRE area was carried out in 2004. An exploration and insitu testing program was carried out during 2007/ 2008 and the findings submitted as a factual report in 2008 with no analysis of the collected data. The original policies (Policy 6.3 and 6.4) were updated to reflect the findings of the 2004 study. At that time, the 2004 study and subsequent policy updates represented a state of practice understanding of the FRE area.

The following comments are provided with respect to the current Policy 6.23 and 6.24:

- Substantial additional geotechnical data was collected from the FRE area in 2007 (2008 Factual Report). A review of previous stability analysis work should be carried out based on the new information. The review would be carried out with a view to revise and update previous findings as required. It is anticipated that the current policies would be revised to reflect updated findings.
- The current policies imply conditional approval of population densification within both hazard zones of the FRE area. Densification exposes a greater number of occupants to FRE hazards that may be confirmed by additional study carried out to update findings. It is anticipated that the current policies would be revised or expanded to address this potential exposure concern.

- Policy 6.24 identifies an expected geotechnical exploration work scope that currently may not be practically achievable in all cases for individual lot development. Current policies should be updated to include links to the area-wide geotechnical and electronic CPT data (2008 Factual Report) for use by geotechnical professionals practicing in the FRE area in order to meet work scope requirements presented in the policies.

10.0 SUMMARY OF STUDY AND MANAGEMENT TASKS

The following tables provide a summary of study and management tasks recommended for the FRE area. The tables also identify task priority and provide an approximate range cost burden for each task. Some task items require ongoing efforts to ensure understanding of the FRE area remains current. An estimate of task frequency for these elements is also provided.

10.1 Study Tasks

Report Section	Study Item	Priority (Execution)	Freq.	Discussion
7.1.2	Soil Conditions	Medium (3)	1[1]	Based on single contiguous exploration and testing program that includes at least one deep test hole to confirm depth to 'firm ground'
7.1.3	Groundwater	High (2)	1	Hydrogeological Study that includes piezometers, pumping tests and assessment of CPR inclined drain system performance
7.1.4	Existing Landslides	Medium (1B)	1	Geomorphological Study of key FRE landslide feature (Port Hammond Slide) including deep test pit exploration
7.1.5	Ravine/ CPR Slopes	Low (4)	1	Geotechnical assessment of intact ravine slopes and CPR cut slopes
7.2	Seismic Hazard	High (1A)	NBCC[2]	Update liquefaction factors of safety and displacements to current state of practice and seismic hazard calculations (NBCC2015)[3,4]

See notes below in Section 10.2

10.2 Management Tasks

Report Section	Management Item	Priority	Freq.	Discussion
7.3.2	Monitoring	Low	Seasonal[5]	Scope of monitoring requirements may be substantially less than anticipated based on findings of Hydrogeological Study (and if slope drain program is implemented)

7.3.3	Stormwater Management	Low	Ongoing	Net impact of partially installed and connected system is not currently known. Mandatory connection to existing system should be made mandatory for property owners in the interim.
7.3.4	Private/ Public Design Measures	High	NBCC	Hazard avoidance/ acceptance and resilient design measures should be carried out concurrent with updates to seismic hazard (Study Task 7.2 above).
7.3.5	Fraser River Erosion	Low	1[7]	CPR carries out ongoing bank erosion protection for the track alignment.
7.4	Information Management	High	Setup & Annual	Post-compilation of hazard information should be updated and disseminated to Owners, stakeholders and consultants preferably by an online GIS-based management system.
8.1	Roles and Responsibilities	High	1	Opinion on process for review and approval of geotechnical aspects of development activities in the FRE area including confirmation of consultant qualifications.
8.2.1	FRE Land Use	Medium	Ongoing	Inspection and Enforcement is recommended with respect to land use restrictions that are developed for selected areas within the FRE.
8.2.2 8.2.4	Policy Update and Revisions	High	NBCC	Update current policies with respect to out-dated technical findings and to include minimum (feasible) technical requirements for FRE geotechnical analysis and reporting.
8.2.5	Risk Communication	High	1[11]	It is anticipated that a Risk Consultant would be consulted during advancement of Section 7.4 Information Development measures adopted by the City.

1. Assumes level of effort completed to final report requirements and may include Section 7.2 study task. Note that additional work effort requirements could be identified during execution of the selected study item.
2. Frequency of updates to seismic considerations should generally be expected to occur with each new release of the NBCC (approximately 5 year periods). Additional updates may be required in the event the seismic hazard model is superseded between Code release dates.
3. Current 5th generation fully probabilistic seismic hazard model.
4. Liquefaction Task Force (2007) Deaggregation by Site Class method has been superseded.
5. Seasonally for two years, annually thereafter.
6. Budget estimate for revised findings based on updates to seismic hazard model only. Costs for resilient design would be specific to proposed and/or existing structure(s).
7. Post-inventory, protection measures should be reviewed on a per incident basis.

8. Initial setup cost is expected to be high with substantially lower ongoing maintenance costs annually.
9. Additional resource costs not anticipated. May consider a nominal budget for consultation fees.
10. Initial policy revision cost is expected to be relatively high with substantially lower review and revision costs at approximate 5yr intervals (~NBCC release interval).
11. Suggest review and revision consistent with Building Code release intervals.

11.0 CLOSURE

The City of Maple Ridge may rely on the findings presented in this Geotechnical Gap Analysis report.

The use of this report is subject to the Report Interpretation and Limitations, which is included with the report. The reader's attention is drawn specifically to those conditions, as it is considered essential that they be followed for proper use and interpretation of this report.

We hope the above meets with your requirements. Should any questions arise, please do not hesitate to contact the undersigned.

Yours truly,

Braun Geotechnical Ltd.

ORIGINAL SIGNED BY AUTHOR

James Wetherill, P.Eng.
Geotechnical Engineer

Reviewed By,

Sonny Singha, P.Eng.
Geotechnical Engineer

Attachments: Report Interpretation and Limitations
Appendix I – Technical Discussion

REPORT INTERPRETATION AND LIMITATIONS

1. STANDARD OF CARE

Braun Geotechnical Ltd. (Braun) has prepared this report in a manner consistent with generally accepted engineering consulting practices in this area, subject to the time and physical constraints applicable. No other warranty, expressed or implied, is made.

2. COMPLETENESS OF THIS REPORT

This Report represents a summary of paper, electronic and other documents, records, data and files and is not intended to stand alone without reference to the instructions given to Braun by the Client, communications between Braun and the Client, and/or to any other reports, writings, proposals or documents prepared by Braun for the Client relating to the specific site described herein.

This report is intended to be used and quoted in its entirety. Any references to this report must include the whole of the report and any appendices or supporting material. Braun cannot be responsible for use by any party of portions of this report without reference to the entire report.

3. BASIS OF THIS REPORT

This report has been prepared for the specific site, development, design objective, and purpose described to Braun by the Client or the Client's Representatives or Consultants. The applicability and reliability of any of the factual data, findings, recommendations or opinions expressed in this document pertain to a specific project at described in this report and are not applicable to any other project or site, and are valid only to the extent that there has been no material alteration to or variation from any of the descriptions provided to Braun. Braun cannot be responsible for use of this report, or portions thereof, unless we were specifically requested by the Client to review and revise the Report in light of any alterations or variations to the project description provided by the Client.

If the project does not commence within 18 months of the report date, the report may become invalid and further review may be required.

The recommendations of this report should only be used for design. The extent of exploration including number of test pits or test holes necessary to thoroughly investigate the site for conditions that may affect construction costs will generally be greater than that required for design purposes. Contractors should rely upon their own explorations and interpretation of the factual data provided for costing purposes, equipment requirements, construction techniques, or to establish project schedule.

The information provided in this report is based on limited exploration, for a specific project scope. Braun cannot accept responsibility for independent conclusions, interpretations, interpolations or decisions by the Client or others based on information contained in this Report. This restriction of liability includes decisions made to purchase or sell land.

4. USE OF THIS REPORT

The contents of this report, including plans, data, drawings and all other documents including electronic and hard copies remain the copyright property of Braun Geotechnical Ltd. However, we will consider any reasonable request by the Client to approve the use of this report by other parties as "Approved Users." With regard to the duplication and distribution of this Report or its contents, we authorize only the Client and Approved Users to make copies of the Report only in such quantities as are reasonably necessary for the use of this Report by those parties. The Client and "Approved Users" may not give, lend, sell or otherwise make this Report or any portion thereof available to any other party without express written permission from Braun. Any use which a third party makes of this Report – in its entirety or portions thereof – is the sole responsibility of such third parties. BRAUN GEOTECHNICAL LTD. ACCEPTS NO RESPONSIBILITY FOR DAMAGES SUFFERED BY ANY PARTY RESULTING FROM THE UNAUTHORIZED USE OF THIS REPORT.

Electronic media is susceptible to unauthorized modification or unintended alteration, and the Client should not rely on electronic versions of reports or other documents. All documents should be obtained directly from Braun.

5. INTERPRETATION OF THIS REPORT

Classification and identification of soils and rock and other geological units, including groundwater conditions have been based on exploration(s) performed in accordance with the standards set out in Paragraph 1. These tasks are judgemental in nature; despite comprehensive sampling and testing programs properly performed by experienced personnel with the appropriate equipment, some conditions may elude detection. As such, all explorations involve an inherent risk that some conditions will not be detected.

Further, all documents or records summarizing such exploration will be based on assumptions of what exists between the actual points sampled at the time of the site exploration. Actual conditions may vary significantly between the points investigated and all persons making use of such documents or records should be aware of and accept this risk.

The Client and "Approved Users" accept that subsurface conditions may change with time and this report only represents the soil conditions encountered at the time of exploration and/or review. Soil and ground water conditions may change due to construction activity on the site or on adjacent sites, and also from other causes, including climactic conditions.

The exploration and review provided in this report were for geotechnical purposes only. Environmental aspects of soil and groundwater have not been included in the exploration or review, or addressed in any other way.

The exploration and Report is based on information provided by the Client or the Client's Consultants, and conditions observed at the time of our site reconnaissance or exploration. Braun has relied in good faith upon all information provided. Accordingly, Braun cannot accept responsibility for inaccuracies, misstatements, omissions, or deficiencies in this Report resulting from misstatements, omissions, misrepresentations or fraudulent acts of persons or sources providing this information.

6. DESIGN AND CONSTRUCTION REVIEW

This report assumes that Braun will be retained to work and coordinate design and construction with other Design Professionals and the Contractor. Further, it is assumed that Braun will be retained to provide field reviews during construction to confirm adherence to building code guidelines and generally accepted engineering practices, and the recommendations provided in this report. Field services recommended for the project represent the minimum necessary to confirm that the work is being carried out in general conformance with Braun's recommendations and generally accepted engineering standards. It is the Client's or the Client's Contractor's responsibility to provide timely notice to Braun to carry out site reviews.

The Client acknowledges that unsatisfactory or unsafe conditions may be missed by intermittent site reviews by Braun. Accordingly, it is the Client's or Client's Contractor's responsibility to inform Braun of any such conditions.

Work that is covered prior to review by Braun may have to be re-exposed at considerable cost to the Client. Review of all Geotechnical aspects of the project are required for submittal of unconditional Letters of Assurance to regulatory authorities. The site reviews are not carried out for the benefit of the Contractor(s) and therefore do not in any way effect the Contractor(s) obligations to perform under the terms of his/her Contract.

7. SAMPLE DISPOSAL

Braun will dispose of all samples 3 months after issuance of this report, or after a longer period of time at the Client's expense if requested by the Client. All contaminated samples remain the property of the Client and it will be the Client's responsibility to dispose of them properly.

8. SUBCONSULTANTS AND CONTRACTORS

Engineering studies frequently requires hiring the services of individuals and companies with special expertise and/or services which Braun Geotechnical Ltd. does not provide. These services are arranged as a convenience to our Clients, for the Client's benefit. Accordingly, the Client agrees to hold the Company harmless and to indemnify and defend Braun Geotechnical Ltd. from and against all claims arising through such Subconsultants or Contractors as though the Client had retained those services directly. This includes responsibility for payment of services rendered and the pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. These conditions apply to specialized subconsultants and the use of drilling, excavation and laboratory testing services, and any other Subconsultant or Contractor.

9. SITE SAFETY

Braun Geotechnical Ltd. assumes responsibility for site safety solely for the activities of our employees on the jobsite. The Client or any Contractors on the site will be responsible for their own personnel. The Client or his representatives, Contractors or others retain control of the site. It is the Client's or the Client's Contractors responsibility to inform Braun of conditions pertaining to the safety and security of the site – hazardous or otherwise – of which the Client or Contractor is aware.

Exploration or construction activities could uncover previously unknown hazardous conditions, materials, or substances that may result in the necessity to undertake emergency procedures to protect workers, the public or the environment. Additional work may be required that is outside of any previously established budget(s). The Client agrees to reimburse Braun for fees and expenses resulting from such discoveries. The Client acknowledges that some discoveries require that certain regulatory bodies be informed. The Client agrees that notification to such bodies by Braun Geotechnical Ltd. will not be a cause for either action or dispute.

APPENDIX I
TECHNICAL DISCUSSION

Fraser River Escarpment Area
Maple Ridge, BC

Date: December 19, 2018
File: 16-6970

Prepared by:

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1.0 INTRODUCTION

The Fraser River Escarpment (FRE) area is currently defined by the City of Maple Ridge (CMR) as the development area described by the area confined by:

- South of 124th Avenue;
- Fraser River Escarpment crest of slope (variably located north of the CP Rail property alignment flanking the right bank of the Fraser River or private property);
- East of 207th Street (including the Maple Ridge Golf Course);
- West of 224th Street.

The title page includes an airphoto image with limits of the FRE Development Area marked for reference. A low resolution LiDAR (Light Detection and Ranging) image of the FRE development area is also provided below for reference (see Figure 1).

Historically, the FRE area has been subjected to large (multi-hectare) scale retrogressive flow slides that fail back from the river cut escarpment crest and smaller sloughs and shallow slides from the escarpment slope. Two large flow slide scars bracket the east and west ends of the FRE area: the Haney Slide feature to the east and the Port Hammond Slide feature to the west. Two smaller flow slide features of sufficient size to disrupt the FRE crest are identified as the minor Port Hammond Slide and Fir Street Slide features. Ongoing surficial sloughing and shallow slides on the escarpment slope have occurred across the FRE resulting in private and public property loss and on-going maintenance issues for the active rail line (CP Rail) located at the toe of the escarpment. FRE surficial geological conditions have been identified in regional studies as possessing moderate to high risk of failure during strong earthquake shaking with retrogressive impact to ground surfaces located well back from the escarpment crest considered likely.

Measures to address FRE stability concerns have thus far been limited to establishment of preliminary geotechnical zones of concern and initiation of stormwater control measures to reduce the potential for elevated piezometric water pressures recommended in previous studies. A comprehensive risk assessment study has been recommended but has not been carried out at the time of this report.

It is understood that the City is currently considering population densification (large lot subdivision, secondary dwellings, multi-family development, etc.) of existing residential subdivision development that occupies most of the FRE area.

In order to manage private development and public infrastructure, the CMR wishes to update current geological and geotechnical understanding of the FRE area. To this end, CMR requested a proposal to carry out a geotechnical information gap analysis of existing regional geological and geotechnical studies carried out on behalf of CMR by Golder Associates (2004, 2008).

The objectives of this Technical Discussion are to:

1. Provide a summary of geological and geotechnical processes that are important in describing the morphology of the FRE area and the level of understanding at present.
2. Identify existing geotechnical and geological information and understanding.
3. Identify additional information required for improved understanding of FRE morphological processes and assessment of escarpment hazards.
4. Suggest appropriate monitoring mechanisms for the collection and control of new data sets for management of areas considered to be impacted by FRE slope hazards.

This gap analysis report was prepared specifically and solely for the FRE area as described previously. Further, this report should be interpreted as a geotechnical information gap analysis only, and not an external peer review of geotechnical information provided and/ or available to Braun Geotechnical.

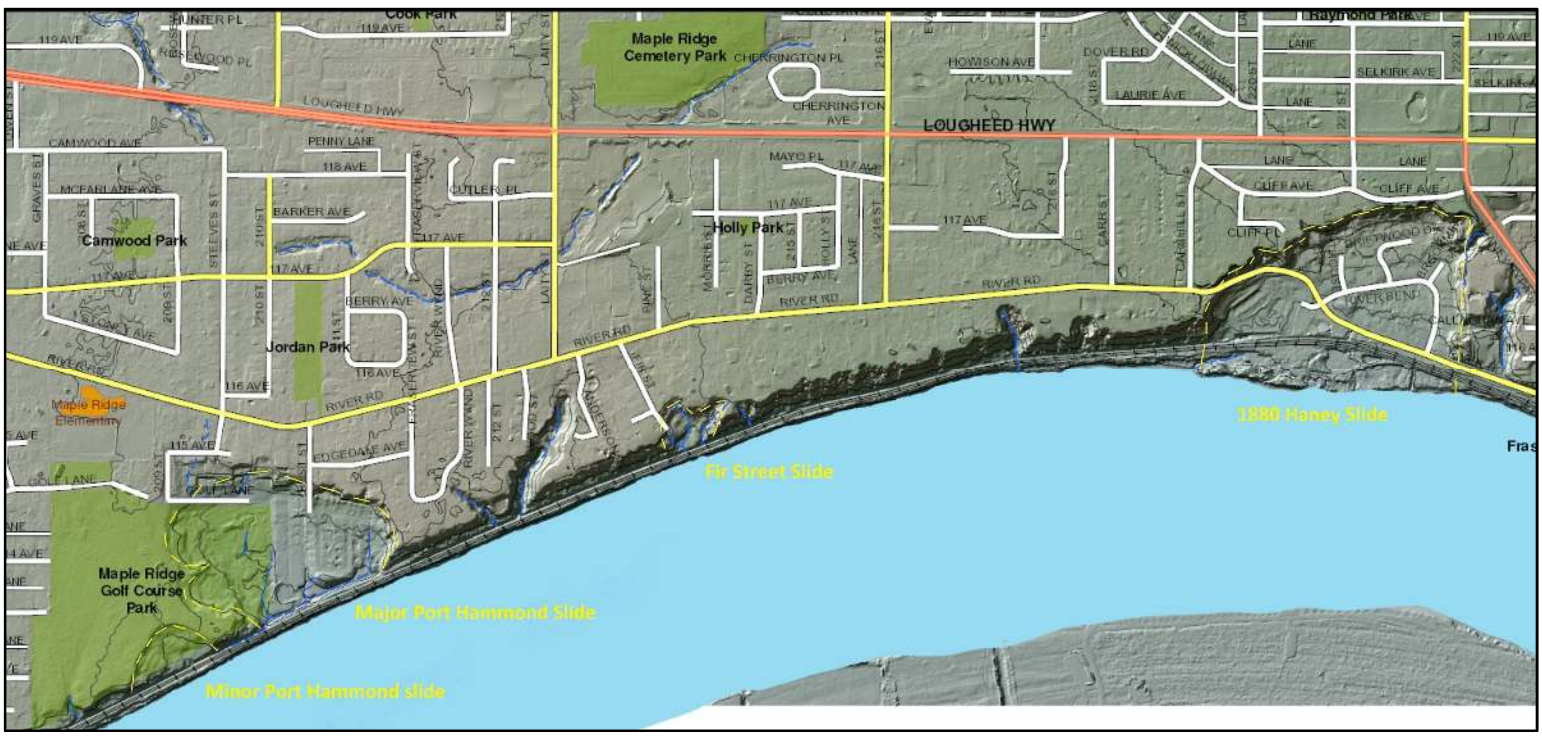

Figure 1 – LiDar image - Fraser River Escarpment

2.0 FRE STUDY INFORMATION AND BACKGROUND

The following geological, hydrotechnical, and geotechnical reports on the FRE area were provided to Braun Geotechnical by CMR and are summarized below:

1. *Northwest Hydraulic Consultants Ltd. (1979). "Fraser River – Haney to Port Hammond Bank Erosion", March 23, 1979.*
2. *Golder Associates Ltd. (1979). "Report to Ministry of Environment, Water Investigations Branch on Stability Study, Fraser River North Bank, Haneey to Port Hammond, British Columbia", August 14, 1979.*
3. *Northwest Hydraulic Consultants Ltd. (1983). "River/ Hydraulic Aspects of Fraser River Bank Stabilization, Haney, British Columbia", March, 1983.*
4. *Golder Associates Ltd. (1983). "Report to British Columbia Ministry of Environment, Water Investigation Branch on Ground Water Monitoring and stabilization Study, Fraser River North River Bank, Maple Ridge, British Columbia", July, 1983.*
5. *Northwest Hydraulic Consultants Ltd. (1986). "Fraser River at Haney, Review of Channel Stability and Protection and Monitoring Options", February, 1986.*
6. *Golder Associates Ltd. (1986). "Report to British Columbia Ministry of Environment ion Fraser River Bank Stability, Maple Ridge, British Columbia", March, 1986.*
7. *Golder Associates Ltd. (2004). "Geotechnical Seismic Vulnerability of Fraser River Escarpment, Maple Ridge, BC", March 23, 2004.*
8. *Golder Associates Ltd. (2008). "Factual Report on Geotechnical Investigation Fraser River Escarpment Maple Ridge, British Columbia", February 12, 2008.*

Other supporting documents and in-house information used in the preparation of this report are attached as references.

The FRE area has been affected by landslide activity both prehistorically and historically, and contains two prominent geomorphological features: the Port Hammond slide feature (date unknown) near the western limit of the escarpment, and the 1880 Haney slide feature near the eastern limit of the escarpment. Between the major slide features and above the CP Rail track grade, shallow slides and sloughing present ongoing maintenance issues to warrant installation of electronic slide warning fencing by CP Rail. In addition, property owners along the escarpment have experienced periodic property loss and landscape/ structure damage. Below the rail grade, ongoing river bank erosion periodically requires repair by CP Rail (rip rap slope armoring).

Area wide geotechnical studies on the FRE area have been carried out by Golder Associates Ltd. (Golder) since the 1970's. The earlier studies (1979, 1983, and 1986) were carried out for BC Ministry of Environment, while the later studies (2004 and 2008) were carried out for the City of Maple Ridge. A substantial component of the historical background information pertaining to the FRE was obtained from the Golder reports (see reference list).

It is not clear in the regional reports as to the trigger for the initial 1979 report, but it is inferred that the study may have been initiated in response to shallow escarpment slides that are typically triggered during extended heavy rainfall events during the wet weather season. The report findings included the assumption that additional deep-seated slopes failures could potentially retrogress 300m from escarpment crests (similar to the Haney and Port Hammond slides).

The 1983 and 1986 Golder reports appear to be updates to the 1979 static stability assessment based on the findings of piezometer and submerged bank erosion monitoring efforts. The 1983 findings noted that simple hydrostatic conditions assumed in the 1979 study were not valid (i.e. 30 to 70 percent of hydrostatic with depth) and that shallow piezometric pressure heads (less than 10m depth) exhibited substantial seasonal fluctuations, while deeper piezometer pressures heads were found to fluctuate only moderately. Potential for slope instability (static) beyond 40m from the escarpment was deemed low in the 1983 Golder report, but a preliminary 100m geotechnical setback of land use and development from the escarpment was recommended in the 1986 report. The findings of the 1986 report also considered that earthquake shaking was not a critical contributing factor to escarpment instability under conditions of controlled surface water infiltration and river bank erosion.

In 1983, Northwest Hydraulic Consultants (NHC) reviewed river survey data as a sub-consultant to Golder, and identified potential concerns with substantial river bank erosion (up to 20m) that could occur during the 25-year return Fraser River flood event. Subsequently, regular river surveys were carried out to monitor erosion rates. In 1986, NHC noted that river surveys over an eight year period had not identified erosion of significance and recommended that a 10-year flood event could be adopted as a trigger for future river survey efforts.

The 2004 Golder study included review and update to previous static stability assessments and a preliminary seismic vulnerability assessment. It is likely that the 2004 study was triggered by numerous slides that occurred during periods of heavy rainfall that occurred during the 2003/2004 winter season. A review of Google Earth imagery from March, 2004 noted several fresh slide scarps and evidence of track repairs. The 2004 study determined that the steep bluffs along the north bank of the Fraser River should be considered stable under static conditions, but likely to fail when subjected to design earthquake ground motions with a return period of of 1:475 per annum. Note that the current design earthquake (2012 BC Building Code) is greater (1:2475 per annum) than that adopted in 2004, significantly increasing the earthquake demand and the risk of earthquake-induced slope failure. The 2004 report also recommended an additional 300m geotechnical setback from the escarpment. It was recommended that for new development within this zone, the City of Maple Ridge should require input from a qualified geotechnical engineer that has carried out site exploration and analysis efforts adequate to assess the potential retrogressive impact of escarpment failure on the property. The Golder (2004) assessment was based on desk top review of limited geotechnical data compiled by Golder up to that time. No additional site exploration or in-situ testing was carried out to support the analysis,

The 2008 Golder report was likely initiated in response to numerous shallow slides that occurred during the heavy rainfall event on March 11, 2007 (117mm in 24 hours). Escarpment slides resulted in damage to at least one house on Wood Street, and deposited slide debris on the rail tracks (City of Maple Ridge, pers. comm.). . It is understood that CP Rail typically contracted a geotechnical consultant to conduct slide assessments; however, these reports were not available for review. The 2008 study was limited to, re-sampling of existing functional piezometers, cone penetration testing with and without shear wave velocity measurements (SCPT and CPT), and submission of a factual report (February 12, 2008). The 2008 geotechnical site investigation data was not used in any additional geotechnical analysis to update the previous findings.

FRE study findings to date are discussed in further detail below (Sections 7, 8 and 9), with additional commentary provided in selected subsections.

3.0 LANDSLIDE TYPES AND STUDY IMPLICATIONS

Current understanding of the FRE suggests that there may be at least three kinematically distinct types of slope movements that have occurred historically or that are ongoing in this area. These can be described as slides, spreads, and flows. These movement types are discussed in further detail below.

Slides

Slides refer to downslope movement of soil on relatively discrete rupture surfaces or thin zones of intense shear strain. Deeper seated slides tend to occur in homogenous fine-grained soils (exhibit cohesive behavior) occurring as rotational failures that move along a discrete rupture surface that is curved and concave (upward). Translational slides tend to occur in coarse-grained (non-cohesive) soils occurring as shallow seated downslope movements along a planar or undulating rupture surface. Translational slides are also common on steep slopes where weathering processes have resulted in development of slope-parallel soil strength contrast. Compound slides exhibit both rotational and translational sliding characteristics such as development of a steep backscarp that flattens with depth and that develops an upslope rupture surface at the toe of the slide mass. Compound slides commonly occur in layered soils where significant contrasts in soil strengths can facilitate internal deformation and movement along shear surfaces within the displaced material.

Geological and geotechnical assessment of study areas that are considered susceptible to simple soil sliding requires a good understanding of study site topography, geological features (including occurrence and approximate age of historical slides and slope movements), study site soil stratigraphy, piezometric conditions, and soil strength characteristics. In most cases, geological information obtained from surface mapping (geological observation) can help focus site exploration/ testing efforts in order to characterize the site and complete a deterministic slope stability assessment (simplified limit equilibrium methods, slope charts, etc).

It is speculated that FRE areas that may be considered susceptible to slide hazard include the escarpment railway cut slopes, steep natural ravine slopes, steep backscarp slopes in the Fir Street slide area, and possibly the minor Port Hammond slide that did not appear to have undergone substantial retrogression.

Spreads

Spreads refer to subsidence and/or lateral displacement of overlying non-liquefiable soils into and along underlying zones of weak (or weakened) soils that have liquefied or that are exhibiting strain-softening behavior. The movements may also result in the disintegration, liquefaction or flow of overlying soils. Liquefaction spreads can develop in sensitive fine-grained clays with soil structure that exhibits substantial loss of strength when disturbed, such as during earthquake shaking. Translational and retrogressive movements are typical for conditions that are favourable for spreading type failure.

Geological assessment of study areas that are considered susceptible to spreads also requires a good understanding of study site topographic and geological features (including mapping of vulnerable sediments, detailed stratigraphic models, and geochronology of identified remnant slide features). Glaciomarine sediments are architecturally variable and internally complex, making them difficult to characterize for stability modeling (Cordilleran Geoscience 2010). Geotechnical assessments of the study areas that are considered susceptible to spread type failures typically require advanced site characterization efforts including additional in-situ and laboratory testing to determine liquefaction potential (static and/or seismic triggered), and soil strength response to deformation and/ or cyclic loading. In some cases, pseudo-static analysis using limit equilibrium methods and accepted empirical models (based on simplified site configurations) may be sufficient to assess stability of slopes to a reasonable degree of reliability. For critical structures, complex soil-structure interaction effects, and/ or complex site geological and geotechnical conditions empirical methods may not be adequate. Under these conditions, numerical methods may be necessary to assess soil liquefaction triggering and consequences. The scope and scale of site investigation and stability analyses efforts can be expected to reflect the spatial variability in subsurface conditions.

It is speculated that the FRE areas that may be susceptible to spread type failure, include the major Port Hammond slide, and possibly the minor Port Hammond (without retrogression) and Haney slides, and areas in between, extending landside from the escarpment several hundred metres to the north.

Flows

Flows can be described as spatially continuous soil movement such that shear surfaces that may develop are short-lived, closely spaced and typically not preserved. Retrogressive flowslide (or earth flow) type of soil movements can occur in marine and glacio-marine sediments comprising soft to firm sensitive silts and clays. Soils are considered sensitive when their ratio of intact peak undrained shear strength to remolded shear strength is large (i.e. typically in the range of 4 to 6). Highly sensitive silts and clays can exhibit quick condition (i.e. peak/ remolded strength ratio greater than approximately 30) where remolded shear strengths are so low they become viscous fluid when disturbed. This type of failure suspected in the study site area would likely be classified as complex, rapid to very rapid, wet to very wet earthflow (Cruden and Varnes, 1996). Recent research has noted that in addition to liquefaction flow triggers, these types of marine sediments may also become weaker over time due to reductions in pore water salinity (Carson, 1981).

Geological assessment of study areas that are considered susceptible to earth flows requires a good understanding of topographic and geological features consistent with historical occurrence earth flows. Geotechnical assessments of study areas that are considered susceptible to earth flow typically require advanced site characterization efforts including additional in-situ and laboratory testing to determine soil sensitivity and strength loss during deformation under monotonic and/ or cyclic load testing in the laboratory. As mentioned previously, to improve confidence in stability modelling for these type of complex sediments, research is currently being undertaken to carry out statistical analysis of spatial variability in liquefaction potential to better predict liquefaction effects.

At the current level of understanding, it is speculated that the entire FRE area that may also be susceptible to retrogressive flow slide. The major Port Hammond slide feature is believed to represent a liquefaction flow slide (Gerath, personal communication).

4.0 ISSUES IDENTIFIED BY CITY OF MAPLE RIDGE

CMR provided information on staff issues and concerns (during August, 2016) with respect to monitoring and hazard mitigation efforts historically or currently implemented in the FRE area as follows:

Groundwater Monitoring Program

Historically, periodic monitoring of standpipe piezometers that was carried out over a 20 year period gave representative seasonal water levels that correlated with annual precipitation. The 2008 CPT dissipation tests (to estimate equilibrium water pressure) were consistent with standpipe piezometer measurements with respect to shallow (less than ~20m) and deep piezometric levels in the FRE area.

Findings by Golder (2004) concluded the following;

"there appears to be little justification for ongoing monitoring at frequent intervals. However it's suggested that occasional further monitoring of functional instrumentation be considered

following record wet weather over an extended period of time (e.g. if monthly precipitation for two consecutive months is at least 90 percent of the maximum on record)".

Currently the CMR is not fully aware of the location and status of standpipe piezometers installed during previous studies.

CMR Fraser River Escarpment Development Area - Policy 6.23 and 6.24 (March 24, 2004)

These policies govern the potential subdivision of, or building on, land within 300 meters of the crest of the Fraser River Escarpment (FRE) and surficial or groundwater discharge within the area bounded by 207 Street, 124 Avenue, and 224 Street.

The policies were last amended based on Golder (2004). A factual report describing in-situ testing using CPT methods was provided in 2008 with a view to obtain addition information subsurface information in the FRE area. However, the report provided was factual only and was not used to update previous analytical work and to update the above mentioned policies.

The policies reflect preliminary geotechnical findings that are based on limited information. It is anticipated that the policies would be updated by improved geological and geotechnical understanding of the FRE as the current policies may be conservative or unconservative with respect to development in the FRE area.

Stormwater Management

Preliminary findings presented in a report by Golder (1986) recommended construction of a municipal stormwater drainage system to reduce groundwater recharge in the escarpment area.

In response to the early recommendations provided by Golder, during 2010 and 2011, the CMR constructed a storm sewer on River Road with the ultimate plan to have all adjacent residents connect within 5 years. At the time of construction, a bylaw was drafted that was intended to make it mandatory for residents to connect. However, the bylaw was never adopted, and of the properties adjacent to installed municipal stormwater drainage, there are currently only 22 of 64 residential properties that have connected to the system voluntarily.

To the south of Lougheed Highway, the majority of the streets without municipal storm sewers are located east of 216 Street. It was believed at the time of construction that the ultimate plan would be to have storm sewers constructed in this area. This developed area makes funding more difficult, and there is currently no plan in place to construct storm sewers. The CMR requires confirmation as to whether or not municipal storm sewers are required for the FRE area.

A summary of CMR concerns is presented below:

- CMR does not currently have a Groundwater Monitoring Plan in place, and is not fully aware of the location and status of standpipe piezometers installed during previous studies by consultants.
- Current growth is placing pressure on additional development (and associated population densification) and current FRE development policies (6.23 & 6.24) are based on limited geological and geotechnical information and on the 475-year design earthquake that is not the design earthquake in the current (2012) BC Building Code.
- Mandatory connection to installed municipal storm sewers in the FRE area is not currently enacted, and as such, limited voluntary connections may not accurately reflect impacts to shallow water level fluctuations.
- Additional detailed study could determine that installed and fully-connected municipal storm sewers may not be a cost-effective approach in controlling shallow water level fluctuations.

5.0 SCOPE OF WORK FOR GEOTECHNICAL INMFORMATION REVIEW

The geotechnical analysis involved review of available FRE studies commissioned by CMR, review of available published geological and geotechnical information, and a brief site walkover to review baseline conditions at accessible areas of the FRE.

6.0 UNDERSTANDING OF GEOLOGICAL/ GEOTECHNICAL CONDITIONS

6.1 Quaternary Geology

Maple Ridge and the FRE area are underlain by a succession of Quaternary deposits extending from the last interglacial period (Olympia Interglacial) to present. The glacial and post glacial part of the succession comprises Vashon Drift comprised of lodgement till with lenses and interbeds of glaciolacustrine laminated stoney silt (Armstrong and Hicock, 1976). In the Maple Ridge area, the Vashon Drift is overlain by Fort Langley Formation comprising glacio-marine silty clay to fine sand with substantial sequences of silty clay (locally identified as blue Haney Clay) deposited by marine waters that inundated the isostatically depressed Fraser Lowland upon retreat of the Vashon Ice lobe. To the north and west of the FRE area, Fort Langley Formation is overlain by Sumas Drift deposits comprising raised proglacial deltaic gravel and sand. These sediments interfinger with Fort Langley formation in complex ways, and the depositional sequence can be disturbed by syndepositional landsliding and loading features making it difficult to extend a detailed geologic model across the study area.

The geologic origins of these units described by Armstrong (1981) are summarized from oldest to youngest, as follows:

Vashon Drift-

Vashon Drift comprises glacial till and glaciofluvial and ice-contact sediments deposited during the last advance and retreat of Cordilleran ice during the Vashon Stade of the Fraser Glaciation between approximately 13,000 and 18,000 years ago (Figure 2). The maximum advance of the Fraser ice sheet occurred about 15,000 years ago, covering the Fraser Lowland and out into the Strait of Juan de Fuca to the continental margin. The retreat of the Fraser ice sheet back toward the mountains coincided with inundation of the isostatically depressed Fraser Lowland region by the sea, with maximum inundation reaching 200-230 m elevation about 13,000 years ago. Subsequently, the land surface rebounded and relative sea level fell rapidly to below present by 9000 years ago.

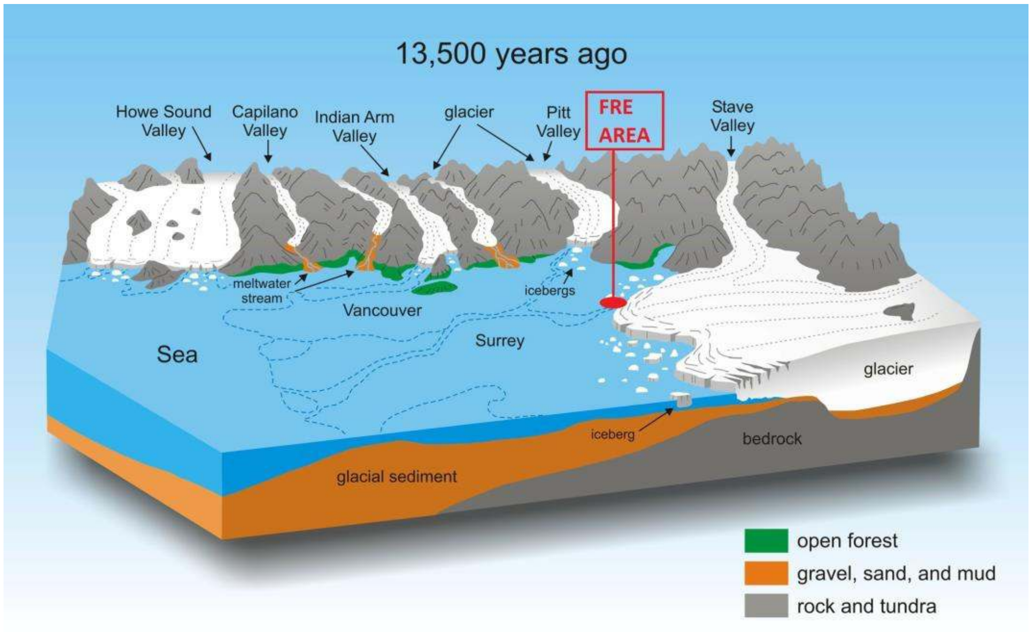

Figure 2 – Vashon Stade (Clague and Turner, 2003)

Fort Langley Formation-

The glacio-marine sediments of the *Fort Langley Formation* were deposited into the sea in front of the remaining Fraser Valley Ice lobe during deglaciation between about 13,000 and 11,500 years ago (Figure 3). During this time sea-level was rapidly falling from the marine limit, and proglacial waters were receiving high sediment loads from meltwaters draining the waning ice mass. This dynamic environment would result in the Fort Langley Formation being a vertically and spatially heterogeneous deposit, which could have important implications for stability analysis.

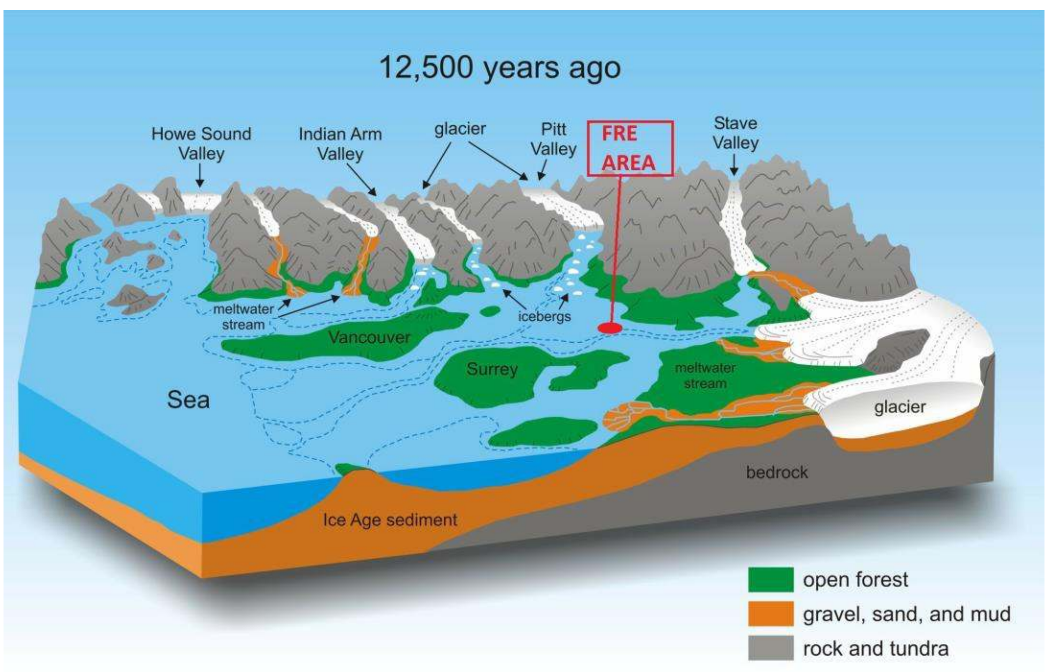

Figure 3 – Fort Langley Formation (Clague and Turner, 2003)

Sumas Drift-

These soils were deposited at the distal margin of a valley glacier that advanced as a wide lobe into the eastern Fraser Lowland (piedmont glacier) approximately 11,500 years ago and finally retreated again approximately 11,000 years ago (Clague et al. 1997). At the time of retreat isostatic rebound had allowed marine sediments to rise to an elevation above mean sea level that is close to that of present time (Figure 4). The Sumas Drift sediments in the Haney and Port Hammond areas of Maple Ridge represent an outwash delta that formed in front of the valley glacier on top of, and interdigitated with, the Fort Langley Formation glacio-marine sediments.

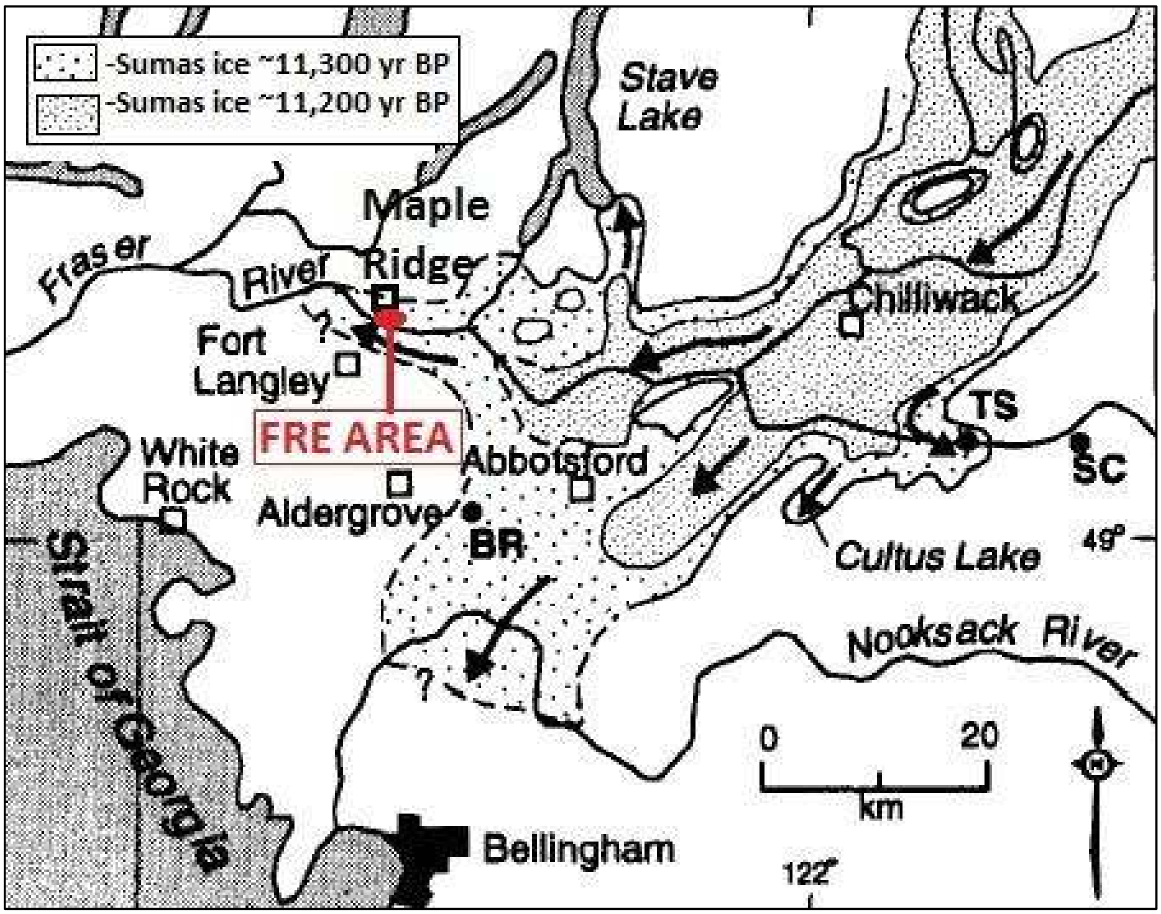

Figure 4 - Sumas Advance (Clague and Turner, 2003)

6.2 General Soil Stratigraphy

Based on the information presented in the Golder Factual Report (2008), the FRE stratigraphy encountered at testhole locations was summarized as follows:

"Mainly firm to stiff fine-grained soil (typically silty clay but including lower plasticity clayey silt and higher plasticity clay) interlayered in places with seams of fine to medium sand to silty fine sand with highly variable thickness and strength. The thickness of the interbedded sandy layers varies from lenses that are 1 to 5 mm thick, to layers that are several metres in thickness. It was noted that the degree of interlayering varies with depth and from east to west along the bluffs, and the greatest amount of sand appears to occur within the upper 17 to 19 m, particularly at the east end of the bluffs near the Haney Slide and at the west end of the bluffs near the Port Hammond slide."

A testhole advanced in 1979 at the east end of the escarpment near the Haney Slide encountered very dense silty sand and gravel at a depth of approximately 82m below ground surface.

Additional Commentary:

Note that based on the very dynamic depositional environment with falling sea levels, advance and retreat of a proglacial outwash delta with a laterally unstable channel mouth, and with the occurrence of syndepositional instability at the delta front with turbidity flows affecting the foreslope, the sedimentary sequence will be highly variable, sediment sequences will vary from core to core, with correlations between cores not possible. While it may be possible to provide a generalised sedimentary sequence, the description may not be detailed enough on which to base reliable geotechnical stability calculations.

6.3 Groundwater Conditions

Monitoring of standpipe-type piezometers appears to have been carried out since the 1970's with an extensive standpipe piezometer installation and monitoring program initiated in 1982 by Golder.

During the 1982 to 1986 monitoring period, semi-static water level fluctuations in the range of 0.2 to 1.1 m were recorded in piezometers installed to a depth ranging 8 to 12 m deep. Fluctuations in semi-static water levels at piezometers installed to a depth of approximately 45 m ranged approximately 0.1 m to 0.3 m.

Groundwater pressure increase with depth at nested piezometers in upland areas of the FRE was noted to average 50 percent of hydrostatic (ranging 30 to 70 percent) , and approximately 80 to 90 percent of hydrostatic near the toe of the FRE slopes along the CP Rail alignment.

A summary of findings presented in the 2004 study by Golder (and repeated in their 2008 study) suggested that the effects of stormwater infiltration are limited to granular soils at relatively shallow depths, and that influence of stormwater infiltration on deeper granular soil layers is not substantial due to confinement by overlying fine-grained low-permeability soil layers. However, it was noted that standpipe piezometer data may not reflect fluctuations in pore water pressure within the fine-grained soil sequences in response to individual precipitation events. Pneumatic or electric-type piezometers were recommended to monitor pore pressure response within these soils.

Groundwater pressure heads measured in standpipes during the 1983 to 1986 monitoring period were compared to the vertical distribution of u_o interpreted from the CPT dissipation data collected by Golder in 2007, and were found to be in general agreement and led them to conclude that the water levels measured in the standpipes during the earlier studies has provided a realistic average estimate of semi-static water levels in the FRE area and in variation in of groundwater pressures with depth.

Additional Commentary:

Climate change impacts were not discussed in the recent regional studies (2004, 2008). Climate change trends in groundwater may be expected due to wetter winters. Global downscale climate modelling is available for assessment of impacts.

6.4 Fraser River Erosion

Over a 20 year study period, substantial erosion of the submerged Fraser River right bank below the FRE area has not been observed. This includes the 1997 flood freshet that was noted to have exceeded the 10-year return period event identified by NHC (Northwest Hydraulic Consultants) as a potential trigger for right bank erosion in the order of 10 to 15m. Further, study findings concluded that localized failures of the river bank below the CP Rail line would likely be reported and repaired before additional grade loss is allowed to occur sufficient in extent to trigger deep-seated movement of the escarpment slopes. Localized failures that may be identified by CP Rail's track monitoring program were considered to provide early warning of significant right bank erosion that may occur during subsequent large Fraser River flood events.

6.5 Port Hammond Landslide

The large Port Hammond landslide feature is not well understood. Preliminary study by Golder (1979) based on limited field observations suggested a retrogressive type landslide occurred here sometime prior to 200 years ago. Although this characterization is presented in subsequent reports, there appears to be little detailed study to support the original findings.

The smaller Port Hammond landslide feature is located adjacent and to the west of the large Port Hammond slide. A testhole (BH-106) advanced near the back scarp of this slide identified soft sensitive clays to a depth of approximately 18m. The 1979 study assigned an age of at least 50 to 75 years to this slide feature without supporting discussion, and this date is also presented in subsequent reports.

Additional Commentary:

Other researchers suggest the Port Hammond slide was a retrogressive flow slide that failed laterally into a ravine eroded by meltwater streams during de-glaciation (Gerath, personal communications). Further, 200 years is considered a poor minimum age constraint for the Port Hammond slide. The true age could be anytime between subaerial emergence 10 ka and the cited 200 year minimum.

6.6 Haney Landslide

The Haney Slide that occurred on January 30, 1880, was documented in newspaper articles due to the size of the slide, and the destruction of riverside property from the flood wave on both sides of the Fraser River (including one fatality in the Fort Langley area).

Thesis research by Davies (1985) indicated 9 to 11m depths below grade within the slide area to a highly disturbed silty clay zone. Davies concluded that the Haney Slide must have been retrogressive in nature to allow the extension of the headscarp up to approximately 250 m back from the crest of the escarpment on the right and left flanks of the slide area.

The proposed triggering mechanism for the Haney Slide is considered to be a rapid increase in groundwater pressures due to infiltration of rain and snow melt from the relatively thick snow cover at the time of the slide. The ability for the granular soils to drain to the face of the bluffs or to nearby ravine slopes could have been impeded by frozen soil slopes and allowed water levels within permeable soil layers to rise rapidly.

6.7 Fir Street Landslide

The Fir Street landslide features is thought to represent a single slump event with sufficient debris buttress of the back scarp such that retrogressive failures did not occur. Similar to the minor Port Hammond slide, early work by Golder (1979) assigned an age of the Fir Street slide to be at least 50 to 75 years old without supporting discussion. A testhole (BH-104) advanced near the Fir Street slide back scarp identified soft to firm sensitive clays to a depth of approximately 13.5m

6.8 FRE Ravines

Ravine features cut by surface runoff from the emergent surface are located near River Wynd, Wood Street, and to the south of River Road (approximate 217 Street alignment). These features are believed to reflect surface erosion and gullying processes that occurred during the last period of de-glaciation and uplift (Turner and Clague, undated).

Additional Commentary:

At the northwest back scarp area older topographic mapping shows a ravine feature that may be the remnant of a larger ravine that once cut through the major Port Hammond slide area. Residential development subsequent to 2000 has obliterated this feature.

6.9 CP Rail Slopes & Historical Landslide Activity

It is understood that various geotechnical consultants have carried out site assessments, exploration and geotechnical consulting services to CP Rail in the FRE area. However, this information was not available for review at the time of this report.

Additional Commentary:

Historical information available for the Hammond area of Maple Ridge noted that during the 1880's, excavation for the section of railway between Haney and Hammond as many as seventy rail workers were killed, including one incident where three rail workers were swept away in a landslide caused by a steam-shovel excavation near the major Port Hammond slide area (Luxton, 2015).

7.0 SUMMARY OF SEISMIC CONSIDERATIONS PROVIDED TO DATE

7.1 General

A review of available FRE reports prepared by Golder (1979) noted that a stability analysis of slopes under seismic conditions was considered. However liquefaction potential was not considered as the assessment was limited to the application of a design horizontal force of 0.08g. Seismic considerations were not updated by Golder (1986).

The seismic vulnerability assessment of the FRE that was presented by Golder (2004) was based on re-evaluation of testhole exploration carried out in 1979, and on CPT data collected from the Haney Slide as part of a UBC undergraduate thesis (M. Davies, 1985). No additional site exploration efforts were carried out for the 2004 study. Seismic slope stability analysis was carried out using the simple sliding block model developed Newmark (1965). Current landslide assessment guidelines (APEGBC, 2010) note that this method assumes a constant seismic yield coefficient (k_y) during earthquake shaking and is thus not appropriate for analysis of slopes that comprise saturated soil layers that can be expected to liquefy (e.g. loose sands), strain soften (e.g.. low plastic or sensitive silts/ clays), or otherwise undergo significant strength loss.

During 2007, additional site exploration using CPT equipment was carried out by Golder. However, update and review of previous analyses recommended in their previous 2004 report was not carried out in Golder's (2008) factual report.

7.2 Design Seismic Event

The GSC produced third generation seismic hazard maps in 1985 that presented the peak ground acceleration (PGA) spectrum for firm ground (Site Class C) sites and with a probability of exceedance of 10% in 50 years (1:475 return period). This information was adopted as the design earthquake for the 2004 Golder study.

Additional Commentary:

The Geological Survey of Canada (GSC) is responsible for producing seismic hazard maps that present design response spectra for "firm ground" soil sites based on a selected probability of exceedance. The following summarizes revisions to design seismic criteria that have occurred since the 2004 FRE study:

- *2003:* The GSC released the fourth generation seismic hazard maps for incorporation into the 2005 National Building Code (and adopted into the 2006 and 2012 BC Building Codes) that moved to the use of site values (rather than zone values) in designs and the adoption of a lower probability earthquake shaking with a probability of exceedance 2% in 50 years (1:2,475 return period) on which to base design forces. The firm ground (Site Class C) design response spectra included peak ground acceleration (PGA), Sa(0.2), Sa(0.5), Sa(1.0) and Sa(2.0) spectral values.
- *2014:* The GSC released the GSC fifth generation seismic hazard model for the 2015 National Building Code based on new ground motion models (Atkinson & Adams, 2013). These seismic hazard values have not yet been adopted for the BC Building Code at the time of this report. The firm ground (Site Class C) design response spectra were updated to include peak ground acceleration (PGA), peak ground velocity (PGV), Sa(0.05), Sa(0.1), Sa(0.2), Sa(0.3), Sa(0.5), Sa(1.0) Sa(2.0), Sa(5.0) and Sa(10.0) spectral values.

The above information is provided to demonstrate that the current design earthquake has increased since the last evaluation in 2004 and therefor the risk of seismic induced failure or deformations has also increased.

7.3 Geotechnical Seismic Hazards

7.3.1 General

A summary of FRE geotechnical seismic hazards were presented in the 2004 Golder report and included the following:

- direct impact of earthquake ground motions on structures and services (i.e. non-permanent displacements),
- permanent vertical and horizontal ground displacements due to ground deformations (earthquake-induced differential lateral movements, settlement and/ or deviatoric deformations assuming no liquefaction),
- liquefaction of saturated granular soils with potential to cause lateral spreading, post-liquefaction subsidence, uplift of buried structures, loss of soil resistance sufficient to cause bearing failure, and/ or flow slides,
- slope failures including large deformations in fine-grained soils (in particular low plastic silts and sensitive clays) caused by reduction of soil strength to residual values due to generation of excess pore water pressure and strain-softening,
- and landslide-induced flood waves.

7.3.2 Permanent Displacement

The 2004 study presented three slope sections for analysis and provided preliminary estimates for permanent ground displacements and maximum extent of yielding for a suite of PGA values based on Newmark block-sliding methods (1965) for selected drained soil strength conditions and no liquefaction. The findings were compared to firm ground PGA values (factored by 1.5 to account for soft soil amplification) for the 100-year and 475-year return events obtained for the study site area from the Pacific Geoscience Centre in 2003.

The findings included comment that strain-softening behavior of FRE area soils is not known such that there remains considerable uncertainty in calculated permanent displacements.

Additional Commentary:

Shortcomings of the estimated permanent displacements presented in the 2004 Golder study include the following:

- Design earthquake was based on the old BC Building Code 475-return earthquake,
- Soil amplification assumption was over-simplified. A site response analysis was not carried out,
- Permanent displacement estimates did not consider liquefaction,
- The analysis for estimation of displacements was based on limited data and over-simplified,
- There is no rational for adoption of drained shear strength in pseudostatic analysis.

7.3.3 Liquefaction Potential

Area-wide study to date has provided a preliminary assessment of liquefaction potential of FRE area soils based on very limited information. Further, ground motions are based on an assumed depth to firm ground and in the absence of site specific response analyses.

For FRE area Haney clay soils, the “Chinese” criteria were used to screen for liquefaction susceptibility and it was determined from available information that these soils should not be considered liquefiable.

For FRE area granular soils, potentially liquefiable soils were identified in data collected from CPT data collected in 1985 from a test hole advanced at the Haney Slide location, and from SPT N-values recorded at testholes advanced in 1979.

Additional Commentary:

Work by other researchers has found that liquefaction has occurred in fine-grained soils classified as non-liquefiable by the Chinese criteria and this classification approach is no longer recommended (Liquefaction Task Force Report, 2007). Cyclic behavior and strain softening response of the FRE fine-grained soils requires further study.

7.3.4 Slope Stability (during and after earthquake)

To date, evaluation of earthquake-induced slope instability in the FRE area has been limited to pseudostatic analysis where the effects of earthquake shaking by accelerations are applied as inertial horizontal (and vertical) forces in a Limit Equilibrium slope model. The seismic slope stability analysis carried out by Golder (2004) on three selected sections noted that drained shear strength parameters were assumed for all sections.

Assessment of post-earthquake stability of slopes was limited to retrogression of backscarps of slope failures initiated during earthquake shaking for the condition of over-steepened backscarp slopes and assuming worst-case elevated (pre-failure) piezometric conditions. Potential for backscarp retrogression due to seepage erosion was also discussed as a possibility, but not evaluated further. Previous (1979) estimation of the 300m maximum extent of retrogression was deemed “unrealistic” in the 2004 study. However, based on limited understanding of FRE subsurface conditions the 300m retrogression assumption presented by Golder (1979) was not revised.

Additional Commentary:

The assumption of drained shear strength for fine-grained soils in the LE stability analysis work by Golder is considered unconservative. Under rapid dynamic loading during earthquake shaking, the undrained shear strengths of saturated clayey soils is considered the more appropriate and conservative approach.

Recent dynamic analysis research (Naesgaard, 2010) has demonstrated that during earthquake shaking of layered fine- and coarse-grained deposits (similar to the FRE area) with contrasting grain-size and permeability, induced liquefaction can generate pore water gradients and flow. Pore water outflow can result in contraction of the soil skeleton in some areas and expansion with inflow of pore water in other areas. The effect of pore water inflow results in soil strengths substantially lower than those assumed for simple undrained conditions. Further, the migrating pore water can be impeded beneath a low permeability layer and form a zone of low effective stress (localized expansion or water filming) sufficient to develop near zero shear strength conditions.

7.4 Potential Consequences of Seismic Hazards

An overview of potential consequences of geotechnical seismic hazards resulting in failure and a brief discussion of probability and risk was presented by Golder (2004). The consequence list included:

- damage to, or destruction of roads,
- damage to, or destruction of surface or buried services,
- damage to, or destruction of houses,
- property loss,
- damage to, or destruction of the CP Rail line,
- impact to Fraser River flows and traffic,
- injury or loss of life.

Assessment of risk (defined as failure probability times consequences of failure) was discussed briefly in the study. However, a comprehensive Risk Assessment has not been carried out on the FRE area to date.

8.0 SUMMARY OF CURRENT RECOMMENDED MITIGATION/ MONITORING

8.1 General

Based on available information, area-wide study of the FRE has been carried out by Golder since 1979. Golder (1979) was initiated at the request of the BC Ministry of Environment, presumably to assess escarpment slope stability with respect to ongoing slope sloughing and shallow sliding of slopes above and below the CP Rail tracks near the toe of escarpment slopes. At that time, conditions of potential geotechnical concern in the order of importance included river erosion of submerged slopes, high piezometric levels in escarpment slopes and upland areas, and earthquake-induced landslides.

Golder (1983) focused efforts on escarpment areas previously deemed to have low slope stability factors of safety. At that time, high piezometric levels in escarpment slopes and upland areas was considered to be more critical to stability of slopes than river erosion. As such, the field program included installation of nested standpipe piezometers at ten escarpment upland locations and five locations along the CP Rail alignment. Falling head tests were carried out at selected piezometers to provide preliminary estimates of soil layer hydraulic conductivity. In addition, a pump test program was initiated near piezometer location 114 to determine potential for escarpment dewatering using a deep pumped well system. Discussion of seismic vulnerability of the FRE area was limited.

Golder (2004) provided a report on the geotechnical seismic vulnerability of the FRE, based on existing data. No field investigation was carried out at the time of this report and it appears that the study was carried out to compile available geotechnical data, update previous assessments to current geotechnical understanding and state of practice with respect to seismic slope stability.

8.2 Drainage Improvement/ Permanent Dewatering

Active permanent dewatering measures included deep vertical wells to permanently lower FRE piezometric levels by 15m were recommended by Golder (1979) but they revised this recommendation in 1983 to reduce the levels by 5m, and only if deemed necessary by additional study. A drainage gallery or inclined slope drains driven into the escarpment at the CP Rail track elevation were discussed in the 1979 report but were not mentioned in later studies.

Passive measures to improve surface drainage were recommended in the Golder reports from 1979 to 1986. These included development of a storm drainage plan to reduce water infiltration to the lowest practical level in the FRE area, including septic field sources and rainwater runoff from upslope areas. It is understood that the CMR is implementing the stormwater management plan by installing storm water services. However, in areas of the FRE where storm sewer has been installed, it is understood that less than 30 percent of buildings have been connected to the system.

8.3 Fraser River Erosion Protection

Measures to control subsurface erosion of the FRE slopes at selected locations below the CP Rail track alignment were discussed in the Golder reports from 1979 to 1986 and conceptual rip rap erosion protection designs were provided.

Ongoing monitoring of erosion rates were recommended and hydraulic assessments and river erosion rates were assessed between 1978 and 1997. As mentioned previously, Golder (2004) noted that appreciable erosion of the submerged slopes has not been detected over a 20 year period that included the 10-year return freshet in 1997 where erosion of 10 to 15 m were estimated by NHC in an earlier river study.

Further, active measures to address erosion or shallow sliding below the rail tracks is currently carried out by CP Rail in response to ongoing shallow bank sliding. It was noted that a substantial erosion event would initially express as localized failures of the bank below the CP Rail track alignment to provide early warning of potential for triggering escarpment slope movements.

8.4 Avoidance

Golder (1979) recommended an approximate backscarp distance from the crest of the FRE of approximately 300 m for the Haney Slide and the major Port Hammond slide, and identified this as a possible retrogression limit. The imaginary line joining the backscarps of these major landslides was recommended as a zone restricting land use or development. Golder (1986) recommended reduction of the restricted development zone to 100 m from the FRE slope crest between the two major landslide zones without further discussion. Within the 100 m zone and dependant on implementation of river erosion control measures, the following individual property and/ or development restrictions were recommended and adopted by Maple Ridge in 1993 (Fraser River Escarpment Development Area Policies No. 6.04 and 6.05):

- A nominal minimum 10 m setback of all improvements (inferred to mean buildings, structures, and hard/soft landscaping) from the crest of slope,
- A restriction to control removal of trees and vegetation from the escarpment slopes,
- A restriction to control discharge of runoff, seepage, or other water onto the escarpment slopes,

- A restriction to control fill placement onto escarpment slopes, in ravines, or at the crest of escarpment slopes.

Policy 6.05 effectively prohibited development or subdivision of land within 100 m of the escarpment until river erosion control measures were implemented.

Golder (2004) provided additional comment on the above measures that included recommendations for additional zones including; i) within approximately 100 m from the backscarp of the major landslide features and ii) within approximately 300 m from the existing escarpment crest. In these areas, it was recommended that development require input from a qualified geotechnical engineer (based on site exploration and stability analysis) to assess potential retrogressive impacts.

The report provided comment that within 100 m of the escarpment located between the major landslide features, subdivision of property increases density and thereby risk to human life and as such, should not be permitted without site exploration and analysis sufficient to quantify risks. Site development involving replacement of an existing building was considered a financial risk but no greater risk to human life than already existed.

It is understood that the existing CMR Fraser River Escarpment Development Area policies were amended to reflect Golder (2004) (Policies 6.23 and 6.24).

At the time of this report, risks to structures and occupants are limited to qualitative descriptions of likelihood of occurrence only (i.e. high or low) and a brief discussion on potential consequences with no range of relative probability of occurrence identified

Additional Commentary:

Existing risk to human life for occupants of the FRE area has not been quantified to date, as per APEGBC (2010)

The current CMR Fraser River Escarpment Development Area - Policy 6.24 requires that proposed site development within the current geotechnical setback areas requires input by a qualified geotechnical engineer based on site exploration and stability assessment sufficient to assess the risk of potential retrogressive impact of escarpment failure on the property. It is considered that property scale geotechnical investigation cannot adequately assess the risk and this work should be done on a regional scale.

9.0 DATA AND INFORMATION GAPS

9.1 Geological and Geotechnical Conditions

9.1.1 General

The following sections present identified data gaps and information shortcomings in the existing geological and geotechnical information that currently impede efforts to quantify FRE area hazards. Work additional to this gap analysis is expected to include prioritization of additional efforts to resolve identified shortcomings.

9.1.2 Soil Conditions

Additional site exploration is recommended with a view to

1) Improve and update the geologic model(s) to provide a better understanding of the depositional environment, especially with respect to how the dynamic depositional environment led to vertical and spatial heterogeneity in both sedimentology and

structures of the Fort Langley Formation, and how this affects ability to conduct reliable stability analysis.

2) Collect high quality soil samples for further classification and detailed laboratory testing (i.e. cyclic strain softening behaviour, etc). Additional exploration efforts should be focused by evaluation of CPT data collected from the FRE area in 2007.

Review of existing deep exploration (i.e., drilling; geophysics) information, or acquisition of additional subsurface information if required, should be carried out to confirm depth to firm ground for use in site specific response analysis efforts.

9.1.3 Groundwater

An inventory of operating and destroyed standpipe piezometers should be developed, including piezometers along the CP Rail alignment.

Replacement of selected destroyed standpipe piezometers with electric (vibrating wire) piezometers equipped with data loggers should be carried out. Consideration should also be given to replacing key standpipe piezometers with electric piezometers.

Functioning piezometers should be read and the data set updated.

A piezometer monitoring plan based on environmental triggers should be developed and implemented.

A review of historical piezometer data with respect to impacts (if any) in FRE areas of implemented stormwater management works should be carried out.

New global downscale climate modelling is available, and should be incorporated in further study to assess potential impacts to semi-static groundwater levels.

9.1.4 Haney, Major/ Minor Port Hammond, and Fir Street Landslides

Additional stability analysis should be carried out utilizing updated methods, 2007 CPT data, additional detailed exploration at slide margins and within side area itself, (using current 5th generation seismic hazard model (NBCC2015) for seismic slope stability assessment), with a view to identifying geotechnical soil sequences of potential concern.

A detailed geological exploration and assessment of the Port Hammond landslide area should be carried out with a view to characterize (i.e. liquefaction flow slide, retrogressive slide, etc) and if possible estimate the date of occurrence.

Once characterized, a landslide model based on additional detailed geological/ geotechnical study should be compared to 'intact' FRE areas.

Limit Equilibrium (LE) analysis and Finite Element/Finite Difference Numerical Modelling (FEM/FDM) of flow and retrogressive sliding (both static and seismic) should be carried out.

9.1.5 FRE Ravines

Additional stability analysis should be carried out utilizing updated methods, 2007 CPT data, additional detailed exploration at slide margins and within side area itself, (using current 5th generation seismic hazard model adopted in NBCC2015) for seismic slope stability assessment.

9.1.6 CPR Slopes & Slides

Additional stability analysis should be carried out utilizing updated methods, 2007 CPT data, additional detailed exploration at slide margins and within side area itself, (using current 5th

generation seismic hazard model (NBCC2015) for seismic slope stability assessment), with a view to identify potential geotechnical soil sequence of potential concern.

It is suggested that the City initiate communication with CPR Geotechnical Group with a view to develop in-house exchange of confidential (under a possible mutual non-disclosure agreement) and non-confidential geological, and geotechnical data and information (including Fraser River hydrotechnical and hydrological information) and shared access to real-time CPR slide-detection fence data, if possible.

Study findings have down-graded the likelihood of substantial bank erosion in a 10-year Fraser River flood event. However, a FRE Monitoring Plan should include installation of permanent slope inclinometers near the toe of selected escarpment slopes along the north side of the CP Rail alignment. The inclinometers would be measured based on triggering events such as 10-year (or rarer) freshet events, and following bank slide events below the CP Rail lines that are substantial enough to alert workers and initiate repairs. Consideration could also be given to installation of in-place inclinometer array systems with data loggers to provide real-time monitoring (i.e. Shape Acceleration Array systems). These systems are more costly than conventional single probe inclinometers but may prove safer and lower-cost over the long term.

Regular topographic-bathymetric LiDAR surveys of the FRE area should be considered with a view to quantify changes in escarpment topography and submerged river bank slopes that may be occurring over time. Current understanding of the impact to Fraser River bank erosion processes is that the debris from the Haney Slide (current eroding at approximately 1m per year) impedes erosion rates, and that these rates will increase to pre-slide rates over time.

9.2 Seismic Considerations

9.2.1 General

The following sections present identified data gaps, and obsolete design earthquake parameters and/ or seismic slope stability design approaches in the existing seismic vulnerability assessment that could impede efforts to quantify FRE area risks.

9.2.2 Design Seismic Event

As mentioned previously, as of Golder (2004), the design seismic event consistent with the design earthquake identified in the BC Building Code was a 10% probability of exceedance in 50 years (i.e. 475-year return period) and for the GSC 3rd generation seismic hazard calculations. It is recommended that for the purposes of seismic vulnerability assessment, the current GSC 5th generation seismic hazard calculations be adopted (NBCC 2014) and for the design earthquake specified in the current Building Code and identified as having a 2% probability of exceedance in 50 years (i.e. 2,475-year return period).

9.2.3 Geotechnical Seismic Hazard & Potential Effects

A comprehensive liquefaction assessment should be carried out for the FRE area based on the additional CPT data collected in 2007 and updated liquefaction assessment methodologies. In the event that additional recommended site exploration and high quality soil sampling is carried out, it is expected that the assessment would include the findings of detailed laboratory testing on selected fine-grained soils (i.e. cyclic direct simple shear) to estimate cyclic response of these soils during earthquake shaking.

LE slope stability assessments should be updated to seismic slope displacement methods in the current (2010) APEGBC landslide assessment guidelines.

As mentioned previously, intensity of near surface ground shaking (based on amplification or possibly de-amplification) of softer soils overlying firm ground at substantial (but unknown) depth is not well understood at the FRE area. Appropriate earthquake records should be selected and modified to the design response spectrum, for carrying out a Site Specific Response Analysis (SHAKE type of analysis or more advanced FLAC type of analysis, etc) for use in liquefaction assessments.

In view of the complex soil stratigraphy within the FRE, consideration may be given to carrying out preliminary numerical modelling at critical locations, including effects of lateral spatial variability of soil conditions on liquefaction-induced displacements.

Updated geological and geotechnical information, data, and analysis should be used to advance understanding of geotechnical hazard impacts to selected FRE escarpment areas with a view to refine current "first approximation" geotechnical zones of concern (100 m from crest/headscarp, 300 m from crest/headscarp). Further, review and selection of performance criteria should be carried out. For residential structures, adoption of the performance criteria presented in the APEGBC landslide guidelines could be considered.

As mentioned previously, at the time of this report, risks to structures and occupants are limited to qualitative descriptions of likelihood of occurrence only (i.e. high or low) and a brief discussion on potential consequences with no range of relative probability of occurrence identified. The level of occupant exposure to identified hazards should be assessed area wide by quantitative risk assessment and tested against societal risk aversion. The common format plots points defined by computed probabilities of failure and corresponding quantified failure consequences, and the points compared to a societally acceptable boundary between "safe" and "unsafe" exposure. These are called *f*-N diagrams, where N is defined as the number of lives lost and f is the determined frequency.

9.3 Current Recommended Mitigation/ Monitoring Measures

9.3.1 General

The following sections present preliminary commentary on currently implemented hazard mitigation measures and monitoring plans. It is anticipated that review and update of existing FRE information will result in additional revision to the existing recommended mitigation measures.

9.3.2 Drainage Improvement

A detailed review of the recommended and implemented storm drainage control measures should be carried out to assess effectiveness of this approach in managing shallow piezometric levels. It is expected that prior to construction of additional municipal storm water drainage, design and implementation of a functional Groundwater Monitoring Plan (as discussed previously) would be invaluable in accurate assessment of future drainage improvement measures.

9.3.3 Fraser River Erosion Protection

CPR erosion/scour protection measures that have been implemented in the FRE area should be inventoried. A review of design details (if possible) and/ or constructed works should be reviewed by a hydrotechnical consultant.

9.3.4 Avoidance and Resilient Designs

It is expected that some refinement of the preliminary 100 m and 300 m zones of potential geotechnical concern would result from update, review and analysis of FRE information collected since 2007. Prior to consideration of additional mitigation measures, it would be prudent to carry out a preliminary geotechnical failure modes and effects analysis (FMEA). This is a proven qualitative technique for understanding the behavior of elements (and failure influence between elements) within a larger engineered system (e.g. selective ground improvement project - Annacis Island Sewage Treatment Plant).

Consideration should be given to developing 'resilient' geotechnical design concepts for structures or elements within selected geotechnical hazard zones that have been advanced to a suitable level of understanding (i.e. flexible service connections, deformation tolerant structures, critical service re-routing, etc.)

10.0 MANAGEMENT OF FRE GEOTECHNICAL HAZARD INFORMATION

The following general suggestions for management of geotechnical hazard information are provided for reference;

- Collect and categorize all available geological, geotechnical and hazard reports specific to the FRE area. General categories could be used (i.e. sedimentary facies model, geotechnical hazard assessment, slope stability assessment, peer review report, etc) and the reports recorded on a tracking sheet for digital inventory in a GIS-based (geographic information system) report management system.
- Archive reported and published instability events in the FRE area (newspapers, etc).
- Collect and compile a digital inventory of published (or by outside agency) hydrological/ geological information (regional provincial studies, university theses, CP Rail reports, etc).
- Compile a collection of submitted and released reports for mandatory review by consultants carrying out geotechnical assessments in the FRE area. http://www.fvrd.ca/EN/main/services/planning-development/application_forms.html
- Develop external access measures for dissemination of FRE hazard-related information. http://www.geoweb.dnv.org/applications/hazardsapp/
- Develop or adopt geohazard/risk acceptability criteria for existing and new development. https://www.dnv.org/programs-and-services/risk-tolerance
- Develop geotechnical reporting and peer review requirements specific to hazard assessment reporting in the FRE Area. http://www.delta.ca/docs/default-source/steep-slope-geotechnical-requirements/geotechnical-requirements-steep-slope-guide.pdf?sfvrsn=2

11.0 CLOSURE

The City of Maple Ridge may rely on the findings presented in this review of geotechnical data and information report.

The use of this report is subject to the Report Interpretation and Limitations, which is included with the report. The reader's attention is drawn specifically to those conditions, as it is considered essential that they be followed for proper use and interpretation of this report.

We hope the above meets with your requirements. Should any questions arise, please do not hesitate to contact the undersigned.

Yours truly,

Braun Geotechnical Ltd.

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REPORT INTERPRETATION AND LIMITATIONS

1. STANDARD OF CARE

Braun Geotechnical Ltd. (Braun) has prepared this report in a manner consistent with generally accepted engineering consulting practices in this area, subject to the time and physical constraints applicable. No other warranty, expressed or implied, is made.

2. COMPLETENESS OF THIS REPORT

This Report represents a summary of paper, electronic and other documents, records, data and files and is not intended to stand alone without reference to the instructions given to Braun by the Client, communications between Braun and the Client, and/or to any other reports, writings, proposals or documents prepared by Braun for the Client relating to the specific site described herein.

This report is intended to be used and quoted in its entirety. Any references to this report must include the whole of the report and any appendices or supporting material. Braun cannot be responsible for use by any party of portions of this report without reference to the entire report.

3. BASIS OF THIS REPORT

This report has been prepared for the specific site, development, design objective, and purpose described to Braun by the Client or the Client's Representatives or Consultants. The applicability and reliability of any of the factual data, findings, recommendations or opinions expressed in this document pertain to a specific project at described in this report and are not applicable to any other project or site, and are valid only to the extent that there has been no material alteration to or variation from any of the descriptions provided to Braun. Braun cannot be responsible for use of this report, or portions thereof, unless we were specifically requested by the Client to review and revise the Report in light of any alterations or variations to the project description provided by the Client.

If the project does not commence within 18 months of the report date, the report may become invalid and further review may be required.

The recommendations of this report should only be used for design. The extent of exploration including number of test pits or test holes necessary to thoroughly investigate the site for conditions that may affect construction costs will generally be greater than that required for design purposes. Contractors should rely upon their own explorations and interpretation of the factual data provided for costing purposes, equipment requirements, construction techniques, or to establish project schedule.

The information provided in this report is based on limited exploration, for a specific project scope. Braun cannot accept responsibility for independent conclusions, interpretations, interpolations or decisions by the Client or others based on information contained in this Report. This restriction of liability includes decisions made to purchase or sell land.

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5. INTERPRETATION OF THIS REPORT

Classification and identification of soils and rock and other geological units, including groundwater conditions have been based on exploration(s) performed in accordance with the standards set out in Paragraph 1. These tasks are judgemental in nature; despite comprehensive sampling and testing programs properly performed by experienced personnel with the appropriate equipment, some conditions may elude detection. As such, all explorations involve an inherent risk that some conditions will not be detected.

Further, all documents or records summarizing such exploration will be based on assumptions of what exists between the actual points sampled at the time of the site exploration. Actual conditions may vary significantly between the points investigated and all persons making use of such documents or records should be aware of and accept this risk.

The Client and "Approved Users" accept that subsurface conditions may change with time and this report only represents the soil conditions encountered at the time of exploration and/or review. Soil and ground water conditions may change due to construction activity on the site or on adjacent sites, and also from other causes, including climactic conditions.

The exploration and review provided in this report were for geotechnical purposes only. Environmental aspects of soil and groundwater have not been included in the exploration or review, or addressed in any other way.

The exploration and Report is based on information provided by the Client or the Client's Consultants, and conditions observed at the time of our site reconnaissance or exploration. Braun has relied in good faith upon all information provided. Accordingly, Braun cannot accept responsibility for inaccuracies, misstatements, omissions, or deficiencies in this Report resulting from misstatements, omissions, misrepresentations or fraudulent acts of persons or sources providing this information.

6. DESIGN AND CONSTRUCTION REVIEW

This report assumes that Braun will be retained to work and coordinate design and construction with other Design Professionals and the Contractor. Further, it is assumed that Braun will be retained to provide field reviews during construction to confirm adherence to building code guidelines and generally accepted engineering practices, and the recommendations provided in this report. Field services recommended for the project represent the minimum necessary to confirm that the work is being carried out in general conformance with Braun's recommendations and generally accepted engineering standards. It is the Client's or the Client's Contractor's responsibility to provide timely notice to Braun to carry out site reviews.

The Client acknowledges that unsatisfactory or unsafe conditions may be missed by intermittent site reviews by Braun. Accordingly, it is the Client's or Client's Contractor's responsibility to inform Braun of any such conditions.

Work that is covered prior to review by Braun may have to be re-exposed at considerable cost to the Client. Review of all Geotechnical aspects of the project are required for submittal of unconditional Letters of Assurance to regulatory authorities. The site reviews are not carried out for the benefit of the Contractor(s) and therefore do not in any way effect the Contractor(s) obligations to perform under the terms of his/her Contract.

7. SAMPLE DISPOSAL

Braun will dispose of all samples 3 months after issuance of this report, or after a longer period of time at the Client's expense if requested by the Client. All contaminated samples remain the property of the Client and it will be the Client's responsibility to dispose of them properly.

8. SUBCONSULTANTS AND CONTRACTORS

Engineering studies frequently requires hiring the services of individuals and companies with special expertise and/or services which Braun Geotechnical Ltd. does not provide. These services are arranged as a convenience to our Clients, for the Client's benefit. Accordingly, the Client agrees to hold the Company harmless and to indemnify and defend Braun Geotechnical Ltd. from and against all claims arising through such Subconsultants or Contractors as though the Client had retained those services directly. This includes responsibility for payment of services rendered and the pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. These conditions apply to specialized subconsultants and the use of drilling, excavation and laboratory testing services, and any other Subconsultant or Contractor.

9. SITE SAFETY

Braun Geotechnical Ltd. assumes responsibility for site safety solely for the activities of our employees on the jobsite. The Client or any Contractors on the site will be responsible for their own personnel. The Client or his representatives, Contractors or others retain control of the site. It is the Client's or the Client's Contractors responsibility to inform Braun of conditions pertaining to the safety and security of the site – hazardous or otherwise – of which the Client or Contractor is aware.

Exploration or construction activities could uncover previously unknown hazardous conditions, materials, or substances that may result in the necessity to undertake emergency procedures to protect workers, the public or the environment. Additional work may be required that is outside of any previously established budget(s). The Client agrees to reimburse Braun for fees and expenses resulting from such discoveries. The Client acknowledges that some discoveries require that certain regulatory bodies be informed. The Client agrees that notification to such bodies by Braun Geotechnical Ltd. will not be a cause for either action or dispute.