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Geotechnical Hazards Report: Egmont/Pender Harbour OCP Area

Final Report
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1. Introduction

1.1 Background

The OCP area of Egmont/Pender Harbour is located on the Sunshine Coast, approximately 30 km northwest of Sechelt. The OCP area is bounded by the community of Halfmoon Bay to the south, Spipiyus Park to the east and the Malaspina Straight and Agamemnon Channel to the west and north, respectively.

The Sunshine Coast is typical of many areas in south-coastal British Columbia, being subject to a number of geohazards conditioned by steep terrain and a maritime climate:

- Steep mountain slopes are sources of potential landslide activity that may affect lower slopes;
- Creeks may be subject to flooding and may serve as conduits for debris flow events;
- The sea presents a coastal erosion and littoral flood hazard;
- Tall coastal bluffs present an erosion and landslide hazard; and
- Earthquakes present a landslip and liquefaction hazard.

1.2 Project Scope

The Sunshine Coast Regional District (SCRD) has retained Kerr Wood Leidal Associates Ltd. (KWL) to produce a Geotechnical Hazards Report for the Egmont / Pender Harbour OCP area based on the RFP closed in August 2014.

The work scope was to assess and recommend revisions to the existing Development Permit Areas (DPAs) included in the Official Community Plan pertaining to the area of Egmont / Pender Harbour. The study provides the SCRD with technical guidance on possible amendments to existing DPAs.

The project involves a number of key goals that include:

- Develop a consistent DPA framework based on natural hazards, and provide a rationale for development based on the current guidelines and regulations (e.g., *Flood Hazard Area Land Use Management Guidelines*, *Guidelines for Legislated Landslide Assessments for Residential Developments in BC*, *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC*, BC Building Code, the Riparian Areas Regulation, and the SCRD Risk Assessment and Liability Policy); and
- Propose DPAs based on the assessment framework, utilizing a combination of GIS base mapping files, air photo interpretation, and prioritized field investigation.

1.3 Project Team

The project team includes:

- Erica Ellis, M.Sc., P.Geo., KWL (Geoscientist, Project Manager);
- Mike Currie, M.Eng., P.Eng., KWL (Senior Water Resources Engineer, Technical Review);
- Chad Davey, M.Sc., KWL (Fluvial Geomorphologist);
- Scott Cowan, KWL (Junior Geoscientist),G.I.T., CTech, and
- Pierre Friele, M.Sc., P.Geo., PG (WA), Cordilleran Geoscience (Senior Geoscientist).

2. Data Sources

2.1 Background Reports

A number of reports were reviewed in the course of this project, including:

- "*Geotechnical Reconnaissance Study of Geotechnical and Hydrological Hazards of the Egmont/Pender Harbour Official Community Plan Area*" (Golder Associates, 1996);
- *Egmont/Pender Harbour Official Community Plan* (SCRD, 2009);
- "*Hazard Risk and Vulnerability Analysis for the Sunshine Coast Regional District*" (EmergeX Planning, 2005); and
- Terrain Inventory maps for the Sunshine Coast.

Brief summaries of selected reports are provided below:

2.1.1 Golder Associates (1996)

This report summarizes a reconnaissance geotechnical hazard evaluation and provides maps of hazard areas for the Egmont/Pender Harbour OCP area. A number of different hazards were evaluated, including: watercourse hazards (e.g. flooding and erosion, debris flows/floods), rockfall, landslides, shoreline hazards (e.g. flooding and erosion), earthquakes, and gravel extraction and forestry harvesting.

The work touches upon several areas of concern, including: areas within Bargain Bay and Pender Harbour (shoreline erosion), Anderson Creek (ravine steep slopes), Pender Hill, Harbour Peak, and Mount Daniel (rockfall) and Oyster Bay (flooding). The report recommends a bylaw that would limit tree and soil removal, as well as ensuring new developments are sited in areas suitable for installation of septic disposal fields.

2.1.2 EmergeX Planning (2005)

EmergX Planning conducted a general risk assessment for the entire SCRD. Geological hazards were reviewed and historic events (e.g. flooding, landslides, etc.) were discussed. The resultant risk matrix from EmergeX analyses shows that natural hazards within the SCRD are frequent, high severity events: a significant risk to people and infrastructure if left unmitigated.

2.2 Orthophotos

Digital orthophotos (i.e., air photographs given a spatial position via orthorectification) from 2006, 2009 and 2014 were obtained from the SCRD and reviewed.

In general, the relatively small size of the creeks in combination with the forest canopy cover prevented detailed observations of the channels. Thus, the digital orthophotos were mainly used for:

- Geographic reference;
- Confirmation of previously identified hazards;
- Noting land-use changes over time;
- Confirmation of steep terrain indicating a potential start zone for slope failures; and
- Assessment of creek confinement.

2.3 GIS Analysis

GIS data were obtained from the SCRD including:

- Topographic data:
  - 1 m contours (coverage of most of the OCP area); and
  - TRIM digital elevation data (full coverage of OCP and areas upslope that may affect OCP area).
- Creeks and rivers.
- Administrative data:
  - OCP Boundary (old and revised);
  - parcels; and
  - existing DPAs.
- Roads.
- Orthophotos (2006, 2009 and 2014).

In addition, the Provincial 1:50,000 scale DEM data were downloaded to provide additional coverage of the watersheds that are contained, or cross, the Egmont/Pender Harbour OCP area.

3. Hazard Analysis

3.1 Background

3.1.1 Topography

The Egmont/Pender Harbour OCP area mainly consists of moderately sloping bedrock hummocks, rising from sea level to elevations of 500 m along eastern OCP boundary. Development is typically on gently sloping terrain (less than 30% slopes). Steeper slopes generally occur in the following locations:

- associated with local rock outcrops;
- along creek ravines; and
- along the coastal bluffs.

3.1.2 Climate and Hydrology

The study area lies within the Coastal Western Hemlock biogeoclimatic zone (Meidinger and Pojar, 1991). This zone experiences relatively cool summers and mild winters, with an annual precipitation range from 1,000 mm to 4,400 mm. Less than 15% of annual precipitation occurs as snowfall.

Local creeks have two runoff peaks: a summer snowmelt freshet that typically occurs between May and July, and a fall peak. Although monthly discharges are largest during the freshet, both the annual maximum instantaneous and annual maximum daily flood peaks typically occur as a result of rain or rain-on-snow runoff events from September through March.

3.1.3 Quaternary Geology

The surficial deposits along the Sunshine Coast are the product of multiple episodes of glaciation and deglaciation. The modern landscape is dominated by the deposits of the most recent cycle of glaciation. The last, or Fraser, glaciation began 29,000 years ago and reached its peak 14,500 years ago. The region was ice free by 13,000 years ago.

Outwash sediments associated with the advancing ice front, known as the Quadra Sands, are found throughout the Strait of Georgia at elevations up to 100 m. After 19,000 years ago, the outwash was overridden by the advancing ice margin, depositing till, known as Vashon Drift (a complex of till, glaciofluvial and glaciolacustrine sediments). After 14,000 years ago, glaciofluvial, glaciomarine and marine sediments were deposited up to an elevation of 180 m, indicating a relative sea level much higher than that of present day. These sediments are known as Capilano Formation. Following deglaciation, fluvial and mass wasting processes rapidly reworked glacial sediments. Process rates declined over time such that by no later than 6,000 years ago the landscape was similar to today. Post-glacial sediments, formed in modern fluvial, beach and bog environments, are referred to as Salish sediments.

Thus a typical succession of Quaternary sediment in the study area would consist of Quadra Sand overlain by Vashon Drift overlain by Capilano sediments and locally by Salish sediments. Close to the mouths of major creeks and rivers, the Capilano sediments consist of large gravelly deltas, locally exploited for their aggregate potential. Away from these fluvial settings and below the former marine limit, there are blankets of stoney clay and more localized sand and gravel beach strands. Total thickness of overburden ranges from nothing to 100 m or more.

3.2 Hazard Overview

As previously mentioned, the Sunshine Coast is subject to a number of geohazards resulting from steep terrain and a maritime climate. Hazards have been grouped into three main categories:

1. Coastal Zone Hazards;
2. Creek Hazards; and
3. Slope Hazards.

Hazards associated with the three zones are discussed below. The hazard screen maps are presented in Figure 3-3 through Figure 3-5 (Sheets 1 through 3).

3.3 Coastal Zone Hazards

Coastal hazards include flooding from a combination of regular coastal processes (e.g., storm surge, waves, etc.), but also could occur from rare seismically-induced events, such as seiche[1] and tsunami. In addition to flooding, coastal zone hazards include erosion and failure of coastal bluffs.

Current observations and climate change science indicate that sea level rise is currently occurring and that the rate of sea level rise is expected to increase in the near future (e.g., 20 years). Sea level rise compounds regular and rare coastal hazards, where the magnitude and frequency of the hazards will increase over time.

3.3.1 Coastal Zone Flooding

Coastal flooding can arise from the combination of a number of elements, including:

- astronomic tide;
- atmospheric (storm) surge;
- wind and wave setup;
- wave run-up;
- sea level rise, and
- tsunami

Astronomic Tide

Tidal fluctuations occur daily, and the magnitude of high tides varies throughout the month (e.g., week by week) and seasonally throughout the year, called a semidiurnal tidal regime. Highest tides are usually experienced in the winter months; however, the peak tide level will vary slightly from year to year. The tide level recommended for assessment of coastal zone flooding is the Higher High Water, Large Tide (HHWLT), the average of the highest high waters, one from each of 19 years of predictions.

Recently, the term “King Tide” has been adopted in the Pacific Northwest. King Tide is reportedly a popular term used to refer to an especially high tide, or the highest tides of the year. King Tide is not a scientific term, nor is it used in a scientific context. King Tides would occur when the moon and sun are aligned at extreme distances to the earth in both January and July, resulting in the largest tidal range seen over the course of a year. Alignments that result in relatively high tides occur during approximately

[1] A standing wave in an enclosed or partially enclosed body of water.

three months each winter and again for three months in the summer. During these months, the high tides are higher than the average highest tides for three or four days. Use of the term 'King Tide' is reported to have originated in Australia, New Zealand and other Pacific nations and has been adapted for use in other parts of the world. King Tides would generally be lesser tide events than a HHWLT tide by definition.

In December 2012, a large tide/surge event was coined a "King Tide" for the region, that resulted in flooding in many parts of the Lower Mainland. This event also included a storm surge component, and strong wind generated to raise water levels further. A similar event also occurred in December 2014, resulting in damage to Stanley Park and Boundary Bay. The two images below illustrate flooding from the December 2012 event.

Coastal Flooding at Ambleside Park, West Vancouver (Image from Vancouver Sun)

Inundation at Kitsilano Pool, City of Vancouver

Atmospheric (Storm) Surge

Storm surge is caused by large prolonged low pressure storm systems. The low pressure system will locally raise water levels above normal tide levels. In the past two decades of observation, the maximum storm surge at Point Atkinson just exceeded 1 m, has reached values higher than 0.9 m several times, and is annually greater than 0.3 m. For the developed coastal areas of Howe Sound (Squamish), the suggested design annual exceedence probability (AEP) is 1 in 500 years (Table 6-1, Ausenco Sandwell, 2011a). The estimated 500-year return period storm surge is 1.3 m for the Strait of Georgia. It should be noted that a 200-year return period surge is only nominally less at 1.2 m.

Wind and Wave Setup

Wind setup is a rise of the water surface above the water level on the open coast due to the local action of wind stress on the water surface. This process acts to raise the overall water surface and is not the same as the wave effect. Wave setup is a shorter duration and more locally raising of the water surface similar to wind setup, but not associated with individual waves. This is not a site specific (e.g., shoreline specific) value, but rather a regional value based on the design wind speed and direction and could vary over the Sunshine Coast, but would not vary significantly from site to neighbouring site.

A wind setup analysis could be conducted by the Regional District based on a larger analysis; however, often these values are quite small for the wind experienced on the protected BC coast and can be lumped with wave processes.

Wave Runup

Wave runup is the vertical component of the total distance that the wave travels once meeting the shoreline. An appropriate setback (horizontal) should be applied to address wave runup on a site specific basis to avoid flooding and limit damage from spray.

Wave runup is a site specific value, and is driven by the design wind event, but is dependent on the orientation, shoreline slope and shoreline material. A general rule of thumb, is that the maximum sea state may be between 0.5 and 1.2 times the depth of water at the shoreline (e.g., seawall, dike, etc.), where sea state includes wind waves and swell (Ausenco Sandwell, 2011b). To minimize damage from waves and spray, structures should be set back from future HHWLT level, and considering climate change (Ausenco Sandwell, 2011c). This value would best be assessed for each site under a DPA technical report.

Sea Level Rise

Global sea level rise (SLR) allowances are suggested for the 2100 and 2200 year planning horizons (+1.0 m and +2.0 m, respectively). However, for structures with a short to medium-term design life, a reduced SLR allowance of +0.5 m is suggested (Ausenco Sandwell, 2011a). Typically, residential houses would represent a medium to long-term design life (50 to 100 years), given that renovations that do not alter the building foundation often prolong the life of a house. The regional adjustment is based on consideration of the local effect of vertical land movements (uplift or subsidence).

Tsunami

Hamilton and Wigen (1987) suggested that slumping of the Fraser delta could induce a tsunami of perhaps several metres height in Georgia Strait. However, Clague et al (1994) concluded that within low lying coastal wetland settings around Georgia Strait there is no evidence of tsunami deposits; therefore, had they occurred, the wave(s) would have been less than about 1 m in height.

Given the tsunami findings referenced above, the governing coastal flood hazard is assumed to be posed by coastal processes other than tsunami. Furthermore, given the relative rarity of tsunami events, it is not reasonable to compound probabilities by assuming the occurrence of a tsunami at the same time as an extreme tide, storm surge and sea level rise.

3.3.2 Coastal Flood Level and Sea Level Rise

The Ministry of Forests, Lands and Natural Resources Operations (MFLNRO) (Inspector of Dikes) has recently released three reports outlining guidelines for management of coastal flood hazard land use that incorporates consideration of sea level rise, sea dikes, and sea level rise policy (Ausenco Sandwell, 2011a,b,c). The reports outline coastal flood level components and incorporate allowances for flooding arising from tides, storms and associated waves, and sea level rise.

The report cites a potential sea level rise of about 1 m by the year 2100, and 2 m by the year 2200 (Ausenco Sandwell, 2011c). The rate at which sea level rises is also anticipated to increase over time, rather than remaining constant.

Ausenco Sandwell (2011) provides examples of preliminary flood levels for the year 2100 for selected locations around BC:

- For the Fraser River delta, the preliminary year 2100 flood level including freeboard is 6.2 m CGD[2].
- For Vancouver Harbour the preliminary year 2100 flood level including freeboard is 5.6 m CGD.

Note that both of these levels have been developed assuming wave runup on a natural gravel-pebble beach shoreline, and both include a freeboard allowance of 1.0 m.

Additional, site-specific engineering work would be required to develop FCLs for the Sunshine Coast that incorporate sea level rise; such work is beyond the scope of the current project.

Example – Trail Bay Seawall

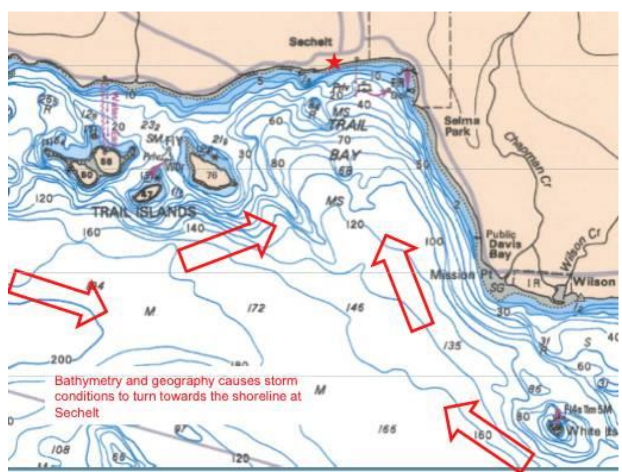
KWL recently conducted a high-level coastal flood hazard assessment for Trail Bay in Sechelt for the purposes of planning a long-term approach for the seawall and shoreline area (KWL, 2012)[3].

The Strait of Georgia dominates conditions at Trail Bay with west to northwest winds or southeast winds and the resulting wave environment. Other controlling conditions are summarized in Table 3-1.

Table 3-1: Summary of Meteorological and Oceanographic Conditions

	Description
Winds	SE, SW and W-NW gale and storm force winds 34-47 knots
Wave Heights	3 m (annual), 5 m (100-year storm)
Surge	0.7 m (annual) , 1.3 m (100-year storm)
Storm severity	Depends on chances of storm track, tide timing, surge and wind

Typical winds along the Strait of Georgia are modified as they approach Trail Bay and turn toward the shoreline. This results in wave crests aligning themselves more or less perpendicular with the shoreline. At high tide the waves break about 10-15 m horizontal from the top of the existing rock wall and at low tide waves break further out onto the gravel beach. During winter storms, surges can bring waves onto the top of the seawall. The wave run-up effect can result in substantial overtopping of the wall.



2 Elevation referenced to Canadian Geodetic Vertical Datum.

3 KWL, 2012. *Trail Bay Foreshore Conceptual Design*. Report prepared for the District of Sechelt.

In Trail Bay, the seawall at 4.0 to 4.5 m elevation is overtopped annually. Raising the seawall to about 5.5 m GCD would provide protection and lower annual restoration costs annually. A seawall height of 8.0 m was proposed in the study to limit damage under sea level rise for the year 2060.

Summary

To delineate the potential area of impact for coastal flooding, a conservative elevation of 8 m CGD is proposed as a screening criterion for this project.

Typical coastal water level values for the near term reach 6.15 m CGD as follows:

- High Tide: 2.05 m CGD;
- Storm Surge: 1.3 m CGD;
- Global Sea Level Rise to 2100: 1.0 m;
- Wave Effect Allowance: 1.2 m;
- Freeboard Allowance: 0.6 m;
- **TOTAL: 6.15 m CGD.**

Freeboard is applied to these values to allow for uncertainty that could be due to wave effects, etc., and further sea level rise allowances provide for a second metre for the year 2200. Accounting for the additional 1 m provides a planning elevation for assessment of 7.15 m CGD, rounded up to 8 m.

Basing the coastal flood hazard on the area encompassed by the 8 m CGD elevation is intended to identify any sites that should be assessed by a qualified professional to address flood hazards, but is not intended to preclude development.

3.3.3 Oceanfront Slopes

Coastal erosion and instability of coastal bluffs is a recognized issue globally. Erosion or failure of high soil slopes results in retreat of the top of bank, and possible risk to structures both at the top and/or toe of the failed slope. A rising sea level poses an increasing coastal erosion hazard, since the level at which storm-generated waves impact the shore will increase over time, exposing new portions of the slope to erosion.

For this project, oceanfront bluffs have been defined as steep slopes facing the ocean and subject to potential toe slope erosion at the high watermark, under present or future sea level conditions. The location of oceanfront bluffs within the Egmont/Pender Harbour OCP area was mapped using GIS. The crest of the oceanfront bluffs was defined by the slope break to steeper terrain, and was well defined by LIDAR survey. Slope height varies along the shoreline and can be as low as one to two metres.

In order to delineate a setback for slope hazards for oceanfront slopes, a future sea level reference level of 5 m was used to set an initial 15 m horizontal setback. From that point, a three-times horizontal setback is applied to the total slope height at that point to determine the setback line. The 5 m reference level and 15 m setback is intended to address climate change and the effects of sea level rise. This is the approach outlined in the provincial guidelines (Ausenco Sandwell, 2011).

3.4 Creek Hazards

3.4.1 Background

Steep mountain creeks may be subject to a spectrum of events, ranging from clear water floods to debris flows. Creek events are typically categorized by sediment concentration, with clear water floods having the lowest concentrations of sediment, debris floods having an intermediate concentrations and debris flows having the highest concentration.

Debris floods and debris flows are very rapid flows of water and debris along a steep channel (Hungr et al., 2001). The sediment may be transported in the form of massive surges. Flow velocities for debris flows may be 5 m/s to 10 m/s. These events leave sheets of poorly sorted debris ranging from sand to large boulders and logs. The peak discharge (flow rate) of debris floods and flows is commonly two to five times higher than that of 200 year return period water floods (Jakob and Jordan, 2001).

These types of events would be expected to initiate in the upper watershed, along open slopes or within channels, and be conveyed along confined channels. As the channel gradient drops and/or the channel becomes less confined, sediment is deposited. Repeated deposition forms alluvial fans, but deposition may also occur at road crossings or other human modifications in the landscape, especially where transport capacity has been reduced by encroachment.

Potential for debris floods and debris flows on alluvial fans or floodplains at basin mouths is primarily dictated by the basin characteristics, including gradient, watershed size, channel length, and the underlying geology/lithology of the area. Smaller, steeper watersheds may be debris flow prone; whereas larger, gentler watersheds may only be vulnerable to flooding.

Poor land-use management can also contribute to debris flood and debris flow potential. A debris flow event occurred on Clough Creek in Roberts Creek in November 1983 (MOE, 1984). This event was attributed to logging practices in the upper watershed.

The watercourses in the Egmont/Pender Harbour OCP area are not typically incised channels but are contained between bedrock hummocks, where potential hazards are somewhat restricted to the immediate creek or river corridor. Areas without good confinement are usually floodplain areas or small localized fans. In these areas, flood hazards can be more extensive and unpredictable channel shifting (avulsion) is possible due to debris blockages or sediment deposition. Avulsion events are also possible due to land-use management impacts or construction of undersized culvert crossings. Debris blockages at culvert crossings can result in overland flow paths that convey floodwaters along roads and into developed areas.

3.4.2 Defining the Dominant Creek Hazard

GIS data were used to assess the creeks draining through the Egmont/Pender Harbour OCP area for debris flow or debris flood potential. It has been shown that the Melton Ratio[4] can successfully discriminate between floods, debris floods and debris flow watersheds in BC (Millard et al., 2006). This is related to the physics of initiation, transport and deposition of these events (determined by the viscosity/rheology of the material).

[4] The Melton Ratio is defined as the ratio of total watershed relief to the square root of the drainage area.

The screening tool was applied in two ways:

1. For the entire watersheds, with the outlet at the ocean.
2. For the upper part of the watersheds, with outlets either at major tributary junctions or where the creeks cross the upper limit of existing development.

The results are displayed in Figure 3-1 and Figure 3-2, and summarized in Table 3-2.

Table 3-2: Summary of Screening for Creek Flood Processes

Creek Name	Process Category (Ocean Outlet)	Process Category (Tributary Junction or at Upper Limit of Existing Development)
Scott Brook	Flood	N/A[1]
Silversands Creek	Flood	N/A[1]
Haslam Creek	Flood	N/A[1]
Laughlin Creek	Debris flood	Debris flood
Anderson Creek	Flood	Debris flood/flow
South Sakinaw Creek	Debris flood	Debris flow
North Sakinaw Creek	Debris flow	Debris flow
Haskins Creek	Debris flow	Debris flow
Pollock Brook	Debris flow	Debris flow
Klein Creek	Debris flood	Debris flood
Unnamed Creek #1	Debris flood	N/A[1]
Unnamed Creek #2	Debris flow	N/A[1]

Notes:
1. Very little or no drainage area upstream of existing development according to mapping.

As indicated by the results of the morphometric screening, of the 12 creeks included in Table 3-2, 5 may experience debris flows.

It should be noted that the morphometric screening alone is insufficient basis to determine the likelihood of a debris flood or debris flow event or the frequency with which they may occur, but will provide a basis for future detailed investigation.

3.4.3 Ravines

Ravines are landforms associated with creeks that have become incised into thick deposits of surficial material. Typically there is an abrupt slope break from adjacent terrain onto a steep erosional slope. At the toe of slope there may or may not be a floodplain between the toe and the creek's natural boundary.

Since ravines are inherently associated with creeks, they are included within the creek hazard group.

To be consistent with the Riparian Assessment Regulations (RAR), RAR definitions are followed:

- **Ravine:** a narrow, steep-sided valley that is commonly eroded by running water and has an average grade on either side greater than 3:1 measured between the high water mark of the watercourse contained in the valley and the top of the valley bank, being the point nearest the watercourse beyond which the average grade is less than 3:1 over a horizontal distance of at least 15 m measured perpendicularly to the watercourse; a narrow ravine is a ravine less than 60 m wide, and a wide ravine is a ravine with a width of 60 m or more.

- **Top of the Ravine Bank:** the first significant break in a ravine slope where the break occurs such that the grade beyond the break is flatter than 3:1 for a minimum distance of 15 m measured perpendicularly from the break, and the break does not include a bench within the ravine that could be developed.
- **Riparian Assessment Area:**
  - **for a stream**: the 30 m strip on both sides of the stream, measured from the high water mark;
  - **for a narrow ravine**: a strip on both sides of the stream measured from the high water mark to a point that is 30 m beyond the top of the ravine bank; and
  - **for a wide ravine**: a strip on both sides of the stream measured from the high water mark to a point that is 10 m beyond the top of the ravine bank.

Ravine crests were mapped in the GIS based on slope (by including areas of 30% or steeper terrain within the ravine), and also using slope breaks identified on the contour maps. Since creeks may or may not be incised in ravines, ravine crests are not necessarily continuous along creeks.

3.4.4 Floodplains, Fans and Channel Confinement

Flood hazards and channel avulsion occur in areas of low channel freeboard where the channel is not well confined by high ground on either side (i.e., floodplains and fan areas) LIDAR contour data (1 m contour interval) were reviewed to identify potential areas of low channel confinement, or fans, based on judgment.

3.4.5 Creek-Road Crossings

The majority of the major crossings in the OCP are reported to be BC Ministry of Transportation and Infrastructure (MOTI) assets, not Regional District structures.

Flooding and or avulsion may occur at road crossings (i.e., culverts and bridge openings) due to insufficient conveyance of creek flow, or blockage. An evaluation of the conveyance capacity of all creek crossings is beyond the scope of this project; rather, these locations are flagged for reference and to highlight the number of potential flood/avulsion sources that may exist within the OCP area given the drainage/road network density.

Avulsion at road crossings can often result in unexpected overland flooding, as roads and roadside ditches tend to convey floodwaters quickly and often directly to driveways and developments. An inventory of drainage infrastructure (e.g., size, material, age) could be developed to assist in master drainage planning and further revisions to DPA conditions.

The conveyance capacity of culverts and bridges should be designed for the process expected to occur within a selected design return period (i.e., water flood, debris flood or debris flow). The crossings are considered permanent. In forested settings a return period of 1/100 year would be recommended. However, in the residential setting, the Ministry of Transportation and Infrastructure (MOTI, 2007) makes the following recommendations for return periods:

- **culverts with a span of less than 3 m**: design event return period between 1/50 and 1/100;
- **culverts with a span equal to or greater than 3 m**: design event return period between 1/100 and 1/200; and
- **bridges**: design event return period between 1/100 and 1/200.

The variation in MOTI-recommended return periods depends on consideration of the road classification (e.g., low volume, local, collector, arterial or freeway). Bridges have a recommended design event return period of 1/200 for all roads except low volume roads (MOTI, 2007).

Where debris floods are a possibility (e.g., Table 3-2), extra allowance should be provided for sediment and debris.

Where debris flows are anticipated (e.g., Table 3-2), analysis of the debris flow recurrence interval should be conducted, and findings should inform the design, before it is finalized.

Design of road crossings for return periods less than 200 years may have an impact on legislated flood assessments (APEGBC 2012) for residential areas.

3.5 Slope Hazards

3.5.1 Slope Thematic Mapping

DEM data were used to classify the terrain within the OCP based on slope steepness categories, after Howes and Kenk (1997). The LiDAR-based DEM was used where available, which yields 1 m by 1 m cells, and the 1:50,000 DEM was used for the remainder of the OCP (approximately 30 m by 30 m cells).

The following slope categories were used:

- 0 to 5%: plain;
- 5 to 30%: gentle;
- 30 to 50%: moderate;
- 50 to 60%: moderately steep (1);
- 60 to 70%: moderately steep (2); and
- >70%: steep.

(Note that 45° is equivalent to 100%.)

The slope classification was used to aid delineation of potential open slope landslide initiation areas, as well as ravine sidewalls and oceanfront slopes. LIDAR allowed accurate definition of these slope areas and slope breaks. In the areas beyond LIDAR coverage, definition of slope breaks is less accurate.

Many jurisdictions define development permit areas based solely on arbitrarily selected slope classes without reference to a particular hazard affecting the site. The intent of such slope-defined development permit areas is typically to govern residential growth based on environmental and other planning considerations, rather than purely geotechnical considerations. Further, there is no geotechnical basis for using slope alone to define DPAs for hazards.

The APEGBC (2010) Legislated Guidelines for Landslide Risk Assessment and Residential Development provide guidance for conducting seismic slope hazard assessments. The APEGBC guidelines use a screening process based on a factor of safety calculation. Factor of safety considers slope, but includes other variables also. Depending on the site conditions, lands that are gently-sloped could be seismically vulnerable, while lands that are steep could be seismically stable. Given the considerations outlined above, KWL has not recommended DPAs based on slope categories alone, without additional consideration of hazard mechanism.