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| Type | **Request for Decision** | | |
| Title | **Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 – Consideration of First Reading and Scheduling of a Public Information Meeting** | | |
| Author | **Steven Olmstead,<br>Planning Consultant and<br>Peter DeJong, CAO** | **Reviewed By:** | |
| Date | **April 6, 2018** | **Version** | **1** |
| Issued for | **April 10, 2018 Council Meeting** | | |

**Recommendations:**

1. THAT the Request for Decision report titled "Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 - Consideration of First Reading and Scheduling of a Public Information Meeting" dated April 6, 2018 be received;

2. THAT the Table of DPA Guidelines attached be endorsed as a communication tool;

3. THAT Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 be read a first time;

4. THAT Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 is consistent with the Village of Lions Bay 2017-2021 Five Year Financial Plan and the MVRD Integrated Solid Waste and Resource Management Plan;

5. THAT a public information meeting regarding Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 be held at 7:00 p.m. on Thursday, April 19, 2018 at Broughton Hall, 400 Centre Road, Lions Bay.

**Attachments:**

A. Table of Development Permit Area (DPA) Guidelines;

B. Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018.

on what they need to do so that their land may be used safely for the use intended. The bylaw also addresses from a community perspective the minimum safety standards to be achieved for new development.

**Summary of Changes:**

A number of changes have been incorporated into the draft bylaw to better reflect the information and recommendations contained throughout the Cordilleran Report, to ensure that the guidelines are not overly prescriptive and to respond to comments and concerns raised at the public meeting and in feedback received since then.

In many cases the changes made are for clarity and consistency in wording of guidelines. The Cordilleran Report was further reviewed and some additional guidelines and text that were not included in the draft (by reason of oversight or misunderstanding) are now included.

In addition, all maps were updated after receipt by the Municipality of additional LiDAR mapping covering portions of the Municipality which were not previously included.

This summary will start with changes to the bylaw which address two concerns raised at the public meeting:

1. How property owners can deal with hillslope risks originating beyond the boundaries of the Village is at least partially addressed in a revised section 10.4.4.2 which, while acknowledging that specific technical analysis should be undertaken, it is not always possible or feasible to do so. In such cases, "In lieu of hard data, expert judgment supported by sound geomorphic reasoning must be relied upon." Similarly, the bylaw now notes that it is very difficult to predict individual landslide paths given the complex micro terrain above Lions Bay. However, use of high resolution LIDAR topography would aid defining specific travel paths for various landslide volumes and rheologies. [Rheology is the study of the flow of matter. An understanding of a rock's rheological properties tells us how it behaves when a force is applied to it.] Property owners wishing to develop will have some options for assessing risk beyond the Village boundary while the Municipality seeks cooperation from the Province to undertake further study of hazards originating on Crown land above the Village.

2. Regarding guidelines that may be at cross-purposes where there are multiple hazards affecting a property, language has been included in section 10.5.3.3 to ensure a coordinated approach is taken where there may be conflicting objectives. Language in the guidelines has also been softened. For example, wildfire mitigation practices or conditions, including non-structural roof and siding replacements, should now be "considered" as opposed to "required". Clarification is also included to indicate that geohazards will usually take precedence over wildfire hazard, "where potentially

10. At the public meeting, Mr. Friele indicated to the Planning Consultant that the wording regarding guidelines for DPA 2A and DPA 2B should be similar, especially with respect to the "tanking" comment and in terms of making reference to scour protection. Guidelines in sections 10.3.2.2 and 10.3.3.3.2 now read the same in this respect.
11. In sections 10.3.4.2 and 10.3.4.3 there was some confusion about ravine setbacks in DPA 2C. The Professional Geoscientist noted that there is no minimum 15 m setbacks from ravines and that it is recommended that, for land within 30 metres of ravine crests, the minimum setback be determined by the qualified registered professional on a site specific basis. References to 15 and 30 metre setbacks have been deleted from the DPA 2C guidelines.
12. Section 10.4.2 Landslide Safety Policy has been revised to include specific reference to Table A of section 10.1.1.
13. With respect to section 10.4.5.2 Rockfall guidelines, specific statements in the Cordilleran Report (guidelines 2, 3 and 4 in the revised bylaw) were mistakenly omitted or not recognized by the Planning Consultant as guidelines.
14. In the steep slopes DPA 3C, a guideline has been included from the Cordilleran Report outlining basic considerations for a qualified professional's report.
15. In addition to softening the language regarding Wildfire Hazard DPs, the application of DPA 4 Wildfire Hazards has been amended so that Development Permits will only be required for development/construction that requires a building permit.

**Options:**

1. Receive the report, endorse the changes to the draft bylaw, read the bylaw a first and second time and set the public hearing date for March 8, 2018 per the recommendations at the beginning of this report.
2. As above, with potential changes to the recommended amendments;
3. Otherwise as Council may direct.

**Preferred Option:** The first option to accept the recommendations as per the beginning of the report.

**Organizational and Intergovernmental Implications:**

The *Local Government Act* requires that amendments to Official Community Plans be considered by the Council with respect to implications for financial and waste management plans. This is required after First Reading and before the public hearing.

## Table of Development Permit Area (DPA) Guidelines

| Development Permit Area | | Applies to | Reason | Minimum requirements for Development Permit* |
|---|---|---|---|---|
| 1: Ocean natural hazard areas | | Areas lower than 8 m Above Sea Level (ASL) potentially subject to coastal erosion and other consequences of climate change and rising sea level | Area potentially subject to coastal erosion and other impacts of climate change and sea level rise | Habitable space located above the site specific FCL as determined by QRP |
| 2: Creek natural hazard areas | A: Mitigated debris fan areas | Areas of the respective fans downstream of flood works/barriers | May be subject to residual flood hazard | Building designed to withstand debris flood impacts with the top of concrete steel reinforced foundations established 1 m or more above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. |
| | B: Upper Bayview Fan area | Lots on Upper Bayview Road subject to potential debris flood/debris flow hazard | Potential hazard identified in BGC report from 2012 | Debris flow/debris flood assessment. Building designed to withstand debris flood impacts with the top of concrete steel reinforced foundations established 1 m or more above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. |
| | C: Ravine areas | Land within 30 m of a ravine crest | Ravine slope instability and erosion hazards | Siting and conditions determined on a site specific basis by QRP. Management of on-site storm water drainage management and on-site sewage disposal are key considerations. |
| 3: Slope natural hazard areas | A: Open-slope slide areas | From Highway 99 upslope to the municipal boundary | High to Very High potential consequence from landslide risk | Landslide Risk Assessment for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes. Foundation design, lift of habitable space, barrier walls and other measures determined by QRP. |
| | B: Rockfall areas | 27.5 degree rockfall shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other smaller scattered bluffs | High to Very High potential consequence from rockfall risk | Landslide Risk Assessment by QRP for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes. |
| | C: Slopes >30% | Slopes >30% - See hillshade map | Worksafe BC requirement and general threshold used in BC. | For areas below Highway 99 – compliance with Worksafe Regs and any site specific QRP requirements. For areas above Highway 99 – compliance with Worksafe Regs and requirements under DPA 3A |
| 4: Wildfire natural hazard areas | | Entire municipality | Wildfire hazards | Consideration of fire resistive roofing, siding and decking and vegetation management within 10m of buildings and structures. |

***Use and Indemnity Covenants required for DPAs 1, 2 &3. *See Bylaw for additional DP requirements and exemptions.**

READ A THIRD TIME

ADOPTED

Mayor

Corporate Officer

Certified a true copy of
Bylaw No. 525, 2018 as adopted.

Corporate Officer

**Schedule A**
Village of Lions Bay Official Community Plan Designation Bylaw
No. 408, 2008, Amendment Bylaw No. 525, 2018

## 10.0 Development Permit Areas

## 10.1 General

### 10.1.1 Introduction – Purpose and Policy

The technical study by Cordilleran Geoscience titled "The Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards", dated January 18, 2018 (the "Cordilleran Report", available from the Village of Lions Bay by request or from the Village of Lions Bay online Reports and Documents Library at lionsbay.ca), identifies land potentially subject to geological natural hazards. The study notes that in Lions Bay, given the steep terrain and the coastal maritime setting there are a number of geohazards that may affect the community, including coastal hazards, creek hazards and hillslope hazards.

As described in the Cordilleran Report, a hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (Table 1).

**Cordilleran Report, Table 1: Qualitative hazard frequency categories**

| Qualitative frequency | Annual return frequency | Probability | Comments |
|---|---|---|---|
| Very high | >1:20 | >90% in 50 years | Hazard is well within the lifetime of a person or typical structure. Clear fresh signs of hazard are present. |
| High | 1:100 to 1:20 | 40% to 90% in 50 years | Hazard could happen within the lifetime of a person or structure. Events are identifiable from deposits and vegetation, but may not appear fresh. |
| Moderate | 1:500 to 1:100 | 10% to 40% in 50 years | Hazard within a given lifetime is possible, but not likely. Signs of previous events may not be easily noted. |
| Low | 1:2500 to 1:500 | 2% to 10% in 50 years | The hazard is of uncertain significance. |
| Very low | <1:2500 | <2% in 50 years | The occurrence of the hazard is remote. |

Consequence (Table 2) is a product of factors, including whether a given hazard will reach a site, whether elements at risk (e.g., houses/people) will be present when the site is affected by the hazard, how vulnerable the elements at risk are to the hazard affecting the site, and the value of the elements at risk or the number of persons exposed.

In the circumstances, the Municipality considers that the level of risk tolerance for new development ought to consider the scale of such development in comparison to generally accepted levels of risk tolerance for existing development, as indicated in the first line of Table 11. If new development is within a smaller scope as described in the first two types of application in Table A below, then it is reasonable to set a safety standard which is generally appropriate for existing development. Typically, as noted in the Cave Report from the Fraser Valley Regional District, such smaller scale development is in the nature of infill or extension of existing development which may already be subject to the same hazard. Accordingly, balancing concerns for safety with economic, social and political considerations, the levels of risk tolerable and acceptable to the Village of Lions Bay in respect of new development is in accordance with the risk thresholds set out in Table A below.

**Table A: Risk Tolerance Policy for New Development, Village of Lions Bay**

Risk tolerance thresholds in accordance with development type:

| Type of Application | 1:10,000 + ALARP | 1:100,000 | *FOS >1.3 (static) | *FOS >1.5 (static) |
|---|---|---|---|---|
| Building Permit or Land Alteration Permit for development on existing RS1 parcel as permitted by zoning | X | | X | |
| Subdivision and/or Rezoning to create 4 or fewer fee simple or strata parcels (including the original parcel) | X | | X | |
| Subdivision and/or Rezoning to create 5 or more fee simple or strata parcels (including the original parcel) | | X | | X |

* Ratios denote annual probability of individual loss of life

* FOS means Factor of Safety, generally in relation to engineered slopes and ravines

+ ALARP means As Low As Reasonably Practicable

For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. In Lions Bay, this principle of mitigation is to be applied across all Development Permit Areas (DPAs), particularly where the level of hazard uncertainty is significant. Qualified Registered Professionals will be responsible for indicating that all methods to reduce risk to As Low As Reasonably Practicable have been considered or implemented.

The Municipality specifically and explicitly chooses *not* to set a risk tolerance threshold in respect of existing development in Lions Bay. The risk tolerance policy set out herein is in respect to new development only, including any application for subdivision of land, any application for rezoning, and any application for a Development Permit, howsoever triggered or required.

### 10.1.3 Activities that Require a Development Permit

1. In a Development Permit Area:
    a. land within the area must not be subdivided;
    b. construction of, addition to or alteration of a building or other structure must not be started;
    c. land within the area must not be altered;

    unless the owner first obtains a development permit or an exemption under section 10.1.4 applies.

2. For the purpose of section 10.1.3.1,
    a. construction of, addition to or alteration of a building or other structure includes, but is not limited to:
        i. new building construction;
        ii. building additions and alterations;
        iii. construction of, addition to or alteration of accessory buildings and structures, including pools, hot tubs, sheds and other structures; and
        iv. construction of, addition to or alteration of retaining walls 1.2 metres or higher;

    b. alteration of land includes, but is not limited to:
        i. site clearing or removal of vegetation;
        ii. landscaping, including planting and clearing;
        iii. site grading;
        iv. tree removal;
        v. placement of fill, or disturbance of soils, rocks or other native materials;
        vi. creation of impervious and semi-impervious surfaces, such as patios and driveways;
        vii. installation, construction or alteration of flood protection or erosion protection works.

3. The Municipality may impose in a development permit, any condition permitted by law in order to ensure compliance with the guidelines set out in this document.

4. Where a parcel is designated as being within more than one type of development permit area, a single development permit may be issued, provided that the guidelines for all applicable development permit areas are addressed in the development permit.

### 10.1.4 Exemptions

The following activities are exempt from the requirement to obtain a development permit:

1. public works, services and maintenance activities carried out by, or on behalf of, the Village of Lions Bay, and approved by the CAO;

2. non-structural repairs or renovations, including roof and other exterior repairs or replacements;

3. repair or replacement of an existing deck, provided that the location and dimensions do not substantively change;

2. Where applicable, a report by a qualified registered professional should include the following:
    i. Report name and date;
    ii. Client Information;
    iii. Qualified registered professional information (training, experience, insurance);
    iv. Property information (legal and civic);
    v. Description of development proposal;
    vi. Review of relevant Village of Lions Bay bylaws and other statutory requirements;
    vii. Review of background information (site-specific and overview archived & provided by the Village of Lions Bay and others);
    viii. Description of geologic and geomorphic setting;
    ix. Description of field work conducted on and, if required, beyond the proposed development;
    x. Identification of natural hazards or other hazards identified in background reports and field work. Includes also a description of all potential hazards and rationale for excluding some;
    xi. Provides site plan and other mapping required to show hazards affecting, minimum scale 1:5000;
    xii. Provides maps, illustrations and diagrams to illustrate risk scenarios referred to in the Report;
    xiii. For all hazards, separate and in aggregate, analyses of the georisk affecting the proposed development and evaluation against the Village of Lions Bay safety policy;
    xiv. Discusses the effect of changed conditions to slope stability caused by the project, by future potential natural factors or land-use (fire, forestry) or climate change;
    xv. Discusses uncertainties and describes any residual risk that would remain;
    xvi. Provides technically justified siting constraints or protective measures, as required;
    xvii. States whether all methods to reduce risk to As Low As Reasonably Practicable (ALARP) have been considered or implemented;
    xviii. Provides implementation steps for the identified structural mitigation works (in terms of design, construction and approval). Where protective works are recommended, the report must identify where follow up field verification is required to ensure conformance to design.
    xix. States that "the land may be used safely for the use intended" with siting constraints, protectives measures or restrictive covenant, as stipulated in the report.
    xx. Provides permission to Village of Lions Bay to include the Report in the online geo-hazard report library (as background information, not for other parties to rely on);
    xxi. Acknowledges that report may be attached to covenant registered on title to the property;
    xxii. Provides time limitation or condition statement to describe extent the Village of Lions Bay may rely on the Report for development approvals, and when resubmittal is recommended;
    xxiii. Provides an assurance statement (after APEGBC 2010, 2012);
    xxiv. Signed and sealed by coordinating qualified registered professional.
3. For sites located within multiple hazard DPAs, a coordinated approach will be required to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met.
4. Where a report by a qualified registered professional identifies protective works or measures to mitigate hazard(s) affecting a lot, those works or measures must not transfer risk to any other lots.

## 10.2 DPA 1 – Coastal Zone Hazards (Map 3)

### 10.2.1 Justification

Ocean front land in the Village of Lions Bay is subject to hazards such as flooding of low-lying terrain, erosion and instability of oceanfront slopes. Coastal zone hazards are expected to be exacerbated over the coming decades by sea level rise. DPA 1 is intended to designate sites that should be assessed by a qualified registered professional to address coastal flood hazards, but does not preclude development. For Coastal Zone Hazards, year 2100 high water mark (HWM), and site specific factors such as wave effects, storm surge, shoreline erosion, shore face stability and associated setbacks should be considered.

### 10.2.2 Extent

DPA 1 extends from the existing natural boundary of the sea to a height of 8 metres CGD (Canadian Geodetic Datum) and is outlined on Map 3. The 8 metre level is conservatively selected to represent a potential future Flood Construction Level (FCL). DPA 1 includes all lots fronting the ocean within the Village of Lions Bay.

### 10.2.3 Background

In the Village of Lions Bay, many steep slopes into the sea are rock controlled or are fill slopes below the railway line. These are not a stability concern for residential development. Most residential lots on surficial materials are located on bouldery debris fan deposits of Magnesia, Alberta and Harvey Creeks, and while the shorefronts may be steepened to 70-80% by wave attack, the sea scarp is not tall (<6 m) and materials are coarse and relatively resistant to erosion at the timescale of the life of a structure (e.g., 100-years).

The sites most vulnerable to erosion are those low-lying areas at the south end of Brunswick Beach Road, where housing has been developed on a gravel tombolo that has linked a small rock outcrop with the mainland. The beach gravels forming the tombolo stand just above the HWM, being formed by storm waves, and the terrain between the north and south facing beaches is slightly lower, just at the high water mark (HWM). Future breaching and erosion of these beach ridges places all these low-lying areas at risk.

### 10.2.4 Guidelines and Requirements

1. Within DPA 1, development applications shall include a coastal flood hazard assessment prepared by a qualified registered professional to define the year 2100 shoreline position and the derived flood construction level, appropriate setback and any necessary mitigation work. Determination of the Year 2100 flood construction level shall follow the Ausenco Sandwell "Combined Method" as referenced in the Flood Hazard Area Land Use Management Guidelines. The FCL is determined as the sum of:

    - Allowance for future sea level rise to the year 2100;

    - Allowance for regional uplift, or subsidence to the year 2100;

    - Higher high water large tide (HHWLT);

    - Estimated storm surge for the Designated Storm with an annual exceedance probability of 1:200, or 1:500 as per the Ausenco Sandwell method referenced in the Flood Hazard Area Land Use Management Guidelines;

## 10.3 DPA 2 - Creek Hazards

### 10.3.1 Justification

In the Village of Lions Bay, DPA 2, Creek Hazards include consideration of flooding, debris flooding and debris flow from large creeks with existing debris flow hazard mitigation (Magnesia, Alberta, Harvey), unmitigated creeks (upper Bayview) and ravine hazards arising from deeply channelized unmitigated creeks and escarpment slope instability (parts of Battani and Rundle). Small creeks captured in part by the residential drainage network of ditches, culverts and storm sewers (upper School Yard Creek) are addressed in the DPA 3C - Slopes >30%.

### 10.3.2 DPA 2A- Mitigated Debris Fans

#### 10.3.2.1 Extent

DPA 2A is shown on Map 4 and includes land on the formerly active portion of the Magnesia Creek fan and the composite Alberta/Harvey Creek fans that could be affected should existing mitigation structures become overwhelmed by a large, rare event.

#### 10.3.2.2 Guidelines and Requirements

1. For debris fan hazards in DPA 2A, a description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay is required.
2. At a minimum, until residual risk is better understood by detailed study, and as per development on alluvial fans (WLAP 2004, 2018), house foundations should be designed to withstand debris flood impacts with the top of concrete steel reinforced foundations established a minimum of 1 m above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level for habitable space a minimum of 1 m above finished grade, or the design should include measures to prevent water ingress. For example on the downslope side there could be openings such as doors or garage doors as long as the ground is contoured to prevent water ingress.

### 10.3.3 DPA 2B - Upper Bayview Creek Fan

#### 10.3.3.1 Justification

DPA 2B is vulnerable to debris flow and stream flooding including channel shifting (avulsion). Should the historically diverted channel jump its banks, then the flow could further erode the gullies downslope, causing similar instability and impacts to lots downslope as those experienced during development in 1972. Channel blockage at the point of the 1972 diversion could redirect the creek back into its natural channel, thereby

### 10.3.4.3 Guidelines and Requirements

1. For land within 30 metres of ravine crests in DPA 2C, a description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.
2. A qualified registered professional's report shall include the following:
   a. a recommendation of required setback from the ravine crest, and a demonstration of suitability for the proposed use;
   b. a field definition of the required setback from the top of a ravine or other steep slope;
   c, where building sites are located within ravines, a landslide assessment will be required for ravine slopes affecting the site, and to establish FCLs and other measures based on flood, debris flood and debris flow from affecting creeks; and
   d. the required setback to top of bank and recommendations relating to construction design requirements for the above development activities, on-site storm water drainage management, on-site sewage disposal and other appropriate land use recommendations.
   e. seismic slope stability assessments will be required to assess foundation stability.

1. Applicants will be required to provide a preliminary assessment report and may be required to provide a detailed assessment report prepared by a qualified registered professional in accordance with the subsequent guidelines and requirements as applicable.
2. Some background information on potential slope hazards in some areas is available through the Cordilleran Report. The information in the Cordilleran Report should be referenced as part of any development permit application.
3. Development should minimize any alterations to steep slopes, and the development should be designed to reflect the site rather than altering the site to reflect the development.
4. Terracing of land should be avoided or minimized and landscaping should follow the natural contours of the land.
5. Buildings and structures and landscaping should be located as far as reasonably possible from steep slopes or channel discharge/runoff points at the base of slopes.
6. Potential slope hazard areas should remain free of development, or, if that is not possible, then:
    i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level, and
    ii. conditions (for example conditions relating to the permitted uses, density or scale of building) should be recommended as necessary to reduce potential risk to acceptable levels,

   as determined by a qualified registered professional in a preliminary assessment or detailed assessment report for the consideration of the municipality.
7. Stepped and articulated building forms that integrate and reflect the natural site contours and slope conditions should be used, and large unbroken building masses that are unsuitable for sloped conditions should be avoided.
8. The construction of structures, pathways/trails, driveways, utilities, drainage facilities, septic fields, swimming pools, hot tubs, ponds, landscaping or other uses at or near the top or base of steep slopes should be avoided. A minimum ten metre buffer area from the top or base of any steep slope should be maintained free of development except as otherwise recommended by a qualified registered professional. On very steep slopes, this buffer area should be increased.
9. Vegetation should be maintained and/or reinstated on the slopes and within any buffer zone above the slopes to filter and absorb water and minimize erosion.
10. No fill, including yard clippings, excavated material, sand or soil, should be placed within ten metres of the top of slopes or along pre-existing drainage channels. This applies to ravine slopes as well.
11. The base of slopes shall not be undercut for building, landscaping or other purposes except in accordance with the recommendations of a qualified registered professional and a permit issued under this section.
12. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.

conditions. The required factor of safety calculation references many data sources, including (but not limited to):

a. seismic hazard maps and reports;
b. ground motion data;
c. seismic Site Class; and
d. modal magnitude values of the design earthquake.

Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability may also be necessary.

21. Risk Analysis for open-slope slides requires knowledge of the frequency-magnitude model. Stratigraphic and radiometric methods should be considered to estimate historic return periods and gauge landslide intensity at the site. Such materials/methods may or may not be present or practicably attained from a single lot or group of lots. In lieu of hard data, expert judgment supported by sound geomorphic reasoning must be relied upon.

22. The area included within DPA 3A has complex micro terrain, with very irregular to hummocky topography, and it is very difficult to predict individual landslide paths. Thus, while some local topographic features may shelter or protect certain sites, safe sites cannot be predicted using simple rules, and caution is warranted. Landslide modeling by qualified registered professionals using high resolution LIDAR topography would aid defining specific travel paths for various landslide volumes and rheologies.

23. If required by the outcome of risk analysis and evaluation, siting constraints and/or design of protective measures may be required. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures.

24. Open slope landslide source areas requiring assessment may exist on a parcel or far upslope of a parcel.

## 10.4.4 DPA 3B – Rockfall

### 10.4.4.1 Extent

The DPA 3B area is drawn by projecting a $27.5^0$ rockfall shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other smaller scattered bluffs in and above Lions Bay. In the case of the former, since the rock avalanche headscarp is located high above the Village, and since the cliffs are tall and potential rockfall volumes are reasonably large (e.g., 10s – 1000s $m^3$), the reach of these events extends far downslope, almost reaching the highway in the vicinity of Schoolyard Creek. Elsewhere, the smaller and lower elevation bluffs, result in less extensive reach of potential rockfall. DPA 3B is outlined on Map 8.

### 10.4.4.2 Guidelines and Requirements

In DPA 3B, a report by a qualified registered professional shall be prepared that includes the following:

13. Large single plane retaining walls should be avoided, where possible. Where retaining walls are necessary, smaller sections of retaining wall should be used. Any retaining structures 1.2 metres or higher, or a series of terraced retaining walls with a combined height of greater than 1.2 metres, in steeply sloped areas must be designed by a qualified registered professional.

14. Disturbed slopes should be reinforced and revegetated, especially where gullied or where bare soil is exposed. Planting should be done in accordance with the recommendations of a Certified Horticulturalist, Landscape Architect or qualified registered Professional Forester.

15. Native species, including trees, shrubs and other plants, should be used for any new planting.

16. Any structural mitigation measures must be designed by a qualified registered professional and confirmation must be received by the Village of Lions Bay that the mitigation measures were implemented as recommended.

17. Water should be diverted away from slopes, yards and structures in a controlled manner and ponding should be avoided near slopes. Small unidentified drainages intercepted by proposed development should be conveyed by structures with adequate capacity (i.e. 200 year flood) and lots should be graded so that water is directed away from slopes and toward storm drainage systems as indicated in the following guideline.

18. Landscaping; and building, roof, pavement, and other impervious surface drainage should be designed and maintained to shed water away from slopes (especially steep slopes) and shall be connected to a storm drainage system, infiltration pit, or alternative method, recommended by a qualified registered professional and approved by the Village of Lions Bay.

19. The extent of paved or hard-surfaced areas should be limited, and absorbent or permeable surfaces should be used instead to encourage infiltration where appropriate and reduce runoff.

20. Where applicable, a report by a qualified registered professional should include the following:

    i. For slope hazards, description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.

    ii. If required by the risk assessment, then siting constraints and/or design of protective measures. Siting constraints may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots. For this reason, area wide protection measures might be considered by the Village of Lions Bay.

    iii. For stability of slopes on or about the proposed development site, assessment of slope failure modes and limiting factors of safety, and stability during seismic events. Seismic slope analysis requires comparatively detailed knowledge of subsurface bedrock, soil and groundwater

### 10.4.5.2 Guidelines and Requirements

1. Applicants will be required to provide a preliminary assessment report and may be required to provide a detailed assessment report prepared by a qualified registered professional in accordance with the subsequent guidelines and requirements as applicable.
2. Some background information on potential slope hazards in some areas is available through the Cordilleran Report. The information in the Cordilleran Report should be referenced as part of any development permit application.
3. Development should minimize any alterations to steep slopes, and the development should be designed to reflect the site rather than altering the site to reflect the development.
4. Terracing of land should be avoided or minimized and landscaping should follow the natural contours of the land.
5. Buildings and structures and landscaping should be located as far as reasonably possible from steep slopes or channel discharge/runoff points at the base of slopes.
6. Potential slope hazard areas should remain free of development, or, if that is not possible, then:
    i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level, and
    ii. conditions (for example conditions relating to the permitted uses, density or scale of building) should be recommended as necessary to reduce potential risk to acceptable levels,

    as determined by a qualified registered professional in a preliminary assessment or detailed assessment report for the consideration of the municipality.
7. Stepped and articulated building forms that integrate and reflect the natural site contours and slope conditions should be used, and large unbroken building masses that are unsuitable for sloped conditions should be avoided.
8. The construction of structures, pathways/trails, driveways, utilities, drainage facilities, septic fields, swimming pools, hot tubs, ponds, landscaping or other uses at or near the top or base of steep slopes should be avoided. A minimum ten metre buffer area from the top or base of any steep slope should be maintained free of development except as otherwise recommended by a qualified registered professional. On very steep slopes, this buffer area should be increased.
9. Vegetation should be maintained and/or reinstated on the slopes and within any buffer zone above the slopes to filter and absorb water and minimize erosion.
10. No fill, including yard clippings, excavated material, sand or soil, should be placed within ten metres of the top of slopes or along pre-existing drainage channels. This applies to ravine slopes as well.
11. The base of slopes shall not be undercut for building, landscaping or other purposes except in accordance with the recommendations of a qualified registered professional and a permit issued under this section.
12. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.

conditions. The required factor of safety calculation references many data sources, including (but not limited to):

- a. seismic hazard maps and reports;
- b. ground motion data;
- c. seismic Site Class; and
- d. modal magnitude values of the design earthquake.

Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability may also be necessary.

21. A report from a qualified registered professional is required in DPA 3C for excavations, roads, drainage, fillslopes and foundations. Local rockfall assessment and mitigation may also be required. Evaluation of onsite and nearby municipal drainage structures to identify potential undersizing, blockages and overland flow, and design of buildings to prevent water ingress is also required.

22. A Risk Assessment by a qualified registered professional including evaluation against life safety thresholds established by Village of Lions Bay may be required.

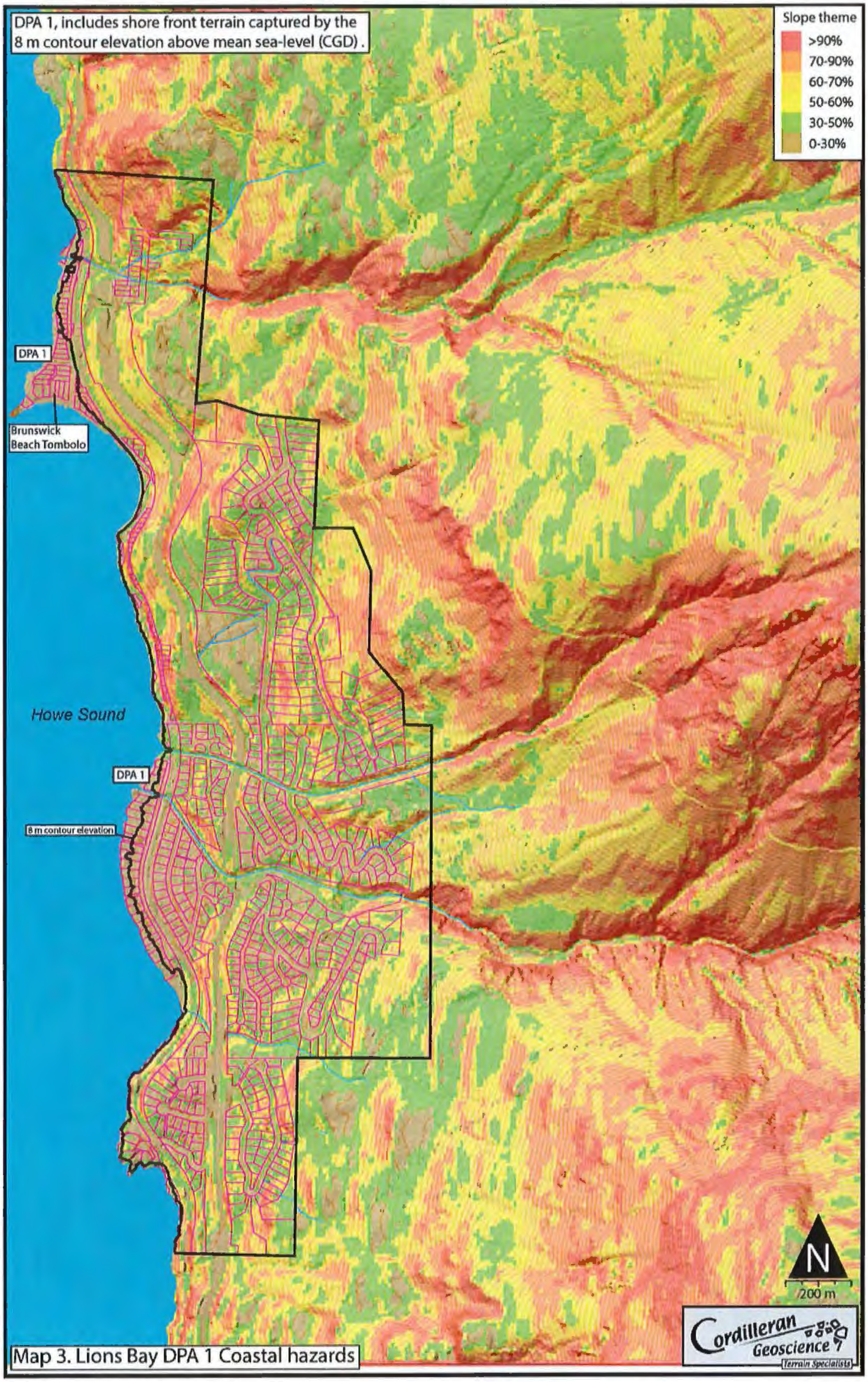
23. If required by the risk assessment, then siting constraints should be assessed and/or design of protective measures undertaken. Siting constraints include the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include engineering design of excavated slopes, fillslopes and foundations and other measures.

    iii. where feasible, a defensible space of 10 metres should be managed around buildings and structures with the goal of eliminating fuel and combustible debris, reducing risks from approaching wildfire and reducing the potential for building fires to spread to the forest, and the required defensible space may be larger in areas of sloping ground where fire behaviour creates greater risk.

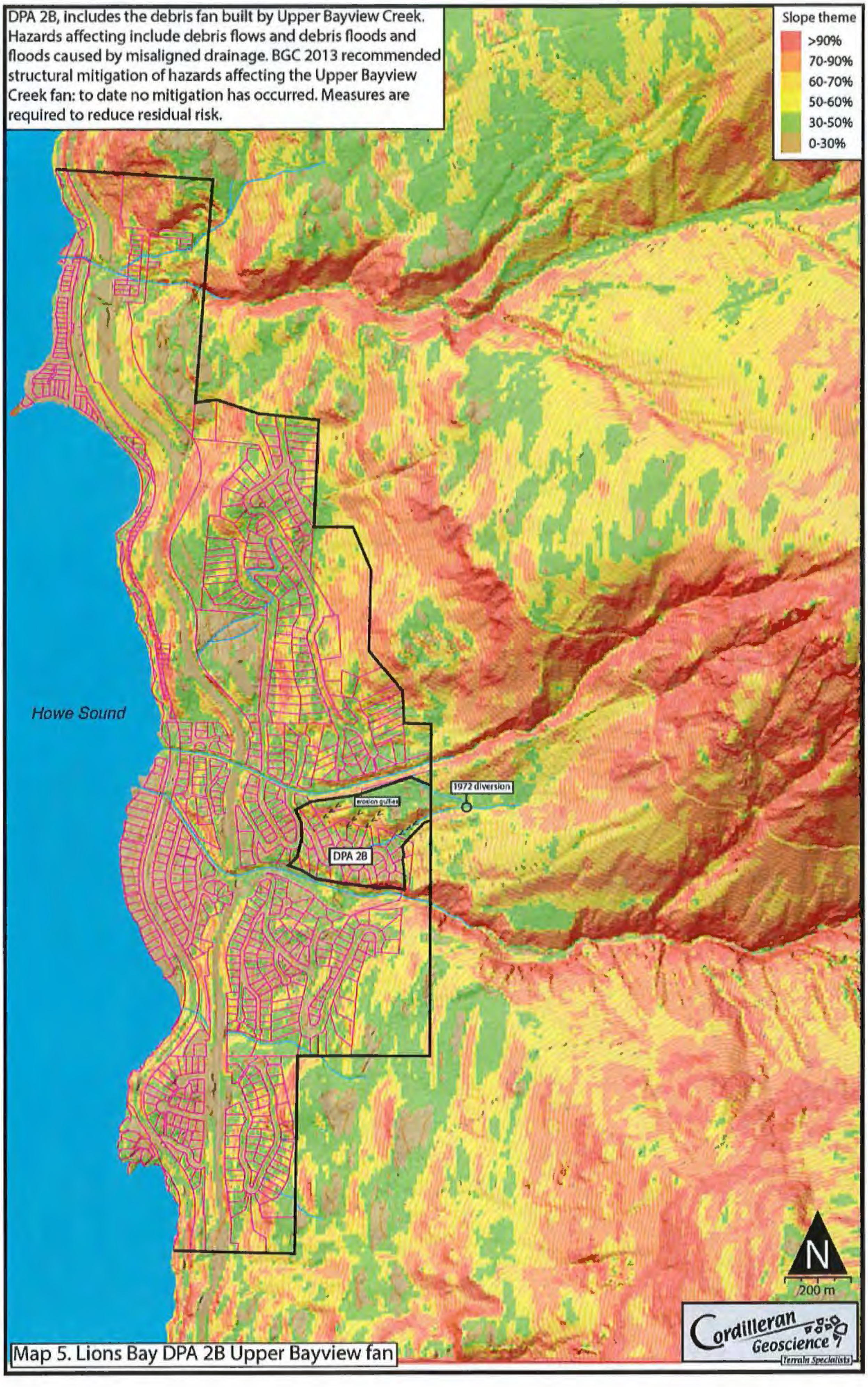
3. For sites located within multiple hazard DPAs, a coordinated approach will be required to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met. Risk associated with geohazards should usually take precedence over wildfire risk where potentially conflicting mitigation measures are recommended (e.g. vegetation retention for slope stability would take precedence over vegetation removal for wildfire protection).

4. In addition to the exemptions listed in section 10.1.4, all development is exempt from the requirement to obtain a Wildfire Hazard Development Permit other than the construction and installation of a new building or structure for which a building permit is required. For the purposes of this DPA, a new building or structure shall be include an alteration to a residentially zoned building where the value of the alteration as specified in the applicable building permit is more than 75% of the replacement value of the building, as determined by multiplying the gross floor area of the building by $300.

5. A report from a qualified registered professional should include an acknowledgement of receipt of the report by the qualified registered professional dealing with the reporting requirements of all other Development Permit Areas.

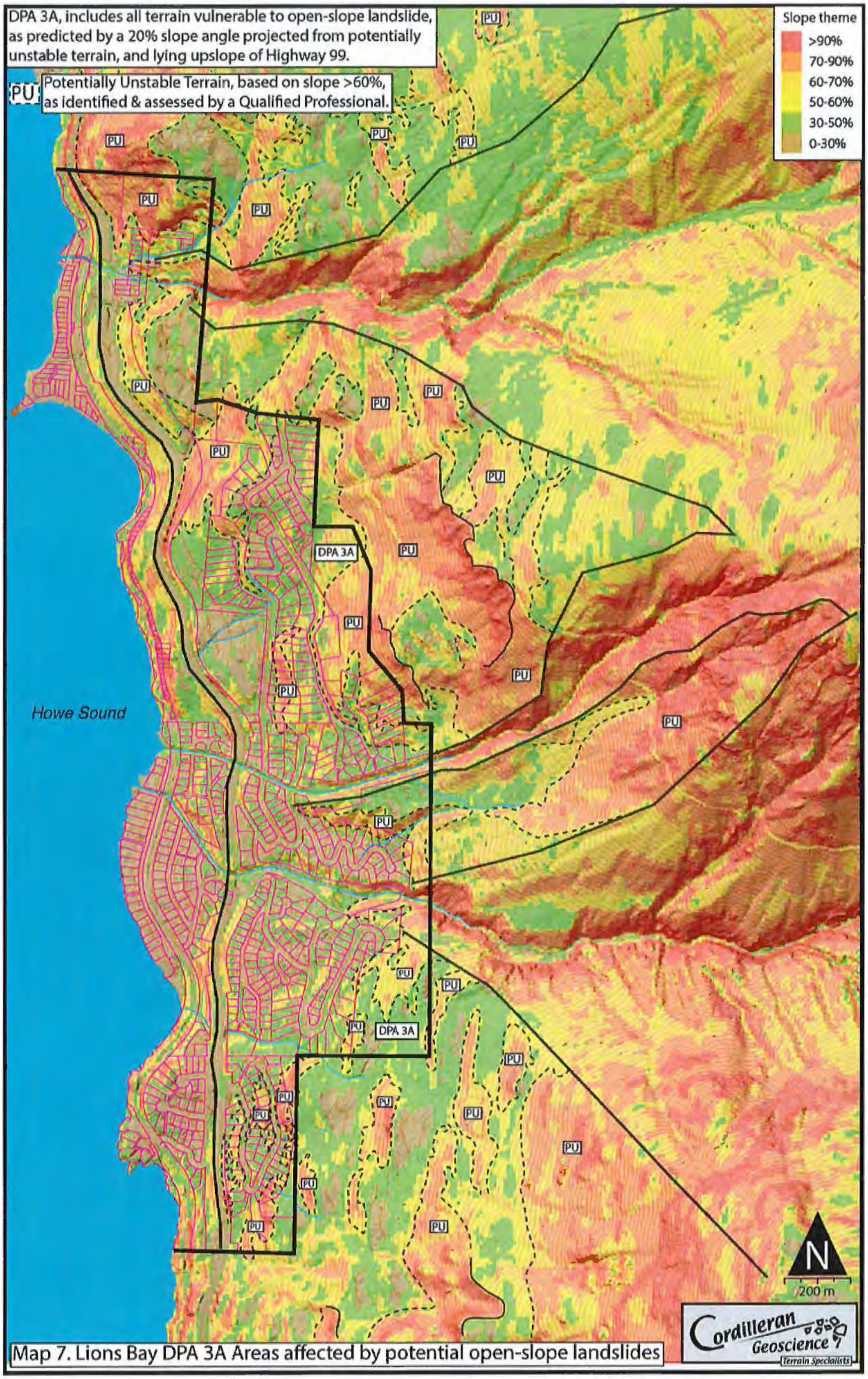


Map 3. Lions Bay DPA 1 Coastal hazards



DPA 2B, includes the debris fan built by Upper Bayview Creek. Hazards affecting include debris flows and debris floods and floods caused by misaligned drainage. BGC 2013 recommended structural mitigation of hazards affecting the Upper Bayview Creek fan: to date no mitigation has occurred. Measures are required to reduce residual risk.

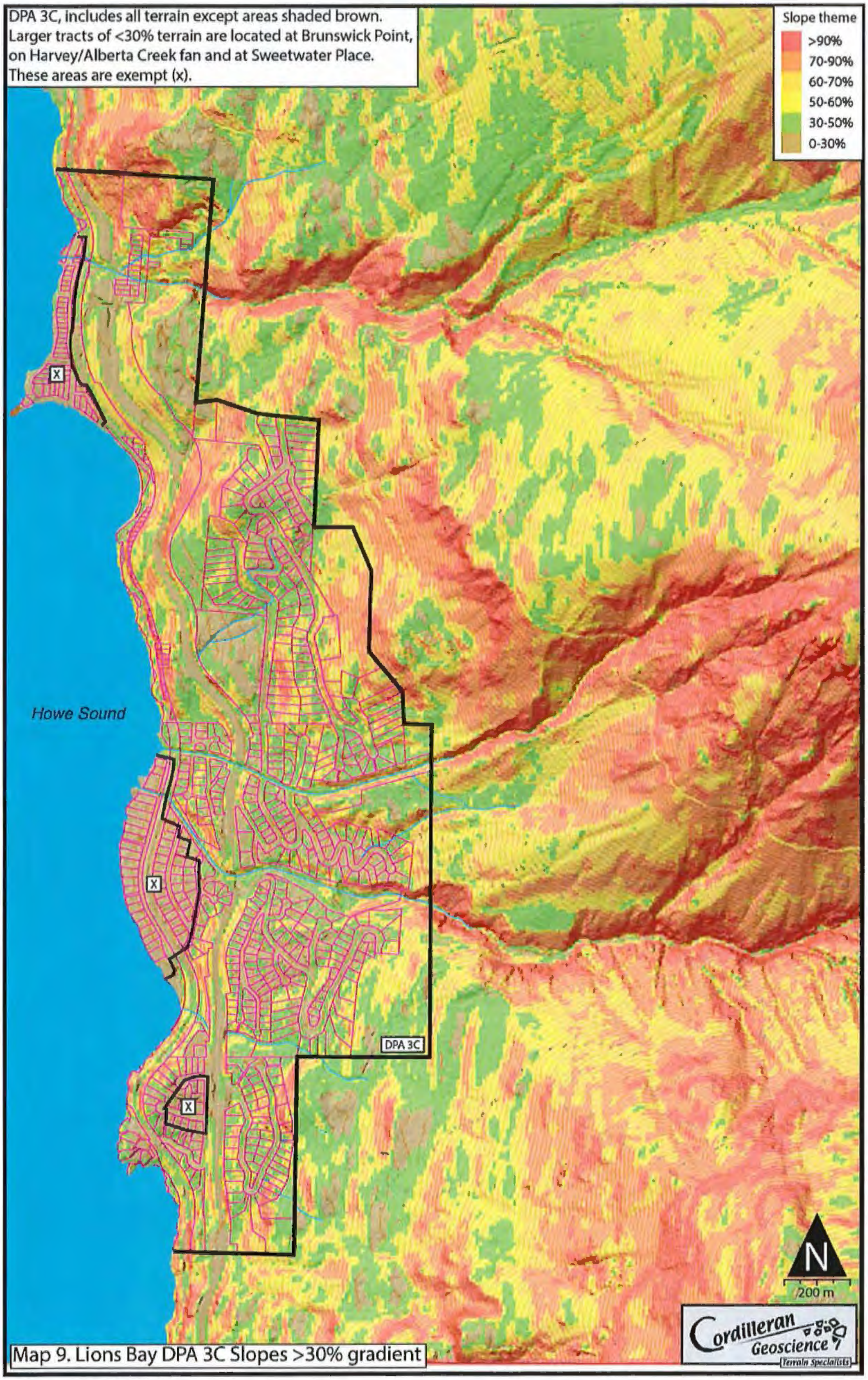
Map 5. Lions Bay DPA 2B Upper Bayview fan



DPA 3A, includes all terrain vulnerable to open-slope landslide, as predicted by a 20% slope angle projected from potentially unstable terrain, and lying upslope of Highway 99.

PU Potentially Unstable Terrain, based on slope >60%, as identified & assessed by a Qualified Professional.

Map 7. Lions Bay DPA 3A Areas affected by potential open-slope landslides



Map 9. Lions Bay DPA 3C Slopes >30% gradient

THE MUNICIPALITY OF THE VILLAGE OF LIONS BAY

| | | | | |
|---|---|---|---|---|
| Type | **Request for Decision** | | | |
| Title | **Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 – Consideration of First and Second Reading and Scheduling of the Public Hearing** | | | |
| Author | **Peter DeJong, CAO** | Reviewed By: | | **Steven Olmstead, Planning Consultant** |
| Date | **June 10, 2018** | | Version | **1** |
| Issued for | **June 19, 2018 Council Meeting** | | | |

**Recommendations:**

1. THAT the Request for Decision report titled "Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 - Consideration of First and Second Reading and Scheduling of the Public Hearing" dated June 10, 2018 be received;

2. THAT the Table of Natural Hazard Assessment Area Guidelines appended as Attachment A to the June 10, 2018 report be endorsed as a communication tool;

3. THAT Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018, appended as Attachment C to the June 10, 2018 report be read a first and second time;

4. THAT Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 be held to be consistent with the Village of Lions Bay 2018-2022 Five Year Financial Plan and the 2010 GVRD Integrated Solid Waste and Resource Management Plan;

5. THAT a public hearing regarding Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 be held at 7:00 p.m. on Tuesday, July 10, 2018 at Broughton Hall, 400 Centre Road, Lions Bay.

**Attachments:**

A. Table of Natural Hazard Assessment Area (NHAA) Guidelines;

B. Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 in revised draft form, including a clean copy of Schedule A.

**Key Information:**

On April 10, 2018, Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018, came to Council for first reading and referral to a Public Information Meeting. As the bylaw was then conceived, it was based on the introduction of Development Permit Areas under section 488 of the *Local Government Act (LGA)*. For a variety of reasons, the bylaw did not receive any readings and staff were directed to pursue a means of meeting the common law and statutory obligations of the Municipality for development in the face of hazardous conditions through means other than Development Permit Areas.

With corporate knowledge of hazards, the Municipality has a duty to warn and, arguably, a duty of care in relation to new exposures to such risks. The Municipality requires a policy to address these issues. Under the *LGA*, section 473 (1):

> an Official Community Plan (OCP) must include statements and map designations for the area covered by the plan respecting:
>
> (d) restrictions on the use of land that is subject to hazardous conditions.

One way to address these requirements is through the implementation of a Development Permit scheme under sections 488-491 of the *LGA*. As noted above, Council decided not to utilize this legislative regime and requested staff to look for ways to meet these requirements through the legislative powers of the Building Inspector and the Approving Officer.

Under section 56 of the *Community Charter* and section 86 of the *Land Title Act*, a Building Inspector or Approving Officer may require an applicant for a building permit or a subdivision to provide a report by a professional engineer or geoscientist experienced in geotechnical study and geohazards, where it is considered that construction or subdivision would be in respect of lands that are or may be subject to a variety of geotechnical hazards.

As well, under section 460 of the *Local Government Act,* a local government that has adopted an official community plan or a zoning bylaw must, by bylaw, define procedures under which an owner of land may apply for: (a) an amendment to the plan or bylaw. Development Applications Procedure Bylaw No. 431 meets this requirement and provides the CAO authority to require geohazard, wildfire and flood risk assessments in conjunction with zoning (and OCP) amendment applications as part of the Preliminary Review Process.

Additionally, Soil Deposit, Soil Removal and Land Alteration Bylaw No. 510, 2018 provides the Public Works Manager with authority to impose conditions and require reports, specifications and plans from an applicant under that bylaw to ensure that the requirements of land alterations permitted therein are in compliance with that bylaw.

The attached draft of Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018 incorporates policy and procedures to enable the Municipality to address its common law and statutory obligations while providing guidance to its employees regarding applications for "New Development", to the qualified professionals who are tasked with reporting on whether the lands in such applications are safe for the uses intended, and to its residents who may wish to develop their lands.

The risk tolerance policy incorporated in the draft bylaw treats small scale development (i.e. building permits for RS-1 lands and subdivisions of 4 or fewer lots) similar in terms of risk tolerance thresholds to how other jurisdictions view existing development, the idea being that small scale development is more in the nature of infill housing or replacement of existing housing stock than the introduction of any significant new housing projects which may bring with them substantially increased exposures to known hazards. The policy explicitly stipulates that the Municipality chooses *not* to set a risk tolerance threshold in respect of existing development in Lions Bay. The risk tolerance policy set out is in respect to New Development only.

New Development, as defined in the bylaw, within any of the hazard areas identified in the Cordilleran Report, triggers the requirement for a natural hazard assessment in accordance with the guidelines and requirements set out in the bylaw. These Natural Hazard Assessment Areas (NHAAs) take the place of the previous Development Permit Areas and all mapping as required by section 473 of the *LGA* is adopted for the purposes of the NHAAs.

This framework will provide the CAO, the Building Inspector, the Approving Officer and Qualified Professionals with a policy and set of procedures that will enable them to address applications for New Development in a clear and consistent manner. If lands are determined by a QP to be safe for the use intended without any conditions, then no section 219 covenant will need to be registered in the Land Title Office; if conditions are attached to the QP's report, then such a covenant will be required in accordance with Provincial enactments.

It should be noted that New Development includes a temporary use permit (TUP) for short-term rentals. This was inserted after receipt of legal advice. A briefing on that legal advice can be found in the Closed Agenda for Council's consideration.

It should be further noted that Pierre Friele, the geoscientist who wrote the Cordilleran Report, does not agree with or support the proposed quadrupling of residential density in the Village of Lions Bay in the guise of existing development under the proposed risk tolerance policy, which varies from the District of North Vancouver policy in respect of "small-scale development" (i.e. anything less than a 5 lot subdivision or rezoning). His considered opinion is that this type of decision should not be undertaken without a Qualified Professional first conducting a thorough societal risk assessment to understand: 1) what the existing group risk is affecting the Village of Lions Bay; and 2) what the future group risk will be once the policy is adopted. Without such an analysis being conducted, his view is that policy is being created and advocated without sufficient knowledge, by people (Council) who lack technical expertise, and who are effectively making decisions for others regarding tolerable risk levels without the necessary societal risk factors being taken into account.

Council may wish to review staff's Village Update piece of March 9, 2018 and consider whether the Municipality should, in fact, request a *Societal Risk Assessment*. Staff notes that the Province has not yet responded to queries about further investigation by the Province of the unquantified geohazard risks in and above the Village of Lions Bay.

**Options:**

1. Approve the recommendations as set out at the beginning of this report.
2. As above, with potential changes to the draft bylaw;
3. Refer the bylaw back to staff with alternative directions;
4. Direct staff to seek quotes for a Societal Risk Assessment, whether the recommendations above are approved or not;
5. Otherwise as Council may direct.

**Preferred Option:** The first option to accept the recommendations as per the beginning of the report, with consideration for option 4 as well.

**Organizational and Intergovernmental Implications:**

The *Local Government Act* requires that amendments to Official Community Plans be considered by the Council with respect to implications for financial and waste management plans. This is required after First Reading and before the public hearing.

The Chief Financial Officer reviewed the amendments and determined that they would not result in any material impacts to the Five Year Financial Plan (2018-2022).

Regarding waste management, this amendment has no implications with respect to the 2010 GVRD (Metro) Integrated Solid Waste and Resource Management Plan.

**Follow Up Action:** Staff will place the advertising in a newspaper in accordance with the requirements of the *Local Government Act* and the *Community Charter* and prepare for the public hearing. Communications will also go out via the Village Update and be advertised on the Municipality's website.

## Table of Natural Hazard Assessment Area (NHAA) Guidelines

| NHAAs | | Applies to | Reason | Minimum requirements for Permits and Approvals* |
|---|---|---|---|---|
| 1: Ocean natural hazard areas | | Areas lower than 8 m Above Sea Level (ASL) potentially subject to coastal erosion and other consequences of climate change and rising sea level | Area potentially subject to coastal erosion and other impacts of climate change and sea level rise | Habitable space located above the site specific FCL as determined by QP. |
| 2: Creek natural hazard areas | A: Mitigated debris fan areas | Areas of the respective fans downstream of flood works/barriers | May be subject to residual flood hazard | Building designed to withstand debris flood impacts with the top of concrete steel reinforced foundations established 1 m or more above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. |
| | B: Upper Bayview Fan area | Lots on Upper Bayview Road subject to potential debris flood/debris flow hazard | Potential hazard identified in BGC report from 2012 | Debris flow/debris flood assessment. Building designed to withstand debris flood impacts with the top of concrete steel reinforced foundations established 1 m or more above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. |
| | C: Ravine areas | Land within 30 m of a ravine crest | Ravine slope instability and erosion hazards | Siting and conditions determined on a site specific basis by QP recommendations. Management of on-site storm water drainage management and on-site sewage disposal are key considerations. |
| 3: Slope natural hazard areas | A: Open-slope slide areas | From Highway 99 upslope to the Municipal boundary | High to Very High potential consequence from Landslide risk | Landslide Risk Assessment for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes. Foundation design, lift of habitable space, barrier walls and other measures determined by QP. |
| | B: Rockfall areas | 27.5 degree rockfall shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other smaller scattered bluffs | High to Very High potential consequence from rockfall risk | Landslide Risk Assessment by QP for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes. |
| | C: Slopes >30% | Slopes >30% - See hillshade map | Worksafe BC requirement and general threshold used in BC. | For areas below Highway 99 – compliance with Worksafe Regs and any site specific QP requirements. For areas above Highway 99 – compliance with Worksafe Regs and requirements under DPA 3C. |
| 4: Wildfire natural hazard areas | | Entire Municipality | Wildfire hazards | Consideration of fire resistive roofing, siding and decking and vegetation management within 10m of buildings and structures. |

***Use and Indemnity Covenants required for NHAAs 1, 2 & 3. *See Bylaw for additional NHAA requirements and exemptions.**

# Bylaw No. 525, 2018

## A bylaw to amend Official Community Plan Bylaw No. 408, 2008

**WHEREAS** the Council of the Village of Lions Bay has adopted Official Community Plan Bylaw No. 408, 2008, as amended;

**AND WHEREAS** Section 473 (1) of the *Local Government Act* states that an official community plan must include statements and map designations for the area covered by the plan respecting:
(d) restrictions on the use of land that is subject to hazardous conditions or that is environmentally sensitive to development;

**AND WHEREAS** a Public Hearing has been held in accordance with Division 3 of Part 14 of the *Local Government Act*;

**NOW THEREFORE** the Council of the Village of Lions Bay, in open meeting assembled, enacts as follows:

1. This Bylaw may be cited as "Village of Lions Bay Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018."

2. "Village of Lions Bay Official Community Plan Bylaw No. 408, 2008" is amended by:

    (a) Adding "(Map 1)" after the title: "8.0 Land Use Map";

    (b) Inserting Section 10 – Natural Hazard Assessment Areas after Section 9 of Official Community Plan Bylaw No. 408, 2008, as amended, the content of which is contained within Schedule "A" of this Bylaw and which includes Maps 2-9.

**PURSUANT TO SECTION 475 OF THE LOCAL GOVERNMENT ACT CONSULTATION REQUIREMENTS CONSIDERED** **July 4, 2017**

**READ A FIRST AND SECOND TIME AND CONSIDERED IN CONJUNCTION WITH THE VILLAGE OF LIONS BAY FINANCIAL PLAN AND ANY APPLICABLE WASTE MANAGEMENT PLANS PURSUANT TO THE LOCAL GOVERNMENT ACT** **June 19, 2018**

**PUBLIC HEARING HELD ON** [illegible]

**READ A THIRD TIME** [[illegible], 2018]

**ADOPTED** [July [illegible], 2018]

**Mayor**

**Corporate Officer**

**Certified a true copy of**
**Bylaw No. 525, 2018 as adopted.**

**Corporate Officer**

## Schedule A

Village of Lions Bay Official Community Plan Designation Bylaw
No. 408, 2008, Amendment Bylaw No. 525, 2018

## 10.0 Natural Hazard Assessment Areas

### 10.0.1 Definitions

"Accessory" means accessory as defined in the *Zoning Bylaw;*

"Buffer" or "Buffer Area" means an area that remains undeveloped in order to protect slope stability or to provide a setback from a natural hazard or riparian area;

"Council" means the Council of the *Municipality*;

"Debris Flood" means a flood of water that carries an unusually large amount of sediment and/or wood debris, and that is often triggered by severe channel and bank erosion or a Landslide dam outbreak;

"Debris Flow" means a fast moving, liquefied and channelized Landslide of mixed and unconsolidated debris that may occur during unusually wet weather on a steep mountain creek with abundant debris sources;

"Defensible Space" means the area around a structure where Fuel and vegetation should be managed to reduce the risk of structure fires spreading to the forest or vice versa and to provide safe working space for fire fighters;

"Detailed Assessment" means a detailed, site-specific study and field review to delineate hazard areas and provide quantitative estimates of hazard or risk, the minimum requirements of which Detailed Assessment are set out in this policy described as Schedule A, attached to and forming part of the Municipality's Official Community Plan Bylaw No. 408, 2008, as amended;

"EGBC" means the Engineers and Geoscientists of British Columbia or any replacement or successor professional association;

"Elements at Risk" means anything of social, environmental or economic value, including human lives and well-being that may be affected by a natural hazard;

"Exemption" means an exemption from the requirement for an approval or permit in connection with a given development;

"Fire Resistive Materials" means materials resistant to fire, such as stucco, metal, brick, rock, stone, lumber treated for fire resistance and cementitious products (including hardiplank), but excludes, without limitation, untreated wood, aluminum and vinyl products;

"Fire Retardant Roofing" means Class A and Class B roofing as specified in the Homeowners FireSmart Manual, BC Edition, 2004, Province of B.C., as the same may be amended or replaced from time to time, or such other roofing as may be specified by the Municipality from time to time;

"Freeboard" means a vertical distance typically added to the designated flood level to account for variation in local hydraulic conditions (such as river bend or large boulders in a stream), to allow for wave affects arising from winds, and to address uncertainties inherent in engineering assumptions and calculations, and to introduce a factor of safety to such calculations;

"Fuel" means a combustible material;

"Gross Floor Area" means gross floor area as defined in the Zoning Bylaw;

"Habitable Space" means any room or space within a building or structure, which room or space is or can be used for human occupancy, commercial sales, or storage of goods, personal property or mechanical or electrical equipment (including furnaces);

"Landslide" means a movement of rock, debris or earth down a slope, and can be the result of wet weather, erosion, earthquake or other natural sequences of events and/or human activities; Landslides may be rapid or slow moving, and include landslip, rock falls, rock slumps, rockslides, rock avalanches, avalanches, rock creep, debris falls, debris slides, debris flows, debris floods, debris torrents, mud flows, earth falls, earth slumps, earth slides, earth flows, earth creep, flow slides and subsidence;

"Municipality" means, depending on the context, the municipal corporation of the Village of Lions Bay or all of the land falling within the jurisdictional boundaries of the Village of Lions Bay;

"New Building or Structure" means a building or structure, excluding an Accessory building or structure, that generally contains Habitable Space and that is newly constructed or being constructed, or intended to be constructed, or that is or is being or is intended to be substantially reconstructed, and shall include:

(a) a retaining wall as set out the Zoning Bylaw;
(b) a pool as set out in Building Bylaw No. 234, 1994, as amended; or
(c) an alteration to a residentially zoned building where
    (i) the footprint of the building is to be increased by 25% or more, or
    (ii) the value of the alteration as specified in the applicable building permit is more than 50% of the replacement value of the building, as determined by multiplying the Gross Floor Area of the building by $300;

"New Development" means.

(a) construction of a New Building or Structure requiring a building permit;
(b) construction of a retaining wall over 1.2 meters in height, or a series of terraced retaining walls with a combined height of greater than 1.2 metres;

(c) development requiring a permit under Soil Deposit, Soil Removal and Land Alteration Bylaw No. 510, 2018 (the "Land Alteration Bylaw");
(d) subdivision;
(e) rezoning; or
(f) a temporary use permit for the purpose of short-term rentals;

"Preliminary Assessment" means a preliminary or overview assessment by a Qualified Professional to determine the extent, location or presence of a hazard, the probability of a hazardous event affecting an element at risk, and whether a Detailed Assessment is required;

"Qualified Professional" or "QP" means a professional with appropriate education, training and experience, fully insured and in good standing with the relevant professional association, and means:

(a) for the purposes of the NHAAs 2A, 2B, 2C, 3A, 3B, and 3C, a specialist Professional Engineer or Professional Geoscientist, as appropriate, with experience or training in geotechnical and geohazard assessments, Landslides, river hydraulics and hydrology and, where appropriate, specialist engineering expertise in connection with selection and design of appropriate mitigation works; and

(b) for the purpose of NHAA 4, a Registered Forest Professional qualified by training or with at least two years' experience in the assessment, fuel management prescription development and mitigation of wildfire hazards in British Columbia;

"Ravine" means a narrow, steep-sided valley that is commonly eroded by running water and has a ravine sidewall slope gradient greater than 3:1;

"Top of Bank" means:

(a) for a floodplain area contained in a Ravine, the point closest to the boundary of the active floodplain of a stream where a break in the slope of the land occurs such that the grade beyond the break is flatter than 3:1 at any point for a minimum distance of 15 metres measured horizontally from the break; and

(b) for a floodplain area not contained in a Ravine, the edge of the active floodplain of a stream where the slope of the land beyond the edge is flatter than 3:1 at any point for a minimum distance of 15 metres measured horizontally from the edge;

"Top of Ravine Bank" means 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 metres measured horizontally from the break, and the break does not include a bench within the Ravine that could be developed;

"Watercourse" means any natural or man-made depression with well-defined banks and a bed 0.6 metre or more below the surrounding land that serves to give direction to a current of water at least six months of the year, or having a drainage area of two square kilometres or more upstream of the point of consideration;

"Wildfire Mitigation" means any action taken to eliminate or reduce the long-term risk of wildfire; and

"Zoning Bylaw" means the Zoning and Development Bylaw No. 520, 2017, as amended, consolidated or re-enacted from time to time.

## 10.1 General

### 10.1.1 Introduction – Purpose and Policy

The technical study by Cordilleran Geoscience titled "The Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards", dated January 18, 2018 (the "Cordilleran Report", available from the Village of Lions Bay by request or from the Village of Lions Bay online Reports and Documents Library at lionsbay.ca), identifies land potentially subject to geological natural hazards. The study notes that in Lions Bay, given the steep terrain and the coastal maritime setting there are a number of natural hazards that may affect the community, including coastal hazards, creek hazards and hillslope hazards. Where the Cordilleran Report references Development Permit Areas (DPAs), this bylaw uses the term Natural Hazard Assessment Areas (NHAAs), but these terms should be considered as synonymous in relation to the physical areas mapped as DPAs in the Cordilleran Report and its technical recommendations.

As described in the Cordilleran Report, a hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (Table 1).

**Cordilleran Report, Table 1: Qualitative hazard frequency categories**

| Qualitative frequency | Annual return frequency | Probability | Comments |
|---|---|---|---|
| Very high | >1:20 | >90% in 50 years | Hazard is well within the lifetime of a person or typical structure. Clear fresh signs of hazard are present. |
| High | 1:100 to 1:20 | 40% to 90% in 50 years | Hazard could happen within the lifetime of a person or structure. Events are identifiable from deposits and vegetation, but may not appear fresh. |
| Moderate | 1:500 to 1:100 | 10% to 40% in 50 years | Hazard within a given lifetime is possible, but not likely. Signs of previous events may not be easily noted. |
| Low | 1:2500 to 1:500 | 2% to 10% in 50 years | The hazard is of uncertain significance. |
| Very low | <1:2500 | <2% in 50 years | The occurrence of the hazard is remote. |

Consequence (Table 2) is a product of factors, including whether a given hazard will reach a site, whether Elements at Risk (e.g., houses/people) will be present when the site is affected by the hazard, how vulnerable the Elements at Risk are to the hazard affecting the site, and the value of the Elements at Risk or the number of persons exposed.

**Cordilleran Report, Table 2: Simplified consequence assessment**

| Consequence | Description |
|---|---|
| Very High | Direct impact with extensive structural damage; loss of life & limb. |
| High | Direct or indirect impact with some potential for structural damage; loss of life & limb. |
| Moderate | Indirect debris impact. No structural damage but damage to houses and property. |
| Low | Minor property damage only. |
| Very Low | Virtually no damage. |

The product of the factors Hazard Frequency and Hazard Consequence equals Hazard Risk.

No activity is free of risk, and the concept of safety embodies risk tolerance. In Canada and BC there is no legislated guidance for risk tolerance to geohazards, and the term "safe" has not been defined. In considering risk tolerance, an important concept, and one accepted by the Village of Lions Bay (the "Municipality") is that risk of loss of life from natural hazards should not add substantially to the combined risk of loss of life to which one is typically exposed (e.g., driving, health, recreation, etc). For reference, the risk of injury and death from driving in Canada is approximately 1:1000 and 1:10,000 per annum, respectively (Transport Canada 2011).

The Municipality wishes to set acceptable levels of risk tolerance with respect to New Development within the Village in the circumstances identified in the Report. Quoting from the Landslide Risk Policy of the District of North Vancouver, "tolerable and acceptable risks are somewhat different: tolerable risks can be tolerated in order to realize some benefit, but they are not negligible, and should be kept under review and reduced further if possible. In contrast, acceptable risks are considered broadly acceptable to the public and efforts to further reduce risks are not warranted."

As an example, the levels of risk tolerable and acceptable to the District of North Vancouver are in accordance with the risk thresholds set out in Table 11 below.

**Cordilleran Report, Table 11: Landslide risk policy, District of North Vancouver**

| Type of Application | 1:10,000 + ALARP | 1:100,000 | FOS >1.3 (static) | FOS >1.5 (static) |
|---|---|---|---|---|
| Building Permit (<25% increase to Gross Floor Area) | X | | X | |
| Building Permit (>25% increase to gross Floor Area and/or retaining walls >1.2m) | | X | | X |
| Re-zoning | | X | | X |
| Sub-division | | X | | X |
| New Development | | X | | X |

The ostensible rationale for differing thresholds (1:10,000 vs 1:100,000) is that for any form of New Development (substantial addition (>25%), new building, rezoning, sub-division, new development) the extra involuntary risk posed by a hazard should be much less than for existing development (existing building, or addition <25%) on the premise that risk avoidance through development elsewhere in the municipality is an option. Nevertheless, 1:100,000 could be considered a very high threshold for Lions Bay. The Municipality is substantially built out and there are very few options within the Village for risk avoidance through location choice. This means that hazards may need to be mitigated through other means, such as reinforced or raised foundations, siting considerations within a parcel, design considerations for Habitable Space within a structure, rockfall fencing, and other methods of reducing risk.

In the circumstances, the Municipality considers that the level of risk tolerance for New Development ought to consider the scale of such development in comparison to generally accepted levels of risk tolerance for existing development, as indicated in the first line of Table 11. If New Development is within a smaller scope as described in the first two types of application in Table A below, then it is reasonable to set a safety standard which is generally appropriate for existing development (i.e., 1:10,000 plus ALARP). Typically, as noted in the Cave (1993) Report from the Fraser Valley Regional District, such smaller scale development is in the nature of infill or extension of existing development which may already be subject to the same hazard. Accordingly, balancing concerns for safety with economic, social and political considerations, the levels of risk tolerable and acceptable to the Village of Lions Bay in respect of New Development is in accordance with the risk thresholds set out in Table A below and as expanded upon in the text following Table A.

**Table A: Risk Tolerance Thresholds for New Development, Village of Lions Bay**

Risk tolerance thresholds in accordance with development type:

| Type of Application | 1:10,000 + ALARP | 1:100,000 | *FOS >1.3 (static) | *FOS >1.5 (static) |
|---|---|---|---|---|
| New Development not requiring subdivision or rezoning | X | | X | |
| Subdivision and/or rezoning to create 4 or fewer fee simple or strata parcels (including the original parcel) | X | | X | |
| Subdivision and/or rezoning to create 5 or more fee simple or strata parcels (including the original parcel) | | X | | X |

* Ratios denote annual probability of individual loss of life per the calculation set out in section 10.4.2 of this bylaw

* FOS means Factor of Safety, generally in relation to engineered slopes and Ravine sidewall stability

+ ALARP means As Low As Reasonably Practicable

For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. In Lions Bay, this principle of mitigation is to be applied across all Natural Hazard Assessment Areas (NHAAs), particularly where the level of hazard uncertainty is significant. Qualified

Professionals will be responsible for indicating that all methods to reduce risk to As Low As Reasonably Practicable have been considered or implemented.

The Municipality specifically and explicitly chooses *not* to set a risk tolerance threshold in respect of existing development in Lions Bay. The risk tolerance policy set out herein is in respect to New Development only, as defined above, howsoever triggered or required. The Municipality's risk tolerance thresholds for both the annual probability of individual loss of life and the Factor of Safety should be considered by the Qualified Professional and the Municipality for any New Development in NHAAs 2A, 2B, 2C, 3A, 3B, and 3C. Risk tolerance for New Development in NHAAs 1 and 4 is in accordance with the guidelines and requirements in each of those Natural Hazard Assessment Areas.

The goal of the NHAA boundary delineation is to categorise natural hazards by landform type and/or process domain and create a natural hazard planning framework to provide a consistent basis for managing natural hazard risks. The Cordilleran Report identifies potential hazards and assesses the potential reach of these hazards. The likelihood or magnitude of possible hazards is not explicitly estimated, as that is the role and responsibility of site specific studies to be undertaken by property owners wishing to develop their land, or to be undertaken by senior government as further work recommended in the Cordilleran Report.

Additionally, a Community Wildfire Protection Plan was prepared for the Village of Lions Bay in 2007 by B.A. Blackwell and Associates (the "Blackwell Report") and it forms the basis for the Wildfire Natural Hazard Assessment Area, along with other Wildfire Mitigation best practices.

The following sections outline the NHAA framework for natural hazard areas in the Village of Lions Bay, based on the hazards identified and assessed in the Cordilleran and Blackwell reports. A generalized, process-based approach to NHAA delineation is used, with four main categories:

NHAA 1, Coastal Zone Hazards (flooding and erosion);
NHAA 2, Creek Hazards (alluvial fans; Ravines, small creeks);
NHAA 3, Slope Hazards (Open-slope failures, rockfall, and seismic slope stability); and
NHAA 4, Wildfire Hazard

Coastal zone hazards (NHAA 1) include flooding and erosion from a combination of processes including tides, storm surge, wave action and sea level rise. Creek hazards include residual Debris Flow hazards on creeks that have flood control works (NHAA 2A - Alberta, Harvey and Magnesia Creeks) and flooding, Debris Flow and channel avulsion on Upper Bayview Creek (NHAA 2B), and channel and slope hazards associated with creek Ravines (NHAA 2C). Three categories of slope hazard have been identified – open slope failures (NHAA 3A), rockfall hazards (NHAA 3B) and terrain with slopes >30% (NHAA 3C). All land within the Village of Lions Bay is included in the wildfire hazard area (NHAA 4), but particular attention should be given to areas within the residential-wildland interface.

In determining the NHAA boundaries for the hazard categories, it is recognized that there is uncertainty in the extent of influence of possible hazards. Therefore, NHAA boundaries were drawn conservatively so as not to exclude terrain that could be affected by the range of magnitudes considered within future studies. While boundaries are drawn from high-resolution LIDAR-derived mapping products, for proposed development purposes, surveys and professional assessment(s) may be needed to confirm lot layout, natural features, and setback recommendations on a site-specific basis (e.g., top of Ravine vs. setbacks).

### 10.1.2 Designation of Natural Hazard Assessment Areas

Under the authority of section 473 (1) (d) of the *Local Government Act*, the areas outlined on Maps 3-9 are designated as Natural Hazard Assessment Areas as follows:

NHAA 1, Map 3: Coastal Zone Hazards (flooding and erosion);
NHAA 2, Maps 4, 5, and 6: Creek Hazards (alluvial fans; Ravines, small creeks);
NHAA 3, Maps 7, 8, and 9: Slope Hazards (Open-slope failures, rockfall, and seismic slope stability); and
NHAA 4, Wildfire Hazard (all land within the boundaries of the Village of Lions Bay).

### 10.1.3 Activities that Require a Natural Hazard Assessment

1. In a Natural Hazard Assessment Area, there shall be no New Development permitted unless an Exemption applies under section 10.1.4 or the owner first obtains a Natural Hazard Assessment and a permit or approval from the Municipality.

2. The Municipality may impose in an approval or permit, any condition permitted by law in order to ensure compliance with the guidelines set out in this document.

3. Where a parcel is designated as being within more than one type of NHAA, a single natural hazard assessment report may suffice, provided that the guidelines for all applicable NHAAs are addressed in the assessment report.

### 10.1.4 Exemptions

The following activities are exempt from the requirement to obtain natural hazard assessment:

1. public works, services and maintenance activities carried out by, or on behalf of, the Village of Lions Bay, and approved by the CAO;

2. non-structural repairs or renovations, including roof and other exterior repairs or replacements which do not require a building permit;

3. construction of an Accessory building of less than 10 square metres as permitted by the Zoning Bylaw;

4. alteration of land which constitutes routine maintenance of existing landscaping and lawn areas, or construction of Minor Works; Minor Works means the removal or deposit of soil or alteration of land where:
   (i) at any point the depth of the soil removed or deposited does not exceed 1.2 meters;
   (ii) the unrestrained slope of the filled or excavated surface does not exceed three (3) horizontal to one (1) vertical (30%);
   (iii) retaining walls associated with the work do not exceed a height of 1.2 meters measured from the natural ground elevation; and
   (iv) for deposit of soil, the slope of the existing ground does not exceed thirty percent (30%) at any point or, where the existing ground is filled, the underlying natural ground surface does not exceed thirty percent (30%) at any point;

5. habitat creation, streamside restoration or similar habitat enhancement works in accordance with Village of Lions Bay bylaws and a plan approved by the CAO;

6. planting of vegetation, provided that within 10 metres of the Top of Bank or Top of Ravine Bank, or within 10 metres of any part of a building containing a dwelling, the vegetation should not exceed 9 metres in height at maturity;

7. setbacks may be reduced where coastal zone or riparian area regulation setbacks would preclude development on a lot provided that reports by QPs be supplied to support any Exemption and/or variance; or

8. emergency procedures to prevent, control or reduce erosion, or other immediate threats to life and property provided they are, to the extent possible in the circumstances, undertaken in accordance with the provincial *Water Act* and *Wildlife Act* and the Federal *Fisheries Act*, and are reported immediately to the Municipality.

### 10.1.5 Expectations for professional scope and reporting

1. All professional reports pertaining to NHAAs should be consistent with applicable qualified professional practice guidelines and their various report requirements, and provincial regulations (as updated from time to time), including but not exclusive to the list below:
    i. Flood Hazard Area Land Use Management Guidelines (WLAP 2004; amended January 1, 2018);
    ii. Guidelines for Legislated Landslide Assessments for Residential Developments in BC (2008, 2010);
    iii. Guidelines for Legislated Flood Assessments in a Changing Climate in BC (2012, 2017);
    iv. Riparian Areas Regulation;
    v. BC Building Code; and
    vi. Worksafe BC.

2. Where applicable, a report by a Qualified Professional should include the following:
    i. Report name and date;
    ii. Client information;
    iii. QP's information (training, experience, insurance);
    iv. Property information (legal and civic);
    v. Description of development proposal;

vi. Review of relevant Village of Lions Bay bylaws and other statutory requirements;

vii. Review of background information (site-specific and overview archived & provided by the Village of Lions Bay and others);

viii. Description of geologic and geomorphic setting;

ix. Description of field work conducted on and, if required, beyond the proposed development;

x. Identification of natural hazards or other hazards identified in background reports and field work. Includes also a description of all potential hazards and rationale for excluding some;

xi. Provides site plan and other mapping required to show hazards affecting, minimum scale ~1:5000-1:10,000;

xii. Provides maps, illustrations and diagrams to illustrate risk scenarios referred to in the Report;

xiii. For all hazards, separate and in aggregate, analyses of the georisk affecting the proposed development and evaluation against the Village of Lions Bay safety policy;

xiv. Discusses the effect of changed conditions to slope stability caused by the project, by future potential natural factors or land-use (fire, forestry) or climate change;

xv. Discusses uncertainties and describes any residual risk that would remain;

xvi. Provides technically justified siting constraints or protective measures, as required;

xvii. States whether all methods to reduce risk to As Low As Reasonably Practicable (ALARP) have been considered or implemented;

xviii. Provides implementation steps for the identified structural mitigation works (in terms of design, construction and approval). Where protective works are recommended, the report must identify where follow up field verification is required to ensure conformance to design.

xix. States that "the land may be used safely for the use intended" with siting constraints, protective measures or restrictive covenant, as stipulated in the report.

xx. Provides permission to Village of Lions Bay to include the Report in the online geo-hazard report library (as background information, not for other parties to rely on);

xxi. Acknowledges that report may be attached to covenant registered on title to the property;

xxii. Provides time limitation or condition statement to describe extent the Village of Lions Bay may rely on the Report for development approvals, and when resubmittal is recommended;

xxiii. Provides an assurance statement (after APEGBC 2010, 2012);

xxiv. Signed and sealed by coordinating qualified registered professional.

3. For sites located within multiple hazard NHAAs, a coordinated approach will be required to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met.
4. Where a report by a QP identifies protective works or measures to mitigate hazard(s) affecting a lot, those works or measures must not transfer risk to any other lots.
5. Where an owner has provided a natural hazard assessment report by a QP, the CAO or the Approving Officer may direct that the report be peer reviewed by a QP selected and retained by the Municipality. The peer review will be completed at the owner's expense and the owner must pay the invoice for same within 30 days of the invoice date. If the invoice amount is not paid when due, the CAO, at his or her discretion, may direct the Public Works Manager, the Building Inspector or a Building Official to issue a Stop Work Order Notice in respect of any Soil Deposit and Removal or Land Alteration Permit or Building Permit, as the case may be. The unpaid invoice amount may be deducted from a security deposit paid in respect of any development on or subdivision of the parcel.
6. Where a Preliminary Assessment only has been provided by an owner, the Municipality may require a Detailed Assessment to be provided by the owner at the owner's cost, whether the QP has recommended one or not.

### 10.1.6 Registration of Covenants as to Use and Indemnification

A covenant as to use and indemnification, in wording satisfactory to the Municipality and in accordance with Provincial enactments, will be required to be placed on the land title for all approvals and permits in NHAAs 1, 2A, 2B, 2C, 3A, 3B and 3C where the QP has specified conditions in his or her report in order for the land to be used safely for the use intended. The covenant shall include the report of the QP as a schedule.

### 10.1.7 Conditions and Requirements

All development must comply with the conditions and requirements that may be imposed by the Municipality following the review of QP reports as identified in this section.

### 10.1.8 Council Reconsideration

If a building inspector is authorized to issue a building permit in accordance with the conditions specified in a QP's report but refuses to do so, the Council may, on application of the parcel owner within 30 days of the building inspector's decision being conveyed to the property owner in writing via email or letter, direct the building inspector to issue the building permit subject to the requirements of the QP's report after reconsideration in accordance with section 35 (5) of Council Procedures Bylaw No. 476, 2015, as amended.

## 10.2 NHAA 1 – Coastal Zone Hazards (Map 3)

### 10.2.1 Justification

Ocean front land in the Village of Lions Bay is subject to hazards such as flooding of low-lying terrain, erosion and instability of oceanfront slopes. Coastal zone hazards are expected to be exacerbated over the coming decades by sea level rise. NHAA 1 is intended to designate sites that should be assessed by a qualified registered professional to address coastal flood hazards, but does not preclude development. For Coastal Zone Hazards, year 2100 high water mark (HWM), and site specific factors such as wave effects, storm surge, shoreline erosion, shore face stability and associated setbacks should be considered.

### 10.2.2 Extent

NHAA 1 extends from the existing natural boundary of the sea to a height of 8 metres CGD (Canadian Geodetic Datum) and is outlined on Map 3. The 8 metre level is conservatively selected to represent a potential future Flood Construction Level (FCL). NHAA 1 includes all lots fronting the ocean within the Village of Lions Bay.

### 10.2.3 Background

In the Village of Lions Bay, many steep slopes into the sea are rock controlled or are fill slopes below the railway line. These are not a stability concern for residential development. Most residential lots on surficial materials are located on bouldery debris fan deposits of Magnesia, Alberta and Harvey Creeks, and while the shorefronts may be steepened to 70-80% by wave attack, the sea scarp is not tall (<6 m) and materials are coarse and relatively resistant to erosion at the timescale of the life of a structure (e.g., 100-years).

The sites most vulnerable to erosion are those low-lying areas at the south end of Brunswick Beach Road, where housing has been developed on a gravel tombolo that has linked a small rock outcrop with the mainland. The beach gravels forming the tombolo stand just above the HWM, being formed by storm waves, and the terrain between the north and south facing beaches is slightly lower, just at the high water mark (HWM). Future breaching and erosion of these beach ridges places all these low-lying areas at risk.

### 10.2.4 Guidelines and Requirements

1. Within NHAA 1, New Development applications shall include a coastal flood hazard assessment prepared by a qualified registered professional to define the year 2100 shoreline position and the derived flood construction level, appropriate setback and any necessary mitigation work. Determination of the Year 2100 flood construction level shall follow the Ausenco Sandwell "Combined Method" as referenced in the Flood Hazard Area Land Use Management Guidelines. The FCL is determined as the sum of:

   - Allowance for future sea level rise to the year 2100;
   - Allowance for regional uplift, or subsidence to the year 2100;
   - Higher high water large tide (HHWLT);
   - Estimated storm surge for the Designated Storm with an annual exceedance probability of 1:200, or 1:500 as per the Ausenco Sandwell method referenced in the Flood Hazard Area Land Use Management Guidelines;
   - Estimated wave effects associated with the Designated Storm; and
   - A minimum Freeboard of 0.6 metres. However, because the Combined Method assumes the Designated Storm occurs in conjunction with a high tide; the Freeboard may be reduced from 0.6 m to 0.3 m for situations where the full FCL may be difficult to achieve.

2. Provincial guidance refers to a 15 m ocean setback, while Village of Lions Bay applies a 7.5 m coastal setback (subject to potential variations down to 4.5 m in Brunswick Beach). Siting could be further constrained by consideration of potential erosion. A factor of safety analysis may also be required to support foundation design and determine building setbacks from escarpment crests.

3. A report by a Qualified Professional in NHAA 1 shall include recommendations for any structural measures required to achieve the FCL or protect against coastal flood hazard (e.g. engineered fill or foundations or coastal bank protection or building envelope design).

4. Where a lot does not have sufficient area to accommodate a dwelling under these siting conditions, a variance may be needed to relax setback requirements. This will be determined on a site by site basis, and a report by a QP would be required to support any variance.

## 10.3 NHAA 2 - Creek Hazards

### 10.3.1 Justification

In the Village of Lions Bay, NHAA 2, Creek Hazards include consideration of flooding, Debris Floods and Debris Flows from large creeks with existing Debris Flow hazard mitigation (Magnesia, Alberta, Harvey), unmitigated creeks (upper Bayview) and Ravine hazards arising from deeply channelized unmitigated creeks and escarpment slope instability (parts of Battani and Rundle). Small creeks captured in part by the residential drainage network of ditches, culverts and storm sewers (upper School Yard Creek) are addressed in the NHAA 3C - Slopes >30%.

### 10.3.2 NHAA 2A- Mitigated Debris Fans

#### 10.3.2.1 Justification

Design of mitigation for Harvey, Alberta and Magnesia Creek hazards in the 1980s was based on an estimation of the largest volume that could reasonably occur during the life of each structure (the "Design Event"). However, present day standards need to consider 500 to 2450 year return periods, especially given potential earthquake triggering, and multiple failure mechanisms could lead to larger volumes than the Design Event for each creek. This is supported by recent reviews of small, steep watersheds with areas of 1-7 square kilometres.

#### 10.3.2.2 Extent

NHAA 2A is shown on Map 4 and includes land on the formerly active portion of the Magnesia Creek fan and the composite Alberta/Harvey Creek fans that could be affected should existing mitigation structures become overwhelmed by a large, rare event.

#### 10.3.2.3 Guidelines and Requirements

1. For debris fan hazards in NHAA 2A, a description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay is required.

2. At a minimum, until residual risk is better understood by detailed study, and as per development on alluvial fans (WLAP 2004, 2018), house foundations should be designed to withstand Debris Flood impacts with the top of concrete steel reinforced foundations established a minimum of 1 m above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level for Habitable Space a minimum of 1 m above finished grade, or the design should include measures to prevent water ingress. For example on the downslope side there could be openings such as doors or garage doors as long as the ground is contoured to prevent water ingress.

### 10.3.3 NHAA 2B - Upper Bayview Creek Fan

#### 10.3.3.1 Justification

NHAA 2B is vulnerable to Debris Flow and stream flooding including channel shifting (avulsion). Should the historically diverted Upper Bayview creek channel jump its banks, then the flow could further erode the gullies downslope, causing similar instability and impacts to lots downslope as those experienced during development in 1972. Channel blockage at the point of the 1972 diversion could redirect the creek back into its natural channel, thereby affecting housing at the fan apex. Moreover, a Debris Flow could directly impact several houses near the apex. In either of these scenarios, water and debris could spread throughout the NHAA in unpredictable ways.

#### 10.3.3.2 Extent

NHAA 2B captures the entire Upper Bayview Creek fan including areas vulnerable to flooding and slope instability in case of misalignment of the diverted channel as outlined on Map 5.

#### 10.3.3.3 Guidelines and Requirements

1. For the Upper Bayview Creek fan, a description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.
2. Until comprehensive mitigation of the Upper Bayview fan hazard is in place, the Village of Lions Bay will require Debris Flood and Debris Flow assessment by a qualified registered professional, with consideration for earthquake triggered Landslides from slopes above, failure of excessive and irretrievable road spoil sites, open-slope slides, misaligned drainage and local instability caused by misdirected water.
3. At a minimum, as per development on alluvial fans (WLAP 2004, 2018), house foundations should be designed to withstand Debris Flood impacts with the top of concrete steel reinforced foundations established a minimum of 1 m above finished grade, with foundations protected from scour, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level for Habitable Space a minimum of 1 m above finished grade, or the design should include measures to prevent water ingress. For example on the downslope side there could be openings such as doors or garage doors as long as the ground is contoured to prevent water ingress.

### 10.3.4 NHAA 2C – Ravines

#### 10.3.4.1 Justification

Ravines are landforms associated with creeks that have become incised into bedrock or thick deposits of surficial material. Typically, there is an abrupt slope break from adjacent terrain onto a steep erosional slope that may be susceptible to Landslides. 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 also encompass creek hazards.

### 10.3.4.2 Extent

Land within 30 metres of Ravine crests is included within NHAA 2C. This NHAA captures Battani and Rundle Creeks, and the Ravines upstream of fan apices on Magnesia, Alberta and Harvey Creeks.

### 10.3.4.3 Guidelines and Requirements

1. For land within 30 metres of Ravine crests in NHAA 2C, a description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.

2. A QP's report shall include the following:

    a. a recommendation of required setback from the Ravine crest, and a demonstration of suitability for the proposed use;

    b. a field definition of the required setback from the top of a Ravine or other steep slope;

    c. where building sites are located within Ravines, a Landslide assessment will be required for Ravine slopes affecting the site, and to establish FCLs and other measures based on flood, Debris Flood and Debris Flow from affecting creeks; and

    d. the required setback to Top of Bank and recommendations relating to construction design requirements for the above development activities, on-site storm water drainage management, on-site sewage disposal and other appropriate land use recommendations.

    e. seismic slope stability assessments will be required to assess foundation stability.

## 10.4 NHAA 3 - Slope Hazards

### 10.4.1 Landslide Safety Policy

For all Landslide hazards, the Village of Lions Bay adopts a Landslide safety policy that employs Landslide risk assessment for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes as determined relevant by the Qualified Professional. Risk assessments may be qualitative or quantitative in nature, but the QP must satisfy the Municipality that the risk tolerance thresholds for both annual probability of individual loss of life and Factor of Safety set out in Table A of section 10.1.1 of this bylaw have been met. As part of the risk assessment approach, a minimum Landslide magnitude to consider is the 1:500-year event, but larger events up to the 1:2450-year earthquake triggered Landslide should be considered where deemed appropriate by the QP. Reference shall be made to the Cordilleran Report and to the risk tolerance thresholds adopted by the Village of Lions Bay and set out in Table A of section 10.1.1 of this bylaw.

The risk of annual probability of loss of life to an individual is calculated in accordance with the following equation:

$R = P_H * P_{S H} * P_{T \cdot S} * V * E$ , where:

- $P_H$ = the annual probability of the Landslide occurring;
- $P_{S H}$ = the spatial probability that the Landslide will reach the individual most at risk;
- $P_{T \cdot S}$ = the temporal probability that the individual most at risk will be present when the Landslide occurs;
- V = the vulnerability, or probability of loss of life if the individual is impacted; and
- E = the number of people at risk, which is equal to 1 for the determination of individual risk.

| Annual Probability of Death for the Individual Most at Risk | Qualitative Descriptor |
|---|---|
| $>10^{-3}$ | Very High (Unacceptable) |
| $10^{-4} - 10^{-3}$ | High (Unacceptable) |
| $10^{-5} - 10^{-4}$ | Moderate (Tolerable) |
| $10^{-6} - 10^{-5}$ | Low (Acceptable) |
| $<10^{-6}$ | Very Low (Acceptable) |

Three sub-categories of slope hazards that present a risk to people and property are identified in sections 10.4.2, 10.4.3 and 10.4.4.

### 10.4.2 NHAA 3A - Open-slope Landslides

#### 10.4.2.1 Justification

Open-slope Landslides (NHAA 3A) typically involve fragmented bedrock, organic debris, and mineral sediment. A typical slide is triggered by rockfall from a bluff, by windthrow of large trees on a steep slope, or by slab failure of a weathered soil veneer. The headscarp failure plane is typically >60%, but sometimes as low as 40%, or less. Typical, or generic steep terrain where Landslide initiation is most likely has 60-120% slope, and is overlain by a veneer/blanket of till/colluvium. The initial slip then impacts timber downslope clearing a swath through the forest, and may be very destructive to infrastructure.

### 10.4.2.2 Extent

Open-slope Landslide hazard areas within NHAA 3A are identified on Map 7. NHAA 3A extends from Highway 99 upslope to the municipal boundary. Source areas are in moderately steep to steep terrain within and above the Village of Lions Bay, and require identification and field assessment as part of the QP report.

### 10.4.2.3 Guidelines and Requirements

In NHAA 3A, a report by a QP should consider the following:

1. Applicants will be required to provide a Preliminary Assessment report and may be required to provide a Detailed Assessment report prepared by a QP in accordance with the subsequent guidelines and requirements as applicable.
2. Some background information on potential slope hazards in some areas is available through the Cordilleran Report. The information in the Cordilleran Report should be referenced as part of any geohazard assessment.
3. Potential slope hazard areas should remain free of development, or, if that is not possible, then:
    i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level, and
    ii. conditions (for example conditions relating to the permitted uses, density or scale of building) should be recommended as necessary to reduce potential risk to acceptable levels,

    as determined by a QP in a Preliminary Assessment or Detailed Assessment report for the consideration of the Municipality.
4. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.
5. Where applicable, a report by a QP should include the following:
    i. For slope hazards, description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.

ii. If required by the risk assessment, then siting constraints and/or design of protective measures. Siting constraints may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of Habitable Space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots.

6. Landslide (open slope or rockfall) risk assessment requires knowledge of a magnitude-frequency model, with reference to event return frequencies that may affect the site, including the 500-year and 2500 year events, or greater return, as considered appropriate by the QP". Stratigraphic and radiometric methods should be considered to estimate historic return periods and gauge Landslide intensity at the site. Such materials/methods may or may not be present or practicably attained from a single lot or group of lots. In lieu of hard data, regional analysis and expert judgment supported by sound geomorphic reasoning must be relied upon.

7. The area included within NHAA 3A has complex micro terrain, with very irregular to hummocky topography, and it is very difficult to predict individual Landslide paths. Thus, while some local topographic features may shelter or protect certain sites, safe sites cannot be predicted using simple rules, and caution is warranted. Landslide modeling by Qualified Professionals using high resolution LIDAR topography would aid defining specific travel paths for various Landslide volumes and rheologies.

8. Open slope Landslide source areas requiring assessment may exist on a parcel or far upslope of a parcel, and field assessment of terrain beyond the parcel is typically required.

### 10.4.3 NHAA 3B – Rockfall

#### 10.4.3.1 Justification

Rockfall hazard (NHAA 3B) is the falling, bouncing and rolling of detached rock fragments from cliffs and steep slopes. Natural rockfall source areas are readily identified by slope thematic mapping, keying into slope areas with >70% slopes, and especially bluffs with slopes >90%. Rockfall volumes can range from individual blocks to

100s or 1000s of cubic metres of fragmented rock debris. Over time, rockfall material may form a veneer/blanket or apron of material below a source bluff. These deposits are known as scree or talus. Field assessment of the source area is required to characterise rock structure and quantify potential volumes.

### 10.4.3.2. Extent

The NHAA 3B area is drawn by projecting a 27.5$^0$ rockfall shadow angle from the base of the rock cliff between Magnesia and Alberta Creeks, and from other smaller scattered bluffs in and above Lions Bay. In the case of the former, since the rock cliff is located high above the Village, and since the cliff is tall and potential rockfall volumes are reasonably large (e.g., 10s – 1000s m$^3$), the reach of these events extends far downslope, almost reaching the highway in the vicinity of Schoolyard Creek. Elsewhere, the smaller and lower elevation bluffs, result in less extensive reach of potential rockfall. NHAA 3B is outlined on Map 8.

### 10.4.3.3 Guidelines and Requirements

In NHAA 3B, a report by a QP shall be prepared that includes the following:

1. Applicants will be required to provide a Preliminary Assessment report and may be required to provide a Detailed Assessment report prepared by a QP in accordance with the subsequent guidelines and requirements as applicable.
2. Some background information on potential slope hazards in some areas is available through the Cordilleran Report. The information in the Cordilleran Report should be referenced as part of any geohazard assessment.
3. Potential slope hazard areas should remain free of development, or, if that is not possible, then:
    - i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level, and
    - ii. conditions (for example conditions relating to the permitted uses, density or scale of building) should be recommended as necessary to reduce potential risk to acceptable levels,

   as determined by a QP in a Preliminary Assessment or Detailed Assessment report for the consideration of the Municipality.

4. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.

5. Where applicable, a report by a QP should include the following:

    i. For rockfall hazards, description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.

    ii. If required by the risk assessment, then siting constraints and/or design of protective measures. Siting constraints may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of Habitable Space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots.

6. Within NHAA 3B, a rockfall risk assessment is required. Landslide (open slope or rockfall) risk assessment requires knowledge of a magnitude-frequency model, with reference to event return frequencies that may affect the site, including the 500-year and 2500 year events, or greater return, as considered appropriate by the QP. Rockfall modelling should be applied to aid design of protection measures. Protective measures may include scaling, bolting, shot-creting application, fencing, or building fortification as determined by a specialist QP.

8. Rockfall assessments must consider the hazard intensity of fall of individual blocks to the detachment of larger masses up to several thousand $m^3$, such as the prehistoric Kelvin Grove wedge failure and rockfall located off Kelvin Grove Way, on Lots 48, 60 & 61. Specialist bedrock structure and kinematic analysis may be required to determine potential event volumes.

9. Rockfall source areas requiring assessment may exist on a parcel or far upslope of a parcel, and field assessment of terrain beyond the parcel is typically required.

### 10.4.4 NHAA 3C - Slopes >30%

#### 10.4.4.1 Justification

Worksafe BC regulation requires a Natural Hazard Assessment Area category based on simple slope class. NHAA 3C is a slope-based hazard assessment area concerned with stability of foundations, excavations, fill slopes, the existence of very local rockfall and/or slide hazards, and with consideration of water control as it affects local stability, erosion and sedimentation.

#### 10.4.4.2 Extent

1. NHAA 3C applies to areas where natural average ground slope is >30%. It is noted that Part 20.78 of the Worksafe BC Occupational Health and Safety (OHS) Regulation (BC Reg. 296/97) states that excavation work must be done in accordance with the written instructions of a Qualified Professional if:
    - (i) the excavation is more than 6 m (20 ft) deep,
    - (ii) an improvement or structure is adjacent to the excavation,
    - (iii) the excavation is subject to vibration or hydrostatic pressure likely to result in ground movement hazardous to workers, or
    - (iv) the ground slopes away from the edge of the excavation at an angle steeper than a ratio of 3 horizontal to 1 vertical.
2. Areas where natural average ground slope is >30%, but which have been filled and paved (for example the tennis courts and school parking areas) are included in NHAA 3C. Small areas of gentle terrain exist along Bayview Road toward Mountain Drive, but most lots encompass some areas of steeper slope. Thus, these areas are included in the NHAA.

### 10.4.4.3 Guidelines and Requirements

1. Applicants will be required to provide a Preliminary Assessment report and may be required to provide a Detailed Assessment report prepared by a QP in accordance with the subsequent guidelines and requirements as applicable.

2. Some background information on potential slope hazards in some areas is available through the Cordilleran Report. The information in the Cordilleran Report should be referenced as part of any geohazard assessment.

3. Development should minimize any alterations to steep slopes, and the development should be designed to reflect the site rather than altering the site to reflect the development.

4. Terracing of land should be avoided or minimized and landscaping should follow the natural contours of the land.

5. Buildings and structures and landscaping should be located as far as reasonably possible from steep slopes or channel discharge/runoff points at the base of slopes.

6. Potential slope hazard areas should remain free of development, or, if that is not possible, then:
    i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level, and
    ii. conditions (for example conditions relating to the permitted uses, density or scale of building) should be recommended as necessary to reduce potential risk to acceptable levels,

    as determined by a QP in a Preliminary Assessment or Detailed Assessment report for the consideration of the Municipality.

7. Stepped and articulated building forms that integrate and reflect the natural site contours and slope conditions should be used, and large unbroken building masses that are unsuitable for sloped conditions should be avoided.

8. The construction of structures, pathways/trails, driveways, utilities, drainage facilities, septic fields, swimming pools, hot tubs, ponds, landscaping or other uses at or near the top or base of steep slopes should be avoided. A minimum ten metre Buffer Area from the top or base of any steep slope should be

maintained free of development except as otherwise recommended by a QP. On very steep slopes, this Buffer Area should be increased.

9. Vegetation should be maintained and/or reinstated on the slopes and within any Buffer zone above the slopes to filter and absorb water and minimize erosion.

10. No fill, including yard clippings, excavated material, sand or soil, should be placed within ten metres of the top of slopes or along pre-existing drainage channels. This applies to Ravine slopes as well.

11. The base of slopes shall not be undercut for building, landscaping or other purposes except in accordance with the recommendations of a QP and a permit issued in accordance with this bylaw.

12. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.

13. Large single plane retaining walls should be avoided, where possible. Where retaining walls are necessary, smaller sections of retaining wall should be used. Any retaining structures 1.2 metres or higher, or a series of terraced retaining walls with a combined height of greater than 1.2 metres, in steeply sloped areas must be designed by a QP.

14. Disturbed slopes should be reinforced and revegetated, especially where gullied or where bare soil is exposed. Planting should be done in accordance with the recommendations of a Certified Horticulturalist, Landscape Architect or qualified registered Professional Forester.

15. Native species, including trees, shrubs and other plants, should be used for any new planting.

16. Any structural mitigation measures must be designed by a QP and confirmation must be received by the Village of Lions Bay that the mitigation measures were implemented as recommended.

17. Water should be diverted away from slopes, yards and structures in a controlled manner and ponding should be avoided near slopes. Small unidentified drainages intercepted by proposed development should be conveyed by structures with adequate capacity (i.e. 200 year flood) and lots should be graded

so that water is directed away from slopes and toward storm drainage systems as indicated in the following guideline.

18. Landscaping; and building, roof, pavement, and other impervious surface drainage should be designed and maintained to shed water away from slopes (especially steep slopes) and shall be connected to a storm drainage system, infiltration pit, or alternative method, recommended by a QP and approved by the Village of Lions Bay.

19. The extent of paved or hard-surfaced areas should be limited, and absorbent or permeable surfaces should be used instead to encourage infiltration where appropriate and reduce runoff.

20. Where applicable, a report by a QP should include the following:

    i. For slope hazards, description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay.

    ii. If required by the risk assessment, then siting constraints and/or design of protective measures. Siting constraints may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of Habitable Space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots.

    iii. For stability of slopes on or about the proposed development site, assessment of slope failure modes and limiting Factors of Safety, and stability during seismic events. Seismic slope analysis requires comparatively detailed knowledge of subsurface bedrock, soil and groundwater conditions. The required Factor of Safety calculation references many data sources, including (but not limited to):

        a. seismic hazard maps and reports;
        b. ground motion data;

c. seismic Site Class; and

d. modal magnitude values of the design earthquake.

Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability may also be necessary.

21. A report from a QP is required in NHAA 3C for excavations, roads, drainage, fillslopes and foundations. Local rockfall assessment and mitigation may also be required. Evaluation of onsite and nearby municipal drainage structures to identify potential undersizing, blockages and overland flow, and design of buildings to prevent water ingress is also required.

23. If required by the risk assessment, then siting constraints should be assessed and/or design of protective measures undertaken. Siting constraints include the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include engineering design of excavated slopes, fillslopes and foundations and other measures.

## 10.5 NHAA 4 - Wildfire Hazard

### 10.5.1 Justification

A Wildfire Risk Management System (WRMS) was developed by B.A. Blackwell and Associates in 2007 as part of the Village of Lions Bay Community Wildfire Protection Plan (CWPP). The WRMS identified the core area of the Village as being at moderate to high risk from wildfire. The entire Village of Lions Bay is identified in the CWPP as being a high vulnerability interface area with respect to risk from "spotting". The Community Wildfire Protection Plan noted that public safety, and many of the important values, facilities and structures, may be severely impacted by a major fire in the Village.

### 10.5.2 Extent

All land within the Village of Lions Bay is designated as NHAA 4.

### 10.5.3 Guidelines and Requirements

While there are no mandatory requirements for Wildfire Mitigation, the following recommendations are applicable for assessments required under NHAA 4:

1. Consideration should be given to the use of Fire Resistive Materials and construction practices for all subject developments in the Wildfire Natural Hazard Assessment Area:
    i. Fire Retardant Roofing materials should be used, and asphalt or metal roofing should be given preference;
    ii. decks, porches and balconies should be sheathed or coated with Fire Resistive Materials;
    iii. all eaves, attics, roof vents and openings under floors should be screened to prevent the accumulation of combustible material, using 3mm, non-combustible wire mesh, and vent assemblies should use fire shutters or baffles;
    iv. exterior walls should be sheathed with Fire Resistive Materials;

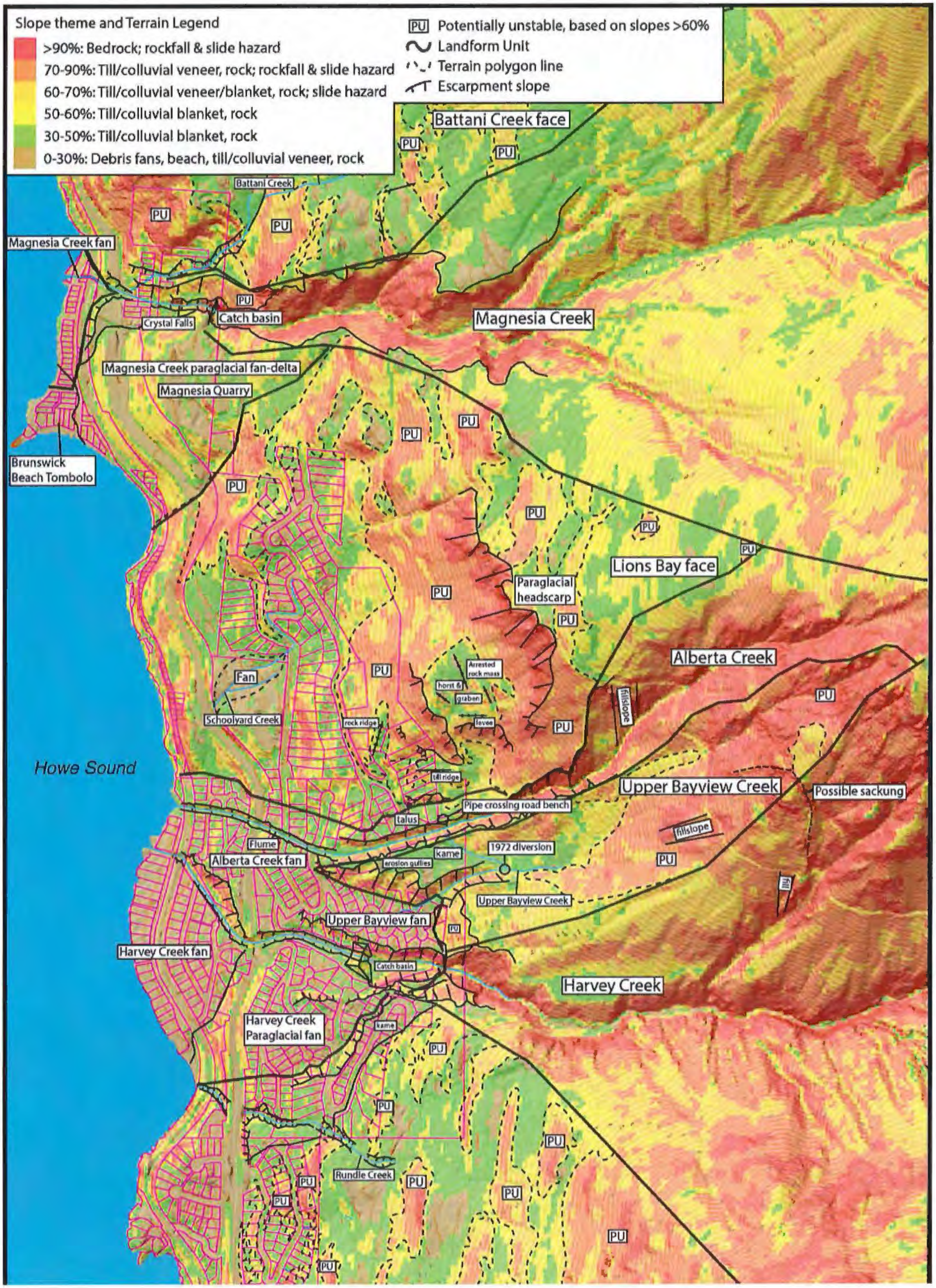
   - v. fire-resistive decking materials, such as solid composite decking materials or fire-resistive treated wood, should be used;
   - vi. all windows should be tempered or double-glazed to reduce heat and protect against wind and debris that can break windows and allow fire to enter the building or structure;
   - vii. all chimneys and wood-burning appliances should have approved spark arrestors; and
   - viii. building design and construction should generally be consistent with the highest current wildfire protection standards published by the National Fire Protection Association or any similar, successor or replacement body that may exist from time to time.

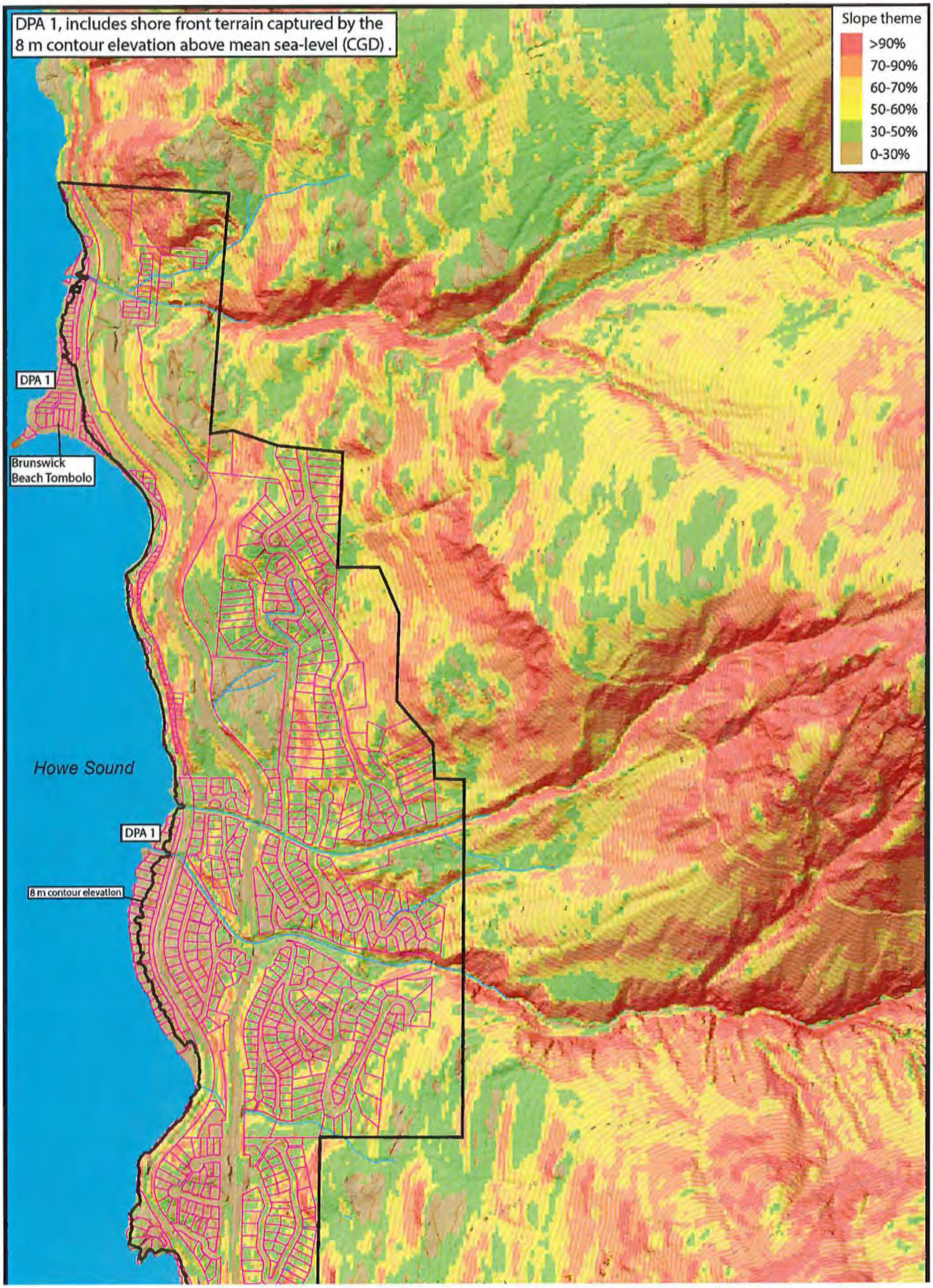
2. The following landscape conditions should be considered within 10 metres of a New Building or Structure requiring a building permit:
   - i. wildfire risk mitigation and landscaping should be designed and installed to protect, conserve and enhance natural features of the site;
   - ii. if removal of trees or vegetation is recommended by the QP for the purpose of reducing wildfire risk, Village of Lions Bay approval is required, and replacement trees or vegetation may be required by the Municipality; and
   - iii. where feasible, a Defensible Space of 10 metres should be managed around buildings and structures with the goal of eliminating Fuel and combustible debris, reducing risks from approaching wildfire and reducing the potential for building fires to spread to the forest, and the required Defensible Space may be larger in areas of sloping ground where fire behaviour creates greater risk.

3. For sites located within multiple hazard NHAAs, a coordinated approach should be employed to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met. Risk associated with geohazards should usually take precedence over wildfire risk where potentially conflicting mitigation measures are recommended (e.g. vegetation retention for slope stability would take precedence over vegetation removal for wildfire protection).

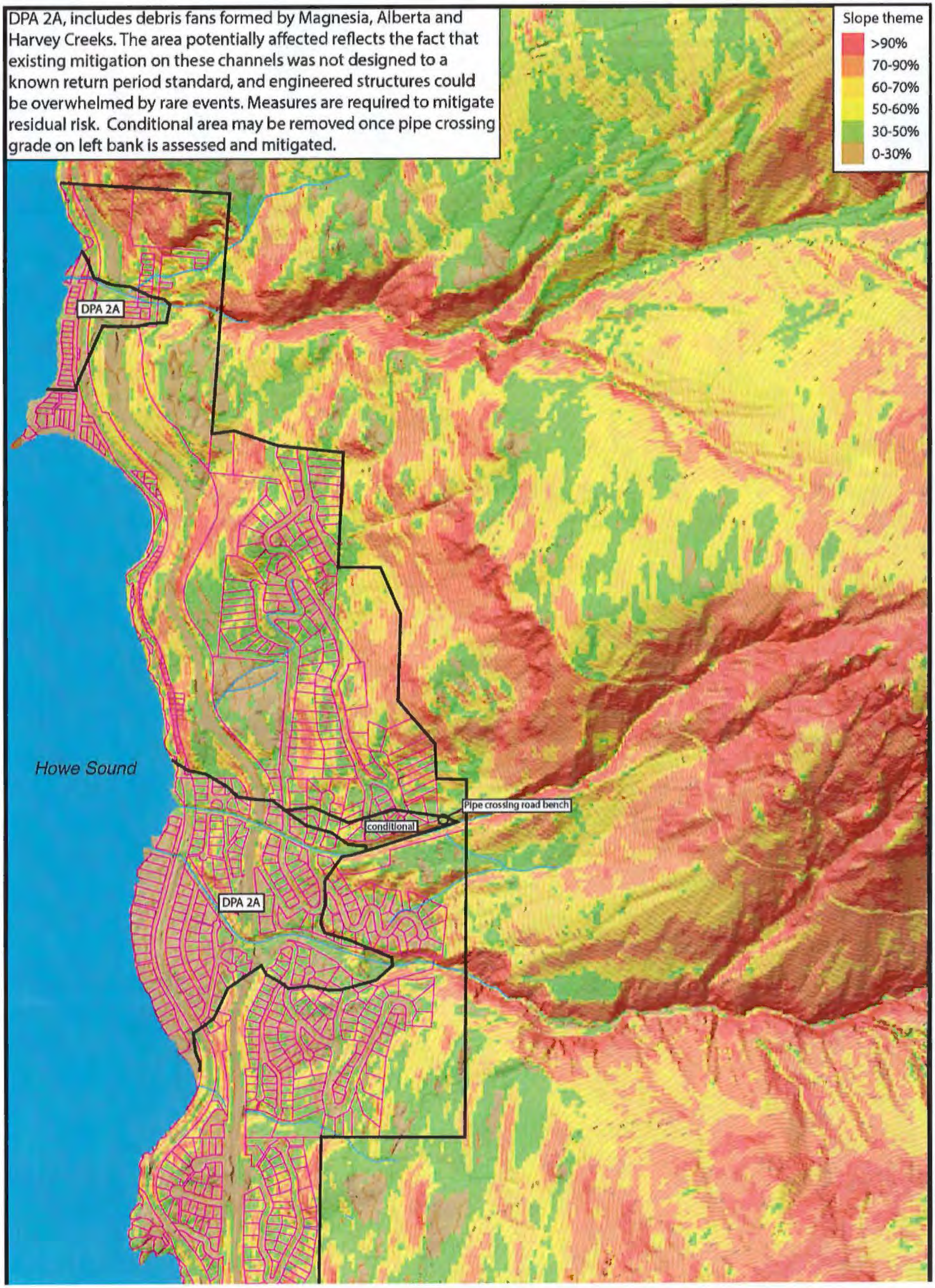
4. In addition to the Exemptions listed in section 10.1.4, all development is exempt from the requirement to obtain a Wildfire hazard assessment other than the construction and Installation of a New Building or Structure for which a building permit is required.

5. A report from a QP should include an acknowledgement of receipt of the report by the QP dealing with the reporting guidelines and requirements of all other Natural Hazard Assessment Areas, if applicable.

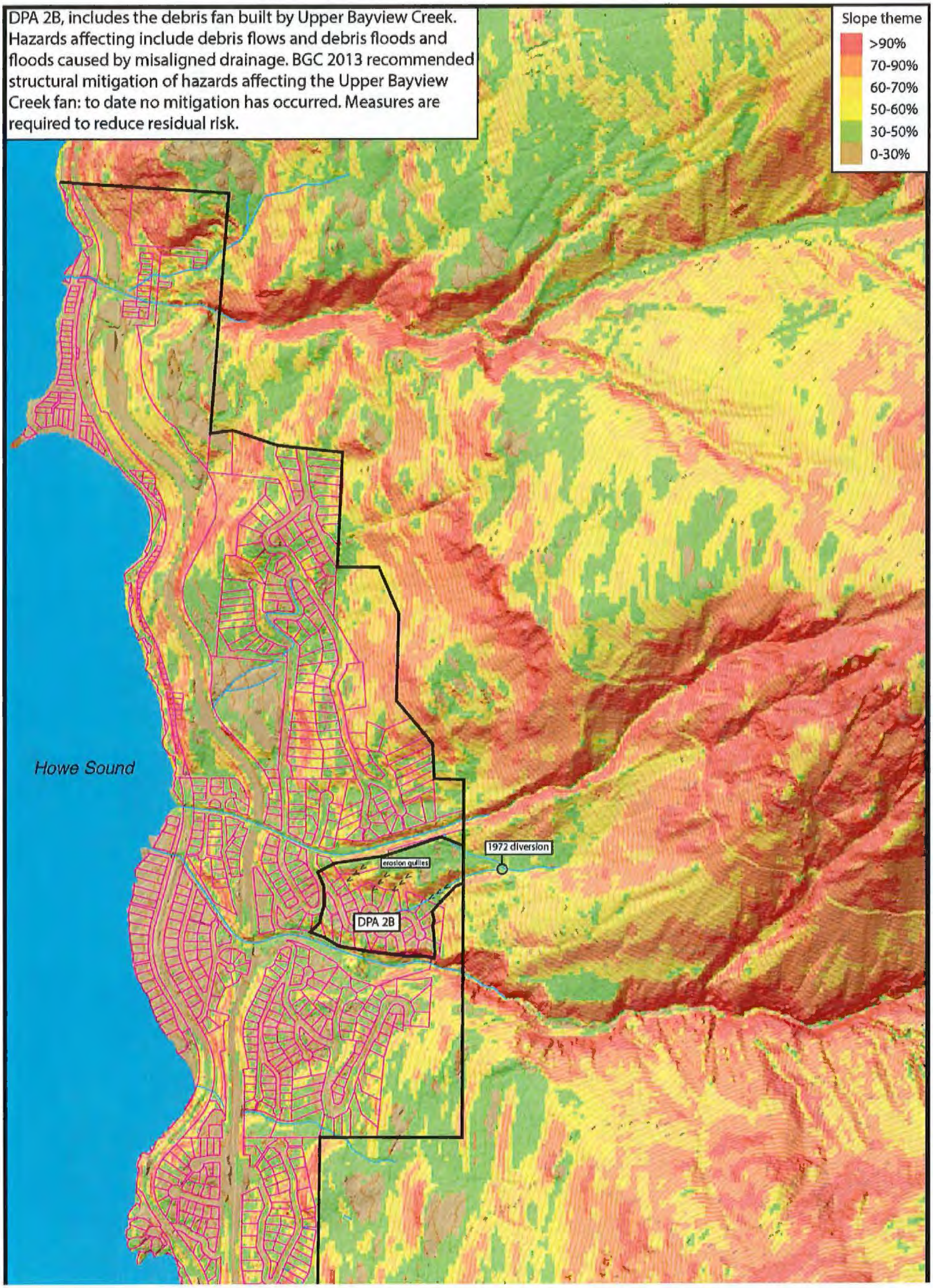

Slope theme and Terrain Legend
>90%: Bedrock; rockfall & slide hazard
70-90%: Till/colluvial veneer, rock; rockfall & slide hazard
60-70%: Till/colluvial veneer/blanket, rock; slide hazard
50-60%: Till/colluvial blanket, rock
30-50%: Till/colluvial blanket, rock
0-30%: Debris fans, beach, till/colluvial veneer, rock
PU Potentially unstable, based on slopes >60%
Landform Unit
Terrain polygon line
Escarpment slope
Battani Creek face
Battani Creek
Magnesia Creek fan
Catch basin
Crystal Falls
Magnesia Creek
Magnesia Creek paraglacial fan-delta
Magnesia Quarry
Brunswick Beach Tombolo
Lions Bay face
Paraglacial headscarp
Arrested rock mass
horst &
graben
levee
Alberta Creek
fillslope
Fan
Schoolyard Creek
rock ridge
till ridge
Howe Sound
Upper Bayview Creek
Possible sackung
Pipe crossing road bench
talus
Flume
Alberta Creek fan
kame
erosion gullies
1972 diversion
fillslope
fill
Upper Bayview Creek
Upper Bayview fan
Harvey Creek fan
Catch basin
Harvey Creek
Harvey Creek Paraglacial fan
kame
Rundle Creek
PU



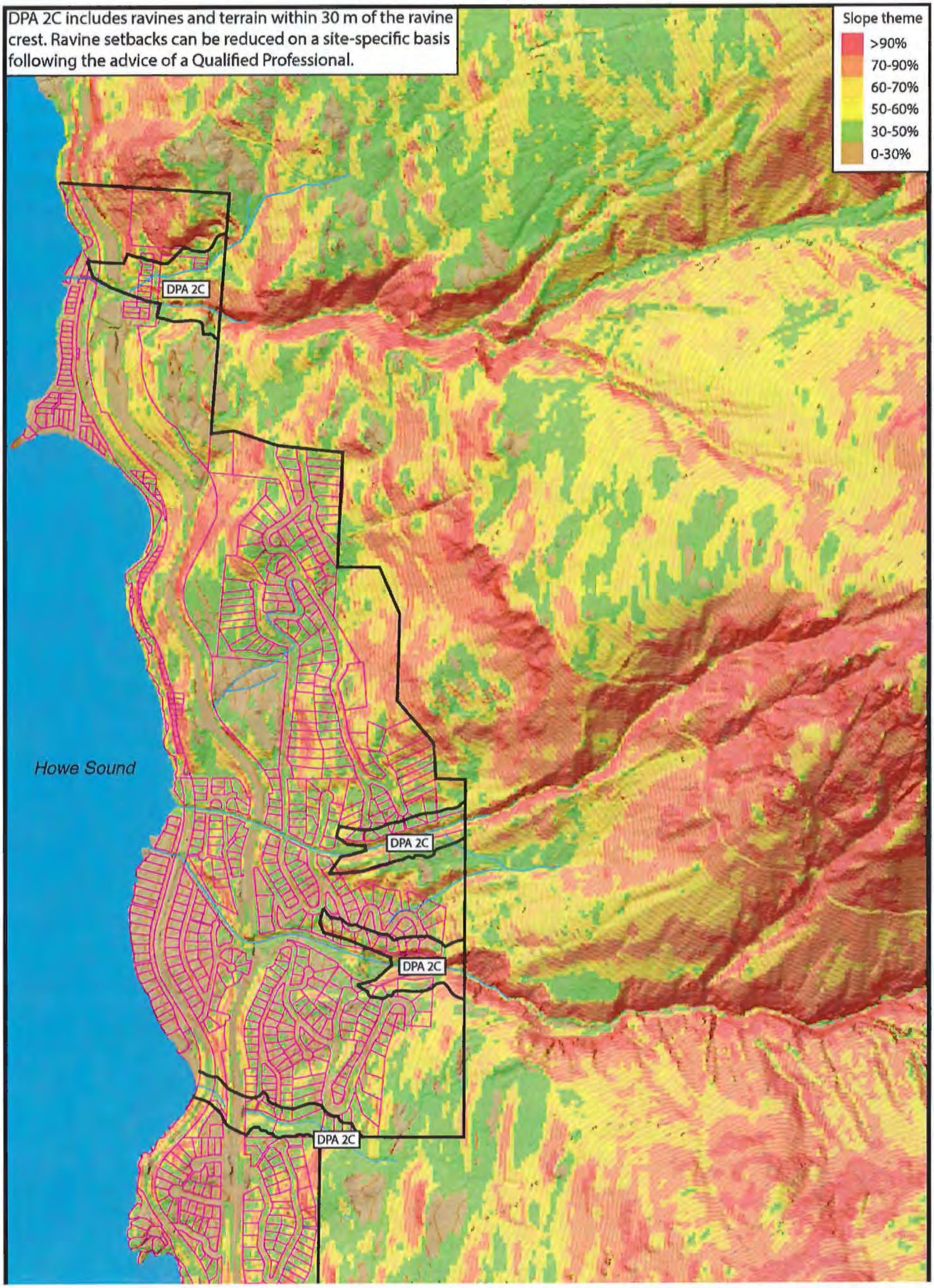
DPA 1, includes shore front terrain captured by the 8 m contour elevation above mean sea-level (CGD) .



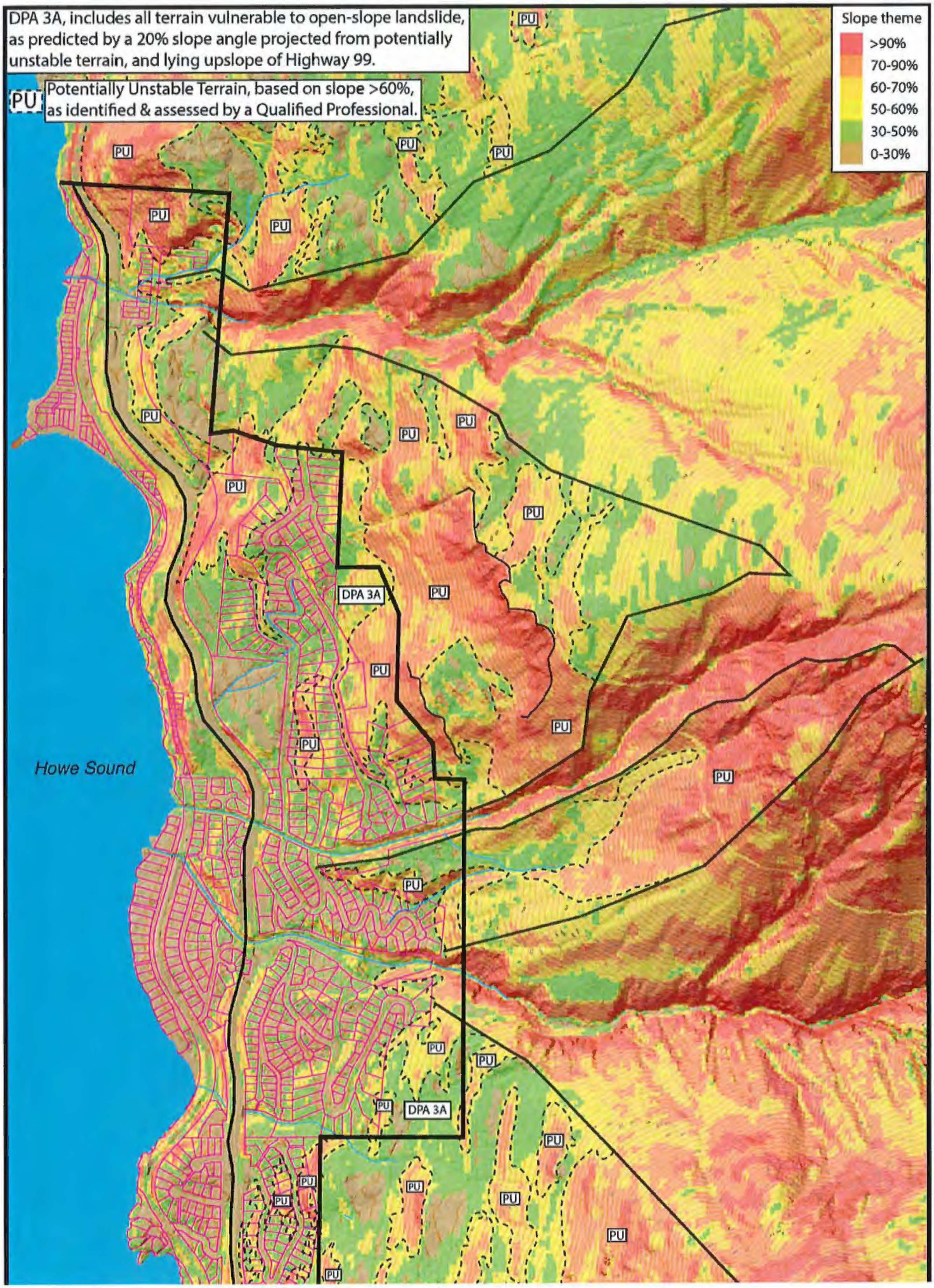
DPA 2A, includes debris fans formed by Magnesia, Alberta and Harvey Creeks. The area potentially affected reflects the fact that existing mitigation on these channels was not designed to a known return period standard, and engineered structures could be overwhelmed by rare events. Measures are required to mitigate residual risk. Conditional area may be removed once pipe crossing grade on left bank is assessed and mitigated.



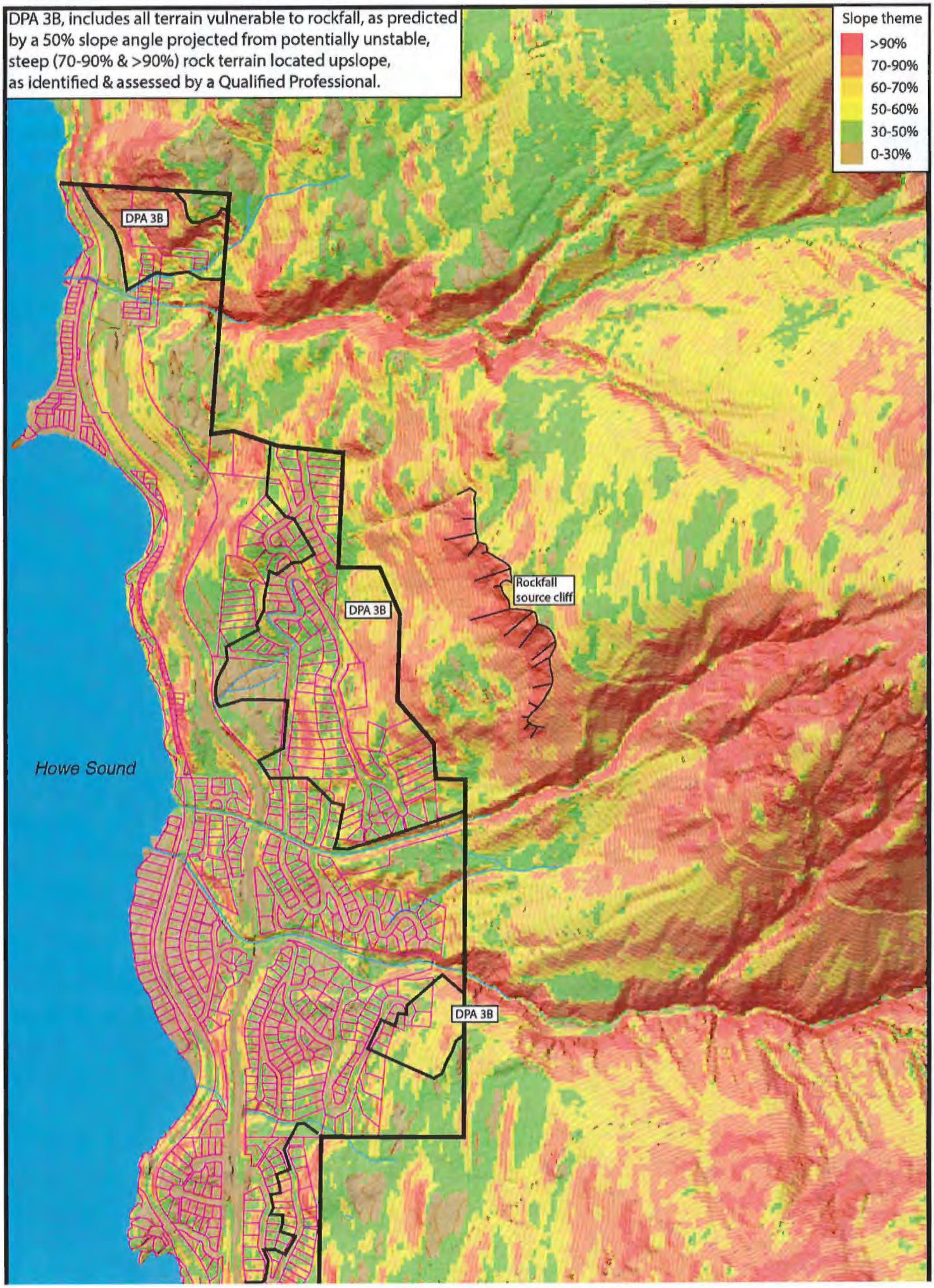
DPA 2B, includes the debris fan built by Upper Bayview Creek. Hazards affecting include debris flows and debris floods and floods caused by misaligned drainage. BGC 2013 recommended structural mitigation of hazards affecting the Upper Bayview Creek fan: to date no mitigation has occurred. Measures are required to reduce residual risk.



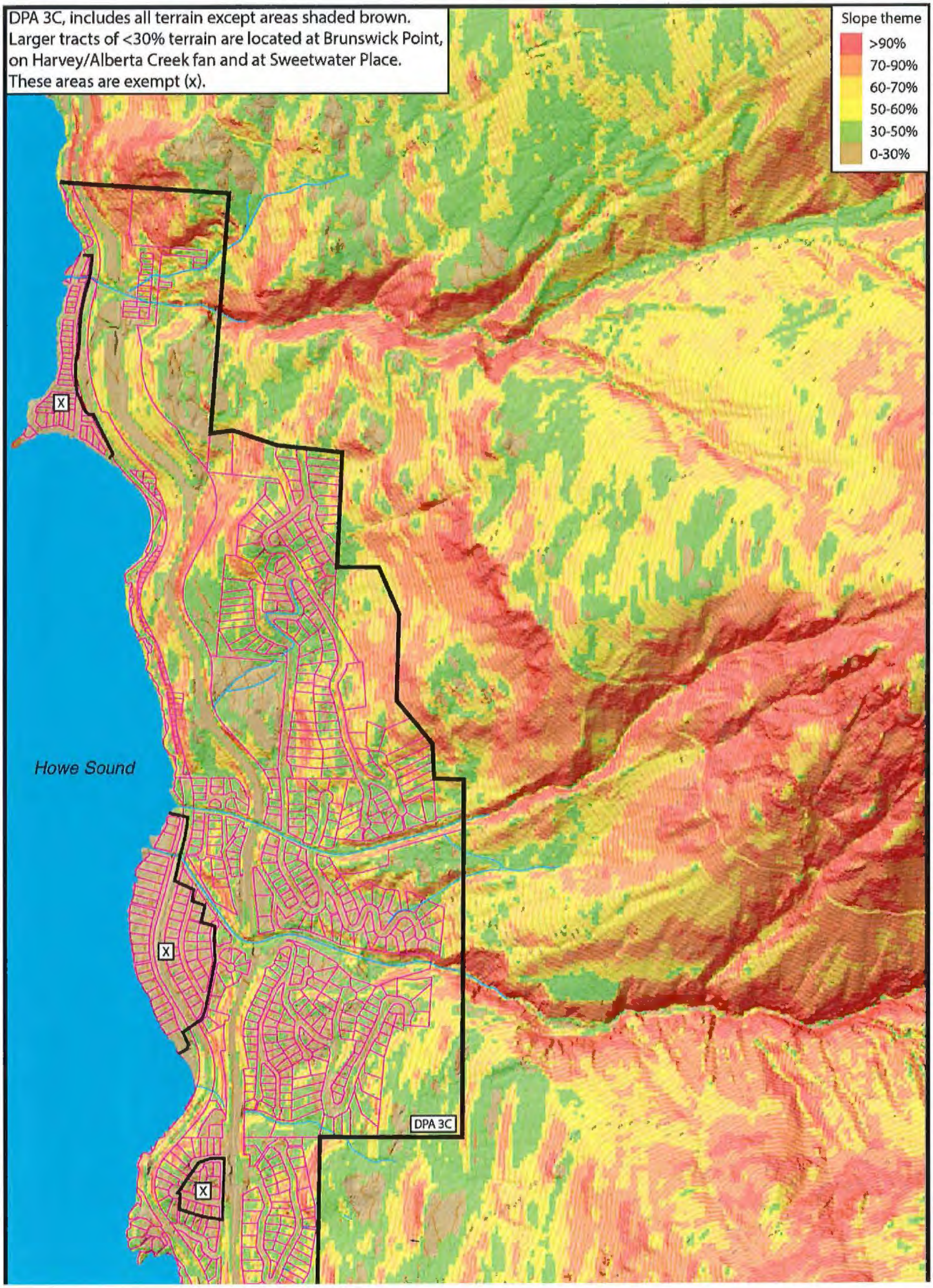
DPA 2C includes ravines and terrain within 30 m of the ravine crest. Ravine setbacks can be reduced on a site-specific basis following the advice of a Qualified Professional.


DPA 3A, includes all terrain vulnerable to open-slope landslide, as predicted by a 20% slope angle projected from potentially unstable terrain, and lying upslope of Highway 99.

PU Potentially Unstable Terrain, based on slope >60%, as identified & assessed by a Qualified Professional.



DPA 3B, includes all terrain vulnerable to rockfall, as predicted by a 50% slope angle projected from potentially unstable, steep (70-90% & >90%) rock terrain located upslope, as identified & assessed by a Qualified Professional.



DPA 3C, includes all terrain except areas shaded brown. Larger tracts of <30% terrain are located at Brunswick Point, on Harvey/Alberta Creek fan and at Sweetwater Place. These areas are exempt (x).

# Village Update

*Friday, March 9, 2018*

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## From the Mayor's Desk

Hello Lions Bay,

Trees are a fraught issue in Lions Bay. The other two are dogs and parking. Trees are very much fraught when they grow into the previous view of the people behind, sometimes many streets away. Previously neighbours have been expected to reach consensus, but as Lions Bay grows up, that's not always working these days. It's no accident that Council recently changed the name of the Trees, Views and Landscapes Bylaw. So far it's just the name, but I know that eventually officialdom is going to get involved. Some municipalities require a covenant to preserve existing views when a property changes ownership. Others will only allow construction after a stick frame has been erected for neighbours to see what's what. Others places require binding arbitration. I'm in the very early stages of looking at what a Lions Bay approach might be - suggestions are welcome (my email below). In the meantime, tree cutting on private land is not under municipal purview, so be very sure what trees you are agreeing to cut. We hear too often of residents returning home to find something entirely different to what they expected. Marking either the ones to go or the ones to stay, doesn't work: marking disappears with the trees. Consider a written agreement, or a map, or marked photos, and certainly insist on being there for the removal.

Lions Bay School PAC has engaged a new preschool service, Saplings Outdoor Program, to take over when the current Montessori program ends late-June. An information session is set for next Tuesday, March 13th 6-7pm at the ex-

Library*. There will be a presentation and a chance for parents to ask any questions about the new program starting in September.

Our CAO has inserted a piece in these pages regarding the proposed new Development Permit Area guidelines for our OCP. Important information which I hope all will read and provide feedback on as requested.

Regards,
Karl Buhr (mayor.buhr@lionsbay.ca)

*BTW, Council also seeks suggestions for a new name for the anteroom of the ex-Library, in time for the first phase of the funded community signage makeover. It's intended to be a community conference room, a gathering space, a moot court....

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# FROM THE CAO's DESK

## DEVELOPMENT PERMIT AREAS: PROTECTION OF DEVELOPMENT FROM HAZARDOUS CONDITIONS

In BC, we are blessed with a full bounty of dramatic natural landscapes, snowcapped mountains rising out of deep fjords left by retreating glaciers 10,000 years ago, rivers and streams rushing down steep slopes back to the sea as the sun dips below the horizon, painting the western sky with original masterpieces on a regular basis. Our license plates state the obvious: Beautiful British Columbia.

In the Village of Lions Bay, at the edge of Metro Vancouver in the Sea to Sky corridor, we get to experience both splendor and serenity. But creating a settlement on these steep slopes is fraught with hazards... read more.

# DEVELOPMENT PERMIT AREAS:
# PROTECTION OF DEVELOPMENT FROM HAZARDOUS CONDITIONS

## INTRODUCTION

In BC, we are blessed with a full bounty of dramatic natural landscapes, snowcapped mountains rising out of deep fjords left by retreating glaciers 10,000 years ago, rivers and streams rushing down steep slopes back to the sea as the sun dips below the horizon, painting the western sky with original masterpieces on a regular basis. Our license plates state the obvious: Beautiful British Columbia.

In the Village of Lions Bay, at the edge of Metro Vancouver in the Sea to Sky corridor, we get to experience both splendor and serenity. But creating a settlement on these steep slopes is fraught with hazards. Early developers did not do the kind of land use planning risk analysis that is required today. Indeed, the Village of Lions Bay is a community susceptible to a variety of natural hazards and has a history of significant events, including events involving loss of life. Hazards potentially impacting Lions Bay include coastal flooding, debris flows, debris torrents, erosion, landslide, landslip, rockfall, and wildfire.

Lions Bay is not alone in facing these kinds of natural hazards, a fact recognized by the Province of BC through the *Local Government Act*, which provides for "protection of development from hazardous conditions" through the designation of Development Permit Areas (DPAs) in Official Community Plans (OCPs). This is accomplished through guidelines incorporated into the OCP which are intended to ensure that the known hazards are taken into consideration on any development applications. It provides a framework to identify the hazardous conditions and set out the requirements for qualified professionals to address those hazards in order to enable development safely in a hazardous environment. *Click here to view the DPA requirements in a table format (see document titled "Table of Development Permit Area Guidelines").*

## RISK TOLERANCE

Clearly, within the Village of Lions Bay, there is risk associated with *any* development, including existing development. Knowledge of risk creates an obligation on the part of government to share that knowledge and to exercise a duty of care in relation to persons who may be affected by that risk. In respect of new development, knowledge of risk requires that such development address the risk in a manner which will ensure it meets acceptable levels of risk tolerance. Gone are the days when local government could approve development, particularly in hazardous areas, without professional assurance that a development site or structure is safe for the use intended.

The concept of safety embodies risk tolerance. In BC, landslide risk tolerance criteria are often based upon factors of safety, hazard probability, or risk of loss of life. Unfortunately, there are no province-wide acceptance criteria, notwithstanding a recommendation in the Coroner's report after the fatal 2005 landslide in North Vancouver that Provincial landslide safety criteria be established. As the authority having jurisdiction over land use planning, it is therefore the responsibility of the Village of Lions Bay to set acceptable levels of risk tolerance with respect to development within the Village.

The District of North Vancouver provides a good example of a municipal policy setting an acceptable level of risk tolerance, with *existing* development having a risk tolerance threshold based upon risk of loss of life of 1 in 10,000 per annum. This is a similar to one's chances each year of dying in a car accident. All other development has a much lower risk tolerance threshold at 1 in 100,000 per annum. These criteria are consistent with those in Hong Kong, Australia and the United Kingdom, jurisdictions which were researched in the course of North Vancouver's policy development.

**Cordilleran Report, Table 11: Landslide risk policy, District of North Vancouver**

| Type of Application | 1:10,000 + ALARP | 1:100,000 | *FOS >1.3 (static) | *FOS >1.5 (static) |
|---|---|---|---|---|
| Building Permit (<25% increase to gross floor area) | X | | X | |
| Building Permit (>25% increase to gross floor area and/or retaining walls >1.2m) | | X | | X |
| Re-zoning | | X | | X |
| Sub-division | | X | | X |
| New Development | | X | | X |

+ ALARP means As Low As Reasonably Practicable

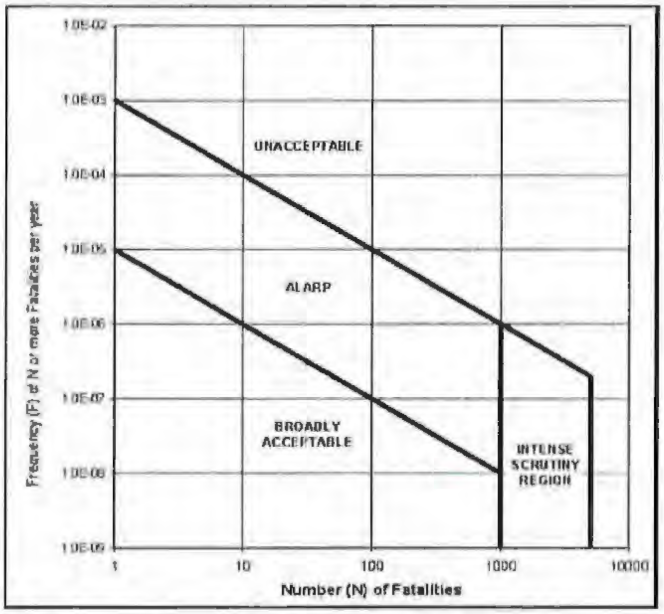
* FOS means Factor of Safety, generally in relation to engineered slopes and ravines

The ostensible rationale for differing thresholds is that for new development, the extra involuntary risk posed by a hazard should be much less than for existing development on the premise that risk avoidance through development elsewhere is an option. Given that Lions Bay is substantially built out and there are very few options within the Village for risk avoidance through location choice, 1:100,000 per annum may be a very high threshold for Lions Bay, depending upon potential options for mitigation of risks.

But what kind of development are we speaking of? Using the North Vancouver policy, a property owner looking to build a single family home on bare land, or demolish and rebuild on their lot, would be tasked with meeting a safety threshold 10 times as stringent as that which applied to the existing house (and to the neighbouring houses). Did the risk change? Are the lives of new residents more valuable or require greater protection than those of existing residents? Or is the intent to eventually have all structures meet the higher safety threshold for new development that has been accepted in other jurisdictions? In some areas of North Vancouver, there are homes which, if redeveloped, will never meet the higher threshold because the risk cannot be further diminished to achieve it. (Porter et al., 2009)

One possible solution would be to limit the application of the more stringent criteria to the approval of new subdivisions or rezonings which substantively increase the number of people exposed to the risk. Another would be to rely more heavily upon the principle of reducing risk to "as low as reasonably practicable" (ALARP). For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. In Lions Bay, the ALARP principle of mitigation could be applied across all DPAs, particularly where the level of hazard uncertainty is significant. Treating less impactful development in a similar manner to existing development (subject to the ALARP principle) could be said to represent more of a "risk neutral" approach, as opposed to a "risk averse" approach.

When the expected area impacted by a hazard is small and density of development is low, safety thresholds are governed by the estimated level of *individual risk*. However, when large groups are exposed to a hazard, considerations applicable to *societal risk* may determine if development is acceptable or unacceptable from a risk perspective. Societal risk considers the total potential for loss of life when all people exposed to a hazard are factored into the equation. It is usually described as the relationship between the probability of a catastrophic incident, expressed as the average frequency with which it can be expected to occur, and its consequences. It is usually represented as an F-N graph, where F equals the expected frequency of the event and N equals the number of fatalities. The concept is generally expressed with a range of acceptable outcomes, shown here as lying between 1:1000 and 1:100,000 per annum. In the United Kingdom, the Health and Safety Executive (HSE), which sets maximum tolerable risk for individual members of the public, has proposed that the frequency of 50 or more people being killed or seriously injured in a single event should not exceed 1:5,000 per annum.



While risk tolerance levels may vary across different jurisdictions, and individual vs. societal risk criteria may differ, there are some common principles which have been identified:

- the incremental risk from a hazard to an individual should not be significant compared to other everyday risks the person is exposed to;
- the incremental risk from a hazard should be reduced as low as reasonably practicable (ALARP);
- the higher the number of fatalities, the lower the probability of the event occurring needs to be in order to be within a tolerable or acceptable range;
- higher risks are likely to be tolerated for existing developments than for new proposed developments. (Leroi et al., 2005)

Statistics Canada reports from 2005 indicate that, over the five preceding years, the age-standardized risk of loss of life by *all* causes was about 1:175 per year. It has been noted that the impact of moving from a 1:100,000 landslide risk threshold to a 1:10,000 standard was low, making a difference of less than 0.2% to the cumulative risk of loss of life. (Porter et al, 2009) This may lead one to conclude that a 1:10,000 + ALARP threshold is perhaps the most reasonable policy approach for DPAs 2 and 3 in the Village of Lions Bay, if not as a blanket approach then at least for the forms of development which are less significant in nature (eg: single family homes, cottage additions, and minor lot splits).

### WILDFIRE RISKS

With respect to risk tolerance related to wildfire, recent events in BC and Alberta should certainly give pause to anyone living within or near an urban/wildland interface area. The accumulation of forest fuels and the effects of climate change, including more weather extremes, have resulted in more, and more severe, wildfire events affecting thousands of residents in BC and Alberta. After the record-breaking 2003 fire season, the Filmon Report provided the government of BC with a number of recommendations, many of which have not been adopted at our own peril. One of them was:

> that municipalities within fire prone areas should formally adopt the Firesmart standard for community protection for both private and public property. At a minimum, this standard should be applied to all new subdivision developments.

Another of the recommendations was to require wildfire-proofing across the Province:

> The BC government should require municipal and regional governments to implement building codes and land use requirements that have proven useful elsewhere in limiting the impact of interface fires.

The draft guidelines in the Lions Bay Wildfire DPA4 are intended to address these goals, to the extent reasonable and practicable. They will be amended and re-presented with changes to soften the requirements and recognize the potential conflicts between Firesmart goals and slope stability goals, as well as to address concerns about applicability to existing development. However, they do present a set of "best practices" to help address this potential hazard and it is hoped that they will be implemented by property owners whenever and wherever feasible.

An updated draft of the DPA guidelines can be viewed here *(see document titled "Draft 2 OCP Development Permit Area Guidelines").*

Peter DeJong
Chief Administrative Officer
Village of Lions Bay

REFERENCES
Leroi, E., Bonnard, C., Fell, R., and McInnes, R. 2005. Risk assessment and management, *International Conference on Landslide Risk Management*, Vancouver, Canada, Hungr, Fell, Couture, and Eberhardt (eds).

Porter, M., Jakob, M., and Holm, K. 2009. Proposed Landslide Risk Tolerance Criteria, BGC Engineering Inc., Vancouver, BC, Canada.

Friele, P. 2018. The Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards, Lions Bay, BC, Canada.

## **HAVE YOUR SAY!**

How do you feel about your own risk tolerance levels?

Do you take everyday risks for granted or do you ever consider them?

Do you think Lions Bay should be risk neutral or risk averse when it comes to geohazard risk tolerance for new development?

Does it depend on the type of development, including the number of new people exposed to a particular risk?

Should it depend on whether it's above or below the highway?

How about wildfire hazard risk tolerance?

To what extent should wildfire risk mitigation be mandated vs. voluntary?

If voluntary, how will your neighbour's choices impact your safety?

Please send your comments and questions to feedback@lionsbay.ca

# Village Update

*Friday, March 16, 2018*

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## FROM THE CAO's DESK

### DEVELOPMENT PERMIT AREAS: PROTECTION OF DEVELOPMENT FROM HAZARDOUS CONDITIONS

Hello Lions Bay:

For those of you who may have missed my piece in last week's Village Update regarding the proposed Development Permit Areas (DPAs) for Protection of Development from Hazardous Conditions, I strongly urge you to read it here. For a quick overview of the DPA framework, click here. And to go straight to the draft OCP policy and guidelines, click here. To review the Cordilleran Report, which provided an overview of geohazards affecting property in Lions Bay, click here and then on "Village of Lions Bay Natural Hazards Development Permit Area Strategy: Coastal, Creeks and Hillside Hazards".

Why should you review this complex material? How does this proposed OCP amendment affect you? Well, it might not affect you at all - if you have no plans to ever build on or subdivide or rezone your property. But if you want to do any of these things, and if you're within one or more of the DPAs, you'll need to have a qualified professional assess your property against the risks identified in the Cordilleran Report, and the DPAs themselves, and indicate that the land is safe for the use intended.

Like almost every other municipality, Lions Bay already requires a geotechnical review of development applications. However, these are presently done with little or no guidance as to the safety thresholds and standards which must be achieved, despite best practices set out in the Association of Professional Engineers and Geoscientists of BC guidelines. That is because ultimately, those thresholds must be established by, in this case, the Village of Lions Bay.

Moreover, in a place like Lions Bay, those safety assessments must take into consideration the numerous hazards presenting both within and beyond the borders of the Village which may affect the parcel to be developed. Without a framework for assessment and stated policy requirements to be met, the engineer working for an individual property owner would be left floundering and having to attempt a complete assessment of all hazards with no guidance. This would be more expensive and inefficient for property owners in Lions Bay wishing to do something with their land. Providing this guidance also benefits tax payers who have no intention of developing their property because it reduces risk to the Municipality.

The owners of existing development (i.e. your current home) should also be interested in this matter because in the course of establishing minimum safety or risk tolerance thresholds for new development, a minimum is effectively established for existing development. What if your existing home doesn't meet the minimum risk tolerance threshold? That's a question worthy of another article next week, a cliffhanger worthy of inclusion in DPA 3C (steep slopes). Perhaps by then we'll have some indication from the Province of BC as to their intentions regarding some of the unquantified risks associated with hazards identified in the Cordilleran Report. In the interim, we really do want your feedback@lionsbay.ca regarding some of the questions asked at the end of last week's article. Thank you.

Regards,
Peter DeJong
Chief Administrative Officer
Village of Lions Bay

# Village Update

*Friday, March 23, 2018*

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## From the Mayor's Desk

Hello Lions Bay,

Tuesday, and another marathon Council meeting, this one 'till 11:45 pm, a recent record. We received last year's financial results (no major surprises), we reviewed correspondence (keep it coming), and we approved the recommendations of the Beach Park Advisory Committee arising from the recent community survey. Thanks to Committee members Oliver Brunke, Mathilde Gildenhuys, Heather Hood, Russ Meiklejohn, Robin Spano and Public Works Manager Nai Jaffer, plus Chair Cllr. Ron McLaughlin plus me. On a $30,000 budget, in time for summer, we will see a new kayak rack with 100 spaces on the south wooden fence, a beach-level fresh water shower, handrails and pavers for the south stone steps, and temporary patching of the landscape timber stairs down from the play structures. Larger renovations will be implemented over multiple budget years--a billboard this year will display renderings of the proposals. One recommendation occasioned a gulp: the ugly but loved shady cedar and fir near the southerner stone steps are shuffling off their mortal coil, now dropping the massive leaders (a horticultural word for branches, apparently) growing out of past topping exercises. A recent professional survey also finds signs of rot and splitting up in the crown. Staff now judge the risk of injury and worse from these trees unacceptably high, and unfortunately they are coming down before the season begins. They had a good innings, and this has been coming, but still.

Council also approved revamped terms for the Curly Stewart Scholarship Award. Applications for Lions Bayers currently in their final year of secondary education are now open. Look for the promo piece below for details.

Staff are getting down to the nitty gritty on 2018's parking provisions. At Lions Bay Beach park, the parking lot will be improved for visitor pay parking June - Sep. That's all the parking there is for visitors near Lions Bay beach, and when it's full, it's full. Parking over the rail line is reserved for residents. What makes pay and resident parking work is enforcement, so expect more and improved of that this year too. Parking in most of the Village remains laissez-faire, but signage updates will say what can be done rather than what can't; where a parking type is defined for a given stretch of street, it will be very clear. We tighten up on street parking near the Sunset/Mountain hiking trailheads parking and Kelvin Grove Beach and Marine Park, for example.

As before, Annual Parking Permits are required for residents to park in high-demand permit areas. From feedback from the 2015 parking survey (remember that?), they will now be on tamperproof stock to thwart theft and prevent use on multiple vehicles. They also mount in a new place: on the outside lower left rear window. That's so the parking people don't have to walk between vehicles on the street or in parking lots to see if there's a decal, and so that it's no longer obscured by shaded glass and glare, and to avoid damaging inside defog tracing. An alternative valid location is the left side of the rear bumper. Yes, it has to go in one of those two places, for the reasons given, and if it's not, you may as well not have one. This approach seems to work for other communities that need to handle high visitor demand for scarce parking. Annual Permits will come with the June tax bill this year (and with the Feb. utility bill from 2019). Yes, I know that doesn't guarantee that they all go only to residents, but it's the simplest administratively. They can be given to other Lions Bay residents (e.g. tenants), but not sold, and additional permits are available for purchase ($40) with proof of residence. Books of Guest Parking Permits for parking in permit zones will be available from the municipal office for free to residents.

Regards,
Karl Buhr (mayor.buhr@lionsbay.ca)

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# FROM THE CAO's DESK

Hello Lions Bay:

To begin my third and final installment on the topic of Development Permit Areas (DPAs) for Protection of Development from Hazardous Conditions, I would like to apologize for the insensitive "cliffhanger" pun at the end of my last communication. It was not appropriate given the seriousness of the topic and I'm sorry to have included it.

If you missed the first piece in the March 9th Village Update, you can read it here. For last week's article, click here. For a quick overview of the DPA framework, click here. And to go straight to the draft OCP policy and guidelines with updated maps, click here and then on "Draft 3 OCP Development Permit Area Guidelines". To review the Cordilleran Report, which provided an overview of geohazards affecting property in Lions Bay, click here and then on "Village of Lions Bay Natural Hazards Development Permit Area Strategy: Coastal, Creeks and Hillside Hazards".

As I noted at the end of last week's article, establishing minimum safety or risk tolerance thresholds for new development may effectively establish a minimum level for existing development. But without site specific assessments of risk, it is very difficult to know what level of safety any particular property presently meets. Ensuring that all properties meet a new development minimum level of safety is a process that will evolve over time in Lions Bay as people develop or redevelop their properties. In the course of that process, they will obtain the necessary geotechnical reports in accordance with the parameters set by the DPA guidelines.

In the interim, however, it is important for the Municipality to designate what level of safety will apply to all existing development. For example, in North Vancouver, the minimum safety threshold for existing development is 1:10,000 per annum (roughly the same risk of death you face each year driving a car). If a property doesn't meet that threshold the owner is required to take immediate steps to bring it up to that level. For Lions Bay, this type of regime would be extremely difficult to enforce without the site specific assessments necessary to make a determination in each case. But it would be very costly for the Municipality to fund that kind of project scope and staff is *not* recommending that this be done.

Therefore, to deal with the issue of risk tolerance for existing development staff is proposing (subject to legal review) the potential option of only requiring existing development to meet a risk threshold of ALARP, or As Low As Reasonably Practicable. For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. Building upon last week's iteration of a draft risk tolerance table in the DPA guidelines, an additional line has been inserted at the top of Table A:

**Table A: Risk Tolerance Policy, Village of Lions Bay**

Risk tolerance thresholds in accordance with development type:

| Type of Application | ALARP | 1:10,000# + ALARP | 1:100,000# | *FOS >1.3 (static) | *FOS >1.5 (static) |
|---|---|---|---|---|---|
| Existing Development | X | | | | |
| Building Permit or Land Alteration Permit for development on existing RS1 parcel as permitted by zoning | | X | | X | |
| Subdivision and/or Rezoning to create 4 or fewer fee simple or strata parcels (including the original parcel) | | X | | X | |
| Subdivision and/or Rezoning to create 5 or more fee simple or strata parcels (including the original parcel) | | | X | | X |

# Ratios denote annual probability of individual loss of life
+ ALARP means As Low As Reasonably Practicable
* FOS means Factor of Safety, generally in relation to engineered slopes and ravines

In Lions Bay, this principle of mitigation could be applied across all DPAs, particularly where the level of hazard uncertainty is significant, such as with some of the unquantified risks identified on Crown land above and within the Village. At this point in time, the Province has reviewed the Cordilleran Report but has not yet decided on whether it will undertake further, detailed assessments of those risks. Staff will be following up with the Province to pursue this level of inquiry.

In the interim, we really do want your feedback@lionsbay.ca regarding the questions asked at the end of the March 9th article, along with any questions or concerns that you may have with respect to this topic. Thank you.

Regards,
Peter DeJong
Chief Administrative Officer
Village of Lions Bay

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## EARLY DISCOUNT APPLICABLE UNTIL MARCH 31

Boat Space and Dog License renewals are due by January 1, 2018 each year; the early discount payment fees are due by March 31, 2018.

Please be advised that per the Parks and Regulations Bylaw No. 448, 2012, boats will be seized after June 1, 2018 if payment has not been received.

# THE MUNICIPALITY OF THE VILLAGE OF LIONS BAY

| | | | |
|---|---|---|---|
| **Type** | **Information Report** | | |
| **Title** | **Public Correspondence re. Development Permit Areas (DPAs)** | | |
| **Author** | **Peter DeJong** | **Reviewed By:** | |
| **Date** | **February 15, 2018** | **Version** | |
| **Issued for** | **February 20, 2018** | | |

**Recommendation:**

THAT the Information Report, "Public Correspondence re. Development Permit Areas" be received.

**Attachments:**

(1) Correspondence from Ian Mackie;
(2) Correspondence from Peter Wreglesworth;
(3) Correspondence from Heather Mossakowski;
(4) Correspondence from Jennifer Monroe.

**Key Information:**

After the DPA Public Information Meeting on January 30, 2018, Council received feedback from a few residents regarding the presentation of the Cordilleran Report and the proposed DPA bylaw framework. Those comments are attached to this report. Staff notes that the correspondence raises many issues for Council's consideration. There are also points that staff wishes to address in order to provide context and clarity to the discussion.

Firstly, with respect to Mr. Mackie's letter, the Cordilleran Report was commissioned to provide an "all hazard" review for the Village of Lions Bay. This was necessary because of the policy choice made by Council last year through the new zoning bylaw to permit development through subdivision, cottages as other opportunities that were identified in the Official Community Plan. As pointed out in Mr. Wreglesworth's letter, no one is under any illusions about there being serious hazards in and around Lions Bay. In order to proceed with *any* development, Council must be fully cognizant of such hazards and must provide for a means of dealing with them through the mechanisms provided in the *Local Government Act* – namely, through Development Permit Areas.

The methodology employed by Pierre Friele, the author of the Cordilleran Report, was to provide a thorough review of all historical factors and available data to identify geohazard risks affecting land in Lions Bay, regardless of their origins or any mitigation that has taken place up until now. Return periods for hazard assessments are dictated by legislation, professional guidelines and other generally accepted criteria. Mr. Friele is not the only expert who has expressed concerns about the capacity of the creek hazard mitigation structures constructed by the Province in the 1980s. His opinion that there is an unmitigated residual risk requiring further assessment does not mean that there is nothing which can be done by the Municipality in the interim. On the contrary, he has provided minimum criteria to address the residual risk, with additional mitigating measures, if any, to be determined by a Qualified Registered Professional (QRP). The alternative to this for Council would likely entail a freeze on all development within DPA 2A pending Provincial review, which the Province may not elect to do. Even if the Province proceeds with such a review, the preliminary data suggests that the result will indicate a residual risk. They may not choose to rebuild the structures to address such risk. The more likely solution will be that anyone affected by such risk needs to take appropriate steps to mitigate the risk, indeed, as recommended by Mr. Friele.

With respect to the responsibility of the Village of Lions Bay, it is to set acceptable levels of risk tolerance with respect to development within the Village. It is not to conduct a full risk assessment of how each and every hazard may affect each and every property. That is, and has always been, the role and responsibility of site specific studies to be undertaken by property owners wishing to develop their land. That may not have been entirely clear in the first draft of the bylaw, but the amended version will seek to clarify those responsibilities right up front. The fact that there are significant hazards on Crown land for which the risks are hard to quantify does add an element of difficulty for the property owner. The Municipality has begun the process of seeking Provincial funding of that endeavour, which would provide not only financial benefit but also the benefit of consistency of assessment of the risk. But again, in the interim, the idea is to give property owners an opportunity to seek site specific assessments of their properties should they want to develop sooner, particularly if there are favourable features associated with the land. The present requirements for Geotechnical reports contain no guidance to the QRP. The proposed bylaw will provide a legislative framework and guidance for the QRP to enable site specific risk assessments measured against the Municipality's risk tolerance policy. It will provide a clear basis for the QRP to certify whether the land is safe for the use intended.

Much of what is suggested by Mr. Wreglesworth is covered above and by the bylaw itself. All natural hazards originating within Village boundaries are identified and guidelines for dealing with them on a site specific basis are contained within the draft bylaw. The suggestion that there is a devolution of authority to QRPs to vary zoning is misplaced. QRPs will make recommendations as to what they determine is required, but the Municipality retains control over varying the zoning bylaw or not, which is done through its issuance of the DP. The particular provisions referenced have been amended to clarify this retention of control by the Municipality.

The comments in all the correspondence regarding the guidelines for the Wildfire Hazard DPA4, have been considered and amendments of that DPA reflect more of a "best efforts" framework to provide recommendations on addressing the risks presented by this hazard.

Respectfully submitted,

PDJ

**From:** Ian Mackie [redacted]]
**Sent:** Wednesday, January 31, 2018 10:27 AM
**To:** Council @ Lions Bay <council@lionsbay.ca>
**Subject:** Draft Amended OCP

Mayor And Council

I write in regards to the report prepared for the Village by Pierre Friele M.Sc. P. Geo. of Cordilleran Geoscience (the "Report") and the draft O.C.P.amendment to incorporate Development Permit Areas (" DPA's)
A review of the Report shows that the author has identified every conceivable risk that he can think of that might occur in Lions Bay as infrequently as on a 1:2500 year return basis.

As stated at the Meeting on January 30, 2018 it appears that the majority of the risks identified in the Report originate on Crown Lands uphill from the Village boundaries.

The Report includes the following significant statements:

" No activity is free from risk and the concept of safety embodies risk tolerance. In Canada and BC there is no legislated guidance for risk tolerance to geohazards and the term "safe" has not been defined. P1.

"This report will identify potential hazards and assess the potential reach of these hazards. It is beyond the scope of work to assess the frequency of occurrence of identified hazards, as that is typically a very detailed assessment, often requiring subsurface examination, stratigraphic analysis ... Thus, this report cannot make judgments on hazard or risk acceptability at any given site" P2.

Illustrative of the fact that the Report does not discriminate in any way between risks is the following reference to the multi million dollar remediation of , inter alia, the Alberta Creek risk undertaken by the Province in the 1980's:

"Design of mitigation for Harvey, Alberta and Magnesia Creek hazards in the 1980's was based on the Design Event. Since there was no data available to prepare debris flow frequency analysis, the Design Event was based on the "largest volume that could reasonably occur during the life of the structure ... The storage structure volume was then made 15 to 25% larger than the design debris flow. The channelled work downstream of catchments was sized to accommodate twice the design event" P 11.

At page 27 of the Report the author comments on the Alberta Creek remediation by the Province as follows:

"On Alberta Creek lots border the flume on both sides. The lower flume below 150M elevation has a reasonably constant configuration with 5M depth and 13 M to crest width, as measured at the bridge on Isleview Place. It is CONCEIVABLE ( my emphasis) that events exceeding the Design Event COULD (my emphasis) overwhelm this channel with partial overtopping onto the surface"

It is because it is CONCEIVABLE that the remediation on Alberta Creek COULD be overtopped that this area is included in the DPA as DPA 2A thus requiring expensive professional assessment and flood and scour proofing as described in section 10.3.2 of the draft amended O.C.P.

This is proposed to be required by the Village without ANY assessment of the risk of this event occurring. This is contrary to the recommendations made in the Report as follows at page 21:

"Therefore, it is the responsibility of the Village of Lions Bay to establish levels of acceptable risk for development approval process "

Rather than developing any assessment of the risk for each DPA the Village has simply adopted the approach of the author of the Report by including everything mentioned in the Report as a risk to be addressed by the property owners in the Village. This is a failure on the part of the Village to properly assess the risks as is recommended by the author of the Report.

If the risk is that the Province has failed to adequately address the risks on the Creeks mentioned, and elsewhere, then the Province should immediately be advised of this hazard as it affects not only the residents of the Village but also all of the thousands of daily users of the 4 lanes of highway 99 that pass through Lions Bay and over the Creeks in question.

It is premature to require the property owners in the Village to comply with the proposed DPA's prior to the Province assessing and addressing any risks that may be present.

To enact the proposed DPA without first obtaining input from the Province as to the actual risk is to burden the property owners of the Village with excessive and potentially unnecessary expense.

WILDFIRE HAZARD SECTION 10.4.6.2

This provision does not appear to have been carefully considered in its potential effects. It's requirements will apply to any structure in the Village that requires a building permit for repair or replacement. This is unreasonable.

As well it appears that it does not apply to lands in the Village owned by the Village; the Province or Highways. These are the owners of significant lands in the Village that have large numbers of trees that present a fire hazard.

Regards
Ian D. Mackie
185 Isleview Place

**February 5th, 2018**

**Attention – Village of Lions Bay - Mayor and Council,**

**Re: Public Open House - January 30th, 2018**

After reading the extensive materials supplied prior to the open house meeting last Tuesday, and some reflecting after that meeting - I would like to share my comments – observations, impressions and concerns respecting the content and the direction Council appears to want to pursue.

It was noted at the Open House meeting on the 30th, that Council intends to have 1st and 2cd reading at the Council meeting tomorrow – I think that this is too aggressive a schedule for such a complex and far reaching agenda. Particularly with what appeared to be less than 50 attendees at the meeting.

Changes contemplated are the most far reaching, and potentially very costly that residents are being asked to consider – and the Public Process needs to reflect this. The subject matter is not easily understood by many residents and I believe that at the very least a couple of additional meetings, better publication of those meetings, and a far more detailed "context" discussion from the Administration at the beginning of each meeting of "why" and "what" the issues are that are driving these considerations needs to precede the "expert's" in attendance commentary. In my opinion the intro was too short and the reliance on the experts to quick.

In the absence of such a preamble, I simply assumed that considerations under discussion must be a requirement of being a part or Metro – I am told by Councillor Bains, that it is not. This suggests to me that this subject and consideration is under our purview and direction as Residents of Lions Bay. And it is something that we must take financial responsibility for.

We have all individually decided to live in wonderful Lions Bay, and not for a second has any of us been unaware that we live on the side of a Mountain and that we may be due for an earthquake at some point in time, and that a 1:500 year and a 1:2500 year geological event could happen – the information presented last Tuesday was very interesting to me respecting the geology and fault lines of the mountain as well as respecting linking geological time to our own time frame and spans.

**Respecting jurisdiction:**

We are a very small Village of some 560 homes/lots and about 1500 residents. Our legal boundaries are fixed, and within them we are responsible. Outside those boundaries the responsibility lies with the Province.

My own impression from the Presentation last week is that the bulk of significant hazardous risks to Lions Bay would emanate in the areas of Provincially owned land – and that events in these areas could be catastrophic to Lions Bay in the absence of significant remediation investments being made by the Province at a scale of expenditures like those made after the events of 1983/4.

Respecting what I do consider to be our own Village responsibility – I do believe that there are areas on Village lands that we must identify and attend to, and that these are in anticipation of events that originate on Village property. These involve both public and private lands. A geological review that focusses on the Village lands, and highlights specific areas of concern, such as large rocks susceptible to downhill movement, poorly constructed rock walls/retaining walls on village and private property that pose a threat to neighboring property and possible erosion.

Respecting how this is done – I believe it is the Village's responsibility at the very least is to outline the scale and focus of circumstance and remediation for conditions within the Village lands, and preferably undertake an inventory of these conditions.

**Respecting Certified Professionals, and Land Owner responsibilities;**

As I understood the presentation of last week, much of the focus regarding hazardous "events" emanated from the steep sloped Provincial lands and possible concurrent/ensuing impacts on the Village lands. I believe we need to be very clear respecting Certified Professional focus and context in making their recommendations. Certified Professionals looking at individual private properties without a clear sense of what scope/level of hazardous event they are seeking to avert, through their observations and commentary, could result in a wide range /scale of recommendations and cost. Potentially to the detriment of development.

My own judgement underlying this comment is that there is virtually nothing that individual property owners can do on their own lands to avert/offset major events originating on the Provincial lands above Lions Bay.

Noting item **10.4.2 General Guidelines for Development on Land Subject to Potential Slope Hazard for DPA areas 3A,3B,3C, - and item 6. i, ii, and iii.**

This item places a great deal of scope and responsibility on the Certified Professional and could have a considerable impact on the scope of development and concurrent value of the land. The new proposed process being considered of what can and cannot be done on privately owned village lands being articulated by multiple individually retained Certified Professionals could have very significant unintended consequence's affecting size and design of residences and land value. Item 6 iii notes that the CP may rule on building's use, density and size. Currently we have much more certainty – size of lot, building areas/site ratios allowed, height and setbacks creating certainty and clarity of value.

I also would like a discussion respecting what it would take for the Village to be responsible for general recommendations (w Professional input) for DPA - 3A, 3B and 3C. rather than encumbering individual home owners with considerable costs and potentially a wide range of Certified Professional's interpretations of required actions on a site by site basis.

My last comment relates to concerns regarding the broader "public perception" of Lions Bay and the desirability of living here as well concerns that those perceptions may negatively impact our home and land values. With much of the presentation and focus on geological and seismic events etc. on lands outside our control, (Provincial lands) we need to be very careful and our focus should be on what our responsibilities are as a Village.

I apologize for any repetition and potential "broad brushing" at this time – the scope of the endeavour under consideration is large, complex – and needs to be scaled to what we can reasonably execute, and as a Village will support.

**Peter Wreglesworth,** Retired Architect AIBC, FRAIC

Dear Mayor and council,

Upon hearing that a bylaw for cutting trees 30 feet around buildings is a NO!!! This does not comply to our lots on a mountain. Also paying five thousand for a geotechnical report is a NO!!!! We need a bylaw protecting our trees especially healthy big trees that are here for a reason they stabilize preventing slides.

As a resident for over 40 years having one of the two Rhododendron gardens in the village where people have come from all over the world to see rare species and beautiful huge trees that naturally soak up lots of underground water, as we do live on the side of a mountain with lots of underground streams. Lions Bay is unique and cannot be compared to other places we have always lived in harmony with nature.

Sadly clear cutting has began in Lions Bay and the media has become involved again. This is a reminder of our slide over 40 years ago due to unsafe logging practises which caused such tragedy for the village, you see the slides in our water shed area now!! I have found this old letter from Lions Bay Development Ltd.

Lions Bay NEWSLETTER dated August 19, 1959

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Your water system.

Lions Bay is one of the few communities in Metropolitan Vancouver that has its own independent water supply. It is also one of the few systems hat does not require chlorinating.

The water system installed by the development company, draws its supply from Harvey Creek, feeding all sections of the community by gravity flow. The present water licence provides for 175,000 gallons per day, and the lowest stream level recorded on Harvey Creek has been 350,000 gallons per day. The water system will be turned over to the residents without charge as soon as an Improvement District is organized, and the only charges to be levied against the property owners will be for maintenance. As pumps and reservoirs are not required, these charges should be nominal.

Laboratory tests have shown that the water supply is pure and chlorination is not required. Further tests will be made regularly to make certain that this purity is maintained.

We need to ensure Lions Bay respects our natural landscape it is such a gift.

Sincerely,
Heather

To Whom It May Concern,
I am very much opposed to the introduction of Development Permit By-Laws in Lions Bay!
I have reviewed the details of the By-law and will be looking at this Cordilleran Report as well. It's just that seeing the details of the new DPA By-law for Lions Bay concerned me so greatly that I felt I wanted to send this email straight away to announce my objection.

I will be looking to hear more at the upcoming Meetings.

Sincerely,
Jennifer Monroe

THE MUNICIPALITY OF THE VILLAGE OF LIONS BAY

## PUBLIC INFORMATION MEETING

## NATURAL HAZARDS ASSESSMENT STUDY

## FOR DEVELOPMENT PERMIT AREA GUIDELINES

The public is invited to attend a Public Information Meeting regarding the recent natural hazards assessment study and the creation of development permit areas and associated guidelines to be held on:

**Date: Tuesday, January 30, 2018**

**Time: 7:00 – 9:00 pm**

**Location: Broughton Hall, 400 Centre Road, Lions Bay**

The purpose of the meeting will be to provide residents with information about the natural hazards report and about Lions Bay's initiative to create development permit areas for the protection of development from hazardous conditions.

Guidelines for these proposed development permit areas will be introduced as a proposed amendment to the Official Community Plan to deal with identified hazards related to coastal flooding, creeks, slope stability and wildfire.

Copies of the geoscientist's report and the planning consultant's report can be found on our Planning and Development Services page at lionsbay.ca.

For those who are unable to attend but wish to provide input, please send your comments and/or questions to: feedback@lionsbay.ca

# Public Info Meeting "Ground Rules"

## Safe and respectful environment

- Respect each other's' thinking and value everyone's contributions.
- You can respect another person's point of view without agreeing with them.
- We want to hear all points of view. Clapping can be intimidating. Regardless of whether you favour or oppose any particular statement, we ask that you refrain from clapping so that all speakers will feel comfortable making their views known.
- Be respectful of each speaker and allow the speaker to make his or her point without interruption.
- Focus on the issue, not the individual. challenge the idea, not the person

## Share time so that all can participate

- In the interests of giving the maximum number of people the opportunity to speak, please refrain from speaking a second time before everyone has a chance to speak a first time
- Respect the groups' time and keep comments brief and to the point.
- We can discuss detailed issues or property specific issues offline.

# DEVELOPMENT PERMIT AREAS FOR NATURAL HAZARDS
# PUBLIC INFORMATION MEETING AGENDA

1. Mayor: Thanks everyone for coming out tonight to our Public Information Meeting regarding our recent Natural Hazards Assessment Study and the proposed new Development Permit Areas. There's water on the table at the north end of the hall and of course washrooms are here and exits are there. And without further ado I'll turn things over to our Chief Administrative Officer, Peter DeJong.

2. Peter: Thank you Mayor Buhr and welcome all to this Public Information Meeting. This isn't a Council meeting or a Public Hearing; rather, it's an opportunity to have local geoscientist Pierre Friele present his report: Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards, for Lions Bay. We'll also have a presentation from our Planning Consultant, Steven Olmstead, regarding the draft Development Permit Area Guidelines proposed for inclusion in the OCP. There will be an opportunity to ask questions and provide comments after the presentations. In February, Council will consider 1st and 2nd reading of a bylaw incorporating the proposed guidelines into the OCP and there will then be a Public Hearing before the bylaw goes back to Council for consideration of adoption.

   We have been fortunate to have Pierre Friele and Steven Olmstead working on this project for us. Pierre is a professional geoscientist, doing business as Cordilleran Geoscience, and a member of the Association of Professional Engineers and Geoscientists of BC (APEGBC), licensed under the Engineers and Geoscientists Act. He specializes in Engineering Geology, typically involving landslide hazard and risk assessment, flooding and erosion protection, and paleo-environmental reconstruction (i.e. studying the landscapes of previous geological epochs). In addition to contract work, he has published a number of research papers on the Quaternary geology (last 2.6 million years or so) and volcanic hazards of the Sea to Sky corridor, including the late-glacial history of Howe Sound, the evolution of debris flow hazards on the Cheekye fan, and landslide hazard and risk at Mount Meager. Pierre lives, works and plays in the Sea to Sky corridor and is very familiar with the terrain and geologic features of Lions Bay, even more so now, I suspect, after having prepared this report.

Steve is recently retired from the Sunshine Coast Regional District, where he was the General Manager of Planning and Development for the past 5 years, after holding a similar position in Pemberton for the Squamish-Lillooet Regional District for 12 years. Prior to that, he was on the Sunshine Coast, the Central Kootenays and the Cariboo. In addition to his 35 years of experience, he holds a Masters in Community and Regional Planning from UBC as well as a Diploma in Urban Land Economics (UBC). He's a long-time member of the Canadian Institute of Planners and is a past Chair of the Association of Regional District Planning Managers, along with holding certificates in Local Government Administration. And of course he guided us through our recent zoning bylaw project, so he's getting to know Lions Bay pretty well.

Pierre will provide his presentation on his natural hazards assessment study and the mapping he has created for the proposed Development Permit Areas; and then Steve will provide his presentation regarding the proposed Guidelines, and we'll wrap up with a Q & A session.

There's a Speaker's List at the front table to avoid any line-ups at the mic, as well as Question Cards for those who'd like to put their thoughts to paper or have someone else read out their question.

If you wish to provide feedback after the meeting, you may do so by sending an email to feeback@lionsbay.ca. The materials on which tonight's presentations are based can be found via on the Reports and Documents page of our website, or via the link on the Planning and Development page.

3. Pierre: Thank you....[commences presentation]
4. Steve: Thanks [commences presentation].
5. Pierre/Steve: Question and Answer Session (Peter: Reminder re. speaker's list, question cards, etiquette, etc.)

# Village of Lions Bay
# Official Community Plan Designation Bylaw No. 408, 2008, Amendment Bylaw No. 525, 2018
# (Development Permits OCP Amendment)

**Public Information Meeting**

January 30, 2018

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## Purpose of the Meeting

To inform residents of the proposed Development Permit Area maps and guidelines to be incorporated in the Official Community Plan.

| | |
|---|---|
| Format: | Presentation followed by Q & A<br>Question cards available at the front table<br>(read or have read on your behalf) |
| Next Steps | |

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## Background

The original Lions Bay Zoning Bylaw contained provisions regarding Development Permits (DPs). This project was identified in the terms of reference for the 2016 Zoning Bylaw review and consolidation project; however additional geotechnical information was necessary to be able to implement Development Permits.

Cordilleran Geoscience was retained in the fall of 2017 to undertake the first community wide geotechnical assessment for Lions Bay. Cordilleran's work forms the technical basis for the Development Permit Areas under consideration.

## Local Government Act Authority for DPs

*Local Government Act* requires that DP areas be designated in an Official Community Plan.

**Designation of development permit areas**

**S. 488** (1) An official community plan may designate development permit areas for one or more of the following purposes:

**(b) protection of development from hazardous conditions;**

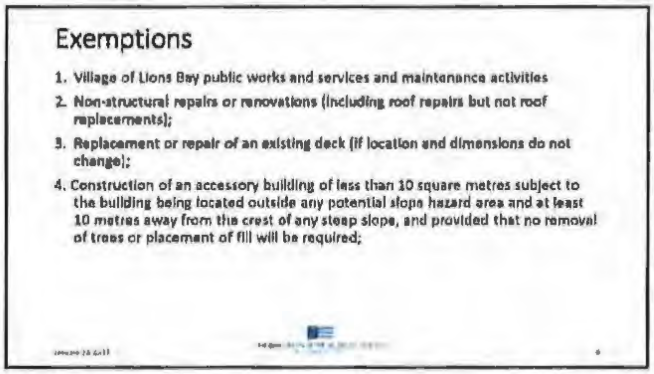
Development permits may also be implemented for protection of the natural environment; to guide the "form and character" of various types of development; protection of farming, energy conservation, water conservation and reduction of GHGs

## Activities that Require a Development Permit

In a Development Permit Area:

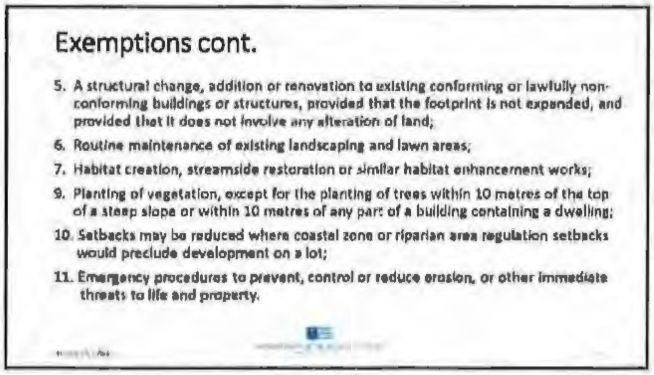
a. land within the area must not be subdivided;
b. construction of, addition to or alteration of a building or other structure must not be started;
c. land within the area must not be altered;

unless the owner first obtains a development permit or an exemption under section 3 applies.



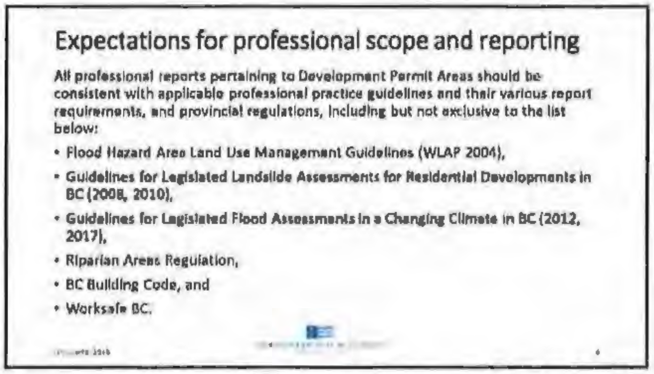
## Exemptions

1. Village of Lions Bay public works and services and maintenance activities
2. Non-structural repairs or renovations (including roof repairs but not roof replacements);
3. Replacement or repair of an existing deck (if location and dimensions do not change);
4. Construction of an accessory building of less than 10 square metres subject to the building being located outside any potential slope hazard area and at least 10 metres away from the crest of any steep slope, and provided that no removal of trees or placement of fill will be required;



## Exemptions cont.

5. A structural change, addition or renovation to existing conforming or lawfully non-conforming buildings or structures, provided that the footprint is not expanded, and provided that it does not involve any alteration of land;
6. Routine maintenance of existing landscaping and lawn areas;
7. Habitat creation, streamside restoration or similar habitat enhancement works;
9. Planting of vegetation, except for the planting of trees within 10 metres of the top of a steep slope or within 10 metres of any part of a building containing a dwelling;
10. Setbacks may be reduced where coastal zone or riparian area regulation setbacks would preclude development on a lot;
11. Emergency procedures to prevent, control or reduce erosion, or other immediate threats to life and property.



## Expectations for professional scope and reporting

All professional reports pertaining to Development Permit Areas should be consistent with applicable professional practice guidelines and their various report requirements, and provincial regulations, including but not exclusive to the list below:

- Flood Hazard Area Land Use Management Guidelines (WLAP 2004),
- Guidelines for Legislated Landslide Assessments for Residential Developments in BC (2008, 2010),
- Guidelines for Legislated Flood Assessments in a Changing Climate in BC (2012, 2017),
- Riparian Areas Regulation,
- BC Building Code, and
- Worksafe BC.

## Qualified Registered Professional Reports

- Identification of natural hazards or other hazards identified in background reports and field work. Includes also a description of all potential hazards and rationale for excluding some.
- For all hazards, separate and in aggregate, analyses of the georisk affecting the proposed development and evaluation against the Village of Lions Bay safety policy.
- Provides technically justified siting constraints or protective measures, as required.
- Provides implementation steps for the identified structural mitigation works (in terms of design, construction and approval). Where protective works are recommended, the report must identify where follow up field verification is required to ensure conformance to design.
- Discusses uncertainties and describes any residual risk that would remain.
- States that "the land may be used safely for the use intended" with siting constraints, protectives measures or restrictive covenant, as stipulated in the report.

## Multiple Hazards and Adjacent Properties

- For sites located within multiple Hazard DPAs: a coordinated approach between the respective qualified registered professionals will be required to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met.
- Where a report by a qualified registered professional identifies protective works or measures to mitigate hazard(s) affecting a lot, those works or measures must not transfer risk to any other lots.

## Lions Bay Natural Hazard DPAs

Four broad categories of Development Permit Area are proposed:

Coastal Zone Hazards,
Creek Hazards,
Slope Hazards and
Wildfire Hazards.

Cordilleran Geoscience undertook the technical assessment to define the boundaries and recommended guidelines for the first three proposed DPA's while the Planning Consultant prepared the Wildfire Hazard DPA based on the 2007 Lions Bay Community Wildfire Protection Plan prepared by Blackwell and Associates and current best municipal practice.

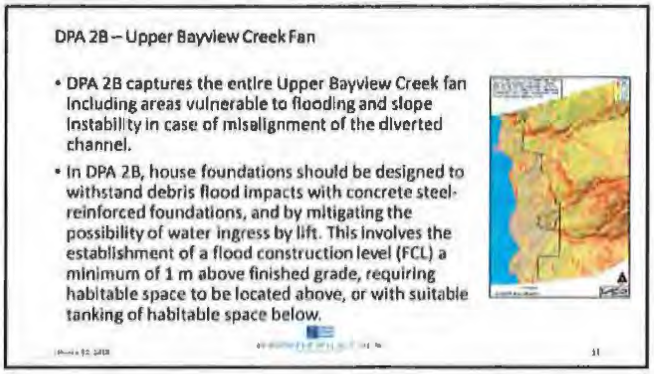
## DPA 1: Coastal Hazards

- Coastal zone hazards (DPA 1) include flooding and erosion from a combination of processes including tides, storm surge, wave action and sea level rise.
- DPA 1 extends from the existing natural boundary of the sea to the 8 metres CGD (Canadian Geodetic Datum)
- Within DPA 1, development applications shall include a coastal flood hazard assessment prepared by a qualified registered professional to define the year 2100 shoreline position and the derived flood construction level, appropriate setback and any necessary mitigation work.

## DPA 2 - Creek Hazards

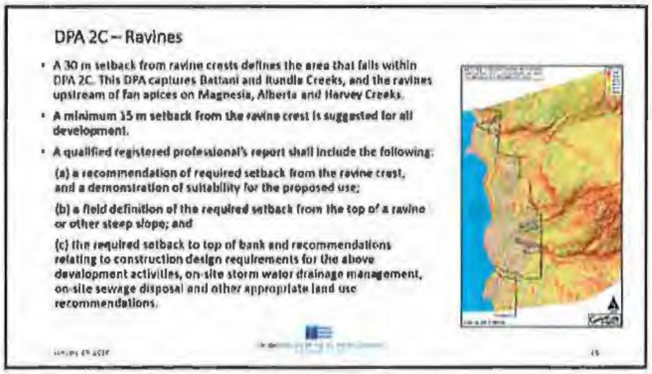
### DPA 2A- Mitigated Debris Fans

- DPA 2A includes land on the formerly active portion of the Magnesia Creek fan and the composite Alberta/Harvey Creek fans that could be affected should existing mitigation structures become overwhelmed by a large, rare event.
- All development within DPA 2A must be supplied with appropriate flood proofing against potential overland flows by establishing an FCL a minimum of 1 m above finished grade and construction using concrete reinforced foundation to the FCL



### DPA 2B – Upper Bayview Creek Fan

- DPA 2B captures the entire Upper Bayview Creek fan including areas vulnerable to flooding and slope instability in case of misalignment of the diverted channel.
- In DPA 2B, house foundations should be designed to withstand debris flood impacts with concrete steel-reinforced foundations, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level (FCL) a minimum of 1 m above finished grade, requiring habitable space to be located above, or with suitable tanking of habitable space below.



### DPA 2C – Ravines

- A 30 m setback from ravine crests defines the area that falls within DPA 2C. This DPA captures Battani and Rundle Creeks, and the ravines upstream of fan apices on Magnesia, Alberta and Harvey Creeks.
- A minimum 15 m setback from the ravine crest is suggested for all development.
- A qualified registered professional's report shall include the following:

  (a) a recommendation of required setback from the ravine crest, and a demonstration of suitability for the proposed use;

  (b) a field definition of the required setback from the top of a ravine or other steep slope; and

  (c) the required setback to top of bank and recommendations relating to construction design requirements for the above development activities, on-site storm water drainage management, on-site sewage disposal and other appropriate land use recommendations.

## DPA 3 - Slope Hazards

### General Guidelines for Development on Land Subject to a Potential Slope Hazard

- Development should minimise any alterations to steep slopes, and the development should be designed to reflect the site rather than altering the site to reflect the development.
- Potential slope hazard areas should remain free of development, or, if that is not possible, then:
  a) appropriate mitigation measures shall be identified to reduce risk to an acceptable level. Risk for both the subject property and any adjacent or nearby lands should be addressed; and
  b) conditions (for example conditions relating to the permitted uses, density or scale of building) shall be imposed as necessary to reduce potential hazard to acceptable levels,

both as determined by a qualified registered professional in a preliminary assessment or detailed assessment report.

## Landslide Safety Policy

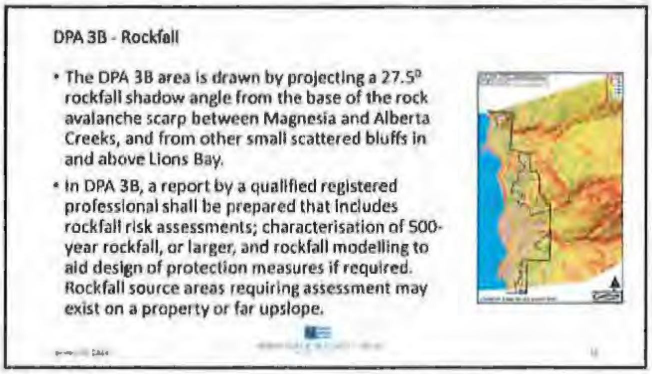
For all landslide hazards, the Village of Lions Bay adopts a landslide safety policy that employs Landslide Risk Assessment for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes as determined relevant by the qualified registered professional.

Risk assessments may be qualitative or quantitative in nature. As part of the risk assessment approach, a minimum landslide magnitude to consider is the 1:500-year event, but larger events up to a 1:2450-year earthquake triggered landslide may be considered where deemed appropriate by the qualified registered professional.

## DPA 3A - Open-slope Landslides

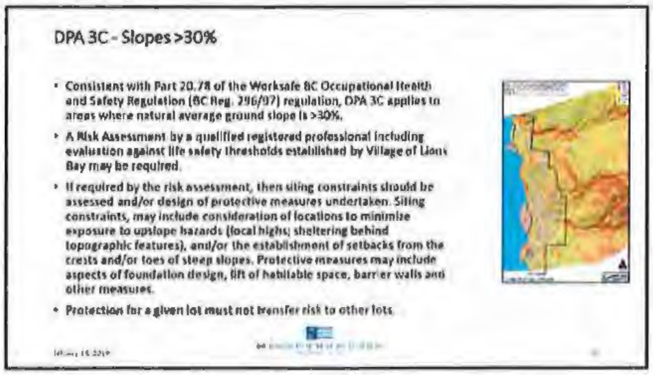
In DPA 3A, a report by a qualified registered professional should consider the following:

- Description of the magnitude and frequency of the hazards.
- A Risk Assessment, including evaluation against life safety thresholds established by Village of Lions Bay.
- If required by risk assessment, then siting constraints and/or design of protective measures may be required.
- For stability of slopes on or about the proposed development site, assessment of slope failure modes and limiting factors of safety, and stability during seismic events.
- Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability.



### DPA 3B - Rockfall

- The DPA 3B area is drawn by projecting a 27.5° rockfall shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other small scattered bluffs in and above Lions Bay.
- In DPA 3B, a report by a qualified registered professional shall be prepared that includes rockfall risk assessments; characterisation of 500-year rockfall, or larger, and rockfall modelling to aid design of protection measures if required. Rockfall source areas requiring assessment may exist on a property or far upslope.

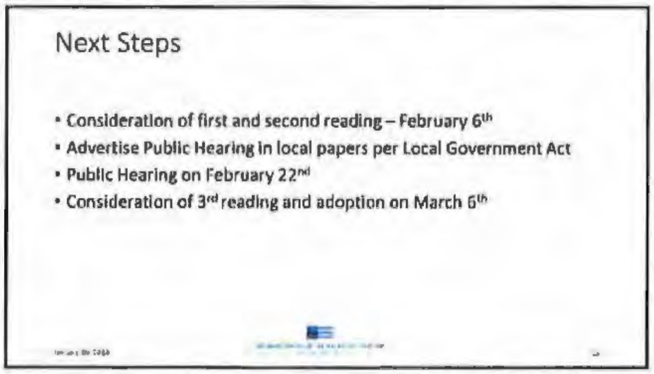


### DPA 3C - Slopes >30%

- Consistent with Part 20.78 of the Worksafe BC Occupational Health and Safety Regulation (BC Reg. 296/97) regulation, DPA 3C applies to areas where natural average ground slope is >30%.
- A Risk Assessment by a qualified registered professional including evaluation against life safety thresholds established by Village of Lions Bay may be required.
- If required by the risk assessment, then siting constraints should be assessed and/or design of protective measures undertaken. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures.
- Protection for a given lot must not transfer risk to other lots.

## DPA 4 - Wildfire Hazard

- A Wildfire Risk Management System (WRMS) was developed by B.A. Blackwell and Associates in 2007 as part of the Village of Lions Bay Community Wildfire Protection Plan (CWPP). The WRMS identified the core area of the Village as being at moderate to high risk from wildfire. The entire Village of Lions Bay is identified in the CWPP as being a high vulnerability interface area at risk from "spotting".
- All land within the Village of Lions Bay is designated as DPA 4.
- Guidelines include requirements for fire resistive materials such as fire retardant roofing materials and construction practices such as exterior walls should be sheathed with fire resistive materials.
- Landscaping guidelines for land within 10 metres of a building.



## Next Steps

- Consideration of first and second reading – February 6th
- Advertise Public Hearing in local papers per Local Government Act
- Public Hearing on February 22nd
- Consideration of 3rd reading and adoption on March 6th

## Discussion

# THE MUNICIPALITY OF THE VILLAGE OF LIONS BAY

| | | | |
|---|---|---|---|
| **Type** | **Information Report** | | |
| **Title** | **Village of Lions Bay OCP Amendment – Development Permit Areas** | | |
| **Author** | **Steven Olmstead,**<br>**Planning Consultant** | **Reviewed By:** | **Peter DeJong, CAO** |
| **Date** | **January 4, 2018** | **Version** | **1** |
| **Issued for** | **January ~~9~~, 2018** 16 csc - | | |

**Recommendations:**

THAT the Information Report, "Village of Lions Bay OCP Amendment – Development Permit Areas" be received.
AND THAT a public information and consultation meeting be scheduled for January 30, 2018 at 7:00 p.m. at Broughton Hall, Lions Bay.

**Attachments:**

1. Cordilleran Geoscience report titled "The Municipality of the Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards" and dated January 4, 2018;
2. Draft OCP amendment schedule to incorporate Development Permit Areas.

**Background:**

Lions Bay is a community susceptible to a variety of natural hazards and has a history of significant events, including events involving loss of life. Hazards potentially impacting Lions Bay include landslide, landslip, rockfall, erosion, debris flows, debris torrents, coastal flooding and wildfire.

Following the debris torrent events of the early 1980s, Thurber Engineering prepared a report on behalf of the Province which looked at stream hazards in Howe Sound, including Lions Bay. The Thurber report formed the basis for Provincial construction of infrastructure designed to mitigate future flood risk. Since then, while many "site specific" geotechnical engineering reports have been prepared in conjunction with building permit applications, a reconnaissance level of technical analysis of terrain hazards has never been undertaken.

In conjunction with the recent zoning bylaw update, reference to Development Permits (DPs) was removed from zoning, as Development Permit Areas must be established in the Official Community Plan. At the direction of Council, staff put out an RFP and in early fall 2017, a consultant (Cordilleran Geoscience, Attachment 1) was retained to provide an assessment of natural hazards affecting the Village of Lions Bay. Based on the report prepared by Cordilleran Geoscience, a draft amendment to the OCP bylaw has been prepared (Attachment 2) to designate Development Permit Areas (DPAs) and provide guidelines in the OCP related to the issuance of DPs. The priority is to establish DPAs for protection of development from hazardous conditions.

The primary objectives of the hazards assessment study project were to:

a) conduct a review and update of any existing geotechnical information, reports or studies pertaining to Lions Bay available to the consultant;

b) develop DPA descriptions and a map, including the rationale and guidelines for land alteration, building construction and subdivision; and

c) utilize the latest version of the APEGBC "Guidelines for Landslide Assessments for Proposed Residential Developments in BC" and the BC Building Code.

Four broad categories of Development Permit Area are proposed: Coastal Zone Hazards, Creek Hazards, Slope Hazards and Wildfire Hazards. Cordilleran Geoscience undertook the technical assessment to define the boundaries and recommended guidelines for the first three proposed DPA's while the Planning Consultant prepared the Wildfire Hazard DPA based on the 2007 Lions Bay Community Wildfire Protection Plan prepared by Blackwell and Associates and current best municipal practice. For each DP category, the justification for the designation as a development permit area is provided, the extent of the DP area is described (and mapped) and guidelines relating to development within the DP area are provided.

**Next Steps:**

1. Schedule a public information/consultation meeting for January 30, 2018
2. Consideration of first and second reading – February 6th
3. Advertise Public Hearing in the Pique Newsmagazine – February 8th and 15th
4. Public Hearing on February 22nd
5. Consideration of 3rd reading and adoption on March 6th.

**Communication Plan:** Schedule public information and consultation meeting.

# The Municipality of the Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards.

Submitted by
Cordilleran Geoscience
PO Box 612,
Squamish, BC
V8B 0A5

Submitted to
Peter DeJong, BA, LLB, CRM
Chief Administrative Officer
The Municipality of the Village of Lions Bay
400 Centre Road,
Lions Bay, BC
V0N 2E0,
Canada

Draft V1: November 30, 2017; Revised V2 December 19, 2017; Final V3 January 4, 2018

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# 1. Introduction

The Village of Lions Bay is a residential community located on the east side of Howe Sound, southwestern British Columbia, approximately 10 km NE of Horseshoe Bay, West Vancouver. It is part of the Metro Vancouver Regional District. The first residences were developed in the 1960s and the Village was formally incorporated in 1971.

The timing of development just precedes the beginnings of landslide hazard/risk management in British Columbia. At Rubble Creek below the Barrier, near Whistler, the Garibaldi Station subdivision expropriation (~1971) and subsequent court case established a precedent for land use decisions based on perceived risk (Berger 1973). At the same time (~1974/75), there was reversal on subdivision approval on Cheekye fan in Squamish; the Cataline subdivision of Lillooet Lake was permitted with conditions with respect to debris flow hazards (Piteau 1976); and Sunset Highlands, West Vancouver, was permitted with conditions specific to rockfall hazard (Piteau 1981).

At Lions Bay, the sidewall of Howe Sound rises steeply from sea-level to the ridge crest at 1500 m elevation, with the highest peaks being Brunswick Mountain at 1788 m and the West Lion at 1646 m. There are several large watersheds which bisect the fjord sidewall and traverse the community, including Magnesia Creek, Alberta Creek and Harvey Creek. Smaller creeks include Battani, Lions Brook and Rundle creeks.

Given this steep terrain and the coastal maritime setting there are a number of geohazards that may affect the community. These include coastal hazards, creek hazards and hillslope hazards. While there is existing Provincial legislation that gives local government the authority to require geotechnical assessment on a case by case basis when triggered by development proposals, to date, due to establishment of the Village before geohazards were regularly considered in development approvals, the Village of Lions Bay has no overarching hazard and risk management framework that allows a consistent approach to guide land development. This is the first all-hazard (coast, creek & slopes) review for the Village of Lions Bay.

# 2. The Concept of Hazard & Risk

A hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (see Table 1). Consequence (Table 2) is a product of factors, including whether a given hazard will reach a site, whether elements at risk (e.g., houses/people) will be present when the site is affected by the hazard, how vulnerable the elements at risk are to the hazard affecting the site, and the value of the elements at risk or the number of persons exposed. The product of the factors Hazard and Consequence equals Risk.

No activity is free of risk, and the concept of safety embodies risk tolerance. In Canada and BC there is no legislated guidance for risk tolerance to geohazards, and the term "safe" has not been defined. In considering risk tolerance, an important concept is that risk of loss of life from natural hazards should not add substantially to those that one is typically subject to (e.g., 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).

**Table 1.** Qualitative hazard frequency categories.

| Qualitative frequency | Annual return frequency | Probability | Comments |
|---|---|---|---|
| Very high | >1:20 | >90% in 50 years | Hazard is well within the lifetime of a person or typical structure. Clear fresh signs of hazard are present. |
| High | 1:100 to 1:20 | 40% to 90% in 50 years | Hazard could happen within the lifetime of a person or structure. Events are identifiable from deposits and vegetation, but may not appear fresh. |
| Moderate | 1:500 to 1:100 | 10% to 40% in 50 years | Hazard within a given lifetime is possible, but not likely. Signs of previous events may not be easily noted. |
| Low | 1:2500 to 1:500 | 2% to 10% in 50 years | The hazard is of uncertain significance. |
| Very low | <1:2500 | <2% in 50 years | The occurrence of the hazard is remote. |

**Table 2.** Simplified consequence assessment.

| Consequence | Description |
|---|---|
| Very High | Direct impact with extensive structural damage; loss of life & limb. |
| High | Direct or indirect impact with some potential for structural damage; loss of life & limb. |
| Moderate | Indirect debris impact. No structural damage but damage to houses and property. |
| Low | Minor property damage only. |
| Very Low | Virtually no damage. |

## 3. Project Scope

The purpose of this report is to review geohazards affecting the Village of Lions Bay and to create a geohazard Development Permit Area (DPA) planning framework to provide a consistent basis for managing georisk.

This report will identify potential hazards and assess the potential reach of these hazards. It is beyond the scope of work to assess the frequency of occurrence of identified hazards, as that is typically a very detailed assessment, often requiring subsurface examination, stratigraphic analysis, radiometric dating of soil layers and advanced computer modelling. Thus, this report cannot make judgements on hazard or risk acceptability at any given site. To avoid deeming an area safe, when in fact rare but destructive hazards might affect a site, the Development Permit Areas (DPA) framework needs to be conservative, erring on the side of caution.

The primary deliverable will be a natural hazards DPA framework that will provide a rationale for development based on existing professional guidelines and regulations. The proposed DPAs are based on review of the geomorphic setting, site-specific geotechnical reports, historic airphotos, high resolution topographic mapping and field observation.

The work is conducted by Pierre Friele, M.Sc., P.Geo., of Cordilleran Geoscience with technical support provided by Gioachino Roberti, M.Sc.

# 4. Geomorphic Context

## 4.1 Bedrock geology

Bedrock geology within Village of Lions Bay consists of lower-Cretaceous Gambier Group marine sedimentary and volcanic rocks (imapbc, https://maps.gov.bc.ca/ess/hm/imap4m/). Outcrops viewed in the field appear primarily to consist of greenish volcanic rock that is highly fractured (decimeter fracture spacing) with red oxidation on exposed surfaces. Upslope, the headwaters of Magnesia, Alberta and Harvey Creeks are underlain by mid-Cretaceous granodiorite of the Coast Plutonic Complex which has intruded into the older Gambier rocks. These plutonic rocks are more competent. Prominent northwest trending faults and jointing creates structural discontinuities that may be source of instability.

## 4.2 Quaternary history and surficial geology

Surficial geology in the area is a product of Pleistocene glaciation and post-glacial erosional processes (Blais-Stevens 2008). The last, or Fraser, glaciation began 33,500 years ago (all ages converted to calendar from radiocarbon scale) and reached its peak 17,500 years ago. Howe Sound south of Porteau Cove was ice free by 15,000 yr BP (Fairbanks et al. 2005), but ice retreat was delayed several thousand years by grounding, with several minor readvances forming the Porteau end moraine (Friele and Clague 2002a, 2002b). The inner basin of Howe Sound was not ice free until after 12,500 yr BP. According to Jackson et al. (2014), glacial marine sedimentation (mud with stones dropped from icebergs) had ceased by 10,600 yr BP.

The weight of Pleistocene ice depressed the land surface. During deglaciation, the sea flooded the land to a level of up to 220 m higher than today. Sea-level fell rapidly as the land rebounded such that by about 10,000 years ago sea-level had fallen to 10 m below present. By 5700 years ago sea-level had risen to approximately modern levels (Clague et al. 1988).

Morainal materials deposited during the last glaciation are known as Vashon Drift (a complex of till, glaciofluvial and glaciolacustrine sediments) (Photo 1). Glaciofluvial deltaic and glaciomarine sediments were deposited up to an elevation of 220 m (Photo 2).These sediments are known as Capilano Formation. Glaciofluvial deltaic sediments are found in the gravel quarry at Magnesia Creek (120-140 m elevation) and the fan-delta morphology extends upslope to its apex at 280 m elevation, while bouldery fan-delta sediments at Harvey Creek extend up to 220 m elevation. Fine grained marine sediments are typically found on benchlands, such as the east point of Anvil Island where clays were mined for manufacturing of brick.

Following deglaciation, fluvial and mass wasting processes rapidly reworked glacial sediments. Process rates declined over time such that by no later than 7,500 years ago the landscape was similar to today (the paraglacial paradigm; Church and Ryder 1972). In Howe Sound, in subaqueous fjord settings, Jackson et al. (2014) reported that in areas removed from valley side influence significant deposition had ceased by 10,600 yr BP, but in fjord sidewall areas within influence of debris fan-deltas at Lions Bay significant sedimentation did not cease until 5500 yr BP. While mass movement processes were much more active in the deglacial and immediate post glacial periods owing to the steep relief, these processes are still active today (Jordan and Slaymaker 1991; Friele and Clague 2009), albeit at a much-reduced rate.

Post-glacial sediments, formed in modern colluvial, fluvial and beach environments, are referred to as Salish sediments. In post-glacial time, erosion by streams and mass movement (debris slides, debris flow, rockfall, rock avalanche, snow avalanche) will have continued to rework bedrock and soil mantled slopes. Steep rockfall talus aprons have developed on mid to lower slopes (Photo 3). Magnesia, Alberta and Harvey Creeks have become incised into their respective paraglacial debris cones and inset alluvial fans have formed at their mouths.

## 4.3 Climate

Howe Sound is subject to a maritime climate with moderated temperature regime and winter precipitation peak driven by cyclonic storms. Climate Normals (Environment Canada, 2017) for a nearby station, Squamish STP at 4 m elevation, are provided in Figure 1. Temperatures are cool from December through February, rising to a peak in July and August. There is a pronounced precipitation peak starting in October and extending through January, diminishing to a low in June through September. At that station, mean annual precipitation is 2230 mm and the extreme recorded daily precipitation was 128 mm/24 hrs on February 1, 1991.

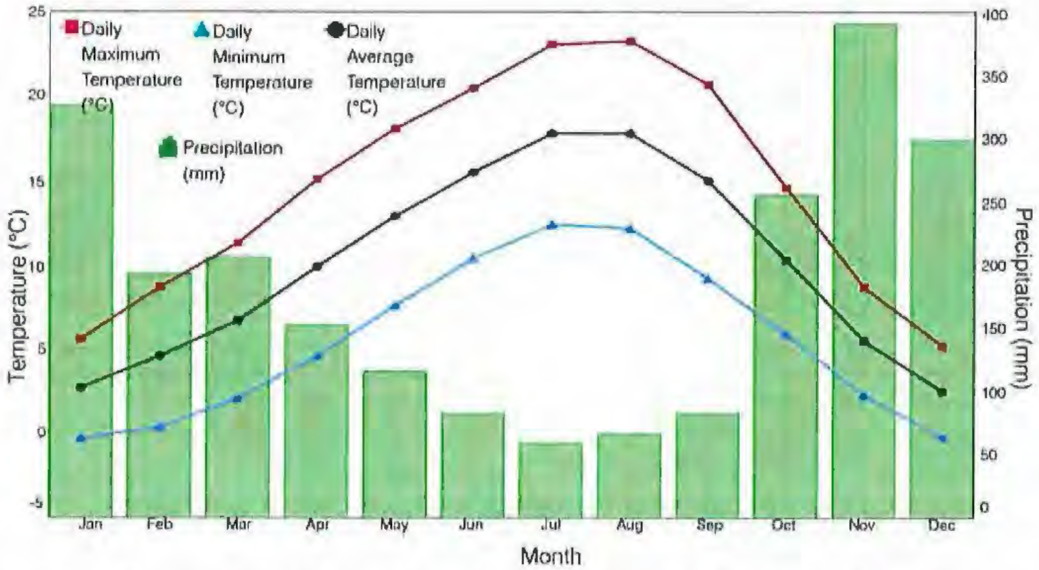


**Figure 1.** Temperature and Precipitation Graph for 1981 to 2010, Canadian Climate Normals, Squamish STP (4 m elevation).

Precipitation is strongly enhanced with elevation as mountain slopes drive air masses upward, a phenomenon known as orographic uplift. Climate statistics (2001-2010) for various elevations were estimated using the web-based tool ClimateBC (http://www.climatewna.com/ClimateBC_Map.aspx) and are presented in Table 3. Annually, approximately 2000 mm precipitation falls at sea-level, increasing to 4000 mm at the ridge crest. Assuming a wet snow density of 50%, then 15 cm of snow, amounting to 5% of winter precipitation, may be experienced at sea-level, increasing to 1 m, or 25% of winter precipitation, at mid elevation and 3 m, or 50% of winter precipitation, at the ridge crest. This indicates that at mid and high elevations, both rain and rain-on-snow are important drivers of winter runoff.

**Table 3.** Climate statistics for Lions Bay, showing the effect of elevation.

| Elevation (m) | Mean annual temperature (C) | Mean annual precipitation (mm) | Mean winter precipitation (mm) | Precipitation as snow (mm water equivalent) |
|---|---|---|---|---|
| 0 | 9.3 | 1938 | 1552 | 83 |
| 500 | 8.2 | 2228 | 1779 | 158 |
| 1000 | 5.7 | 3106 | 2464 | 635 |
| 1500 | 3.1 | 3872 | 3055 | 1665 |

Intensity-duration-frequency (IDF) curves were prepared for Metro Vancouver by BGC (2009). Their Zone 8, the North Shore Mountain slope, is most representative of conditions at Lions Bay. The IDF for Zone 8 is provided in Table 4. It indicates that a 24hr rainfall of about 100 mm would be considered a 2-year storm, while a 100 yr storm could deliver upwards of 200 mm/24 hrs.

**Table 4.** Intensity-duration-frequency data (mm/hr) for Zone 8, Metro Vancouver. Source: BGC 2009.

| Duration | 2-year | 10-year | 50-year | 200-year |
|---|---|---|---|---|
| 1 hr | 14.9 | 23.2 | 30.4 | 36.5 |
| 24 hr | 3.9 | 6.2 | 8.1 | 9.8 |
| 48 hr | 2.9 | 4.6 | 6.1 | 7.3 |
| 72 hr | 2.5 | 3.9 | 5.1 | 6.2 |

## 4.4 Hydrology

MacKay Creek in North Vancouver provides a good analog for the hydrologic regime in Lions Bay creeks (Figure 2). From October through April, the hydrologic base level is driven by rain and rain on snow, and sustained from May through June by a snowmelt freshet. Instantaneous storm peaks may occur in any season, but typically in the fall and early winter, from October through December.

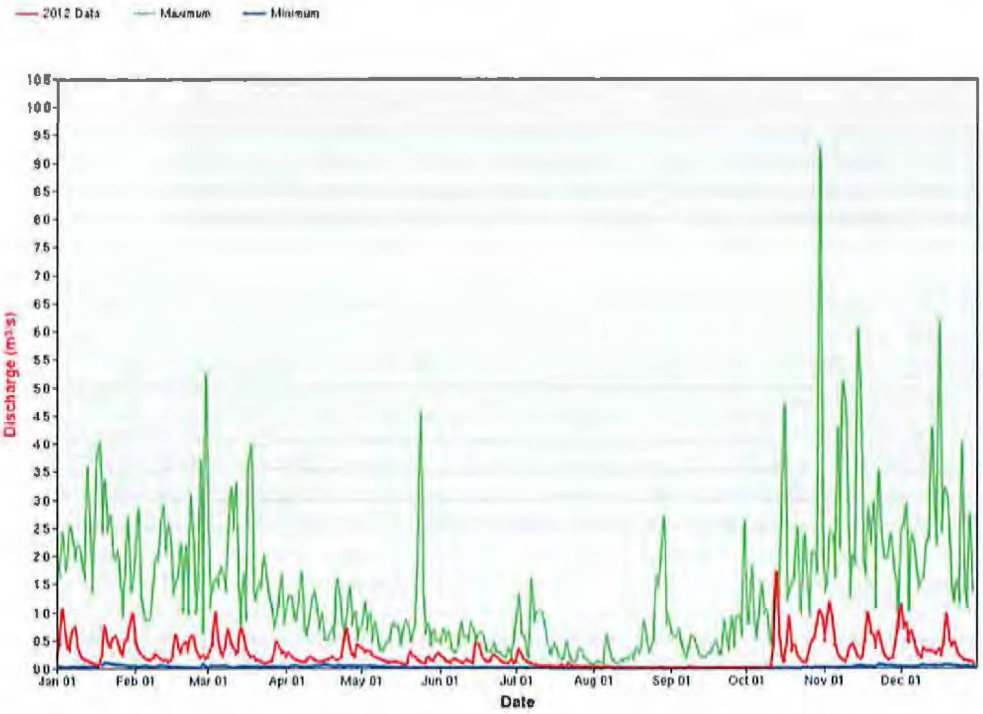


**Figure 2.** Daily discharge Mackay Creek at Montroyal Boulevard (08GA061), 1970-2012. Basin area is 3.63 km$^2$, compared to 7, 1.2 and 4.7 km$^2$ for Harvey, Alberta and Magnesia creeks respectively.

# 5. Methods and Materials

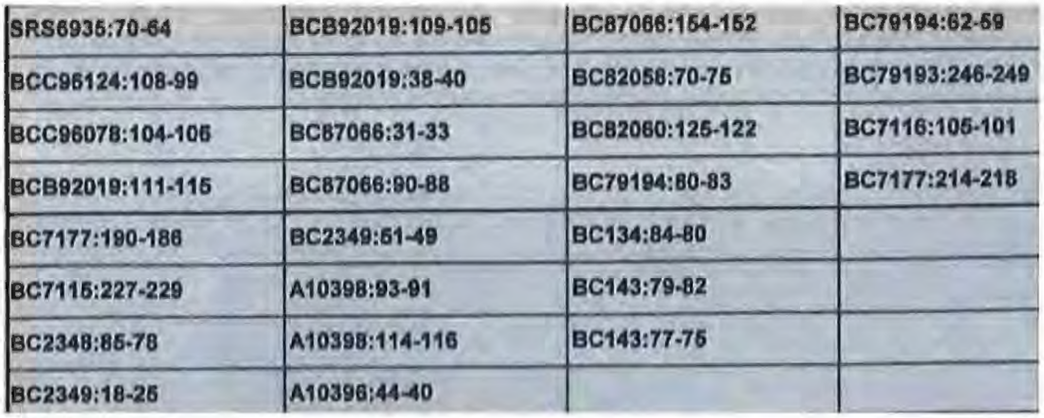
## 5.1 Background review

A list of background documents provided by the Village of Lions Bay have been reviewed and summarised below and in Appendix 1.

## 5.2 Airphoto review

Table 5 provides a list of airphotos reviewed for this project. The area includes Lions Bay and areas to the north including M-Creek. Airphoto flight lines include the years 1939, 1946, 1957, 1968, 1979, 1982, 1992, 1996 and 2004.

**Table 5.** Airphotos reviewed in this study.



| | | | |
|---|---|---|---|
| SRS6935:70-64 | BCB92019:109-105 | BC87066:154-152 | BC79194:62-59 |
| BCC96124:108-99 | BCB92019:38-40 | BC82058:70-75 | BC79193:246-249 |
| BCC96078:104-106 | BC87066:31-33 | BC82060:125-122 | BC7116:105-101 |
| BCB92019:111-115 | BC87066:90-88 | BC79194:80-83 | BC7177:214-218 |
| BC7177:190-186 | BC2349:51-49 | BC134:84-80 | |
| BC7115:227-229 | A10398:93-91 | BC143:79-82 | |
| BC2348:85-78 | A10398:114-116 | BC143:77-75 | |
| BC2349:18-25 | A10396:44-40 | | |

These airphotos have been reviewed many times by previous authors to identify landslide events affecting torrents channels. In this study, we applied a new photogrammetric technique, Structure from Motion (SfM), to generate orthophotos and Digital Elevation Models (DEMs) for subsequent photo years. The intent was to provide a chronology of land development from orthophoto observations, and, following the methods outlined by Roberti et al. (2017), to test if DEMs could be differenced to identify areas of slope movement. The orthophoto analysis provided valid information but the topographic differencing did not provide good results. Due to poor photo quality, and tree cover in areas of interest, the required DEM accuracy could not be achieved. Orthophotos and DEMs are provided for use of Village of Lions Bay.

## 5.3 LIDAR base map

In 2012, airborne LIDAR was flown for Lions Bay. Various products including hillshade, slope thematic and high resolution (e.g., 1 m contour interval) topographic mapping were derived from the LIDAR. The hillshade model shows ground surface expression in great detail and is utilised to map specific landforms and structural features. Slope thematic mapping is useful in delineating areas with different landslide susceptibilities, as slope is characteristic of certain landform types, like fans, talus or ravine slopes, and is one of the primary factors governing stability. Slope classes used include 0-30%, gentle terrain including debris fans; 30-50%, moderate sloping terrain with variable cover; 50-60% and 60-70%, moderately steep terrain with variable cover; and 70-90% for steep terrain, typically rock covered with till and colluvial veneer; and >90% slopes typically bedrock outcrop. Topographic maps are similarly useful. All derived map bases are georeferenced and are used within Tablet devices for field mapping. The Geomorphic

Map and Development Permit Maps that accompany this report are presented at 1:10,000 scale, with 5 m contours, hillshade and slope theming. For final presentation, slope theming is averaged over 10 m pixels to smooth anthropogenically terraced topography.

## 5.4 Cadastral data

The Village of Lions Bay has provided shapefiles delineating lots and spreadsheets with various information for each.

## 5.5 Field traverses (Map 1)

Field traverse conducted by Cordilleran in Lions Bay include:

- On November 9, 2011, the terrain in the vicinity of the water tank near Rundle Creek was examined.
- On April 26 and May 8-9, 2012, Cordilleran traversed slopes between Alberta and Magnesia Creek to assess terrain potentially affected by the old logging road, now the Harvey Trail.
- On July 6, 2012, the vicinity of Rundle Creek was traversed to examine the potential consequence of windthrow.
- On October 26, 2014, Cordilleran conducted a review of a small landslide that occurred directly upslope the Harvey Creek water intake.
- On June 9, 2016, Cordilleran conducted a review of 251 Stewart Road and terrain upslope within the newly identified potential rock avalanche scarp.
- In 2017, as part of this project, field traverses were conducted on October 17, 25, and November 2, 8, 9 & 29.

All observation sites from traverses indicated have been plotted on the appended Map 1 to provide an indication of the level of ground trothing. Map 2 provides an overview of Geomorphic Features. Appendix 3 presents annotated photos from select field observation sites discussed in the report text. Maps 3-9 delineate Development Permit Areas (DPAs).

# 6. Background Reports

## 6.1 Channelised torrents and highway cut rockfalls, Howe Sound

Since the development of the highway in the 1960s and the occurrence of numerous destructive debris torrents on steep creeks in the early 1980s, rockfalls and channelized debris flows affecting the highway, and mitigation of both, have featured in numerous reports.

Reports by Hungr and Morgan (1984), Hungr et al. (1984), Lister et al. (1984), VanDine (1985) and Bovis and Dagg (1987) describe the steep creek debris flow, or "torrent" phenomenon and provide methodologies to identify, assess magnitude and frequency, and design remedial measures. Such measures were implemented in Lions Bay in 1985 and 1987 on Magnesia, Alberta and Harvey Creeks, and on other steep channels affecting Highway 99 along Howe Sound.

Reports by Bunce et al. (1997) and Hungr et al. (1999) document the rockfall hazard affecting highway and railway corridors in BC with special attention to Highway 99.

Eisbacher (1983), Evans and Savigny (1994) and Couture and VanDine (2004) (and others) are field trip guidebooks that draw from earlier reports to present useful summaries of the hazards in the region. Earle

(2003) provides a very nice collection of photos documenting the damages caused by the 1980s debris flows and the construction of remedial measures.

The Septer (2006) and Blais-Stevens (2008) reports are catalogues of flood and landslide hazard events collated from media and other reports. The Septer (2006) document was scanned using the keywords Lions Bay, Magnesia, Alberta, and Harvey to create a list of hazards that have affected the Lions Bay area in historic time (Appendix 2). Aside from the well-known creek and rockfall hazards that have affected the Lions Bay area, some useful insight into the Upper Bayview area was gained, documenting the timing of the diversion of Lions Brook toward Alberta Creek and subsequent slope instabilities that resulted in 1972 affecting several properties.

## 6.2 Site-specific reports in Lions Bay

Several site-specific reports conducted within Village of Lions Bay were reviewed for this project. Short summaries of each are provided in the Appendix 1. Overall, the reports provide an indication of the types of hazard issues affecting Lions Bay, including rockfall (Golder 1989; Fieber Rock Engineering Services, 2011; Geopacific 2016; Cordilleran 2016); open-slope slides (Cordilleran 2014a; BGC 2012/2013); road stability and associated downslope risks (Golder 2006; Cordilleran 2011; Cordilleran 2012b, 2013); creek hazards (Hungr 2007; BGC 2012/2013; Cordilleran 2012a, 2012b, 2014b); and coastal processes (Westmar 2005).

# 7. Development History

The 1939 airphotos show bright scour on Alberta Creek channel, implying a recent scouring flood or debris flow. In addition, there appeared to be some near shore clearings on Harvey Creek fan, south of the creek mouth. These could be old camps, as extensive logging had converted most forest within the future Village boundaries to younger seral age stands. A private dock is apparent on the south end of Harvey Creek fan, and hydro right-of-way has also been cleared. On the 1946 photos there is little change. By 1957, there was extensive construction in the railway and highway corridors, mining of the Magnesia Creek raised delta deposit, and there was the development of logging roads up onto midslopes between Magnesia and Alberta creek, with some large fill/spoil sites evident with sidecast directly into Alberta Creek. The logging road did not cross Alberta Creek. By 1968 the subdivisions at Brunswick Beach and on the Harvey/Alberta Creek fans below the highway were well established, and there was one tier of subdivision road above the highway. Also by 1968, the high elevation logging road system and associated clearcuts were pushed into Magnesia and Harvey Creeks. By 1979 the existing subdivision road network was near completion, with only the uppermost length of Oceanview Road pioneered but not finished. In 1982, the Kelvin Grove subdivision above and below the highway was under construction. Also, notably, Harvey Creek was heavily scoured and bright. The 1992 airphotos show the extant subdivision with protective structures completed on Magnesia, Alberta and Harvey Creeks. No substantial change was noted on 1996 and 2004 airphotos.

# 8. Hazard Identification and Analysis (Map 2)

Geohazards addressed in this framework include coastal zone hazards; creek hazards and hillslope hazards, as discussed in the subheadings that follow. During the discussion refer to the Geomorphic Features map, attached as Map 2.

## 8.1 Coastal zone hazards

Coastal hazards include flooding from a combination of processes including tides, storm surge and wave action. Landslide or earthquake induced tsunami waves are also important coastal hazards in some areas. Also important in some settings is coastal shoreline erosion.

Climate change science indicates that sea-level rise is currently occurring and that the rate is expected to increase in the near future (e.g., 20-years) (Englander 2014). Sea level rise increases the vulnerability of littoral elements at risk to coastal flooding and erosion.

### 8.1.1 Coastal zone flooding

Coastal flooding is the product of a number of contributing factors, including astronomically forced tidal cycles, storm surge, wind/wave setup, wave run-up onshore, sea-level rise, and possible tsunami.

***Astronomic tide***

Tide cycles are driven by the gravitational forces of astronomical bodies, with repetition over 19-year periods. Coastal BC experiences a mixed semidiurnal tidal regime, with two high and two low tides per day, with unequal levels for the successive highs and lows. Further, the tide amplitude varies month to month, with the deepest cycles in summer and winter. The highest tides are usually experienced in the winter. The tide level recommended for assessment of coastal zone flooding is the Higher High Water, Large Tide (HHWLT), the average of the 19 annual highest high waters, or 2.05 m CGD[1].

***Atmospheric (storm) surge***

Storm surge is caused by rising of the water level during intense low pressure storm systems. In the past two decades, the annual maximum storm surge at Point Atkinson exceeds 0.3 m, while the maximum experienced was about 1 m. For Howe Sound, the predicted 1:200-year and 1:500-year storm surge values are 1.2 and 1.3 m (Ausenco Sandwell, 2011).

***Wave effects***

Just as low pressure allows water surface to rise, the drag by wind can also cause the local water surface to rise, and this is called wind setup. This can be further augmented by wave action, or wave setup. In protected waters wind setup is typically small and subsumed with wave setup.

When waves meet the shoreline they typically break, and rush onshore. Wave runup is the vertical reach of the break. Wave runup varies greatly with orientation to the wind, subtidal water depth, shoreline slope and roughness, and is a value requiring site-specific assessment.

In the Salish Sea area, these combined wave effects may vary greatly from near zero in protected settings to >1 m in exposed sites.

***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)(Ausenco Sandwell, 2011). However, for structures with a short to medium-term design life, a reduced SLR allowance of +0.5 m was suggested for consideration. Typically, residential houses would represent a medium to long-term design life (50 to 100 years), and 1 m SLR allowance is recommended.

Englander (2014) cautions that the Intergovernmental Panel on Climate Change (IPCC) only sanctions predictions affirmed by complete scientific consensus, that their predicted rate for this century is actually less than observed, and that should tipping point scenarios arise like collapse of the Arctic and Antarctic ice shelves, and other factors, coastal sea-level rise will be more rapid and severe than reckoned. This century could see double the rate advocated by IPCC and BC provincial guidelines (Ausenco Sandwell, 2011; APEBC, 2017). With this in mind, coastal communities are advised to practice adaptive management for Coastal Land-use Planning.

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[1] CGD, all elevations are referenced to Canadian Geodetic Datum.

***Tsunami***

Clague et al. (2003) conclude that megathrust triggered tsunami would attenuate to less than 1 m before reaching Georgia Straight. They also concluded that tsunami induced by landslides or delta foreslope slumps within coastal inlets could reach 2 m, but there is no evidence for them in the late Holocene, and therefore they are considered extremely rare. These conclusions were reiterated by Clague and Orwin (2005). Jackson et al. (2014) attempted to locate large rockslide deposits on the floor of Howe Sound that might be responsible for generating tsunami waves. They identified only one rockslide, located off the northwest side of Bowen Island, and determined that no evidence exists for such events in the late Holocene. After Clague et al. (2003), Westmar (2005) concluded the maximum credible tsunami in Howe Sound was cited as 2 m with a return period of 100-1000 years. Their conclusion is based on judgment, and in light of lack of tsunami evidence reported by Clague et al. (1993) and Jackson et al. (2014), the frequency appears somewhat conservative. Nevertheless, given a 4-5 m tidal range, such an event would have to be coincident with HHW to cause damage, resulting in a very low probability of severe consequence occurring. On this basis, local sea-level Flood Construction Level (FCL) estimates do not factor in tsunami.

***Combining factors to set the shoreline FCL***

Various future sea-level scenarios may be contemplated using different sea-level rise values, storm surge return frequencies, and site-specific estimates of wave setup and runup. Several available studies (e.g., Ausenco Sandwell, 2011; NHC 2014; KWL 2014) appear to settle on the use of the base variables, as such:

| | |
|---|---|
| Higher High Tide: | 2.05 m CGD; |
| 500-year Storm Surge: | 1.3 m CGD; |
| Global Sea Level Rise to 2100: | 1.0 m; |
| Total base estimate: | **4.35 m CGD.** |

Yet, factors such as wave setup/runup allowance and freeboard are varied according to location exposure and uncertainty tolerance, to yield a range of estimates, as such:

| | |
|---|---|
| Wave setup/runup Allowance: | 0.0 m, 0.3 m, 0.65 m, 1.2 m; |
| Freeboard Allowance: | 0.3 m, 0.6 m, 1.0 m; |
| **Final FCL range (average)** | **4.65-6.55 m (5.6 m) CGD.** |

Furthermore, accounting for an additional 1 m sea-level rise allowance to year 2200 provides a planning elevation for assessment of 7.55 m CGD, which is rounded up to 8 m.

### 8.1.2 Coastal zone erosion

Where coastlines are composed of unconsolidated sediment, coastal erosion may be a serious problem. This may be severely aggravated by sea-level rise. At Lions Bay, shoreline materials may be of several types, including bedrock, fillslope materials, blocky talus, bouldery debris flow colluvium and beach gravel. Erodibility will be in part a function of the material calibre (size of clasts), but will also depend on steepness of the shore and exposure to wave and current. Natural colluvium, such as boulder debris and talus are reasonably resistant to erosion. Fillslope materials may be oversteepened and vulnerable to erosion. Highly erodible are beach gravels, especially landforms formed by sediment transport (Photo 4).

## 8.2 Creek hazards

The main creeks crossing Village of Lions Bay include Magnesia, Alberta and Harvey Creeks. These have large steep watersheds with known debris flow hazard and have been mitigated by use of catchment basins or flumes to direct debris to the sea. Other smaller creeks are Battani, School Yard, Lions Brook and Rundle. These smaller creeks drain the mountain face between the divides of the larger watersheds.

### 8.2.1 Harvey, Alberta and Magnesia Creeks

Debris flow is the rapid movement of rock, debris and water down a steep confined channel. In the study area, historic debris flows have ranged from 1000s $m^3$ to several 10,000s $m^3$ in volumes. Velocity of debris along its path varies from 3-10 m/s and higher. Due to the large volumes, boulder material with logs and high impact velocities, debris flows are very destructive phenomenon (Table 6).

**Table 6.** Landslide size class ratings describing impacts for each class (Jakob 2005). Size classes are within the range expected for the Village of Lions Bay.

| Class | Volume ($m^3$) | Peak discharge ($m^3$/s) | Potential consequences |
|---|---|---|---|
| 1 | $<10^2$ | <5 | Very localized damage, known to have killed workers in small gullies and damaged small buildings. |
| 2 | $10^2$-$10^3$ | 5-30 | Bury cars, destroy small wooden buildings, break trees, block culverts, and damage heavy machinery. |
| 3 | $10^3$-$10^4$ | 30-200 | Destroy larger buildings, damage concrete structures, damage roads and pipelines, and block creeks. |
| 4 | $10^4$-$10^5$ | 200-1500 | Destroy several buildings, destroy sections of infrastructure corridor, damage bridges and block creeks. |
| 5 | $10^5$-$10^6$ | 1500-12,000 | Destroy camps and forest up to 2 $km^2$ in area, block creeks and small rivers. |

Design of mitigation for Harvey, Alberta and Magnesia (Photo 5) creek hazards in the 1980s was based on the Design Event (Table 7). Since there was no data available to prepare a debris flow frequency analysis, the Design Event was based on the "largest volume that could reasonably occur during the life of the structure" (Hungr et al. 1984). The method assigned an estimated channel yield rate ($m^3$/m) to the total channel length in the watershed; 10% might have been added to account for point sources. The storage structure volume was then made 15-25% larger than the design debris flow (Table 7). The channel works downstream of catchments were sized to accommodate twice the design event.

Note that these design criteria were judgment-based, following a Probable Maximum Magnitude (PMM) approach (Morgan et al. 1992). The design events and the design storage capacities were not based on estimated return periods; therefore, it was not possible to assign return period safety levels to the mitigation works. This is critical to understand when considering the residual risk affecting residential development at Village of Lions Bay because landslide safety evaluation criteria (Cave 1983; DNV 2009) make explicit reference to return periods ≥500-years.

Multiple failure mechanisms could lead to larger design events than estimated by the method outlined by Hungr et al. (1984). Primarily, significant point source volumes, >10% of overall channel yield, could be added. Potential triggering for a large point failure could be an earthquake, or simply could be the combined effect of climate/weather, chemical weathering, time and gravity. Thus, larger, more rare events, should be accounted for in the full spectrum of debris flow hazards on Harvey, Alberta and Magnesia Creeks.

A few local examples were examined to assess debris flow frequency-magnitude from similarly sized basins. Charles Creek, with a 1.8 $km^2$ watershed area, is the most active of the Highway 99 mitigated creek channels (Figure 3). Morgan et al. (1992) presented a reanalysis of Charles Creek data (n=10 events) using probabilistic methods and judgment. They estimated the 500-year event to have a volume on the order of 50,000 $m^3$, somewhat exceeding the former design event of 29,000 $m^3$. Jakob (2012) again reanalysed Charles Creek (n= 19 events) by fitting and evaluating multiple probability distributions, and concluded the 1000-year return event might have a volume on the order of 50,000-60,000 $m^3$, but with the uncertainty ranging from 20,000 to 300,000 $m^3$. The caveat was provided that this includes only debris flows from mobilised talus, and not large point source events. Jakob (2012) also reported on Jones Creek, with a 6.8 $km^2$ watershed area, located in the Cascade Mountains, Washington State. Based on analysis of data derived from test pitting and radiocarbon dated stratigraphy, Jakob estimated volumes for the 500-year and 2500-year events of 100,000 $m^3$ and 200,000 $m^3$, respectively. This review suggests that small steep watersheds with areas of 1-7 $km^2$ could have 500-year to 2500-year return period volumes that exceed the design volumes of 15,500 $m^3$ to 62,500 $m^3$ for Harvey, Alberta and Magnesia creeks.

**Table 7.** Geomorphic character and design details for Harvey, Alberta and Magnesia Creeks. After Couture and VanDine 2004.

| Item | Harvey | Alberta | Magnesia |
|---|---|---|---|
| Event record | 1969 (debris flood), 1972, 1973, 1981 (floods) | 1982, 1983 (debris flows) | 1960 (flood), 1962, 1981 (debris flows) |
| Debris flow probability | Moderately high | High | Very high |
| Elements at risk | Multiple residences, subdivision roads, highway and railway | Multiple residences, subdivision roads, highway and railway | Multiple residences, access roads, highway and railway |
| Drainage area | 7 $km^2$ | 1.2 $km^2$ | 4.7 $km^2$ |
| Ruggedness | 50% | 110% | 65% |
| Creek length | 5.25 km | 2.6 km | 4.7 km |
| Process Domain | Debris flood | Debris flow | Debris flow |
| Design debris flow | 62,500 $m^3$ | 15,500 $m^3$ | 44,500 $m^3$ |
| Design debris discharge | 500 $m^3/s$ | 350 $m^3/s$ | 400 $m^3/s$ |
| 200-year flood | 107 $m^3/s$ | 22.7 $m^3/s$ | 75.7 $m^3/s$ |
| Debris control measure | Debris basin, barrier and downstream channelization completed in 1985. | 800 m long flume to sea, completed in 1988. | Debris basin and barrier, completed in 1985. |
| Design storage volume | 77,500 $m^3$ | n/a | 51,500 $m^3$ |
| Spillway design capacity | 1000 $m^3/s$ | n/a | 800 $m^3/s$ |

**Figure 3.** Charles Creek retention structure with debris flow infill. Downloaded from Internet (https://www.flickr.com/photos/tranbc/8510095573).

Present day standards for residential development would have to consider 500-year and perhaps more rare event scenarios (e.g., 1:2500), especially given potential earthquake triggering. Thus, it is concluded that the degree of safety provided by the mitigation structures at Lions Bay is unknown, and they may be undersized when considering modern safety criteria. If this is the case, there will be some unknown level of residual risk affecting fan areas. As channels are highly confined upstream of the structures, the residual risk only presents on terrain downslope of the catch basins, where channels lose the confinement of deep rock gullies and incised raised fan deposits.

Water flood and debris flood hazard may present downstream of catchment structures as well. Where an engineered flume is present it has more than enough capacity to accommodate water floods and bulked debris floods. However, it was noted that for example on Harvey Creek, the engineered flume does not extend right to the beach, so in that area lots may be vulnerable to floods and debris floods (Photo 6).

### 8.2.2 Other creeks

Other creeks in the Village of Lions Bay include Battani Creek, tributary to Magnesia Creek at the highway; Schoolyard Creek discharging from municipal drainage below Bayview Road and flowing north of the school; Lions Brook, diverted into Alberta Creek just above upper Bayview Road; and Rundle Creek, tributary to the sea. Each of these creeks have smaller catchments, <1 km$^2$, and based on other DPA frameworks reviewed (e.g., Roberts Creek; District of North Vancouver), such small basins are not often not formally recognised as creeks for DPA designation. Despite this, they may be prone to local flooding and debris flow. Battani and Rundle creeks flow within ravines and are captured within the DPA framework on that basis. Lions Brook supports an identified hazard and its fan is allocated a DPA. Schoolyard Creek is not specifically included in the DPA framework. In addition, there may be other non-identified drainages that affect properties and need assessment at the site-specific level. These latter would be accounted for in assessments required in other DPAs.

Flooding and or avulsion may occur at road crossings or other places where drainages are intercepted by pipes (i.e., culverts and bridge openings) due to insufficient conveyance of creek flow, or blockage (Photo 7). 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 evaluation of the conveyance capacity of all creek crossings is beyond the scope of this project.

## 8.3 Hillslope hazards

Hillslope hazards include any non-channelised mass movements events such as snow avalanche, open-slope debris slides, rockfall or rock avalanche. Also included are structural features, such as terrain with lineaments, that might indicate a deep-seated bedrock instability.

### 8.3.1 Snow avalanche

Snow avalanche, the rapid movement of snow on steep slopes, occurs primarily within alpine terrain during fall, winter and spring months, but may reach down into forested terrain along well defined tracks in the timber. While snows avalanches occur in headwater areas in Magnesia, Alberta and Harvey Creeks, and may contribute to channelized hazards in those creek basins, the hillslope areas within Village of Lions Bay are not considered vulnerable snow avalanche activity.

### 8.3.2 Open-slope debris slides

Open-slope landslides typically involve fragmented bedrock, organic debris, and mineral sediment (Photo 8). A typical slide is triggered by rockfall from a bluff, by windthrow of large trees on a steep slope, or by slab failure of a weathered soil veneer. The headscarp failure plane is typically >60%, but sometimes as low as 40%, or less.

Typical, or generic steep terrain where landslide initiation is most likely has 60-120% slope, and is overlain by a veneer/blanket of till/colluvium (e.g., see Rollerson et al. 2001, 2005). Natural factors that contribute to the failure rate are wetter climate, higher frequency of extreme rainfall, gullied or escarpment landforms, increasing soil moisture, aspect, and fine grained sediments (Rollerson et al. 2001). Regional storms with severe localised precipitation cells may trigger numerous events (Guthrie and Evans 2004).

The initial slip then impacts timber downslope clearing a swath through the forest, and may be very destructive to infrastructure (Table 6). Slide types may be differentiated as open-slope, gullied types (headwall, sidewall, channel), road-related, or single track versus multiple track events (Fannin and Rollerson 1993).

***Volume and damage potential***

Open slope landslides in Coastal BC typically have headscarp dimensions that are 10-50 m wide by 0.5-1.0 m thick. At Lions Bay slope length of steep slope segments above residential areas range from 150-600 m long, and longer. If these track dimensions are applied to steep slope lengths, where scour and entrainment is predicted, and used to estimate potential slide volumes, then slide volumes affecting residential areas may be on the order of 750 $m^3$ to 30,000 $m^3$, or Class 2 to 4 events (Table 6).

***Frequency***

No data on open-slope landslide density is available for Lions Bay or Howe Sound. While historic open-slope failures are known from within valleys tributary to the sound (e.g., M Creek, Bovis and Dagg, 1992; Magnesia, Harvey, Alberta and others, e.g., Jakob and Weatherly 2003), historic landslides on the valley sidewall or fjord "face units" are not evident.

Thus, the landslide rate for slopes directly upslope of Lions Bay housing is not known, but appears to be less than 1:100-years based on airphoto inventory, Google Earth review and personal observation. This is a poor minimum estimate, as a 100-year return is a high to moderate hazard (Table 1), when in fact the hazard may be moderate (<1:100 per annum) to Low (<1:500 per annum), or less.

In lieu of known landslide frequency, regional landslide density may be used to approximate frequency (Hantz et al. 2003; Catani et al. 2016). Post logging landslide densities have been studied in Coastal British Columbia. Since the slopes above Lions Bay have been logged, this data provides an analog for the present study. Regional landslide mapping in the Coast Mountains conducted within a window of 20 years since logging (Rollerson et al. 2001) indicates densities on steep terrain of 0.015-0.035 sl/ ha; while this doubles to 0.03-0.06 for Cascade Mountains near Chilliwack (Millard et al. 2002), perhaps owing to poorer rock types.

As a first approximation, one can take the low range of the landslide density, or 0.015-0.035 sl/1 ha/20-years (Rollerson 2001), and apply this to Village of Lions Bay. For example, above the Village, between Magnesia and Alberta Creek there is 40 ha of steep terrain that could generate open-slope landslides. This ground occupies a belt about 1000 m wide across the slope and 400 m horizontal distance along the fall line. Assuming a slide width of 20-50 m, then there are 20-50 independent paths. Thus, 0.015-0.035 sl/1 ha/20yrs portions to 0.03-0.07 slides per annum for a 40 hectare area. This then needs to be allocated to 20-50 independent slide tracks, suggesting there is a 1:500 to 1:1000 per annum hazard for a landslide in any given track.

Only detailed subsurface testing could reveal actual landslide rates for the study area. An example of a prehistoric debris slide is provided from excavation conducted at Ansel Place exit, Sunset Highlands, West Vancouver. At that site, excavation on the east abutment of the overpass exhumed two Douglas fir logs buried by slide debris. Radiocarbon dating gave ages of 1090±50 (GSC-6574) and 1060±50 (GSC-6573) $C^{14}$ yr BP, or 965 calendar years BP for the landslide that buried the trees (Cordilleran, 2001). Note, this age appears consistent with the Low frequency (Table 1) estimated above.

### *Landslide runout or travel angle*

Landslides will typically travel to the base of slope, with the deposition zone being a 50-200 m wide belt of terrain less than 30% slope (Fannin and Rollerson 1993). Travel angle, H/L, or ratio of total drop to total horizontal length of the landslide is widely used to characterise travel distance (Corominas 1996), and this measure can be used in terrain hazard mapping as a first order estimate of potential impact areas.

No landslide travel data exists for the southern windward Coast Mountains. For open-slope slides with similar length and volume characteristics to potential open-slope slides at Lions Bay, two data sets were examined: one collected from Google Earth review for 70 landslides near Bella Bella by Cordilleran (unpublished), and a second from Horel (2007) for a sample of 33 landslides on Northern Vancouver Island (Table 8). Measured travel angles for each slide were binned in 10 percentile categories and cumulative frequencies "farther than" were tallied. Qualitative hazard categories extend from Very High to Very Low with cumulative frequency probability in 20 percentile categories: Very low=0-20%; Low=20-40%; Moderate=40-60%; High=60-80%; and Very high=80-100%)(Table 8).

**Table 8.** Travel angle (H/L) vs frequency of occurrence, cumulative frequency and qualitative hazard affecting. Data for Bella Bella and Northern Vancouver Island.

| Bella Bella (n=70) (Cordilleran) | | | Northern Vancouver Island (n=33) (Horel) | | |
|---|---|---|---|---|---|
| Travel angle (m/m) | Cum. Freq. (probability) | Qualitative $P_{S:H}$ | Travel angle (m/m) | Cum. Freq. (probability) | Qualitative $P_{S:H}$ |
| 0.11-0.2 | 0.04 | Very low | 0.11-0.2 | 0.00 | Very low |
| 0.21-0.3 | 0.10 | Very Low | 0.21-0.3 | 0.09 | Very Low |
| 0.31-0.4 | 0.24 | Low | 0.31-0.4 | 0.55 | Moderate |
| 0.41-0.5 | 0.41 | Moderate | 0.41-0.5 | 0.76 | High |
| 0.51-0.6 | 0.71 | High | 0.51-0.6 | 0.88 | Very high |
| 0.61-0.7 | 0.80 | Very high | 0.61-0.7 | 0.94 | Very high |
| 0.71-0.8 | 0.96 | Very high | 0.71-0.8 | 0.97 | Very high |
| 0.81-0.9 | 0.99 | Very high | 0.81-0.9 | 0.97 | Very high |
| 0.91-1.0 | 0.99 | Very high | 0.91-1.0 | 0.97 | Very high |
| 1.01-1.1 | 1.00 | Very high | 1.01-1.1 | 1.00 | Very high |

A Quantitative Risk Assessment (QRA) is applied as a sensitivity analysis to determine a reasonable shadow angle for setting the Open-slope Development Permit Area (DPA) boundary. QRA requires estimates of probabilities of the hazard and the consequence to estimate risk, as per the formula below:

Individual risk = $P_H*P_{S:H}*P_{S:T}*V*E$, where

$P_H$=probability of design event hazard occurring, open-slope landslide;
$P_{S:H}$ = probability of spatial affect given the hazard, landslide travel category;
$P_{S:T}$ = probability of temporal effect given spatial effect, occupancy;
V = vulnerability of structure and risk of loss of life to person most at risk in the home; high;
E = elements at risk = 1

Since there is no landslide travel data for Howe Sound, probabilities for various reach angles were assigned from regional data (Table 8), as such: VH, $P_{S:H}$=0.9, H/L>50% slope; H, $P_{S:H}$=0.7, H/L is 40-50% slope; M, $P_{S:H}$=0.5, H/L is 30-40% slope; L, $P_{S:H}$=0.3, H/L is 20-30% slope; and VL, $P_{S:H}$=0.1, H/L<20% slope.

The sensitivity analysis (Table 9) applies three hazard ($P_H$) scenarios to the five reach classes ($P_{S:H}$), with 50% building occupancy ($P_{T:S}$) and high vulnerability (V=1). Then for any single damage corridor, the individual risk is tolerable (i.e., <1:10,000) only for Very Low landslide reach probability, or for increasing reach probability (Low to Very High) with increasingly reduced landslide frequency. The risk is only acceptable (i.e., <1:100,000) with VL reach probability with $P_H$ at 1:5000, or less.

**Table 9.** QRA sensitivity analysis to validate choice of landslide reach category used to establish DPA.

| Damage corridor hazard frequencies (per annum) applied in sensitivity analysis | | | Reach category | | | | | Risk Estimates for a range of hazard levels | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | R1 | R2 | R3 |
| 1:500 | 1:2500 | 1:5000 | Qualitative | $P_{S:H}$ | $P_{T:S}$ | V | E | 1:500 | 1:2500 | 1:5000 |
| 0.002 | 0.0004 | 0.0002 | VH | 0.9 | 0.5 | 1 | 1 | 1111 | 5556 | 11111 |
| 0.002 | 0.0004 | 0.0002 | H | 0.7 | 0.5 | 1 | 1 | 1429 | 7143 | 14286 |
| 0.002 | 0.0004 | 0.0002 | M | 0.5 | 0.5 | 1 | 1 | 2000 | 10000 | 20000 |
| 0.002 | 0.0004 | 0.0002 | L | 0.3 | 0.5 | 1 | 1 | 3333 | 16667 | 33333 |
| 0.002 | 0.0004 | 0.0002 | VL | 0.1 | 0.5 | 1 | 1 | 10000 | 50000 | 100000 |

On the basis of the analysis above, to reduce the probability to no less than tolerable (1:10,000 per annum) of Type 1 error, that is, declaring a site free of hazard when in fact hazard exists, it was determined that the lower boundary for the open-slope DPA 3A should be established using the lower limit of the Low reach probability category, equating to an H/L of 20% ($11^0$). Projecting this slope from some potential start zone high on the slope above the subject property captures essentially the entire municipality (Figure 4), and it was judged that reach would be reduced by travel obstructions. Road benches tend to mitigate open-slope landslide travel distance (Guthrie et al 2009). For any given landslide path in Village of Lions Bay there are multiple road crossings (range is 2-8) and the Highway 99 road bench. Given the highway is a four-lane highway, divided and bounded by no-post barriers, it was judged these multiple road obstructions will limit reach. The outside edge of Highway 99 was used to truncate the runout, with the DPA extending upslope of the highway.

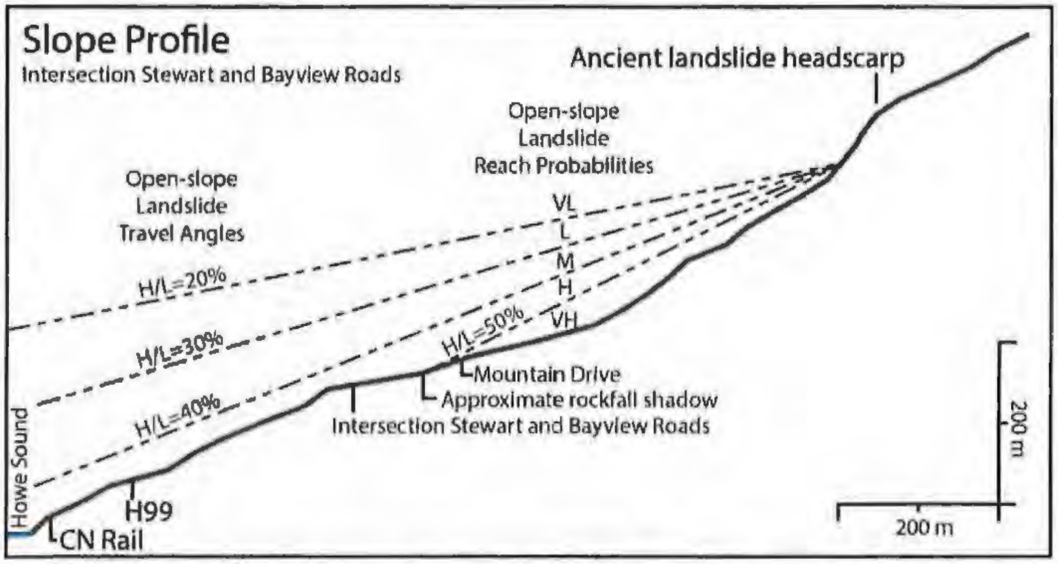

**Figure 4.** Topographic slope profile through the intersection of Stewart and Bayview Roads. Open-slope travel angles are plotted from a hypothetical start zone on the slope below the cliff and show that runouts can extend very far down the slope.

### 8.3.3 Rockfall

Rockfall is the falling, bouncing and rolling of detached rock fragments from cliffs and steep slopes. Over time, rockfall material may form a veneer/blanket or apron of material below a source bluff. These deposits are known as scree or talus. Volumes can range from individual blocks to 100s of cubic metres.

Natural rockfall source areas are readily identified by slope thematic mapping, keying into slope areas with 70-90% slopes, and especially bluffs with slopes >90%. A number of steep rock areas were visited in the field to confirm rock condition.

The Gambier Group rocks within the Village of Lions Bay are typically highly fractured, with fracture spacing of decimeters to meters, with multiple orientations in any rock mass, including steeply dipping sets allowing topple, slide and wedge type failure (Photo 9). Field inspection indicates that many bluff areas support surfaces with open joints. Thus, in steep terrain, rockfall presents as a common hazard affecting downslope areas. The 50-100 m tall cliff above Mountain Drive is a significant rockfall source area (Photos 10, 11). Rockfall debris is very common on the slopes above Mountain Drive and Timbertop Road (Photos 12, 13). Klohn Leonoff (1992) identified an "ancient slide" of about 5000 $m^3$ volume located "about 400 m south of Kelvin Grove Way." No further details were provided, but the slopes directly above the highway are mantled with rockfall colluvium derived from collapse of the bluff spanning Lots 48, 60 & 61, Kelvin Grove Way (Photo 3).

A method of identifying areas vulnerable to rockfall is the shadow zone concept introduced by Hungr and Evans (1993), whereby an angle of $27.5^0$ is plotted from the top of a talus slope and extended down to where the angle intersects natural ground, typically somewhat beyond the toe of the talus slope. Hungr and Evans (1993) demonstrated that in most cases, 99.9% of rockfall will not exceed this angle of travel. However, there are special site conditions that can lead to excess travel, and the method must be used with caution.

Artificial rockcuts may be especially vulnerable to rockfall. This is evident from the large number of rockfalls that have affected Highway 99 and other road systems throughout BC.

### 8.3.4 Rock avalanche

Rock avalanches are large fragmental rock failures originating in bedrock and traveling rapidly downslope as an unsorted mass. Several large rock avalanche deposits are known from Howe Sound. Eisbacher (1983) mapped a rock avalanche deposit, with a volume of 300,000-400,000 $m^3$, draping the benchland underlying the Sunset Highland subdivision, West Vancouver. The rockslide originated from the collapse of a rock spur at 600 m elevation below Black Mountain on the Howe Sound Crest. The landslide has not been dated, but Piteau (1981) attributed a paraglacial age. Jackson et al. (2014) document rockslide deposits on the sea floor off the northwest side of Gambier Island, with radiocarbon ages indicating an early paraglacial age.

At Lions Bay, on the hillshade rendering derived from the recently acquired LIDAR, a prominent cliff located north of Alberta Creek has been identified as a potential rockslide scarp by BGC (2012/2013):

> "A landform that may be a large rock slide is visible on the slope to the north of Alberta Creek. Several [house] structures are located on or near the toe of this feature, but apparently no ground movement in the area has been reported. It is possible that this suspected rock slide occurred as the slope was debuttressed during glacial retreat and that it is not currently active; however, further investigation of this feature may be warranted.

In 2016 and for this project, Cordilleran traversed the headscarp crest and terrain below to look for evidence of ongoing and potential instability. The headscarp is 600 m long and southwest facing, with the crest between 550-650 m elevation with cliffs between 30-110 m tall (see Map 2, Geomorphic Features). The crest does not show evidence of sackung, but there are sites of open and unfavourable jointing with several identified rockfall sources of 10s $m^3$ to 1000s $m^3$ volume.

The slopes below the large landslide scar (see Map 2) are divided into the north half and the south half. On the north half, there are 150-300 m long, 60-80% slopes of rubble talus, extending from 450 m elevation to a concave break at 200-300 m elevation. The subdivision is on the benchland at the toe, extending from 80-250 m elevation. This area is predominantly rock outcrop with lows covered with till and glaciofluvial veneer; only areas fringe to the slope above support fragmental rockfall. There is no extensive rockslide deposit.

Below the south end of the landslide scarp is a distressed slope area, 300 m wide by 300 m long, with the irregularly sloped surface between 370-540 m. The mass consists of fragmented rock with three extensional horst and graben structures and a lateral boulder levee on the south margin (see Map 2, Geomorphic Map). The thickness of the mass is unknown, but could be on the order of 10-20 m. Thus, the total volume estimate is 1-2 M $m^3$.

On the basis that the lower slopes below about 150 m elevation are largely rock with partial till veneer, it was judged that the rockslide was likely a deglacial event that deposited partially onto the receding ice sheet. Only point source rockfall is expected from the modern headscarp. The distressed area in the south is interpreted as a failed rock mass, arrested on the slope during initial failure. Its present state of stability is not known, and the hazard/risk the feature presents is uncertain.

### 8.3.5 Deep-seated bedrock instability

Deep seated bedrock instabilities are locations where gravitational stresses have caused or continue to drive slow failure in bedrock slopes. The slopes are said to be sagging, and these areas are referred to by the german word "sackung." Sackung are typically identified by extensive areas of linear tension cracks and uphill facing scarps. There are many such features throughout the Coast Mountains. Jackson et al. (2014) recently identified an extensive area of sackung on Bowen Island, with a small part of the slope having failed into the sea during the deglacial period. Sackung slopes exists in the Britannia Creek watershed within Jane Basin. Both these examples are in Gambier Group rock similar to Lions Bay.

The 1-2 $Mm^3$ arrested rock mass below the Lions Bay headscarp displays structural features typical of sackung. In its case, the tectonic structures formed during initial collapse. However, it is not known if there is ongoing, or perhaps intermittent slow mass movement of this feature.

Another potential bedrock weakness is an open-downward, horseshoe-shaped headscarp located on the divide between Lions Brook and Harvey Creek (see Map 2, Geomorphic Map). This feature is 250 m wide and extends from its crown at 880 m elevation downslope about 150 m distance. The stability of this feature is unknown.

Just 100 m south of the Village of Lions Bay, the whole slope from sea level to 1100 m elevation shows signs of weakness. The area is sided by two linear depressions defining an area about 500 m width and delimitated by a horseshoes-shaped headscarp at the top and by a convex toe at sea level (Figure 5). The convex toe dictates the highway path. The stability of this feature is unknown. This area is outside the LIDAR coverage but it has been recognized and mapped on the historic orthophotos. In personal communication, this area was previously identified to Cordilleran Geoscience by Karen Savage, P.Eng., of Horizon Engineering. Even if this feature might not directly affect Village of Lions Bay, it affects the highway and may pose significant hazard to the access to the Village of Lions Bay.

These examples of potential deep-seated instability require characterisation and assessment by a qualified geological engineer.

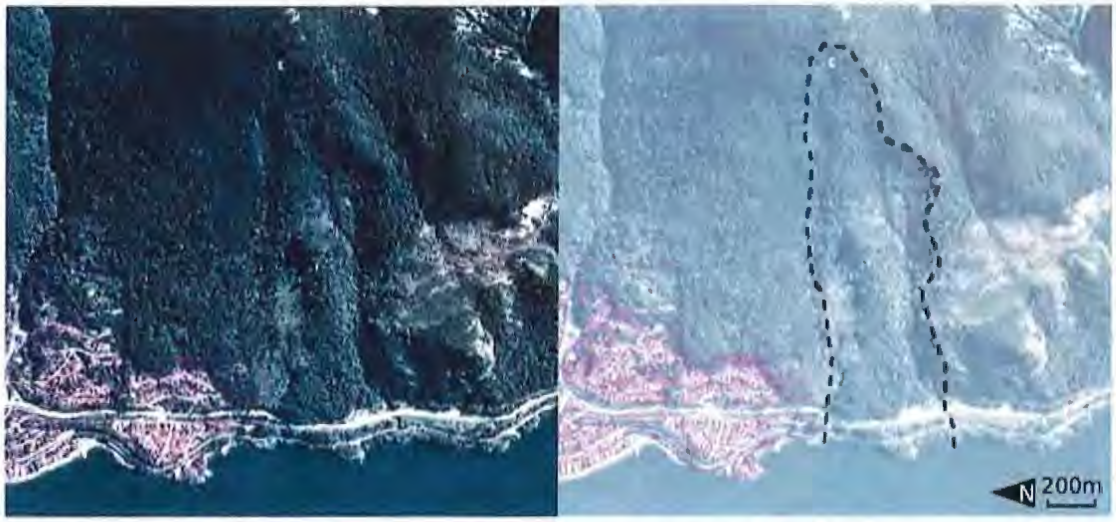

**Figure 5.** Potential sackung slope identified just south of Village of Lions Bay.

### 8.3.6 Seismic slope instability

The study area is vulnerable to seismicity from a Cascadia subduction zone earthquake as well as more frequently-occurring crustal earthquakes. The National Building Code (2005) and the BC Building Code (2012) require building design to conform to the 2% in 50-year return period event (1:2475 per annum)(Table 1). This standard is also referenced by APEGBC (2010).

APEGBC (2010) states:

> "earthquakes can destabilize slopes leading to landslides, can cause liquefaction leading to landslides and/or can cause slope displacements. Therefore, seismic slope stability analysis, or seismic slope displacement analysis (collectively referred to as seismic slope analysis) may be required as part of the landslide analysis."

It must be emphasized that the seismic slope stability analysis applies to the design of foundations and engineered slopes (Photos 14-16). The assessment of natural landslides potentially affecting a site considers the frequency and magnitude of historic and prehistoric landslides, as revealed through the historic record, peer-reviewed publications, anecdotal evidence and geologic fieldwork. The historical record extends back thousands of years and over many earthquake cycles, thereby implicitly including seismicity as a triggering agent. Nevertheless, when considering future triggering of landslides, for example within Magnesia, Alberta, Lions Brook and Harvey catchments, or rockfall, then seismic shaking at potential start zones should be considered.

# 9. Recommended DPA Framework

## 9.1 Overview

The goal of the DPA boundary delineation is to categorise natural hazards by landform type and/or process domain. The likelihood or magnitude of possible hazards is not explicitly estimated, as that is the role and responsibility of site specific studies or recommended further work.

The following sections outline the proposed development permit area (DPA) framework for natural hazard areas in the Village of Lions Bay, based on the hazards identified and assessed in the previous section. A generalized, process-based approach to DPA delineation is proposed, with three main categories.

DPA 1, Coastal Zone Hazards (flooding and erosion);
DPA 2, Creek Hazards (alluvial fans; ravines, small creeks); and
DPA 3, Slope Hazards (Open-slope failures, rockfall, and seismic slope stability).

## 9.2 Uncertainty

In determining the DPA boundaries for the hazard categories, it is recognized that there is inherent uncertainty in the frequency-magnitude data upon which the DPA categories have been based, as well as uncertainty in the extent of influence of possible hazards. Therefore, DPA boundaries were drawn conservatively so as not to exclude terrain that could be affected by the range of magnitudes considered within future studies. While boundaries are drawn from the high-resolution LIDAR-derived mapping products, for proposed development purposes, surveys and professional assessment(s) may be needed to confirm lot layout, natural features, and setback determination on a site-specific basis (e.g., top of ravine vs. setbacks).

## 9.3 Legislated authority

By authority vested from the Crown, The Village of Lions Bay may require a Development Permit on lands identified as being within various DPAs for the following activities:

1. Subdivision as defined in the Land Title Act and Strata Property Act;
2. Building Permit under the Community Charter; and
3. Land alteration, which includes, but is not limited to the removal and deposition of soils and aggregates, construction of retaining walls, paving, and removal of trees.

## 9.4 Georisk evaluation criteria

The Association of Professional Engineers and Geoscientists of British Columbia are clear that defining levels of geohazard safety is "not the role of a Professional Engineer or Professional Geoscientist." Rather, acceptable risk must be "established and adopted by the local government or provincial government after considering a range of social values" (APEGBC 2010, 2012).

Therefore, it is the responsibility of the Village of Lions Bay to establish levels of acceptable risk for development approval process, and then for each hazard being considered, the qualified professional is responsible for estimating the hazard/risk affecting the proposed development, and then comparing this estimated hazard/risk against the established safety criteria.

### 9.4.1 Traditional hazard-based geo-safety management in British Columbia

In British Columbia, geohazards have traditionally been managed using a hazard based approach. For hydrologic floods an event with a 200-year return interval is used as the safety level (WLAP 2004). This relatively low level is used because floods can usually be forecast, allowing residents to prepare by evacuation or other means, and also because flooding is less life threatening than other geohazards.

Floods carrying high volumes of gravel are termed debris floods. These can be more damaging, and therefore, some agencies have used a 500-year return interval as the safety level for these events (Cave 1993; MoTI 2009). More recently, APEGBC (2012) recommended consideration of the 1:2500 year return debris flood and debris flow event, where feasible[2]. Reference to the 1:2500 year return event is based on

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[2] APEGBC (2010) makes no recommendations regarding use of various hazard criteria.

National Building Code (NBCC 2005), including the requirement to design for earthquake hazards, and recognizing the potential for earthquake induced landslides.

Large landslides with the potential to destroy extensive areas and cause loss of life, were originally considered by Justice Berger (1973), ruling on the risk of landslide from the Rubble Creek Barrier. Justice Berger opined that where even a low risk of death might exist, then that risk was deemed unacceptable; he recommended that the hazard assessment review geologic evidence extending back over the 10,000-year length of the post glacial period. That notion was subsequently interpreted and applied by Cave (1983) and more recently by MoTI (2009) and Clague et al. (2014) to imply that where major catastrophic or life threatening events affect a site/community, then the design criteria should reference the 1:10,000 per annum event.

A summary of hazard criteria currently applied in British Columbia was provided by Clague et al. (2015) who reviewed global and regional hazard safety thresholds for the purpose of risk management within District of Squamish. They found that 1:500-year, 1:2500-year and 1:10,000-year landslide events should be considered (Table 10).

Cordilleran is of the opinion that for most sites the application hazard acceptability criteria that cite very remote hazard thresholds, like 1:10,000 per annum, are not feasible for both scientific and practicable reasons (Jakob et al. 2018). Stationarity of the process mechanism is a requirement of most statistical analyses; the decline of sediment yield through the paraglacial period and natural climate change are factors which result in non-stationarity over the 10,000 years of the non-glacial period. While human induced climate change is altering future landslide probabilities. Further, for statistical frequency-magnitude analysis, a data set of sufficient size and confidence is required for statistical treatment; while for most landslide assessments it is rarely possible as this requires extensive subsurface examination, stratigraphic analysis, radiometric dating; and is conditioned on the sedimentary archive being available and complete, when in most cases it is inaccessible or fragmentary. In this context, the uncertainty in frequency-magnitude estimates for extremely rare events may vary over several orders of magnitude. All these issues make inclusion of the 1:10,000 year return period event highly problematic, except for a few exceptional data-rich settings (e.g., Jakob and Friele 2010).

**Table 10.** Event frequencies that should be considered in landslide risk assessments, as recommended by the Cheekye Expert Panel (Clague et al. 2015).

| Event frequencies used in georisk assessment in BC | **Rationale** |
|---|---|
| 10,000-year return period event | Rubble Creek (Berger 1973)*<br>Regional District of Fraser Valley (Cave 1993) District of Squamish (2009)<br>BC MOTI (2009 revised 2015) |
| 2,500-year return period event | APEGBC (2012) (for debris flows and debris floods) NBCC (2005) (for earthquakes) |
| 500-year return period event | BC MOTI (1993, 2009 revised 2013) |

* Berger actually recommended consideration of a 10,000 year (e.g., Holocene) sample time frame, not a return period event.

## 9.4.2 Recommended risk assessment, after District of North Vancouver

Risk Assessment is a relatively recent approach to landslide safety assessment in BC. The District of North Vancouver (DNV) has adopted a Risk Assessment approach to assess development following the

2006 Berkley landslide fatality on Riverside Drive in that municipality. The adopted DNV (2009) policy recommendation is located at https://www.dnv.org/programs-and-services/risk-tolerance).

Assuming a good planning model, consistency in georisk management policy among communities is a preferred planning outcome. District of North Vancouver presents a modern and tried framework for managing georisk, and has set a bar that should be emulated. For all creek and hillslope hazards, it is recommended that the Village of Lions Bay adopt georisk safety policy consistent with the District of North Vancouver. With respect to risk tolerance, the District of North Vancouver (2009) report to council provided the following discussion and policy:

> "Areas of potential landslide hazard can be assessed using a risk-based approach or by means of a factor-of-safety approach. The APEGBC Guidelines (2010) state that "the decision whether to carry out and report the results of a landslide analysis quantitatively or qualitatively depends on how the adopted level of landslide safety is expressed, and/or the requirements of the Approving Authority." A qualitative hazard assessment or partial risk analysis should be performed by a Qualified Professional as an initial step in estimating whether a landslide hazard may be present for areas identified on the slope hazard map. If these preliminary analyses demonstrate that risks to life are likely broadly acceptable, then further risk assessment may not be required.
>
> Where a qualitative hazard assessment and/or partial risk analysis demonstrates that risks to life are likely tolerable or possibly unacceptable, the District requires that a more detailed risk assessment be performed. Where a detailed landslide risk assessment is required by the District, the Qualified Professional shall determine which approach is most appropriate for the local site conditions, based on the nature of the potential landslide hazard and its location relative to the area of existing development, re-development, or proposed new development. It is recognized that landslide hazard and risk assessment is not an exact science and that some factors in the risk estimation process are subjective by nature.
>
> Tolerable and acceptable risks are somewhat different: tolerable risks can be tolerated in order to realize some benefit, but they are not negligible, and should be kept under review and reduced further if possible. In contrast, acceptable risks are considered broadly acceptable to the public and efforts to further reduce risks are not warranted.
>
> The "as low as reasonably practicable (ALARP)" principle applies to risks within the tolerable range. Under the common-law system, risk reduction should be achieved if reasonable opportunities exist. For a risk to be ALARP it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.
>
> Society is generally less accepting of risks today as in the past. The proposed risk tolerance criteria takes this into consideration by proposing two-tiered criteria, with more stringent criteria for new development. Table 11 below illustrates the application of the proposed policy on risk tolerance criteria."

**Table 11.** Landslide risk policy, District of North Vancouver.

| Type of Application | 1:10,000 + ALARP | 1:100,000 | FOS >1.3 (static) | FOS >1.5 (static) |
|---|---|---|---|---|
| Building Permit (<25% increase to gross floor area) | X | | X | |
| Building Permit (>25% increase to gross floor area and/or retaining walls >1.2m) | | X | | X |
| Re-zoning | | X | | X |
| Sub-division | | X | | X |
| New Development | | X | | X |

The link to their geohazard DPA Bylaw 7900 (Part 4) is provided for reference[3]. The method employs Risk Assessment, indicating consideration of both hazard and consequence. In the Village of Lions Bay, risk is assessed for ocean, creek and hillslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes as determined relevant by the qualified professional. The varied tasks encountered in georisk analysis and design of protective measures require both P.Geo.and P.Eng. qualifications and experience, with specialist skill sets required for specific tasks. Risk assessments may be quantitative or qualitative, with the understanding that, as APEGBC (2010, Section 3.4.2) notes,

> Quantitative estimates use numerical values or ranges of values, while qualitative estimates use relative terms such as high, moderate and low. Both quantitative and qualitative estimates can be based on either objective (statistical or mathematical) estimates or subjective (professional judgmental or assumptive) estimates, or some combination of both.
>
> Quantitative estimates may be no more accurate than qualitative estimates. The accuracy of an estimate does not depend on the use of numbers. Rather, it depends on whether the components of landslide hazard and landslide risk analyses have been appropriately considered; and on the availability, quality and reliability of required data.

Further, debris flood and debris flow risk assessment should be based on a minimum 500-year return period and include higher (1:2500 year) return periods where appropriate and practicable. Cordilleran judges that it is unreasonable to expect estimation of a 1:10,000-year event (see argument in Innovation 2018) as required by District of Squamish, Fraser Valley Regional District or MoTI. Flood construction levels should be clearly defined with appropriate freeboard to reflect analysis uncertainties and potential channel bed aggradation.

## 9.5 Expectations for professional scope and reporting

All professional assessments pertaining to Development Permit Areas should be consistent with applicable professional practice guidelines and their various report requirements; and provincial regulations, including but not exclusive to the list below:

i. Flood Hazard Area Land Use Management Guidelines (WLAP 2004),
ii. Guidelines for Legislated Landslide Assessments for Residential Developments in BC (2008, 2010),
iii. Guidelines for Legislated Flood Assessments in a Changing Climate in BC (2012, 2017),
iv. Riparian Areas Regulation,
v. BC Building Code, and
vi. Worksafe BC.

FVRD, District of North Vancouver and District of Squamish are jurisdictions that have experience requiring and reviewing geotechnical hazard reports. In all cases, these jurisdictions have developed specific standards for geotechnical report content (e.g., District of Squamish 2017). Based on their experience, where applicable, a report by a qualified professional should include the following:

1. Report name and date;
2. Client information;
3. Qualified professional information (training, experience, insurance);
4. Property information (legal and civic);
5. Description of development proposal;
6. Review of relevant local bylaws and other statutory requirements;

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[3] http://www.dnv.org/sites/default/files/bylaws/Bylaw%207900.pdf#page=203

7. Review of background information (site-specific and overview archived & provided by Lions Bay and others);
8. Description of geologic and geomorphic setting;
9. Description of field work conducted on and, if required, beyond the proposed development;
10. Identification of natural hazards or other hazards identified in background reports and field work. Includes also a description of all potential hazards and rationale for excluding some;
11. For all hazards, separate and in aggregate, analyses georisk affecting the proposed development and evaluates against the Village of Lions Bay safety policy;
12. Discusses the effect of changed conditions to slope stability caused by the project, by future potential natural factors or land-use (fire, forestry) or climate change;
13. Discusses uncertainties and describes any residual risk that would remain;
14. If applicable, states that "the land may be used safely for the use intended" with siting constraints, protective measures or restrictive covenant, as stipulated in the report.
15. Provides technically justified siting constraints or protective measures, as required;
16. Provides implementation steps for the identified structural mitigation works (in terms of design, construction and approval).
17. Provides site plan and other mapping required to show hazards affecting, minimum scale 1:5000;
18. Provides maps, illustrations and diagrams to illustrate risk scenarios referred to in the Report;
19. Recommends restrictive covenants registered against the property title that pertain to geo-hazards, as required;
20. Provides permission to Village of Lions Bay to include the Report in the online geo-hazard report library (as background information, not for other parties to rely on);
21. Provides time limitation or condition statement to describe extent the Village of Lions Bay may rely on the Report for development approvals, and when resubmittal is recommended;
22. Provides an assurance statement (after APEGBC 2010, 2012);
23. Signed and sealed by coordinating qualified professional.

## 9.6 DPA 1 - Ocean hazards (Map 3)

Ocean hazards include flooding of low-lying terrain, and erosion and instability of oceanfront slopes. DPA 1 extends from the existing natural boundary of the sea to the 8 m contour line. The 8 m level is conservatively selected to represent the future FCL. This captures all lots fronting the sea within the Village of Lions Bay. The DPA is intended to identify any sites that should be assessed by a qualified professional to address coastal flood hazards, but does not preclude development. For Ocean Hazards, site specific factors including wave effects, year 2100 HWM, shoreline erosion, shoreface stability and associated setbacks.

At Village of Lions Bay, many steep slopes into the sea are rock controlled or are fillslopes below the railway line. These are not a stability concern for residential development. Most lots on surficial materials are located on bouldery debris fan deposits of Magnesia, Alberta and Harvey Creeks, and while the shorefronts may be steepened to 70-80% by wave attack, the sea scarp is not tall (<6 m) and materials are coarse and relatively resistant to erosion at the timescale of the life of a structure (e.g., 100-years).

The sites most vulnerable to erosion are those low-lying areas at the south end of Brunswick Beach Road, where housing has been developed on a gravel tombolo that has linked a small rock outcrop with the mainland (Photo 5). The beach gravels forming the tombolo stand just above the HWM, being formed by storm waves, and the terrain between the north and south facing beaches is slightly lower, just at the HWM. Future breaching and erosion of these beach ridges places all these low-lying areas at risk.

Within DPA 1, building siting would require that development applications include a coastal flood hazard assessment to define the year 2100 shoreline position and the derived flood construction level and appropriate setback. Provincial guidance refers to a 15 m ocean setback, while Village of Lions Bay applies a 7.5 m coastal setback. Siting could be further constrained by consideration of potential erosion.

A factor of safety analysis may also be required to support foundation design and determine building setbacks from escarpment crests.

Some lots do not have allowable room to accommodate houses under these future conditions. In these cases, setback constraints might be exempted, or in other cases land may be deemed non-developable. This will need to be determined on a site by site basis, and reports by qualified engineering and/or environmental professionals (QPs) would be required to support any exemption and/or variance.

Note that Englander (2014) cautioned that IPCC projections are low. Nhc (2014) noted that the predicted global sea-level estimates may change with time and similarly, they did not factor in potential climate change induced changes in storm intensity and frequency. Accordingly, they recommended adaptive management for coastal zone flood planning, with consideration given to potential future increases in the estimates of sea-level rise and changes in storm intensity and frequency.

## 9.7 DPA 2 - Creek hazards (Maps 4, 5 & 6)

In the Village of Lions Bay, DPA 2, Creek Hazards includes consideration of flooding, debris flooding and debris flow from both large creeks with existing debris flow hazard mitigation, hazards from unmitigated creeks and ravine escarpment slope stability. The debris flow mitigated channels (Magnesia, Alberta and Harvey) each have unique site conditions (watershed area, ruggedness, geomorphic condition) and are best treated individually. Similarly, the smaller unmitigated channels cannot be treated in a uniform way as in some cases their natural channels are within ravines (parts of Battani and Rundle), or in contrast may be unconfined by ravines and completely diverted from their natural course to bypass residences (lower Lions Brook) or captured in part by the residential drainage network of ditches, culverts and storm sewers (upper School Yard Creek).

After District of North Vancouver (Bylaw 7900, Part 4, DPA 2A & DPA 3A), the Creek Hazard DPA and corresponding Development Permit Area are established to address the following objectives:

1. minimize the risk to people and property from creek and slope hazards;
2. encourage safety in the construction, location and manner of development;
3. minimize development in high hazard areas due to debris flow, debris flood areas;
4. mitigate the impacts of flooding within areas already developed;
5. avoid increasing the hazard to or vulnerability of others on the floodplain; and
6. maintain a natural riverine and floodplain regime.
7. develop safely and minimize the impacts on or near steeply sloped lands, including the potential run out area below steep slopes;
8. reduce slope hazards and landslide risk to people and property by carefully managing development and construction practices on or near steeply sloped lands;
9. avoid alteration of steeply sloped lands that may cause increased instability of the land or adjacent areas;
10. encourage professional design of structures and mitigative works and to ensure field review during construction and post-construction certification; and
11. encourage ongoing maintenance and monitoring of steeply sloped lands.

An example list of guidelines to meet these objectives are provided in DNV Bylaw 7900, Part 4, DPA 2C & DPA3C.

DNV Bylaw 7900, Part 2B sets out a list of exemptions. These were recently updated (amended October 13, 2017) reflecting 8-years of experience with their Risk Management system. Most are directly applicable and Village of Lions Bay could decide to use in whole or in part (the Village of Lions Bay must consider legal third party reliance issues).

Bylaw 7900, Part 2B, Exemption 2, which pertains to the reference plane for the flood construction level for habitable space, should be deleted, as for all recognised creeks within Village of Lions Bay, including

Battani, Magnesia, School Yard, Alberta, Lions Brook, Harvey, Rundle, and other smaller non-identified creeks intercepted by residential development (upper School Yard), the FCL should be determined by a qualified professional(s) based on consideration of the risk presented by all hazards (flood, debris flood and debris flow). Specialist, multi-disciplinary skill sets may be required, with either or both P.Geo./P.Eng.

The list of exemptions does not include the "25% rule" which nevertheless is included in adopted (DNV 2009) Risk Tolerance criteria (Table 11). To be consistent with many community bylaws in BC, the 25% rule should be taken into account in the DP guidelines.

### 9.7.1 DPA 2A - Mitigated debris fans (Map 4)

Without more detailed assessment of debris flow hazard, the level of safety offered by existing mitigation is unknown, as is the tolerability of residual risk. Thus, DPA 2A is drawn to capture the inset fan surface that extends up to the catchment basin on Magnesia and Harvey creeks, or on Alberta Creek, up to where ravine confinement exists.

For residential developments, the 1:500-year and 1:2500-year return period events need to be considered when evaluating life safety. Thus, DPA 2A captures terrain that could be affected should existing mitigation structures become overwhelmed by a large, moderate to low hazard event.

Note that, consistent with flood-proofing principles for floodplain areas, since the presence of diking (in this case partial debris flow mitigation) does not guarantee safety, all residential development within mitigated areas must still be supplied with appropriate flood proofing as additional protection and/or failsafe protection. This principle should be applied within alluvial fan areas within the Village of Lions Bay. Measures that may be required on mitigated debris fans include accounting for potential overland flows by establishing an FCL a minimum of 1 m above finished grade and construction using concrete reinforced foundation to the FCL (WLAP 2004). House foundations should be designed to mitigate the possibility of water ingress, requiring habitable space to be located above FCLs, or suitable tanking of habitable space below FCLs.

On Magnesia Creek, note that above Highway 99 there are several lots below Crystal Falls that border natural stream banks with relief of 2-4 m above the channel bed. These lots could be vulnerable to debris floods from water and debris that passes the decant structure during debris floods, from rare large catchment overtopping events or from ravine sidewall failures. Any debris that overtops the bank could then be directed down the surface onto the highway and down the Brunswick Beach access to Brunswick Beach Road.

On Alberta Creek, lots border the flume on both sides. The lower flume below about 150 m elevation has a reasonably constant configuration with 5 m depth and 13 m crest to crest width, as measured at the bridge on Isleview Place. It is conceivable that events exceeding the Design Event could overwhelm this channel with partial overtopping onto the fan surface. Depending on the overtopping elevation and the event magnitude, overflow debris could be directed anywhere on the modern fan. Upstream, between 150-255 m elevation (255 m elevation is the upper extent of the engineered flume), the flume is confined in ravine sidewalls 10-20 m deep, and there is little chance of debris escape in this section.

At ~260 m elevation there is a municipal water line crossing Alberta Creek. On the right bank, the buried pipe follows a bulldozed grade toward Timbertop Road. The channel cross section is 5 m deep by 10 m wide from the right bank crest to the left bank sidewall, which is higher. Any overtopping debris here could avulse onto the right bank, follow the 3% descending grade and affect houses on Timbertop Road and downslope. This is an isolated vulnerability, and its potentially affected area is not included in the DPA. Upstream of this point Alberta Creek is deeply incised in a bedrock ravine.

On Harvey Creek, the channel is deeply confined downslope to the former fan apex where the catchment structure is located. Residual risk exists on the fan surface downslope of the catch basin. Below the catchment basin the creek is confined within an engineered flume, yet the flume does not extend to the sea. Local flood and debris flood hazard may affect coastal lots adjacent to Harvey Creek (Photo 6).

DPA 2A may be revised by more detailed assessment of debris flow hazard and risk. This is anticipated to be a project exceeding the scope expected of individual lot owners. This is a responsibility likely needing to be undertaken by Village of Lions Bay or another level of government.

### 9.7.2 DPA 2B- Lions Brook fan (Map 5)

DPA 2B captures the entire Lions Brook fan including areas vulnerable to flooding and slope instability in case of misalignment of the diverted channel. This DPA is vulnerable to debris flow and stream flooding including channel shifting. Should the diverted channel jump its banks, then the flow could further erode the gullies downslope, causing similar instability to that experienced in 1972; while minor sedimentation at the point of the 1972 diversion could redirect the creek back into its natural channel affecting housing at the fan apex. Moreover, a debris flow could directly impact several houses near the apex. In either of these scenarios, water and debris could spread throughout the DPA in unpredictable ways.

BGC (2013) recommended mitigation of the debris flow hazard affecting this area (Appendix 1), but to date none has occurred. Until mitigation is in place, as part of the development permit process, Village of Lions Bay should require debris flood and debris flow assessment, with consideration for earthquake triggered landslides from slopes above, failure of excessive and irretrievable road spoil sites, open-slope slides, misaligned drainage and local instability caused by misdirected water. In addition, covenants detailing the landslide risk should be attached to title.

At a minimum, as per development on alluvial fans (WLAP 2004), house foundations should be designed to withstand debris flood impacts with concrete steel reinforced foundations, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level (FCL) a minimum of 1 m above finished grade, requiring habitable space to be located above, or with suitable tanking of habitable space below.

### 9.7.3 DPA 2C- Ravines (Map 6)

Ravines are landforms associated with creeks that have become incised into bedrock or 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 creek hazards. Ravine areas have been defined following RAR criteria and using ravine crest lines mapped on LIDAR.

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

> A ravine is a narrow, steep-sided valley that is commonly eroded by running water and has a sidewall slope greater than 3:1 measured between the high water mark of the watercourse contained in the valley and the top of the ravine bank. The top of the ravine bank is the first significant break in a ravine slope where the slope beyond the break is flatter than 3:1 for a minimum distance of 15 meters measured perpendicularly from the break, and the break does not include a bench within the ravine that could be developed. The ravine setback area is a 30 m wide strip on both sides of the ravine measured the top of the ravine bank.

A 30 m setback from ravine crests defines the area that falls within DPA 2C. This DPA captures Battani and Rundle Creeks, and the ravines upstream of fan apices on Magnesia, Alberta and Harvey Creeks.

As mapped, the DPA represents a maximum, cautious delineation. The setback from ravine crest could be reduced on the basis of a report from a qualified engineering/environmental professional, considering issues such as creek flood and debris flow hazard, factor of safety of the ravine sidewall slope and the riparian area regulation.

Within DPA 2C, as part of the development permit process, for building sites beyond the ravine top of bank seismic slope stability assessments will be required to assess foundation stability; where building sites are located within ravines, a landslide assessment will be required for ravine slopes affecting the site, and to establish FCLs and other measures based on flood, debris flood and debris flow from affecting creeks.

## 9.8 DPA 3 - Slope hazards (Maps 7, 8 & 9)

Three sub-categories of slope hazards are identified: open-slope failures, rockfall hazards, and stability of foundations and engineered slopes.

After District of North Vancouver (Bylaw 7900, Part 4.2A, DPA 3), the Slope Hazard DPA and corresponding Development Permit Area are established to address the following objectives:

1. minimize the risk to people and property from slope hazard;
2. develop safely and minimize the impacts on or near steeply sloped lands, including the potential run out area below steep slopes;
3. reduce slope hazards and landslide risk to people and property by carefully managing development and construction practices on or near steeply sloped lands;
4. avoid alteration of steeply sloped lands that may cause increased instability of the land or adjacent areas;
5. encourage professional design of structures and mitigative works and to ensure field review during construction and post-construction certification; and
6. encourage ongoing maintenance and monitoring of steeply sloped lands.

An example list of guidelines to meet these objectives are provided in DNV Bylaw 7900, Part 4, DPA3C. DNV Bylaw 7900, Part 4, DPA 3B sets out a list of exemptions. These were recently updated (amended October 13, 2017) reflecting 8-years of experience with their Risk Management system. All are directly applicable and Village of Lions Bay could decide to use in whole or in part (the Village of Lions Bay must consider legal third party reliance issues).

The list of exemptions does not include the "25% rule" which never the less is included in adopted (DNV 2009) Risk Tolerance criteria (Table 11). To be consistent with many community bylaws in BC, the 25% rule should be taken into account in the DP guidelines.

### 9.8.1 DPA 3A - Open-slope slides (Map 7)

On the basis of analysis presented in Section 8.3.2, DPA 3A extends from Highway 99 upslope to the municipal boundary.

Risk Analysis for open-slope slides requires knowledge of the frequency-magnitude model. Stratigraphic and radiometric methods must be applied to estimate historic return periods and gauge landslide intensity at the site. Such materials/methods may or may not be present or practicably attained from a single lot or group of lots. In lieu of hard data, expert judgment supported by sound geomorphic reasoning must be relied upon.

The area included within DPA 3 has complex micro terrain, with very irregular to hummocky topography, and it is very difficult to predict individual landslide paths. Thus, while some local topographic features may shed or protect certain sites, safe sites cannot be predicted using simple rules, and caution is warranted. Landslide modeling by QPs using high resolution LIDAR topography would aid defining specific travel paths for various landslide volumes and rheologies.

If required by the outcome of risk analysis and evaluation, then siting constraints and/or design of protective measures may be required. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots.

Development of frequency-magnitude models and protective measures might be best suited to area-wide assessment and mitigation. These tasks should be future work for consideration by the Village of Lions Bay or the Provincial Government.

### 9.8.2 DPA 3B – Rockfall (Map 8)

DPA 3B, areas affected by rockfall encompass the $27.5^0$ rockfall shadow angle (Hungr and Evans 1993). The authors suggest that the shadow zone captures 99% of all rockfall events. Thus, the probability of escape beyond is low, and the DPA boundary may be regarded as a safeline with Very Low risk beyond. Rockfall source areas requiring assessment may exist on a property or far upslope. The DPA area is drawn by projecting the shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other small scattered bluffs in and above Lions Bay.

Within DPA 3B, the Village of Lions Bay should require rockfall risk assessments, including characterisation of 500-year to 1:2500 year return rockfall, and potential earthquake triggered events. Rockfall modelling should be applied to aid design of protection measures. Protective measures may include scaling, bolting, shot creting application, fencing as determined by specialist P.Eng.

Rockfall must consider the hazard intensity of fall of individual blocks to the detachment of larger masses up to several thousand $m^3$, such as the prehistoric Kelvin Grove wedge failure and rockfall located off Kelvin Grove Way, on Lots 48, 60 & 61. Specialist bedrock structure and kinematic analysis may be required to determine potential event volumes.

Since the Magnesia-Alberta Face unit rock avalanche headscarp (Map 2) is located high above the Village, and since the cliffs are tall (10s m) and potential rockfall volumes are reasonably large (e.g., 10s-1000s $m^3$), the reach of these events extends far downslope, almost reaching the highway in the vicinity of Schoolyard Creek. Elsewhere, the smaller and lower elevation bluffs with benched terrain below, result in less extensive reach of potential rockfall.

### 9.8.3 DPA 3C - Slopes >30% (Map 9)

Various guidelines and precedents set by other jurisdictions requires a DPA category based on simple slope class. This slope-based DPA is concerned with stability of foundations, excavations, fillslopes, the existence of very local rockfall and/or slide hazards, and with water control.

Worksafe regulation Section 20.78 of the OHS Regulation ("Regulation") states:

> (1) excavation work must be done in accordance with the written instructions of a qualified registered professional if
> (a) the excavation is more than 6 m (20 ft) deep,
> (b) an improvement or structure is adjacent to the excavation,
> (c) the excavation is subject to vibration or hydrostatic pressure likely to result in ground movement hazardous to workers, or
> (d) the ground slopes away from the edge of the excavation at an angle steeper than a ratio of 3 horizontal to 1 vertical.

Note regulation 20.78(1)d refers to slopes of 3HD:1VD, or 33%; this criteria is rounded down and adopted in the DPA framework. Following the Worksafe regulation, DPA 3C applies to areas where natural average ground slope was >30%. Most areas in Village of Lions Bay have average slopes >30% and require hillslope excavation and fillslope construction to develop building sites. Village of Lions Bay should require written reports from qualified professional for excavations, roads, drainage, fillslopes and foundations proposed at these sites. Local rockfall assessment and mitigation may also be required. Evaluation of onsite and nearby municipal drainage structures, and design of buildings to prevent water ingress is also required.

Areas like the tennis courts and local parking are expansive flat areas, but they are built in part on fill, and included in DPA 3C. Small areas of gentle terrain exist along Bayview Road toward Mountainview Drive, but most lots encompass some areas of steeper slope. Thus, these areas are included in the DPA.

Current guidelines for assessment of slope hazards provided by the National and Provincial Building Code and the Association of Professional Engineers and Geoscientists BC (2010), indicate seismic-initiated slope instability needs to be considered. Seismic slope analysis requires comparatively detailed knowledge of subsurface bedrock, soil and groundwater conditions. The required factor of safety calculation references many data sources, including but not limited to:

i. seismic hazard maps and reports;
ii. ground motion data;
iii. seismic Site Class; and
iv. modal magnitude values of the design earthquake.
v. assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, septic fields, footing drains, etc., on local slope stability.

With respect to water control off small non-identified drainages, the conveyance capacity of drainage structures should be designed for 200-year floods to be consistent with legislated flood assessments (APEGBC 2012) for residential areas. It could be required that as part of the development permit application developers conduct a review of adjacent/nearby storm drainage structures to identify which may be undersized and presenting risk of blockage and overland flow affecting the development site.

The only areas within Village of Lions Bay exempt from DPA 3C are below Highway 99, along Brunswick Beach, Harvey Creek fan excluding sites adjacent to the engineered flume, and Sweetwater Place inside the road center line of Tidewater Way and Periwinkle Place.

## 9.9 Additional possible exemptions

In addition to the Exemptions considered for each DPA in the previous sections, The Village of Lions Bay may choose to grant general exemptions in the following circumstances:

For "Low Importance" structures, as defined in the BC Building Code: Buildings that represent a low direct or indirect hazard to human life in the event of failure, including: low human-occupancy buildings, where it can be shown that collapse is not likely to cause injury or other serious consequences, or minor storage buildings.

Where the proposed construction involves a structural change, addition or renovation to existing conforming or lawfully non-conforming buildings or structures, provided that the footprint of the building or structure is not expanded, and provided that it does not involve any alteration of land.

A subdivision where an existing registered covenant or proposed covenant with reference plan based on a qualified professional's review, relating to the protection of the environment or hazardous conditions outlined in the subject development permit area, is registered on title or its registration secured by a solicitor's undertaking.

Immediate threats to life and property provided they are undertaken in accordance with the provincial Water Act and Wildlife Act and the Federal Fisheries Act, and are reported to the Village of Lions Bay.

Emergency procedures to prevent, control or reduce erosion, or other immediate threats to life and property provided they are undertaken in accordance with the provincial Water Act and Wildlife Act and the Federal Fisheries Act, and are reported to the Village of Lions Bay.

## 10. Discussion

In this report for the first time geohazards affecting Lions Bay have been reviewed and analysed in a comprehensive assessment. Since the community was developed before georisk was commonly considered a fundamental part of the subdivision process, and since Lions Bay was developed in and below steep terrain, it is not unexpected that much of the community is apparently vulnerable to multiple geohazards, including ocean, creek and hillslope hazards.

The Development Permit Areas (DPAs) proposed in this report are necessarily conservative. This is because it is judged that, given the preliminary level of assessment applied in a complex topographic setting, it would be unwise and improper to attempt to refine and reduce the extent of DPA zones beyond the level predicted by the simple empirical tools available. This would amount to provision of a false "positive" assessment for properties thereby excluded, and would expose the consultant and the Village of Lions Bay to excess liability. The designation of conservative DPA boundaries does not preclude development. Rather the boundaries outline where and in what context more detailed assessments are required.

Further, while it may be appropriate with some DPAs, to allow the developer to carry the burden of a more detailed assessment, for the assessment of others, the burden may more logically be the responsibility of the Village of Lions Bay or a higher level of government. For example, the ocean hazards, ravines, rockfall and slopes >30% slope development permit areas are sufficiently refined and reasonable such that they may be applied on a site by site basis. On the other hand, the DPAs for Magnesia, Alberta and Harvey creek fans and the area potentially affected by open-slope slides are quite extensive, and refinement producing consistent results may be most efficiently and fairly pursued as a single area wide analysis, rather than repeated assessments conducted by multiple and various consultants. This refined analysis should apply more sophisticated tools such as some or all of the following methods: subsurface exploration, stratigraphy, radiometric dating, regional analysis, computer modelling and risk assessment.

## 11. Recommendations for Future Work

For DPA 1, Ocean hazards, adaptive management is recommended, applying periodic, ongoing monitoring of future sea-level rise by literature review and attention to government guideline updates.

For all landslide hazards, it is recommended that Village of Lions Bay adopt a landslide safety policy consistent with the District of North Vancouver (DNV 2009). As part of the risk assessment, a minimum landslide magnitude to consider is the 1:500-year event, but larger events up to the 1:2450-year earthquake triggered landslide should be considered. It is unreasonable to expect estimation of a 1:10,000-year event as required by District of Squamish, Fraser Valley Regional District or MoTI.

It is recommended that Village of Lions Bay assess residual risk affecting DPA 2A. A qualified professional should estimate a frequency-magnitude (F-M) model for debris flows on Magnesia, Alberta and Harvey Creeks. The F-M model will include consideration of channel yield and point source volumes, and the event scenarios may include event process chains, such as point source failures mobilizing channel debris, with peak discharge augmented by temporary jams and outburst. Once developed, the runout of various landslide scenarios should be modelled to assess residual risk on the debris fans. Modeling should be conducted using high resolution (0.5-1.0 m contour) topography with various landslide volumes and rheologies.

It is recommended that the isolated vulnerability at the pipe crossing on Alberta Creek at 260 m elevation be assessed and mitigated to provide continuous confinement for the revised design event.

Even with partial or full mitigation of creek hazards, consistent with flood hazard management on dike protected floodplains, development on debris fans of Magnesia, Alberta and Harvey Creeks should employ failsafe mitigation. At the very least this will entail measures for low hazard areas on alluvial fans as recommended by WLAP (2004).

Similarly, DPA 2B for Lions Brook should be revisited, but must consider rockfall, debris flow, open-slope slide and potential avulsion of the diverted channel; stability of the irretrievable road-related fillslopes below the old logging road should be considered.

It is recommended that Village of Lions Bay refine DPA 3A, open-slope hazards, and hire a qualified professional to estimate the frequency-magnitude (F-M) of open-slope landslides affecting Lions Bay and to suggest, using computer modeling, more refined runout limits for the design event. Depending on the results of a more detailed study, Village of Lions Bay may require proposed developments within the revised DPA to implement site-specific measures, or it may be more practicable that Village of Lions Bay implement area wide protection. Alternatively, a higher level of government might be lobbied to effect these recommendations.

Similarly, it might be reasonable for Village of Lions Bay or the Province to conduct a Village or neighbourhood wide rockfall analysis and implement extensive protection strategy, as done a-priori at Sunset Highlands as a condition of development.

Potentially large but uncertain sackung hazards loom above parts of Lions Bay and Highway 99. These features require more detailed assessment to determine if they are stable or represent potential catastrophic hazards. Remote sensing using high resolution radar and optical satellites and LIDAR imagery is being applied to screen for unstable terrain, by differencing images and digital elevation models produced from sequential acquisitions. Interferometric Synthetic Aperture Radar (InSAR) satellite technique can detect cm/mm-scale displacements of slow deforming slopes over large areas. This technique has been applied to obtain multi-year national scale ground deformation map and it has been proven applicable for landslide early warning systems. If screening with LIDAR, optical satellite and InSAR were to identify movement, these same techniques can be applied to monitor the slopes. Analytical methods are then available to predict catastrophic failure providing an effective early warning system framework.

Where existing homes exist in areas potentially affected by hazards, there may be a duty to warn. The Village of Lions Bay is advised to carry out public education and make hazard information available to all landowners and to prospective purchasers by means of various methods like public meetings, information mail out, and having material available on the Village website. The permit approval process should also be used as a trigger to attach save harmless covenant on title. The Village of Lions Bay is advised to consult with a lawyer for advice on these matters.

An archive of area-wide and site-specific hazard/risk reports should be created and made available to professionals conducting georisk assessment reports. This will allow professionals to become informed about previously identified hazards, and will promote efficiency and consistency of results and recommendations.

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**Appendix 1.** Summaries of site specific reports at Lions Bay

Golder Associates Ltd., 1989. Kelvin Grove Developments, Rock Slope Stability on Lot 48. Report to Village of Lions Bay, Lions Bay.

Four natural bluff areas were identified as potential rock fall hazards on Lot 48 and adjacent areas, including Lots 58-70 inclusive. Rockfall was described as fragmental blocks in the range of 0.5 m to 10 m diameter. Potential triggering mechanisms were listed as water or ice pressures developing during periods of wet or cold weather, tree roots growing in a crack and causing it to open, or an earthquake. Stabilization work was recommended before development work proceeded.

Westmar, 2005. Tsunami probability and magnitude study, summary report. Report to Village of Lions Bay, Lions Bay.

This was a literature review to determine tsunami hazard at Lions Bay. It was concluded that while mechanisms can be postulated (Hamilton and Wigen 1987), there is no geological or historical evidence of tsunami within Georgia Basin(Clague et al. 1994), megathrust earthquake induced tsunami generated at the continental margin would attenuate to ~1 m before reaching Lions Bay (Clague et al. 2003), local sources for landslide induced tsunami are not evident, and events such as submarine slope failure at Squamish delta would not amplify in the deep water offshore at Lions Bay. The maximum credible tsunami was cited as 2 m with a return period of 100-1000 years. Given a 4-5 m tidal range, such an event would have to be coincident with HHW to cause damage, resulting in a very low probability of severe consequence occurring.

Golder Associates Ltd., 2006. Slope condition assessment phase 4 & 5 access road, Lions Bay.Report to Village of Lions Bay, Lions Bay.

This report provides fillslope pullback recommendations to remediate roadfill instability that had developed on Oceanview Road. Apparently, the work was completed immediately.

Hungr Geotechnical Research Inc, 2007.Aerial inspection of the check dam on Alberta Creek. Report to BC Ministry of Transportation, Burnaby, BC.

In 2007, the administrator of the Village of Lions Bay expressed concerns about the check dam on Alberta Creek at about 700 m elevation. Hungr stated the check dam was built for a temporary purpose before the completion of the concrete lined debris chute channel in 1985. Its foundation and abutments are anchored into strong rock and it was well built with a design life of more than 100-years. They are left to naturally fill with debris to full capacity, and thereby protect the structure from dynamic impact by debris. The incipient shallow slide upstream of the check dam, that was the original reason for its construction, seems to be still perched on the steep hillside. Thus, the check dam reduces the hazard and will continue to do so, as long as it is structurally sound. No works were recommended, in fact attempting cleanout was discouraged.

Fieber Rock Engineering Services, 2011. Rock Slope Stability - 300 Block Mountain Drive, Lions Bay, BC. Report to Village of Lions Bay, Lions Bay.

An area of recent rockfall extending an approximate 100 m length of slope, from roughly the driveway at 340 Mountain Drive to the driveway at 390 Mountain Drive. Ditch improvements were recommended to act as a catch for small rockfall sourced a limited distance up the slope. It was noted that the recommended ditch improvements will not provide protection from rockfall originating from the higher areas of the mountain slope.

Cordilleran Geoscience 2011.Terrain Stability Assessment along access road beyond Oceanview Road. Report to Village of Lions Bay, Lions Bay.

Residents expressed concern about terrain stability and downslope risk as a result of recent hauling, handling and storage of construction aggregate on the access road extending beyond Oceanview Road and the construction of a skid trail from a private property up to the access road. The area of concern consisted of interspersed moderate (30-50%) and moderately steep (50-70%) slopes mantled by weathered till veneer on bedrock, with local seepage on impermeable bedrock. Under natural conditions there was judged to be a very low to negligible potential for landslide initiation. However, with human modification, fill materials perched on locally steep slopes could result in small failures, likely less than 1000m$^3$ in total volume, but of a size could cause property damage and death should they directly impact a house or persons. Following this assessment some unstable fillslope areas were remediated and the lockblock storage bin was removed from the fillslope shoulder. It was recommended that the Village of Lions Bay review their development policies to ensure that they require developers to involve qualified professionals when development (including roads) is proposed in "steep" terrain.

Cordilleran Geoscience 2012a.Rundle Creek windfall and creek hazard assessment, Lions Bay. Report to Sea to Sky District, Ministry of Forests, Lands and Natural Resource Operations, Squamish, BC.

Concern was expressed regarding recent windfall and its effect on Rundle Creek, specifically with regard to aggravating creek hazards and risk to lots downslope. Based on field inspection, it was noted Rundle Creek is a very small channel with low water power, and there is low debris flow initiation potential at the windfall site and immediate vicinity. For such small streams, typically no cleaning would be required, even after logging had introduced substantial woody debris. No action was recommended.

Cordilleran Geoscience 2012b.Alberta/Harvey Creek face, Lions Bay landslide hazard assessment. Report to Sea to Sky District, Ministry of Forests, Lands and Natural Resource Operations, Squamish, BC.

This report was commissioned following a SAR member reporting a cutslope failure on the old logging road above Lions Bay. While the cutslope failure was deemed to be of little concern, two major findings were discovered. Firstly, it was noted that the logging road construction spoiled excessive sidecast onto the slopes below, and that there were several sites where the fillslope was presenting tension cracking and settlement and thereby deemed unstable; and secondly, in traversing the slopes below it was noted there was an error in both the 1:50,000 and 1:20,000 scale topographic mapping which showed a small basin on the Harvey/Alberta face draining into Alberta Creek; while in fact it was identified that this drainage was directed downslope to a fan apex on 545 Upper Bayview Drive. In the Septer (2006) report this drainage is identified as Lions Brook. This newly identified slope condition implied that there was a previously unappreciated hazard affecting 545 Upper Bayview and environs. Two key recommendations followed from the report: 1) pullback the unstable fillslopes as much as practicable, and 2) have a second QP conduct a QRA to assess the landslide risk affecting Upper Bayview Road.

BGC Engineering Inc., 2012 & 2013. Upper Bayview Road debris flow hazard and risk assessment. Reports for BC Ministry of Forests, Lands and Natural Resource Operations and Emergency Management BC.

Following from Cordilleran (2012b), BGC (2012) conducted a preliminary QRA that concluded that unacceptable risk existed at several properties on Upper Bayview Road, and that measures would be required to reduce the risk. They recommended several items that would permit a refined analysis, including acquiring a high resolution topographic map base, radiocarbon dating of stratigraphic exposures, and debris flow modelling. The results of BGC (2013) suggest that individual risks at 540 and 545 Upper Bayview Road were unacceptable when compared with individual risk tolerance criteria adopted by the District of North Vancouver (DNV). Four potential mitigation options were identified, including 1) construction of a deflection berm and excavation of a channel that would direct debris flows from the mid-slope area of Bayview Creek towards Alberta Creek before they could enter the lower gully; 2) installation of flexible debris flow nets in the lower gully and near the fan apex; 3) construction of an earthworks barrier in the lower gully; and 4) acquisition of the property at 545 Upper Bayview Road and construction of an earthworks barrier near the location of the existing home.

Cordilleran Geoscience 2013. Lions Trail fillslope pullback-Alberta/Harvey Creek face, Lions Bay. Report to Sea to Sky District, Ministry of Forests, Lands and Natural Resource Operations, Squamish, BC.

Final V3: January 4, 2018

This report signs off on deactivation work conducted to reduce logging road related landslide risks affecting Lions Bay identified by Cordilleran (2012b). Sites where road-fillslope material presented a potential landslide hazard were pulled back as much as is practicable given access constraints. There is residual risk remaining that affects residential areas downslope; it arises from road-related fills that are too far below the existing bench and cannot be retrieved or from natural hazard areas above the road. The risk from these areas is best mitigated through constructed protection measures.

Cordilleran Geoscience 2014a. Rock Chamber Slide, Harvey Creek, Lions Bay. Report to Village of Lions Bay, Lions Bay.

On October 22, 2014 rainfall at low elevation stations was 30-50 mm/24 hr, with maximum gusts of 50-70 kmh in Howe Sound. The storm triggered a small slide on the north facing sidewall of Harvey Creek, directly upslope of the domestic water intake and rock chamber building. The slide debris impacted the intake access road downstream of rock chamber building, partly inundating the building with sediment. High sediment transport on Harvey Creek on the same day filled the rock chamber plugging the water intake. Debris, from the slide and from a debris flood on Harvey Creek partly filled the debris catchment basin above Highway 99.

Cordilleran Geoscience 2014b. Channel assessments: Magnesia, Upper Bayview and Harvey Creeks, Lions Bay. Report to Village of Lions Bay, Lions Bay.

On December 9-10, 2014, a storm delivering precipitation >70 mm/24hr for 2 consecutive days, totalling 146 mm/48 hr with 40-60 kmh winds affected Lions Bay with debris flows and creek erosion causing damage to both Magnesia and Harvey community water intakes. As well there was anomalous flow on the 545 Upper Bayview (Lions Brook) debris fan. On Magnesia Creek, the intake access road was undermined by high flows and sections of rock stack fillslope had collapsed. The Magnesia Creek washout was triggered by a debris flow on a south facing slope at 1300 m snowline. The debris stopped 200 m downslope on a bench, and damage farther downstream consisted mostly of bank scour. The Harvey debris catchment was partially filled with deltaic gravel and woody debris. The Harvey Creek flood event was not related to landslide activity. High peak discharges entrained rubble from colluvial veneer and talus slopes and this resulted in high bedload, but not debris flow.

Geopacific 2016. Rock Fall Review, Harvey Creek Intake Access Road, Lions Bay, BC. Report to Village of Lions Bay, Lions Bay.

Geopacific conducted a review ofa rock fall onto the Harvey Creek intake road that occurred between January 18-20, 2015, possibly in response to a small earthquake. Further, we understand that a small rock fall occurred at this location after a small earthquake occurred in the area on December 30th, 2015 (Fig. 2).

Cordilleran Geoscience 2016. Georisk Assessment, 251 Stewart Road, Lions Bay. Report for Horizon Engineering Inc., North Vancouver, BC.

This was an onsite assessment for a proposed home on an undeveloped lot on Stewart Road.The property is situated on bare rocky terrain with little to no till cover or fragmental rock colluvium. No other landslide material is present on the lot. On that basis it was judged that no severely damaging or lethal hazards have affected the site since deglaciation.

The large suspect landslide scar identified by BGC (2012) was inspected. On the basis that the lower slopes below about 150 m were bare rock, but mantled with colluvium above that, it was judged that the rockslide was likely a deglacial event that deposited partially onto the receding ice sheet, as suggested by BGC (2012). On the south edge of the suspect slope it was noted that there was a stepped-rock area that maybe a distressed slope remnant from the original slide. Instability of this feature was judged to be uncertain.

**Appendix 2.** List of geohazards affecting East side of Howe Sound near Lions Bay, up to 2006. Source: Septer 2006.

| Year | Date | Hazard | Description |
|---|---|---|---|
| Ca 1935 | ? | Debris flow | Identified on airphotos, debris flows on Newman and unnamed #1 creeks. |
| Ca 1935 | ? | Debris flow | Identified on airphotos, a debris flow on Alberta Creek reaches the sea. |
| Ca 1935 | ? | Debris flow | Identified on airphotos, a debris flow on small creek (Lions Brook) between Alberta and Harvey Creek stopping at 550 m elevation. |
| Ca 1935 | ? | Debris flow | Identified on airphotos, a debris flow on Harvey Creek stopping at 500 m elevation. |
| 1969 | Feb 9 | Rockfall | 1-tonne boulder falls onto highway at Porteau, kills 3 people |
| 1969 | Feb 13 | Rockslide | 6000 m3 rockslide at Brunswick Point. Highway blocked for several days. |
| 1969 | Sept 17 | Debris flow | Water supply intake destroyed on Harvey Creek and flooding and erosion threatened 5 houses on alluvial cone |
| 1969 | Sept 18 | Debris flow | Torrent on Charles Creek destroys 4 bridges between Highway 99 and sea. |
| 1969 | Sept 18 | Debris flow | Newman Creek bridge buried. |
| 1972 | Dec 15 | Debris flow | Highway blocked and house damaged. |
| 1972 | Dec 25-26 | Debris slide | Small landslide affecting 6 homes. Caused by creek diversion of tributary to Harvey Creek into Alberta Creek. Referred to as Lions Brook. This is the creek affecting 545 Upper Bayview. |
| 1973 | May 23-25 | Flooding and erosion | Harvey Creek flooding and erosion, Lot 33 Cloudview affected by overflow; Lot 17 Seaview affected by bank undermining. |
| 1976 | Aug 25 | Rockfall | 1500 m3 rockfall at Brunswick Point closes highway and causes railway derailment. |
| 1976 | Sept 1 | Rockfall | Rockfall north of Lions Bay causes train derailment. |
| 1978 | Sept 9-10 | Flooding and erosion | Erosion of riprap on Harvey Creek |
| 1981 | Oct 27 | Debris flow | M-Creek debris flow destroyed highway bridge claiming 9 lives, covered the rail line and a destroyed a house at creek mouth |
| 1981 | Oct 28 | Debris flow | Rail bridge blocked diverting water onto private property affecting a truck and garage. |
| 1981 | Dec 4 | Flooding and erosion | Channel constriction almost forces avulsion of Harvey Creek into subdivision below highway. |
| 1981 | Dec 4 | Debris flow | Small debris flow on Newman Creek, overflow of debris affecting marina |
| 1981 | Dec 4 | Debris flow | Small debris flow on Alberta Creek. |
| 1981 | Dec 4 | Debris flow | Small debris flow on Charles Creek. |
| 1981 | Dec 20 | Rockfall/debris slide | Small landslide blocks Highway |
| 1982 | Jan 16 | Rockfall | Vehicles stopped on highway due to snow. At Brunswick Point single rock, dislodged by tree-topple, falls onto car kills one occupant injures another. |

| | | | |
|---|---|---|---|
| 1982 | Oct 6 | Flooding, erosion & sedimentation | Floods on Harvey, Newman and Magnesia Creeks. Erosion on Newman Creek triggered overflow and sedimentation at marina. |
| 1982 | Dec 2-3 | Landslide | Landslide blocks highway north of M-Creek |
| 1982 | Dec 3 | Debris flow | Small event on Alberta Creek |
| 1983 | Feb 11 | Debris flow | A large debris flow destroyed all bridges except railway, damaged 6 houses and claimed 2 lives, another person rescued from damaged residence. |
| 1983 | Feb 11 | Debris flow | Debris flow on Charles Creek blocks highway bridge and floods road. |
| 1983 | Feb 11 | Debris flows | Smaller debris flows also occurred on Newman and Turpin Creeks blocking crossings and causing overflows. |
| 1983 | Nov 15 | Debris flow | Debris flows on Charles, Newman and Montizambert Creeks. Bridges destroyed on Charles Creek. |
| 1984 | Oct 8 | Debris flow | Small debris flow on Sclufield Creek. |
| 1984 | Oct 8 | Flooding | Harvey Creek flooding washed away 6 weeks of work on protection structure under construction. |
| 1987 | Apr 29 | Rockfall | Small earthquake triggers rockfall onto highway between Lions Bay and Britannia, affecting 2 vehicles. |
| 1990 | Oct 21 | Rockfall/debris slide | Slide 6 km north of Lions Bay at Tunnel Point blocks highway and railway |
| 1990 | Oct 25 | Rockfall/debris slide | Repeat event at Tunnel Point injures workers clearing highway. |
| 1990 | Nov 16 | Rockfall/debris slide | Another Tunnel Point slide closes highway |
| 2005 | Jan 23 | Rockfall | Large rock fell on highway north of Lions Bay. |
| 2006 | Nov 17 | Tension cracking | A 5 m long by 10 cm wide fissure observed at Lions Bay. |

**Appendix 3.** Annotated photos.

**Photo 1.** Till in house excavation, Lot 60 Oceanview Road.

**Photo 2.** Glaciofluvial fan-delta sediments, 160 m elevation, Lot 22 Highview Place.

**Photo 3.** Blocky talus slope on Lots 60-61, Kelvin Grove Way.

**Photo 4.** View of the tombolo spit, Brunswick Beach. Low lying land is subject to flooding and erosion given sea level rise.

**Photo 5.** Magnesia Creek catch basin.

**Photo 6.** Lots 21 & A Lions Bay Avenue have natural banks not significantly raised above Harvey Creek, and could be vulnerable to flood hazard.

**Photo 7.** Lot 66 Kelvin Grove Way. Small Creek captured by drainage system undersized for full range of flows requires sand bagging to prevent overflow onto local road.

**Photo 8.** Open-slope landslide, North Vancouver mountains, triggered by rain on snow, November 22, 2017.

**Photo 9.** Unfavourable jointing in road cut, Lot 85 Kelvin Grove Way.

**Photo 10.** Waypoint 46. Antislope ridge indicating steep joint cutting crest of cliff. Several 10s $m^3$ to 1000s $m^3$ could be released from this site.

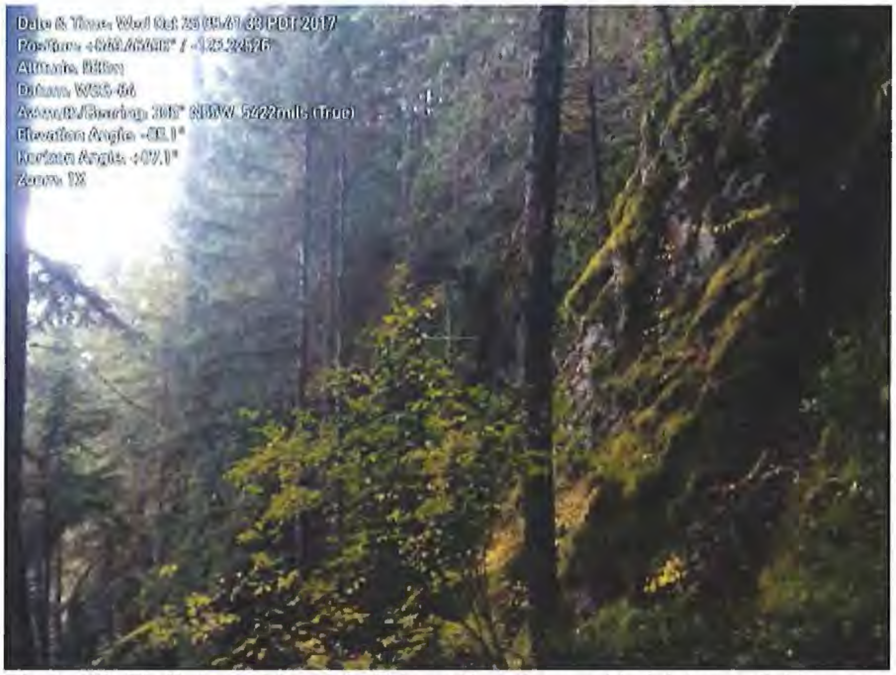


**Photo 11.** Bluff above Mountain Drive with unfavourable joint, parallel to steep slope.

**Photo 12.** Rockfall debris, Lots A & B Timbertop Road. Note the person for scale.

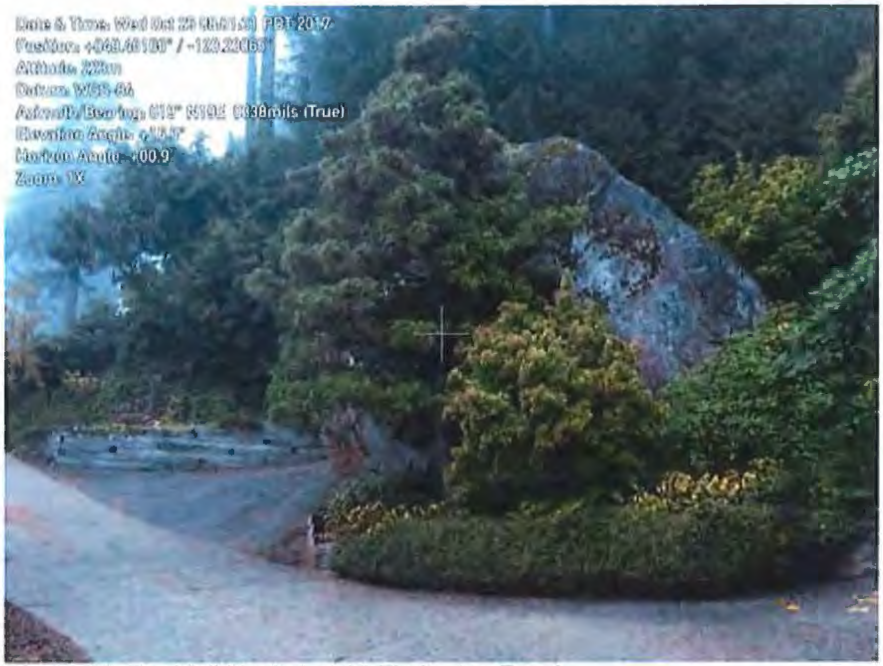
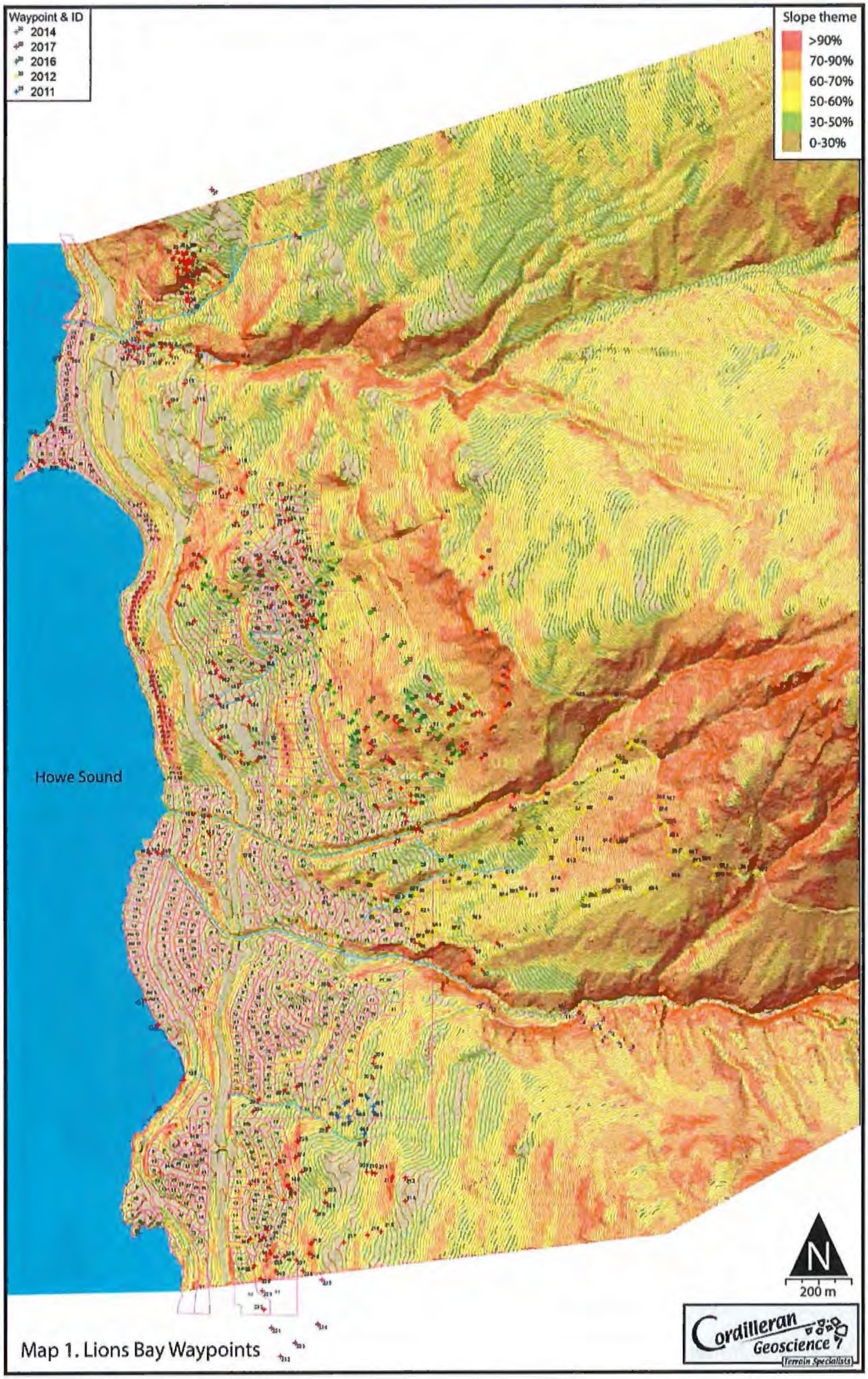


**Photo 13.** Rockfall block, Lot 36 Timbertop Road.

**Photo 14.** Lot 8 Isleview Place. Retaining walls in steep terrain require engineered design.

**Photo 15.** Stacked rock wall in steep terrain using geotextile to tie back into slope.

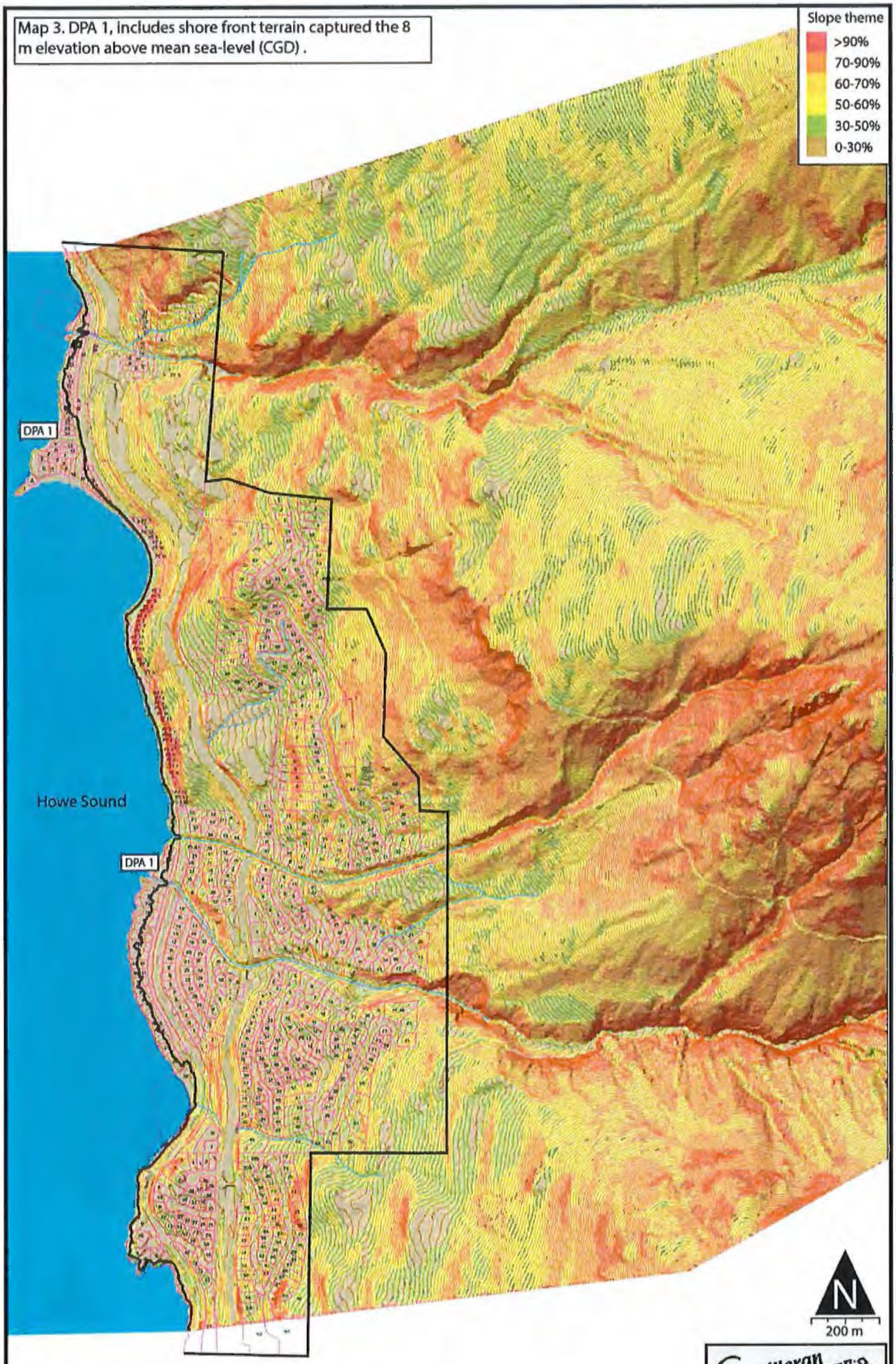
**Photo 16.** Substandard retaining walls represent a slope hazard.



Map 1. Lions Bay Waypoints

Map 2. Lions Bay Slope Theme and Geomorphic Features Map

Map 3. DPA 1, includes shore front terrain captured the 8 m elevation above mean sea-level (CGD) .



Lions Bay DPA 1 Coastal hazards

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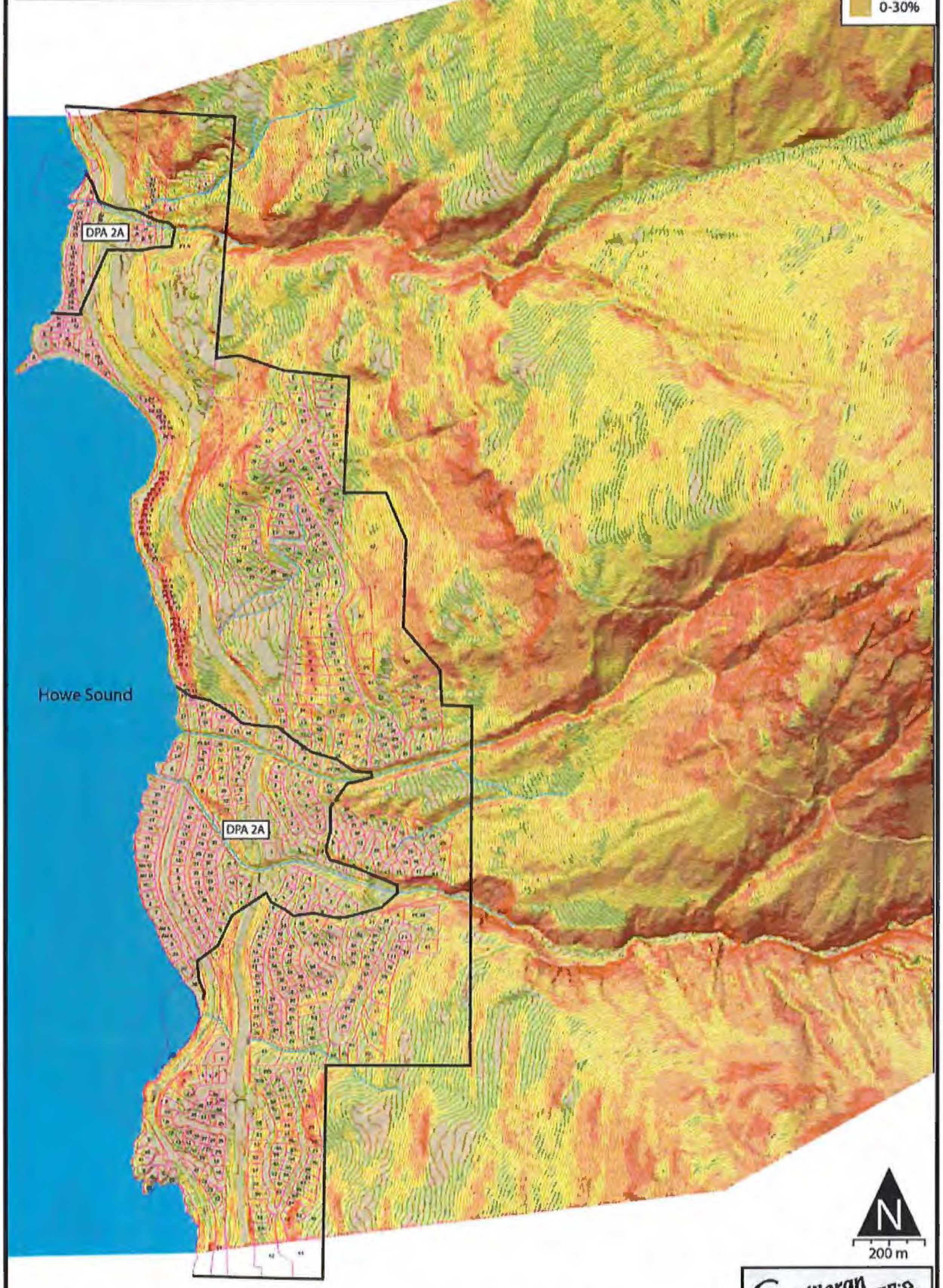
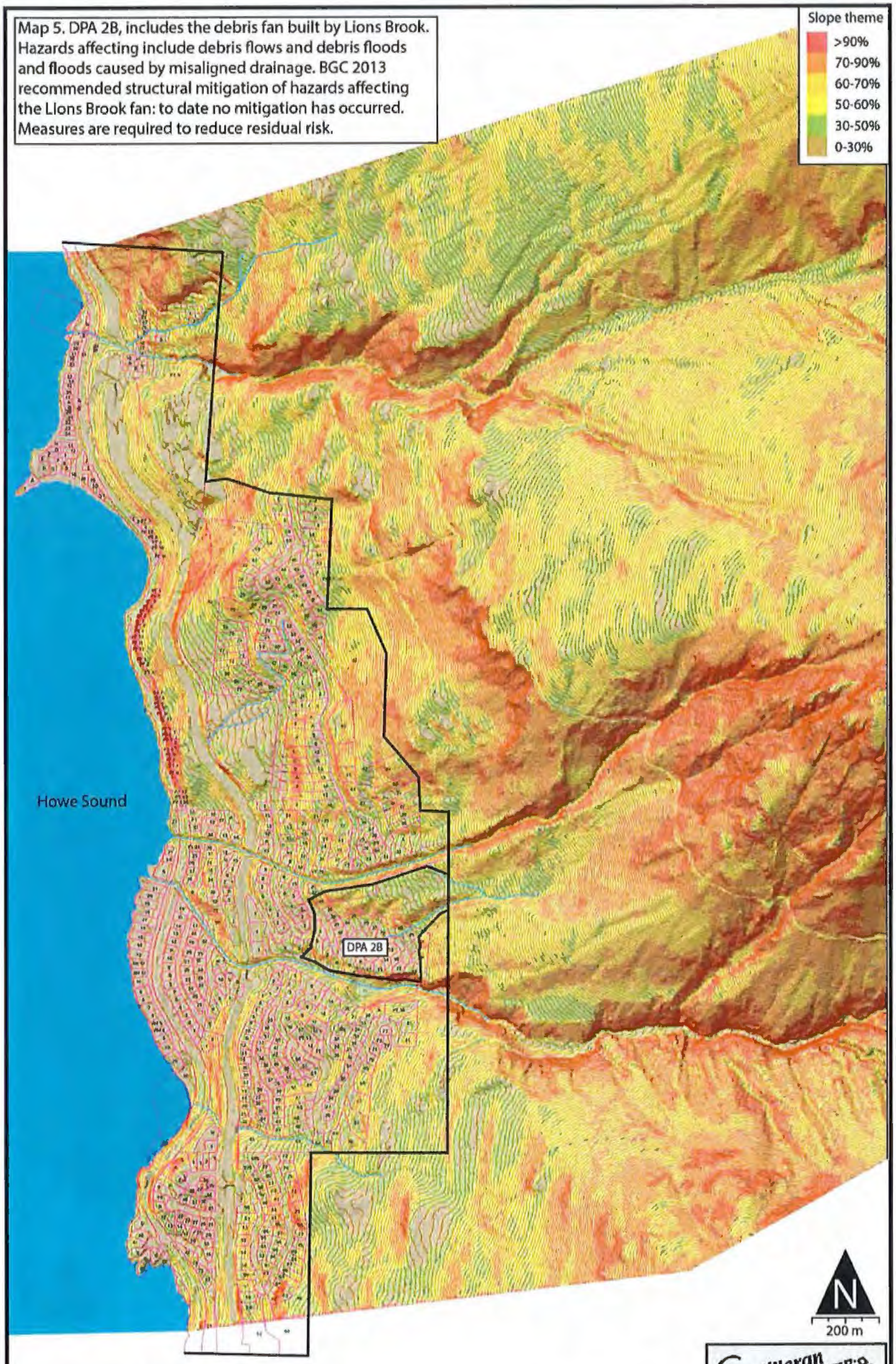
Terrain Specialists

Map 4. DPA 2A, includes debris fans formed by Magnesia, Alberta and Harvey Creeks. The area potentially affected reflects the fact that existing mitigation on these channels was not designed to a known return period standard, and likely does not include events up to 500-year return or larger. Measures are required to mitigate residual risk.



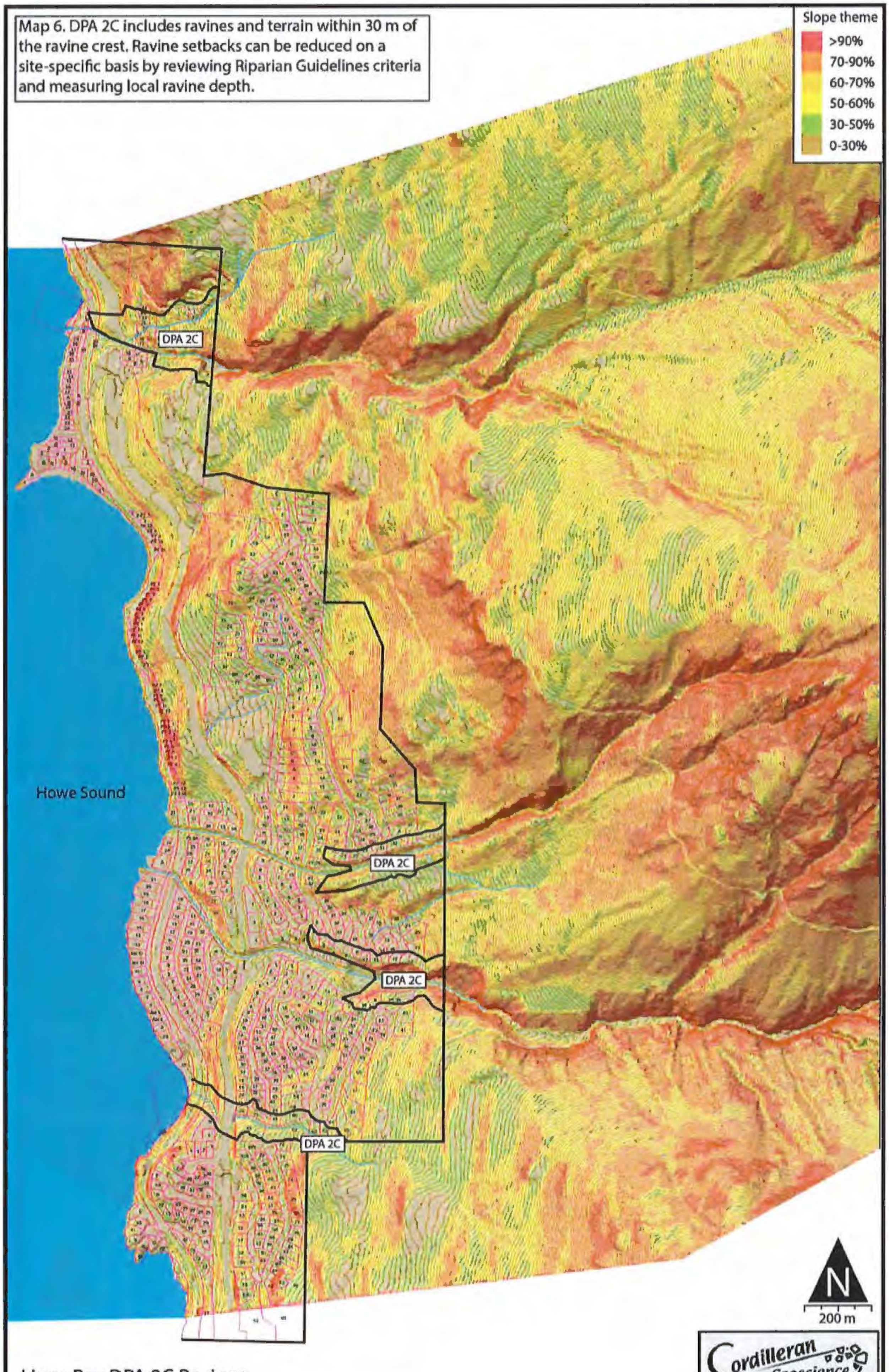
Lions Bay DPA 2A Debris fans of partially mitigated channels


Map 5. DPA 2B, includes the debris fan built by Lions Brook. Hazards affecting include debris flows and debris floods and floods caused by misaligned drainage. BGC 2013 recommended structural mitigation of hazards affecting the Lions Brook fan: to date no mitigation has occurred. Measures are required to reduce residual risk.

Lions Bay DPA 2B Lions Brook fan

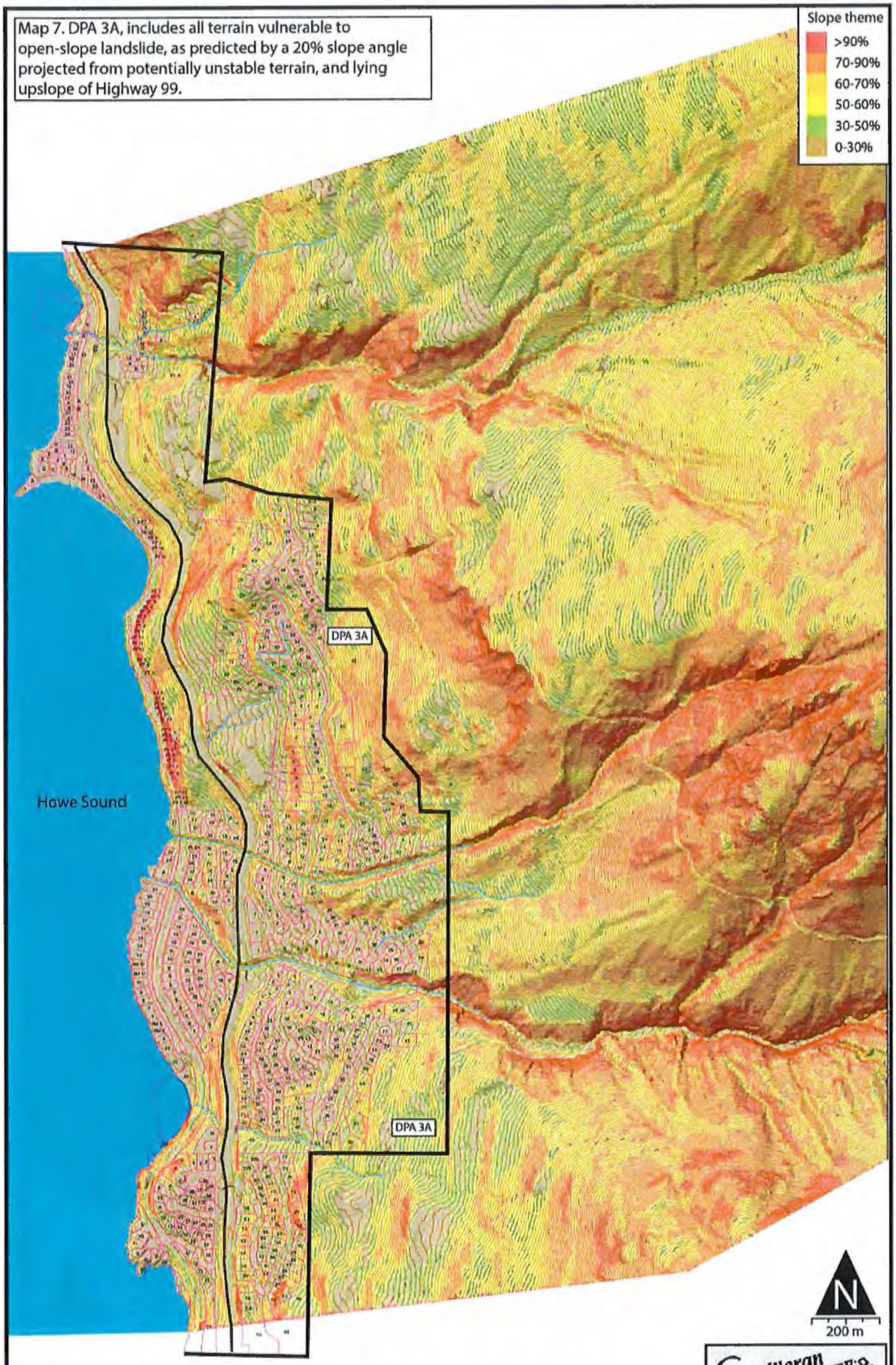
Cordilleran Geoscience
Terrain Specialists

Map 6. DPA 2C includes ravines and terrain within 30 m of the ravine crest. Ravine setbacks can be reduced on a site-specific basis by reviewing Riparian Guidelines criteria and measuring local ravine depth.



Lions Bay DPA 2C Ravines

Cordilleran Geoscience Terrain Specialists

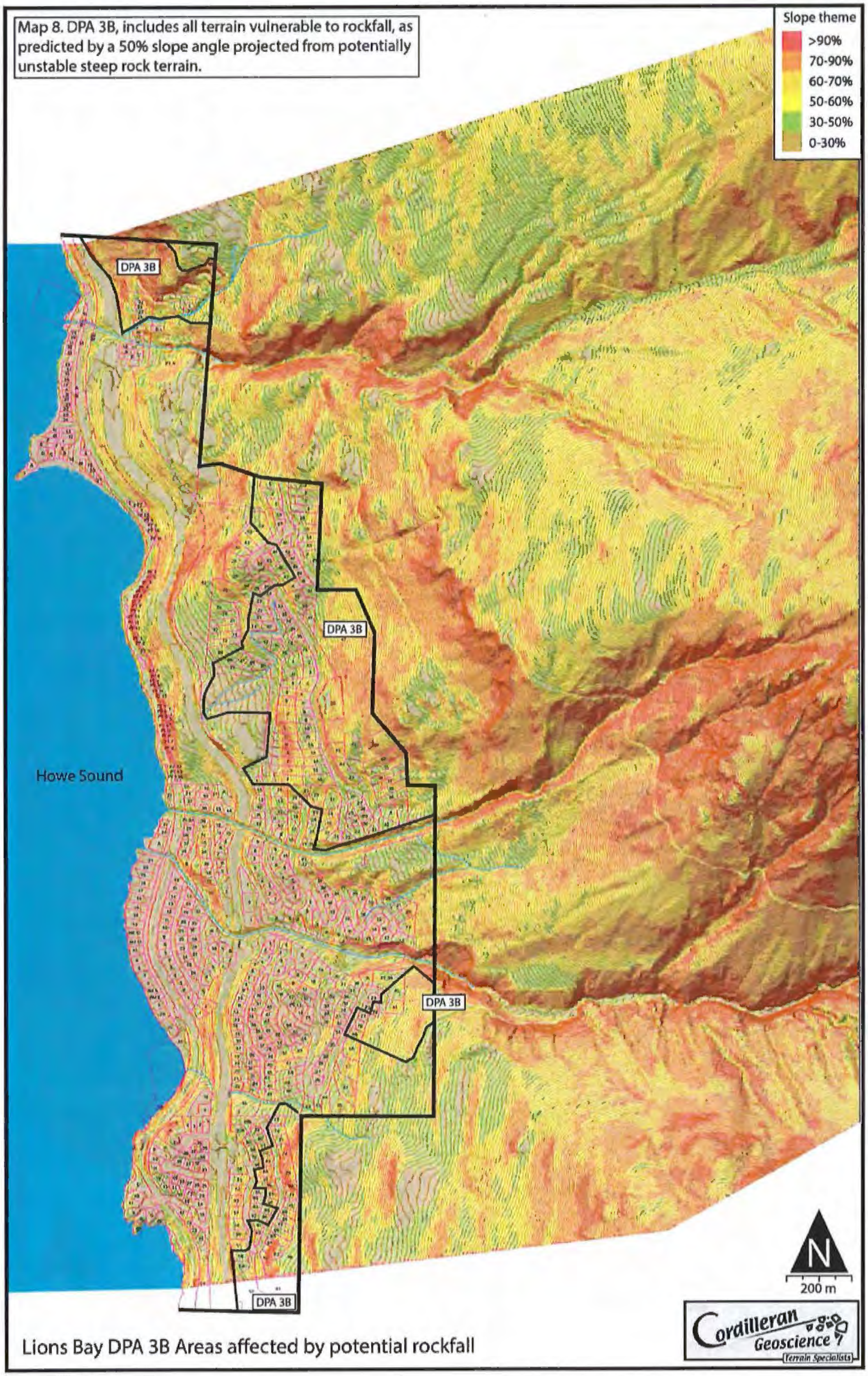


Map 7. DPA 3A, includes all terrain vulnerable to open-slope landslide, as predicted by a 20% slope angle projected from potentially unstable terrain, and lying upslope of Highway 99.

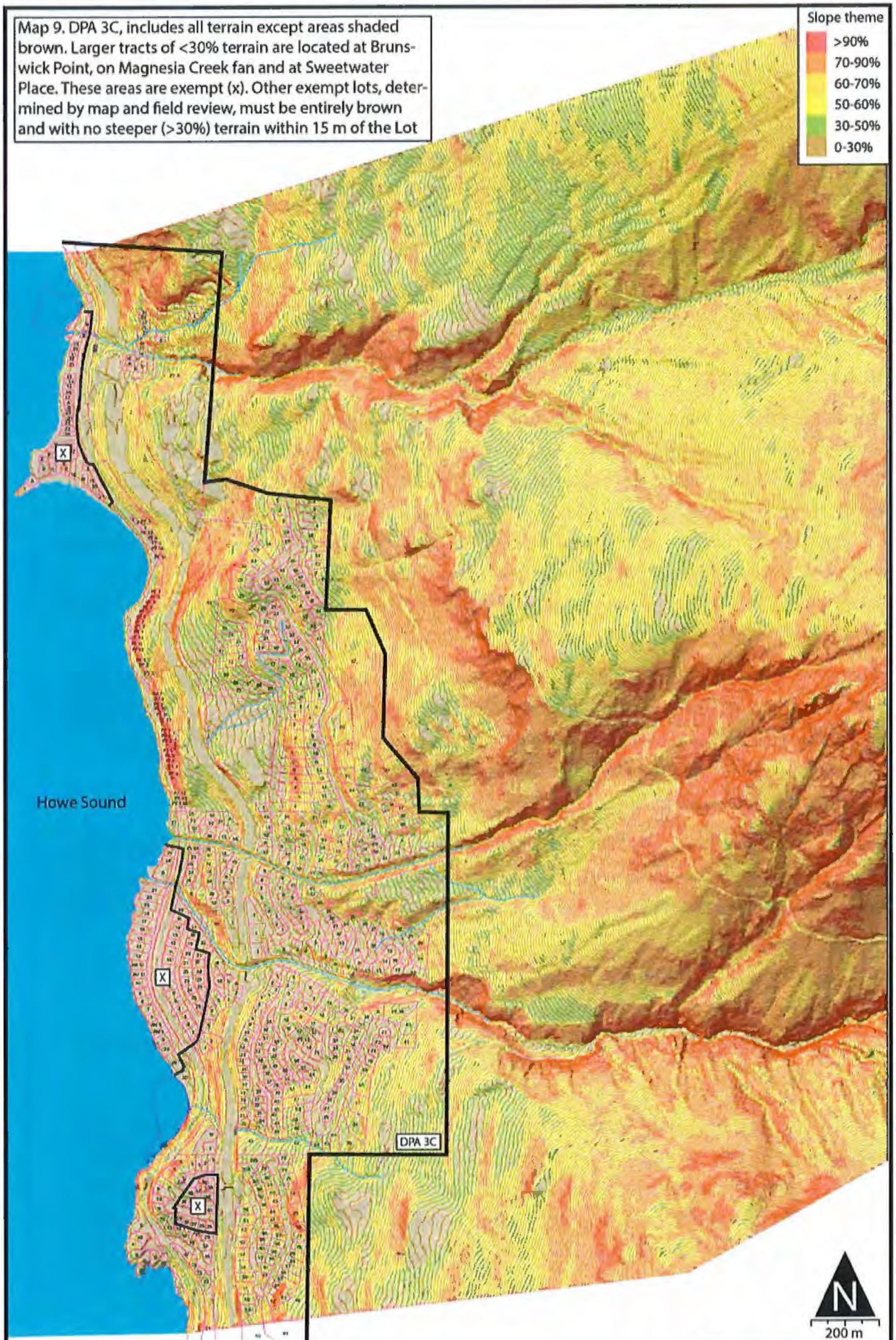
Lions Bay DPA 3A Areas affected by potential open-slope landslides

Cordilleran Geoscience
Terrain Specialists

Map 8. DPA 3B, includes all terrain vulnerable to rockfall, as predicted by a 50% slope angle projected from potentially unstable steep rock terrain.



Lions Bay DPA 3B Areas affected by potential rockfall



Map 9. DPA 3C, includes all terrain except areas shaded brown. Larger tracts of <30% terrain are located at Brunswick Point, on Magnesia Creek fan and at Sweetwater Place. These areas are exempt (x). Other exempt lots, determined by map and field review, must be entirely brown and with no steeper (>30%) terrain within 15 m of the Lot

Lions Bay DPA 3C Slopes >30% gradient

# Schedule A

Village of Lions Bay Official Community Plan Designation Bylaw
No. 408, 2008, Amendment Bylaw No. 525, 2018

## 10.0 Development Permit Areas

## 10.1 General Requirements

### 10.1.1 Introduction

The draft technical study titled "The Municipality of the Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards" prepared by Cordilleran Geoscience on December 19, 2017 (the "Cordilleran Report", available at ---), identifies land potentially subject to natural hazards. The study notes that in Lions Bay, given the steep terrain and the coastal maritime setting there are a number of geohazards that may affect the community, including coastal hazards, creek hazards and hillslope hazards. A Community Wildfire Protection Plan was prepared for the Village of Lions Bay and it forms the basis for the Wildfire Hazard Development Permit Area.

The goal of the DPA boundary delineation is to categorise natural hazards by landform type and/or process domain. The Cordilleran Report identifies potential hazards and assesses the potential reach of these hazards. The likelihood or magnitude of possible hazards is not explicitly estimated, as that is the role and responsibility of site specific studies or recommended further work.

The following sections outline the proposed development permit area (DPA) framework for natural hazard areas in the Village of Lions Bay, based on the hazards identified and assessed in the Cordilleran Report. A generalized, process-based approach to DPA delineation is used, with four main categories:

DPA 1, Coastal Zone Hazards (flooding and erosion);
DPA 2, Creek Hazards (alluvial fans; ravines, small creeks);
DPA 3, Slope Hazards (Open-slope failures, rockfall, and seismic slope stability); and

DPA 4, Wildfire Hazard

Coastal zone hazards (DPA 1) include flooding and erosion from a combination of processes including tides, storm surge, wave action and sea level rise. Creek hazards include residual debris flow hazards on creeks that have flood control works (DPA 2A - Alberta, Harvey and Magnesia Creeks) and flooding and debris flow on a smaller creek (DPA 2B – Lions Brook). Also included under creek hazards are hazards associated with creek ravines (DPA 2C) such as erosion and ravine wall landslide. Three categories of slope hazard have been identified – open slope failures (DPA 3A), rockfall hazards (DPA 3B) and areas with steep slopes >30% (DPA 3C).

In determining the DPA boundaries for the hazard categories, it is recognized that there is inherent uncertainty in the frequency-magnitude data upon which the DPA categories have been based, as well as uncertainty in the extent of influence of possible hazards. Therefore, DPA boundaries were drawn conservatively so as not to exclude terrain that could be affected by the range of magnitudes considered within future studies. While boundaries are drawn from the high-resolution LIDAR-derived mapping products, for proposed development purposes, surveys and professional assessment(s) may be needed to confirm lot layout, natural features, and setback determination on a site-specific basis (e.g., top of ravine vs. setbacks).

### 10.1.2 Designation of Development Permit Areas

Under the authority of section 488 (1) (b) of the Local Government Act, the areas outlined on Maps 2-9 are designated as Development Permit Areas as follows:

DPA 1, Map 3: Coastal Zone Hazards (flooding and erosion);
DPA 2, Maps 4, 5, and 6: Creek Hazards (alluvial fans; ravines, small creeks); and
DPA 3, Maps 7, 8, and 9: Slope Hazards (Open-slope failures, rockfall, and seismic slope stability); and
DPA 4, Wildfire Hazard (all land within the boundaries of the Village of Lions Bay).

### 10.1.3 Activities that Require a Development Permit

In a Development Permit Area:

1. land within the area must not be subdivided;
2. construction of, addition to or alteration of a building or other structure must not be started;
3. land within the area must not be altered;

unless the owner first obtains a development permit or an exemption under section 3 applies.

For the purpose of this section,

4. construction of, addition to or alteration of a building or other structure includes, but is not limited to:
    - i. new building construction;
    - ii. building additions and alterations, including alterations to exterior materials;

    iii. construction of, addition to or alteration of accessory buildings and structures, including pools, hot tubs, sheds and other structures; or
    iv. construction of, addition to or alteration of retaining walls;
    v. in the case of a wildfire development permit area, replacement of a roof; and

5. alteration of land includes, but is not limited to:
    i. site clearing or removal of vegetation;
    ii. landscaping, including planting and clearing;
    iii. site grading;
    iv. tree removal;
    v. placement of fill, or disturbance of soils, rocks or other native materials;
    vi. creation of impervious and semi-impervious surfaces (such as patios and driveways);
    vii. installation, construction or alteration of flood protection or erosion protection works.

### 10.1.4 Exemptions

The following activities are exempt from the requirement to obtain a development permit:

1. public works and services and maintenance activities carried out by, or on behalf of, the Village, and approved by the CAO;

2. non-structural repairs or renovations (including roof repairs but not roof replacements) to a structure;

3. replacement or repair of an existing deck, provided that the location and dimensions do not change;

4. construction of an accessory building of less than 10 square metres permitted by the Zoning Bylaw provided that the accessory building is located outside any potential slope hazard area and at least 10 metres away from the crest of any steep slope, and provided that no removal of trees or placement of fill will be required;

5. where the proposed construction involves a structural change, addition or renovation to existing conforming or lawfully non-conforming buildings or structures, provided that the footprint of the building or structure is not expanded, and provided that it does not involve any alteration of land;

6. routine maintenance of existing landscaping and lawn areas;

7. habitat creation, streamside restoration or similar habitat enhancement works in accordance with Village of Lions Bay bylaws and a plan approved by the CAO; or

8. planting of vegetation, except for the planting of trees within 10 metres of the top of a steep slope or within 10 metres of any part of a building containing a dwelling;

9. setbacks may be reduced where coastal zone or riparian area regulation setbacks would preclude development on a lot provided that reports by qualified registered engineering and/or environmental professionals be supplied to support any exemption and/or variance;

10. emergency procedures to prevent, control or reduce erosion, or other immediate threats to life and property provided they are undertaken in accordance with the provincial Water Act and Wildlife Act and the Federal Fisheries Act, and are reported to the Village of Lions Bay.

### 10.1.5 Delegation of Authority

The authority to issue a development permit is delegated to the Chief Administrative Officer of the Village of Lions Bay.

### 10.1.6 Expectations for professional scope and reporting

1. All professional reports pertaining to Development Permit Areas should be consistent with applicable professional practice guidelines and their various report requirements, and provincial regulations, including but not exclusive to the list below:
    i. Flood Hazard Area Land Use Management Guidelines (WLAP 2004);
    ii. Guidelines for Legislated Landslide Assessments for Residential Developments in BC (2008, 2010);
    iii. Guidelines for Legislated Flood Assessments in a Changing Climate in BC (2012, 2017);
    iv. Riparian Areas Regulation;
    v. BC Building Code; and
    vi, Worksafe BC.

2. Where applicable, a report by a qualified registered professional should include the following:
    i. Report name and date;

ii. Client information;

iii. Qualified registered professional information (training, experience, insurance);

iv. Property information (legal and civic);

v. Description of development proposal;

vi. Review of relevant Village of Lions Bay bylaws and other statutory requirements;

vii. Review of background information (site-specific and overview archived & provided by Lions Bay and others);

viii. Description of geologic and geomorphic setting;

ix. Description of field work conducted on and, if required, beyond the proposed development;

x. Identification of natural hazards or other hazards identified in background reports and field work. Includes also a description of all potential hazards and rationale for excluding some;

xi. For all hazards, separate and in aggregate, analyses of the georisk affecting the proposed development and evaluation against the Village of Lions Bay safety policy;

xii. Discusses the effect of changed conditions to slope stability caused by the project, by future potential natural factors or land-use (fire, forestry) or climate change;

xiii. Discusses uncertainties and describes any residual risk that would remain;

xiv. States that "the land may be used safely for the use intended" with siting constraints, protectives measures or restrictive covenant, as stipulated in the report.

xv. Provides technically justified siting constraints or protective measures, as required;

xvi. Provides implementation steps for the identified structural mitigation works (in terms of design, construction and approval). Where protective works are recommended, the report must identify where follow up field verification is required to ensure conformance to design.

xvii. Provides site plan and other mapping required to show hazards affecting, minimum scale 1:5000;

xviii. Provides maps, illustrations and diagrams to illustrate risk scenarios referred to in the Report;

xix. Recommends restrictive covenants registered against the property title that pertain to geo-hazards, as required;

xx. Provides permission to Village of Lions Bay to include the Report in the online geo-hazard report library (as background information, not for other parties to rely);

xxi. Provides time limitation or condition statement to describe extent the Village of Lions Bay may rely on the Report for development approvals, and when resubmittal is recommended;

xxii. Provides an assurance statement (after APEGBC 2010, 2012);

xxiii. Signed and sealed by coordinating qualified registered professional.

3. For sites located within multiple Hazard DPAs: a coordinated approach between the respective qualified registered professionals will be required to ensure recommended prescriptions do not conflict and the overall project objectives are successfully met.

4. Where a report by a qualified registered professional identifies protective works or measures to mitigate hazard(s) affecting a lot, those works or measures must not transfer risk to any other lots.

## 10.2 DPA 1 – Coastal Zone Hazards (Map 3)

### 10.2.1 Justification

Ocean front land in the Village of Lions Bay is subject to hazards such as flooding of low-lying terrain, erosion and instability of oceanfront slopes. Coastal zone hazards are expected to be exacerbated over the coming decades by sea level rise. DPA 1 is intended to designate sites that should be assessed by a qualified registered professional to address coastal flood hazards, but does not preclude development. For Coastal Zone Hazards, year 2100 high water mark (HWM), and site specific factors such as wave effects, storm surge , shoreline erosion, shore face stability and associated setbacks should be considered.

### 10.2.2 Extent

DPA 1 extends from the existing natural boundary of the sea to the 8 metres CGD (Canadian Geodetic Datum) and is outlined on Map 3. The 8 metre level is conservatively selected to represent the future Flood Construction Level (FCL). DPA 1 includes all lots fronting the ocean within the Village of Lions Bay.

### 10.2.3 Background

In the Village of Lions Bay, many steep slopes into the sea are rock controlled or are fill slopes below the railway line. These are not a stability concern for residential development. Most lots on surficial materials are located on bouldery debris fan deposits of Magnesia, Alberta and Harvey Creeks, and while the shorefronts may be steepened to 70-80% by wave attack, the sea scarp is not tall (<6 m) and materials are coarse and relatively resistant to erosion at the timescale of the life of a structure (e.g., 100-years).

The sites most vulnerable to erosion are those low-lying areas at the south end of Brunswick Beach Road, where housing has been developed on a gravel tombolo that has linked a small rock outcrop with the mainland. The beach gravels forming the tombolo stand just above the HWM, being formed by storm waves, and the terrain between the north and south facing beaches is slightly lower, just at the high water mark (HWM). Future breaching and erosion of these beach ridges places all these low-lying areas at risk.

### 10.2.4 Guidelines

1. Within DPA 1, development applications shall include a coastal flood hazard assessment prepared by a qualified registered professional to define the year 2100 shoreline position and the derived flood construction level, appropriate setback and any necessary mitigation work. Provincial guidance refers to a 15 m ocean setback, while Village of Lions Bay applies a 7.5 m coastal setback. Siting could be further constrained by consideration of potential erosion. A factor of safety analysis may also be required to support foundation design and determine building setbacks from escarpment crests.

2. Where a lot does not have sufficient area to accommodate a dwelling under these siting conditions, a variance may be included in the development permit to relax setback requirements. This will need to be determined on a site by site basis, and reports by qualified registered engineering and/or environmental professionals would be required to support any variance.

## 10.3 DPA 2 - Creek Hazards

### 10.3.1 Justification

In the Village of Lions Bay, DPA 2, Creek Hazards includes consideration of flooding, debris flooding and debris flow from both large creeks with existing debris flow hazard mitigation, hazards from unmitigated creeks and, for ravines, ravine escarpment slope stability and consideration of creek hazards. The debris flow mitigated channels (Magnesia, Alberta and Harvey) each have unique site conditions (watershed area, ruggedness, geomorphic condition) and are best treated individually. Similarly, the smaller unmitigated channels cannot be treated in a uniform way as in some cases their natural channels are within ravines (parts of Battani and Rundle), or in contrast may be unconfined by ravines and completely diverted from their natural course to bypass residences (lower Lions Brook) or captured in part by the residential drainage network of ditches, culverts and storm sewers (upper School Yard Creek).

### 10.3.2 DPA 2A- Mitigated Debris Fans

#### 10.3.2.1 Extent

DPA 2A is shown on Map 4 and includes land on the formerly active portion of the Magnesia Creek fan and the composite Alberta/Harvey Creek fans that could be affected should existing mitigation structures become overwhelmed by a large, rare event.

#### 10.3.2.2 Guidelines

All development within DPA 2A must be supplied with appropriate flood proofing against potential overland flows by establishing an FCL a minimum of 1 m above finished grade and construction using concrete reinforced foundation to the FCL (WLAP 2004). House foundations should be designed to mitigate the possibility of water ingress, requiring habitable space to be located above FCLs, or suitable tanking of habitable space below FCLs.

### 10.3.3 DPA 2B - Lions Brook Fan

#### 10.3.3.1 Justification

DPA 2B is vulnerable to debris flow and stream flooding including channel shifting. Should the diverted channel jump its banks, then the flow could further erode the gullies downslope, causing similar instability and impacts to lots downslope as that experienced in 1972, while minor sedimentation at the point of the 1972 diversion could redirect the creek back into its natural channel affecting housing at the fan apex. Moreover, a debris flow could directly impact several houses near the apex. In either of these scenarios, water and debris could spread throughout the DPA in unpredictable ways.

#### 10.3.3.2 Extent

DPA 2B captures the entire Lions Brook fan including areas vulnerable to flooding and slope instability in case of misalignment of the diverted channel as outlined on Map 5.

#### 10.3.3.3 Guidelines

1. Until comprehensive mitigation of the Lions Brook fan hazard is in place, Village of Lions Bay will require debris flood and debris flow assessment by a qualified registered professional, with consideration for earthquake triggered landslides from slopes above, failure of excessive and irretrievable road spoil sites, open-slope slides, misaligned drainage and local instability caused by misdirected water. In addition, covenants detailing the landslide risk shall be attached to title.
2. At a minimum, as per development on alluvial fans (WLAP 2004), house foundations should be designed to withstand debris flood impacts with concrete steel reinforced foundations, and by mitigating the possibility of water ingress by lift. This involves the establishment of a flood construction level (FCL) a minimum of 1 m above finished grade, requiring habitable space to be located above, or with suitable tanking of habitable space below.

### 10.3.4 DPA 2C – Ravines

#### 10.3.4.1 Justification

Ravines are landforms associated with creeks that have become incised into bedrock or thick deposits of surficial material. Typically, there is an abrupt slope break from adjacent terrain onto a steep erosional slope that may be susceptible to landslides. 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 creek hazards.

#### 10.3.4.2 Extent

Ravine areas have been defined following provincial Riparian Area Regulation (RAR) criteria and using ravine crest lines mapped on LIDAR. DPA 2C is outlined on Map 6. To be consistent with the Riparian Assessment Regulations, 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.

A 30 m setback from ravine crests defines the area that falls within DPA 2C. This DPA captures Battani and Rundle Creeks, and the ravines upstream of fan apices on Magnesia, Alberta and Harvey Creeks.

### 10.3.4.4 Guidelines

1. A minimum 15 m setback from the ravine crest is suggested for all development.
2. For ravines that are deeper than 15 m, the setback from ravine crest should be 30 m, or a specialist report from an appropriately qualified registered professional is required to reduce the setback according to creek flood and debris flow hazard, factor of safety and/or riparian area regulation.
3. Seismic slope stability assessments will be required to assess factor of safety for ravine escarpment slopes and foundation stability near the slope crest.
4. Where lots are located within ravine sidewalls, the Village of Lions Bay will require a landslide assessment for properties affected by ravine sidewalls, and FCL based on flood, debris flood and debris flow assessments for affecting creeks.
5. A qualified registered professional's report shall include the following:
    - i. a recommendation of required setback from the ravine crest, and a demonstration of suitability for the proposed use;
    - ii. a field definition of the required setback from the top of a ravine or other steep slope; and
    - iii. the required setback to top of bank and recommendations relating to construction design requirements for the above development activities, on-site storm water drainage management, on-site sewage disposal and other appropriate land use recommendations.

## 10.4 DPA 3 - Slope Hazards

### 10.4.1 Justification

Three sub-categories of slope hazards that present a risk to people and property are identified: open-slope failures, rockfall hazards, and slopes greater than 30 percent.

Open-slope landslides (DPA 3A) typically involve fragmented bedrock, organic debris, and mineral sediment. A typical slide is triggered by rockfall from a bluff, by windthrow of large trees on a steep slope, or by slab failure of a weathered soil veneer. The headscarp failure plane is typically >60%, but sometimes as low as 40%, or less. Typical, or generic steep terrain where landslide initiation is most likely has 60-120% slope, and is overlain by a veneer/blanket of till/colluvium. Natural factors that contribute to the failure rate are wetter climate, higher frequency of extreme rainfall, gullied or escarpment landforms, increasing soil moisture, aspect, and fine grained sediments. Regional storms with severe localised precipitation cells may trigger numerous events. The initial slip then impacts timber downslope clearing a swath through the forest, and may be very destructive to infrastructure. Slide types may be differentiated as open-slope, gullied types (headwall, sidewall, channel), road-related, or single track versus multiple track events.

Rockfall hazard (DPA 3B) is the falling, bouncing and rolling of detached rock fragments from cliffs and steep slopes. Over time, rockfall material may form a veneer/blanket or apron of material below a source bluff. These deposits are known as scree or talus. Volumes can range from individual blocks to 100s or 1000s of cubic metres. Natural rockfall source areas are readily identified by slope thematic mapping, keying into slope areas with >70% slopes, and especially bluffs with slopes >90%.

Various guidelines and precedents set by other jurisdictions require a DPA category based on simple slope class. DPA 3C is a slope based development permit area concerned with stability of foundations, excavations, fill slopes, the existence of very local rockfall and/or slide hazards, and with water control.

### 10.4.2 General Guidelines for Development on Land Subject to a Potential Slope Hazard

The following guidelines apply in DPAs 3A, 3B and 3C:

1. Applicants may be required to provide a preliminary assessment report and detailed assessment report prepared by a qualified registered professional.
2. Some background information on potential slope hazards in some areas is available through the report by Cordilleran Geoscience titled *The Municipality of the Village of Lions Bay, Natural Hazards Development Permit Area Strategy: Coastal, Creek and Hillslope Hazards*.

The information in this report should be referenced as part of any development permit application.

3. Development should minimize any alterations to steep slopes, and the development should be designed to reflect the site rather than altering the site to reflect the development.

4. Terracing of land should be avoided or minimized and landscaping should follow the natural contours of the land.

5. Buildings and structures and landscaping should be located as far as reasonably possible from steep slopes or channel discharge/runoff points at the base of slopes.

6. Potential slope hazard areas should remain free of development, or, if that is not possible, then:

    i. appropriate mitigation measures shall be identified to reduce risk to an acceptable level;

    ii. risk for both the subject property and any adjacent or nearby lands should be addressed; and

    iii. conditions (for example conditions relating to the permitted uses, density or scale of building) shall be imposed as necessary to reduce potential hazard to acceptable levels,

    as determined by a qualified registered professional in a preliminary assessment or detailed assessment report.

7. Stepped and articulated building forms that integrate and reflect the natural site contours and slope conditions should be used, and large unbroken building masses that are unsuitable for sloped conditions should be avoided.

8. The construction of structures, pathways/trails, driveways, utilities, drainage facilities, septic fields, swimming pools, hot tubs, ponds, landscaping or other uses at or near the top or base of steep slopes should be avoided. A minimum ten metre buffer area from the top or base of any steep slope should be maintained free of development except as otherwise recommended by a qualified registered professional. On very steep slopes, this buffer area should be increased.

9. Vegetation should be maintained and/or reinstated on the slopes and within any buffer zone above the slopes to filter and absorb water and minimize erosion.

10. No fill, including yard clippings, excavated material, sand or soil, should be placed within ten metres of the top of slopes or along pre-existing drainage channels. This applies to ravine slopes as well.

11. The base of slopes shall not be undercut for building, landscaping or other purposes except in accordance with the recommendations of a qualified registered professional and a permit issued under this section.

12. For homes at the base of slopes, it is preferable for bedrooms to be constructed on the downslope side of the home.

13. Large single plane retaining walls should be avoided, where possible. Where retaining walls are necessary, smaller sections of retaining wall should be used. Any retaining structures in steeply sloped areas must be designed by a qualified registered professional.

14. Disturbed slopes should be reinforced and revegetated, especially where gullied or where bare soil is exposed. Planting should be done in accordance with the recommendations of a Landscape Architect or qualified registered Professional Forester, and a permit issued by the Village of Lions Bay.

15. Native species, including trees, shrubs and other plants, should be used for any new planting.

16. Any structural mitigation measures must be designed by a qualified registered professional.

17. Water should be diverted away from slopes, yards and structures in a controlled manner and ponding should be avoided near slopes.

18. Flow should be contained by capturing roof and pavement drainage.

19. Property, roof drainage and landscaping should be designed and maintained to shed water away from slopes (especially steep slopes).

20. Buildings shall be connected to a storm drainage system, infiltration pit, or alternative method, approved by the Village of Lions Bay.

21. Concentrated water (such as roof drainage) shall be discharged to the storm drainage system or, where there is no storm drainage system available, be managed by an alternative method approved by the Village of Lions Bay and not over sloped lands.

22. The extent of paved or hard-surfaced areas should be limited, and absorbent or permeable surfaces should be used instead to encourage infiltration where appropriate and reduce runoff.

23. Lots should be graded so water is directed toward the street and away from slopes.

24. Where applicable, a report by a qualified registered professional may include the following:

i. For slope hazards, description of the magnitude and frequency of the hazards, and risk assessment, including evaluation against life safety thresholds established by the Village of Lions Bay. This also applies for creek hazards

ii. If required by the risk assessment, then siting constraints and/or design of protective measures. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures. However, protection for a given lot must not transfer risk to other lots. For this reason, area wide protection measures might be considered by Village of Lions Bay.

iii. For stability of slopes on or about the proposed development site, assessment of slope failure modes and limiting factors of safety, and stability during seismic events. Seismic slope analysis requires comparatively detailed knowledge of subsurface bedrock, soil and groundwater conditions. The required factor of safety calculation references many data sources, including (but not limited to):

    a. seismic hazard maps and reports;
    b. ground motion data;
    c. seismic Site Class; and
    d. modal magnitude values of the design earthquake.

    Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability may also be necessary.

### 10.4.3 Landslide Safety Policy

For all landslide hazards, the Village of Lions Bay adopts a landslide safety policy that employs Landslide Risk Assessment for upslope hazards potentially affecting a site, and seismic slope stability for foundation soils, engineered slopes and adjacent slopes as determined relevant by the qualified registered professional. Risk assessments may be qualitative or quantitative in nature. As part of the risk assessment approach, a minimum landslide magnitude to consider is the 1:500-year event, but larger events up to the 1:2450-year earthquake triggered landslide may be considered where deemed appropriate by the qualified registered professional.

Reference should be made to section 9.4 of the Cordilleran Geoscience report dated December 19, 2017.

### 10.4.4 DPA 3A - Open-slope Landslides

#### 10.4.4.1 Extent

Open-slope landslide hazard areas within DPA 3A are identified on Map 7.

#### 10.4.4.2 Guidelines

In DPA 3A, a report by a qualified registered professional should consider the following in addition to the guidelines at 10.4.2:

1. Description of the magnitude and frequency of the hazards, risk assessment, including evaluation against life safety thresholds established by Village of Lions Bay.
2. If required by risk assessment, then siting constraints and/or design of protective measures may be required. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures.
3. For stability of slopes on or about the proposed development site, assessment of slope failure modes and limiting factors of safety, and stability during seismic events. Seismic slope analysis requires comparatively detailed knowledge of subsurface bedrock, soil and groundwater conditions. The required factor of safety calculation references many data sources, including (but not limited to):
   i. seismic hazard maps and reports;
   ii. ground motion data;
   iii. seismic Site Class; and
   iv. modal magnitude values of the design earthquake.
4. Assessment of shallow groundwater conditions and the anticipated effects of infiltration pits, footing drains, etc., on local slope stability.
5. Other items
   i. include slope profiles with documentation of the limits of slope instability,
   ii. include a field definition of the siting constraint or required setback from the toe/top of steep slope, ravine crest or riparian area,
   iii. consider appropriate land-use recommendations such as restrictions on tree cutting, surface drainage, filling and excavation.

iv. as required by legislation, all flood and landslide hazard reports by qualified registered professionals must state that "the land may be used safely for the use intended" with siting constraints or protectives measures, as stipulated in the report.

v. a Save Harmless Covenant will be required to be placed on the land title, worded in favour of Village of Lions Bay.

### 10.4.5 DPA 3B - Rockfall

#### 10.4.5.1 Extent

The DPA 3B area is drawn by projecting a $27.5^0$ rockfall shadow angle from the base of the rock avalanche scarp between Magnesia and Alberta Creeks, and from other small scattered bluffs in above Lions Bay. In the case of the former, since the rock avalanche headscarp is located high above the Village, and since the cliffs are tall and potential rockfall volumes are reasonably large (e.g., 10s – 1000s $m^3$), the reach of these events extends far downslope, almost reaching the highway in the vicinity of Schoolyard Creek. Elsewhere, the smaller and lower elevation bluffs, result in less extensive reach of potential rockfall. DPA 3B is outlined on Map 8.

#### 10.4.5.2 Guideline

In DPA 3B, a report by a qualified registered professional shall be prepared that includes the following in addition to the guidelines at 10.4.2:

1. rockfall risk, assessments;
2. characterisation of 500-year rockfall, or larger; and
3. rockfall modelling to aid design of protection measures if required.

Rockfall source areas requiring assessment may exist on a property or far upslope.

### 10.4.6 DPA 3C - Slopes >30%

#### 10.4.6.1 Extent

1. Consistent with Part 20.78 of the Worksafe BC Occupational Health and Safety Regulation (BC Reg. 296/97) regulation, DPA 3C applies to areas where natural average ground slope is >30%.

2. Under the current guidelines for assessment of slope hazards developed by the Association of Professional Engineers and Geoscientists BC (2010), seismic-initiated slope instability needs to be considered. Part 20.78 of the OHS Regulation states that excavation work must be done in accordance with the written instructions of a qualified registered professional if:

(i) the excavation is more than 6 m (20 ft) deep,

(ii) an improvement or structure is adjacent to the excavation,

(iii) the excavation is subject to vibration or hydrostatic pressure likely to result in ground movement hazardous to workers, or

(iv) the ground slopes away from the edge of the excavation at an angle steeper than a ratio of 3 horizontal to 1 vertical.

Most areas in Village of Lions Bay have average slopes >30% and require hillslope excavation and fill slope construction to develop building sites.

3. Areas like the tennis courts and school parking are expansive flat areas, but they are built in part on fill, and included in DPA 3C. Small areas of gentle terrain exist along Bayview Road toward Mountainview Drive, but most lots encompass some areas of steeper slope. Thus, these areas are included in the DPA.

#### 10.4.6.2 Guidelines

1. A Risk Assessment by a qualified registered professional including evaluation against life safety thresholds established by Village of Lions Bay may be required.
2. If required by the risk assessment, then siting constraints should be assessed and/or design of protective measures undertaken. Siting constraints, may include consideration of locations to minimize exposure to upslope hazards (local highs; sheltering behind topographic features), and/or the establishment of setbacks from the crests and/or toes of steep slopes. Protective measures may include aspects of foundation design, lift of habitable space, barrier walls and other measures.
3. Protection for a given lot must not transfer risk to other lots.

## 10.5 DPA 4 - Wildfire Hazard

### 10.5.1 Justification

A Wildfire Risk Management System (WRMS) was developed by B.A. Blackwell and Associates in 2007 as pert of the Village of Lions Bay Community Wildfire Protection Plan (CWPP). The WRMS identified the core area of the Village as being at moderate to high risk from wildfire. The entire Village of Lions Bay is identified in the CWPP as being a high vulnerability interface area at risk from "spotting". The Community Wildfire Protection Plan noted that public safety, and many of the important values, facilities and structures, may be severely impacted by a major fire in the Village.

### 10.5.2 Extent

All land within the Village of Lions Bay is designated as DPA 4.

### 10.5.3 Guidelines

1. The following fire resistive materials and construction practices shall be required for all subject developments in the Wildfire Hazard DPA:
    - i. fire retardant roofing materials should be used, and asphalt or metal roofing should be given preference;
    - ii. decks, porches and balconies should be sheathed with fire resistive materials;
    - iii. all eaves, attics, roof vents and openings under floors should be screened to prevent the accumulation of combustible material, using 3mm, non-combustible wire mesh, and vent assemblies should use fire shutters or baffles;
    - iv. exterior walls should be sheathed with fire resistive materials;
    - v. fire-resistive decking materials, such as solid composite decking materials or fire-resistive treated wood, should be used;
    - vi. all windows should be tempered or double-glazed to reduce heat and protect against wind and debris that can break windows and allow fire to enter the building or structure;
    - vii. all chimneys and wood-burning appliances should have approved spark arrestors; and
    - viii. building design and construction should generally be consistent with the highest current wildfire protection standards published by the National Fire Protection Association or any similar, successor or replacement body that may exist from time to time.
2. The following landscape conditions shall be required in respect of development in, or within 10 metres of, a new building or structure requiring a building permit:
    - i. wildfire risk mitigation and landscaping should be designed and installed to protect, conserve and enhance natural features of the site;
    - ii. if removal of trees or vegetation is deemed necessary by the qualified registered professional for the purpose of reducing wildfire risk, Village of Lions Bay approval is required, and replacement trees or vegetation may be required by the Village; and
    - iii. if deemed necessary by the qualified registered professional for the purpose of reducing wildfire risk, a defensible space of at least 10 metres should be

managed around buildings and structures with the goal of eliminating fuel and combustible debris, reducing risks from approaching wildfire and reducing the potential for building fires to spread to the forest, and the required defensible space may be larger in areas of sloping ground where fire behaviour creates greater risk.

# Proposed Landslide Risk Tolerance Criteria

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# Proposed Landslide Risk Tolerance Criteria

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## ABSTRACT

For residential development to proceed on ground potentially exposed to a landslide hazard in British Columbia approving authorities require a letter from a professional engineer or geoscientist stating that the site is safe for the intended use. Safe, however, is nowhere defined and there is no consistent guidance on this matter. APEGBC (2008) discourages its members from making such statements in their reports unless "safe" is explicitly defined. This paper reviews the development and application of the landslide risk tolerance criteria used in North Vancouver and compares the criteria with risks faced by Canadians in everyday life Landslide scenarios most amenable to a quantitative risk-based management approach are distinguished from scenarios where "safe" sites might be more appropriately defined by a factor of safety or hazard probability.

## RÉSUMÉ

En Colombie britannique, avant tout développement résidentiel dans une zone potentiellement exposée à des glissements de terrain, la loi exige la remise d'une attestation de la part d'un ingénieur professionnel ou d'un géoscientifique, stipulant que le site est sans risque pour l'utilisation qui doit en être faite. Cependant, ce que l'on entend par sureté d'un site n'est pas précisé pas plus que ne sont rédigées des directives cohérentes sur la question APEGBC (2008) déconseille à ses membres de délivrer de telles attestations tant que le terme « sureté » n'est pas explicitement défini. Cet article passe en revue le développement et l'application de critéres de tolérance au risque de glissement de terrain mis en œuvre au nord de Vancouver et évalue la pertinence de ces critères au regard des risques auxquels les Canadiens sont quotidiennement confrontés. Les scénarios de glissement de terrain les plus enclins à une approche quantitative de la gestion des risques sont distingués des scénarios où la « sureté » des sites pourrait être définie de façon plus appropriée par un facteur de sécurité ou la période de retour de l'aléa.

## 1 INTRODUCTION

In British Columbia landslides kill approximately 3 people per year and cause an estimated $2.5 to $3.5 million in direct damages to residential development (Hungr 2004) While the average resident's risk of loss of life is low (approximately 1 in 1,000,000 per annum), the statistics are significantly influenced by the much higher risk faced by a relatively small percentage of the population. It is the responsibility of approving authorities, developers, and qualified professionals to manage these risks in a practical way that balances cost and benefit.

According to Association of Professional Engineers and Geoscientists of British Columbia (APEGBC 2008) practice guidelines a landslide "safety" assessment for residential development comprises two principal steps: estimation of the level of hazard or risk, and comparison of the result against acceptance criteria. If the acceptance criteria are met, the site may be deemed "safe for the use intended." Otherwise, means of reducing the hazard or risk to acceptable levels must be prescribed before development is considered further.

Within British Columbia landslide acceptance criteria are most commonly based upon factors of safety, hazard probability, or, more recently, risk of loss of life. Some methods of assessment are better suited to certain landslide types and development scenarios than others. Unfortunately, province-wide acceptance criteria do not exist and it is often left up to the qualified professional conducting the safety assessment to determine which method to use and the acceptance criteria values. This has several significant shortcomings. The minimum level of landslide safety can be expected to vary between municipalities and regional districts, and even between adjacent properties in jurisdictions where such guidance is lacking. Furthermore, qualified professionals conducting these assessments take on unwarranted liability by prescribing a level of landslide risk tolerance, which is a societal issue that should be determined by government as is the case, for example, in Hong Kong, Australia, Switzerland and Austria.

Following a fatal landslide in 2005, the District of North Vancouver adopted, on an interim basis, quantitative risk tolerance criteria to help manage safety where existing developments are potentially subject to debris slides and debris flows. Similar criteria for proposed new developments are being considered by the municipality. A Coroner's report on the landslide fatality further recommended that Provincial landslide safety criteria be established, which is timely since the authors are aware of at least four additional studies in British Columbia where quantitative risk tolerance criteria are being used to determine if risks are acceptable and to define appropriate risk reduction measures.

While it is not the role of the engineer or geoscientist to prescribe an acceptable level of public safety, our professions are in a position to help decision makers better understand the advantages and limitations of the different methods of assessment, how hazard and risk acceptance criteria have been used elsewhere, and some of the technical and economic implications if certain acceptance criteria were to be adopted at a provincial or federal level. This paper attempts to shed light on some of these issues, with particular emphasis on risk of loss of life as a measure of landslide safety.

## 2 ACCEPTANCE CRITERIA OPTIONS

Landslide safety acceptance criteria should form the technical basis for approval of new development and for determining if hazard or risk at existing development is tolerable. The criteria should account for both the potential for economic loss and loss of life, and regardless of the assessment methodology, the respective acceptance criteria should result in approximately the same level of safety. In addition to prescribing a minimum level of safety, approving authorities require systems to ensure that target safety levels are met through the design and construction process, and that landslide risk does not increase over time as a result of slope modification, changes in the upstream watershed, failure of drainage systems, and other factors that cannot always be controlled or forecast at the time of development.

Three types of landslide safety acceptance criteria are discussed below.

### 2.1 Factor of Safety Approach

In a limit equilibrium slope stability analysis, the factor of safety represents the ratio of forces resisting failure to those promoting failure. Factors of safety are used in engineering design to account for uncertainty in the input parameters (soil or rock strength, groundwater conditions, external loads), limitations of the calculation methods, and to avoid small strains that may lead to loss of soil or rock strength and progressive failure. Implicitly, the selection of a factor of safety is a risk-based decision.

It is common engineering practice to use factors of safety equal to or even greater than 1.5 for permanent slopes under static conditions and greater than 1.0 under seismic design loads provided deformations are acceptable. APEGBC (2008) guidelines provide methods to predict the displacement of slopes under seismic loading using factor of safety calculations and recommend that predicted displacement of slopes upon which residential development will be founded not exceed 15 cm during the design earthquake.

There are several instances in British Columbia where development has occurred on large pre-existing landslides that were not detected during the approval and development process. In some of these cases a factor of safety approach might be used to assess the relative improvement in stability achievable through various stabilization options. Compared to first-time failures, pre-existing landslides offer greater opportunity to reduce model and parameter uncertainty through geotechnical investigation, monitoring, and slope stability back analysis, and there may be justification in adopting a lower factor of safety under these circumstances.

Probabilistic slope stability analyses offer a means of assessing the effects of parameter uncertainty on the likelihood that the factor of safety could be less than unity. These techniques, combined with sufficient site investigation data, might be used to support the adoption of lower factors of safety for the design of some slopes.

Lee and Charman (2004) estimate the probability of failure of a slope designed with a factor of safety of 1.5 to be between $10^{-5}$ and $10^{-6}$ per annum if model and parameter uncertainty are low. This contrasts with slopes designed with a factor of safety of 1.3, where the estimated failure probability is between $10^{-2}$ and $10^{-3}$ per annum. In both cases, failure probability could be higher if soil and groundwater conditions, the mechanism of failure, or the effects of human activity on the stability of the slope are poorly understood. The design of slopes in frontier areas where geotechnical experience is lacking, or excavations in stiff, high plastic clays continue to pose challenges, for example, but experience supports the assessment that engineered slopes with factors of safety greater than 1.5 tend to perform well and are generally considered "safe."

### 2.2 Hazard Probability and Partial Risk Approach

Hazard probability in this paper refers to the annual probability of landslide occurrence. In practice, approving authorities make decisions based on the probability of a landslide reaching an existing or proposed development. This is more accurately referred to as the "encounter probability" or "partial risk."

In British Columbia, hazard acceptability thresholds for development approvals were first put forward by Cave (1992), a former Director of Planning for the Regional District of Fraser-Cheam (now FVRD). The thresholds address a range of landslide types, including debris flows, small landslides, rock fall, and large rock avalanches. Recognizing that different landslide types with the same probability can impose different levels of risk, threshold levels were set based on consideration of the hazard type. A distinction was also made between types of development, ranging from minor repairs and reconstruction to permitting of new buildings and approval of new subdivisions, which influences the number of additional people exposed to landslide hazards. Depending on the landslide type and the type of proposed development, unconditional approval can be granted for encounter probabilities ranging from 1:500 to less than 1:10,000.

Most of British Columbia was deglaciated about 10,000 years ago, providing a convenient means of identifying locations where the probability of landslide occurrence is likely less than $10^{-4}$. Confirming the absence of Holocene landslide deposits and ruling out the possibility of large first-time failures, such as might be indicated by sagging slopes, constitutes one of the simplest forms of a landslide safety assessment. Provided this type of assessment is carried out by suitably qualified professionals it will likely result in a level of landslide safety that meets the expectations of approving authorities and the public. Unfortunately, in mountainous terrain it is often quite difficult to identify ground completely free of evidence of past landslide activity.

## 2.3 Risk of Loss of Life Approach

Where rapid landslides are possible, the potential for loss of life may represent the overriding consequence of concern to approving authorities. Criteria based on the risk of loss of life are used to guide the development approval process for landslide prone areas in Hong Kong and Australia, and form part of industrial health and safety regulations in the U.K. and the Netherlands (AGS 2000; AGS 2007; Ale 2005; Leroi et al. 2005; Whittingham 2008). Two measures of risk are considered: risks to individuals and risks to groups (or societal risk).

Individual risk addresses the safety of individuals most at risk at an existing or proposed development. When considering the exposure to a single landslide hazard, this is calculated according to Equation 1:

$$R = P_H * P_{S:H} * P_{T:S} * V * E \qquad [1]$$

where:

- $P_H$ = the annual probability of the landslide occurring;
- $P_{S:H}$ = the spatial probability that the landslide will reach the individual most at risk;
- $P_{T:S}$ = the temporal probability that the individual most at risk will be present when the landslide occurs;
- V = the vulnerability, or probability of loss of life if the individual is impacted; and
- E = the number of people at risk, which is equal to 1 for the determination of individual risk.

Where risk of loss of life criteria are used in countries with a common law legal system, the maximum tolerable level of risk for new development is typically $10^{-5}$ per annum for the individual most at risk (Leroi et al. 2005). A distinction is often made between new and existing development, with risks as high as $10^{-4}$ per annum sometimes tolerated for existing development.

When the expected area impacted by a landslide is small and density of development is low, approval decisions are typically governed by the estimated level of individual risk. When large groups are exposed to a hazard, however, societal risk will often determine if development is approvable from a risk perspective.

Societal risk considers the total potential for loss of life when all people exposed to a hazard are accounted for. For a single landslide hazard societal risk can be estimated using Equation 1, with 'E' set to the number of people at risk. If the spatial and temporal probabilities and the vulnerability varies across the population exposed to the hazard the group will need to be subdivided according to uniform level of exposure with the results summed to arrive at a total expected number of fatalities should the landslide occur.

Societal risk estimates are presented on graphs showing the expected frequency and cumulative number of fatalities, referred to as F-N curves (Figure 1). F-N curves were originally developed for nuclear hazards (Kendall et al., 1977), where the purpose was to illustrate risk tolerance thresholds reflecting societal aversion to multiple fatalities during a single catastrophic event. The graph is subdivided into four areas representing unacceptable risk, tolerable risk which should be reduced further if practicable according to the ALARP principle, risk that is considered broadly acceptable, and a region of low probability but with the potential for >1000 fatalities that requires intense scrutiny. From the perspective of potential loss of life, development might be approved if it can be demonstrated that risks fall in the ALARP or Broadly Acceptable regions on an F-N curve.

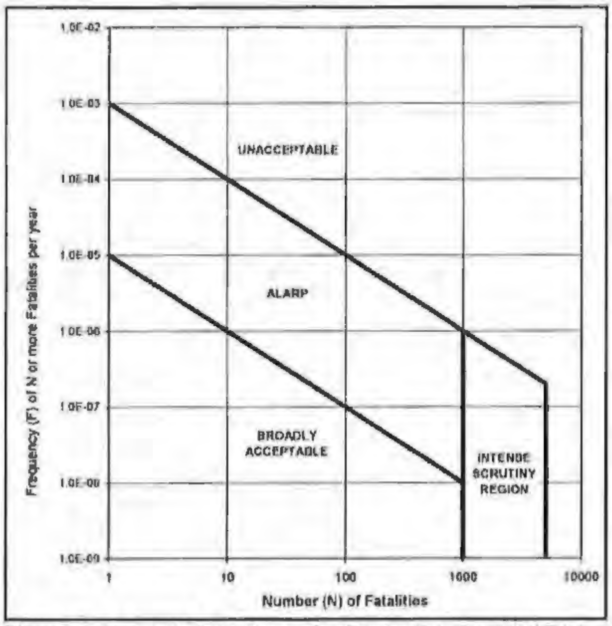

Figure 1. Example F-N Curve for Evaluating Societal Risk

## 2.4 Selection of an Assessment Method

In some instances an approving authority may have adopted a single method of evaluating the level of landslide safety, hence no choice is required. In other jurisdictions multiple options may be available or guidance on which method to use may be absent. Where a choice must be made, how should a qualified professional determine which method of landslide safety assessment is most appropriate? This section presents a thought process which may form the basis for a standardized approach.

Limit equilibrium slope stability analysis can be used to obtain reliable estimates of the factor of safety where the source and mechanism of instability is understood and where the basic model input parameters, such as stratigraphy, shear strength, groundwater conditions and external loads can be determined with reasonable accuracy. The Observational Method, by which predicted ground conditions and slope behaviour are made in advance and verified during construction and management of a slope, helps to minimise the effects of parameter, model, and human uncertainty (Morgenstern 1995). When used in conjunction with the Observational

Method, factors of safety have been applied successfully for decades to the design and management of "engineered" slopes such as cuts, fills, and retaining walls, and for the design of structures located on or at the crest of potentially unstable slopes. Slope stability analyses, in conjunction with liquefaction susceptibility and lateral spreading or deformation analyses can be used to assess the level of landslide safety under earthquake loading scenarios. The factor of safety approach can also be used to help assess and manage the level of landslide safety where it is determined that development is situated on a pre-existing deep-seated landslide.

Where existing or proposed development is located down slope of a potential landslide hazard (and not on the slope itself), hazard probability or risk of loss of life may offer a more suitable means of assessing landslide safety. The application of hazard probability may be limited to situations where it can be demonstrated that landslides do not pose a credible threat to an existing or proposed development. Examples include:

- sites where Holocene-age landslide deposits are absent and no potential source of large-scale instability can be identified up slope;
- sites located outside of the zone of impact of the maximum credible landslide hazard, such as locations outside of the rock fall shadow below a well-defined rock fall source area; and
- situations where the debris from the maximum credible landslide hazard can be prevented from reaching a site through the design and construction of physical barriers such as ditches, berms, or catch nets.

For all other situations it may be more appropriate to conduct a quantitative assessment of the risk of loss of life and encourage the approving authority, in collaboration with the qualified professional, to evaluate the level of landslide safety by comparing the results against published risk tolerance criteria. These special situations generally involve:

- sites located at the base of slopes or in the potential runout zone of a credible landslide hazard;
- sites where it is not practical to demonstrate that the slope stability factor of safety for all credible landslide hazards is greater than the acceptance criteria; and
- sites where providing for physical protection against all credible landslide impacts is not practical.

Where provincial or municipal guidance is lacking, APEGBC (2008) recommends evaluating risk estimates against other published criteria. Examples include those used in Hong Kong, Australia, and the U.K., namely, a maximum tolerable risk to individuals of $10^{-4}$ per annum for existing development and $10^{-5}$ per annum for new development, and use of the F-N curve presented in Figure 1 to evaluate societal risk.

Some jurisdictions may prefer to use qualitative terms to express and evaluate the results of quantitative risk assessments. The Australian Geomechanics Society provides recommended qualitative terms that are reproduced in Table 1 (AGS 2007). Using these qualitative descriptors, "Moderate" risk represents the limit of tolerability for existing development.

Table 1. Qualitative Descriptors for Risk of Loss of Life (after AGS 2007)

| Annual Probability of Death for the Individual Most at Risk | Qualitative Descriptor |
|---|---|
| $>10^{-3}$ | Very High |
| $10^{-4} – 10^{-3}$ | High |
| $10^{-5} – 10^{-4}$ | Moderate |
| $10^{-6} – 10^{-5}$ | Low |
| $<10^{-6}$ | Very Low |

## 3 CONSIDERATIONS FOR USE OF RISK TOLERANCE CRITERIA

In the preceding discussion various options for determining and evaluating the level of landslide safety at existing and proposed residential developments were reviewed and scenarios amenable to use of risk-based criteria were identified. In the sections that follow a number of social and technical considerations are presented that may help guide decision makers and qualified professionals with the adoption and/or application of risk of loss of life tolerance criteria as a means of managing landslide safety.

### 3.1 Origins and General Principles

The use of risk of loss of life tolerance criteria originated in the United Kingdom and the Netherlands during the 1970's and 80's in response to the need to manage risks from major industrial accidents (Ale 2005). Hong Kong adapted the United Kingdom criteria for the management of landslide hazards, and similar approaches have been applied in Australia, Switzerland and Austria.

While risk tolerance levels vary amongst jurisdictions and the evaluation criteria for individual and societal risk are different, some common general principles apply (Leroi et al. 2005):

- the incremental risk from a hazard to an individual should not be significant compared to other risks to which a person is exposed in everyday life;
- the incremental risk from a hazard should be reduced wherever reasonably practicable, i.e. the As Low As Reasonably Practicable (ALARP) principle should apply;
- if the possible number of lives lost from an incident is high, the likelihood that the incident might occur should be low. This accounts for society's particular intolerance to many simultaneous casualties, and is embodied in societal tolerable risk criteria; and,
- higher risks are likely to be tolerated for existing developments than for new proposed developments.

In the United Kingdom, maximum tolerable risk for individual members of the public is set by the Health and Safety Executive (HSE) at $10^{-5}$ per annum for new development. The upper limit of tolerability is set at $10^{-3}$ per annum for workers based on the assumption that the risk faced by workers is somewhat voluntary (Whittingham 2008).

In the Netherlands, maximum tolerable risk is $10^{-6}$ per annum. In practice, however, Ale (2005) has shown that the United Kingdom and Netherlands risk tolerance criteria are very similar as a result of the different legal systems employed by the two countries.

The United Kingdom (and Hong Kong and Canada) are governed by the Common Law legal system while the Netherlands' system is based on Napoleonic law. In the Common Law system it is not legal to put workers or the public at risk. Meeting the minimum regulatory risk requirements is one means of reducing legal liability but the courts impose a further test of gross disproportionality (Ale 2005). To meet this test, the entity that permitted a risky situation to develop that resulted in a loss of life must demonstrate that the cost to achieve a lower level of risk would have been disproportionate to the benefits. The concept is embedded in the ALARP principle that requires that risks be reduced to as low as reasonably practicable. When applied to a level that might meet the satisfaction of the courts, the ALARP principle often results in a maximum level of individual risk that is $10^{-6}$ per annum or less. In the Netherlands, Napoleonic law only requires that regulatory standards be met. Consequently, risk levels in the two jurisdictions are very similar in most circumstances.

### 3.2 Comparison with Canadians' Risk in Everyday Life

While there is precedent for using F-N curves and maximum tolerable risk levels for individuals to evaluate the level of safety posed by landslides, in Hong Kong and Australia, it is logical to question whether it is appropriate to apply similar tolerable risk levels in British Columbia. Comparison of the Hong Kong landslide risk tolerance criteria against Canadians' level of background risk suggests these criteria may indeed be appropriate.

A person's annual risk of loss of life depends on a number of factors including their age, occupation, general state of health and other environmental factors. Statistics Canada (2005) reports the average Canadian mortality rates by cause. Between 2000 and 2005 the age-standardized risk of loss of life by all causes was about $6*10^{-3}$ per annum, or about a 1:175 chance per year. The average risk from accidental causes was about $4*10^{-4}$ per annum, and the average risk from automobile accidents was about $10^{-4}$ per annum.

Table 2 compares the incremental increase in the average Canadian's risk of loss of life if exposed to various levels of landslide risk. As discussed earlier, a general principle in establishing landslide risk tolerance criteria is that the incremental risk from a hazard should not be significant compared to other risks in everyday life. Although 'significant' is not defined, inspection of the percentage increase in risk from various levels of landslide exposure suggests that the incremental risk is low (<0.2%) for landslide risk levels less than $10^{-5}$ per annum.

Table 2. Canadians' Incremental Risk of Loss of Life (per annum) under various Landslide Risk Levels

| Incremental Risk | Total Average Risk | % Increase |
|---|---|---|
| 0 | $5.637*10^{-3}$ | 0 |
| $10^{-6}$ | $6.638*10^{-3}$ | 0.018 |
| $10^{-5}$ | $5.647*10^{-3}$ | 0.18 |
| $10^{-4}$ | $5.737*10^{-3}$ | 1.8 |
| $10^{-3}$ | $6.637*10^{-3}$ | 18 |

### 3.3 Application in North Vancouver

In the early morning of January 19, 2005, prolonged and high intensity rainfall triggered a fill-slope failure at the crest of the Berkley Escarpment in the District of North Vancouver (DNV). The landslide destroyed two homes at the base of the slope, seriously injuring one person and killing another. A review of previous engineering reports, published literature, and aerial photographs revealed that five other fill-slope failures had occurred along the escarpment since 1972. Concerns over the potential impact of future landslides prompted DNV Municipal Council to commission a landslide risk assessment and implement a risk management program. The case history is described in Porter et al. (2007) with key details reproduced below.

A framework for landslide risk management compatible with Canadian guidelines (CAN/CSA Q850-97) was tailored to meet DNV's requirements (Figure 2). The program was implemented in phases: Phase I included risk estimation and risk evaluation; Phase II included evaluation of risk control options and development of a remediation strategy; and Phase III involved execution of the remediation program and re-evaluation of the landslide risks.

Two measures of risk were estimated: the risk to individuals on all occupied properties located on and below the escarpment crest, and the societal risk for hypothetical flow slide source areas. Risk estimates were summed up for the entire escarpment and calibration of the risk model was undertaken so that results matched the historical record.

Calibrated individual risk estimates exceeded an incremental risk of fatality of $10^{-4}$ per year at 43 properties, including two that were located at the crest of the escarpment. Due to the red shading used to highlight these properties on maps made available to the public, these properties became known as the 'Red Zone' properties.

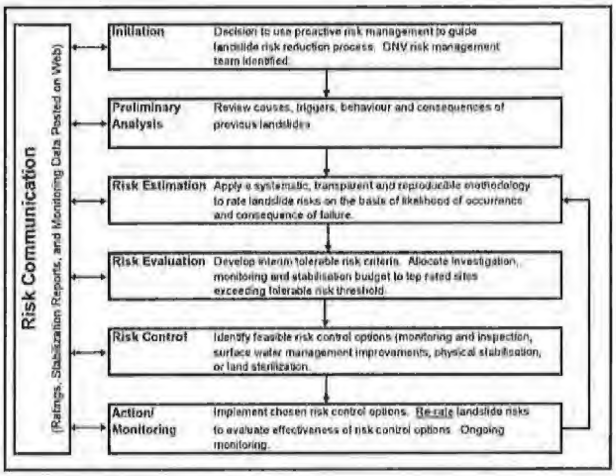

Figure 2. Risk management framework (after CAN/CSA Q850-97

Based on the results of the risk assessment, consultants' recommendations, and informal feedback from the public, the Municipal Council determined that the Hong Kong landslide risk tolerance criteria would be used to prioritise remedial works on the Berkley Escarpment. Measures were required to reduce individual risks to less than $10^{-4}$ per year and to move all hypothetical flow slide source areas out of the 'unacceptable zone' and into the 'ALARP zone' when plotted on the F-N curves utilised in Hong Kong.

Public response to the results of a quantitative landslide risk assessment (QRA) was a considerable source of uncertainty at the outset of the study due to the lack of precedent in British Columbia. Residents living at the top of the Berkley Escarpment tended to argue that the risk estimates were somewhat conservative, perhaps in part because of concern that they would bear the costs of any required mitigation. Residents living at the base of the escarpment tended to argue that the risk estimates were not conservative enough, perhaps in part because they were the ones most vulnerable. However, in general it appeared that there was public support for the process, and presentation of results in the form of risk of fatality did not prompt public outcry. In spite of the published risk levels there has been a change in ownership for several properties along the escarpment, suggesting that at least some members of the public are willing to tolerate these levels of landslide risk. This would suggest that other Canadian communities may be amenable to the application of QRA to landslide and other geohazard risks.

Parallel to management of landslide risk along the Berkley escarpment, quantitative risk estimates were made for a number of existing developments on debris flow fans throughout the District. Most properties had tolerable individual and societal risk levels when evaluated using the Hong Kong criteria, though risks at some properties were determined to be unacceptably high. The results of these estimates have been made public and development of a real-time debris flow warning system is currently being tested to help manage debris flow risk.

In 2007 DNV convened a public task force to review and make recommendations on the landslide risk tolerance thresholds. Upon completion of a number of training sessions, public meetings, and public survey, the Task Force recommended that DNV continue to use the Hong Kong criteria for individual risk.

DNV is currently working on an implementation plan to formally adopt the landslide risk tolerance criteria for new and existing developments. Experience to date suggests the criteria for existing development are generally achievable, but use of the more stringent criteria for new development faces some challenges. Many of these are anticipated to arise from questions over what constitutes "new development." It is known that residents at many homes currently face an individual risk from landslides between $10^{-4}$ and $10^{-5}$ per annum and, short of acquiring the properties and relocating the residents there is little that can be done to reduce these risks further. Major renovations, repairs, or reconstruction of homes on these properties potentially constitute 'new development' and may not be permitted if there is an associated requirement to reduce landslide risk to less than $10^{-5}$ per annum. One possible solution is to limit application of the more stringent criteria to the approval of new subdivisions and infilling of existing subdivisions.

In 2008 the Provincial Coroner issued a report on the 2005 landslide fatality. The report contained a number of recommendations to the Province, the Union of BC Municipalities, and APEGBC. Amongst recommendations to the province was a call to establish a legislated provincial standard for how landslide assessments should be conducted and coordination of the development of provincial landslide safety levels. The Coroner also recommended that a database of landslide hazard and risk information be created and made accessible to all stakeholders to facilitate informed decision-making.

### 3.4 Societal Risk Estimates and the Consultation Zone

The geographic area considered for a landslide safety assessment is known as the "consultation zone" (Geotechnical Engineering Office 1998). The consultation zone has been defined as a zone of standard extent that includes the area of a proposed development within the maximum credible extent of potential landslide hazards (Hungr and Wong 2007). In Hong Kong this typically corresponds to a 500 m wide strip of land at the base of a slope. Altering the size of the consultation zone can change the estimates of societal risk.

The current definition may be effective for proposed development in areas that are the responsibility of a single approving authority, but can be difficult to apply to areas that also contain existing development or that are the responsibility of more than one approving authority. This is often the case in British Columbia where responsibility of development approval has largely been transferred to the municipalities, and where new development often involves infilling of existing subdivisions. For example, consider a potentially unstable slope with both proposed and existing residential housing at the base. If only the area with proposed buildings is defined as the consultation zone, societal risk would be lower than if the entire development was considered, because the entire development contains more elements at risk. Which definition is more appropriate?

Furthermore, situations may exist where a municipal boundary or property line straddles an area potentially impacted by a landslide. While landslides do not recognize property or political boundaries, these boundaries do impose practical limitations on the approving authorities and qualified professionals charged with undertaking landslide assessments. One example includes limitations on access for the investigation of slopes above or adjacent to a subject property, especially where these 'off-site' slopes may be the dominant source of the landslide hazard. Another involves landslides with the potential to impact more than one municipality. While collaboration should be encouraged in these cases, the consultation zone should be defined in a way that allows one of the municipalities to proceed with the estimation of its societal risk without the cooperation of its neighbours.

In an attempt to balance these technical and political realities, the authors propose a more detailed definition of the Consultation Zone. *The Consultation Zone shall include all proposed and existing development in a zone defined by the approving authority that contains the largest credible area affected by landslides, and where fatalities arising from one or more concurrent landslides would be viewed as a single catastrophic loss.*

Examples might include a particular river escarpment, a single or coalescing series of alluvial fans, the area potentially impacted by a rock avalanche, or other areas defined by the community or approving authority. Determining the largest credible area affected by landslides would require an inventory of the hazards, estimation of landslide magnitude and frequency, and landslide runout analyses. This may not be known at the outset of a risk assessment unless regional landslide hazard maps have already been prepared

### 3.5 Data Requirements and Limitations of Risk-Based Assessments

Quantitative estimates for risk of loss of life require estimates of the parameter values and associated uncertainties listed in Equation [1]. Often, data for model calibration are scarce. Guidelines and numerical models have been developed that can be used to help constrain estimates of the spatial probability of impact. For most residential development applications, the temporal probability for individuals will range between 0 5 and 1 and is not a significant source of uncertainty. Data from previous landslides can be used to constrain estimates of vulnerability for different landslide types and intensities (e.g. AGS 2000). Estimating the probability of landslide occurrence, however, can be very challenging and often represents the greatest source of uncertainty when conducting a quantitative risk assessment. The effects of earthquakes and changing conditions (e.g. urbanization, forest fires, beetle infestations, clearcut logging and climate change) pose additional uncertainties that may need to be accounted for in estimates of current and future landslide risk.

Access to historical landslide data, such as location, date of occurrence, causal and triggering factors, type, size, travel distance, and extent of damage, can be immensely helpful in reducing the uncertainty associated with assigning estimates of both landslide probability and risk. Calibration using data from other risk assessments for similar landslide processes and risk scenarios should be carried out whenever possible; however the data necessary for calibration are often scarce in British Columbia. Implementing the Coroner's recommendation to establish a province-wide (or national) landslide database would be a helpful step in this regard. Previous attempts to form and maintain such databases have failed due to a lack of funding and lasting dedication, but this might be mitigated if the initiative was supported at the provincial or federal level.

Budgetary constraints can often pose limitations on the reliability of landslide risk assessments. This is also true of landslide safety assessments based on estimates of factors of safety or landslide likelihood, and therefore budget should never be an overriding factor in determining which method of assessment is most appropriate. Conservative values can be assigned to the input parameters when data are lacking as a result of budgetary constraints or other factors. For example, obtaining a detailed frequency-magnitude relationship for a debris flow fan, or quantitative models of flow runout and intensity, might be beyond the scope of a small project (i.e. an individual house). In this case, partial risk estimates for individuals or groups would be summed based on fewer landslide magnitude-frequency categories and less detailed population groups, using reasonably conservative estimates of landslide magnitude, frequency, and intensity.

Professional judgement pleys an important role in landslide risk assessment. Considerable judgement is required to recognize the types of landslide hazard that might occur, select the appropriate extent of the consultation zone, design the site investigation program, and assign reasonable ranges of values to the input parameters. The importance of experience and judgement is not unique to risk-based assessments of landslide safety.

In the authors' experience, event trees are a helpful means of checking that all reasonable risk scenarios are included in a risk-based assessment and tracking the risk estimate calculations. They help to ensure transparency and repeatability of the methods used and can serve as a visual tool for risk communication with decision makers.

Even under the best of circumstances it is difficult to estimate risks associated with events that occur very infrequently. For example, due to limitations in data and assessment methodology, the margin of error associated with estimates of landslide probability can be expected to increase significantly for event probabilities less than about $10^{-3}$ per annum (Morgenstern 1995). When combined with the uncertainties associated with estimates of spatial and temporal probability and vulnerability, it may not be possible to defensibly differentiate between calculated levels of landslide risk that are less than about $10^{-5}$ per annum under different development or mitigation scenarios, for example, and decision makers must be made aware of these limitations. Use of qualitative terms representing values that range over an order of magnitude to express the results of quantitative risk assessments may help to convey some of the uncertainty associated with estimated risk values.

## 4 DISCUSSION AND SUMMARY

This paper recommends that a consistent level of landslide safety be established at a provincial, if not national level. Consistent landslide assessment methods and acceptance criteria would greatly benefit the process of residential development in areas potentially subject to landslides.

If provincial or national landslide standards are developed, they will need to be sufficiently flexible to allow for development in a wide range of geographic environments subject to different types of landslides, as well as differences in the amount of historical data and local knowledge that are available. It is recommended that landslide safety standards consider three possible approaches to the assessment of the level of safety, including factor of safety, hazard return period, and risk of loss of life. Some guidance is provided here as to which method is best applied under different circumstances.

Where risk of loss of life is determined to represent the most appropriate measure of landslide safety, the Hong Kong and Australia landslide risk tolerance criteria appear to provide a useful starting point for evaluating landslide risk at existing and proposed development in British Columbia. It is recognized, however, that the Hong Kong regulatory and physiographic situation cannot be directly compared to all situations in British Columbia where developable land is relatively more abundant and risk can be avoided to a greater degree

An expanded definition of the "consultation zone" is provided to allow estimation of societal risk over a broader range of development scenarios than addressed by the definition currently used in Hong Kong. Special consideration will need to be given to the definition of "new development" so that the safety criteria can be applied in a fair and balanced manner.

The paper addresses some of the limitations of risk-based assessments, particularly where knowledge of past landslide processes and frequency is limited, and highlights the need for compilation and sharing of landslide data to improve the reliability of these assessments.

Storing landslide monitoring data in a publically accessible database may, in the long-term, also help to improve our understanding of landslide frequency and triggers, allowing for better calibration of risk estimates.

Combining these efforts in Canada with the development and implementation of a unified geohazard and risk mapping approach would further improve consistency to the way public safety is managed. This type of unified approach has been used in other countries for over 30 years, involving the production of geohazard and risk maps using a common scale, legend and symbology. For example, Switzerland is following this approach which will require that geohazard and risk maps be prepared for all of its towns and villages by 2013.

Landslide safety assessments can be very involved and often require that a significant budget be allocated for site investigation and analysis. Budget limitations should not determine the level of landslide safety. Determining the budgetary requirements of a landslide assessment involves some understanding of the scale and intensity of study expected by the approving authority in order to ensure a consistent minimum level of safety. If such understanding is lacking, the assistance of government and / or the professional associations should be sought in formulating adequate work scopes and terms of reference for landslide safety assessments.

When budget constraints for existing development do not allow for construction of engineering solutions to reduce risk to acceptable levels, alternative risk management strategies including public education and awareness, and landslide warning systems should be contemplated, at least on an interim basis, until other solutions can be found.

While this paper focuses on residential development, the assessment methods presented here can likely be expanded to the management of landslide safety affecting workers and the public associated with industry, such as forestry, mining, and power generation, linear facilities such as roads and railways, and public areas such as campgrounds and historical sites. This will require further review of the distinction between risk to workers and risk to the public that currently exists in practice in the United Kingdom, and also the methods to evaluate societal risk for facilities such as highways where very large numbers of individuals are exposed to what usually amounts to a very low level of risk.

A growing population in British Columbia and Canada will continue to increase the demand for safely habitable spaces. At the same time, society's tolerance for risk appears to be diminishing. British Columbia, with its unique topography, geology and geomorphology, has a disproportionately large share of landslide hazards. "Safe" development in this environment requires a unified approach to the management of landslide hazard and risk. This paper has outlined some key elements of such an approach, including applicable methods for assessing landslide safety and potential hazard or risk acceptance criteria associated with each method.

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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7312

# LANDSLIDE RISK EVALUATION

## Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

M. Porter and N. Morgenstern

2013

Natural Resources Canada    Ressources naturelles Canada

Canada

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# LANDSLIDE RISK EVALUATION

## Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

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# Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

## LANDSLIDE RISK EVALUATION

### Note to Reader

This is the seventh in a series of Geological Survey of Canada Open Files that will be published over the next several months. The series forms the basis of the *Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction.* Once all Open Files have been published, they will be compiled, updated and published as a GSC Bulletin. The intent is to have each Open File in the series correspond to a chapter in the Bulletin.

Comments on this Open File, or any of the Open Files in this series, should be sent before the end of March 2013 to Dr. P. Bobrowsky, pbobrows@NRCan.gc.ca

## 1. INTRODUCTION

Landslide risk evaluation compares landslide risks, as determined from the risk analysis, against risk tolerance or risk acceptance criteria to guide the design and approval of proposed development and to prioritize treatment and monitoring efforts for existing development that is or could be exposed to a landslide (Figure 1, VanDine, 2012, and reproduced below). In situations where consequences are not considered, the process is technically *hazard evaluation*, but for simplicity, in this paper the term *risk evaluation* is used throughout. Landslide risk tolerance and risk acceptance criteria are more broadly referred to as landslide safety criteria. The combined process of risk identification, risk analysis and risk evaluation is referred to as risk assessment.

The risk evaluation approach used and the landslide safety criteria adopted can vary depending on the risk scenario (sequence of events with an associated likelihood or probability of occurrence and consequences), the applicable legal framework, regulations and standards of practice and, for governments and corporations, factors such as market capitalization and insurance coverage that can influence the level of risk that can be tolerated or accepted.

This contribution focuses on general principles and approaches of evaluating different measures of landslide risk. The attention is on the evaluation of landslide risk associated with existing and proposed residential development, because it is here that national guidelines can prove most beneficial. Many of the concepts and techniques applied to landslide risk evaluation for residential development can also be applied to other elements at risk (objects or assets such as human health and safety, property, aspects of the environment and/or financial interests that could be adversely affected by a landslide). Many of the examples provided involve sub-aerial landslides, but the risk evaluation concepts can also be applied to submarine landslides and landslide-generated waves.

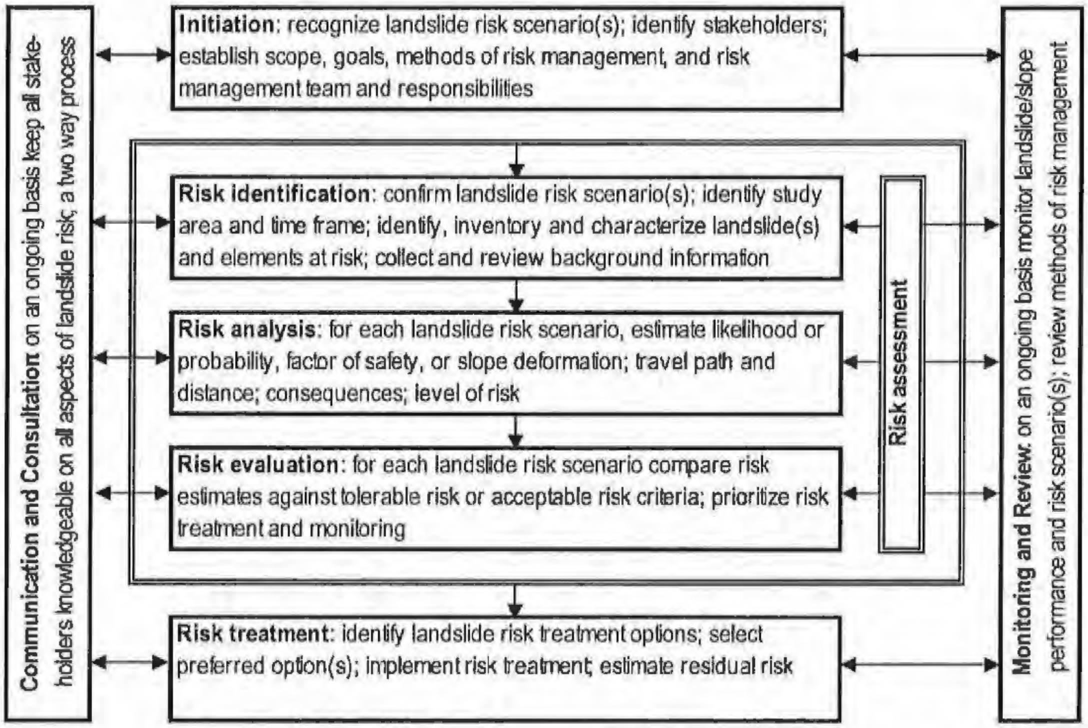


Figure 1: Landslide Risk Management Process (from VanDine, 2012; adapted from ISO, 2009)

Approving authorities across Canada frequently review the results of landslide risk assessments as part of the submissions for development and/or building permits. In such assessment reports, landslide professionals are often required to use a statement similar to *the land may be used safely for the use intended,* but rarely has *safe* been actually defined by the approving authority. Some improvements have been made in this regard, such as those documented in the Association of Professional Engineers and Geoscientists of British Columbia's landslide guidelines (APEGBC, 2010), but provincial and national approaches to risk evaluation and landslide safety criteria are typically lacking. Landslide safety criteria from jurisdictions across Canada and internationally are reviewed and the potential benefits of establishing provincial and/or national criteria are discussed. Considerations for communicating and consulting on landslide safety criteria and the results of risk evaluations are provided herein.

Because risk evaluation is a rapidly evolving topic in Canada, this contribution should be treated as a 'work in progress' and updates will likely be required as Canadian approaches and landslide safety criteria evolve.

## 2. GENERAL PRINCIPLES

### 2.1 Individual versus Societal Risk

Where rapid landslides are possible, the potential for loss of life typically represents the overriding consequence of concern to authorities charged with approving proposed developments above, on or below landslide prone terrain. Safety criteria based on the risk of loss of life guide the development approval process for landslide prone areas such as in Hong Kong, Australia, and recently in the District of North Vancouver, BC, and, although not specific to landslides, form part of industrial health and safety regulations in the United Kingdom and the Netherlands (AGS (Australian Geomechanics Society), 2000; AGS, 2007; Ale, 2005; Leroi et al., 2005; Whittingham, 2009). Two measures of risk are considered: risks to individuals and risks to groups (or societal risk).

Individual risk addresses the safety of individuals who are most at risk in an existing or proposed development. Societal risk addresses the potential societal losses as a whole caused by total potential losses of people in the community from a hazard event. When considering the exposure to a single landslide, risk is calculated according to Equation 1:

$$R = P_H * P_{S:H} * P_{T:S} * V * E \qquad [1]$$

where:
$R$ = risk;
$P_H$ = annual probability of the hazard (i.e. landslide) occurring;
$P_{S:H}$ = spatial probability that the landslide will reach the individual;
$P_{T:S}$ = temporal probability that the individual will be present when the landslide occurs;
$V$ = the vulnerability, or probability of loss of life if an individual is impacted; and
$E$ = the number of people at risk; equal to 1 for individual risk.

Partial risk is the combination of the first two terms, $P_H$ * $P_{S:H.}$ Partial risk is also known as encounter probability.

Where risk of loss of life criteria are used in countries with a common law (case law or precedent) legal system, the maximum tolerable level of risk for a new development is typically 1:100,000 per annum for the individual most at risk (Leroi et al., 2005). A distinction is often made between new and existing development, with individual risks as high as 1:10,000 per annum sometimes tolerated for existing development.

When the area of a potential landslide is small and the density of development is low, approval decisions are typically governed by the estimated individual risk. In contrast, when large groups are exposed to a potential landslide, societal risk analysis is typically used. For societal risk, if the spatial and temporal probabilities and the vulnerability vary across the population exposed to the hazard, the group is subdivided according to uniform levels of exposure with the results then summed to arrive at a total expected number of fatalities from the potential landslide.

Societal risk estimates are typically presented on graphs showing the expected frequency of occurrence and cumulative number of fatalities, referred to as F-N curves (Figure 2 is one example). F-N curves were originally developed for nuclear hazards and the aerospace industries (Kendall et al., 1977) to illustrate thresholds that reflect societal aversion to multiple fatalities during a single catastrophic event. The graph is subdivided into four areas: *unacceptable risk;* tolerable risk that should be reduced further if practicable according to the *as low as reasonably practicable* (ALARP) principle; *broadly acceptable risk*; and a region of very low probability but with the potential for >1000 fatalities that require *intense scrutiny*. From the perspective of potential loss of life from a landslide, development is typically approved if it can be demonstrated that the landslide risk falls in the ALARP or broadly acceptable regions on an F-N curve (Kendall et al., 1977).

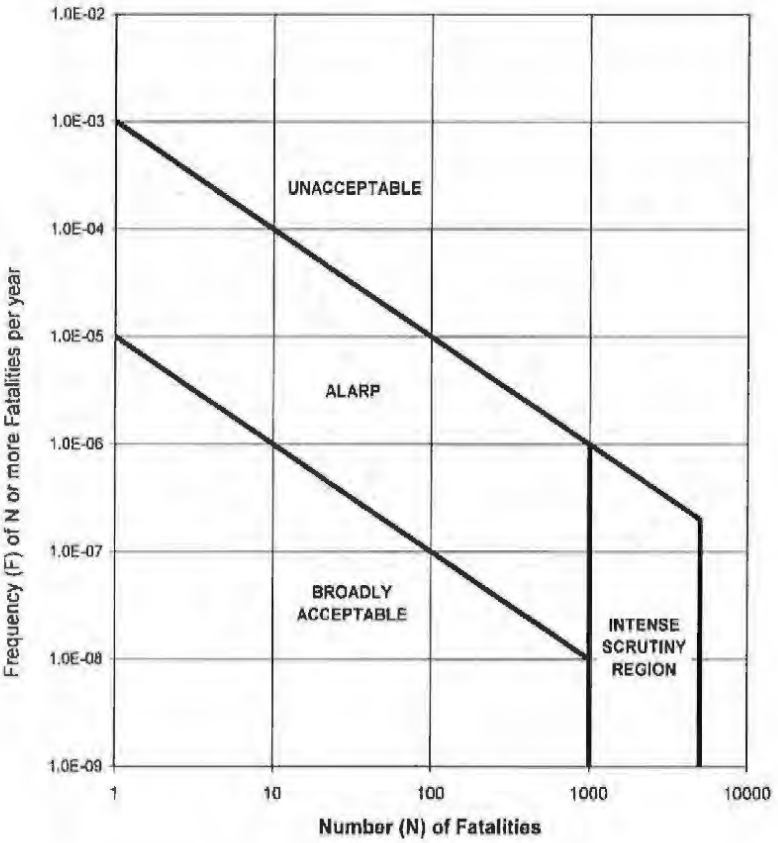


Figure 2. Example F-N Curve for Evaluating Societal Risk.

## 2.2 Consultation Zone

The geographic area considered for a landslide risk assessment is known as the *consultation zone* (Geotechnical Engineering Office, 1998): *a zone of standard extent that includes the area of proposed development within the maximum credible extent of potential landslides* (Hungr and Wong, 2007). In Hong Kong, for example, assessments for potential rock fall, typically corresponds to a 500 m wide strip of land along the base of a slope. Altering the size of the consultation zone can change the estimates of societal risk.

The above definition is effective for proposed or existing development in an area that is the responsibility of a single approving authority, but otherwise has its limitations. A more inclusive definition is proposed (Porter et al., 2009). The consultation zone is: *a zone that includes existing and proposed development in one or more jurisdictional areas, that contains the largest credible area potentially affected by one or more concurrent landslides.*

Determining the largest credible area potentially affected by landslides requires an inventory of past landslides, an estimation of landslide volume, area or discharge and frequency, and a landslide runout analysis. In some cases, a preliminary estimate of the consultation zone can be made based on the area of the landform: for example, talus slopes affected by rock falls and creek fans subject to debris flows are typically well defined. Such information may not be known at the outset of a risk assessment unless regional landslide studies have been carried out and the resulting maps prepared.

### 2.3 Voluntary and Involuntary Risk

Individuals and organizations are typically willing to accept greater *voluntary* risks, that is, risks that are perceived to be within their control. Examples include an individual's risk of fatality from smoking (1:200 per annum), canoeing (1:500 per annum) and driving (1:10,000 per annum) (Whittingham, 2008). Residential occupants, however, rarely consider landslide risks as voluntary. Such landslide risks are typically considered *involuntary,* and thus landslide safety criteria values are likely to be less than the values reported earlier.

Risks to workers from landslides might be considered voluntary because employees know that benefits (income) are, at least, partial compensation for the perceived risks, provided the risks are adequately understood and communicated. For example, Bunce and Martin (2011) suggest that a risk of fatality of 1:10,000 per annum represents a reasonable target for train crews operating in landslide prone terrain.

### 2.4 Tolerable versus Acceptable Risk

The following definitions are modified from VanDine (2012):

- *tolerable risk:* risk within a range that society or an individual can live with so as to secure certain net benefits; a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible (adapted from AGS, 2007); and
- *acceptable risk:* risk that society or an individual is prepared to accept and for which no further risk reduction is required (adapted from AGS, 2007).

The use of risk of loss of life criteria originated in the United Kingdom and the Netherlands during the 1970s and 1980s in response to the need to manage risks from major industrial accidents (Ale, 2005). Hong Kong adapted the United Kingdom criteria for the management of landslide risks, and similar approaches have been applied in Australia (AGS 2007).

While landslide safety criteria may vary amongst jurisdictions and the criteria for individual and societal risk are different, some common general principles apply (Leroi et al., 2005):

- the risk from a landslide to an individual should not be significant when compared to other risks to which a person is exposed in everyday life;
- the risk from a landslide should be reduced wherever reasonably practicable; that is, the ALARP principle should apply;
- if the potential number of lives lost from a landslide is high, the corresponding likelihood that the landslide will occur should be low; this accounts for society's intolerance to many simultaneous casualties, and is embodied in societal landslide safety criteria; and,
- higher risks are likely to be tolerated or accepted for existing developments than for proposed developments.

In the United Kingdom, the maximum tolerable risk to an individual from an industrial accident in a new development has been set by the Health and Safety Executive at 1:100,000 per annum. The maximum tolerable risk for workers, based on the assumption that the risk faced by workers is somewhat voluntary, has been set at 1:1,000 per annum (Whittingham, 2008).

In the Netherlands, maximum acceptable risk to an individual in a new development is 1:1,000,000 per annum. In practice, however, Ale (2005) has shown that the United Kingdom and Netherlands risk tolerance criteria are very similar as a result of the different legal systems employed by the two countries and mandatory application of the ALARP principle in the U.K.

## 2.5 Mortality Rates and Risks in Everyday Life

While there is precedent for using F-N curves and maximum tolerable risk criteria for individuals to evaluate landslides risks in Hong Kong and Australia, is it appropriate to apply similar tolerable risk criteria in Canada? A comparison of the Hong Kong landslide risk tolerance criteria against Canadians' level of background risk suggests these criteria may in fact be appropriate.

An individual's annual risk of loss of life depends on a number of factors including his/her age, occupation, general state of health and other environmental factors. The Government of Canada (Canada, StatsCan, 2005) reports the average Canadian mortality rates by cause. Between 2000 and 2005, the age-standardized risk of loss of life by all causes was approximately 1:175 per annum, the average risk from accidental causes was about 1:2,500 per annum, and the average risk from automobile accidents was about 1:10,000 per annum.

Table 1 compares the increase in the average Canadian's risk of loss of life if exposed to various levels of landslide risk. As discussed earlier, a general principle in establishing landslide safety criteria is that the incremental risk from a landslide should not be significant when compared to other risks in everyday life. Although *significant* is not defined (Leroi et al., 2005), an analysis of the increase in risk from various levels of landslide exposure suggests that the increase is <0.2% (low) for landslide risk levels less than 1:100,000 per annum.

Table 1. Canadians' Incremental Risk of Loss of Life (per annum) under various Landslide Risk Levels (after Canada, StatsCan, 2005).

| **Landslide risk per annum (expressed in a number of different ways)** | | | **Total Average Risk** | **% Increase** |
|---|---|---|---|---|
| 0 | 0 | 0 | $5.637*10^{-3}$ | 0 |
| 1:1,000,000 | $10^{-6}$ | $0.001*10^{-3}$ | $5.638*10^{-3}$ | 0.018 |
| 1:100,000 | $10^{-5}$ | $0.01*10^{-3}$ | $5.647*10^{-3}$ | 0.18 |
| 1:10,000 | $10^{-4}$ | $0.1*10^{-3}$ | $5.737*10^{-3}$ | 1.8 |
| 1:1,000 | $10^{-3}$ | $1*10^{-3}$ | $6.637*10^{-3}$ | 18 |

## 2.6 Economic Risk Evaluation

The level of tolerable economic risk from landslides is a function of an individual's or organization's financial ability to tolerate or survive the potential economic loss. Influencing factors can include income or revenue, net worth or market capitalization, access to insurance, societal responsibilities, awareness of the risks, and availability of suitable emergency response plans to help recover from the potential loss.

For example, large mining corporations and highway, railway and pipeline operators can often plan for, and recover from, multiple landslide incidents affecting their operations. Most local governments have much less experience and capacity to sustain economic losses caused by landslides. Most individual home owners, who typically do not have access to landslide insurance (see VanDine, 2011) have few options to financially recover from a landslide. Because of these different viewpoints, it is difficult to establish economic risk tolerance criteria for landslides that apply across a range of industries and organizational types and sizes, and individuals.

## 2.7 Qualitative Risk Evaluation

The potential consequences of landslides are wide ranging, and organizations and individuals have different levels of risk tolerance. Within some organizations there can also be a reluctance to express landslide risk in quantitative terms. In such cases, qualitative methods are useful to communicate and evaluate risks from landslides (and other hazards) and risks to a wide range of potential consequences. Risk management protocols can be assigned to a range of qualitative risk ratings.

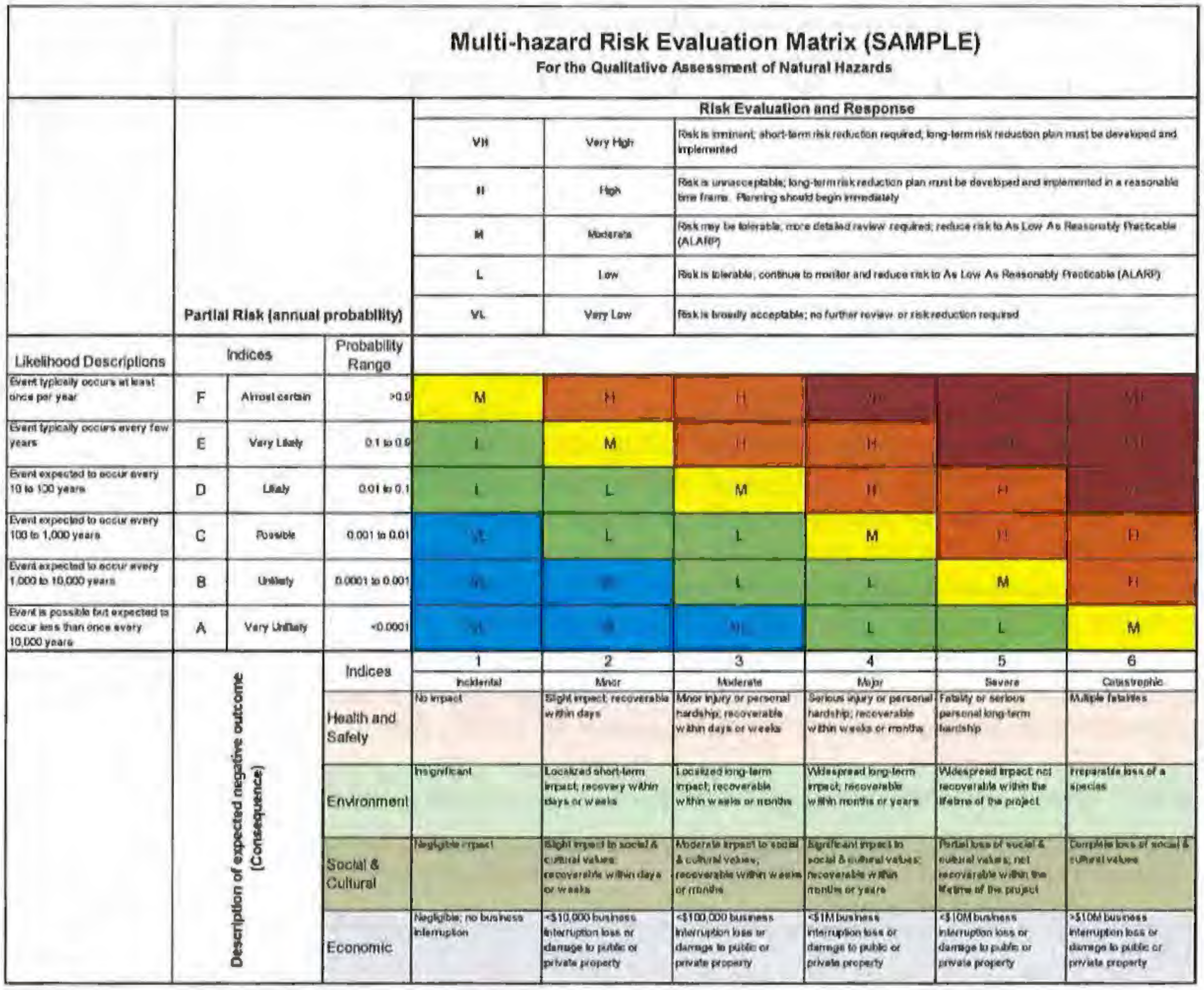
Order-of-magnitude estimates of landslide likelihood of occurrence and consequence are typically required to assign a qualitative risk rating. Thus, qualitative risk evaluation usually requires some numerical calculations to assist with systematically assigning qualitative risk ratings. For consistency, it is suggested that the qualitative descriptor *moderate* represent the limit of tolerable risk for an organization or society. *Moderate* and *low* risks typically fall in the ALARP risk zone and are tracked for further review and risk reduction where practicable, whereas risks ranked as *high* or *very high* are considered intolerable and require risk control.

As one example, Table 2 shows the AGS' recommended qualitative terms for individual risk of loss of life from landslides (AGS, 2007). Using these qualitative descriptors, *moderate* risk represents the limit of tolerance for existing development that was adopted as the landslide risk tolerance criteria for the District of North Vancouver, BC (DNV, 2009).

Table 2. Sample Qualitative Descriptors for Risk of Loss of Life (after AGS, 2007).

| Annual Probability of Loss of Life for the Individual Most at Risk | Qualitative Descriptor |
|---|---|
| >1:1,000 | Very High |
| 1:1,000 to 1:10,000 | High |
| 1:10,000 to 1:100,000 | Moderate |
| 1:100,000 to 1:1,000,000 | Low |
| <1:1,000,000 | Very Low |

Figure 3 provides a sample qualitative risk evaluation matrix modified from many sources by BGC Engineering Inc. for application to landslide and other natural hazard risk assessments associated with large infrastructure projects. Likelihood and partial risk categories (the annual probability of a landslide occurring and reaching an element at risk) are shown on the vertical axis of the matrix; consequence categories for a range of potential consequences (safety, environment, social/cultural, and economic losses) are shown on the horizontal axis. Typically the likelihood and partial risk categories, and risk evaluation and response protocol, are kept constant, whereas the consequence descriptors are modified to match the landslide safety criteria established for a specific organization. For example, the economic loss category *Catastrophic* (risk evaluation and response column 6) would be adjusted to reflect the estimated economic loss that might lead to bankruptcy of the organization.



**Multi-hazard Risk Evaluation Matrix (SAMPLE)**

**For the Qualitative Assessment of Natural Hazards**

**Partial Risk (annual probability)**

| Risk Evaluation and Response | | |
|---|---|---|
| VH | Very High | Risk is imminent; short-term risk reduction required; long-term risk reduction plan must be developed and implemented |
| H | High | Risk is unacceptable; long-term risk reduction plan must be developed and implemented in a reasonable time frame. Planning should begin immediately |
| M | Moderate | Risk may be tolerable; more detailed review required; reduce risk to As Low As Reasonably Practicable (ALARP) |
| L | Low | Risk is tolerable; continue to monitor and reduce risk to As Low As Reasonably Practicable (ALARP) |
| VL | Very Low | Risk is broadly acceptable; no further review or risk reduction required |

| Likelihood Descriptions | Indices | | Probability Range | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Event typically occurs at least once per year | F | Almost certain | >0.9 | M | H | H | VH | VH | VH |
| Event typically occurs every few years | E | Very Likely | 0.1 to 0.9 | L | M | H | H | VH | VH |
| Event expected to occur every 10 to 100 years | D | Likely | 0.01 to 0.1 | L | L | M | H | H | VH |
| Event expected to occur every 100 to 1,000 years | C | Possible | 0.001 to 0.01 | VL | L | L | M | H | H |
| Event expected to occur every 1,000 to 10,000 years | B | Unlikely | 0.0001 to 0.001 | VL | VL | L | L | M | H |
| Event is possible but expected to occur less than once every 10,000 years | A | Very Unlikely | <0.0001 | VL | VL | VL | L | L | M |
| | | | Indices | 1 | 2 | 3 | 4 | 5 | 6 |
| | | | | Incidental | Minor | Moderate | Major | Severe | Catastrophic |
| | Description of expected negative outcome (Consequence) | | Health and Safety | No impact | Slight impact; recoverable within days | Minor injury or personal hardship; recoverable within days or weeks | Serious injury or personal hardship; recoverable within weeks or months | Fatality or serious personal long-term hardship | Multiple fatalities |
| | | | Environment | Insignificant | Localized short-term impact; recovery within days or weeks | Localized long-term impact; recoverable within weeks or months | Widespread long-term impact; recoverable within months or years | Widespread impact; not recoverable within the lifetime of the project | Irreparable loss of a species |
| | | | Social & Cultural | Negligible impact | Slight impact to social & cultural values; recoverable within days or weeks | Moderate impact to social & cultural values; recoverable within weeks or months | Significant impact to social & cultural values; recoverable within months or years | Partial loss of social & cultural values; not recoverable within the lifetime of the project | Complete loss of social & cultural values |
| | | | Economic | Negligible; no business interruption | <$10,000 business interruption loss or damage to public or private property | <$100,000 business interruption loss or damage to public or private property | <$1M business interruption loss or damage to public or private property | <$10M business interruption loss or damage to public or private property | >$10M business interruption loss or damage to public or private property |

Figure 3. Sample Qualitative Risk Evaluation Matrix.

## 2.8 Selecting a Method of Evaluating Landslide Safety

A few organizations and approving authorities have formally adopted methods of evaluating landslide hazard and risk; most others have not. In the latter case, a landslide professional should determine which method of evaluating landslide safety is appropriate. This section suggests a process for making this determination for a number of examples.

### *2.8.1 Limit Equilibrium Slope Stability Analysis and Factor of Safety*

Limit equilibrium slope stability analyses can be used to obtain reliable estimates of the factor of safety where the kinematic failure mode of instability are understood and where the basic model input parameters, such as stratigraphy, shear strength, groundwater conditions and external loads, can be determined with reasonable accuracy. Slope stability analysis can be used:

- to support the selection of residential setback guidelines from the top of potentially unstable slopes; taking into account the potential for future erosion at the base of the slope where appropriate;

- in conjunction with liquefaction susceptibility and lateral spreading or deformation analyses, to assess the level of landslide safety under earthquake loading scenarios; and
- to help assess and manage the level of landslide safety where it is determined that development is situated on a pre-existing deep-seated landslide.

The observational method, by which predicted ground conditions and slope behavior are made in advance and verified during construction and management of a slope, helps minimize the effects of parameter, model, and human uncertainty (Morgenstern, 1995). When used in conjunction with the observational method, with few exceptions slope stability analyses have been applied successfully to the design and management of "engineered" slopes such as cuts, embankment fills, and retaining walls, and for the design of structures located on or at the crest of potentially unstable slopes.

### *2.8.2 Partial Risk (Encounter Probability)*

Where existing or proposed development is located downslope (not on the slope itself) of a potential landslide, or behind a potential retrogressive landslide, partial risk (also known as encounter probability) can offer a suitable means of evaluating landslide safety.

The application of partial risk criteria is best suited where it can be demonstrated that landslides pose a very low risk to an existing or proposed development, or where the probability of a landslide occurring and reaching the development is less than 1:10,000 per annum. Examples include:

- sites where Holocene-age landslide deposits are absent and no potential source of large-scale instability is identified up slope;
- sites located beyond the influence of the maximum credible landslide, such as outside of the rock fall shadow below a well-defined source area;
- sites located behind the potential extent of long-term landslide retrogression as determined through geological mapping, landslide inventory, and the use of ultimate slope angles (e.g., De Lugt et al. 1993); and
- sites where displaced material from the maximum credible landslide can be stopped by the design, construction and maintenance of physical barriers such as ditches, berms, catch nets or walls.

### *2.8.3 Quantitative Evaluation of the Risk of Loss of Life*

For other situations it may be more appropriate to conduct a quantitative evaluation of the risk of loss of life and encourage the approving authority, in collaboration with the landslide professional, to compare the results against published landslide safety criteria. These special situations can for instance involve:

- sites located at the base of slopes or in the potential landslide runout zone;
- sites where it is impractical to demonstrate that the factor of safety for all landslides exceeds common acceptance criteria; and
- sites where providing for physical protection against all credible landslide effects is impractical.

### *2.8.4 Relative Ranking of Likelihood and Consequences*

Relative ranking of the likelihood and consequences is typically used by operators of linear infrastructure, such as highways, railways and pipelines who often have to manage their operations across numerous landslides. In this approach an inventory of landslides is compiled and ranked, often using semi-quantitative methods that consider likelihood and consequences. The relative ranking is used to prioritize sites for follow-up inspection and mitigation. Examples include CN Rail's Rock Fall Hazard Risk Assessment program (Abbott et al., 1998); the BC Ministry of Transportation and Infrastructure's rock fall hazard rating system; and geohazard inspection programs managed by several operators of oil and gas pipelines in western Canada. In such circumstances, the number of sites addressed in a given year is often a function of the available capital or operating budget assigned to landslide management which, indirectly, is a reflection of the organization's landslide risk tolerance.

## 3. PUBLISHED LANDSLIDE SAFETY CRITERIA IN CANADA

Landslide safety criteria for residential development and public infrastructure should reflect societal values. Criteria should be established and adopted by local provincial and/or federal governments. Where such criteria are not available, landslide professionals can advise decision makers as to appropriate criteria based on the risk scenario and criteria adopted elsewhere.

The following summarizes landslide safety criteria that have been adopted or are in use in various jurisdictions across Canada. Much of the information is taken from Appendix C of APEGBC (2010). In that document landslide safety criteria are referred to as levels of landslide safety.

### 3.1 Canada

There are no nationally adopted landslide safety criteria in Canada.

The National Building Code of Canada 2005 (NBCC, 2005) only provides the statement, *Where a foundation is to rest on, in or near sloping ground, this particular condition shall be provided for in the design.*

The Canadian Foundation Engineering Manual (CGS, 2006), although it emphasizes foundation engineering, not landslides, contains several references to landslides:

- the possibility of landslides should always be considered, and it is best to avoid building in a landslide area or potential landslide area; and
- when a potential landslide area is identified, the area should be investigated thoroughly and designs and construction procedures should be adopted to improve the stability.

CGS (2006) does not provide landslide safety criteria. It does, however, address limit equilibrium analysis and factors of safety. Although limit states design is now mandatory for foundation design (NBCC, 2005), limit equilibrium analysis and factors of safety remain applicable for landslide analysis. From CGS (2006):

- factors of safety represent past experience under similar conditions;
- the greater the potential consequences and/or the higher the uncertainty, the higher the design factor of safety should be; and
- over time, similar factors of safety have become common to geotechnical design throughout the world.

CGS (2006) does not provide a range of factors of safety that address landslides specifically; however, based on data from Terzaghi and Peck (1948 and 1967), that document indicates factors of safety for earthworks (engineered fills) that range from 1.3 to 1.5, and for unsupported excavations (engineered cuts) that range from 1.5 to 2.0. CGS (2006) indicates a lower factor of safety can be acceptable if:

- a particularly detailed site investigation has been carried out;
- the analysis is supported by well documented local experience;
- geotechnical instrumentation to measure pore pressure and movement is provided and monitored at regular intervals to check the slope behaviour; or
- where slope failure would only have minor consequences.

CGS (2006) also addresses earthquake loading, and indicates:

- the NBCC (2005) has selected ground motions with a probability of exceedance of 2% in 50 years (1:2,475 per annum) for earthquake-resistant design purposes;
- the factor of safety of a slope under static conditions must usually be significantly greater than 1.0 to accommodate earthquake loads; and
- acceptable factors of safety depend on the uncertainty in the analysis, the soil parameters and the magnitude and duration of seismic excitation, in addition to the potential consequences of slope failure.

## 3.2 British Columbia

### *3.2.1 BC Building Code*

Until 2010, the BC Building Code (BCBC, 2006) did not mention landslide safety for buildings. It stated only *Where a foundation is to rest on, in or near sloping ground, this particular condition shall be provided for in the design.* In December 2009, BC Ministerial Order M297 (BC, Province of, 2009) added:

> *The potential for slope instability, and its consequences, such as slope displacement, shall be evaluated based on site-specific material properties and ground motion parameters in Subsection 1.1.3 [of BCBC, 2006] and shall be taken into account in the design of the structures and its foundations.*

### *3.2.2 Seismic Slope Stability*

In seismically active areas, earthquakes can trigger liquefaction or destabilize slopes leading to landslides or slope deformation. Section 4 and Appendix E of APEGBC (2010) provides recommendations for both methods of assessment and acceptance criteria. Guidance is based on consideration of earthquake ground motions with a 1:2,475 chance of exceedance, as per the NBCC (2005) and BCBC (2006). Where liquefiable soils may be present, it is recommended that a liquefaction susceptibility analysis be carried out. For other 'engineered' slopes, the following guidelines are provided:

- the use of k = PGA with a factor of safety >1.0 in a pseudo-static slope stability analysis is considered as too conservative, and is recommended as only a preliminary screening tool;
- methods by Bray and Travasarou (2007) are recommended to estimate median slope displacements for the design earthquake;
- the proposed procedure is intended to define the critical slip surface that has an estimated 15 cm of median displacement so that the building can be located behind the critical slip surface;

- the tolerable slope displacement of 15 cm is proposed as a guideline, based on experience with residential wood-frame construction. This guideline is not intended to preclude the landslide professional from selecting another value that he/she deems appropriate; and
- since the estimated displacements are median estimates with a 50% of exceedance during the design earthquake (with a 1:2,475 return period), the proposed tolerable slope displacements roughly correlate with a partial risk (of structures being subjected to >15 cm of slope displacement) equal to a 1:5,000 chance of exceedance.

Further details can be found in APEGBC (2010).

### *3.2.3 Ministry of Transportation and Infrastructure*

In British Columbia, the Ministry of Transportation and Infrastructure (BC MOTI) is the approving authority for rural subdivision approval outside of municipal boundaries and within those Regional Districts that have not assumed the role of the rural subdivision Approving Authority.

In 2009, BC MOTI Approving Officers provided guidance on landslide safety criteria in a document entitled "Subdivision Preliminary Layout Review - Natural Hazard Risk." With respect to landslides, landslide safety criteria, paraphrased from that document, are as follows:

- for a building site, unless otherwise specified, an annual probability of occurrence for a damaging landslide of 1:475 (10% probability in 50 years);
- for a building site or a large scale development, an annual probability of occurrence of a life-threatening or catastrophic landslide of 1:10,000 (or 0.5% in 50 years); and
- large scale developments must also consider total risk and refer to international standards.

This guidance document has not yet been published and until the terms 'damaging' and 'life-threatening' are clearly defined, BC MOTI Approving Officers should be contacted for further details.

Although the probabilities above are indicated as probabilities of occurrence in APEGBC (2010), this is considered to be incorrect terminology; they should be considered as probabilities of partial risk (VanDine, pers comm).

### *3.2.4 Fraser Valley Regional District*

In the 1990's the Fraser Valley Regional District published landslide safety criteria for that Regional District for various types of natural hazards for a range of residential development (Cave 1992, revised 1993). These criteria, which are current today, were based on:

- an interpretation of Mr. Justice Thomas Berger's 1973 decision that a return period of 1:10,000 years for a potentially catastrophic landslide affecting a proposed subdivision was unacceptable (Berger, 1973);
- The 200-year return period for provincially sponsored flood-proofing; and
- The BC MOTI's guideline of 10% probability in 50 years (BC MOTI, 1993).

The criteria are lower (return periods as high as 1:50 per annum) for proposed modifications to existing development, while higher standards apply to new development. Higher landslide return periods (as high as 1:1,000 per annum) are tolerated for small landslides with potential to impact a single new residential structure, while only very low landslide return periods (<1:10,000 per annum) are tolerated for larger landslides with potential to impact a new subdivision. Implicitly, therefore, the criteria are risk-based. Although the probabilities above are indicated as probabilities of occurrence in APEGBC (2010), this is considered to be incorrect terminology; they should be considered as probabilities of partial risk (VanDine, pers comm).

### *3.2.5 District of North Vancouver*

Two scenarios commonly encountered in the District of North Vancouver (DNV) are:

- existing or proposed residential developments at the base of steep slopes or on debris-flow fans; most amenable to a risk of loss of life method (Section 2.8.3 above); and.
- existing or proposed residential developments and associated retaining structures on or at the crest of slopes; most amenable to a limit equilibrium slope stability analysis and factor of safety method (Section 2.8.1 above).

Landslide safety criteria were proposed by DNV staff based on discussion and review with landslide professionals and a task force of community citizens convened specifically to explore this issue. The criteria were adopted by DNV Council in 2009 (DNV, 2009).

The DNV criteria were established to help evaluate landslide risk to life associated with both existing and proposed residential developments and for the two common development scenarios described above. They were also established to be compatible with recommended approaches to the landslide risk assessments outlined in APEGBC (2008, a prior version of APEGBC 2010) including use of the landslide assurance statement and the guidelines for seismic slope stability assessment contained in that document. The criteria are summarized in Table 3.

These landslide safety criteria are applied at the development and building permit phases of development. Additional details are presented in Porter et al. (2007) and Porter et al. (2009).

Table 3. DNV Landslide Safety Criteria (DNV, 2009).

| **Application Type** | **Risk <1:10,000** | **Risk < 1:100,000** | **FS >1.3 (static); 1:475 (seismic)** | **FS >1.5 (static); 1:2,475 (seismic)** |
|---|---|---|---|---|
| Less than 25% increase in building footprint | X | | X | |
| Repair or replace retaining structure | | | | X |
| New residence, new retaining structure, or >25% increase in building footprint | | X | | X |

Notes:

1. Risk = annual probability of fatality for individual most at risk
2. FS = limit equilibrium factor of safety for global failure
3. Seismic slope stability criteria based on specified ground motion chance of exceedance and either FS >1.0 or ground deformation <0.15 m in non-liquefiable soils, as per APEGBC (2010)
4. In addition to meeting these criteria, landslide risks must be reduced to ALARP so that the cost of further risk reduction would be grossly disproportionate to any risk reduction benefits gained.

## 3.3 Alberta

### *3.3.1 City of Calgary*

Factor of safety based landslide safety criteria are utilized to guide residential development in the City of Calgary. Guidance documents on slope stability (Calgary, City of 2008 and 2009) state that:

- a geotechnical report, prepared by a qualified geotechnical engineer, is required for all sites where existing or final design slopes exceed 15% or where, in the opinion of the City Engineer, acting reasonably, slope stability is a concern;
- no development shall occur if the factor of safety against slope failure is less than 1.5;
- lands with a factor of safety equal to or greater than 1.5 will be acceptable for development from a slope stability point of view;
- if the factor of safety is less than 1.5, subject to the approval of the appropriate approving authority, the slope may be modified using remedial measures which are to the satisfaction of the City Engineer, to increase the factor of safety to a minimum of 1.5, thus increasing the area of developability; and
- the setback limit, based on a minimum factor of safety of 1.5 shall be shown on the final development plan.

## 3.4 Ontario

The Ontario Ministry of Natural Resources published a guide that describes the province's Natural Hazards Policies (3.1) of the Provincial Policy Statement of the Planning Act (OMNR, 2001). It provides some guidance on landslide safety criteria which are used by municipal and regional approving authorities. Two examples are provided below.

### *3.4.1 Great Lakes and St Lawrence River Slope Setback Guidelines*

Setback guidelines from potentially unstable slopes have been established for some approving authorities along the Great Lakes and St Lawrence River, and other river and stream systems (for example, Cataraqui Region Conservation Authority, 2005). Most of these guidelines call for setbacks that include an allowance for a prediction of 100 years of toe erosion (an erosion allowance) and a stable slope allowance that reflects the long term stability of the existing soil material. Along rivers and streams, an 'erosion access' allowance is also often required to provide access to the site for emergencies, regular maintenance, or unforeseen conditions. If development is proposed within these established limits, a site-specific geotechnical investigation is required.

### *3.4.2 City of Ottawa*

The City of Ottawa has prepared *Slope Stability Guidelines for Development Applications* (Golder Associates Ltd, 2004). In these guidelines, unstable slopes (referred to as *hazard lands)* are defined as those that have a factor of safety of less than 1.5 against slope failure (less than 1.1 for seismic loading conditions). Where appropriate, allowances must also be provided for potential extreme retrogression of flow slides in sensitive clays, future toe erosion, and in some cases, an additional allowance for access to future slope failures. Development of permanent structures, including residential development, is typically precluded within *hazard lands*.

### 3.5 Other Jurisdictions

The Province of Saskatchewan has developed a relative ranking of landslide hazards and risks to aid in prioritizing and mitigating landslides affecting provincial highways (Kelly et al., 2004).

The City of Winnipeg, MB, is developing a relative ranking of landslide hazards and risks affecting public lands within the city (James, 2009).

Most other Canadian provinces, territories and municipal approving authorities have policies or guidelines that outline the need for landslide assessments and types of assessments that should be undertaken (for example in the Saguenay-Lac-Saint-Jean region of Quebec, Bilodeau et al. 2005). However, the authors are not aware of any other formally adopted provincial or municipal landslide safety criteria for residential development. Such criteria likely do exist or are in preparation, and as such criteria are brought to the attention of the GSC, it is hoped they will be incorporated into future versions of the *Canadian Technical Guidelines and Best Practices related to Landslides*.

### 3.6 Requirements for Provincial and National Landslide Safety Criteria

Most of the published landslide safety criteria described above have been developed by local governments (municipal or regional districts) in the absence of provincial or national standards and in response to the types of landslides and development pressures faced in those jurisdictions.

What works well in one municipality or regional district is not necessarily appropriate in another.

However, there are considerable benefits to establishing provincial and/or national landslide safety criteria. Such benefits include:

- more consistent landslide safety criteria between local governments and provinces;
- improved communication between developers, landslide professionals, approving authorities, insurance providers, real estate agencies, and the public; and,
- in some cases reduced levels of landslide risk in jurisdictions where criteria have not been established.

To be applicable across geographically diverse regions and a wide range of development scenarios, such guidelines likely require reference to a range of landslide risk evaluation and risk assessment methods and recommendations to landslide professionals on which methods are appropriate for given conditions and circumstances. Based on the review of available published guidelines, one or more of the following criteria are suggested as appropriate for proposed new residential development:

- <1:10,000 per annum probability for a landslide occurring and reaching the area of proposed development;
- <1:100,000 per annum risk of loss of life to individuals most at risk;
- group or societal risk of loss of life evaluated on an F-N curve, with the ALARP or broadly acceptable regions as the landslide safety criteria;
- tolerable slope deformation under seismic loading = 0.15 m (where it can be demonstrated that
  soils are not prone to earthquake-triggered liquefaction); and,
- where appropriate, an allowance for 100 years of predicted toe erosion along river, lake, ocean, or reservoir shorelines.

It is suggested that less stringent criteria, that is, risks up to one order of magnitude higher, may be appropriate for ongoing occupation of, or the approval of minor modifications to, existing residential development. Greater risks may also be tolerable for employees of organizations with infrastructure exposed to known landslides, provided systematic procedures are followed to understand, prioritize and manage the risks.

Landslide safety criteria based on factors of safety would also be beneficial and are under review. These will need to take into consideration variables such as soil or rock type, site investigation effort, and the methods of analysis used to estimate the factor of safety. Under special circumstances, less stringent factor of safety criteria may also be appropriate for development on large, stabilized landslides if it can be demonstrated that landslide failure geometry and groundwater conditions are clearly defined through very detailed geotechnical investigation and analysis, and that strengths acting on the landslide shear surfaces are already at residual values.

## 4. COMMUNICATION AND CONSULTATION

As shown on Figure 1, and as introduced in VanDine (2012), risk communication and consultation are key components of the landslide risk management process and should be carried out during all stages of the risk management process.

During the early stages of addressing a landslide hazard or risk, communication typically focuses on describing the potential risk scenario(s) and the process to be followed to characterize hazards and assess risks. Consultation focuses on establishing stakeholder objectives, the types of elements at risk, and the values that the stakeholders place on those elements. Maps, photographs and schematic illustrations are very useful to help convey technical information.

Once risk estimates are available, communication focuses on an improved description of the potential landslides causative factors, the associated hazards, the potential range of consequences, and the estimated risk levels. Uncertainties need to be described along with proposed methods of managing uncertainty. Risk levels need to be placed into context through analogy (for example, comparison with other risks that stakeholders encounter in everyday life). If landslide safety criteria have not been established, consultation is needed to address what levels of risk the stakeholders are willing to tolerate and how those compare with what is used in other jurisdictions.

Where, through comparison with available landslide safety criteria or through the consultation process, it is determined that landslide risks are unacceptable, the communication process needs to focus on describing the range of options available to reduce risk, the associated costs, the likelihood of success, and ongoing maintenance requirements to treat residual risks. The feasibility and cost of achieving extremely low risk levels needs to be described. Consultation is required to determine stakeholder preferences for risk treatment.

During the treatment and monitoring phases, communication can involve use of warning signs, publication of hazard and risk maps and technical reports, testing of emergency response protocols, and making the results of instrument monitoring, slope inspection and updated hazard or risk ratings available to interested stakeholders. Web-based communication of landslide stabilization, monitoring and inspection results is becoming a more feasible and common means of timely dissemination of information to interested stakeholders.

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# HAZARD ACCEPTABILITY THRESHOLDS FOR DEVELOPMENT APPROVALS BY LOCAL GOVERNMENT.

(Revised November 1993)

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# HAZARD ACCEPTABILITY THRESHOLDS FOR DEVELOPMENT APPROVALS BY LOCAL GOVERNMENT.

Amendments to the Municipal Act in 1985 empowered and required local governments to address the question of geotechnical hazards in their development policies and permits. The wording of the legislation at the policy level speaks of "...designating areas ... restricting the use of land ...[and] the protection of development from hazardous conditions ..." (Section 945). The Act states that development permits for new developments may "...specify areas of land that ... must remain free of development..." (Section 976) and that "... where the geotechnical engineer ... determines that the land may not be used safely for the use intended, the building inspector shall refuse to issue the building permit." (Section 734). Basing their decisions on policies and designations in the community plan and on reports from geotechnical engineers, therefore, it is the building inspector in the case of new construction and the approving officer in the case of new subdivisions who must ultimately determine what is acceptable or "how safe is safe enough".

The methodology employed by Fraser-Cheam Regional District to implement these provisions of the Municipal Act has been reported elsewhere.[1] The procedure involves, first, the identification of potential hazards through overview, secondary and site-specific geotechnical studies which provide a characterization of each hazard in descriptive terms and in terms of its probability of occurrence. Risk estimation, or exposure to hazard, is the second step in the procedure and this is simplified somewhat by the fact that it is the risk to the aggregate community over a period of time which is important for decision-making rather than the (much lower) risk to any given individual. As well as a quantitative aspect, however, risk has a "qualitative" component which reflects the type of hazard. The occurrence of some hazards, for example, will normally provide adequate time to alert the population, thereby limiting the risk only to property damage rather than personal injury also, whereas other types of hazard will exhibit few preliminary signs to forewarn of danger. Again some hazards are associated with so-called "voluntary" risks whereas others expose people involuntarily.[2] Both these qualitative and the quantitative aspects of risk are important in assessing acceptability.

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[1] Cave, P.W., Sloan, H. and Gerath, R.F.: "Slope Hazard Evaluations in Southwest British Columbia", in Procs. Canadian Geotechnical Conference, Tome I, Univ. Laval, 1990.

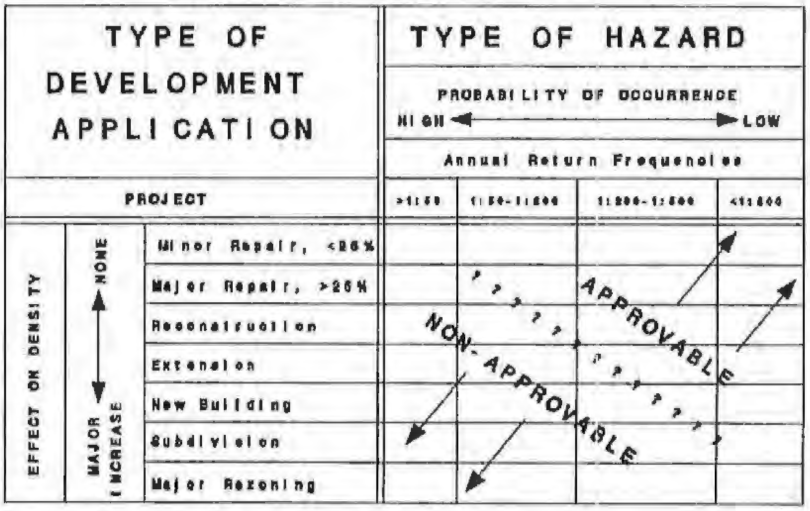
[2] These issues are well catalogued in. Pack, R. & Morgan, G.: "Evaluation and Acceptance of Risk in Geotechnical Engineering", in Procs. Vancouver Geotechnical Society, May 27, 1988

Once the engineer has characterized the hazard and quantified its occurrence and its related risks, its acceptability to the regulatory authority will involve an evaluation of:-

a) the type of risk,
b) the type of development, and
c) any possible remedial or protective measures.

These factors are analyzed in the eight matrices shown as Figures 3-10 which are used in Fraser-Cheam to secure consistency in the development approvals process. These matrices all take the same form which is illustrated in the stylized "Hazard Acceptability for Development" Chart shown as Figure 1 below. This illustrates how developments which involve greater increases in land use density and those exposed to greater risks are less likely to be approvable. Each of the matrices Figures 3-10 relates to a different type of geotechnical hazard specified in the Act and the content of each cell reflects a judgement as to whether the risk is acceptable. In fact, this question of acceptability is not a simple black and white issue and the figures show that there are at least five levels of acceptability implied by the regulatory responses ranging from outright refusal to unconditional acceptance (see Figure 2).

**Figure 1. Hazard Acceptability for Development**



## THE GEOTECHNICAL HAZARDS

The following descriptions of geotechnical hazards focus upon those characteristics which most affect whether or not the risk of exposure is acceptable. The distinctions, therefore, are based on the effects of the hazards rather than upon strict geotechnical classifications.

### 1. INUNDATION BY FLOOD WATERS.

Of those named in the Act, this is the hazard which threatens the greatest amount of development in Fraser-Cheam. In some areas, particularly along certain reaches of the Fraser, it is also the most benign of the hazards because it is predictable, because rates of flow are relatively slow and because depth and duration of flooding are moderate. Bank-full conditions are also less frequent on the Fraser than on the more volatile mountain tributaries. In other areas, the hazard is much greater. Those portions of the flood-plain known as "primary" flood areas, roughly equivalent to the flood channel itself, are to be avoided completely.

### 2. MOUNTAIN STREAM EROSION AND AVULSION.

The Chilliwack River, the Coquihalla River, and Silverhope Creek are notoriously volatile wild tributaries to the Fraser on which settlements have been established. Others, such as Yale, Frosst, and Hallecks Creeks are less well known but also have settlements built on the alluvial fans at their mouths.

All these are mountain streams with steep gradients and in flood they are extremely dangerous. They have enormous concentrated energy and erosion of the banks can occur rapidly where the channel is cut in alluvium, and there is constant danger of avulsion at high water in the flood-plain areas and on the depositional fan. Their speed of attack is such that they must be regarded as potentially life-threatening.

### 3. DEBRIS FLOWS AND DEBRIS TORRENTS.

The threat from debris flows and torrents is virtually ubiquitous in Fraser-Cheam associated, as it is, with steep, unstable first- and second-order drainages which can become choked with debris from erosion and vegetation. Fortunately the effects of these hazards are localised in that they do not extend far into the flatter reaches of the drainages but they have great destructive power and may occur without warning.

## 4. DEBRIS FLOODS.

The lower reaches of these first- and second-order drainages, at the point where the debris torrent spreads out and releases its energy, are typically subject to debris flows which grade into debris floods. The former still carry sufficient energy and destructive power to be capable of causing serious damage to buildings and even to people under certain conditions, while the latter is a depositional hazard which will cause property damage and nuisance.

## 5. LANDSLIDES, SMALL-SCALE, LOCALISED.

The potential de-stabilization of steep slopes is a constant concern whenever development takes place on unconsolidated material. In fact, depending upon the physical and chemical properties of the soil and the amount and distribution of water, quite shallow slopes may be subject to landslip. The event may be sudden and rapid, or gradual and incremental, but the danger signs of future movement are usually evident before the event. In Fraser-Cheam, slopes susceptible to localized failure are not uncommon and they pose a constant threat to those living below.

## 6. SNOW AVALANCHE.

For the most part, snow avalanche tracks do not reach down to the settled areas of Fraser-Cheam and these hazards tend to be of far greater importance to the maintenance of transportation routes than they are to the development approval process. At Hemlock Valley ski resort, however, snow avalanches do pose a constraint to subdivision and construction. In the avalanche run-out zones, in their lowermost reaches where most of the energy has already been spent, it is possible to engineer structures to withstand the lateral thrust of moving snow. For the most part, however, the hazard is one entirely to be avoided.

## 7. ROCK FALL.

Rock fall hazard results from the dislocation of rock fragments or small blocks from a slope, usually because of mechanical weathering (freeze-thaw). For the sake of evaluating risk acceptability, rock fall can be taken to include the various forms of rolling rock hazard. It is distinguished, perhaps rather arbitrarily, from massive landslide hazard on the basis of its much more frequent occurrence and its very much more localized effect. There is usually evidence on the ground at the toe of a slope to indicate the extent of land potentially affected by rock fall. Geotechnical studies can define a "rock fall shadow area" susceptible to the hazard and planning regulations can ensure that development avoids it.

### 8. LANDSLIDES, MASSIVE, CATASTROPHIC.

Fraser-Cheam Region is the site of a number of ancient and some recent massive landslides. The best known is the Hope Slide which moved approximately 47 mill.cu.m of material in 1965. Others have been studied in the Fraser Valley at Lake-of-the-Woods, Mount Cheam, and Katz. Of the surficial hazards, they are the least common, the least predictable and by far the most destructive.

## THE TYPES OF DEVELOPMENT.

In the face of these hazards, seven types of development application are distinguished in order to evaluate their acceptability. They are ranked in order of increasing intensity of land use, from a minor building repair to a major rezoning, reflecting corresponding increases in exposure to risk. The following brief description is written, for the sake of simplicity, from the residential perspective only.

### 1. MINOR REPAIR.

In a policy sense, an application for a building permit to repair an existing building is one of the most difficult types to evaluate. The Municipal Act itself distinguishes such applications by exempting the applicant from the requirement to hire a geotechnical engineer to prove the site safe (Sec. 734.(2.1)). It does not, however, exempt the building inspector from the duty to refuse the permit if he already possesses a report which identifies the site as hazardous.(Sec. 734.3).

Apparently, the intent of the Act in this respect is similar to its provisions respecting "non-conformity" of land use which essentially permit the non-conformity to continue for the life-span of the business or the life-span of the building, whichever is the shorter. By discouraging permits for repairs in areas of known hazard, the Act is discouraging the extension of the life-span of those buildings which would not have been approvable under modern regulations.

In reality, of course, the analogy with non-conformity only provides a perspective from which to view the general issue of buildings sited in unsafe areas. It does not provide all the answers to individual applicants who may have lived in their houses for many years and who want simply to repair a leaky roof or to install a safer fireplace. Blanket refusal of all such applications because of off-site hazards would be draconian indeed, particularly for those repairs which are really only stop-gap measures and which do not materially extend the life of the building. Therefore, at Fraser-Cheam a Board policy has been struck to the effect that if the nature of the hazard is not life-threatening, and if the cost of the repair is not greater than 25% of the value of the building before repair, and if the owner will register a covenant against the title guaranteeing to effect protective measures against the hazard in future before any further construction is undertaken, then a permit will be available.[3]

## 2. MAJOR REPAIR.

A major repair is defined as one the cost of which exceeds 25% of the assessed value of the structure before repair. It is seen as having the effect of extending the life-span of the building and therefore of increasing the exposure to the hazard in the long term. For this reason permits are not generally available in the face of significant risk from geotechnical hazard until remedial or protective work is undertaken. However, if the cumulative probability of occurrence throughout the extended life-span of the building is small, as it may be in the case of some low frequency events, then this type of permit may be issued in Fraser-Cheam.

## 3. RECONSTRUCTION.

In one sense, reconstruction is just a more complete form of "major repair" but it differs in two important respects. First, it provides the opportunity to relocate the building to a safer site on the parcel and thereby to lessen the risk. Secondly, it is the type of permit which fire insurance policies typically require to be available to validate the policy. Outright refusal, therefore, could render the site value of a residential parcel virtually worthless. Thus the significance of the availability of reconstruction permits far outweighs the numbers actually ever applied for or issued and these permits are usually a central concern at any public hearings dealing with hazard land management policies. In general, the larger the parcel the easier it is to meet protective siting restrictions and the more likely is a reconstruction permit to be issued.

## 4. EXTENSION.

Whereas reconstruction may simply amount to replacement and may not increase the density of use, an application to increase the size of a building does imply an increased density of use and therefore a greater annual risk. Moreover while reconstruction may facilitate relocation, extension does not. Thus, a permit to extend a building in a hazardous area is often more difficult to secure than is a permit to reconstruct.

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[3] It should be noted that some types of repair costing less than $2000 do not require a permit under local bylaws.

## 5. NEW BUILDING.

The right to construct a new home on an existing vacant lot is the issue most frequently discussed in the context of the new legislation on hazards. It is, in a sense, the "acid test".

Denial of such a permit, in most instances, is tantamount to rendering the lot unsaleable at anything like its former value and almost inevitably this leads to threats of legal action both against those who now deny the permit and against those who previously approved the subdivision. It also leads, just as inevitably, to claims that the owner should somehow be compensated by the government for the difference between the market value of the lot and the value which it could command were the hazard not present. Such reactions are natural and understandable responses to perceived financial loss. It is rarely appreciated, however, that the act of identifying the hazard neither creates nor materially alters the level of risk; it merely raises awareness. Equally, the act of refusing the permit does not cause the loss of value. It is the knowledge that the property is unsafe to live on which is the specific detriment to market value; the refusal of the permit is the consequence. Indeed to grant approval to construct an unsaleable building would be more likely to compound than to mitigate the financial losses of the land owner.

Fortunately, the number of occasions on which permits cannot be issued for vacant lots is very few. Recent subdivisions will not have been approved unless they contain a building site which complies with the new provisions of the Municipal Act and the Land Title Act. It is the older subdivisions which may have problems. Indeed, the very physical and site difficulties which have kept these older lots vacant in the past generally prove now to be the very reasons why the permit is refused under Section 734. From this perspective, again, the refusal causes no real loss of value now; instead, it serves only to confirm how unrealistic were the owner's former expectations of value. Less common is the possibility, whenever the time interval is long between subdivision approval and building permit application, that the state of geotechnical knowledge will have advanced and will have identified a hazard on a lot formerly certified as safe.

## 6. SUBDIVISION.

The regulations which subdivision approving officers must administer respecting geotechnical hazards are embedded in the Land Title Act (Sec. 86(1)(c)(v) and Sec.

82). They are charged with the duty of ensuring that all new lots registered are suited "...to the use intended..." (Sec. 82) and that they comply with all local government bylaws, thereby invoking the planning and building regulations discussed above. In addition, Section 82 requires the approving officer specifically to take into account whether "the land is subject, or could reasonably be expected to be subject, to flooding, erosion, land slip, or avalanche."

Together, these regulations ensure that adequate detailed site planning is undertaken and that each new lot is safe to develop. They are not intended, however, to dictate the basic patterns of density at which new development will occur. The designation of density, the principal regulatory determinant of land value, is supposed to be done through zoning based upon community plan policies. Then the subdivision approval process, which is administrative rather than political in nature, can concern itself with issues of site planning and layout. If the overall planning and approval system is operating properly therefore, the approving officer's impact on land value should not be great.

Nevertheless, the level of hazard acceptable for a new subdivision will tend to be less than for other types of permit application for two reasons. First, these lots are new and should comply fully with modern safety standards in the same way that new buildings have to comply with the Building Code even if their building sites are less than ideal. Secondly, the subdivision will increase density of use of land and the exposure to the hazard.

Some low degree of hazard, however, is generally acceptable even in new subdivisions for two reasons. One reason is that subdivisions are typically in the nature of infill or extension of existing development and this established development may already be subject to the same hazard. Also, the zoning and community plan density designations can be taken by the approving officer as a general indication that elected authorities have deemed that level of risk to be acceptable.

## 7. MAJOR REZONING and COMMUNITY PLAN AMENDMENT.

The distinction between development which is in the nature of infilling or extension and development which involves creating new communities, new patterns of growth on new areas of land is one which is reflected in the distinction between subdivision applications and applications for major rezonings and amendments to the community plan.

The community plan amendment raises the question as to whether, in the long term, the community should grow in one direction, or on one type of land, or another. It confronts the issue of whether any degree of exposure to the hazard is necessary or unavoidable. In the case of these far-reaching policy decisions, which could seriously impact the community for hundreds of years to come, the level of acceptable risk should be very small indeed. Areas which are known to be hazardous should simply be avoided unless there are simple mitigative measures or no viable alternatives.

## REMEDIAL AND PROTECTIVE MEASURES.

Where the risk is considered unacceptably high, some action is necessary to mitigate the hazard or to reduce exposure before approval can be given. These actions fall naturally into two classes discussed below, viz. (i) avoidance (i.e. exposure reduction) and (ii) protection (i.e. hazard reduction). Note that both purport only to reduce the hazard, or to change the probabilities. A third action, the granting of "waivers" to "save-harmless" the approving agency is an attempt to transfer liability for the hazard and this will also be discussed briefly.

### Avoidance Measures:

Reduction of exposure to risk by simple avoidance is obviously the most desirable mitigative measure. Examples embodied in regulation include elevation of construction above a "flood construction level", set-back requirements from streams to avoid the hazard of erosion and the primary flood area, and set-backs from the toe of a slope to avoid a rock-fall hazard or from a watercourse to avoid a debris torrent hazard. More complex techniques, such as slope stability monitoring devices coupled with warning and evacuation programs, have only rarely been employed in Fraser-Cheam for institutional reasons but they do seem to offer promise in the future for those hazards which are may affect communities already established.

At the policy level, simple avoidance is the preferred technique for official plans and zoning bylaws. Land can be designated for uses which minimize exposure to the hazard such as daytime summer tourist commercial uses in areas which are exposed to winter debris flow hazards, or industrial storage uses in areas which may have low probability rockfall hazard. From a technical perspective, it is worth noting that the Municipal Act encourages the use of the Development Permit regulations to implement such risk avoidance policies even to the point of allowing the permit to over-ride the use and density variations in the zoning bylaw.

### Protective Measures:

Protective measures are more visible and generally more popular than regulated avoidance but they are less secure in their results and they usually involve a commitment to maintenance which is more difficult to achieve. In Fraser-Cheam the most common examples are rip-rap protection of river banks to prevent erosion and raised re-enforced foundations to protect against debris floods. Others include various types of protective berms and dykes designed to protect the immediate area against flooding, debris floods, rolling rock etc. and various forms of traps, grizzlies and debris basins designed to protect downstream areas from similar hazards.

### Transference of Liability:

One of the most common arguments relating to development applications in hazardous areas is whether approval can be granted in return for some form of waiver of the right to sue the regulatory authority in the event that damage or death occurs. This is usually coupled with some form of indemnity to protect the regulatory authority against suits launched by others. Such waivers are known as "save-harmless" covenants and, if linked to land use restrictions, can be registered as legal incumbrances against the title of the property pursuant to Section 215 of the Land Title Act.

It should be noted that these covenants are in the nature of private agreements between the landowner and the government. Thus third parties, such as visitors to the property, will be exposed involuntarily to the hazard while not being party to the agreement. Their statutory rights to protection cannot really be transferred by these agreements.

Nevertheless, these covenants do serve a valuable function as an instrument on title, in informing prospective purchasers of known hazards. They may also have value, in some cases, as an attempt to recognize and assign the residual liability after all reasonable remedial and protective measures have been undertaken. They do not, however, provide an alternative to implementation of the requirements of the Municipal Act and the Land Title Act by elected officials, planners, building inspectors and approving officers. The duties of each are rather clearly spelled out in the statutes, and no private agreements or covenants can over-ride these obligations.

## THE ACCEPTABILITY OF RISK IN FRASER-CHEAM

Figure 2 lists the range of regulatory responses to development applications. These are the numbers in the individual cells in fig.3-10. In practice, this spectrum from unconditional approval to outright refusal is far more complex and subtle than this list implies because each individual case confronts different specific hazards and presents different mitigative opportunities.

**Figure 2. Hazard-Related Responses to Development Approval Applications**

1. Approval without conditions relating to hazards.
2. Approval, without siting conditions or protective works conditions, but with a covenant including "save harmless" conditions.
3. Approval, but with siting requirements to avoid the hazard, or with requirements for protective works to mitigate the hazard.
4. Approval as (3) above, but with a covenant including "save harmless" conditions as well as siting conditions, protective works or both.
5. Not approvable.

There are few generally accepted yardsticks which can provide help in calibrating regulatory approvals charts like those in Figs.3-10 below. One such yardstick derives from the Provincially sponsored flood-proofing program which provides financial support for protective measures and regulatory control over many forms of development. The design event for this program has a return frequency of once-in-200-years. Floods greater than this are regarded as too costly to protect against, too unlikely, or both; lesser floods are seen as too frequent and costly to be acceptable.

A second yardstick can be inferred from Provincial policy on subdivision approval in hazardous areas where advice is given to geotechnical engineers "...to think in terms of a 10% probability [of occurrence] in 50 years..." (i.e. 1:500 annually). This appears to be an appropriate standard for infill or extension subdivision or for rezoning.

A third guideline derives from the B.C. Supreme Court decision of Berger, J. in 1973 which found a site exposed to a very low probability of landslide occurrence (1:10,000) to be unsuitable for development.[4] In this case, the development would have formed the nucleus of a new community while the suspected hazard was a type of massive and destructive landslide. Thus it provides a solid precedent for broad community planning policy. A 1:10,000 probability is assigned to an event the

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[4] Berger, T.B.: "Reasons for the judgement of the Honourable Mr. Justice Berger on the matter of the Land Registry Act - and an application for approval of a proposed subdivision by Cleveland Holdings Ltd." Report, Supreme Court of British Columbia, 1973.

occurrence of which, though apparently possible at any time, has not taken place within the last 10,000 years (i.e. not since the climatic change at the end of the last glacial episode). In this sense, the 1:10,000 standard has absolute significance in that such hazards have not occurred under existing climatic conditions. It may be the best practical definition of "safe".

Apart from these few guidelines, the other entries on the regulatory approvals charts (Figures 3-10) are all relative and subjectively determined. They are derived, as inevitably they must be, from experience in adjudicating numerous individual applications and from the constant search for consistency and for that elusive threshold of acceptability. Once compiled the charts are deceptively simple in their appearance. However, it must be emphasized that what is classified here, for example, simply as a "type 4" approval (see Figure 2) in fact includes a wide variety of conditions both on the ground and in the covenant.

Nevertheless, together these charts comprise a public policy statement on development safety standards. As such, they are dynamic and will change as societal standards change and as scientific knowledge improves.

## CONCLUSION

The principal value of a set of formalised approvals charts like those presented here is to facilitate consistent application of safety regulations and to permit comparison. Undoubtedly, these standards could be enforced with even more conviction, and with more certainty of fairness, if they had been debated more generally and if a provincial consensus had already been achieved. For the future, and after that consensus is achieved, it is even possible to envisage a regulatory scheme analogous to the Building Code which already specifies standards for such hazards as earthquake, wind, snowloads, weak soils and fire-spread. There is no intrinsic reason why geotechnical hazards should not be included in the Code in the long term.

Figure 3.

**Inundation[1] by Flood Waters from Fraser River & Tributaries[2]**

| | 1:40 | 1:40-<br>1:200 | <1:200 |
|---|---|---|---|
| Minor Repair (<25%) | 2 | 1 | 1 |
| Major Repair (>25%) | 4 | 3 | 1 |
| Reconstruction | 4 | 3 | 1 |
| Extension | 4 | 3 | 1 |
| New Building | 4 | 3 | 1 |
| Subdivision (infill/extend) | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 1 |

[1] Flooding Hazard involves both inundation and erosion/avulsion. Hazard acceptability thresholds must therefore involve assessment of both types of hazards at a given site.

[2] Revised 7/21/92.

Figure 4.

**Debris Flood**

| | 1:50 | 1:50-<br>1:200 | 1:200-<br>1:500 | 1:500-<br>1:10,000 |
|---|---|---|---|---|
| Minor Repair (<25%) | 2 | 2 | 1 | 1 |
| Major Repair (>25%) | 4 | 4 | 1 | 1 |
| Reconstruction | 4 | 4 | 3 | 1 |
| Extension | 4 | 4 | 3 | 1 |
| New Building | 4 | 4 | 3 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 4 | 2 |
| Rezoning (for new community) | 5 | 5 | 5 | 3 |

Figure 5.

**Mountain Stream Erosion or Avulsion[1]**

| | 1:10 | 1:10-<br>1:100 | 1:100-<br>1:200 | 1:200-<br>1:500 | <1:500 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 2 | 1 | 1 | 1 |

**Mountain Stream Erosion or Avulsion**[1]

| | 1:10 | 1:10-1:100 | 1:100-1:200 | 1:200-1:500 | <1:500 |
|---|---|---|---|---|---|
| Major Repair (>25%) | 5 | 4 | 2 | 1 | 1 |
| Reconstruction | 5 | 5 | 2 | 2 | 1 |
| Extension | 5 | 5 | 2 | 2 | 1 |
| New Building | 5 | 5 | 4 | 2 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 1 |

[1] Revised 7/21/92.

Figure 6.

**Debris Flow/Debris Torrent**

| | 1:50 | 1:50-1:200 | 1:200-1:500 | 1:500-1:10,000 | <1:10,000 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 2 | 2 | 1 | 1 |
| Major Repair (>25%) | 5 | 4 | 2 | 1 | 1 |
| Reconstruction | 5 | 5 | 4 | 3 | 1 |
| Extension | 5 | 5 | 4 | 2 | 1 |
| New Building | 5 | 5 | 4 | 3 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 1 |

Figure 7.

**Small-Scale Localised Landslip**

| | 1:50 | 1:50-1:200 | 1:200-1:500 | 1:500-1:10,000 | <1:10,000 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 2 | 2 | 1 | 1 |
| Major Repair (>25%) | 5 | 4 | 4 | 1 | 1 |
| Reconstruction | 5 | 4 | 4 | 3 | 1 |
| Extension | 5 | 4 | 4 | 3 | 1 |
| New Building | 5 | 4 | 4 | 3 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 1 |

Figure 8.

**Snow Avalanche**

| | 1:30 | 1:30-1:100 | 1:100-1:500 | 1:500-1:10,000 | <1:10,000 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 4 | 4 | 4 | 1 |
| Major Repair (>25%) | 5 | 4 | 4 | 4 | 1 |
| Reconstruction | 5 | 4 | 4 | 4 | 1 |
| Extension | 5 | 4 | 4 | 4 | 1 |
| New Building | 5 | 4 | 4 | 4 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 1 |

Figure 9.

**Rockfall**
**Small-Scale Detachment**

| | 1:100 | 1:100-1:500 | 1:500-1:1,000 | 1:1,000-1:10,000 | <1:10,000 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 2 | 1 | 1 | 1 |
| Major Repair (>25%) | 5 | 4 | 2 | 1 | 1 |
| Reconstruction | 5 | 4 | 2 | 1 | 1 |
| Extension | 5 | 5 | 4 | 1 | 1 |
| New Building | 5 | 5 | 4 | 1 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 4 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 1 |

Figure 10.

**Major Catastrophic Landslide**

| | 1:200 | 1:200-1:500 | 1:500-1:1,000 | 1:1,000-1:10,000 | <1:10,000 |
|---|---|---|---|---|---|
| Minor Repair (<25%) | 5 | 2 | 1 | 1 | 1 |
| Major Repair (>25%) | 5 | 5 | 2 | 1 | 1 |
| Reconstruction | 5 | 5 | 5 | 1 | 1 |
| Extension | 5 | 5 | 5 | 1 | 1 |
| New Building | 5 | 5 | 5 | 1 | 1 |
| Subdivision (infill/extend) | 5 | 5 | 5 | 5 | 1 |
| Rezoning (for new community) | 5 | 5 | 5 | 5 | 5 |

Figure 11.

| **Chilliwack River Valley Erosion or Avulsion** | | | |
|---|---|---|---|
| Setback: | Setback within the "Erosion setback line"[1] | Setback between "100 year erosion limit line" and "Erosion setback line"[1] | Setback greater than "100 year erosion limit" line[1] |
| Minor Repair (<25%) | 2[2] | 2[3] | 1 |
| Major Repair (>25%) | 4[4] | 2[3] | 1 |
| Reconstruction | 4[4] | 2[3] | 1 |
| Extension | 4[4] | 2[3] | 1 |
| New Building | 4[6] | 2[3] | 1 |
| Subdivision (infill/extend) | 5 | 4[5] | 1 |
| Rezoning (for new community) | 5 | 4[6] | 1 |

Table Revised Oct.27/93.

[1] The terms "erosion setback line" and "100 year erosion limit line" are explained and defined in the Official Settlement Plan, and in the HayCo reports on river hazard management in the Chilliwack River Valley.

[2] Where the threat of river avulsion or erosion is deemed to be immediate and extreme a building permit may not be available until approved bank protection is provided.

[3] A save harmless covenant to acknowledge potential future erosion hazard is implied in this approval.

[4] Where the property cannot be protected by on-site works, a building permit may not be available until the community protection scheme outlined in the Hazard Management Plan has been implemented.

[5] Approved Bank Protection may mean on-site protection on an individual lot, or where it is not possible to protect the property with on-site works, it may mean installation of works recommended in the community protection scheme outlined in the Hazard Management Plan which are administered by a local Service Area.

[6] Same as 5 above.

# GLOSSARY OF TECHNICAL TERMS

(In alphabetic order. Words in italics are defined elsewhere in the Glossary)

### Alluvium

Alluvium is material eroded, carried and deposited by active creeks or rivers.

### Bedrock-Controlled Slopes

Mountain or hill slopes with fundamental forms shaped by surface or near-surface bedrock.

### Colluvium

Slope material that has reached its present position under the influence of gravity. Landslide debris, *talus* and *soil creep* materials are varieties of colluvium.

### Creek Channel Avulsion

Sudden change in alignment of a creek channel, generally during flood flows. Creek avulsions can generate unexpected hazards in locations distant from formerly active channels. This hazard is addressed in District Bylaw 56 but may also occur in areas not covered in the Bylaw..

### Debris Fan

A fan-shaped surface created by *debris flows* and *debris floods* and formed of coarse, bouldery to gravelly debris carried and deposited by these processes. Fan debris is derived and reworked from mountain basins.

### Debris Flows

Rapid, saturated flows of coarse debris and mud, damaged trees, stumps and smaller organic material. These flows may be contained in steep creek channels or they may spread out on debris fan surfaces. Debris flows can damage or destroy property and result in human injury or death. Potential debris flow areas are indicated by the symbol Df on the Hazard Map that accompanies this report. This hazard is addressed in District Bylaw 56 but is also mapped in areas not covered in the Bylaw..

Debris Floods

Debris floods often run out beyond debris flows. Water flows control deposition and there is a tendency to rapidly deposit cobbles, gravel, sand and finer material as water drains from this material. Debris floods are sometimes identified as 'sediment-laden water flows' and are a normal occurrence in floods issuing from mountain creeks. The primary hazard may come from flood water but human injury or property damage is possible. This hazard is addressed in District Bylaw 56 but is also mapped in areas not covered in the Bylaw.

Debris Landslides

These rapid landslides usually occur on comparatively steep, *bedrock controlled slopes*. The debris usually consists of weathered bedrock and thin *colluvium*. They are often generated by small slides in wet areas at the head of the slide slope. They have considerable destructive force.

Flood Inundation

Submersion by flood water. This hazard is addressed in District Bylaw 56.

Geotechnical Hazard

A hazard derived from soil or bedrock instability. In formal geotechnical hazard and risk assessment, the estimated magnitude and annual probability of occurrence are defined. Generally a synonym for geologic hazard.

Glacial Drift (Terrace)

Undifferentiated, layered and unlayered glacial deposits. Glacial drift terraces are plateau-like features formed by drift and later eroded by flowing water, often ancient glacial meltwater.

Glacial Lake (or Glacial Marine) Silt and Clay

This is muddy, often layered material deposited in lake (or marine) environments during deglaciation about 12,500 years ago. Armstrong (1976, 1977) describes possible glacial marine deposits in the area. Fine grained glacial lake and glacial marine soils are often associated with slope hazards.

### Perched Soil Aquifers

An aquifer is a subsurface water-bearing zone. Perched soil aquifers often appear on steep soil slopes where multiple water-bearing zones carry water to the slope face. Perched soil aquifers often promote soil landslides.

### Rock Fall

These are free falls of loose rock from cliff faces. Sustained rock fall activity may build *talus* at the base of the rock fall slope. There is much rock fall activity along Upper Phillips Creek and on Harrison Hill slopes.

### Snow Avalanches

These are rapid, often destructive snow movements on and below steep mountain slopes. Phillips Creek basin has snow avalanche activity. There are no apparent snow avalanche hazards on land conventionally suited for residential development in the Lake Errock study area.

### Soil Creep

This is slow, shallow movement of seasonally or permanently saturated soil on steep mountain slopes. Soil creep involves *colluvium* and is not perceptible except by evidence of bowed or thrown trees or stretched tree roots.

### Soil Slumps

These are rotational soil movements typical of landslides on steep soil slopes.

### Talus

Talus is an accumulation of *rockfall* debris at the foot of a cliff slope. Talus is common in Boulder Basin. There are no apparent taluses on land conventionally suited for residential development in the Lake Errock study area.

### Till

This is earth material deposited directly by glacial ice. It is generally very dense and is well graded from clay to boulder-size rocks. Till or till-like soils are noted in exposures along the glacial drift terraces.

# Review of Landslide Management in British Columbia

**Ministry of Forests, Lands and Natural Resource Operations**

**Province of British Columbia**

**April 16, 2013**

## Acknowledgments

This report is an internal review of the current practices associated with the management of landslides in BC. The review was initiated at the request of the Minister of Forests, Lands and Natural Resource Operations in response to the damaging landslides and debris flow events of the summer of 2012, including the fatal landslide at Johnsons Landing on Kootenay Lake.

Staff of the Ministry of Forests, Lands and Natural Resource Operations, Ministry of Justice (Emergency Management BC), Ministry of Transportation and Infrastructure, and other ministries contributed to this review. In particular we would like to acknowledge the contributions of Peter Jordan, Dwain Boyer and Neil Peters of FLNRO; Ralph Morhmann and David Curtis of EMBC; and Don Gillespie and David Fisher of MOTI. In addition, hydrologist Arelia Werner of the Pacific Climate Impacts Consortium has provided a summary of current climate change projections and the potential impact on the frequency and severity of landslides in British Columbia. We wish to thank these individuals for their contributions on the subject of landslide hazard management in BC.

The authors of the report offer our condolences to those affected by the events of 2012. It is our hope that this document will guide discussions which will lead to improved landslide hazard management in BC.

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February 21, 2013

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**Cover Photos** (Jeremy Zandbergen):
Top – Johnsons Landing/Gar Creek
Bottom – Fairmont Creek

## EXECUTIVE SUMMARY

In June and July 2012 numerous landslide events occurred across southern British Columbia. Most events occurred in the backcountry, without significant negative impacts to infrastructure or people. However, some populated and developed areas in the fore country or valley bottoms experienced significant damage to private property and public infrastructure. A landslide at Johnsons Landing in the Kootenays resulted in four fatalities.

On July 17, 2012 the Minister of Forests, Lands and Natural Resource Operations requested a review of how landslide hazards are managed in BC and the circumstances of the most damaging events of 2012 to identify lessons to be learned. The review examined the management of landslide hazards under the four pillar approach of preparedness, mitigation, response and recovery. The review found that generally the greatest effort by government staff and other stakeholders is directed at preparedness as success in preparedness sets up and reduces pressure on the remaining three pillars.

Natural hazards, of which landslides are only one type, occur in most areas of BC. The province is typically steep and with limited land readily amenable to development. Long-established communities are exposed to some risk of hazards from flooding and landslides. Both small and large landslide events have impacted numerous communities across the province for over 100 years, and many lessons have already been learned in managing new developments. Previous reviews on a fatal landslide in North Vancouver in 2005 and the Testalinden Dam Failure near Oliver in 2010 have provided recommendations and spurred some new initiatives in the province. Recommendations herein are made to build on these previous reviews.

The most damaging events in 2012 occurred near Sicamous, Johnsons Landing and Fairmont Creek. Each of these events had different circumstances, however high precipitation and previous winter high snowpacks were common contributing trigger mechanisms. The Sicamous and Fairmont Hot Springs sites were known debris flow or flood hazard areas with existing management tools in place designed to mitigate the risks. In Johnsons Landing, a landslide was initiated on relatively pristine steep terrain above the small remote community.

Recent climate change models project that British Columbia will experience more frequent and severe rainstorm events and years with higher snowpacks at high elevations. The models also project earlier onset of freshets and more prevalent summer droughts and wildfires. These projections are in line with observed trends over the past several decades and have the potential to increase the likelihood of landslides occurring. Given ever-increasing pressure for more development in areas potentially exposed to landslide hazards, these projections will need to be taken into consideration in the preparation and planning of measures to reduce the landslide risks to existing and future developments.

The best practice to reduce landslide hazard risks to people and infrastructure is to be aware of and avoid the hazard altogether or reduce exposure and risk. Landslide and flood hazard maps have been created in the past to help inform development decisions however, the management of the information is relatively uncoordinated making it difficult to access. Furthermore, resources for mapping programs have been reduced over time. Key to preparedness for landslide (and flood) hazards is a modern and comprehensive all-hazard mapping program.

As noted above, mapping programs help to identify developments and resource use proposals which should be studied through more detailed hazard mapping and assessments. Some guidelines for landslide and terrain stability assessments have recently been published in collaboration between government and professional associations in BC. However, outstanding issues of reaching agreement on a common definition of what constitutes safe and acceptable risk and further clarifying the scope of the assessments require further work and direction.

Local and provincial government staff and the public would benefit from greater awareness and training into landslide hazards near their communities. Currently local governments are required by law to write and maintain emergency response plans for events such as landslides and other natural hazards as part of their emergency preparedness roles. The proper application of mapping and hazard information to support timely and effective early response depends on users' competence and field recognition skills. Preparedness for various types of emergencies is generally well set up in British Columbia however the landslide preparedness appears to be somewhat slight and recommendations have been made to improve in this regard.

Where new or existing developments and infrastructure are identified as being at risk of landslide hazards, various physical methods can be employed to mitigate the risks. Such measures include the use of deflection berms and catch basins, as well as prediction and early warning systems. These approaches have been implemented in British Columbia and worldwide, however high costs and difficult implementation and maintenance has generally meant that these methods are only used as a last resort in densely populated areas where there is a high known probability of damaging landslides or other natural hazards. In rural areas with low population densities, local governments may be challenged to acquire the funding to construct and assume responsibility for the long term ownership of operation and maintenance of the works. The presence of old and unmaintained structures as well as requirement for some new structures presents liabilities to public safety and to governments. Recommendations have been made to address the funding models to work around these challenges.

The *Emergency Program Act* details the roles and responsibilities of local governments and authorities, and provincial agencies in response to emergency events. Typically the various groups work together with shared responsibility to provide optimum response and service to communities and individuals. For example, in the Kootenay Boundary Region, long standing relationships between staff in provincial ministries and local governments have resulted in landslide and flood event response rosters which are updated annually with specialist staff and a phone contact list, to provide rapid response time of the most local and appropriate individuals in a coordinated fashion. This system has proved to be effective in responding to many landslide and flood emergencies. Recommendations are made to continue efforts to increase public awareness of who to contact during emergencies, maintain the necessary emergency responder training, and ensure that all regions of the province maintain coordinated landslide and flood response rosters.

Disaster Financial Assistance is made available in certain cases under established guidelines and thresholds to support response and recovery efforts. As well, the federal government may provide additional funding for these efforts under its own programs.

A full list of recommendations made in this review is summarized below. The recommendations are grouped into different categories and presented in the sequence they appear in the body of the report.

**Background:**

**Recommendation 1:** The Province should update the terms of reference for the inter-ministry Landslide Policy and Mitigation Working Group to include responsibility for overseeing the implementation of the approved recommendations from this review, including undertaking detailed cost/benefit analyses of individual recommendations where appropriate. The membership of the working group should be renewed to ensure it has capacity for providing ongoing provincial leadership on landslide management issues in BC.

**Climate Change:**

**Recommendation 2:** Provincial and local governments should consider projected impacts of climate change on the level of landslide risk expected over the life of any proposed developments, resource use activities and the construction and maintenance of infrastructure projects when authorizing these activities.

**Preparedness (Risk Identification):**

**Recommendation 3:** The Province, in cooperation with local governments and qualified professionals, should investigate the feasibility of reinstating a mapping program to update and maintain maps of landslides, debris flows, alluvial fans and related natural hazards on both public and private lands. The program should place emphasis on mapping areas of greatest potential risk to public safety.

**Recommendation 4:** Pursuant to the recommendation in the 2008 Coroner's Report, the Province, local governments and professional associations should engage in discussions to explore the feasibility of building a publicly accessible central databank of natural hazard information.

**Recommendation 5:** The Province should work with the Association of Professional Engineers and Geoscientists of British Columbia, the Union of BC Municipalities, academia, industry and other stakeholders to identify a provincial standard for minimum acceptable risk thresholds for landslide hazards which would be applicable to Crown land dispositions, new developments, subdivision approvals and the design of mitigative works to protect existing development.

**Recommendation 6:** Agencies with responsibility for authorizing or regulating resource development activities, including the design, construction and maintenance of roads in steep, potentially unstable terrain, should be explicitly required to consider the landslide risks to public safety, both upslope and downslope of the activity being authorized or regulated. Policy direction should be provided to staff in these agencies with respect to the use of qualified professionals to evaluate landslide risks.

**Preparedness (Subdivisions and Land Development Approval):**

**Recommendation 7:** The Province should work with the Union of BC Municipalities and the Association of Professional Engineers and Geoscientists of BC to prepare a comprehensive training package for provincial and local government staff summarizing landslide hazard identification and what to do when hazards are identified.

**Recommendation 8:** Land Officers involved in the disposition of Crown land and provincial approving officers should receive training and policy direction in recognizing and managing landslides and related natural hazards. Local government development and land use staff should also receive their own training and policy direction on managing landslides.

**Recommendation 9:** The Province should encourage local governments to enact bylaws and policies to guide development away from areas at risk of landslides and to require the use of qualified professionals to assess the risk in hazard zones.

**Recommendation 10:** With regard to public education, the Province should undertake a review of available best practices, reference materials and websites information used in other jurisdictions in the management of landslide risks.

**Recommendation 11:** The Province should update its websites on public education and information related to landslide risks, awareness, mitigation, response and recovery, and undertake ongoing outreach activities to raise awareness and promote the use of these websites.

**Mitigation of Risk:**

**Recommendation 12:** FLNRO should complete its recent Terrain Stability Guidance Project to develop policies and other guidance material for staff working in Crown lands to ensure that terrain stability risks are managed on an appropriate basis.

**Recommendation 13:** The Province should identify standards for landslide mitigation works design and maintenance, as well as consider legislative changes to enable regulation of ownership and operation of landslide protection works using the model used for regulating flood protection works under the *Dike Maintenance Act*.

**Recommendation 14:** The Province and the Union of BC Municipalities should explore new funding models to better facilitate the ownership of orphan landslide and flood mitigation structures, and the construction of new flood and landslide protective measures.

## Emergency Response and Recovery:

**Recommendation 15:** The provincial and local governments should update their websites and other information media to ensure they provide clear guidance to the public on emergency phone numbers and purposes of each call centers.

**Recommendation 16:** The Province, in collaboration with provincial ministries and local governments, should establish annually updated landslide and flood response rosters of trained persons in each region.

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## INTRODUCTION

The winter of 2011-2012 produced a high snowpack in the southern interior of British Columbia and was followed by record spring rainfalls in the Okanagan and Kootenay regions. The preceding year also experienced a high snowpack and above normal precipitation. These two wet years triggered several landslide events in June and July 2012 across southern British Columbia. Many dozens of landslides occurred in unpopulated backcountry area where impacts were largely limited to damage to resource roads. A few events occurred in more populated areas where they caused significant damage in communities such as Sicamous, Johnsons Landing and Fairmont Hot Springs.

In the community of Johnsons Landing on the east side of Kootenay Lake some residents observed uncharacteristic pulsating mud and water flows with debris in the Gar Creek gully upslope of the community in the day or two preceding the event. Their concerns prompted them to send an email message of alarm and appeal for advice to fellow community members. The next day this email was relayed to a provincial government hydrologist. Unfortunately, the hydrologist was doing fieldwork that morning and did not read the email message until later that day. By the time the message was read a landslide and debris flow had travelled down Gar Creek and jumped onto a bench at a sharp bend in the creek destroying houses and killing four people. Emergency responders and governmental professionals immediately acted to assess and evacuate the hazard area and worked to recover the missing persons.

The events at Johnsons Landing and elsewhere attracted considerable public, media and political interest into landslides management practices in BC. This attention raised questions regarding the circumstances surrounding the individual landslides and what could be done to reduce the risks and consequences of future landslides in the province.

## PURPOSE OF THE REPORT

On July 17, 2012 the Minister of Forests, Lands and Natural Resource Operations requested an internal review of the recent landslide events to identify lessons to be learned and to prepare recommendations for the Province to consider which will improve landslide risk management in BC. The review considers the circumstances of select historic landslide events and examines the potential for climate change to impact the frequency and severity of future events. Finally the review summarizes and assesses current practices in landslide risk management in BC including risk identification, assessment and mitigation, and considers general roles and procedures in landslide response and recovery.

## BACKGROUND

### NATURAL HAZARDS IN BRITISH COLUMBIA

The geological history, topography and climate in British Columbia expose communities, individuals and property to a variety of natural hazard risks. Similar circumstances also exist in places like the European Alps, Japan, the Andes, and other parts of North America. Landslides are just one type of natural hazard within this suite of hazards which also include:

- floods,
- wildfires,
- extreme weather events (lightning, hailstorms, tornadoes, hurricanes, windstorms, etc.),
- snow avalanches,
- earthquakes,
- tsunamis, and
- volcanic eruptions.

These natural hazards have different probabilities of occurrence and different consequences. For example, damaging earthquakes are infrequent but if a large earthquake occurs near an inhabited area very large consequences are possible. In addition earthquakes may trigger landslides and tsunamis.

Floods and wildfires are arguably the most commonly occurring hazards in BC and cause the greatest amount of damage to property and infrastructure. However, they seldom result in death, partly because of well-organized programs to manage the risks and because they are relatively slow to initiate and are quite predictable. By contrast snow avalanches occur suddenly and cause the greatest number of deaths in most years, mainly to backcountry recreationists, but cause relatively little property damage. Most risks to the general public from snow avalanches are to travelers along highways, and these risks are managed effectively by the Ministry of Transportation and Infrastructure.

This document focuses primarily on landslides but does provide some comments on related hazards such extreme weather events, floods and earthquake-induced landslides.

In British Columbia natural hazards, which pose different types of risk to public safety, property and infrastructure are managed in different ways by government agencies, corporations, and individuals. However, most use the four pillars approach to natural hazard management: Preparedness, Mitigation, Response and Recovery. The four pillars are led by and involve different local, provincial, First Nation and federal government agencies, as well as volunteer search and rescue groups. There are numerous areas of overlap and the roles are typically fulfilled through collaborative relationships and processes as described in later sections.

## LANDSLIDES

On average, landslides result in the death of about one person per year in British Columbia. On this basis they could be considered a less significant risk relative to some of the other natural hazards. However, fatal landslide incidents are treated as high profile disasters because they sometimes kill people in their own homes, with little or no warning and are dramatic to observe. They also cause considerable long lasting damage to property and infrastructure. Management of landslide risks is a major consideration in land use planning, zoning, subdivision, building permitting, and construction of highways and industrial infrastructure.

### Landslide Types

"*Landslide* is a generic term used to describe the downward movement of soil, rock, or other earth material under the influence of gravity" (Geertsema et al., 2010). There are many kinds of landslides – they are named on the basis of the type of material (e.g. rock, debris, earth) and the type of movement (e.g. slide, fall, flow, avalanche). This report will not attempt to give a thorough description of landslide classification as such reviews are available elsewhere (e.g. Cruden and Varnes, 1996). Some common types of landslides which can present risks to public safety in British Columbia are briefly described below.

*Debris flows* are probably the most common type of landslide which can present risks to dwellings, other buildings, and infrastructure in valley bottoms. A debris flow is a saturated slurry of earth, rock, and vegetation, which most often flows in a confined channel. It can originate as a debris slide which then enters a gully or steep channel, or it can result from an unusual discharge of water entering a steep channel and entraining sediment from the channel bed and banks. Most debris flows terminate on alluvial fans; most steep (over about 5°) fans were formed in whole or in part by repeated debris flows. Alluvial fans are subject to a continuum of hazards, from debris flows (which have more sediment than water by volume), to debris floods (which have more water than sediment), to floods (Wilford et al., 2009). Many communities in British Columbia were constructed long ago on alluvial fans as these are more gently sloped areas amid steep mountain slopes, and typically contain a surface water source.

*Debris slides* and *debris avalanches* are landslides consisting mainly of unconsolidated earth materials ("soil") which occur on open slopes, usually in an unsaturated state. These landslides can move at rates from very slow to very rapid, and the movement is usually more or less planar. Debris avalanches refer to events which travel very rapidly, and may have long runout distances.

*Rock slides* and *rock avalanches* are similar, consisting of bedrock sources. They can be extremely large. Notable examples are the Hope slide of 1965, and Alberta's Frank slide of 1903.

*Slumps* are a type of complex landslide in which the failure plane is more or less circular. Slumps can occur in cohesive (clay-rich) soil, or in weak bedrock. The rate of movement is usually slow. Many slumps persist for centuries or millennia, moving very slowly or not at all, until they are reactivated by some disturbance or by unusually high groundwater levels. Slumps are common in the Prince George area and especially in the Peace region.

*Rockfall* is a common process on steep or vertical rock slopes, both natural and constructed. Rockfall is the most common hazard affecting highways in steep terrain. It can range from individual boulders, to large masses of rocks which completely cover the highway.

A mudslide is a particular type of landslide which is very rare in mountainous regions of BC. The word "mudslide" should not be used as a general term for landslide.

### Landslide Triggers

In general, most landslides are caused by an increase in the supply of water, either high groundwater levels or soil moisture contents in the case of deep-seated landslides, or surface flows and near surface flows leading to a gully in the case of debris flows. Therefore, most landslides occur in the wet season, which in the interior is the snowmelt period of April to June; at the coast this occurs in the fall and winter. Landslide hazard risk can be increased by any development activity which leads to an increased supply of water to a potentially unstable location. Concentration or diversion of water by roads is a very common cause of shallow debris slides and debris flows in the interior. At the coast, loss of root strength following logging is a common cause of landslides. Research in forest geomorphology has shown that forest development typically increases the incidence of landslides by 5 to 10 times (Jordan et al., 2010). Landslides can also be caused directly by mechanical excavation which removes material from the base, or adds material to the top of a slope.

Landslides may also be triggered by seismic activity such as earthquakes and volcanoes.

## EXAMPLES OF LOCAL HISTORIC LANDSLIDE EVENTS

Many large landslides occurred soon after deglaciation about 12,000 years ago. Landslide scars, hummocky deposits in valley bottoms, and raised or inactive debris flow fans from this period are common throughout BC. These features are, in most cases, of little or no concern, and do not indicate a continuing landslide hazard under present climatic and geologic conditions. Most were formed in early post-glacial times as over steepened valley sides adjusted. However, prehistoric landslides which have been dated as younger than the early postglacial period may be of concern, because they indicate that there could be a landslide hazard under present conditions.

Ridge-top cracks and other signs of previous slow movement exist above many large landslides (e.g. Frank, Hope and Mount Meager landslides). However, such ridge-top cracking is common throughout mountain ranges in BC and elsewhere, and the vast majority of such sites have never produced rapid landslides in historic time.

Some landslide incidents that have occurred in or near British Columbia, focusing on events which have caused fatalities or serious damage to property and infrastructure, include:

- The Frank slide was a rock avalanche which buried part of the town of Frank, Alberta in the Crowsnest Pass in 1903, killing at least 70 people. Signs of instability, including cracks in the mountaintop and movement in the coal mines, had been observed before the landslide. Underground coal mining at the base of the mountain may have contributed to the failure. There is ongoing movement in the mountaintop, which is being monitored with geotechnical instruments.

- The Jane Camp rock avalanche of 1915 caused 56 deaths in a mining camp near Britannia Beach (Evans and Savigny, 1994).

- The Hope slide of 1965 is one of the largest landslides to have occurred in Canada in historic time, with an estimated volume of 47 million cubic meters. It caused four fatalities on Highway 3. Like most very large landslide events, it was a rock avalanche and it originated on a mountain slope which had indications of ongoing instability, including ridge-top cracks and previous smaller landslides.

- Camp Creek near Three Valley Gap (west of Revelstoke) experienced a debris flow in 1968 which apparently originated in a large first-time debris slide in deep glacial soil deposits. The resulting debris flow is reported to have killed five people on the Trans-Canada Highway (VanDine, 1985).

- On the Peace River east of Hudson's Hope, the Attachie landslide of 1973 occurred in glacial lake sediments and temporarily dammed the Peace River.

- The Devastation Glacier landslide of 1975 was a large debris avalanche which originated in weak volcanic deposits and killed four people working on a BC Hydro geothermal exploration crew. Numerous other landslide incidents have occurred in the Meager Creek valley, including a large debris flow in 1984 which damaged a recreation site and several vehicles, and another in 1990 which destroyed a logging maintenance facility.

- Howe Sound debris flows were active in the 1980's and earlier along Highway 99 between West Vancouver and Squamish. Between 1958 and 1983, fourteen debris flows resulted in twelve deaths (Evans and Savigny, 1994). Since 1983, defensive structures have been built on several channels.

- The Belgo Creek landslide in 1990, east of Kelowna, was a large debris avalanche which occurred during a heavy rain-on-snow event. It destroyed a house and caused three fatalities. Old logging roads and more recent logging above the initiation point were identified as causes of the landslide.

- In 1997, a large debris flow descended a relatively low gradient channel on Hummingbird Creek and caused considerable damage to property and infrastructure on a densely developed alluvial fan on Mara Lake near Sicamous. It started as a debris avalanche below a culvert which received water diverted by a spur road and cut block logged three years previously.

- In 1999 at Telkwa Pass (Howson) and in 2002 at the Zymoetz River two large, complex landslides originated as rock slides. Both of them ruptured a natural gas pipeline between Telkwa and Terrace.

- Following a 2003 wildfire at Kuskanook north of Creston, an intense rainstorm in 2004 occurred on severely burned, water repellent soils and triggered a debris flow which destroyed two houses and blocked Highway 3A for several days. This event and several others which followed the 2003 wildfires led to a new realization of the significant landslide and flood hazards that can follow some wildfires which alter the soil structure and composition. As a result, the Ministry of Forests at the time developed a policy and procedure for identifying and analysing post-wildfire natural hazards.

- At Legate Creek near Terrace in 2007, a large landslide caused two fatalities on Highway 16 and closed the highway for several days.

- At Van Tuyl Creek in 2008, following a large wildfire in 2007 (the Springer Creek fire near Slocan), a debris flow resulted in one fatality. The debris flow was triggered by an increased snowmelt rate in the burned area as well as by an accidental drainage diversion on a deactivated old logging road and landing. Several other debris flows in subsequent years occurred on this and nearby creeks in the Springer fire. The potential of post-wildfire landslide risks had been identified by a ministry report written in 2007 (Nicol et al., 2007).

- The Mount Meager landslide of 2010 near Pemberton was of similar size to the Hope Slide. It started as a rockfall or rock avalanche from near the summit of Mount Meager and entrained weak volcanic rock and earth lower on the mountain, progressing to a debris avalanche and then a debris flow. It occurred on the flanks of a large dissected volcano which has had a history of many large landslides as well as one major volcanic eruption since deglaciation. It did not cause any fatalities, but it temporarily dammed Meager Creek and Lillooet River, leading to a possible flood hazard (which did not materialize) to populated areas downstream.

### District of North Vancouver Landslide (January 2005) and Coroner's Report (2008)

On January 19, 2005 a landslide occurred on a steep slope in a residential neighbourhood in the District of North Vancouver. The landslide destroyed one residence and injured two occupants, one fatally. Following the event the BC Coroners Service investigated the circumstance which contributed to the occurrence of the landslide and the death of Eliza Kuttner. A report summarizing the Coroner's findings was released in 2008. The report contained twelve recommendations to improve the management of landslide risks in BC. Of these recommendations nine were directed at the province. A summary of all the recommendations is provided in Appendix A. Two of the key recommendations were:

- "That the Province of British Columbia develop a comprehensive Landslide hazard Management Strategy focused prevention and mitigation of risk."
- "That the Province of British Columbia create an inter-ministry technical working group tasked with overseeing the implementations of recommendations arising out of the report."

After receiving and considering the report the Province's Interagency Emergency Preparedness Council (IEPC) established the Landslide Policy and Mitigation Working Group. Membership on the working group included representatives from the Ministries of Public Safety and Solicitor General; Community and Rural Development; Forests and Range; Transportation and Infrastructure; Environment; and possibly Energy, Mines and Petroleum Resources. The IEPC provided the working group with a number of objectives related to landslide policy and mitigation, and implementation of some of the recommendations from the Coroner's report. Since its establishment the working group has developed or contributed to a number of products such as the landslide guidelines released by the Association of Professional Engineers and Geoscientists of British Columbia in 2010.

## The Testalinden Dam Failure in June 2010

In June 2010, the failure of a small earthen dam on Testalinden Creek south of Oliver triggered a very large debris flow which destroyed or damaged several homes and covered about 24 hectares of agricultural land downstream on the alluvial fan. Although the debris flow hazard on this fan was apparently not appreciated by residents or local government, investigations after the event found evidence of many smaller debris flows in the channel upstream and found much of the fan to be composed of deposits of prehistoric debris flows. A review of the Testalinden Dam failure was published by the Ministry of Public Safety and Solicitor General in July 2010. The review listed twelve recommendations regarding dam safety management and incident response. A summary of all the Testalinden recommendations is provided in Appendix B.

## Sicamous Area (Sicamous and Hummingbird Creeks) in June 2012

On June 23 to 25, 2012, flooding and channel avulsions caused severe damage to houses, businesses and Highway 97A on the alluvial fans of Sicamous Creek and Hummingbird/Mara Creeks. The flooding and avulsions on both creeks were due to high streamflows which followed several weeks of exceptionally heavy rainfall. One small debris flow occurred as a result of a road washout in a tributary of Sicamous Creek; however it appears to have contributed only a small amount of debris to the channel. No significant landslides were reported in the affected watersheds. The Hummingbird Creek fan is the same fan that was affected by the Hummingbird Creek debris flow of 1997. The two events impacted many of the same properties.

## Johnsons Landing in July 2012

The Johnsons Landing landslide occurred in the late morning of July 12, 2012. Its approximate volume was 300,000 cubic meters and its debris covers an area of about 10 hectares. It originated entirely in deep unconsolidated material (soil) consisting of glacial till and colluvium. The initial event, which comprised most of the volume, was a rapid debris avalanche which descended the channel of Gar Creek, a steep narrow valley which had occasionally carried small debris flows and snow avalanches in the past. The avalanche rode up over a low ridge at a sharp bend in the creek channel, and spread out over a terrace which was occupied by forest, cultivated land and houses. Three houses in this ridge area were destroyed, two of which were occupied at the time, and two other houses were damaged. There were four fatalities. A small part of the debris was saturated with water, and it continued flowing down the narrow creek channel as a debris flow, destroying the public road crossing and damaging a house on the fan. About 24 hours later, a second debris flow occurred. This event was formed from loose landslide debris in the channel which had been soaking up the creek flow for the past day and eventually became sufficiently saturated and began to flow. This debris flow was larger than the previous debris flow and covered most of the fan and destroyed one of the previously compromised houses.

The landslide occurred during dry sunny weather, about a week after the end of an unusually rainy period of early summer during which the West Kootenays experienced record rainfall during the month of June. The high June precipitation combined with heavier than normal winter snowpack and a comparatively wet year in 2011 probably produced early July groundwater levels which were at or near record highs.

For at least a few days prior to the event there were indications of increasing instability in the creek in the form of increasingly muddy water. In the day or two immediately preceding, local residents observed small debris flows descending the creek. At 4:56 am on the day of the event an email was sent from a resident to their neighbors expressing concern about possible hazards in the creek. An email was sent to the Ministry of Forests, Lands and Natural Resource (FLNRO) Regional Forest Hydrologist in Nelson at 8:47 am suggesting a helicopter reconnaissance of the upper watershed. At the time the Hydrologist was in the field attending to other business and did not read the email until shortly after the event had already occurred.

The site where the debris avalanche originated is on a densely forested slope on the steep mountainside above the community. There are no roads or trails at the site; although there is a narrow old road nearby, it is not a site which is likely to be visited frequently. The area is covered by terrain stability mapping. The slide initiation site was rated as terrain stability class 3 and 4 (i.e., a low to moderate likelihood of landslides following forest development or road construction). The terrain mapping showed no previous landslide deposits in the valley below. Recent field work following the event confirms that there were no significant landslide deposits younger than the early postglacial period in the area affected by this event.

Although the small alluvial fan of Gar Creek did not have a recorded history of debris flows it was identified as a potential debris flow fan on provincial flood hazard maps created in 2001. The hazard polygon was subsequently incorporated into the Regional District of Central Kootenay Floodplain Bylaw. Therefore, while the debris flow hazard on the Gar Creek fan was previously recognized the potential for the large debris avalanche that inundated the properties on the upper bench was not.

The mountainside above the landslide source consists of weak metasedimentary rocks of a geological formation (the Lardeau Group) which has a high incidence of bedrock landslides, both slow slump-type failures and more rapid debris slides. There is evidence of several old, slow-moving, bedrock failures near the landslide source, with some evidence of slight recent movement. However, this type of slow bedrock failure is common in similar geological formations. There are many locations in the Kootenay Lake area where old landslide scars and ridge-top cracks are visible on air photos or have been observed on the ground.

In summary, preliminary investigations have concluded that a debris flow hazard had been identified for the Gar Creek fan area however, before 2012 there were no obvious indications that there was a significant debris avalanche hazard above the Johnsons Landing bench of sufficient size or mobility to present a risk to the community. In consideration of the thousands of steep mountain slopes in the Kootenay Boundary Region and the absence of any recorded landslide activity at Johnsons Landing, professional geological staff consider it extremely unlikely that the Johnsons Landing landslide could have been predicted ahead of time, especially an event with the magnitude and runout of debris that actually occurred.

A team of landslide specialists, including a consultant retained by the local government and staff from FLRNO and MOTI has been assembled to produce a comprehensive report on the landslide. The anticipated completion date for the report is May 2013.

### Fairmont Hot Springs in July 2012

On Sunday afternoon July 15, 2012, a debris flow ran out onto the Fairmont Creek fan at Fairmont Hot Springs. The landslide caused extensive damage to Fairmont Hot Springs Resort infrastructure, condos, single family homes, flood/debris flow control works and roads. Resort infrastructure damaged included water pipes from the hot springs, a road to an RV and camping area and within a golf course. The debris flow resulted from the mobilization of in-channel debris high in the mountains above the community. The trigger for the event was localized heavy rain on July 14 and 15. Hill slopes were already saturated from record rainfall amounts in June and early July 2012.

The debris flow hazard at the site had been identified in previous studies required by FLNRO and MoTI as a condition of subdivision approvals starting in the late 1980's and early 1990's. As a condition of subdivision approval, FLNRO required the construction of debris flow protection works. In 1996 the Regional District of East Kootenay (RDEK) passed a Local Services Bylaw and debris flow control structures (armoured dike and debris catch basin) were built to protect existing and proposed development on the fan area. The RDEK is the site's Diking Authority under the *Dike Maintenance Act*. Although the 2012 event overwhelmed the debris flow control works, residents have indicated that had the structures not been in place there would have been much more damage and possible personal injury or death.

In 2002, as part of a flood hazard mapping project, FLNRO prepared a flood hazard map of the hazard area to assist the RDEK and MOTI with future land use decision making. The observed debris runout onto the fan was consistent with the flood hazard map polygon prediction.

With funding assistance from Emergency Management BC and technical assistance from FLRNO, the RDEK has hired a consultant to document the 2012 event and assess the residual hazard to the community.

**Findings:**

The events of 2012 have renewed collaboration of experts in government on landslide issues. While some progress has been made since the Kuttner report and Testalinden Dam failure review were released, some recommendations have yet to be addressed.

**Recommendation 1:** The Province should update the terms of reference for the inter-ministry Landslide Policy and Mitigation Working Group to include responsibility for overseeing the implementation of the approved recommendations from this review, including undertaking detailed cost/benefit analyses of individual recommendations where appropriate. The membership of the working group should be renewed to ensure it has capacity for providing ongoing provincial leadership on landslide management issues in BC.

## POTENTIAL IMPACTS OF CLIMATE CHANGE ON FUTURE LANDSLIDES

There are a number of factors which affect slope stability and the likelihood of a landslide occurring. These factors include the steepness of a slope, the integrity of the soil and rock material forming a slope, the amount of precipitation and how wet the ground conditions are, seismic activity, and various human activities which might destabilize a slope. A change in climate that alters precipitation patterns would make a substantial impact on the amount of water introduced to an unstable slope.

Landslides events can be triggered by extreme precipitation, snowmelt, rain-on-snow events and high surface streamflows. When the frequency and severity of these types of events increases, the probability of terrain instability events also increases. Several studies have noted statistical increases in the magnitude and severity of heavy precipitation in BC over the past 50 years. These trends are consistent with the results from global and regional climate models which predict increasing intensity and frequency of extreme precipitation events. In BC the models are projecting higher winter minimum and summer maximum temperatures and increased winter precipitation. A more in depth description of climate change projections in BC and their potential impacts on landslide risks is provided in Appendix C.

The climate change projections for warmer winter temperature and higher winter precipitation are also expected to increase the likelihood of heavier winter precipitation falling as rain at lower elevations as well as more frequent rain on snow events at higher elevations. The warmer and drier summers which are projected to occur may result in more wildfires which in turn can create localized water repellant soils which lead to more rapid rates of runoff and flooding at wildfire sites. Spring freshet could occur earlier in the year, and summer low flows and droughts could be more prevalent.

**Findings:**

These anticipated climate change impacts (storms, rain-on-snow, wildfires and hydrophilic soils) and others such as increases in freeze-thaw cycles and increased glacial runoff are likely to contribute to an increase in the risk of landslides and debris flows in the mountainous areas of BC.

**Recommendation 2:** Provincial and local governments should consider projected impacts of climate change on the level of landslide risk expected over the life of any proposed developments, resource use activities and the construction and maintenance of infrastructure projects when authorizing these activities.

## PREPAREDNESS ASPECTS OF LANDSLIDE MANAGEMENT IN BRITISH COLUMBIA

The preparedness for landslides in British Columbia comprises the widest range of work and activities, and the widest range of participating agencies and stakeholders. A combination of legislation and policy, mapping and professional practice guidelines serve to avoid or reduce risks. Government agencies make land use decisions and authorizations, and undertake resource development planning and permitting. Risk identification and mapping are key decision support tools used by governments and involve professional sciences experts in industry businesses, consultants, and government. Public and government staff education on hazard recognition and management are required to optimize the effectiveness of available tools.

Wherever possible, risk avoidance is generally the most cost effective approach to reducing the long term costs to a development associated with natural hazards. The first step in avoiding a risk is to recognize or otherwise be aware of a potential hazard which could affect or be affected by any development activity on site at the earliest stage of the development process. Where a potential hazard has been identified, it is desirable to undertake a risk assessment of the hazard, including mapping of the hazard and the area at risk.

Finally, emergency preparedness for identified risks is a key part of a successful response and recovery should a landslides occur.

## RISK IDENTIFICATION: HAZARD MAPPING AND SITE ASSESSMENTS

### Mapping as a Screening Tool

Local and provincial governments' subdivision Approving Officers, local government Building Inspectors and Land Officers in the Ministry of Forests, Lands and Natural Resource Operations (FLNRO) often require hazard assessments when adjudicating subdivisions, land tenures or sales, or building permit applications to assess and reduce risk to people and property. Regional hazard maps are useful to these agencies to help them identify and screen where hazard areas may exist and to assist them in determining when to require a land developer to hire a qualified professional to assess natural hazards, including landslides, in a more site specific and detailed manner.

Similarly, in the back country, terrain stability maps and other maps provide general guidance to forest companies and other natural resource developers to know where to require a qualified professional to help reduce risk to the environment, forest values, existing developments and third parties when constructing roads and planning resource development or extraction in these areas.

The following mapping subsections describe mapping types and programs, ending with a summary of findings and recommendations.

### Flood Hazard Management

The Flood Hazard Management program is responsible for administration of the *Dike Maintenance Act* including the oversight of regulated dikes and other mitigative works. The program also provides specialized technical and strategic expertise to other agencies involved in flood hazard management. The program has previously developed a number of tools to assist Approving Officers, building inspectors, qualified professionals and to others involved in adjudication of applications for subdivisions, land tenures and building approvals to identify potential at-risk areas, including alluvial fans and other potential debris flow zones. The tools which were developed include flood hazard maps, floodplain maps and provincial guidelines for managing development in at risk areas.

### Flood Hazard Mapping

The *Flood Hazard Statutes Amendment Act* (2003) removed the authority of the Ministry of Environment, Lands and Parks with respect to flood hazard land use regulation. To assist with the transferring of this authority to others, the Flood Hazard Management Program (now part of FLNRO), with assistance from the Fraser Basin Council, created a set of Flood Hazard Maps for the province. The maps depict flood and debris flow hazard areas that program staff had mapped and accumulated information on during the provincial Floodplain Development Control Program (1975 to 2003). The maps were then provided to local governments and provincial approval authorities to aid them in identifying known alluvial and debris flow fans. Their ongoing use by local governments is unknown but likely varies across the province.

Local and provincial subdivision and building permit approval officers can use the maps to screen applications and, where appropriate, require a proponent to engage a qualified professional to develop site specific, detailed flood and debris flow hazard reports and maps for development on fans. Through this process there has been increased awareness of hazard areas and a reduction in the risk of exposure of new development to landslide hazards.

For example, the 2012 Johnsons Landing landslide inundated properties, destroyed or damaged a number of homes, and killed four people on the Johnsons Landing bench. The initial landslide directly contributed to two debris flows within the following 24 hours that ran onto the Gar Creek fan at the confluence with Kootenay Lake. The debris flows demolished an additional house and covered additional properties. The Gar Creek fan area was previously delineated as a potential debris flow fan area through the FLNRO Flood Hazard Mapping project and as a hazard polygon in the Regional District of Central Kootenay floodplain bylaw. Although the existing private lots on the fan were created and developed long before the creation of the flood hazard map and floodplain bylaw, if the map and bylaw had been available they would have been instrumental in identifying the risk to people and property on this fan if a new land development application had been received after creation of these tools.

### Landslide Hazard and Terrain Stability Mapping

Landslide hazard and terrain stability mapping is used to broadly categorize landslides into four general categories on the basis of the land status of their source and destination areas in the landscape:

a. Landslides that occur entirely within developed areas: The 2005 District of North Vancouver landslide is an example. Typically, these incidents occur within a single municipality or regional district, and may originate on one property and affect another property below. This category also includes landslides that originate from below, such as slumps that retrogress from a river bank and affect a property above.

b. Landslides that originate on undeveloped Crown land, and enter populated areas or highway corridors. Most debris flow incidents are of this type, as are most of the very large landslide incidents described above, such as the Frank, Hope and Johnsons Landing landslides.

c. Landslides that originate on Crown land that are caused, or contributed to, by resource development, and enter populated areas or highway corridors. Examples include the 2010 Testalinden dam failure, and debris slides and debris flows caused by resource roads and/or logging activity.

d. Landslides that occur entirely within unoccupied Crown land. This includes the most landslides by number. These events are of interest if they cause indirect risks, for example, downstream hazards of flooding and sedimentation (e.g. the 2010 Mt. Meager landslide), or if they affect recreational users (e.g. the 1984 Meager Creek Hot Spring debris flow) or industrial workers (e.g. the 1975 Devastation Glacier landslide, also in Meager Creek).

Categories b) and c) represent a large proportion, probably most instances of landslide risk that affect populated areas. Local governments typically do not have Jurisdiction over vacant Crown land which lies above private land. As a result local governments and individual residents may be unaware of development plans or of terrain hazards on upslope Crown land.

Landslide hazard and risk mapping can follow two basic approaches; from the top down, and from the bottom up. As noted above, many landslides originate in upland areas, which are usually (but not always) provincial forest land or other Crown land. Many landslides, including those of primary concern for public safety, terminate in valley bottom areas which may be occupied by private property, habitation, or infrastructure. "Top end" mapping involves mapping the upland areas where landslides may originate, while "bottom end" mapping involves mapping valley bottom features such as alluvial fans and floodplains which might be at the receiving end of landslides, floods, or other natural hazards.

Most systematic mapping of landslide hazard (and other terrain features) in British Columbia has been "top end", and consists of various types of mapping covering large areas of Crown land. These include:

- **Soil mapping** – Early soil maps covered areas with agricultural potential (including both private and Crown land). In general, soil mapping is not useful for identifying landslide hazards.

- **Soil and landform mapping** – In the 1970s and early 1980s, this variation of soil mapping was applied in some project areas, and typically consisted of 1:50,000 scale maps comprising a large map-area block. Mapping projects often concentrated on remote areas for which little or no previous mapping existed, and which were being considered for forestry or other resource development. Soil and landform mapping was based on air photo interpretation combined with field work in accessible areas. Most such mapping was done in-house by provincial government professional staff. This mapping did not have the identification of landslide prone terrain or other natural hazards as an objective, but large landslide features were sometimes identified, or described in accompanying reports.

- **Terrain mapping and terrain stability mapping** – This is the type of mapping is now most commonly used in British Columbia for the purpose of identifying landslide prone terrain. Our present system of terrain mapping originated in the forest industry on the BC coast in the 1970s and was adapted by provincial geoscience professionals who further refined the methodology and produced technical manuals and standards (Howes and Kenk, 1997). Mapping is based on air photo interpretation with field checking. In the 1970s and 1980s, several BC government terrain mapping projects covered large blocks of 1:50,000 map sheets, mainly in northern BC and in several other areas of interest because of impending resource development, such as the East Kootenay coal block. Landslide features are identified on these maps by on-site symbols as well as in the terrain labels for large features. Several interpretive ratings were sometimes applied to the mapped polygons, including terrain stability, using a Class I to V scale (now usually replaced by 1 to 5). Because of the relatively small scale of these maps, they are useful from a natural hazards perspective mainly for identifying large landslide features.

- **Terrain stability mapping for forestry purposes** – In the 1990s, with the introduction of the Forest Practices Code, terrain stability mapping was widely adopted throughout British Columbia in areas of existing or proposed forest development. Standards and methodology were prescribed in a Forest Practices Code guidebook (B.C. Ministry of Forests, 1999). Two types of mapping were defined including reconnaissance and detailed, with several "survey intensity levels" or degrees of field checking. Mapping was usually done at a scale of 1:20,000, on a topographic map base. The mapping was funded in most cases by Forest Renewal BC (FRBC) and was coordinated by Forest Regions or Forest Districts, but was done almost entirely by professional consultants working for the forest industry. Identification of landslide prone terrain is the primary purpose of this mapping, and therefore the maps are highly useful for identifying landslide features, potentially unstable areas, and sometimes other natural hazards such as snow avalanches.

  Maps and associated digital files typically reside with forest companies, but copies were provided to Forest District or Region offices and to the FRBC data repository. The mapping is therefore in the public domain, and is available to government agencies and the public, although not at this time readily accessible. Many Forest Districts produced compilations of terrain stability mapping done in their districts; this usually was limited to a Geographic Information System (GIS) layer identifying unstable and potentially unstable (or class 4 and 5) terrain polygons.

The Ministry of Environment has started a long-term program to compile all the existing biophysical mapping, including terrain stability mapping, and make it available on-line as scanned maps or GIS files.

### *Other landslide hazard mapping projects*

A number of landslide hazard mapping_projects have been completed in various parts of the province, which do not fit into the above categories of systematic mapping. These are typically valuable for some specific purpose in a limited area, but more importantly, they may use methods which can be adopted for future mapping. Some examples are:

- Systematic mapping of debris flow hazards was done by consultants working for the Ministry of Transportation and Infrastructure for the Highway 99 Sea to Sky corridor and some other highway corridors subject to high risks from debris flows.

- Several local or regional landslide inventories were done for research purposes by Forest Service and Ministry of Environment staff. In one case (on Vancouver Island) the mapping included computer modeling of potential debris flow runout over a large area in GIS form. The results of these projects were typically published as research papers, but the mapping itself is not readily available.

- In the southeast a project was conducted by one of the present authors (P. Jordan) in the early 1990s to do reconnaissance landslide hazard mapping of population and highway corridors in the entire region. The mapping was done mainly for the purposes of identifying where detailed terrain stability mapping should be done, and prioritizing forest road deactivation projects. The mapping is still available for most of the region and although it has been largely superseded by more detailed terrain stability mapping. The mapping includes an element of risk mapping, and it may be useful to revisit it for identifying areas where landslide risks potentially affect public safety. Some of the mapping may be archived off-site or potentially even lost following office closures.

- A terrain stability and natural hazard mapping project was begun for a large study area on private land in the Slocan Valley by consultants working for the previous Ministry of Forests and the Regional District of Central Kootenay. The project was initiated by public concerns over proposed forest development on Perry Ridge, and was innovative in that it included a number of attributes describing various types of landslides originating in or affecting each polygon. Half of the project mapping was completed. No similar projects have been conducted on private land, despite the obvious value of this approach in mapping landslide risks at the "bottom end".

- The Regional District of East Kootenay (RDEK), with assistance from FLNRO staff, has recently retained a consultant to complete phase one of a regional flood hazard assessment and mitigation plan that will identify and prioritize flood and debris flow hazard areas within the RDEK boundaries. The first phase of the project will result in an inventory of all available hazard maps and reports. Phases 2 and 3 will include conducting site visits to identified tip prioritized areas and recommended mitigation strategies.

### *Aerial Photography Imagery for Landslide Hazard Mapping*

Air photos are essential for all types of landslide hazard mapping. Typically the mapping process involves inspection of air photo prints under a stereoscope to identify landslide related features and then the delineation of terrain polygons on the photos. For landslide hazard studies, it is often very useful to obtain historical photos to examine changes that may have occurred over time to a landslide, stream channel or suspected unstable area. Many parts of the province have had repeated air photo flights at least every 10 to 20 years, sometimes going back as early as the 1930s. Most air photos have been taken by or for the provincial government, and the original negatives are housed in a collection in Victoria.

In 2010, the provincial government closed its air photo library and photographic lab, which prior to 2010 made and sold air photo prints. This service was replaced by making digital scans of recent air photos, and selling the scans as digital files. For some purposes, this product is useful; however, many geoscientists and engineers have found that the quality of the scans is inferior to photographic prints. Also, most of the older air photos have not been scanned. In 2012, an agreement was reached to transfer the air photo collection to the University of British Columbia, who will make air photo prints available for loan. In addition, several provincial offices in various ministries possess prints of regional air photos.

In the last few years, Google Earth has emerged as a widely used online program for viewing the landscape, and is quite useful for preliminary reconnaissance of landslide features. The imagery used by Google Earth for British Columbia is orthophotos provided by the provincial government, which have been prepared from air photo scans. The orthophotos, which are available in digital form, are of lower resolution than the original photos. The Google Earth imagery is compressed and therefore of still lower resolution. Although orthophotos are useful for an overview of large areas and for making planimetric maps, they do not allow stereoscopic (3D) viewing, and therefore much less useful for terrain mapping and landslide studies than air photo prints.

Other forms of remote sensing are useful for some types of landslide studies, including high-resolution satellite imagery such as Quickbird and Geo-Eye. A very useful remote sensing product is LiDAR, which is a form of airborne imagery which can provide a detailed, digital 3-dimensional image and elevation model of the ground underneath the forest canopy. LiDAR is very expensive, which generally restricts its use to localized, detailed landslide investigations, and mapping for major engineering projects. It may potentially become a valuable tool for landslide hazard mapping, as the cost becomes more affordable.

**Findings on the Mapping Sections:**

Flood Hazard Maps can play an important role during flood and landslide emergency planning and response. As demonstrated in the emergency responses for Johnsons Landing and Fairmont Creek this year, the Flood Hazard Map polygons provide a shelf ready map to assist with declaring areas for a state of emergency.

The hazard maps are also used in development planning and review processes. While the maps have helped steer more recent development away from high hazard areas and have saved lives, they do have limitations and could be improved.

Similarly terrain stability mapping is valuable for identifying landslide-prone terrain and other natural hazards, there are several limitations:

- Mapping usually covers only those areas which were of interest to a forest licensee for development. Many other areas remain unmapped.
- Very little mapping has been done since the end of Forest Renewal BC.
- Some early mapping was done only as hard-copy, or in digital formats which are incompatible with modern GIS systems.
- Forest Districts typically retained as GIS files only the unstable and potentially unstable (or class 4 and 5) attributes of each polygon. The terrain labels and on-site symbols, which contain most of the useful natural hazards information, were not usually captured, and often the original maps were lost or discarded. The full mapping information is currently rarely used and the FRBC archive's permanent storage is no longer readily available.
- Mapping was usually truncated at the Crown-private land boundary. Therefore, in most areas of interest for public safety (i.e., the "bottom end") were never mapped.
- The mapping is technically complex and it cannot be readily interpreted by people other than geoscience specialists (or by some specialists in related subjects such as soils, ecology, and engineering). It is not easily used by most of the general public, or by non-specialists in local government or other agencies. The number of provincial government science specialist positions in district and regional offices has reduced considerably, and so terrain stability mapping is not used to the extent it once was for land management planning or for consultation with the public or local governments. Ongoing staff attrition is further reducing the usefulness and application of this information.
- The Ministry of Environment has a program to compile all the existing biophysical mapping, including terrain stability mapping, and make it available on-line as scanned maps or GIS files. However because of limited staff and resources, this project is proceeding very slowly, and little of the 1:20,000 terrain stability mapping has been compiled.

**Recommendation 3:** The Province, in cooperation with local governments and qualified professionals, should investigate the feasibility of reinstating a mapping program to update and maintain maps of landslides, debris flows, alluvial fans and related natural hazards on both public and private lands. The program should place emphasis on mapping areas of greatest potential risk to public safety.

**Recommendation 4:** Pursuant to the recommendation in the 2008 Coroner's Report, the Province, local governments and professional associations should engage in discussions to explore the feasibility of building a publicly accessible central databank of natural hazard information.

## Site Specific Hazard Assessments

More detailed and site specific mapping and hazard risk assessments are routinely performed as part of the application processes for proposed land development, forestry and other resource use projects. FLNRO's Forest Research Program provides science specialist expertise and support to regional and district operations. This support has included terrain stability mapping of study areas, developing and maintaining local or regional landslide inventories, post-event investigations of selected landslides and undertaking or overseeing individual geotechnical, hydrological and terrain stability research projects.

Government authorizing agencies work under legislation that, where appropriate, requires professional hazard assessments be undertaken to determine if a proposed use is safe. A proponent will then use the completed assessment to inform his or her development plans or activities to either avoid a risk by relocating the development or activity to a safer area or incorporating strategies to reduce or remove the risk. An assessment might also undertaken to evaluate the potential for a proposed development to increase the level of landslide risk for existing nearby developments or the public, and to identify measures which can be taken to avoid increasing the level of risk.

For many years there were inconsistencies and gaps in how hazard assessments were undertaken. As well, there has been extensive debate about how to define the term "safe." Recognizing the need for standard guidelines, government agencies and professional associations have been working in partnership to develop guidelines for landslides and terrain stability assessments. The 2008 Coroner's Report and the failure of Testalinden Dam were two events that accelerated the completion of some of these guidelines.

### Guidelines for Legislated Landslide Assessment for Proposed Residential Development in British Columbia (APEGBC 2010)

Qualified Professionals play a significant role in landslide hazard identification and mapping in the Province of British Columbia, including the preparation of hazard assessment reports and maps for both the land development and resource development sectors. In 2006, with amendments in 2010, the Province contracted the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to help write *Guidelines for Legislated Landslide Assessment for Proposed Residential Development in British Columbia* to assist Qualified Professionals involved in the preparation of landslide hazard assessments. These guidelines provide a risk-based approach for professionals to assess and mitigate building sites and to design structures at the sites. Authorities may also find the guide helpful in defining criteria for and evaluating results from professional geotechnical reports. The document is available online at
http://www.apeg.bc.ca/ppractice/documents/ppguidelines/guidelineslegislatedlandslide1.pdf

The guidelines also outline roles and responsibilities for those involved in land use regulation and provide guidance for professional practice and quality assurance criteria to help qualified professionals provide quality reports on landslide hazards.

### Guidelines for Legislated Flood Assessments in a Changing Climate in British Columbia (APEGBC 2010)

In 2010 the Province contracted APEGBC to begin drafting a guideline document, similar to the residential landslide guideline, to assist professionals in writing flood hazard reports and creating flood hazard maps. The guideline document entitled *Guidelines for Legislated Flood Assessments in a Changing Climate in BC* was released in October 2012. Although the title of the document references flood hazards, the document provides a significant amount of guidance on debris flow hazard assessment. Debris flows and debris flood landslide hazards are gully/stream channel processes that cannot be dealt with as a separate hazard from normal flooding, especially in BC with the predominance of steep mountain terrain and proliferation of alluvial and debris flow fans.

### Guidelines for Professional Services in the Forest Sector - Terrain Stability Assessments (APEGBC & ABCFP, 2010)

In 2010 APEGBC and the Association of British Columbia Forest Professionals (ABCFP) issued the *Guidelines for Professional Services in the Forest Sector – Terrain Stability Assessments* which superseded APEGBC's 2003 *Guidelines for Terrain Stability Assessments in the Forest Sector*. A Terrain Stability Assessment (TSA) is carried out by a qualified terrain specialist to assess the potential for forest operations to affect or to be affected by landslide hazards. A TSA may also be done to evaluate the risk and/or provide options to manage hazards and risks associated with operations. The ultimate goal of a TSA is to protect the safety, health and welfare of the public, to protect the environment and to provide for health and safety with the workplace. TSAs are conducted to:

- assess the potential for landslides to occur as a result of forest development activities,
- identify potential hazards upslope of roads or operational activities,
- assess terrain conditions and landslide hazards along proposed road corridors, and
- prepare strategies and recommendations for managing risks associated with roads and other forest activities.

The 2010 Guidelines establish a standard of care for carrying out TSA related to forest planning and operations in BC.

### Guidelines for Management of Terrain Stability in the Forest Sector (APEGBC & ABCFP, 2008)

In 2008 APEGBC and ABCFP produced the *Guidelines for Management of Terrain Stability in the Forest Sector*. The guidelines were developed for the forest sector to assist in the management of terrain stability by providing guidance for establishing, implementing and updating a Terrain Stability

Management Model. The model provides guidance on when and where a TSA should be conducted and to manage terrain stability, whether a TSA has been conducted or not. A model also provides guidance for establishing risk criteria and selecting strategies for development which are consistent with the risks.

### Mining Industry Project Hazard Assessments

The Ministry of Energy, Mines and Natural Gas (MEMNG) is responsible for administering the *Mines Act*, its regulations and the Health, Safety and Reclamation Code for Mines in British Columbia (the Code). The ministry utilizes provincial delegated Inspectors of Mines, and requires mining operators to make use of professionals such as engineers and geoscientists to explore for and develop mines and quarries in the province. *Mines Act* applications for new mines and expansions are typically very detailed. They are reviewed by provincial science and engineering experts and subject to public consultation. In its Purpose statement, the first two purposes of the Code are to:

"(1) Protect employees and all other persons from undue risks to their health and safety arising out of or in connection with activities at mines.
(2) Safeguard the public from risks arising out of or in connection with activities at mines. "

**Findings on Hazard Assessments and Professional Guidelines:**

The *Forest Act* currently does not identify public safety and potential consequences to downslope people and property as a key value that they must plan for. However, qualified professionals work under the 2010 Guidelines for Professional Service in the Forest Sector – Terrain Stability Assessments and the 2008 Guidelines for Management of Terrain Stability in the Forest Sector, and under Codes of Ethics as part of membership of relevant professional associations. The duty to the public is commonly a top priority in such Codes of Ethics.

Often, professional geoscience consultants and their clients do not distribute reports. Consequently hazard assessment reports (including hazard maps) required for subdivision, building permit and Crown land tenures in many instances do not become public documents, making important information in the reports related to safety of people and property difficult to access.

Similarly, most hazard assessment reports and maps conducted for forestry and resource use development by industry proponents are not made readily available. They may be stored with agencies but not intended to be uploaded to a central databank for broader access.

"The Guidelines for Legislated Landslide Assessment for Proposed Residential Development in British Columbia" point out the need for governments worldwide to define what acceptable risk means in terms of safety for residential development. Currently landslide hazard maps and perceived or defined acceptable risk levels vary significantly across the province. APEGBC maintains that it is not the role of the qualified professional to define what is safe. In the absence of a provincial policy on the definition of acceptable risk for landslides some jurisdictions in British Columbia such as the District of North

Vancouver and the Fraser Valley Regional District have implemented their own landslide hazard risk levels. The establishment of a provincial policy would reduce the risk of inconsistent reporting and mapping of landslide hazards for residential development.

The Guidelines for Legislated Flood Assessments in a Changing Climate in British Columbia discusses the need for provincial policy to establish a consistent description and procedure for establishing acceptable risk for the mapping and regulation of development in debris flow hazard areas.

**Recommendation 5:** The Province should work with the Association of Professional Engineers and Geoscientists of British Columbia, the Union of BC Municipalities, academia, industry and other stakeholders to identify a provincial standard for minimum acceptable risk thresholds for landslide hazards which would be applicable to Crown land dispositions, new developments, subdivision approvals and the design of mitigative works to protect existing development.

**Recommendation 6:** Agencies with responsibility for authorizing or regulating resource development activities, including the design, construction and maintenance of roads in steep, potentially unstable terrain, should be explicitly required to consider the landslide risks to public safety, both upslope and downslope of the activity being authorized or regulated. Policy direction should be provided to staff in these agencies with respect to the use of qualified professionals to evaluate landslide risks.

## NEW SUBDIVISIONS AND DEVELOPMENT

New developments and activities on private rural and municipal properties, and Crown land are managed by various local governments and provincial agencies who are guided by an assortment of legislation, regulations, bylaws, plans and professional practice guidelines. For example, municipalities and regional districts administer subdivision and development approvals, and transportation and land use planning under legislation. Official Community Plans, bylaws and development permits are example tools used by local governments to regulate to development within their boundaries Provincial ministries administer numerous Acts and accompanying regulations and policies addressing Crown land tenures, rural subdivisions, flooding, water use, working in and near streams, dikes, dams, forestry operations and transportation. Irrespective of the applicable approving authority, where a site has been identified as susceptible to known landslide hazards it should not be subject to further development.

### Residential and Commercial Development on Crown Land

Crown Land makes up 94 % of the area of British Columbia. The province operates within a framework of policies that govern the disposition, administration and management of Crown land. These policies have been developed to assist staff, stakeholders and the public by establishing principles on land use, allocation, tenure terms, pricing and all other aspects associated with the tenuring of Crown land.

When making decisions on the disposition of Crown land officials must consider potential natural hazards. For instance, Land Officers must consider the "Flood Hazard Area Land Use Management Guidelines" when selling, tenuring or leasing Crown land. Where there are natural hazards such as landslides, Land Officers may establish conditions which are attached to a new lease, tenure or other disposition with the intent of protecting public safety and future uses of the land from the hazard. For example, where a parcel is located in a floodplain, or where provincial staff express concern about flooding, a restrictive covenant prohibiting development in the floodplain, and a corresponding indemnity covenant are registered on the title.

### Rural Land Subdivision

Provincial Approving Officers in the Ministry of Transportation and Infrastructure (MoTI) are responsible for the approval of subdivision applications in rural areas outside of municipalities. In this capacity the Approving Officers are authorized to consider the natural hazards risk, including landslides, when making a decision on a rural land subdivision application. However, once a decision is made MoTI Approving Officers have no mandate to monitor that risk, nor to forecast or respond to a landslide event.

Approving Officers have the authority to ask for professional assessment of situations where they have reason to suspect a risk of landslide, looking for indication that the land in question is safe for the use intended. However, they do not have criteria in statute as to what conditions define safe. In the absence of provincially accepted criteria various techniques are used by qualified professionals to address this issue. The Approving Officers provide some guidance to qualified professional as to an acceptable level of risk (what is safe) by referring to:

- past practice by MoTI of considering a probability of 1:475 of a property damage only event as a maximum acceptable risk, and
- Referring to case law that cited as unacceptable the risk of a catastrophic event that had a suggested probability of 1:10,000.

For assessment methodology, the qualified professionals refer to the guidelines jointly developed by the Province and APEGBC and which are described elsewhere in this report.

If a risk is present on part of the land, it may require the registration of a restrictive covenant against the title which acknowledges the hazard and that prevents building in unsafe parts of the land to avoid the identified hazard risk. However, after a decision is made to approve a subdivision plan, neither the Approving Officer nor MOTI monitor long term compliance with such covenants.

Where a dike or other works are proposed to mitigate or reduce a landslide or flooding risk, the Approving Officer will require a local government to agree to assuming responsibility for monitoring and maintenance of the works in accordance with provincial policy and legislation. This includes requiring a long-term operation and maintenance plan for the mitigation structures be developed and implemented as a condition of subdivision approval. Usually FLNRO Water Stewardship staff will work informally with local governments and proponents on the specifics of the long-term management of the structures and to establish the local government as the diking authority as regulated by the *Dike Maintenance Act*.

### Local Government Regulation and Planning

There are a number of tools available to local governments which they can use to promote that future land uses that are planned and buildings which are constructed in a manner which take into consideration different natural hazards including landslides.

1. Official Community Plans (OCP) contain general land use policy statements and maps respecting restriction on the use of land that is subject to hazardous conditions such as landslides. OCPs may also be used to designate development permit areas where measures are required to reduce the risk to public safety and protect future developments from specific natural hazards.
2. Bylaws and Development Permits specify and enable enforcement of measures and requirements for new development in designated areas to protect against hazards. Bylaws can be used to regulate parcel configurations, the density of the land use, siting and standards of buildings and structures. Development permits may be used to specify areas of land which may be subject to landslides or other natural hazards, and which should not be developed except in accordance with the conditions contained in the development permit.
3. Subdivision approvals within municipal boundaries are coordinated by municipal governments similar to the MoTI Approving Officers' role in approving rural subdivisions. In this capacity an Approving Officer may require an engineering report from the proponent certifying that the land may be safely used for the intended purpose.
4. Restrictive covenants are used by local governments when a subdivider, developer or other proponent is required to register a restrictive covenant against the title of the property to establish conditions under which the property can be safely developed and/or to provide a waiver of liability in favour of a local government and/or the province for damages due to the natural hazard.

### BC Building Code Amendments for Slope Instability and Seismic Hazard Consideration

Partially driven by the recommendations of the 2008 Coroner's Service "Kuttner" report, effective February 1, 2010, the BC Building Code was amended with the new additions of Sentence 4.1.8.16 (8) and Sentence 9.4.4.4 (2). With the new changes:

1) the consideration of potential for slope instability and its consequences at a building site becomes an explicit requirement in designs of structures and their foundations, and
2) the seismic hazard probability level to be used in the consideration, particularly in assessment of seismic slope stability, will be as referenced in Subsection 1.1.3 of Division B of the BC Building Code, namely a 2%-in-50 year probability of exceedence.

As a result, the Geotechnical Slope Stability (Seismic) Regulation, B.C. Reg. 358/2006 was repealed. The companion Commentary on Geotechnical Slope Stability (Seismic) Regulation issued by the Building and Safety Policy Branch in January 2007 was also withdrawn. As originally intended, the repealed B.C. Reg. 358/2006 served as an interim provision for specifying a seismic hazard probability level to be used for slope assessments for building sites. That level was a 10%-in-50 year probability of exceedence. Copies of the Minister's Orders amending the BC Building Code and repealing the Geotechnical Slope Stability (Seismic) Regulation are available online at http://www.housing.gov.bc.ca/building/regs/codes/index.html (see Revision 7).

Technical guidance on seismic slope assessment to the 2%-in-50 year seismic hazard probability level can be found in the document *Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia,* published by the Association of Professional Engineers and Geoscientists of BC (see earlier section).

### Highway and Resource Road Design, Construction and Maintenance

MoTI is responsible for the design, construction and maintenance of provincial highway infrastructure. Specifically with respect to landslides MoTI is responsible for ensuring provincial highway infrastructure and public safety are protected from landslides by:

- taking the steps to ensure slide risks are identified, assessed, mitigated or avoided during project design and construction,
- monitoring and maintaining mitigation measures, monitoring risk factors and responding to events, and
- if a previously unidentified, extensive natural hazard risk is discovered, advising relevant agencies such as a local government which can respond with appropriate land use controls.

In FLNRO, Forest Service Roads and non-status resource roads are managed similar to the provincial highway network. The Engineering program is responsible for the management, prioritization and maintenance of roads and associated works, including stream crossings and road drainage.

**Findings on New Subdivisions and Development:**

There are available mapping tools and knowledge about landslide hazards, and different provincial ministries have some policies in place which guide landslide hazard risk management for areas under their jurisdiction. However, the application of zoning, OCPs and bylaws by regional districts and many municipalities to address landslides is variable.

Staff in provincial ministries, municipalities and regional districts possess varying levels of knowledge of landslide hazards. As well, many new hires must learn a substantial amount of information and policy in their course of their "on the job" training. Gaps likely exist in the ability of land officers, approving officers, building inspectors, and local government authorizing and land use staff to fully consider the potential hazards.

British Columbia shares the difficulty of managing development and resource use in landslide prone terrain with other jurisdictions in Europe, Japan, Australia, etc. Those countries also continuously assess and improve their landslide management tools.

**Recommendation 7:** The Province should work with the Union of BC Municipalities and the Association of Professional Engineers and Geoscientists of BC to prepare a comprehensive training package for provincial and local government staff summarizing landslide hazard identification and what to do when hazards are identified.

**Recommendation 8:** Land Officers involved in the disposition of Crown land and provincial approving officers should receive training and policy direction in recognizing and managing landslides and related natural hazards. Local government development and land use staff should also receive their own training and policy direction on managing landslides.

**Recommendation 9:** The Province should encourage local governments to enact bylaws and policies to guide development away from areas at risk of landslides and to require the use of qualified professionals to assess the risk in hazard zones.

## PUBLIC EDUCATION ABOUT RISKS OF LANDSLIDES AND RELATED HAZARDS

In the aftermath of the Johnsons Landing landslide, a review of an email exchange between local residents indicated some familiarity but also much uncertainty about the warning signs of a potential landslide, imminent risk indicators and steps for notifying authorities and others of their concerns. Media coverage addressed and questioned what citizens should be looking out for with respect to landslides risks and who they should contact for guidance in regarding terrain stability concerns and in the event of an emergency.

Public knowledge of natural hazards and early warning signs of increasing risk varies with different types of hazards. Hazards involving little or no warning, and which occur infrequently in developed areas, such as landslides, appear to be most wanting.

Highland and Bobrowsky (2008) state that "people living in areas prone to fast-moving, deadly debris flows need information on the likelihood of the hazard; for example, when it is most dangerous to be in the path of potential debris flows (such as during heavy rainstorms) and at what point to evacuate and (or) cease walking or driving in a hazardous area."

Emergency Management BC websites on Emergency Preparedness Information are a source of educational information and important links for numerous types of emergencies including:

- flooding
- weather events
- wildland fires
- tsunamis
- earthquakes
- backcountry accidents
- wildlife interface
- disease outbreaks
- landslides
- avalanches
- HAZMAT and spills
- volcanoes, and
- drought.

Several of these sites, including the flooding site, contain detailed and comprehensive reference information. By contrast the current website for landslides is at present less thorough.

However, there are a number of other sources of information on landslides which are published elsewhere. Available information includes both introductory and advanced technical handbooks, guidelines and other reference materials. These sources provide excellent reference information on landslides which is beyond the scope of this report.

**Recommendation 10:** With regard to public education, the Province should undertake a review of available best practices, reference materials and websites information used in other jurisdictions in the management of landslide risks.

**Recommendation 11:** The Province should update its websites on public education and information related to landslide risks, awareness, mitigation, response and recovery, and undertake ongoing outreach activities to raise awareness and promote the use of these websites.

## EMERGENCY INCIDENT PREPAREDNESS

Much of landslide preparedness work in British Columbia involves risk assessment and informed land use decision making. This work is done to reduce the risk of landslides affecting public safety and new development and infrastructure, and to reduce the potential for proposed resource development and construction to affect pre-existing developments.

An additional aspect of preparedness is response planning and preparing for when landslides actually occur. Preparing for the possibility of an emergency is a shared responsibility of individuals and all levels of government.

All individuals should be aware of the landslide risks in their area and the early warning indicators of an escalating risk of an event occurring. To the extent practical they should also take measures to mitigate the exposure of their property to risks from landslides and ensure they are familiar with the appropriate actions to take should a landslide occur.

At the local government level municipalities and regional governments are required by law to prepare emergency plans and maintain an emergency management organization for all types of emergencies including landslides. This regulation is intended to ensure the safety of citizens when a situation escalates beyond the first responder level.

At the provincial level multi-agency hazard plans for British Columbia are prepared and updated regularly by Emergency Management BC to ensure an effective response strategy is in place to address the many possible types of emergencies and disasters. These plans foster cooperation amongst the multiple organizations which are responsible for public safety, the protection of infrastructure and property, and managing the aftermath of emergency events.

As noted previously, landslides are most often triggered by surface and groundwater conditions changing, which are tied to precipitation patterns. The River Forecast Centre of FLNRO monitors streamflows, snowpacks and weather conditions across the province, models conditions to support flood forecasting and provides flood forecasts and bulletins to provincial and other emergency response agencies as and when required. While this information is targeted to flood hazards, the same climatic conditions which may result in flooding typically coincide with increased risk levels to landslide hazards.

An example of specific landslide response planning is in the Kootenays where a landslide response roster maintained and annually updated to ensure that landslides are responded to as efficiently as designed in preparedness plans set up for other hazards. That roster is discussed later in this report.

## MITIGATING RISKS OF LANDSLIDE HAZARDS TO EXISTING DEVELOPMENTS

There are many communities where the risks of landslides to existing communities are not realized until long after development has occurred. Where the newly assessed risk is determined to be unacceptable it may be most appropriate to relocate the development to a safer location. Unfortunately, in most cases relocation may be neither a practical nor economically viable option. In these situations consideration may be given to other mitigation options such as notification of those at risk, taking action to stabilize the potential initiation zone, constructing structural measures to protect at risk communities or infrastructure, or developing and maintaining a prediction and early warning system. However, experience has found that the costs/benefits ratio for the structural and early warning options can be prohibitive, making them economically viable only in densely developed areas.

### Notification of Potential Landslide Risk

There are situations where a terrain hazard assessment being undertaken for other purposes may indicate a previously unidentified risk of landslides to existing development. Two recent examples of where previously unidentified risks were discovered are:

- an assessment undertaken as part of a BC Timber Sale in the Cascade Bay area of Harrison Lake which identified a risk of slope instability to a number of existing Crown leases for recreational lots, and
- an assessment of a slope near the Village of Lions Bay which found a previously unidentified gully on Crown land which could direct a debris flow towards several private residences.

In both situations, regardless of fault or liability for any resulting landslide, as soon as the Province became aware of the risk there was a requirement under section 25 of the *Freedom of Information and Protection of Privacy Act* to inform the at risk leaseholders and landowners of the possible risk. Failure to warn them of the risk could result in the Province becoming liable for resulting damages in a landslide was to occur.

Partially in response to the circumstances at Cascade Bay the FLNRO Lands Tenure Branch, in partnership with the Ministry of Justice (JAG), has initiated a Terrain Stability Guidance Project to develop a new risk management policy around new, replacement and existing *Land Act* tenures in areas where a terrain stability analysis has determined there is a high risk of landslide.

### Stabilizing the Initiation Zone

For both new and established at risk developments, a review of upslope conditions and the nature of the landslide hazard may reveal that the most viable mitigative options may include stabilization at initiation zones. For example, prescriptions can be developed to unload weight from certain areas and/or undertake other slope stabilization measures such as groundwater drainage as part of an overall solution. It is recognized that not all landslides are natural events; many can be triggered by resource development or other ground disturbances. Therefore, mitigative measures which reduce the impact of these disturbances in the potential initiation zones such as upgrading road drainage can also be used to reduce landslide hazard.

### Structural Measures - Debris Flow Mitigation Structures

Over the past four decades a number of debris flow mitigation structures have been constructed in BC. Most existing structures have been built to protect forestry resources and highways with relatively few structures built to protect residential development. The complexity of design has generally been related to the associated elements at risk. For example, the standard of design for works to protect a remote forestry road is considerably less than the standard required for a major highway. The protection of residential developments has typically warranted the most complex design as well as the establishment of arrangements for ongoing operation and maintenance. This review focuses on works designed to protect residential development.

There are two general types of structures used to protect against debris flows:

- Deflection berms/channel improvements deflect the flow, provide lateral constraint to the deposition area, and/or channelize the material further downstream where there may be less impact. A critical parameter is the design flow rate.
- Debris basins and barriers contain all or part of the debris flow material. A critical parameter is the design volume.

The Provincial Inspector of Dikes has designated several debris flow mitigation structures protecting residential areas as "dikes" and these are regulated under the provincial *Dike Maintenance Act* (DMA). In these cases, local governments own the works, have legal access to the land where the works are located, complete annual inspections and fund ongoing operation and maintenance.

Current practices and issues associated with implementing debris flow mitigation structures are best illustrated by a few examples:

**Port Alice**
Port Alice is a small village of about 800 people on the northwest coast of Vancouver Island. After the town site experienced two damaging and life threatening debris flow events in 1973 and 1975, a system of deflection berms, totalling 2.3 km in length was constructed by the BC Ministry of Environment for a cost of $0.25M (1976 dollars). The Village owns and maintains the dikes as the Diking Authority under the DMA.

Over the last three decades, the berms have protected the town from a number of smaller events. However, in 2011 FLNRO staff noted potential problems with the geometry of the works and have recommended that the Village complete a comprehensive debris flow assessment and dike safety review.

**Lions Bay**
Major debris basins were constructed by the then BC Ministry of Transportation and Highways on three debris flow prone creeks (Charles, Harvey and Magnesia) in the vicinity of Lions Bay in the mid 1980's after debris flows occurred along this section of Highway 99. The cost of the debris basins (in 1986 dollars) was $11 million. While the works were constructed primarily to protect Highway 99, the works also protect residential development. Maintenance costs are currently covered by the Ministry of Transportation and Infrastructure. Because these works are owned and maintained by the Province, they have not been designated as dikes under the *Dike Maintenance Act*.

**Whistler** (Whistler Creek)

A debris barrier was constructed in the late 1990's as part of redevelopment of the "Gondola Base" area at Whistler Mountain (now called "Whistler Creekside"). The structure is designed to retain a 1:2,500 debris flow event with a design volume of more than 25,000 $m^3$, including 12 tonne boulders moving at 5 metres/second. The mass concrete structure is 16 m high and 34 m long and has a 12 m wide central passage furnished with a steel grillage (see photo below).

The barrier was required as a condition of subdivision approval at the time by the Ministry of Environment under the former Section 82 of the *Land Title Act*. The structure and related stream works have been designated as a dike under the DMA with the Resort Municipality of Whistler being the Diking Authority responsible for operation and maintenance. A similar $3.8 million barrier was constructed on Fitzsimmons Creek in 2009 to reduce the impact of a potential debris flood event.

A debris barrier on Whistler Creek, Whistler, B.C., designed to retain 30000 $m^3$ of debris.

**Chilliwack River Valley, Baker Trails Trailer Park - Tank Creek and Guy Creek Works**

In January, 2002 a debris flow on Tank Creek narrowly missed destroying mobile homes in an existing 157-home residential development. A subsequent hazard assessment determined that a number of the homes were at high risk from debris flows originating on both Tank and Guy Creeks. For a cost of approximately $0.25 million the province constructed a deflection berm on Tank Creek and a debris barrier on Guy Creek. The Tank Creek berm has subsequently performed well, protecting the homes from a debris flow event.

The design of these structures were reviewed and approved by FLNRO staff under the *Dike Maintenance Act*. As the Diking Authority, the Fraser Valley Regional District owns and maintains the works. The berms' design volumes and flows were estimated for a 1:500 year event.

**District of Squamish- Cheekye Fan**
The community of Brackendale and a section of Highway 99 are located on a large gently sloping debris flow fan of the Cheekye River, a tributary of the Squamish River. The debris flow hazard was first recognized in the early 1980's, and has resulted in a restriction of development in this area. There is geological evidence that volcanic debris flows of up to several million cubic metres, sourced in the Cheekye headwaters, have reached the fan periodically during the past few thousand years. The largest of these flows covered the surface of the fan with deposits up to 5 m thick approximately 1100 years ago.

Studies aiming at quantifying the debris flow hazard at this site in order to allow major residential development are continuing. Large debris barriers and containment berms have been proposed to mitigate the risk. Outstanding issues include tolerable risk limits, uncertainties in design parameters for the structural works and the high costs of maintenance and rehabilitation of the works after events occur.

**District of North Vancouver**
After a damaging debris flow event on Mackay Creek in 1995, the District of North Vancouver issued an overview study of debris flow hazards and risks in residential areas of the District, which was followed by a detailed study of the highest priority creeks and a quantitative risk assessment of those creeks. A debris flow barrier was constructed in 1996 at Mackay Creek to reduce risk to acceptable levels for adjacent residential properties.

The District is also constructing a debris barrier (metal cable net anchored into rock) on Mosquito Creek. The $240,000 structure is estimated to cost $10,000 per year to maintain. Without the barrier, several homes would be subject to a higher than acceptable risk (defined in the District as a 1:10,000 chance of death of an individual).

Metro Vancouver is currently studying additional measures to reduce the potential impacts on development at the base of Grouse Mountain. New protective works are expected to cost several million dollars.

## Prediction and early warning systems

In densely populated areas where more well known landslide hazards exist, mostly in European and Asian countries, highly technical instrumentation networks and real-time monitoring are utilized to help evacuate risk-prone areas prior to landslide events actually occurring. There is a large range of instrumentation that can be utilized on a slope, using one or a combination of groundwater and actual slope movement instruments. Movements can be detected using antennas and radar type technology, lasers and optical instruments, inclinometers, GPS, extensometers (stretched string, etc), or even manual measurements with tape rules. Many of these technologies are very expensive and have highly specific uses and applicability depending on each site and circumstance. More recent and future technological developments may well provide for more affordable and more widely useful application of this type of method of landslide hazard mitigation. These systems require initial studies and construction costs along with ongoing maintenance and staffing resources. At-ready emergency response protocols and staff would be required for actual triggering of early warning detection systems.

The United Nations Environment Programme recently published a comprehensive document on the topic for numerous hazards, "Early Warning Systems, A State of the Art Analysis and Future Directions" (UNEP, 2012). As well, the International Consortium on Landslides and numerous geo-hazard conferences and organizations have written on the subject.

**Findings:**

Once an unacceptably high risk of debris flow hazard has been identified there are a number of potential issues which may be associated with the design, construction, maintenance and regulation of debris flow mitigation structures. These include:

- High capital cost.
- Lack of an adequate tax base in the protected area to meet high maintenance costs and costs of rehabilitation in the case of major events.
- Various design standards have been applied to historical mitigation works. There is a need to develop and adopt provincial standards, particularly where the works are intended to protect new development.
- The approval of residential development in debris flow hazard areas (*Local Government Act* and *Land Title Act*) may require an engineer's report certifying the land is "safe". However, this approval is not necessarily linked to any requirements for structural mitigation works (Section 82 of the *Land Title Act* was repealed in 2003). Under the current model, the need for structural works may only become apparent after the development has been approved and after an event occurs that brings forward new information or changes the landscape for the future.
- Regulation of ownership, operation and maintenance can be covered by the existing *Dike Maintenance Act*. However, the *Act* could be amended to include special provisions related to debris flow dikes.

- Orphan Works exist in several places in BC. As part of past emergency response and/or recovery work to historical debris flow events the province and other parties have funded or constructed non-standard works on numerous debris flow fans without setting up any ownership or maintenance arrangements. These orphan works currently represent a liability to the province and local governments.

As well, there are instances where new dikes and berms are desired for flood and landslide protection however the cost and long term ownership issues make for difficulty in constructing new works. The separation of roles between the province and local governments are clear in that the Province provides advice and legislative approvals while regional districts have the accountability to make assessments, fund and undertake necessary remedial works and monitor developing situations.

Emergency Management BC 's Strategic Business Services administers the Flood Protection Program which provides funding to assist with the design and construction costs for prescribed flood protection works. Projects qualifying for financial assistance are identified through a review of applications submitted by local authorities. As the focus of the program is to support flood mitigative works on waterways, landslides and debris flows mitigation works do not fall within the mandate of the program and are not eligible for funding.

**Recommendation 12:** FLNRO should complete its Terrain Stability Guidance Project to develop policies and other guidance material for staff working in Crown lands to ensure that terrain stability risks are managed on an appropriate basis.

**Recommendation 13:** The Province should identify standards for landslide mitigation works design and maintenance, as well as consider legislative changes to enable regulation of ownership and operation of landslide protection works using the model used for regulating flood protection works under the *Dike Maintenance Act.*

**Recommendation 14:** The Province and the Union of BC Municipalities should explore new funding models to better facilitate the ownership of orphan landslide and flood mitigation structures, and the construction of new flood and landslide protective measures.

## EMERGENCY RESPONSE AND RECOVERY

### RESPONSE

Communities in British Columbia can experience natural disasters such as landslides and debris flows throughout the year. Local governments often have critical local knowledge and expertise required to provide effective site level response and support for different emergencies. Therefore, legislation, regulations and program have been structured to support municipalities and regional districts in leading the initial response to emergencies and disasters in their communities. In the event of a significant landslide or similar event the local government, as required by the *Emergency Program Act*, will typically initiate a response through the activation of its emergency plan and directly controlling the resources under their jurisdiction for the purpose of emergency response and recovery.

Where required, the BC Emergency Response Management System (BCERMS) will be activated to coordinate provincial support to local governments upon request. BCERMS provides a consistent standard for Incident Command used by the Province. Many local government and other authorities also use BCERMS to guide their local emergency response efforts. Landslide emergency events response activities generally require cross-government provincial coordination and collaboration. Ensuring enhanced readiness and effective response activities require the assistance and participation of all stakeholders including senior levels of government, local government and individuals.

Emergency Management BC (EMBC) supports response activities by local authorities as per the *Emergency Program Act*. EMBC response actions include operation of the 24/7 Provincial Emergency Coordination Centre (PECC) and activation of regional Provincial Regional Emergency Operations Centres (PREOCs) and the PECC. If several ministries are involved in an emergency response, EMBC will coordinate an integrated provincial emergency management through the PREOCs and PECC.

Provincial legislation provides the legal authority for ministries to engage in response activities. The *Emergency Program Act* details roles and responsibilities of the province, provides parameters for declaring local or provincial emergencies and the emergency powers a declaration provides. The Emergency Program Management Regulation details the responsibilities and authorities of provincial Ministers, ministries, programs, and government corporations and agencies. Other relevant legislation may also be applicable depending on the specific event.

British Columbia's Comprehensive Emergency Management Plan (CEMP) aligns with the BC Emergency Response Management System (BCERMS). The CEMP (http://www.pep.bc.ca/hazard_plans/All-Hazard_Plan.pdf ) or All-Hazard Plan provides a detailed outline of the operational structure and responsibilities for a Provincial coordinated all-hazard response. A coordinated provincial response may include:

- Subject matter (professional) experts;
- Access to geographical information systems and mapping;
- Aviation resources for reconnaissance, surveying and planning; and,
- Provincial trained staff for deployment to assist local authorities.

The Emergency Program Management Regulation and All Hazards Plan identify the Ministry of Justice (EMBC) as the technical lead for landslides other than those affecting highways. MOTI takes the lead for coordinating the response to landslides that affect a highway. FLNRO is the provincial ministry primarily responsible for responding to debris avalanche and debris flow events involving Crown land.

### Coordinated Response Model Example – Kootenay Boundary Landslide Response Model

The smaller municipalities and regional district governments in the Kootenay Boundary Region do not have sufficient in-house experts to assist with landslide hazard identification and response during an emergency. Consequently, FLNRO regional staff members are usually involved directly and immediately with local governments in the response to all landslide events in the region wherever they occur.

Due to the high frequency of landslides in the Kootenays, sometime in the 1990's the Ministry of Environment regional Public Safety Section Head started organizing and maintaining a roster of landslide specialists with business and personal phone numbers to respond to landslide emergencies. As a consequence of organizational changes this function is now delivered by FLNRO. Landslide specialists are recruited from FLNRO, MOTI and occasionally a private consultant. At one time a Ministry of Energy, Mines and Natural Gas (MEMNG) geotechnical engineer was on the roster when the position was staffed in the Kootenays. Each spring, landslide specialists along with flood assessors and flood observers are provided with training and refresher sessions/opportunities to become familiar and comfortable with the emergency response system including the incident command system. The EMBC Emergency Manager and PECC response centers have access to this list of specialists via the Public Safety Section Head. The result is a 24/7 response capability.

Landslides, especially debris flows, often start in higher elevation Crown land managed by FLNRO and by forest licensees where logging is occurring. In the Kootenay Boundary Region, FLNRO has regional and district Landslide Standard Operating Procedures (SOP). The SOP provides direction to FLNRO and forest companies on how to report landslide events to reduce risk to people and property. The SOP identifies procedures to follow when a landslide reaches private property or highways. It requires prompt notification to the EMBC emergency response system.

Landslides often impact highway infrastructure. During these events efforts are made to establish a joint response with MOTI and FLNRO specialists in the same helicopter or vehicle for the initial reconnaissance trip. Sometimes the number of events and limited numbers of specialists preclude this but when it happens it provides for a well organized and coordinated response.

On occasion landsides originate from mining properties or mine access roads. While there currently is no MEMNG specialist on the landslide roster team, this year experience was gained towards establishing a coordinated response with MEMNG through Inspectors of Mines and MEMNG geotechnical engineers who are stationed elsewhere in the province.

The recent Johnsons Landing landslide provides an example on how the system works. The landslide occurred at approximately 10:37 am PDT on July 12, 2012. FLNRO staff received a call to investigate the site from the PREOC at 11:15 am. FLNRO staff were in a helicopter and on their way to the site from Nelson at 11:45 am, reaching Johnsons Landing at 12:20 pm. Upon arrival an initial assessment of the area was made from the air. Staff landed at the site and provided a report to the promptly deployed

Regional District Incident Commander at 12:50 pm. The helicopter then became an immediate valuable asset to ferry RCMP and other emergency responders across and onto the slide.

Similarly with the Fairmont Creek debris flow on Sunday, July 15, 2012, geotechnical and flooding specialists from FLNRO and operational staff from MoTI responded to the scene by helicopter within two hours of the event. Once at the site staff viewed the site on the ground and collaborated on the response with Regional District of East Kootenay emergency response staff who had set up a temporary Emergency Operation Center at the Windermere Fire Hall.

**Findings:**

Initial media and public reaction to the Johnsons Landing landslide was that unlike with a medical emergency, citizens may not be sure about whom to call in the case of a natural hazard emergency.

Some local governments may not have a 24-hour reporting number for public to utilize in the event of a landslide.

In the future, EMBC's 24 hour Emergency Coordination Centre (1-800-663-3456) may receive calls from the general public reporting concerns (i.e. muddy waters, restricted flows, etc.) however, there is not a clearly defined or supported provincial escalation process to assess the public calls and to respond or follow up by local government or provincial government staff.

The examination of the 2012 landslide events revealed that response and escalation issues are similar and related to Recommendations 4 and 5 of theTestalinden Dam Failure Review.

As part of a high functioning reporting and escalation process, a quick reference list or roster of key persons and contact numbers, with annual preparation meetings, has proven effective where utilized.

**Recommendation 15:** The provincial and local governments should update their websites and other information media to ensure they provide clear guidance to the public on emergency phone numbers and purposes of each call centers.

**Recommendation 16:** The Province, in collaboration with provincial ministries and local governments, should establish annually updated landslide and flood response rosters of trained persons in each region.

## RECOVERY

Following initial emergency response and the provision of search and rescue, and medical services to affected people at a site, provincial and local government emergency response staff collaborate to restore essential services, utilities and access. Typically, evacuation orders and declared states of emergency are maintained and adjusted as appropriate. In some situations sustained provincial incident management operations and support activities may be required over the long term to support community recovery and mitigation. The damages and response fees from a landslide can be very expensive for citizens and governments.

EMBC administers the Disaster Financial Assistance (DFA) Program which provides financial support to help Local Government Bodies and the private sector recover from disasters. The DFA program operates under the *Emergency Program Act* (the "Act") and the ensuing Compensation and Disaster Financial Assistance Regulation (the "Regulation"). The DFA program is obliged to provide compensation in compliance with this legislation. DFA eligibility criteria, as defined in the Act and the Regulation, have been applied consistently and fairly throughout the province since 1995. The Regulation can be found at http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/10_124_95

The Compensation and Disaster Financial Assistance Regulation details the financial assistance available to local government bodies and the private sector to help them respond to and recover from disasters.

For large costly provincial disasters, the Province (through EMBC) may request federal cost-sharing under Public Safety Canada's Disaster Financial Assistance Arrangements (DFAA). If DFA is approved, the Province can recover a portion of its disaster response and recovery costs including costs incurred by other ministries. The federal government provides emergency assistance to provinces when requested and justified.

## CONCLUSION

The fatal and damaging landslides in the interior of British Columbia in 2012 prompted this review of the most significant events to assess what factors contributed to the occurrence of the events, how they were responded to in early stages, how landslide hazard risks in BC are managed in general, and to identify any lessons that were learned. This review is structured around the four-pillar approach to hazard management which consists of preparedness, mitigation, response and recovery. As with other natural hazards, it is recognized that efforts made on landslide preparedness will significantly reduce the pressure on the other three pillars of landslide hazard management. The review also recognized the close ties between the management of and response to landslide and flood risks and events.

The review found that the landslide at Johnsons Landing, especially in terms of its magnitude and runout extents, was largely unpredictable, and that it was the first such incident to occur at this location in recorded history. In contrast, Fairmont Creek, Sicamous Creek and Hummingbird Creek had each experienced flooding and debris flow events in the past and were known hazard areas.

Overall the responses to the events in 2012 were well handled due to established and practiced emergency response plans and organized networks of prepared persons in local and provincial governments. However, the ability for the province to maintain even its current level of preparedness with in-house landslide specialists may be at risk.

Climate change models indicate that BC's climate appears to be changing in a manner which has the potential to increase the future frequency of landslide and flood events. At the same time there is ongoing pressure for additional development to be approved in areas vulnerable to landslide hazards.

This review recommends ways to improve and expand hazard mapping and other information, along with enhancing its accessibility and application by land use planners, developers and government decision makers.

Given the rapid onset of landslides and their general lack of advance warning, increasing public understanding and awareness of landslide hazards is an important step in avoiding activities which may increase the hazard and in reducing the number of activities which take place in hazard areas during risky times. The report contains recommendations to increase public education and awareness of landslides.

Some established communities are located in hazard areas where there are old mitigation dikes and berms which were constructed to protect the community. Often these works were built to an unknown standard and have been poorly or inconsistently maintained over time. In other communities it may be desirable to construct new and expensive landslide and flood mitigation structures but they are often too difficult for the local governments to fund, operate and maintain. Recommendations are made to standardize the design and construction of mitigative works, supplement existing flood protection regulations to enable them to be used to regulate landslide mitigation works, and to explore funding models that would better enable the construction and operation of protective works.

Landslide and flood emergency response can protect people and infrastructure best when communities are fully prepared and coordinated regionally. Recommendations are made to ensure all areas of the province are optimally ready to respond when a landslide emergency occurs.

Finally it is recommended that incorporating the findings of this review into the mandate of the existing cross ministry Landslide Policy and Mitigation Working Group would help to assess, prioritize and implement these recommendations appropriately and efficiently.

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# APPENDIX A - SUMMARY OF RECOMMENDATIONS FROM THE CORONER'S REPORT INTO THE DEATH OF ELIZA WING MUN KUTTNER (2008)

The BC Coroners Service completed its report in 2008 into the death of Eliza Wing Mun Kuttner who was killed in a landslide on January 19, 2005 in North Vancouver. The report contained twelve recommendations, nine of which were directed at the Province. The following is a verbatim summary of the Coroner's recommendations.

**Coroner's Recommendations**

1. That the Province of British Columbia develop a comprehensive Landslide Hazard Management Strategy focused on prevention and mitigation of risk.

2. That the Province of British Columbia, with input from local governments, coordinate the development of provincial Landslide Safety Levels for proposed and existing residential developments.

3. That the Province of British Columbia consider establishing a legislated provincial standard for how landslide assessments for existing and proposed residential development should be conducted, by referencing Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) *Guidelines for Legislated Landslide Assessments for Proposed Residential Development*, in pertinent regulations.

4. That the Province of British Columbia coordinate the development of a provincial guideline to assist local governments in recognizing when an assessment of landslide risk should be carried out.

5. That the Province of British Columbia coordinate the development and administration of provincially standardized training and education for approving officers, building inspectors, local government planners and councils, in identification of landslide hazard and risk, and interpretation of risk assessments prepared by qualified professionals.

6. That the Province of British Columbia work jointly with local governments to develop an Internet based databank which would allow for depositing, storage, universal access, retrieval and effective use of landslide hazard and risk information, in order to facilitate informed decision-making and effective risk management by all stakeholders, including regulatory bodies, qualified professionals, property owners and the public.

7. That the Province of British Columbia provide leadership and work jointly with local governments towards the development of a strategy for prioritizing, collection, storage and use of landslide hazard information.

8. That the Province of British Columbia create an inter-ministry technical working group tasked with overseeing the implementation of recommendations arising out of this report.

9. That the Union of British Columbia Municipalities, and its members, consider developing a framework through which external qualified professionals are retained to examine local governments' internal procedures for reviewing landslide assessment reports, evaluating landslide risk and implementing mitigation measures in a timely manner.

10. That the Union of British Columbia Municipalities create a forum where local governments can share their knowledge and lessons learned with respect to natural hazard risk prevention and mitigation.

11. That the Province of British Columbia, jointly with the Association of Professional Engineers and Geoscientists of British Columbia, consider the development of a provincial standard, referenced in legislation, which sets specific qualification requirements for professionals conducting landslide analyses and assessments. A consideration should also be given to the development of a professional designation for qualified professionals conducting landslide analyses and assessments.

12. While it is acknowledged that members of the Association of Professional Engineers and Geoscientists of British Columbia are obligated, in relation to work they carry out on behalf of their clients, to keep confidential all information unless disclosure is authorized by the clients, the APEGBC may wish to encourage its members, and their clients, to support initiatives related to the development and maintenance of a publicly accessible landslide information databank.

# APPENDIX B - SUMMARY OF RECOMMENDATIONS FROM THE REVIEW OF THE TESTALINDEN DAM FAILURE (2010)

Following the failure of Testalinden Dam south of Oliver in June 2012, David Morhart, Deputy Solicitor General, conducted an independent review of the circumstances surrounding the failure of and the BC's Dam Safety Program. In his report released in July 2012 Mr. Morhart made 12 recommendations directed to various provincial ministries. The following is a full list of his recommendations.

**Recommendation 1:** The Ministry of Environment should review its record keeping practices to ensure that proper and complete files are kept and archived on all dam structures, including details of water licenses, transfers of appurtenancy, and correspondence with owners.

**Recommendation 2:** The Ministry of Environment should review the historical warnings about the conditions of the dam and any actions taken to hold the owner(s) responsible for inspection and maintenance as per the Dam Safety Regulation.

**Recommendation 3:** The Ministry of Environment should consider implementing signage at all dam locations to make it clear to passersby that the structure is a dam and to provide direction and emergency contact information, including contact information for the owner, to report any issues observed.

**Recommendation 4:** Emergency Management BC should work with local officials, local and provincial policing and first response agencies, and ministry provincial and regional offices to provide a quick reference list of key contact numbers, focused on "who to call when," and develop an alert matrix to quickly escalate priority issues.

**Recommendation 5:** The Ministries of Forests and Range and Environment should review their call-out procedures to ensure that compliance and enforcement personnel are familiar with the issues escalation process noted in Recommendation 4, as they are often among the first individuals aware of local incidents.

**Recommendation 6:** Building on Recommendation 4, Emergency Management BC should continue to coordinate awareness and encourage training and orientation for local emergency response agencies, local government officials, and provincial government agency personnel to prepare for emergency situations. Local governments are required to have emergency plans in place, per the *Emergency Program Act*, and Emergency Management BC can assist with the development and testing of these plans.

**Recommendation 7:** The Ministry of Environment should review and update the Dam Safety Regulation to incorporate best practices on dam safety found in other jurisdictions. This would include but is not limited to an update to the downstream consequence classification tool, inclusion of a requirement for the owner to develop an emergency preparedness plan for the structure, and consideration of further regulatory oversight to enhance enforcement and compliance.

**Recommendation 8:** The Ministry of Environment should complete its Rapid Dam Assessment Project and update its consequence rating system accordingly to determine priority areas in need of attention. The Ministry should develop an action plan to address those areas needing immediate attention and schedule appropriate follow up based on overall findings.

**Recommendation 9:** The Ministry of Environment should continue its work in building a robust Dam Registry, with linkages through to geo-reference tools which can be utilized by other partners.

**Recommendation 10:** The Ministries of Environment and Transportation and Infrastructure need to continue to ensure effective communication and information sharing of community development and transportation initiatives as they relate to downstream consequences for dam safety. This information should be periodically reviewed on a priority basis to account for any historical changes. In addition, other ministries such as Forests and Range and Energy Mines and Petroleum Resources should be linked in to any consequence review initiatives to ensure that all appropriate information is considered on a periodic basis.

**Recommendation 11:** The Ministry of Environment should ensure the consistent oversight and regulation of all water related structures, including licensing, standards and risk assessments, by working with the ministries that have the legislative authority. The Ministry should build a business case to rationalize the types of resources and supports that would be needed to accomplish this recommendation.

**Recommendation 12:** The Ministry of Environment should continue and expand its education and awareness initiatives with dam owners and should work with Emergency Management BC to ensure that dam owners are working directly with local government officials in tying together their emergency preparedness and response plans. In addition, the Ministry of Environment should publish an annual Dam Safety Program report on its public website for the information of the public.

# APPENDIX C - PACIFIC CLIMATE IMPACTS CONSORTIUM – CLIMATE CHANGE TECHNICAL SUMMARY

Arelia T. Werner, Hydrologist. September 7th 2012

**Frequency and Severity of Triggering Weather Events**

Hydro-climate induced terrain stability events can be triggered by extreme precipitation, snowmelt, rain-on-snow and peak streamflow. The frequency and severity of these hydro-climatic events may be increasing with climate change and with them the risk of terrain instability. Several studies have noted increases in the magnitude and frequency of heavy precipitation in BC and the Pacific Northwest over the second half of the past century. Both global and higher resolution regional climate models project future increases in the intensity and frequency of extreme precipitation events. When rain falls on a pre-existing snowpack, large flood events, known as rain-on-snow (ROS) events can result. These events have been increasing at high elevations and decreasing at low elevations in the Western United States. Peak streamflow has been occurring earlier and has decreased in magnitude for many, primarily snowmelt-driven, rivers in BC over the last few decades. This trend is projected to continue with future warming.

**Background**

*Extreme Precipitation*

Trends in extreme precipitation are subject to inter-annual and inter-decadal variability (*Trenberth et al.*, 2007). Nevertheless, there is evidence for a global trend of increasing extreme precipitation (*Min et al.*, 2011; *Trenberth et al.*, 2007). In areas where total accumulation remains constant or even decreases, changes in frequency of heavy events can still occur (*Trenberth et al.*, 2007). For example, the frequency of heavy precipitation events in south-western Canada showed increasing trend from 1950 to 1995, even though total accumulation had a slight negative trend (*Stone et al.*, 2000). Significant increases in heavy rainfall events occurred during May, June and July over this period (*Stone et al.*, 2000). In BC south of 55 °N, from 1910 to 2001, there is evidence of a trend in increasing heavy precipitation (*Groisman et al.*, 2005). Stations in southern BC show significant increases in two extreme indices: (1) the highest annual 5-day precipitation accumulation, and (2) the number of very wet days annually (the number of days with precipitation greater than the 95th percentile) over 1950-2003 and 1900-2003 (*Vincent and Mekis*, 2006). There is a projected increase in the magnitude and frequency of the 20-year return value annual maximum precipitation, $P_{20}$, in BC for 2046-2065 and 2081-2100 versus 1981-2000 with the possible exception of south-eastern BC (*Kharin et al.*, 2007; *IPCC*, 2012). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) report (*IPCC*, 2012) states that based on Global Climate Model (GCM) projections there is *high confidence* that there will be a likely increase in *heavy precipitation days* (when precipitation is greater than the 95th percentile) and *heavy precipitation* *contribution* (when the fraction from precipitation is greater than the 95th percentile). Work with Regional Climate Models (RCMs) in the Columbia River Basin (*Murdock and Sobie*, 2012) and Georgia Basin (*Murdock et al.*, 2012) supports these findings.

### *Rain-on-Snow*

The severity of rain-on-snow (ROS) events depends on the magnitude of precipitation, the ratio of rainfall versus snowfall, the elevation of the freezing level, and the volume and areal extent of the snowpack (*McCabe et al.*, 2007). There has been a trend towards more precipitation falling as rain instead of snow over 1949 to 2004 in response to warming across the western United States (*Knowles et al.*, 2006). Our understanding of historical trends in ROS events in the region are based primarily on studies in US Pacific Northwest. They show a trend of increasing numbers of ROS events at high elevation and decreasing numbers of ROS events at low elevations; however, there is some regional variability (*McCabe et al.*, 2007). Changes in ROS events are correlated with changes in temperature. Generally, the number of ROS events has decreased with increasing temperature due to reduction in snow and thereby the reduced opportunity for ROS. However, the correlation decreases with increasing elevation because higher elevations are still cold enough to maintain snow in spite of temperature increases (*McCabe et al.*, 2007). April 1st snowpack volume decreased for the majority of snow monitoring sites in BC over the longer term (1951-2007) and responses were mixed for the more recent 1978-2007 period, suggesting that there is strong decadal-to-decade variability (*Rodenhuis et al.*, 2009).

### *Peak Streamflow*

Streamflow in BC can be rainfall, snowmelt, rainfall/snowmelt or snowmelt/glacial-driven. Peak-flow events occur during different times of the year in each regime; e.g., in winter in rainfall-driven regimes and in spring/summer in snowmelt-driven regimes. These peak-flow events often contribute to flood risk. Under climate warming, where less precipitation accumulates over winter as snow, spring peak-flow volumes generally decrease and occur earlier. For the most part, negative trends in annual maximum daily flow, or peak-flow, have been observed for BC over the last 30-50 years of the 20th century, especially in the south (*Zhang et al.* 2001; *Cunderlick and Ouarda*, 2009). The date of annual maximum daily mean streamflow has trended to earlier in the season on average over this time (*Zhang et al.* 2001). In a 2009 update to Zhang et al.'s (2001) analysis, Rodenhuis et al. (2009) found that average daily maximum streamflow decreased for the majority of rainfall-dominated streams on the South Coast and was mixed (-8% to 23%) for rainfall/snowmelt-dominated regimes in the same region over 1976-2005. In snowmelt-dominated regimes in the Okanagan and Columbia River basin, daily maximum streamflow decreased and increased, respectively. In snowmelt/glacial-driven regimes maximum annual daily streamflow decreased in regions with less glacier cover and increased in those with more glacial cover (*Rodenhuis et al.*, 2009). Changes in snowpack accumulation are resulting in earlier spring peak-flow in the Okanagan region (*Pike et al.* 2010). In the Fraser and Columbia the snowmelt/glacial systems show increased peak-flows and lower recessional flows, perhaps because they are transitioning from glacier-dominated regime towards snow-dominated regimes with an earlier freshet and faster recessional period (*Pike et al.* 2010). Flood risk has also been affected by climate variability associated with the Pacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO) over the 20th century and is particularly high when ENSO and PDO are in phase (*Hamlet and Lettenmaier,* 2007). Also, Jefferson et al. (2011) found that a key control on flooding in maritime mountainous regions in the Pacific Northwest is the amount of watershed susceptible to rain-on-snow events. Where warming increases the percent of watershed impacted by rain-on-snow events, flood magnitude has increased, but where warming has decreased the percent of watershed impacted by rain-on-snow, flood magnitude has decreased.

Average peak-flows in the Fraser River at Hope are projected to decrease, while average annual flows are projected to increase modestly for the 2070-2099 period (*Morrison et al.* 2002). Hydrologic projections throughout the Fraser River basin suggest that mean annual peak discharge will decrease by mid-century (*Shrestha et al.* 2012). Loukas et al. (2002) found that the magnitude of annual maximum flood peaks will be significantly reduced in the Illecillewaet River in the Columbia basin due to precipitation falling more as rain than snow, snowpack decreasing and snowmelt occurring earlier in the season. In the snowmelt/glacial-driven Columbia above Donald, peak-flows are projected to occur in June instead of July and are projected to not increase (*Bürger et al.* 2011). In a study by Sobie et al. (In prep.), peak-flows in the majority of sub-basins in the Columbia, including the Columbia above Donald, are projected to increase in the 2020s, 2050s and 2080s. Observational data, GCMs, downscaling technique, hydrologic model and representation of glaciers differ between these two studies. Thus, diverging projections in peak-flow are related to the different methodologies applied. Increased magnitude and more numerous storm events are projected to result in increasingly frequent and larger storm-driven streamflow (including peaks) in the winter, in rain-dominated regimes in BC (*Pike et al.* 2010).

**Uncertainties**

The statistical evaluation of changes in extremes, such as trend, is difficult. This is due to challenges in securing datasets long enough for the analysis of these rare events, especially in the case of extreme precipitation. Projecting future changes to extreme precipitation becomes difficult when translating the change in precipitation modelled at the coarse-scale, such as several 100 km a side per grid cell in a GCM or ~50km a side per grid cell in an RCM, to the local-scale where land-slides and debris flows may be triggered. However, while projections of increased frequency and severity of extreme precipitation differ quantitatively between different climate models, qualitatively results are in agreement. Capturing and classifying rain-on-snow events can be highly uncertain in complex topography with a sparse station network. Physically-based models run at high-resolution are therefore required to investigate future projections of changes in ROS events. Such work is limited by the computational expense of running these models and the paucity of observational snow data. Lastly, changes in peak-flows depend upon the nature of the river basin, leading to a diverse response over large regions like BC. However, the majority of basins in BC are snowmelt-driven and have shown decreasing trends in peak-flow. Projected changes to peak-flow, especially in glaciated basins, are sensitive to calibration approach, observational data, the selected GCMs, downscaling technique, hydrologic model and the representation of glaciers.

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