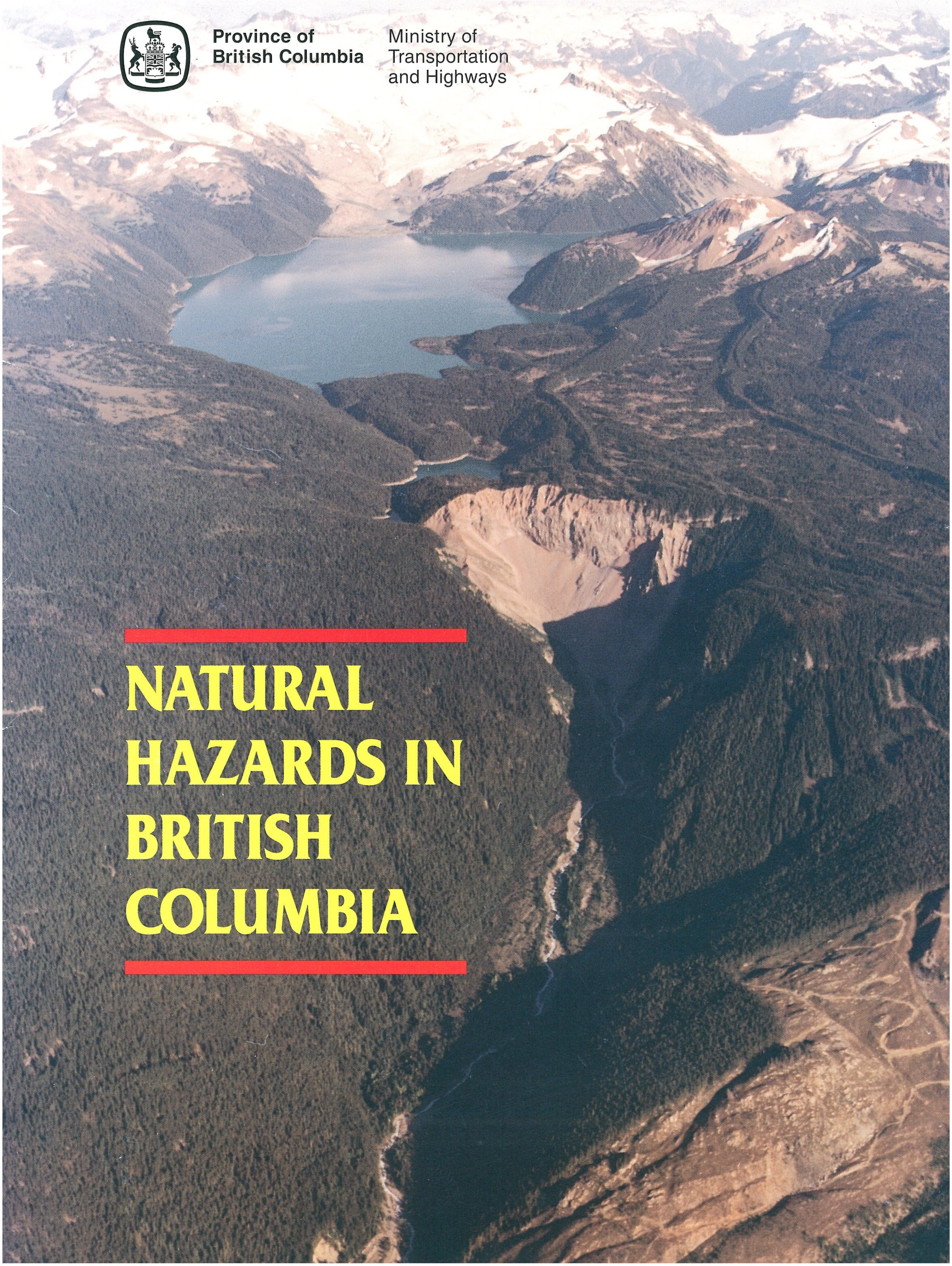
Province of
British Columbia

Ministry of
Transportation
and Highways



NATURAL HAZARDS IN BRITISH COLUMBIA

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Ministry of Transportation
and Highways

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GEOTECHNICAL AND MATERIALS ENGINEERING BRANCH
Victoria, British Columbia

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For further information and distribution information, please contact:

Geotechnical and Materials Engineering Branch
British Columbia Ministry of Transportation and Highways
4A - 940 Blanshard Street
Victoria, British Columbia
V8W 3E6

Telephone: (604)-387-1881
Fax: (604)-356-0624

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Permission to reproduce Biogeoclimatic Zones of British Columbia (Map 2.5), a portion of the Seismic Map of Canada (Map 2.6), and the Index of Designated Floodplain Areas in the Province of British Columbia (Table C.1) was obtained from the British Columbia Ministry of Forests, Canada Department of Natural Resources and British Columbia Ministry of Environment, Lands and Parks, respectively.

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Cover Photo:
The Barrier, source of the Rubble Creek Landslide, Garibaldi

Title Page Photo:
Alberta Creek Debris Flow, Lions Bay, February 1983

SECTION 1: INTRODUCTION

This manual describes the types of natural hazards that exist in British Columbia. It replaces an earlier document entitled "Geological Hazards Evaluation for Highway Personnel." The intent of the manual remains the same, to assist Ministry personnel, particularly those involved with development approvals, in recognizing hazardous areas. The range of hazards described is quite wide and many are included only for completeness. Some of the hazards will have no particular reference to the development approval process.

As legislated by the British Columbia Land Title Act (1979) and outlined in the Subdivision Policy and Procedures Manual, the Ministry regulates the subdivision of land outside municipal boundaries. Where the presence of **landslip (landslide), erosion, rockfall, snowslides** or **avalanche** are suspected on a proposed subdivision, the site requires an investigation by a professional engineer experienced in natural hazards. Advice from the Regional Geotechnical and Materials Engineer should be sought. Assistance in determining the need for an investigation and for review of reports is available.

Although regulation of development within a floodplain is within the jurisdiction of the Ministry of Environment, Lands and Parks, **flooding** is included in this manual because it must be considered during the subdivision approval process.

Because the recognition of land subject to flooding is not always straight forward, all subdivision applications should be referred to the local representative of the Ministry of Environment, Lands and Parks.

The evaluation of snow avalanche hazards for the Ministry is the responsibility of Snow Avalanche Programs, Maintenance Services Branch, who should be contacted if snow avalanche hazards are suspected.

The consequences of not recognizing the existence of geological hazards at a site or not realising the future potential can be very serious. There could be loss of life or severe property damage and the Ministry could be exposed to legal claims and costly settlements. On the other hand, requiring subdivision applicants to retain a professional engineer to carry out an investigation that is not required places an unnecessary financial burden.

This manual was prepared under the direction of the Terrain Evaluation Staff of the Geotechnical and Materials Engineering Branch, Victoria, who can be contacted for questions and comment, particularly with regard to natural hazards. Regional Geotechnical and Materials Branch staff are available to provide guidance on natural hazard investigations and provide advice on site specific conditions.

A subdivision constructed on a glacial lake silt terrace in the Okanagan

1.1 Natural Hazards

This manual specifically addresses those hazards that commonly occur in British Columbia:

- **landslides including rockfall**
- **snow avalanches**
- **subsidence**
- **flooding**
- **erosion**
- **problem soils**

Natural hazards are natural processes that have been occurring since the Earth was formed. Besides geological processes such as earthquakes, volcanic activity, erosion and the effect of gravity on unstable rock and soil slopes, natural hazards include the atmospheric processes of wind, rain and snow. For the purposes of this manual flooding and snow avalanches are included but the hazards associated with wind, rain and snow directly are not.

From a scientific viewpoint natural hazards may be fascinating, but are usually only of interest to us when we, and/or our property, get in the way, get involved and are affected, or in other words, when there is a consequence to the event and someone or something is put at risk. The ultimate consequences can include:

- **settlement or differential settlement of a structure**
- **partial to total destruction of a structure**
- **partial to total loss of ground**
- **personal injury or loss of life**

Hazard multiplied by consequence equals risk.

Hazard x Consequence = Risk

With no hazard, or no consequence, there is no risk. Often, without knowing, we tend to accelerate natural geological processes and therefore geological hazards and the associated risks. Sometimes, we unknowingly increase the consequences of those hazards.

Natural hazards are becoming an increasingly important aspect of land use management. This situation has resulted from an increasing amount of development taking place in areas susceptible to natural hazards. As the population increases, land use is expanding from relatively easy and relatively geologically safe areas to develop, to more difficult and less safe areas. For example, individuals and developers are moving from valley bottoms to hillslopes and into mountainous terrain.

British Columbia is composed of a great variety of physical landforms, many of which are quite spectacular. Along with this spectacular scenery, we have inherited a province which is one of the most geologically active areas in the world. For example, the western portion of British Columbia is located on the "Pacific ring of fire"; approximately 50% of the province is considered to be mountainous, and many portions of the province receive more than 2,500 mm of precipitation each year in the form of rain and snow.

As one might expect in a province as large and as diverse as British Columbia, natural hazards include a wide variety of types, from those that occur infrequently but can have a large impact, such as earthquakes and volcanoes, to those that occur frequently but have a relatively smaller impact. The emphasis of this manual is on the latter type: landslides, snow avalanches, subsidence, flooding, erosion, and problem soils.

Natural hazards, and therefore their recognition, are complex. It is impossible to include all geologically hazardous conditions and situations found throughout the province. This manual provides limited generalized information and only a few examples of each type for illustrative purposes. You must be aware that there may be hazardous conditions and situations that are more or less obvious than those presented herein. If in the field you are in doubt as to whether or not a hazard exists, ask for assistance from Geotechnical and Materials Engineering staff.

Some hazards are region-specific, such as the abandoned subsurface coal mine workings in the Nanaimo area, and the glacial lake silts in the interior of the province. These types of hazards can be addressed in more detail in region-specific training seminars.

Some of the concepts presented herein have been simplified. They may not be rigorously technically correct, but are intended to communicate the important aspects of natural hazard recognition.

1.2 Recognizing Natural Hazards

There are many different ways to reduce the impact of natural hazards on people and their property. Property owners could, for instance, build a massive water proof wall around their houses to protect them from potential flood damage. Alternatively, the houses could be built on higher ground, away from any potential flood waters. The first is an example of **active mitigation,** where the hazard is reduced by doing something. The second is an example of **passive mitigation,** where the hazard is reduced by avoidance. By using passive mitigation, the hazard is usually reduced at a much lower cost, and with much less potential for damage, injury or death, than by using active mitigative methods. The potential hazard must, however, be recognized before it can be avoided. And it must be recognized before development!

This manual is intended to help recognize areas where natural hazards have occurred, are occurring or have the potential for occurring, so they can be avoided. Recognizing hazards is like detective work. It involves looking for clues by reviewing any available background information such as maps, airphotos and available reports, and by visiting the area.

During the assessment, the following questions should be asked:

- **Is there evidence of past or ongoing natural hazards in the area?**
- **Are the conditions in the area suitable for natural hazards to occur?**

When assessing an area, do not restrict your investigation to the boundaries of the area of interest, but also look beyond:

- **upslope**
- **downslope**
- **along slope**
- **elsewhere in the watershed**
- **in neighbouring areas with similar conditions**

It is often outside the study area where clues to the relative safety of the area under scrutiny are found.

In addition, the investigation must not only be limited to existing ground conditions. With time, natural geological processes can change the ground conditions. And when combined with the changes that can be done by individuals and developers, relative safety can change. For example, a hillslope may have been naturally stable for many years, however, should natural groundwater conditions change, or during development should some of the land be cleared, slopes undercut or water added by irrigation or from septic tanks, the existing natural stability may be reduced. If reduced enough, a landslide can result. An awareness of conditions or activities that can initiate a natural hazard, or can create the potential for a hazard, is just as important as being able to recognize an existing natural hazard.

One other point should be kept in mind. Will the proposed development have any impact on the geological conditions off the property, and could these changed conditions lead to a hazard elsewhere?

If, during an application review process, any evidence that a natural hazard has occurred, exists or has the potential for occurring, a "red flag" should go up and the Approving Officer should be notified. In some cases the Approving Officer will refer the situation to the Regional Geotechnical and Materials Engineer.

1.3 Probability of Occurrence

Although relatively frequent, if compared to the occurrence of earthquakes and volcanoes, the hazards addressed in this manual do not occur frequently enough so that they can be predicted with any accuracy. To help overcome our inability to predict hazards accurately, probability is used. **Probability is the chance that a particular event will occur.** For the purpose of subdivision approval, we are asked to think in terms of:

> **a 10% chance of occurrence of a particular hazard over a 50 year period.**

What does this really mean? Lets look at a "rolling the dice" analogy.

If we had a 6-sided die (the singular of dice), and we rolled it once we would have a 1 in 6, or 16.7%, chance of rolling a six. Therefore we would have a 5 in 6, or 83.3%, chance of not rolling a six. If we rolled the same 6-sided die 5 times we would have an extremely small chance of rolling a six every time.

But the chance of not rolling a six every time is not that small, in fact, mathematically, it is 40%. Therefore the chance of rolling a six **at least once** in those 5 rolls is 100% - 40%, or 60%. In other words, there is "a 60% chance of rolling a six at least once in 5 rolls".

If we had a 475-sided die, and we rolled it 50 times, using the same mathematics as above, we would have "a 10% chance of rolling a '475' **at least once** in 50 rolls". Consider a particular hazard to be the die, and the die is rolled once a year. Therefore there is a 1 in 475 chance of the particular hazard occurring in a year (the annual probability), and there is "a 10% chance of occurrence of the particular geological hazard over a 50 year period".

With regards to floods and snow avalanches, they are often referred to as a "200 or 300 year return period event". This means the annual probability is 1 in 200 or 300. Using the same mathematics as above, in any 50 year period, there is a 22% chance of a 200 year flood occurring and a 15% chance of a 300 year snow avalanche occurring.

Chance of rolling a specific number on a die at least once in "n" rolls = $1-(1-(1/\text{number of sides on the die}))^n$

Chance of occurrence = $1-(1-1/s)^n$

Example of rolling a 6-sided dice (s=6)

Number of roll ("n")	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
Chance of rolling a six on any roll	1/6 =16.7%	1/6	1/6	1/6	1/6
Chance of not rolling a six on any roll	5/6 =83.3	5/6	5/6	5/6	5/6
Chance of not rolling a six on <u>every</u> roll	5/6	25/36	125/216	625/1296	3125/7776 = 40%
Chance of rolling a six <u>at least once</u> in "n" rolls	1/6	11/36	91/216	671/1296	4651/7776 = 60%

Example of rolling a 475-sided dice (s=475)

Number of roll ("n")	Roll 1	Roll 20	Roll 30	Roll 40	Roll 50
Chance of rolling a 475 on any roll	1/475	1/475	1/475	1/475	1/475
Chance of rolling a 475 <u>at least once</u> in "n" rolls	0.2%	4.1%	6.1%	8.1%	10.0%

1.4 Organization of the Manual

The remainder of the manual is divided into four sections:

Section 2: Landscapes of British Columbia briefly reviews the main factors that influence the location, frequency and severity of natural hazards in British Columbia:

- **physiography**
- **bedrock geology**
- **surficial geology**
- **precipitation/climate**

Although **earthquake activity** and **volcanic activity** are not directly addressed as natural hazards in this manual, they do have an influence on the hazards which are discussed, and therefore are included in Section 2.

Section 3: Natural Hazards reviews the common hazards of the province **(Table 1.1)**.

Each hazard is discussed under the headings:

- **Brief description**
- **Impact of the hazard upon people and property**
- **Human impact upon the hazard**
- **Recognition of existing and potential hazards**

Section 4: Check List provides a summary and two check lists for the recognition of common natural hazards in British Columbia.

The **Appendices**, at the end of the manual, contain additional information, a glossary of terms and references, for those who wish to delve deeper into the landscapes of British Columbia and natural hazards.

- **Appendix A: More Information on Landscapes**
- **Appendix B: Physiographic Summary of Landscapes**
- **Appendix C: More Information on Natural Hazards**
- **Appendix D: Glossary of Terms**
- **Appendix E: References**

For reference, **Map 1.1** shows the Highway Regions and Districts, and Regional and District offices.

Table 1.1

Landslides	-Rock falls / topples -Debris / Earth falls -Rock slumps -Earth slumps -Rock slides -Debris slides -Rock flows -Debris flows -Earth flows -Earth creep / solifluction -Rock creep
Snow Avalanches	-Snow avalanches
Subsidence	-Subsidence due to underground activities by people -Subsidence due to natural removal of underground materials
Flooding	-Stream / river flooding -Lake / reservoir flooding -Alluvial fan flooding -Flooding due to storm surges and tsunamis
Erosion	-Channel erosion (bed and bank) -Lake / reservoir shoreline erosion -Coastal shoreline erosion
Problem soils	-Glacial lake silts -Glacial marine and marine clays -Organic soils -Soils in discontinuous permafrost and alpine permafrost -Made ground (fill)

No.	REGION/DISTRICT	OFFICE
	REGION 1: SOUTH COAST	Burnaby
4	Howe Sound	North Vancouver
6	Lower Mainland	New Westminster
7	Fraser Valley	Chilliwack
	REGION 2: THOMPSON-OKANAGAN	Kamloops
8	South Okanagan	Penticton
13	Okanagan-Shuswap	Vernon
14	Nicola	Merritt
15	Thompson	Kamloops
16	South Cariboo	100 Mile House
	REGION 3: KOOTENAYS	Nelson
9	Kootenay Boundary	Grand Forks
10	Central Kootenay	Nelson
11	East Kootenay	Cranbrook
12	Selkirk	Revelstoke

No.	REGION/DISTRICT	OFFICE
	REGION 4: CENTRAL/NORTH EAST	Prince George
17	Central Cariboo	Williams Lake
18	North Cariboo	Quesnel
19	Fort George	Prince George
20	Robson	McBride
21	South Peace	Dawson Creek
22	North Peace	Fort St. John
23	Nechako	Vanderhoof
	REGION 5: NORTH WEST	Terrace
24	Lakes	Burns Lake
25	Bulkley Nass	Smithers
26	Skeena	Terrace
28	Stikine	Dease Lake
	REGION 6: VANCOUVER ISLAND	Nanaimo
1	South Island	Victoria (Saanich)
2	Central Island	Nanaimo
3	North Island	Courtenay

MAP 1.1 HIGHWAY REGIONS, DISTRICTS AND OFFICES

NOTES

SECTION 2: LANDSCAPES OF BRITISH COLUMBIA

The main factors that influence the location, frequency and severity of natural hazards in British Columbia are:

- **physiography**
- **bedrock geology**
- **surficial geology/permafrost**
- **precipitation and climate**
- **earthquake activity**
- **volcanic activity**

Snow avalanches, for instance, are more common in areas of high relief which receive large amounts of snow fall. Flooding is more common in low lying areas. The occurrence of rock falls increases with earthquake activity and volcanic activity. This section provides an overview of the above factors for the province, and forms the foundation for the discussions of specific hazards in **Section 3.**

Appendix A, at the end of the manual, provides more information about the factors discussed in Section 2. **Tables B.1 to B.18 in Appendix B** summarize these factors by Physiographic Region:

Mountainous terrain in the Coast Mountains

Terraced valley bottom terrain in the Interior Plateau

2.1 Physiography

British Columbia is composed of a wide variety of landforms, or **physiographic units**, such as:

- **mountains / ranges**
- **highlands**
- **foothills**
- **plateaus**
- **lowlands**
- **trenches**
- **depressions**
- **fiords**
- **plains**

A brief description of these common landforms is included in **Appendix A, Table A.1.** Several physiographic units are grouped together to form **physiographic regions** and several regions are grouped together to form **physiographic systems.** The province is composed of 18 regions grouped into four major northwest-southeast trending systems **(Table 2.1 and Map 2.1).** From west to east these systems are the: Western System, Interior System, Eastern System and Interior Plains System.

The **Western System** includes the two parallel mountain belts along the west coast of the province: the discontinuous St. Elias Mountains - Queen Charlotte Mountains - Vancouver Island Mountains, and the continuous Coast Mountains - Cascade Mountains. These two mountain belts are separated by the Hecate Depression in the north and the Georgia Depression in the south.

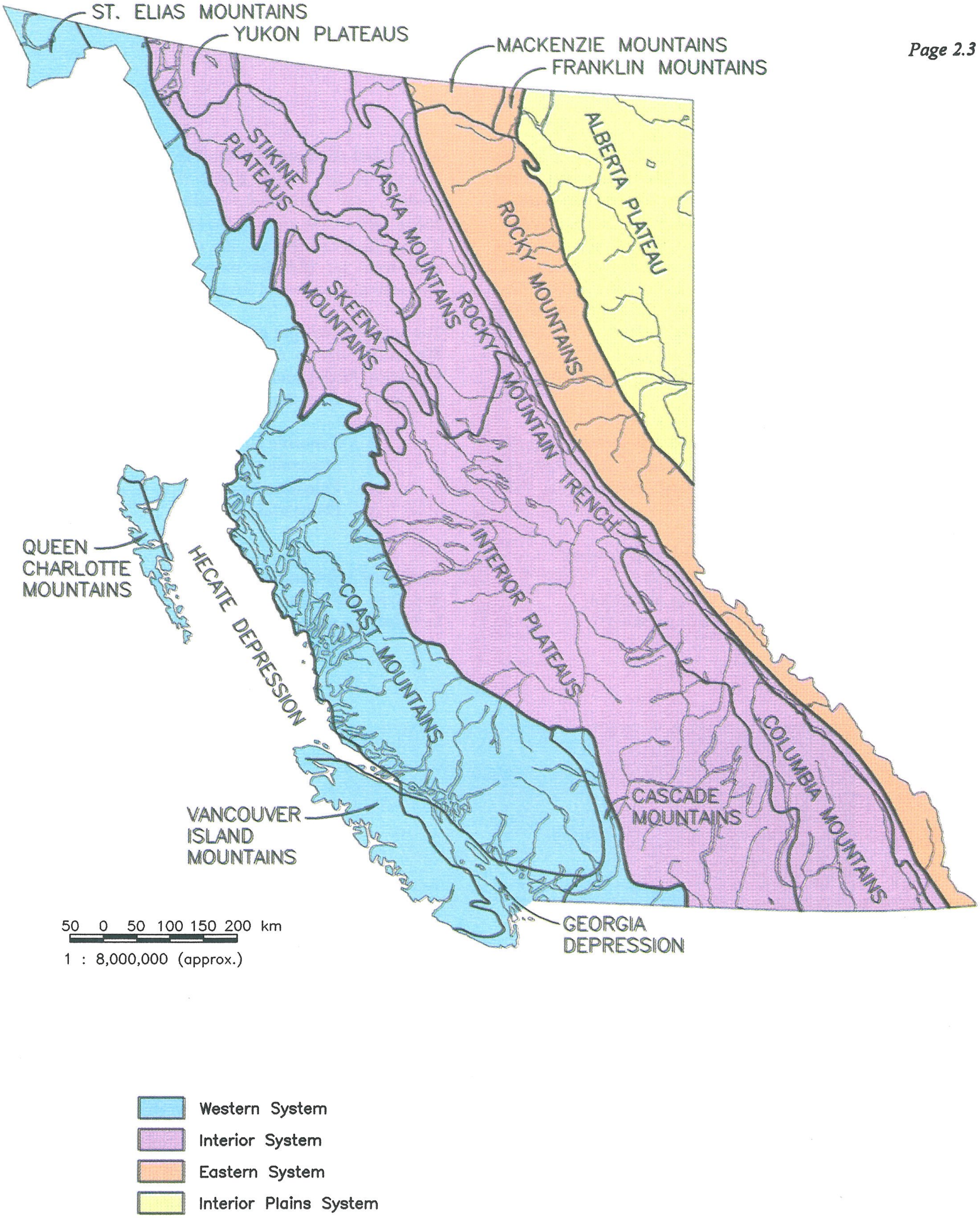
The **Interior System** is dominated by the large plateaus of interior British Columbia and the bordering mountains ranges. The main plateau areas are the Yukon Plateaus, Stikine Plateaus, and Interior Plateaus. Major mountain ranges include the Kaska Mountains and the Skeena Mountains in the north and the Columbia Mountains in the south. The boundary between the Interior System and the adjacent Eastern System is the Rocky Mountain Trench.

The **Eastern System** is dominated by rugged mountains, the Mackenzie and Franklin mountains in the far northern portion of the province, and the Rocky Mountains.

The **Interior Plains System** is represented in the north-eastern portion of British Columbia by the Alberta Plateau.

Table 2.1

Physiographic System	Physiographic Region
Western System	St. Elias Mountains Queen Charlotte Mountains Vancouver Island Mountains Hecate Depression Georgia Depression Coast Mountains Cascade Mountains
Interior System	Yukon Plateaus Stikine Plateaus Skeena Mountains Kaska Mountains Interior Plateaus Columbia Mountains Rocky Mountain Trench
Eastern System	Mackenzie Mountains Franklin Mountains Rocky Mountains
Interior Plains System	Alberta Plateau



MAP 2.1 PHYSIOGRAPHIC SYSTEMS AND REGIONS
(adapted from Holland, 1964 and Mathews, 1986)

2.2 Bedrock Geology

The bedrock geology and geological history of British Columbia are quite complex. The eastern part of the province was formed in place, whereas the western part is made up of a number of "well-travelled" fragments of the Earth's crust, formed elsewhere and added onto the original west coast of North America. These additions and the associated folding and faulting have given British Columbia a strong northwest-southeast structural trend. Although interesting from a geological point of view, the details of the geological history are beyond the scope of this manual.

Map 2.2 is a "simplified" bedrock geology map that shows the distribution of the major rock types and indicates their general structural characteristics. The major rock types are:

- **igneous intrusive** (e.g. granite)
- **volcanic** (e.g. basalt)
- **sedimentary** (e.g. sandstone)
- **metamorphic** (e.g. gneiss)

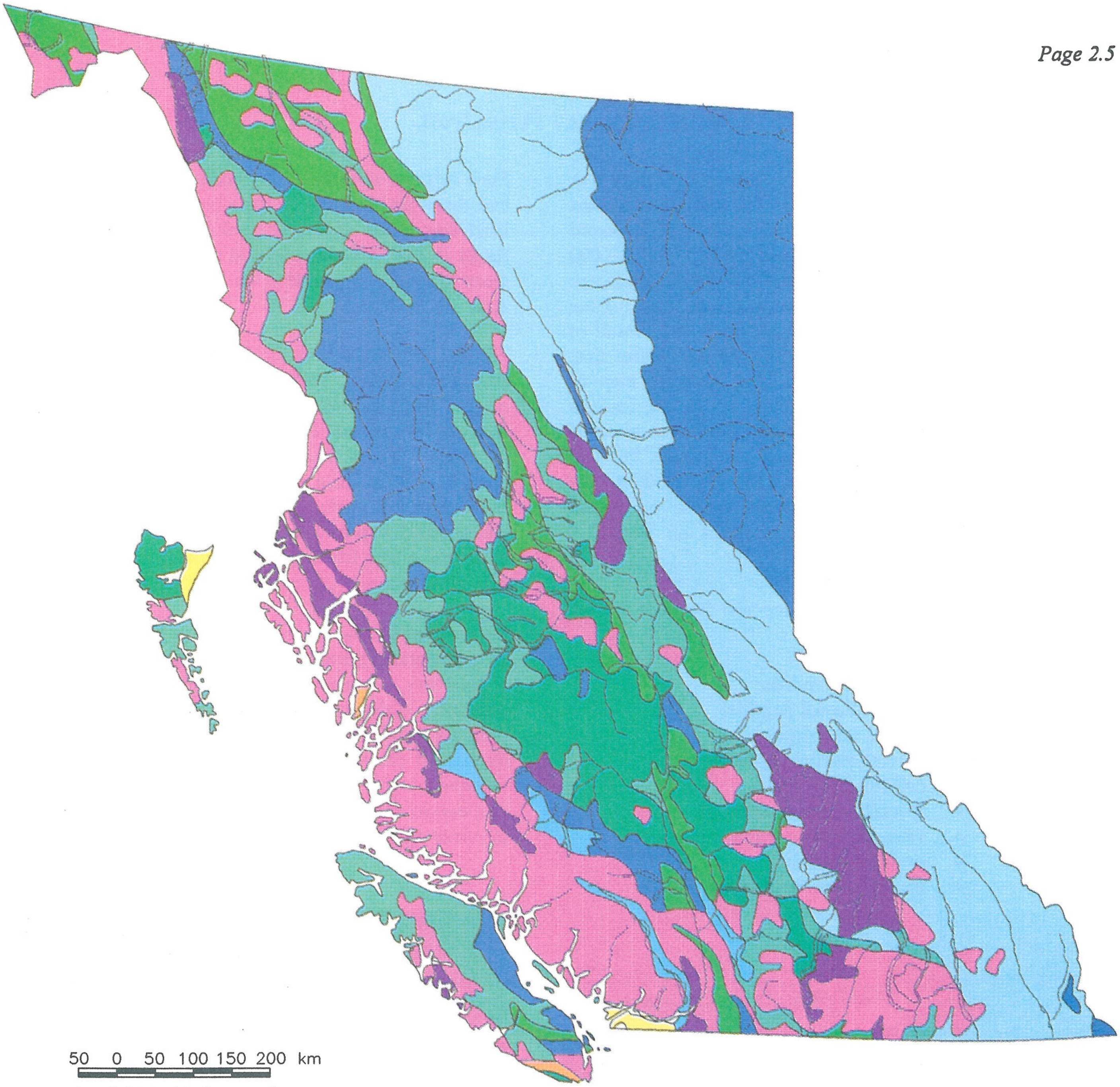
The general structural character indicates whether the bedrock is flat lying, gently dipping, or steeply dipping, and whether the rocks have been folded and/or faulted. In general, the steeper the dip and the more folded and faulted, the potentially weaker the rock mass is, and the more susceptible it is to weathering, erosion and landslides.

The approximate ages of the rocks are also shown on **Map 2.2**, only to differentiate one period of rock formation from another. From youngest to oldest, the rocks are from the:

- **Cenozoic Era**
- **Mesozoic Era**
- **Paleozoic Era**
- **Proterozoic Era**

Additional information about the major rock types, their typical physical characteristics and their ages are included in **Appendix A, Tables A.2 and A.3.**

Gently dipping sedimentary bedrock in the Mackenzie Mountains



50 0 50 100 150 200 km

1 : 8,000,000 (approx.)

- **Cenozoic**, flat lying volcanic rocks, minor sedimentary rocks
- **Tertiary**, flat or gently dipping sedimentary rocks
- **Upper Mesozoic to Tertiary**, folded and faulted sedimentary rocks
- **Mesozoic**, flat or gently dipping sedimentary rocks
- **Mesozoic**, folded and faulted sedimentary and volcanic rocks
- **Lower Mesozoic**, folded and faulted volcanic rocks
- **Paleozoic**, folded and faulted volcanic and sedimentary rocks
- **Proterozoic to Paleozoic**, folded sedimentary and minor volcanic rocks
- **Metamorphic rocks** – high grade – various ages
- **Igneous intrusive rocks** – various ages

MAP 2.2 SIMPLIFIED BEDROCK GEOLOGY
(adapted from Tipper, 1981)

2.3 Surficial Geology / Glacial Features / Permafrost

During the last million years, British Columbia was covered several times by a mass of glaciers and mountain ice sheets. However, the last major period of glaciation, roughly between 25,000 and 10,000 years before present, produced the current landscape of the province. Along with bedrock, most of the surface material covering the province is the result of glacial and post-glacial activity. At the present time there is no "simplified" surficial geology map of British Columbia. **Map 2.3**, is a "glacial features map" of the province and highlights larger areas of glacial lake deposits, the limit of marine flooding following glaciation, and the distribution of permafrost conditions. The distribution of present day glaciers and icefields is shown on **Map 2.5** (biogeoclimatic zones).

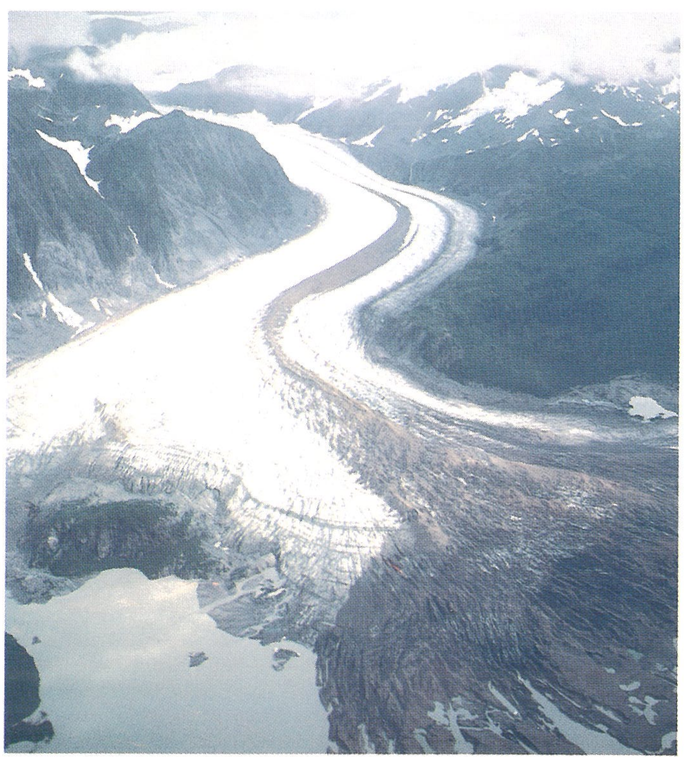
Common surficial geology deposits found in British Columbia include:

- **morainal deposits**
- **glacial fluvial deposits**
- **glacial lake deposits**
- **glacial marine deposits**
- **colluvial deposits**
- **fluvial (alluvial) deposits**
- **recent lake and marine deposits**
- **organic deposits**
- **recent volcanic deposits.**

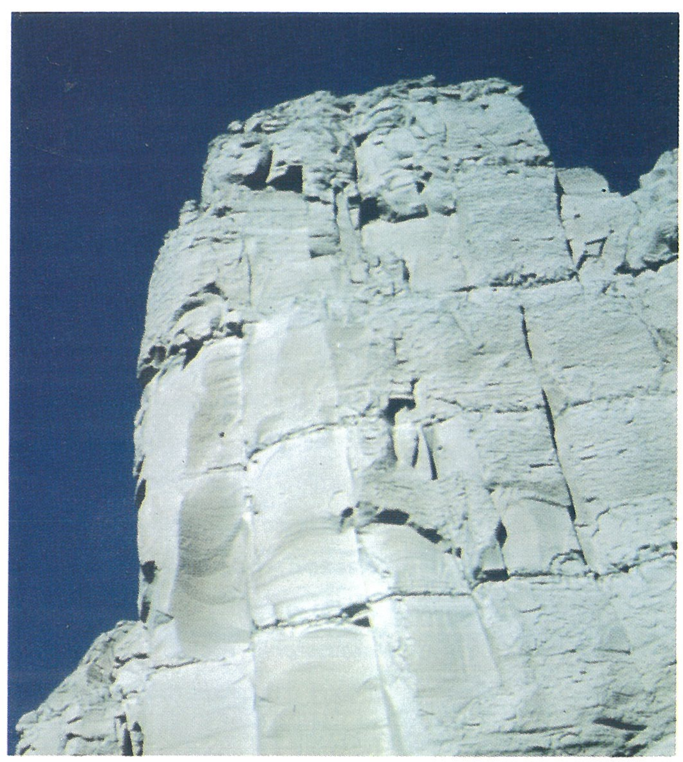
Each surficial material is deposited in a different way and therefore each has its own typical character. A brief description of all the surficial geology deposits found in British Columbia, and some of their typical characteristics, is included in **Appendix A, Table A.4.**

Glacial lake deposits are composed primarily of silt, fine sand and clay. Where ocean water flooded parts of the land following glaciation, **glacial marine deposits** composed of clay and silt soil can be expected. These occur in relatively concentrated areas of the province as shown on **Map 2.3.** The other surficial geology deposits are generally not concentrated deposits and are therefore difficult to show on a simplified map. Surficial deposits can also occur layered one on top of another.

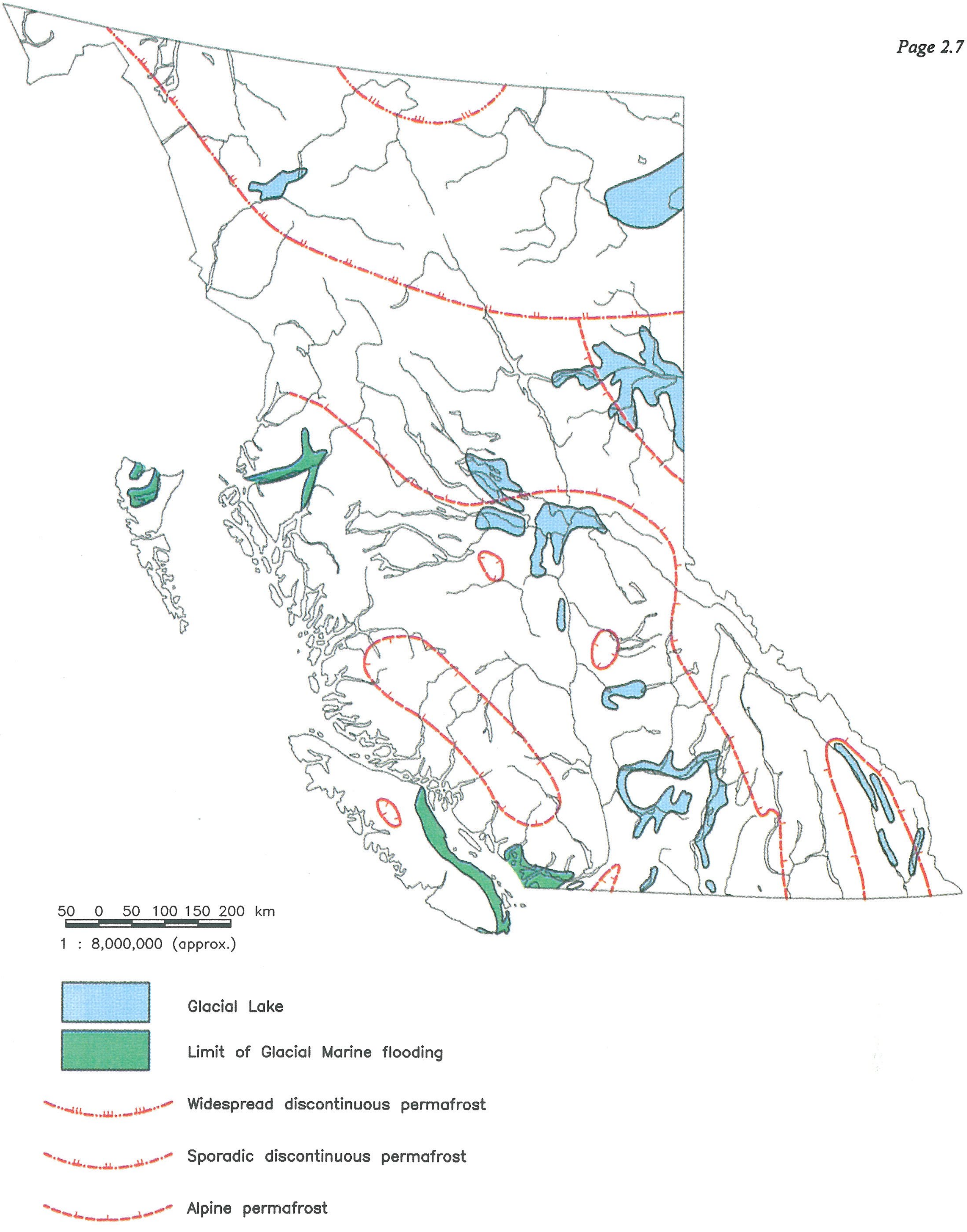
Permafrost is "the thermal condition in soil or rock of temperatures persisting below 0 degrees Celsius for at least two consecutive winters and the intervening summer. Water and ground ice may or may not be present". In the **discontinuous permafrost** zone, permafrost can be **widespread** or **sporadic**, existing together with areas of unfrozen ground. Discontinuous permafrost also exists throughout the province at higher elevations as **alpine permafrost.**



A present day glacier in the St. Elias Mountains



Glacial lake deposits in the Interior Plateaus



MAP 2.3 GENERALIZED GLACIAL FEATURES AND PERMAFROST
(adapted from Prest et al, 1967 and French, 1989)

2.4 Precipitation / Climate / Biogeoclimatic Zones

Map 2.4 shows the **mean annual precipitation** for the province grouped into 5 zones: >2,500 mm, 1,000 to 2,500 mm, 500 to 1,000 mm, 300 to 500 mm and less than 300 mm per year. Generally the greater the mean annual precipitation, the higher the likelihood of landslides, flooding and erosion. Other important factors not shown on **Map 2.4** include **rainfall intensity** (the amount of rain that falls in a given time); the proportion of **rainfall to snowfall**, and the occurrence of **rain falling on snow**.

British Columbia's precipitation, as is its climate, is controlled by its location adjacent to the Pacific Ocean and the topography made up of a series of northwest-southeast trending mountain belts. The dominant air movement is eastwards, with moist air and storms, generated over the Pacific Ocean, moving inland across successive mountain ranges, plateaus and valleys.

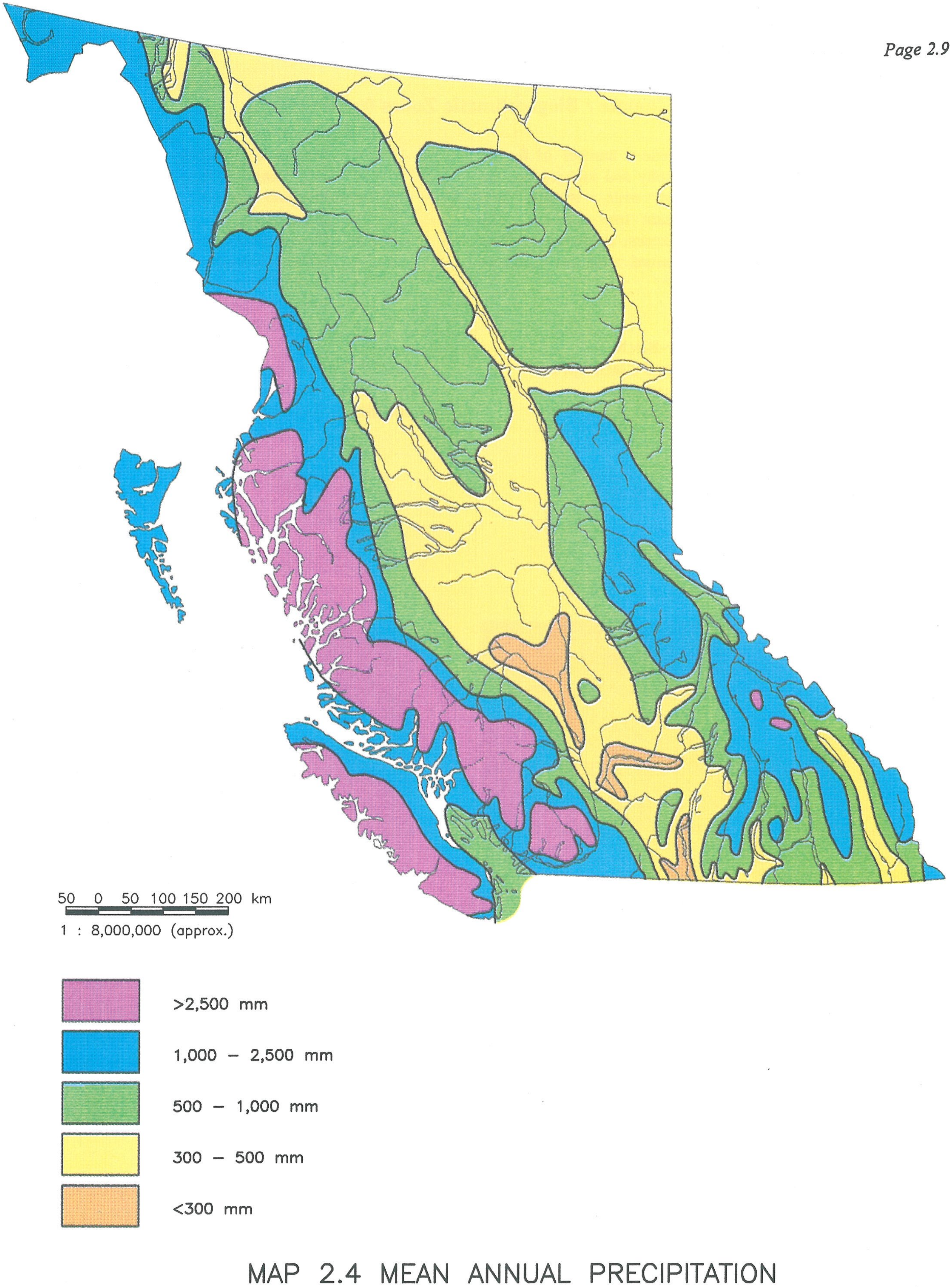
The region west of the crest of the **Western Physiographic System** is dominated by warm, moist Pacific air. Much of this region receives more than 2,500 mm of precipitation annually and is the wettest part of Canada. Winter precipitation near sea level along the coast is predominantly rain, with increased amounts of snow with elevation. Winter rains can be very intense. Thick snowpacks are common at higher elevations. During the summer there is much less rain and relatively long periods of fair weather.

From the crest of the Western Physiographic System and eastward across the **Interior Physiographic System** the climate is characterized by strong contrasts. Precipitation is controlled partly by the maritime air masses that have lost much of their moisture while crossing the western portion of the Western System. Precipitation is more evenly distributed throughout the year than on the coast, although the proportion of snow to rain is greater. Local rain shadows and topography determine the regional distribution. The valleys in the north receive 300 to 500 mm, whereas some valleys in the south receive less than 300 mm of precipitation each year, which is less than the potential amount that can be evaporated. Greater amounts of precipitation fall on the northern plateaus and mountains, 500 mm and more, with 50% to 70% occurring as snowfall.

The Columbia Mountains within the Interior Physiographic System, and the Rocky Mountains within the **Eastern Physiographic System** have similar precipitation. Both areas receive in the order of 1,000 to 2,500 mm annually. Air temperatures decrease northwards and with elevation, and therefore snow dominates in the more northerly and the higher mountainous areas. Approximately 50% of the precipitation occurs as snowfall in the southern Rockies. This figure increases to 70% in the north.

The **Interior Plains Physiographic System** lies east of the Rocky Mountains and therefore has the most continental climate of the province. Precipitation is moderate, averaging 300 to 500 mm annually, most of which occurs during the summer.

A summary of climatic details, including monthly and yearly rainfall, snowfall, and daily extremes, for most settlements in British Columbia are contained in the Environment Canada, Atmospheric Environment Service publication "Canadian Climate Normals (1961-1990): British Columbia" (Environment Canada, 1993). An example of such information for Nanaimo and Nelson is provided in **Appendix A, Table A.5.**



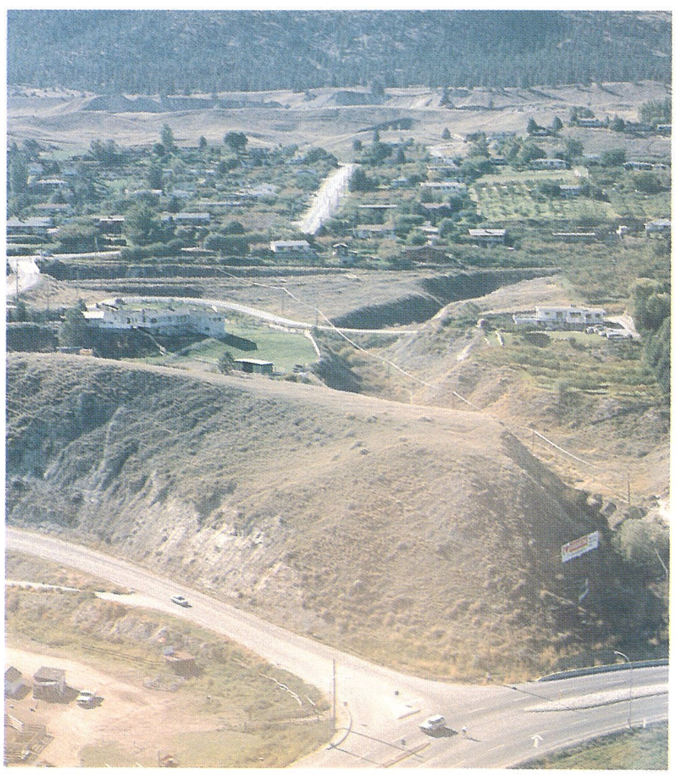
MAP 2.4 MEAN ANNUAL PRECIPITATION
(adapted from Farley, 1979)

2.4 Precipitation / Climate / Biogeoclimatic Zones (continued...)

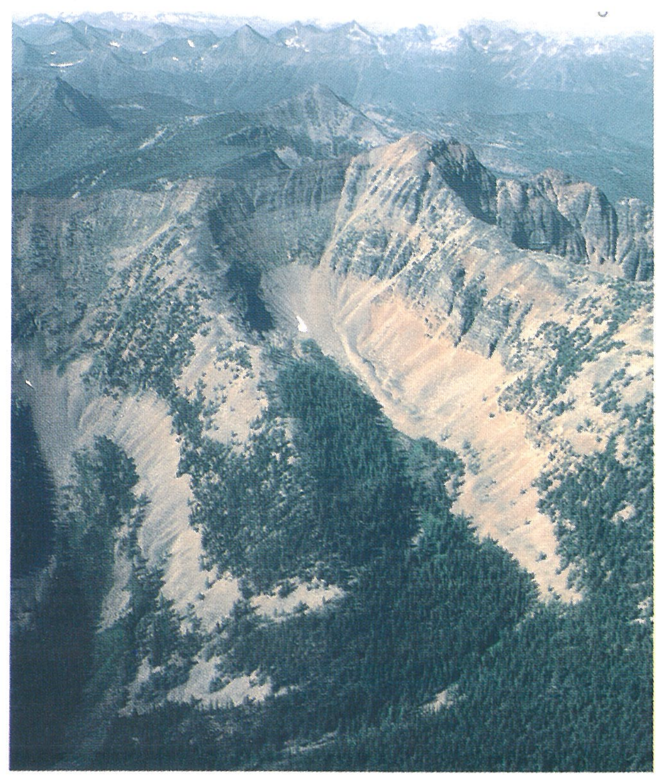
Biogeoclimatic zones combine a number of factors including climate, physiography and topography, the growing characteristics of soils, wildlife and vegetation including dominant tree species. The province is divided into 14 zones, as shown on **Map 2.5**, which are generally named after the dominant tree species found in the zone:

- **Alpine Tundra**
- **Spruce-Willow-Birch**
- **Boreal White and Black Spruce**
- **Sub-boreal Pine-Spruce**
- **Sub-boreal Spruce**
- **Mountain Hemlock**
- **Engelmann Spruce-Subalpine Fir**
- **Montane Spruce**
- **Bunchgrass**
- **Ponderosa Pine**
- **Interior Douglas-Fir**
- **Coastal Douglas-Fir**
- **Interior Cedar-Hemlock**
- **Coastal Western Hemlock.**

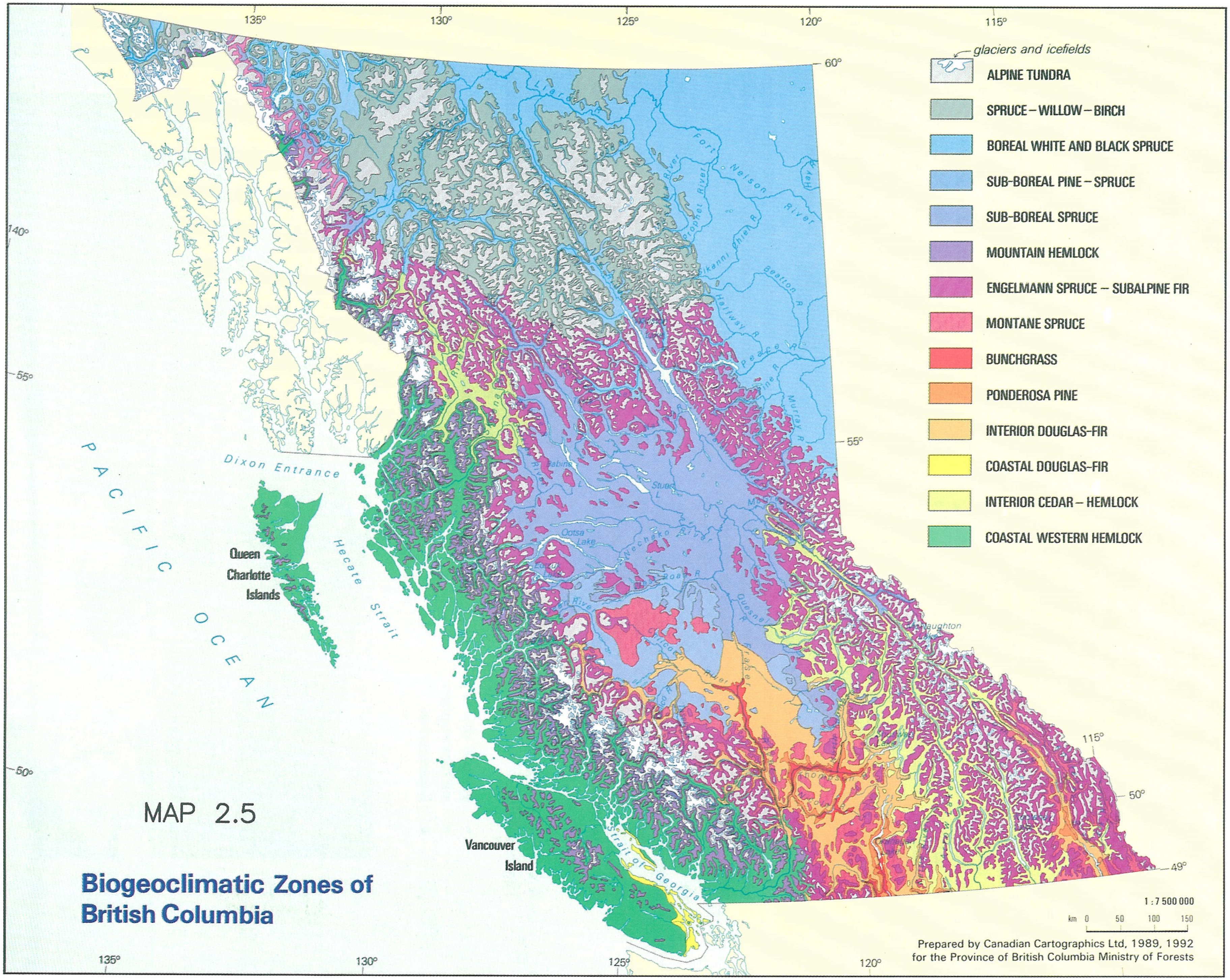
A brief description of the characteristics of each zone, pertinent to geological hazards, is included in **Appendix A, Table A.6.**



Terrain in the Bunchgrass biogeoclimatic zone



Alpine Tundra and Engelmann Spruce-Subalpine Fir biogeoclimatic zones



MAP 2.5

Biogeoclimatic Zones of British Columbia

2.5 Earthquake Activity

The crust of the Earth is not solid, but made up of many different **tectonic plates**. Earthquakes are caused when stress, building up within rocks due to the movement of these plates, is released as a sudden jolt. Rocks slide past each other along **faults** causing the ground to vibrate. The position on the ground surface directly above the fault where slip first occurs is called the **epicentre**. The **magnitude** of an earthquake is a measure of the energy released during the earthquake. It is measured by instruments. The **intensity** of an earthquake is a subjective measure of the effects of the shaking and damage at a given location. These terms and measurements are described further in **Appendix A, Tables A.7 and A.8.**

Because of British Columbia's location on the west coast of North America and its proximity to active tectonic plates in the region, parts of the province have experienced numerous earthquakes in the past. **Map 2.6** shows the earthquakes, with magnitudes 3 or greater, recorded up to the end of 1988. Magnitude 3 is generally the smallest earthquake that can be felt by humans. The dates and magnitudes of some of the larger earthquakes recorded in the British Columbia region are summarized in **Appendix A, Table A.9**.

A number of hazards can result from an earthquake. These include:

- **ground shaking**
- **surface rupture**
- **liquefaction**
- **landslides and snow avalanches**
- **tsunamis**
- **regional tilting and subsidence.**

The amount of damage depends upon many factors. These include:

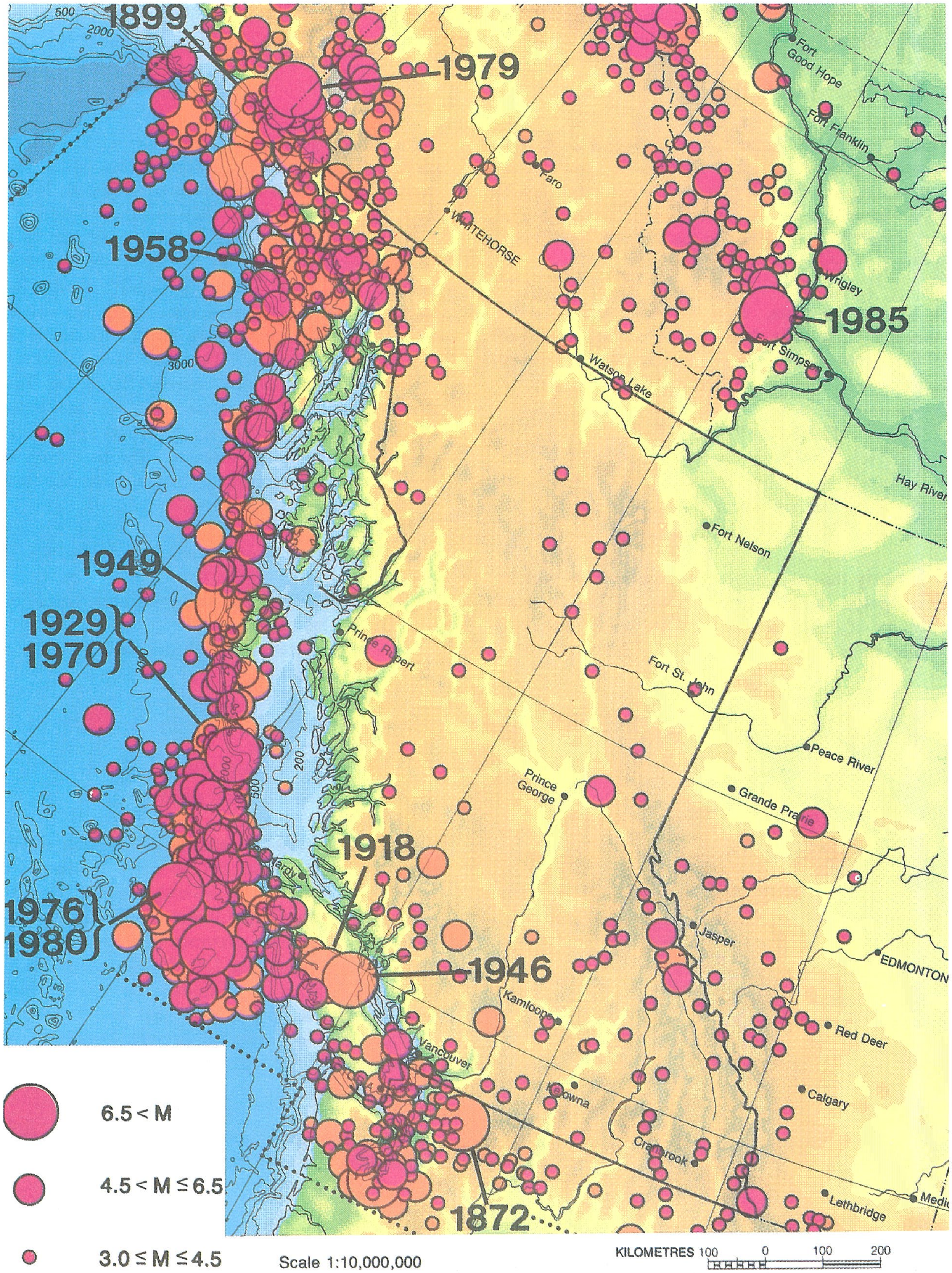
- **magnitude**
- **distance from the epicentre**
- **duration of ground shaking**
- **topography of the area**
- **bedrock and surficial geology underlying the site**
- **type, design and construction of structure**
- **time of day of the earthquake**

The types of hazards and the factors affecting the amount of damage, are described further in **Appendix A, Tables A.10 and A.11.**

Based upon past and predicted earthquake occurrence, the National Building Code (1990) has grouped all communities in British Columbia into **earthquake zones** numbered 0 to 6 based upon the expected peak ground acceleration. The higher the number, the more severe the potential earthquake hazard. Specific design criteria for structures are required for each earthquake zone. A discussion of these criteria is beyond the scope of this manual. The earthquake zones for the Ministry Regional and District offices are summarized in **Appendix A, Table A.12.**

Earthquake risk is not usually considered as part of the subdivision approval process.

A school in Alaska heavily damaged in the 1964 Alaska earthquake



MAP 2.6 EARTHQUAKES OF MAGNITUDE 3 OR GREATER TO THE END OF 1988 (from Anglin et al, 1990)

2.6 Volcanic Activity

Volcanoes are low frequency-high magnitude natural hazards on the West Coast. That is, they don't occur frequently, but when they do they have a great impact on the inhabitants. Just remember the sort of impact that Mount St. Helens had on the State of Washington in 1980!

In British Columbia, there are approximately 100 volcanoes that have been active in the past two million years. These are grouped into five broad volcanic belts shown on **Map 2.7**:

- **Garibaldi Volcanic Belt**
- **Anahim Volcanic Belt**
- **Alert Bay Volcanic Belt**
- **Stikine Volcanic Belt**
- **Wrangell Volcanic Belt**

It is likely that any future volcanic activity will be concentrated within these belts. The general character of these volcanic belts are briefly described in **Appendix A, Table A.13**.

Based on the geology and chemistry of the volcanic magma, or molten rock, volcanoes can either be an **explosive** (eruptive) type, such as Mount St Helens, or a **lava** (flow) type, such as the volcanoes in Hawaii. The most recent explosive volcano in the province erupted from Mt. Meager, about 150 km north of Vancouver in the Garibaldi Volcanic Belt, approximately 2,300 years ago. It spread volcanic ash across much of southern British Columbia and into southern Alberta. The most recent lava type volcano in the province occurred from the Tseax River Cone, near the Nass River in the Stikine Volcanic Belt, approximately 200 years ago. This is the youngest Canadian volcano. The lava from this event flowed approximately 20 km down the Tseax River valley to the Nass River.

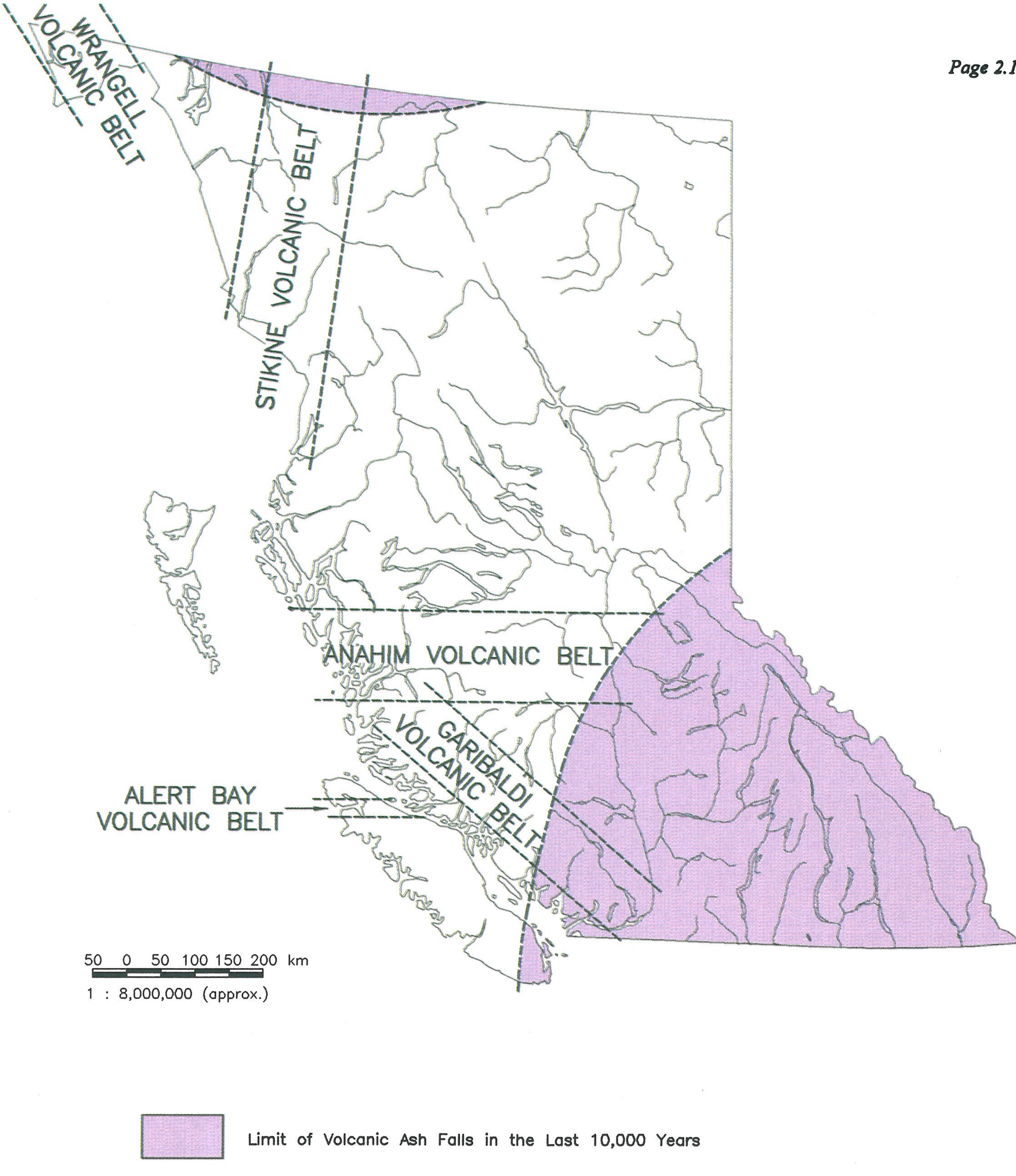
Hazards that result from volcanic activity include:

- **earthquakes and ground deformation**
- **lava flows**
- **ejected material (projectiles)**
- **ash falls**
- **ash flows**
- **landslides**
- **tsunamis**
- **atmospheric effects**
- **acid rain and gases**

The impact of these hazards decreases with distance away from the event, but in some instances, the impact can be felt up to several hundred kilometres away. For example, the limits of ash falls that have blanketed parts of the province over the past 10,000 years are shown on **Map 2.7**. Most of these ash falls originated from volcanoes in neighbouring Washington, Oregon, Alaska and the Yukon. A summary of the geological hazards associated with volcanic activity is included in **Appendix A, Table A.14**.

Subdivision approvals do not consider the possibility or occurrence of a volcano.

Mount St. Helens, State of Washington, 1980



MAP 2.7 VOLCANIC BELTS AND EXTENT OF ASH FALLS
(adapted from Hickson, 1991)

NOTES

SECTION 3: NATURAL HAZARDS

This section of the manual specifically addresses those natural hazards that occur relatively frequently in British Columbia:

- **landslides including rockfall**
- **snow avalanches**
- **subsidence**
- **flooding**
- **erosion**

Where appropriate, most of the above hazards are subdivided further based on type of material, type of movement, where they occur, and/or how they occur (**Table 3.1**). Each geological hazard is discussed under the headings:

- **Brief description**
- **Impact of the hazard upon people and property**
- **Human impact upon the hazard**
- **Recognition of existing and potential hazard**
  - **(i) evidence of past or ongoing hazards**
  - **(ii) conditions suitable for hazards**

The subsection on **problem soils** discusses geological hazards from the viewpoint of a number of geological materials whose geological hazards are significant in British Columbia. These soils are discussed under the headings:

- **Brief description**
- **Distribution**
- **Potential geological hazard**

Table 3.1

Landslides	-Rock falls / topples -Earth falls -Rock slumps -Earth slumps -Rock slides -Debris slides -Rock flows -Debris flows -Earth flows -Rock creep -Earth creep / solifluction
Snow Avalanches	-Snow avalanches
Subsidence	-Subsidence due to underground activities by people -Subsidence due to natural removal of underground materials
Flooding	-Stream / river flooding -Lake / reservoir flooding -Alluvial fan flooding -Flooding due to storm surges and tsunamis
Erosion	-Channel erosion (bed and bank) -Lake / reservoir shoreline erosion -Coastal shoreline erosion
Problem soils	-Glacial lake silts -Glacial marine and marine clays -Organic soils -Soils in discontinuous permafrost and alpine permafrost -Made ground (fill)

A house destroyed by a debris flow

3.1 Landslides

Introduction

Simply defined, a **landslide** is the movement of a mass of rock, debris or earth down a slope. Other terms commonly used are **mass movement, slope instability,** and **terrain instability**. The following paragraphs present a simplified classification of landslides in British Columbia, briefly describe and illustrate the types of material and movements involved, and summarize the causes and effects of landslides. Each of the 11 types of landslides that are common to the province are addressed and illustrated in the following subsections.

There are many different ways to classify landslides. For this manual, the **landslide classification** is based on **type of material and type of movement (Table 3.2).**

Table 3.2: Classification of common British Columbia landslides

Material / Movement	Bedrock	Predominantly Coarse Grained Soils (Debris)	Predominantly Fine Grained Soils (Earth)
Falls / topples	Rock falls / topples	Debris falls	Earth falls
Slides			
Rotational	Rock slumps		Earth slumps
Planar	Rock slides	Debris slides	
Flows	Rock flows	Debris flows	Earth flows
Creep	Rock creep		Earth creep / solifluction
Complex	Rock fall-flows Rock slide-flows	Debris slide-flows	Earth slump-flows

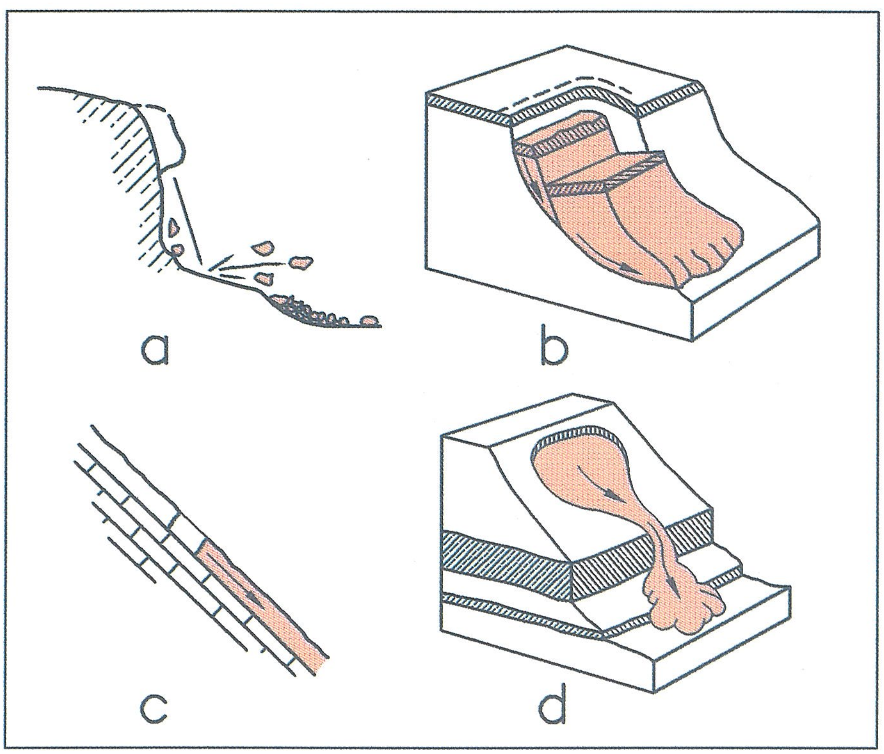


Figure 3.1: Types of Movement (a) fall, (b) rotational slide, (c) planar slide, (d) flow

Types of Movement (refer to **Figure 3.1**)

Falls take place mainly through the air by free-fall, bouncing, or rolling (Figure 3.1a). **Topples** consist of the rotation of a unit of rock or soil about some pivot point. Falls and topples usually occur rapidly.

Slides are classified as either rotational or planar, depending upon the shape of the failure plane. **Rotational slides**, also referred to as slumps, involve movement along a rotational failure plane (Figure 3.1b). Often the failure plane, a plane of weakness, did not exist before the rotational slide occurred. **Planar slides** involve movement along a plane (Figure 3.1c). Often the failure plane or plane of weakness existed before the planar slide occurred. Most rotational and planar slides occur rapidly, however, some earth slumps can occur slowly, over many days or even years.

Flows describe movement that resembles a viscous fluid, such as cement as it comes out of the cement-mixer. Flows usually occur rapidly and in a pre-existing swale or channel (Figure 3.1d). In most cases the flow is accompanied by an abundant amount of water mixed with the material. In the case of large rock flows, however, the medium that transports the flow can be air!

Creep describes a viscous movement similar to flow as described above, except creep occurs much slower than flow, taking pace over many months or even years. It often occurs on an open slope.

Complex forms of movement involve the combination of two or more types of movement. Often one type of movement starts the material moving, such as a debris slide, and once moving, the material takes on the character of another type of movement, such as a debris flow. The name of the complex movement is a combination of the types of movement, in order of occurrence, such a debris slide-flow. The rate of movement depends on the types of movements and materials involved.

Types of Material (Refer to **Photos on Page 3.5**)

Bedrock generally refers to older, harder materials that have undergone some rock-forming processes. As discussed in **Section 2.2**, bedrock can be classified as igneous intrusive, volcanic, sedimentary or metamorphic. The strength of the bedrock depends not only on the actual bedrock type, but also on whether the rocks are flat lying, gently dipping, or steeply dipping, and how much they have folded and/or faulted, and the resulting frequency of **fractures**, physical planes of weakness in the rock mass. For instance, if a strong hard granite contains many fractures, the rock mass may be no stronger than a coarse grained soil, and should be considered as such. Landslides in bedrock are referred to as **rock landslides**.

Coarse grained soils are composed primarily of gravel and sand sized materials, or as mentioned above, can also include highly fractured bedrock. The strength of coarse grained soils is generally derived by the friction between the grain to grain contact. Landslides in predominantly coarse grained soils are referred to as **debris landslides**.

Fine grained soils are composed primarily of silt and clay sized materials. The strength of fine grained soils is generally derived by cohesion, that is the chemical and electrical bonding between silt and clay particles similar to the bonds that hold putty together. Landslides in predominantly fine grained soils are referred to as **earth landslides**.

Causes and Effects

Landslides occur when the gravitational forces (gravity), which act on the materials on a slope, become greater than the resisting forces of those materials. Sometimes the gravitational forces are intensified by earthquakes, water, wind and/or human activities. At other times the resisting forces are mitigated by human activities. As one can imagine, the specific mechanics of landslides involve many different factors, are quite complex, and beyond the scope of this manual.

Table 3.3: Factors affecting slope stability

Factor	Influence
steep slopes	-the steeper the slope, the more likely it is to fail -if a moderate slope is undercut by stream erosion, wave action or activities such as road building, the stability decreases
geology	-some rocks, especially if highly fractured, and some soils are more susceptible to landslides than others
water	-generally the greater the precipitation, or the wetter the ground conditions, the more likely a landslide will occur
earthquake activity	-earthquakes can increase the affect of gravity by up to 30%, and therefore the larger the earthquake, the greater the affect on slope stability
human activities	-humans can modify the natural conditions, for instance by undercutting the lower portion of the slopes, adding weight to the upper portion of the slope, vibrating the ground and/or changing water conditions on the slope by activities such as logging and irrigating

Some of the factors which affect the stability of a slope are summarized in **Table 3.3**. The effects of landslides are numerous, but can be summarized as shown in **Table 3.4**.

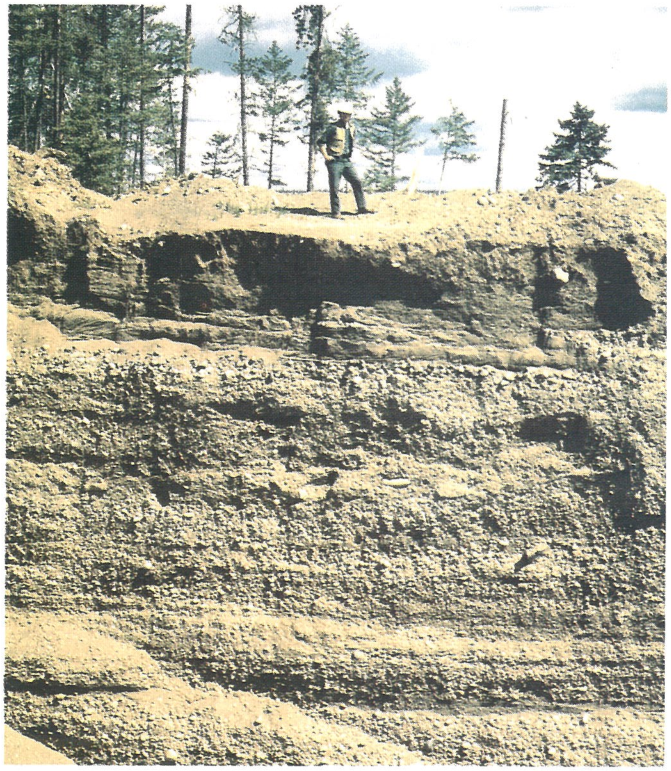
The all inclusive cost of landslides in all of Canada has been estimated to be in the order of $1 billion per year. Since 1855, it is estimated that approximately 350 lives have been lost as a result of approximately 100 separate landslides in British Columbia.

Table 3.4: Effects of landslides

Category	Effect
loss of resources	-land, timber, minerals, fish and fish habitat, recreation and visual quality
physical damage and disruptions	-residential, commercial and industrial structures and property -services such as water, sewer and gas -transportation routes, pipelines, transmission lines, fibre optics cables -dam sites, reservoirs
impacts on people	-disruption of normal patterns -injury and trauma -loss of life

Competent bedrock with few fractures

Highly fractured rock mass



Coarse grained soil (sand and gravel)

Fine grained soil (predominantly silt and clay)

3.1.1 Rock Falls / Topples (refer to **Photos on Page 3.7**)

Brief Description

-associated with steep, near vertical or overhanging natural bedrock bluffs and steep bedrock excavations
-bedrock is usually moderately to highly fractured, with intersecting fractures to form blocks
-some fractures are near vertical in orientation
-often occur rapidly without warning
-can vary in size from a single block of rock to many thousands of m^3
-occurrence increases in wet and freezing conditions
-susceptible to earthquakes

Human Impact on the Hazard

-excavating or oversteepening bedrock bluff or face increases hazard
-blasting near, or at, bedrock bluff or face increases hazard
-developing or disturbing top of bluff or face, including irrigation increases hazard

Impact of the Hazard upon People and Property

-high risk if below bluff or face, and in direct path of falling, bouncing, rolling or toppling rock, even if it is a single block
-some risk if above and close to edge of bluff or face
-large rock falls / topples can continue downslope many hundreds of metres

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing rock falls / topples:
-fresh bedrock surfaces near or at top of bluff or face
-talus and scattered rocks, especially fresh rocks, at base of bluff or face
-open, fresh talus, no vegetation growing

(ii) conditions suitable for rock falls / topples:
-steep or overhanging bedrock bluff or face
-fractured bedrock or loose bedrock blocks on, or at, top of bluff or face
-tension fractures at the top of bluff or face
-for topples, blocks of rock are tilted away from slope
-freeze-thaw conditions

Scattered rocks at base of bedrock bluff

Fractured bedrock face at top of bluff
with fresh talus at base of bluff

Steep bedrock face with fresh surfaces

3.1.2 Debris / Earth Falls (refer to **Photos on Page 3.9**)

Brief Description

-associated with steep, near vertical or overhanging natural coarse grained and fine grained soil bluffs
-surface soil is often dried out and usually fractured to form blocks of soil
-often occur rapidly without warning
-can vary in size from a few coarse grained particles, to a single block of fine grained soil, or up to many hundreds of m^3 of material
-occurrence increases in wet and thawing conditions
-susceptible to earthquakes
-debris / earth topples are rare

Human Impact on the Hazard

-excavating or oversteepening soil bluff or face increases hazard
-blasting near, or at, bedrock bluff or face increases hazard
-developing or disturbing top of bluff or face, including irrigation and removing the vegetative cover increases hazard

Impact of the Hazard upon People and Property

-some risk if below bluff or face, and in direct path of a large volume of falling soil or large block of soil
-some risk if above and close to edge of bluff or face

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing debris / earth falls:
-fresh exposed soil on bluff or face
-build-up, mounds or blocks of soil, especially fresh, at base of bluff or face
-seepage from bluff or face

(ii) conditions suitable for debris / earth falls:
-steep or overhanging soil bluff or face
-dried out and fractured blocks of soil on or at top of bluff or face
-tension fractures at the top of bluff or face
-freeze-thaw condition

Steep coarse grained soil face with fresh accumulation of debris at base.

Steep soil face at top of bluff with build-up of soil at base of bluff

Steep soil face with fresh accumulation of soil at base

3.1.3 Rock Slumps (refer to **Photos on Page 3.11**)

Brief Description

-most frequently involve large tracts of land, up to hundreds of metres across
-usually located along rivers or along steep valley sides
-generally associated with weak, fine grained or finely crystalline bedrock types such as shales and some volcanics
-can occur moderately fast, all at once, or slowly but progressively
-can be triggered by an earthquake

Human Impact on the Hazard

-because of the magnitude of these events, there is generally little people can do to have an impact. However, reservoir flooding assisted with major hydro electric developments may have a potential impact.

Impact of the Hazard upon People and Property

-large events can impose high risk, above, on, or below rock slump

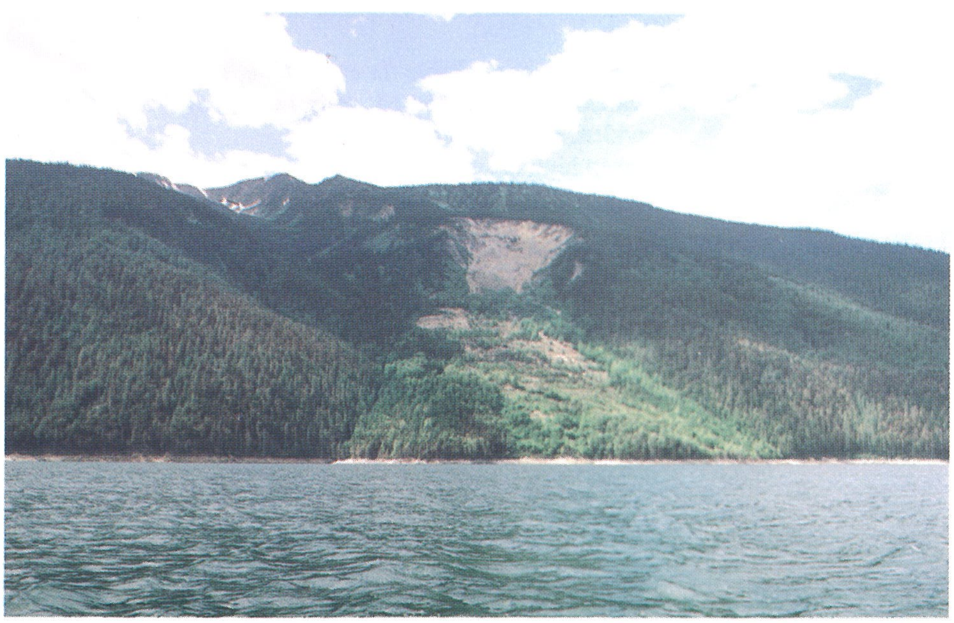
Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing rock slumps:
-large crescent shaped scarps or depressions
-extensive hummocky ground, sag ponds on lower slopes
-disrupted surface drainage both on the slumping mass and at the toe of the slump
-leaning trees, drunken trees (leaning in all different directions), split trees
-tension fractures cutting across terrain
-bulging in the lower portion of the slope
-disrupted roads, fences and/or other linear features

(ii) conditions suitable for rock slumps:
-steep high unsupported rock slopes or faces along rivers or along steep valley sides
-weak rock

Large crescent shaped headscarp (Downie Slide)

Crescent shaped headscarp and bulging lower portion of slope



Crescent shaped depression, hummocky ground and bulging lower portion of slope

3.1.4 Earth Slumps (refer to Photos on Page 3.13)

Brief Description

-usually located along rivers, road cuts or steep valley sides
-involve displacement of one or more rotational blocks of soil
-often associated with slopes composed of weak, predominantly fine grained soils
-can also occur underwater as submarine earth slumps, such as occurred in Howe Sound and Douglas Channel
-can occur extremely slowly to rapidly, all at once, or slowly but progressively, can stabilize then remobilize
-can retrogress landward overtime
-vary in size from small (involving several tens of m^3) to large (involving many hundreds of thousands of m^3)
-can be triggered by an earthquake

Human Impact on the Hazard

-existing or potential small events can be easily mobilized or remobilized by undercutting the lower portion of the slope, surcharging the upper portion of the slope or changing the groundwater conditions (e.g. removing vegetation or directing water onto the slope)

Impact of the Hazard upon People and Property

-small events can be a nuisance
-moderate events can impose some risk above, on, or below landslide
-large events can impose high risk above, on, or below landslide
-earth slumps can continue downslope many metres or even kilometres as an earthflow

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing earth slumps:
-crescent shaped scarps or depressions
-hummocky terrain, sag ponds on lower slope
-disrupted surface drainage both on the slumping mass and at the toe of the slump
-leaning trees, drunken trees, split trees
-tension fractures cutting across upper portion of slope
-bulging in lower portion of slope
-disrupted roads, fences and/or other linear features

(ii) conditions suitable for earth slumps:
-extensive fine grained soils, especially if wet or with evidence of seeps or springs
-steep high unsupported soil slopes

Distinctive scarp (tension crack and leaning trees

Hummocky ground and fallen trees

Crescent shaped scarp in fine grained soil

3.1.5 Rock Slides (refer to Photos on Page 3.15)

Brief Description

-generally associated with stronger rock types that fail along pre-existing planes of weakness
-require a natural steep slope or excavation
-usually occur rapidly and all at once
-can vary in size from very small, involving one or several blocks of rock, to extremely large (e.g. Hope Slide)
-can be triggered by an earthquake

Human Impact on the Hazard

-depending upon bedrock structure, excavating or oversteepening bedrock bluff or face increases hazard
-blasting near or at bedrock bluff or face increases hazard
-developing or disturbing top of bluff or face increases hazard

Impact of the Hazard upon People and Property

-small events can impose some risk, if below slope and in direct path of just one block of rock
-large events can impose high risk if above, on, or below landslide
-large events can continue downslope many metres or even kilometres as rock flows

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing rock slides:
-hummocky ground, sag ponds on lower slopes
-talus and scattered rocks, especially fresh rocks, at base of bluff or face
-disrupted surface drainage both on the sliding mass and at the toe of the slide
-leaning trees, drunken trees, split trees
-tension fractures at the top of bluff or face, or cutting across terrain
-bulging in the lower portion of the slope
-disrupted roads, fences and/or other linear features

(ii) conditions suitable for rock slides:
-steep bedrock bluff or face
-fractured bedrock or loose bedrock blocks on or at top of bluff or face
-steeply dipping fractures or intersections of fractures dipping out of the slope

Steep fractured bedrock face

Fresh bedrock surfaces, steeply dipping intersecting fractures

Steep fractured bedrock at top and landslide debris at toe (Frank Slide, Alberta

3.1.6 Debris Slides (refer to **Photos on Page 3.17**)

Brief Description

-sometimes referred to as debris avalanches
-common to all areas of province with steep slopes and high rainfall
-failure often occurs along weak plane between looser overlying colluvial material and denser underlying material such as till or bedrock
-common along road fills
-once started, usually travels rapidly
-can vary greatly in size from very small (involving an area metres by metres) to large (involving up to many hectares)
-can be triggered by an earthquake

Human Impact on the Hazard

-undercutting slope or side-casting fill, as in road construction, increases hazard
-removing vegetation or adding water to the slope increases hazard

Impact of the Hazard upon People and Property

-small events can be a nuisance
-moderate to large events can impose high risk on, or below, landslide
-if debris slide enters steep creek or gully, can continue down that drainage for many metres or even kilometres as a debris flow

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing debris slides:
-recent or revegetated landslide scars
-trees all of similar age
-landslide debris consisting of a mixture of soil, rock and trees on lower slopes
-debris piled against trees
-tension fractures on upper steep slopes or along roads
-leaning trees, drunken trees, split trees

(ii) conditions suitable for debris slides:
-steep soil slopes including fill slopes
-poorly drained slopes, seeps and springs of groundwater
-distinct plane of weakness at depth (e.g., dense till or bedrock)

Recent landslide scars and trees of similar age

Landslide scar with young second growth

Recent linear downslope scars

3.1.7 Rock Flows (refer to Photos on Page 3.19)

Brief Description

-often travels down a confined valley and once beyond the confined valley, rock debris begins to deposit on a colluvial fan
-water or air can be the transporting medium
-occurs rapidly
-events are often very large involving many thousands of m3
-usually associated as the second type of movement with a rock fall or rock slide (rock fall-flow or rock slide-flow)

Human Impact on the Hazard

-because of magnitude of large events, there is little people can do to have an impact

Impact of the Hazard upon People and Property

-large events can impose high risk along flow path up to several kilometres from where the event began

Recognition of Existing and Potential Hazard

(i) evidence of past rock flows:
-scoured valley, flow lines and trim lines along sides of valley
-rocky deposits along sides of valleys
-hummocky rocky debris at mouth or valley and on fan

(ii) conditions suitable for rock flows:
-confined valley
-steep bedrock headwall

Rocky deposits along sides and at mouth of valley

Scoured confined valley with steep bedrock headwall

Scoured confined valley with steep bedrock headwall

3.1.8 Debris Flows (refer to **Photos on Page 3.21**)

Brief Description

-sometimes referred to as debris torrents or mudflows
-often occurs along creek or gully and once beyond the creek or gully debris begins to deposit on a colluvial fan
-large amounts of water are involved
-occurs rapidly, can occur as several surges
-events can vary from small (involving several tens of m^3) to large (involving thousands of m^3)
-often associated as the second type of movement with a debris slide

Human Impact on the Hazard

-disturbing the creek or gully sidewalls, including removing vegetation, will increase hazard
-inappropriate crossing or blockage of the creek or gully can increase hazard
-adding debris to the channel will increase hazard
-inappropriate development on the fan can increase hazard

Impact of the Hazard upon People and Property

-large events can impose high risk both along the flow path, and on the colluvial fan many metres or even kilometres from where the event began
-debris flows can change the flow direction within the existing channel
-debris flows can change the flow direction of the creek or gully on the fan

Recognition of Existing and Potential Hazard

(i) evidence of past debris flows:
-scoured creek or gully, flow lines, levees and trim lines along sides of creek or gully
-no vegetation or new vegetation in channel
-debris deposits along sides of valleys
-existence of a fan shaped deposit
-hummocky, unsorted, bouldery debris at mouth of creek or gully and/or on fan
-mud lines / scars on tree trunks

(ii) conditions suitable for debris flows:
-steep confined creek or gully
-steep unstable sidewalls
-loose sidewall materials
-source of channel debris

Hummocky, unsorted, bouldery debris at mouth of creek or gully

Scoured valley with flow lines

Evidence of flow well above present water flow

3.1.9 Earth Flows (refer to **Photos on Page 3.23**)

Brief Description

-usually involve weak fine grained soils but can also involve fine grained weathered volcanic rocks
-common in the interior of province
-flow angle can be relatively low
-usually movement is slow to very slow
-can involve very large tracts of land and can flow for many kilometres
-includes wet and dry sand flows, but these are relatively small
-often associated as second type of movement with an earth slump (earth slump-flow)

Human Impact on the Hazard

-removal of material from toe usually increases hazard
-adding water to flowing mass increases rate of movement

Impact of the Hazard upon People and Property

-some risk, but not usually devastating because of slow rate of movement

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing earth flows:
-flow characteristics similar to a glacier
-surface is broken up by sub-parallel tension fractures across the direction of movement, and ridges parallel to the direction of movement
-hummocky surface, sag ponds on lower slopes, disrupted surface drainage
-leaning trees, drunken trees
-off set natural and constructed features such as roads
-bulging toe

(ii) conditions suitable for earth flows:
-extensive fine grained soils or fine, weathered volcanic rocks

Hummocky surface on lower slopes
(Pavilion Slide)

Ridges parallel to the direction of
movement (emphasized by vegetation)

Ridges parallel to direction of flow
(Drynoch Slide)

3.1.10 Earth Creep / Solifluction (refer to **Photos on Page 3.25**)

Brief Description

-also referred to as slope creep
-when associated with permafrost, referred to as solifluction
-involves the downslope movement of thin layers of water-saturated fine grained soils
-can occur on relatively gentle slopes
-movement is relatively slow
-usually affects areas up to several hectares

Human Impact on the Hazard

-adding water to the slope increases hazard
-melting underlying permafrost ground on slope increases hazard

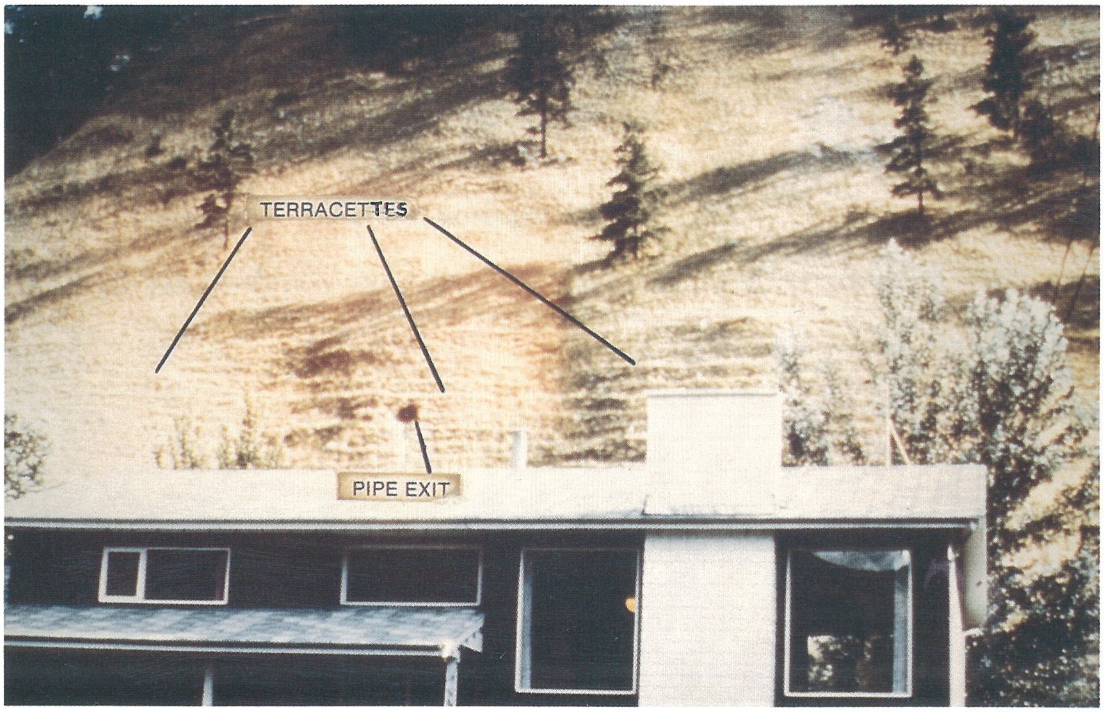
Impact of the Hazard upon People and Property

-some risk to structures such as roads, foundations and walls, but because of relatively slow movement, the impacts are usually not devastating
-can be a precursor to an earth flow

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing earth creep / solifluction:
-disrupted natural or constructed features on the ground
-evidence of "terracettes", "sheep tracks" or "catsteps" across the slope
-disrupted surface drainage
-may have tension fractures of the upper portion of the area of earth creep
-bulging lower portion of the slope, bowed trees, pistol butt trees
-"solifluction lobes", lobes of ground that have moved downslope at differing rates

(ii) conditions suitable for earth creep/solifluction:
-water-saturated fine grained soils
-permafrost in area
-freeze-thaw cycling



Terracettes across slope

Terracettes and bulging lower portion of the slope

3.1.11 Rock Creep

Brief Description

-usually occurs in weak bedrock types or strong bedrock types that contain fractures
-often caused by stress relief and valley rebound
-usually slow to very slow moving
-usually involves a large area, covering many hectares

Human Impact on the Hazard

-because of the magnitude of extensive rock creep, there is little people can do to have an impact

Impact of the Hazard upon People and Property

-some risk, but not usually devastating because of slow rate of movement

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing rock creep:
-hummocky terrain, sag ponds on lower slope, disrupted surface drainages
-leaning trees, drunken trees
-tension fractures running across slope

(ii) conditions suitable for rock creep:
-weak bedrock on a steep slope

3.2 SNOW AVALANCHES

Introduction

A snow avalanche is the movement of a mass of snow which may contain rocks, soil, ice or trees entrained along it's path. The impact of moving snow can have a significant destructive potential to natural or man made facilities. As such, it is important that the development and construction of roads and buildings be made with an awareness to the likelihood of encounter with snow avalanches.

Snow avalanches can occur on slopes with inclines between 20^0 and 60^0. Most however occur at inclines between 30^0 and 45^0. When stress factors such as weight, lubrication or a sudden shock overcome the strength and bonding characteristics within the snowpack, avalanches occur.

Naturally occurring avalanches most commonly result from changing weather conditions. Although rare, it is also possible for natural avalanches to be triggered by the vibrations of an earthquake. Artificially occurring avalanches require the application of forces outside of natural phenomenon to trigger an avalanche. This may include the use of explosives, a skier crossing a slope, a snowmobile, a helicopter or an animal crossing over critical areas of the snowpack.

Identifying where an avalanche will occur requires an ability to recognize specific terrain features, such as a steep slope devoid of trees and vegetation. There are three distinct parts of an avalanche path; the start zone, the track and the runout zone. Predicting when an avalanche will occur requires a knowledge of current and past weather conditions as well as an understanding of the snowpack and how it develops.

Avalanches can occur as either a loose, surface snow or as a cohesive, slab avalanche. Of the two types, slab avalanches represent a significant threat to persons or facilities due to their much greater destructive potential. The speed of an avalanche in motion depends on the length and incline of terrain, mass, density and moisture of snow and the presence of terrain or vegetation features which may affect flow dynamics. Speeds range from a "slow moving" wet avalanche of 40 km/hr to high speed dry "powder" avalanches of 300 km/hr. Although the speeds and motion characteristics of avalanches vary widely, any snow in motion has potential destructive power due to the impact pressures they exert on either fixed or mobile structures. Impact pressure for large dry flowing avalanches have been measured in excess of 1,000 kPa (move reinforced concrete / destroy mature forest).

Table 3.5: Snow Avalanche Zones

Zone	Brief Description
Start Zone	Located at the top of the path where unstable snow fails and begins to move downslope. An avalanche path may have a single or multiple start zones (separated by ridges or vegetation) which connect to a single track. Typical start zone inclines are 30^0 to 45^0. Common terrain features are; smooth, concave sparsely forested bowls and steep slopes on the lee side of ridges where prevailing winds can deposit large amounts of snow.
Track	The track is located directly below the start zone. It is where maximum avalanche speed and impact pressures are attained. Tracks are commonly bordered by trees (trim line) but may be wide open slope. They can be confined to creek beds and narrow gullies or be wide open spaces. Track inclines are usually at least 15^0 to 20^0. Inclines range from these minimum values to vertical. Vegetation is sparse.
Runout Zone	This is the deceleration and deposition area of the avalanche path. It is characterized by a reduction in slope angle. Runout zone inclines range from flat to approximately 15^0. Vegetation type and density is dependent on the frequency of avalanches.

3.2 Snow Avalanches continued....(refer to Photos on Page 3.29)

Brief Description

-snow avalanches involve the rapid movement of wet or dry snow, ice and entrained debris
-they occur in mountainous terrain as a result of snow accumulations and unstable snowpacks
-snow avalanche areas may also be subject to debris flows and alluvial fan flooding

Human Impact on the Hazard

-under the right conditions both natural and artificially triggered snow avalanches can occur
-with the increased demands for development of mountainous terrain for recreation, housing and industry the frequency of occurrence and the change of interaction with snow avalanches is increasing

Impact of the Hazard upon People and Property

-can be highly destructive
-often bury or destroy structures in the runout zone
-flooding can result if a stream is dammed by the snow avalanche deposit
-in terms of impact on human life, snow avalanches are the most frequent and dangerous of the natural hazards in the province

Recognition of Existing and Potential Hazard

Prior to the development of facilities proximal to known or suspected avalanche terrain, it is imperative that a snow avalanche hazard assessment is made. This may involve: the study of map and air photo's; field investigations; numerical models; review of historic events and climate studies. Designers and planners who supervise and or approve the construction of facilities during the summer months must always consider the potential hazards of avalanches which occur primarily in the winter

(i) Indicators of Past Avalanches::
-vertical swaths of destruction (trim lines);
-differences in species and age of trees;
-scars on trunks, broken limbs and tree tops;
-leaning and fallen trees aligned in the direction of avalanche motion;
-accumulation of dead wood and twigs;
-snow plastered on the uphill side of tree trunks and rocks;
-fracture lines (in the start zone);
-rough snow surface;
-mounds and blocks of snow;
-grooves in the snow, oriented in the fall line;
-deep creek gullies filled with snow;
snow harder than the surrounding snow surface

Snow avalanche paths endangering village

Fan shaped deposits with young conifer stand

Snow avalanche deposit with considerable tree debris

3.2 Snow Avalanches continued

Recognition of Existing and Potential Hazard ...continued

(ii) Examples of Vegetation Indicators of Avalanche Frequency:

Frequency - At least one large avalanche in an interval of:	Vegetation Clues
1 -2 years	Alder and willow, bare patches and shrubs No trees higher than about 1 to 2 metres
3 -10 years	No large trees and no dead wood from large trees Presence of trees higher than 1 to 2 metres
10 - 30 years	Dense growth of small trees; Young trees of climax species (e.g. conifers)
25 - 100 years	Mature trees of pioneer species (e.g. deciduous) Young trees of climax species
More than 100 years	Mature trees of climax species

Avalanche Hazard Line

In the event that a detail assessment is required, a hazard line will be determined. The avalanche hazard line indicates the maximum distance an avalanche is expected to run within an approximate return period of 200 to 300 years. The line defines the boundary between areas where no hazard exists and areas with a hazard.

Avalanche Risk and Return Periods

The acceptable risk level for specific facilities is related to the frequency of effect or damage expected from avalanches. The damage threshold for a structure may be expressed as the maximum allowable impact pressure. For a highway, it may be the maximum allowable volume and depth of avalanche debris on the road surface. Other considerations apply such as population figures (for buildings) or traffic volumes (for a highway). Each facility requires specific assessment in consideration of unique circumstances.

Variations will occur based on human usage, importance of the facility, and the local frequency of avalanching. The following displays acceptable return periods for damaging avalanches for different kinds of facilities:

Facility	Return Period
Occupied buildings	200 - 300 years
Bridges and high-voltage transmissions lines	50 - 100 years
Structures with permissible damage and unoccupied buildings	30 years
Avalanches hazardous to road traffic	5 - 10 years

Snow avalanche in progress

Avalanche paths in the Columbia Mountains.

NOTES

3.3 SUBSIDENCE

Introduction

Subsidence is the local or regional sinking or collapse of the land surface with little or no horizontal movement. Subsidence is another form of mass movement, but because it does not involve downslope movement it is not classified as a landslide.

Subsidence in British Columbia can generally be divided into two types:

- **subsidence due to underground activities by people**
- **subsidence due to natural removal of underground materials**

Unusual linear surface depressions in the Interior Plateaus

3.3.1 Subsidence due to Underground Activities by People (refer to **Photos on Page 3.35**)

Brief Description

-due to people's underground activities
-overlying material (bedrock or soil) loses its supporting strength resulting in slow or rapid surface collapse
-usually associated with historic underground mine workings, such as the coal mines beneath Nanaimo and underground placer gold workings in the Cariboo
-sometimes associated with new underground workings, such as large diameter storm sewer installations
-sometimes associated with water main leaks or breaks, and the subsequent washing away of underground material
-infrequently associated with excessive pumping of ground fluids, such as groundwater, oil and gas

Human Impact on the Hazard

-since people are directly responsible for the subsidence, our impact is great
-ignorance of the existence of underground workings or pumping can put people and property at greater risk

Impact of the Hazard upon People and Property

-high risk if directly above an area of rapid subsidence
-some risk to property if above an area of non-rapid subsidence

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing subsidence:
-land that has settled
-unusual surface depressions
-structures that have undergone differential settlement

(ii) conditions suitable for subsidence:
-historic or recent underground workings
-underground pumping of fluids

Sink hole due to leaking water pipe

3.3.2 Subsidence due to Natural Removal of Underground Materials (Photos on Page 3.37)

Brief Description

-due to the natural removal of underground materials
-overlying material (rock or soil) loses its support resulting in surface collapse, caving and the creation of sinkholes
-collapse can be slow or rapid
-in British Columbia, the three most common types of natural removal of underground materials involve:

- removal of silt by water, referred to as piping
- removal of limestone by water erosion, referred to as karstification
- melting of ice rich soil in permafrost areas

Human Impact on the Hazard

-people can accelerate piping by irrigation, and can accelerate the melting of the ice in permafrost soils
-in the past, we have used sinkholes as garbage dumps which has led to the pollution of groundwater

Impact of the Hazard upon People and Property

-high risk if directly above an area of rapid subsidence
-some risk of differential settlement to structures if above an area of non-rapid subsidence

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing subsidence:
-land that has settled
-unusual surface depressions, "bombshell appearance"
-apparent surface drainage without source of water
-structures that have undergone differential settlement

(ii) conditions suitable for subsidence:
-glacial lake silt (refer to **Section 2, Map 2.3** and **Section 3.6.1**), limestone or permafrost ground conditions in the area
-piping or karstification (caves) in the area
-permafrost ground conditions can be recognized by geographic location (refer to **Section 2, Map 2.3** and **Section 3.6.4**), low lying poorly drained conditions, solifluction on side hills, stunted vegetation, earth hummocks, tilted power / communication poles, differential settlement of structures including roads

Area of glacial lake silt showing advanced signs of linear subsidence

Unusual surface depressions or bombshell appearance

Exit hole of underground water (piping)

NOTES

3.4 FLOODING

Introduction

In simple terms, a **flood** is any high level of water. Floods can result from a wide range of conditions associated with climate and geography, but can also be associated with landslides, earthquakes and dams. Most flooding occurs in low lying areas, in valley bottoms, or active alluvial fans and along the coast, however, this is where the largest proportion of British Columbians live. And with the population on the increase, there is more pressure to develop the marginal low lying areas. Within this province, over the past century, more property damage has been inflicted by various forms of flooding than by any other natural hazard. Unlike some of the other natural hazards, flooding is somewhat predictable, and therefore it should be relatively easy to reduce some of the risk.

Conditions that can result in flooding include:

- **intense rainfall (a large amount of rainfall over a short period of time)**
- **a moderate amount of rainfall over a long period of time**

conditions, cont.../

- **snowmelt**
- **rain on snow, which accelerates snow melt**
- **low lying areas**
- **confined, constricted areas**
- **ice damming a stream or river**
- **landslides damming of stream or river**
- **dam failure**
- **dyke failure**
- **extreme high tides combined with winds**
- **storms with excessive winds**
- **earthquake creating a tsunami**
- **submarine landslide causing a tsunami**
- **impact of and activities by people**

Types of flooding common to British Columbia include:

- **stream / river flooding**
- **lake / reservoir flooding**
- **alluvial fan flooding**
- **flooding due to storm surges and tsunamis**
- **glacial outburst floods**

An example of lake flooding

3.4.1 Stream / River Flooding (refer to **Photos on Page 3.41**)

Brief Description

-generally associated with a larger, gentle gradient, permanently flowing, water course
-flooding generally occurs on the floodplain
-floodplain can be divided into two levels:

- the floodway, closest to the stream or river where the flood waters are swiftest, deepest and have the potential to flood most frequently
- the residual flood fringe, further away from the stream or river

-affected by other factors such as geology of region, land use, and channel characteristics
-at confluences with lakes can be affected by "backwater effect"
-near coast, also can be affected by high tides
-can be gentle, or erosive depending upon volume of water involved and gradient of stream or river

Human Impact on the Hazard

-infilling in the floodplain in one location increases flood level elsewhere
-structures constructed in the floodplain can constrict normal flows
-altering the water course can increase flooding
-increased urbanization, including covering the ground surface with buildings, roads, parking lots, etc. and removing vegetation increases runoff and flood potential

Impact of the Hazard upon People and Property

-slow rises in river level, and/or low energy water conditions present low risk to people, but present moderate to high risk to property
-quick rises in river level, and/or high energy flow conditions present high risk to people and property
-the latter leads to erosion, landslides and loss of ground

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing stream / river flooding:
-flood deposits
-recently or historically eroded areas, terraces
-marked trees or structures (high water mark)

(ii) conditions suitable for stream / river flooding:
-low lying, poorly drained, high groundwater table areas close to stream or rivers
-deltas / estuaries at confluence of streams or rivers with lakes or the coast
-floodplains or abandoned channels

Special Note

-there is a **Canada-British Columbia Floodplain Mapping Program**
-to September 1994, approximately 120 floodplains along a number of major streams and rivers of British Columbia have been identified, mapped and designated as having a serious flood risk (see **Appendix C, Table C.1**)
-the maps show the areas potentially affected by the "200-year flood"
-these maps generally **do not** consider:

- smaller tributary streams
- any downstream damming of the stream or river by a landslide or ice
- breaching of upstream natural dam, landslide dam or man-made dam (it is assumed that recently constructed dams are designed for a flood greater than the "200-year flood")

-the maps depict dyked areas as potentially floodable lands

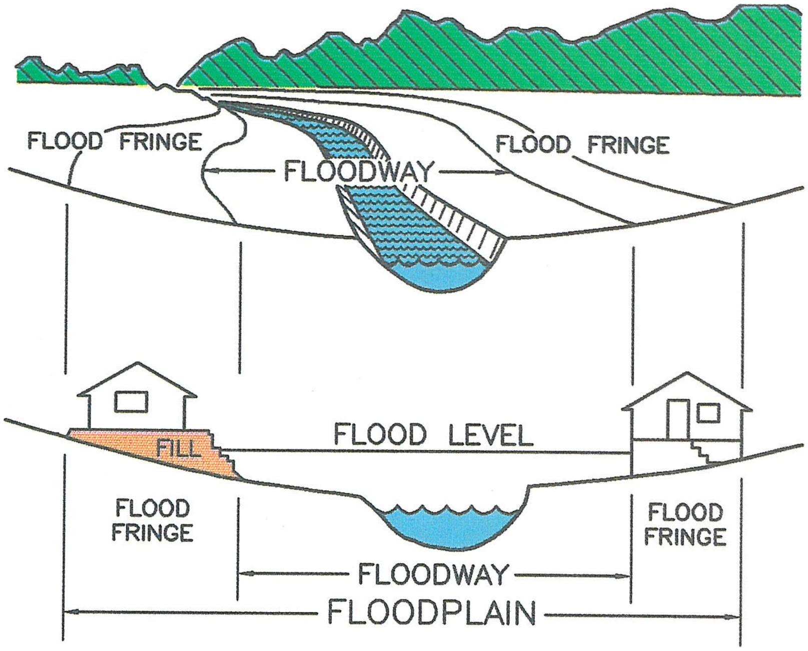


Figure showing the "floodplain", "floodway" and "flood fringe"

River flooding, the result of a landslide dam

Low lying land close to a river

3.4.2 Lake / Reservoir Flooding (refer to **Photos on Page 3.43**)

Brief Description

-occurs along lower lying shoreline of lakes and reservoirs
-can be gentle, if associated with slow rise of water level
-can be erosive, if accompanied by strong winds and a long fetch (the distance across the water over which the wind can pick up speed) creating large waves

Human Impact on the Hazard

-constructing poorly designed retaining walls can actually increase potential hazard
-constructing flood defenses in one area can result in additional damage elsewhere along lake or reservoir shoreline

Impact of the Hazard upon People and Property

-usually minor risk to individuals because of slow rate of lake / reservoir rise
-risk to property results from:

- typical high water flooding damage
- impact due to high energy waves
- erosion and scour resulting from the rising and falling water
- build up of water pressure in the ground

-can result in structural damage and loss of property
-rise and fall of flood waters can increase potential for landslides

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing lake / reservoir flooding:
-flood deposits
-recently or historically eroded areas, terraces
-marked trees or structures (high water mark)

(ii) conditions suitable for lake / reservoir flooding:
-proximity to lake or reservoir shoreline
-little elevation above normal lake or normal maximum reservoir level

Low lying land next to a lake

Low lying land next to a lake

Low lying land next to a lake

3.4.3 Alluvial Fan Flooding (refer to **Photos on Page 3.45**)

Brief Description

-generally associated with smaller, steeper, possibly intermittent, streams, creeks and gullies
-flood waters generally have high energy and can cause a great deal of erosion and destruction along the channel and on the fan
-transportation of eroded material along channel increases erosion further downstream and on the fan
-can be associated with a debris flood or debris flow (refer to **Section 3.1.8**)

Human Impact on the Hazard

-disturbing the stream, creek or gully sidewalls, including removing vegetation, will increase hazard
-inappropriate crossing or blockage of the stream, creek or gully can increase hazard
-adding debris to the channel will increase hazard
-inappropriate development on the fan can increase hazard

Impact of the Hazard upon People and Property

-high risk to property bordering stream, creek or gully due to excessive erosion
-high risk on fan due to high energy debris floods and debris flows
-can result in excessive erosion and/or excessive build up of materials and abrupt changes to channel location (refer to **Sections 3.1.8 and 3.5.1**)
-can cause erosion of a new channel

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing alluvial fan flooding:
-existence of a fan shaped deposit
-hummocky, unsorted, bouldery debris at mouth of stream, creek or gully and/or on fan
-abandoned channels or channel scars on the fan
-scoured stream, creek or gully, flow lines, levees and trim lines along sides of channel
-no vegetation or all young vegetation in channel
-debris deposits along sides of valleys

(ii) conditions suitable for alluvial fan flooding:
-steep gully or creek with steep unstable sidewalls
-active alluvial fan
-the steeper the fan, the greater the hazard

A scoured gully upstream of an alluvial fan

Recent channel scars on an alluvial fan

Flood debris at the mouth of a stream

3.4.4 Flooding due to Storm Surges and Tsunamis (refer to **Photos on Page 3.47**)

Brief Description

-a storm surge is a sudden rise in sea level that accompanies low atmospheric pressure and wind
-a tsunami is a wave or series of waves generated by a large geological event such as an earthquake, a volcano or a large landslide (tsunami is a Japanese word, literally translated as "harbour wave")
-both cause water to flood low coastal areas
-both are exaggerated when coincident with high tide
-storm surge hazard increases as fetch (the distance across the water over which the wind can pick up speed) increases
-tsunami hazard increases when a wave is "funnelled" into a confined location such as the head of a coastal inlet

Human Impact on the Hazard

-there is little people can do to have an impact on the occurrence of a storm surge or tsunami

Impact of the Hazard upon People and Property

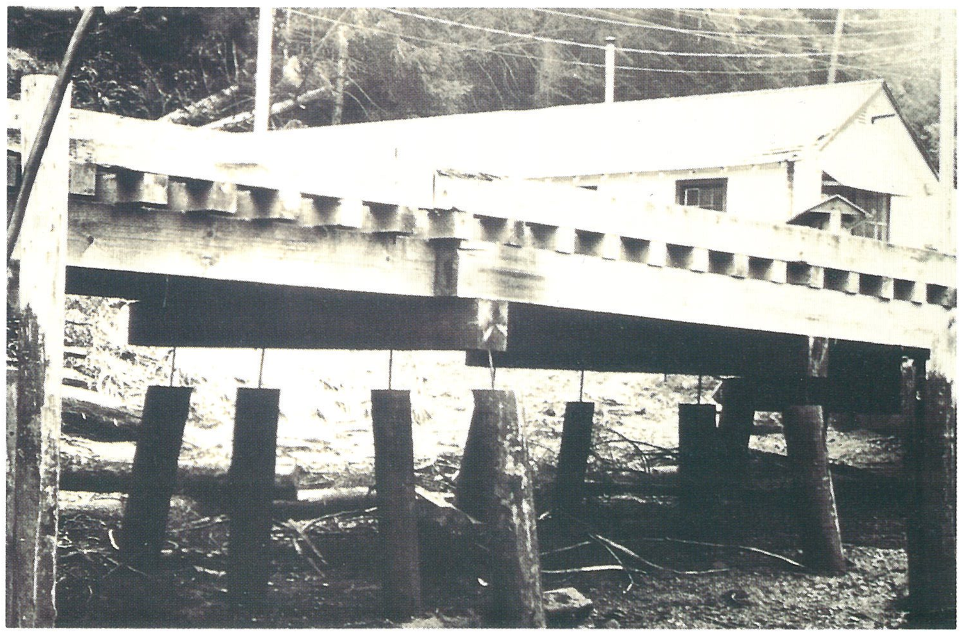
-high risk to low lying coastal areas
-typical high water flooding damage
-tsunamis are associated with impact damage due to speed of advancing wave and erosion due to retreating water
-estimated cost of 1964 Port Alberni tsunami was Ten million Canadian dollars (1964)
-since the Tsunami Warning System in the Pacific was established in the 1960s, the risk to human life from earthquake generated tsunamis has been greatly reduced
-this warning system can not predict landslide generated tsunamis

Recognition of Existing and Potential Hazard

(i) evidence of past storm surge or tsunami flooding:
-flood deposits such as sand layers overlying low lying areas, especially along the coast
-recently or historically eroded areas and/or terraces
-marked trees or structures (high water mark)
-structural damage and coastal erosion from past tsunamis

(ii) conditions suitable for storm surges and tsunamis:
-low lying coastal areas including river estuary flats at the head of coastal inlets
-low lying areas at the end of long narrow lakes may also be susceptible
-especially sections of the coast exposed to a long fetch (for storm surges) and especially at the head of inlets (for tsunamis)
-portions of coastal British Columbia potentially impacted by a tsunami are shown on **Appendix C, Map C.1**

Port Alberni 1964: House on left was pushed up against gas station by tsunami wave



Port Alberni 1964: Deck of dock was lifted off its pilings by force of tsunami wave

Low lying coastal areas are particularly susceptible to storm surges and tsunamis

NOTES

3.5 WATER EROSION

Introduction

Water erosion is the removal of earth materials by moving water, and can take many forms. On a small scale, water erosion can be caused by raindrops on, or water flowing over, non-vegetated soils. This is called sheet erosion. On a larger scale, water erosion can be caused by water moving down a channel of a gully, creek, stream or river; waves being pushed by wind against a lake or reservoir shoreline; and waves being pushed by wind, tides and currents against a coastal shoreline. In all cases the amount or erosion depends upon two factors:

- **the energy of the water or waves**
- **the material the water comes in contact with**

The impact that these two factors have on erosion are summarized in **Table 3.6**.

Although small scale water erosion is important when it comes to considerations such as the protection of fish habitat and erosion of agricultural soils, with regards to natural hazards, we generally limit our discussion to larger scale water erosion. Water erosion can be episodic, that is many years may go by with no erosion, and then conditions become just right for a major amount of erosion.

The three types of larger scale water erosion common in British Columbia are:

- **channel erosion**
- **lake/reservoir erosion**
- **coastal erosion**

Table 3.6: Water erosion factors and impacts

Water Erosion Factor	Impact on Water Erosion
Energy of the water	Erosion increases with: -more intense rainfall -steeper channel gradients -straighter channels -larger volumes of water -higher water levels -stronger winds -higher tides -stronger currents
Material the water comes in contact with	Erosion increases with: -weaker materials: soil is generally less resistant than rock, looser or softer soils are generally less resistant than denser or harder soils

An example of severe channel erosion

3.5.1 Channel Erosion (refer to **Photos on Page 3.51**)

Brief Description

-involves the water erosion of any sized channel: a gully, creek, stream or river
-commonly accompanies flooding conditions (refer to **Sections 3.4.1 and 3.4.3**), especially during spring runoff and rainfall events
-erosion can involve lateral erosion (**channel bank erosion**) or scour (**channel bed erosion**) or both
-channel bank erosion is more common along the outside of channel bends
-rate of erosion depends upon energy of the water and material (see **Table 3.6**)

Human Impact on the Hazard

-loosening, disturbing or oversteepening the channel bank by removing material or by filling over the top of the bank increases hazard
-removal of vegetation increases hazard
-infilling the channel in period of low flow increases hazard
-bank protection on one side of the channel can direct water to the other side, increasing hazard
-bank protection on both sides of the channel (referred to as training) tends to straighten channel and increase flow, and increases both channel bed erosion and channel bank erosion downstream

Impact of the Hazard upon People and Property

-**channel bank erosion** generally leads to bank undercutting and/or eventual loss of ground or landsliding along the channel which puts people and property at some risk
-the risk generally increases with bank height
-**channel bed erosion** generally does not put people or property at risk where the erosion occurs, however, the eroded bed material becomes mixed with the water flow which increases channel bank erosion
-channel bed erosion can affect instream structures such as bridge piers if they have not been properly designed
-the eroded channel bed and bank material eventually deposits somewhere downstream, usually on a lower gradient, and this deposit can result in:

- **abrupt changes in channel direction (an avulsion)**
- **flooding**
- **burying structures**
- **destroying structures**

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing channel erosion:
-meandering rivers, streams
-lost ground or evidence of landslides along the bank, tilting trees on the channel bank, lack of vegetation in the channel, along the channel sides or on the channel banks, deposits of material downstream, abrupt changes in flow direction
-flood deposits downstream
-are the boulders in the channel larger than what you would expect for a channel this size

(ii) conditions suitable for channel erosion:
-steep gradient channels
-steep unstable channel banks
-erodible channel banks and/or channel beds

An example of small scale channel erosion, with steep channel banks and deposition of material downstream

Deposition of material on a fan downstream

Channel bank erosion has lead to lost ground

3.5.2 Lake / Reservoir Shoreline Erosion (refer to Photos on Page 3.53)

Brief Description

-involves water erosion caused by waves along a lake or reservoir shoreline, especially during storm events
-commonly accompanies flooding conditions (refer to **Section 3.4.2**)
-the amount of erosion depends on factors such as water levels, depth of lake, slope of shoreline material, amount of fluctuation above and below normal water levels
-wave height depends upon wind speed, duration and direction, and fetch (the distance across the water over which the wind can pick up speed)
-material removed from the shoreline is deposited elsewhere along the shoreline, or in the bottom of the lake or reservoir

Human Impact on the Hazard

-oversteepening the shore bank by removing material or by filling over the top of the bank increases hazard
-removing vegetation increases hazard
-dumping over the bank during period of low water, constructing structures into the lake or reservoir, and constructing bank protection in one location can increase hazard elsewhere along the shoreline.

Impact of the Hazard upon People and Property

-shoreline erosion generally leads to bank undercutting and/or eventual loss of ground or landsliding which can put people and property at risk
-reservoir levels greater or lesser than the normal operating levels can increase hazard
-depending upon the height and material of the bank, loss of ground and landsliding can retrogress many metres to hundreds of metres from the shore
-deposition of eroded materials can infill or bury near shore facilities such as water intake structures and marinas

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing lake / reservoir shoreline erosion:
-lost ground or evidence of landslides along the bank, tilting trees or lack of vegetation on the bank
-build up of shoreline material

(ii) conditions suitable for lake / reservoir shoreline erosion:
-steep or high banks, unless they consist of sound bedrock
-head lands or promontories are more prone to erosion
-recently flooded reservoirs are more prone to erosion
-fluctuating reservoirs are more prone to erosion

Tree stumps around a reservoir indicate fluctuating water levels

A small landslide with tilting trees is evidence of lost ground around a lake

Shoreline erosion protection must be appropriately designed and constructed to be effective

3.5.3 Coastal Shoreline Erosion (refer to Photos on Page 3.55)

Brief Description

-involves water erosion caused by waves and currents along a coastal shoreline, especially during storm events
-also associated with storm surges and tsunamis (refer to **Section 3.4.4**)
-the amount of erosion depends on factors such as tide height, slope of shoreline material, tidal fluctuation (which affects current) and wave height
-wave height depends upon wind speed, duration and direction, and fetch (the distance across the water over which the wind can pick up speed)

Human Impact on the Hazard

-oversteepening the shore bank by removing material or by filling over the top of the bank increases hazard
-removing vegetation increases hazard
-dumping over the bank during period of low water, constructing structures into the ocean, and providing bank protection in one location can increase hazard elsewhere along shore

Impact of the Hazard upon People and Property

-shoreline erosion generally leads to bank undercutting and/or eventual loss of ground or landsliding which can put people and property at some risk
-depending upon the height and material of the bank, loss of ground and landsliding can retrogress many metres to hundreds of metres from the shore
-deposition of eroded materials can infill or bury near shore facilities

Recognition of Existing and Potential Hazard

(i) evidence of past or ongoing coastal shoreline erosion:
-lost ground or evidence of landslides along the bank, tilting trees or lack of vegetation on the bank
-build up of shoreline material

(ii) conditions suitable for coastal shoreline erosion:
-steep or high banks, unless they consist of sound bedrock
-head lands or promontories are more prone to erosion

Rock is less erodible than soil

Steep soil banks are particularly susceptible to coastal erosion

A small landslide is the result of toe erosion of a steep soil bank by wave action

NOTES

3.6 PROBLEM SOILS

Introduction

The previous **Sections 3.1 to 3.5**, present natural hazards from the viewpoint of the **geological process**:

- **landslides**
- **subsidence**
- **snow avalanches**
- **flooding**
- **erosion**

This section discusses natural hazards from the viewpoint of a number of **geological materials** whose hazards are particularly significant in British Columbia. In all cases these geological materials are associated with soils. These problem soils are:

- **glacial marine and marine clays**
- **glacial lake silts**
- **organic soils**
- **soils in discontinuous permafrost and alpine permafrost**
- **made ground (fill)**

All but the last soil, made ground, are naturally occurring.

Because most of the hazards associated with these problem soils have already been discussed in **Sections 3.1 to 3.5**, in the sub-sections that follow, these soils are discussed under the headings:

- **Brief description**
- **Distribution**
- **Potential hazard**

An example of a small earth slump in a glacial lake deposit whose toe was undercut by a road

3.6.1 Glacial Lake Deposits

Brief Description

-the deposits, presently exposed, were deposited in relatively quiet lake environments during or shortly after the last glaciation (refer to **Section 2, Map 2.3**)
-most deposits are flat to gently dipping, well bedded or layered, unconsolidated silt and clay

Potential Hazards

-landslides, specifically earth slumps (**Section 3.1.4**)
-piping, subsidence and collapse (**Section 3.3.2**)
-settlement
-all of the above can occur very rapidly

Distribution

-the small scale **Map 2.3** does not allow all known glacial lake deposits to be shown
-soils often occur as bluffs or terraces in valley bottoms along existing lakes and/or rivers
-well known areas include the southern interior from the Kamloops area south to the British Columbia-United States border; in the upper Columbia River and Kootenay River areas; in the central interior from the Quesnel area north to Stuart Lake; in the Peace River area; and in the Telegraph Creek area

-the glacial lake deposits in the central interior and Peace River tend to be dominated by clay rather than silt.
-there is little evidence of piping, subsidence, and collapse in the Peace River and Central Interior regions

An example of piping, subsidence and gully erosion in glacial lake deposits

3.6.2 Glacial Marine and Marine Clays

Brief Description

-the deposits, presently exposed on land, were deposited in relatively quiet salt water marine environments during **(glacial marine)** or after **(marine)** the last glaciation **(Section 2, Map 2.3)**
-most deposits are flat to gently dipping and well bedded or layered
-often have stiff (stronger) weathered brownish clay crust, underlain by softer (weaker) fresh grey clay
- those that have been uplifted since placement, and subjected to leaching by fresh water are susceptible to rapid failure on very shallow slopes.

Potential Geological Hazards

-landslides, often very extensive, specifically earth slumps and flaws **(Section 3.1.4)**
-these can occur very rapidly and rarely give any indication prior to falling that problems exist
-can be triggered by natural or small scale human activities such as shallow embankments, with little or no warning of immanent collapse

Distribution

-the small scale **Map 2.3** does not allow all glacial marine and marine deposits to be shown
-it is estimated than during and shortly after glaciation, sea levels extended up to approximately 60m above the present sea level, therefore there is the potential to find glacial marine and marine deposits anywhere below elevation 60m above sea level
-well known sites include areas within the Fraser Valley Lowlands, along the east coast of Vancouver Island, and at the heads of a number of coastal inlets, such as Douglas Channel from Kitimat to the Terrace District Airport and in adjacent drainages where they have occurred up to elevations of 120m above sea level

An example of a small rotational earth slump in glacial marine clay

Relatively flat failure surface of marine clay earthflow with lineations of debris

3.6.3 Organic Soils

Brief Description

-accumulations of peat and organic muck found in depressions, along margins of shallow lakes and other areas of high groundwater table
-can be quite thick
-characterized by very high groundwater table and possibly seasonal flooding

Potential Hazards

-ground shaking during an earthquake
-high groundwater table
-corrosion

-although not a geological hazard, building on organic soils without appropriate measures may produce extreme settlement and differential settlement, and embankment failure

Distribution

-the small scale **Section 2, Map 2.3** does not allow areas of organic soils to be shown
-abundant in the central portion of the province north of Prince George, in northern British Columbia, on the Queen Charlotte Lowlands
-elsewhere restricted to relatively small poorly drained areas

High groundwater table in organic soils

3.6.4 Soils in Discontinuous Permafrost and Alpine Permafrost

Brief Description

-permafrost is the thermal condition in soil or rock where temperatures <0 degrees Celsius persist over at least two consecutive winters and the intervening summer (refer to **Appendix A, A2.3**)
-moisture in the form of water and ground ice may or may not be present
-in areas of discontinuous permafrost, permafrost ground conditions exist along with areas of unfrozen ground
-in areas of alpine permafrost, permafrost ground conditions exist as a result of continuous cold temperatures at high elevations

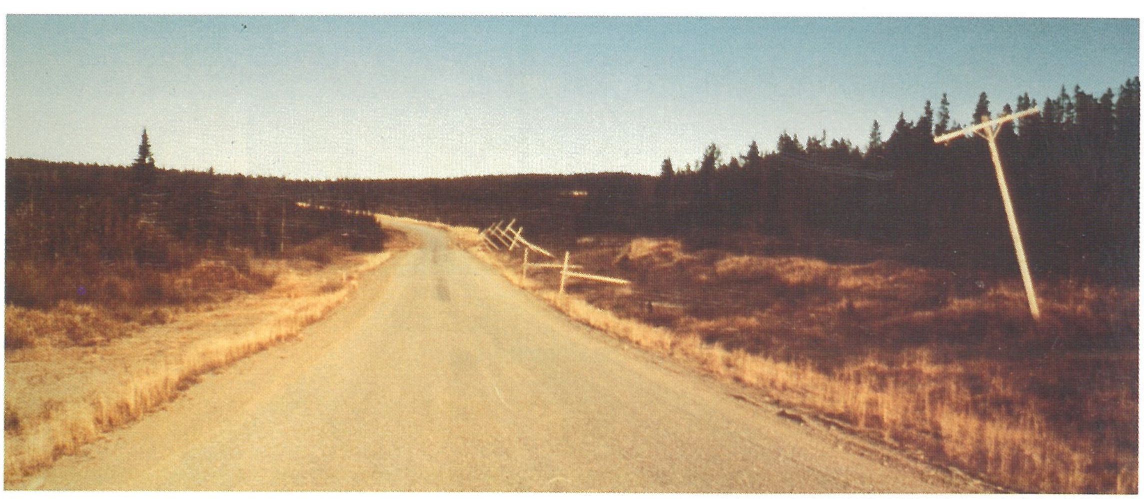
Distribution

-refer to **Section 2, Map 2.3** which shows the general areas of widespread discontinuous permafrost, sporadic discontinuous permafrost and alpine permafrost
-there are no areas of continuous permafrost in British Columbia
-discontinuous permafrost occurs as scattered "islands of permafrost" which range in size from a few square metres to several hectares
-discontinuous permafrost is common in low lying, poorly drained areas and on north-facing slopes
-recognized by poorly drained areas, solifluction on side hills, stunted vegetation, earth hummocks, tilted power/communication poles, differential settlement of structures including roads
-alpine permafrost varies with latitude, with the lower altitude limit decreasing northwards: approximately 2,100 m at the British Columbia-United States border and approximately 1,200 m in the northern portion of the province

Potential Hazards

-discontinuous and alpine permafrost areas become problem conditions where water, in the ground freezes, resulting in ground heaving, or where frozen ground that contains ice, melts, resulting in differential settlement (refer to **Section 3.3.2**)
-fine grained soils are more susceptible to permafrost conditions than coarse grained soils or rock
-solifluction (refer to **Section 3.1.11**)

Ground ice interbedded with frozen silt



Tilted power poles provide a clue that permafrost conditions exist

3.6.5 Made Ground

Brief Description

-made ground can include **engineered fills and embankments**, such as highway fills, earth and rock fill dams, tailings dams, sanitary landfills, and **non-engineered fills and embankments** which are constructed with no design, very little or sorting of materials, and little or no compaction
-may contain organic and/or construction materials
-also includes mine tailings and spoil areas
-some of the older engineered made ground, such as old road fills, older dams and/or garbage dumps, may also be a problem soil

Distribution

-made ground can occur anywhere there has been resource extraction, industry or other forms of construction
-common along shorelines and in poorly drained areas
-usually covers a relatively small geographic area
-recognized by regular topography, straight lines, unusual landforms

Potential Hazards

-unknown materials in fill or embankment
-unknown compaction of fill or embankment
-settlement, collapse, etc.
-contamination potential from material
-methane gas production from materials

An abandoned tailings dam in the Kootenays

SECTION 4: CHECKLIST

This manual addresses natural hazards that are commonly encountered by Development Approvals staff during the assessment of a proposed subdivision of land:

- **landslides**
- **snow avalanches**
- **subsidence**
- **flooding**
- **erosion**
- **problem soils**

The manual is intended to help recognize areas where natural hazards have occurred, are occurring or have the potential for occurring, so they can be avoided during any development.

When assessing an area, the following questions should be considered:

- **Is there evidence of past or ongoing hazards in the area?**
- **Are the conditions in the area suitable for hazards to occur?**

The investigation should not be restricted to the boundaries of the area of interest, but should also look beyond:

- **upslope**
- **downslope**
- **along slope**
- **elsewhere in the watershed**
- **in neighbouring areas with similar conditions**

It is often outside the study area where clues to the relatively safety of the area under study will be found.

In addition, the investigation must not only be limited to existing ground conditions. With time, natural geological processes and development can change the ground conditions. An awareness of conditions or activities that can initiate a natural hazard, or can create the potential for a hazard, is just as important as being able to recognize an existing hazard. Will the development have any impact on the geological conditions off the property, and could these changed conditions lead to a hazard? **Table 4.1** is intended as a mental check list to help determine if development could lead to a hazardous condition on or off the property. If the answer is yes to any of these questions, the Development Approvals staff should notify the Approving Officer and/or contact the Regional Geotechnical and Materials Engineer.

Table 4.2 is intended as a check list when looking for natural hazards. Refer to the appropriate subsections in **Section 3** for more details. If any of the conditions on **Table 4.2** exist, "a red flag" should go up. If a hazard is expected the Development Approvals staff should notify the Approving Officer and/or contact the Regional Geotechnical and Materials Engineer. Remember that all subdivision applications should be referred to the Ministry of Environment, Lands and Parks for review of flooding potential.

Refer to the **Photos on Pages 4.3 to 4.10** for additional clues of existing and potential natural hazards.

Table 4.1: Potential impact of development

Will Development:	Yes	No
Be near any known existing hazard?		
Be near the top or bottom of a bluff, steep slope, or deep excavation?		
Be adjacent to a gully, creek, stream, river, lake, ocean, lowland or wetland?		
Likely undercut any slopes?		
Require the removal of lots of mature trees or other vegetation?		
Add excessive water to the ground, such as through septic fields or irrigation?		
Block or change any existing water course?		
Otherwise lead to changed geological conditions downslope?		

Table 4.2: Things to look for

Natural Hazard	Evidence of Past or Ongoing Hazard	Conditions Suitable for Hazard
Landslides	-fresh rock or soil surfaces on a steep slope -fresh rock or soil piles at the base of a steep slope -tension cracks across a slope -crescent shaped scarps or depressions -hummocky ground, sag ponds -disrupted surface drainages -leaning trees, "drunken" trees, split trees -bulging in the lower portion of a slope -disrupted roads, fences, or other linear features -vegetation, including trees of similar age -scoured channels and valleys, trim lines, levees, or new vegetation in channel bottoms -large fans at the mouths of gullies or creeks -"terracettes" across the slopes, "solifluction lobes"	-steep slope, bedrock bluff, steep soil face or steep excavation -fractured bedrock, loose blocks of soil, tension cracks on a steep slope, bluff, face or excavation -steeply dipping rock fractures -weak rock, masses of rock, or soil -wet to saturated fine grained soil (clay, silt) -distinct planes of weakness -poorly drained slopes, seeps, or springs -steep confined valleys, especially with steep unstable sidewalls -permafrost conditions in the area -sensitive marine clays
Snow Avalanches	-snow in track or runout zone in late spring and early summer -dense and dark snow deposits -obvious openings in the forest cover, especially up and down slope -damaged trees, bent trees, new vegetation, lots of deciduous scrubs	-starting zones: high elevation, steep open or sparsely forested areas, mountain bowls, lee side of ridges -tracks: steep slopes, channels or gullies, sparsely forested -runout zones: open areas below steep slopes or gullies, sparsely forested
Subsidence and Collapse	-land that has settled, unusual surface depressions, sink holes, "bombshell appearance" -structures that have undergone differential settlement -low lying, poorly drained areas	-historic or recent underground workings, or pumping of fluids from the ground -glacial lake silt, limestone, or permafrost ground conditions -piping or karstification (caves) in the area
Flooding	-eroded or scoured channels or valleys -no, or recent, vegetation in channel or valley -marked or damaged trees or structures (high water marks) -debris or flood deposits along, or at mouth of, gully or river, or along shoreline -alluvial fan deposits	-steep confined valleys, especially with steep unstable sidewalls -low lying, poorly drained, high groundwater table areas, especially close to water course or body of water -floodplain or abandoned channel -head of coastal inlets, estuaries
Erosion	-lost ground or evidence of landslides along the channel or shoreline -abrupt changes in flow direction -flood deposits downstream, or along shoreline -large exposed boulders	-steep unstable channel or shore banks -erodible channel banks and beds, or shore banks -land in direct path of moving water or along outside bends of river bends

A steep fractured bedrock face can lead to rock falls

Scattered rock boulders may indicate past rock falls

Crescent shaped tension cracks and/or disrupted fence line indicate imminent slope failure

Hummocky terrain and sag ponds indicate landslide debris

Leaning trees indicate slope movement

"Drunken" trees (trees leaning in all directions) indicate slope movement

Bulging toe and outward leaning trees indicate a rock or earth slump

Hillslope scars and trees of the same age indicate debris slide activity

Levees indicate debris flow activity

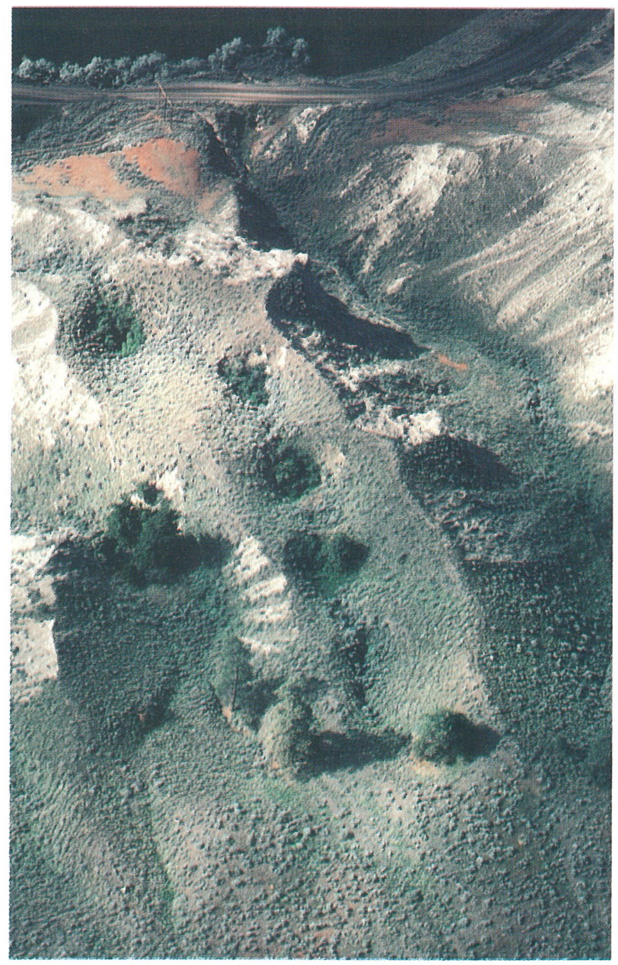
Trim lines indicate the occurrence of a debris flow

A deposit of coarse granular material near the mouth of a gully or creek indicates a debris flow

Recognition of a snow avalanche can be obvious just after one has occurred

Snow avalanche tracks and fans are often first re-established by deciduous trees

Exit hole of an underground water pipe



Typical "bombshell" appearance of an area susceptible to piping and subsidence

Low lying lands along rivers are susceptible to flooding

An example of low lying lands along a river

An alluvial fan may be susceptible to a debris flow

An abrupt change in flow direction may be evidence of channel erosion

An example of erosion along a portion of a reservoir shoreline

Steep, exposed soil banks are susceptible to coastal erosion

APPENDIX A: MORE INFORMATION ON LANDSCAPES

A2.1 Physiography

Table A.1: Brief description of common physiographic units

Physiographic Unit	Brief Description
Mountains/Range	-a number of individual mountains and ridges, dominated by bedrock, generally with ragged summits, and sometimes mantled with glaciers
Highland	-an elevated area, higher than a plateau, dominated by bedrock, in which the summits lack a ragged character
Foothill	-an area containing hills or low mountains, dominated by bedrock, adjacent to a much higher mountain belt
Plateau	-an elevated area in which the summits commonly have gentler slopes than those of nearby incised valleys
Lowland	-a low area commonly mantled by glacial deposits with little or no exposed bedrock
Trench	-an elongated valley, dominated by glacial deposits, generally occupied by streams or rivers
Depression	-an irregular to elongated area of low elevation relative to the surrounding land; some depressions may lie below sea level
Fiord	-a long, narrow, steep-walled, deep inlet or arm of the sea
Plain	-a widespread, uniformly gently sloping surface

References: Clague, 1989; Holland, 1964; Mathews 1986; Ryder, 1986; Slaymaker, 1989

A2.2 Bedrock Geology

Table A.2: Brief description of major rock types

Bedrock Type	Brief Description and Typical Characteristics
Igneous intrusive **Examples: granite, syenite, diorite, granodiorite**	-coarse crystalline rock types formed from igneous magma, molten rock, that has cooled slowly beneath the Earth's surface -relatively strong and resistant to chemical weathering, but can be subject to mechanical weathering, such as frost shattering -fractures in the rock form planes of weakness
Volcanic **Examples: basalt, andesite, tuff, pyroclastics**	-fine crystalline rock types formed from igneous magma, molten rock, erupted from volcanoes (lava) -weaker and less resistant to mechanical and chemical weathering than igneous intrusive rock types -typically contains many fractures which are planes of weakness
Sedimentary **Examples: sandstone, shale, limestone, conglomerate**	-formed by the induration, compaction or lithification of sediments by cementation, pressure and heat -strength and resistance to weathering depends upon composition of original sediment (e.g. shale vs. limestone) and degree of induration -bedding planes and fractures form planes of weakness
Metamorphic **Examples: gneiss, schist, marble, slate**	-formed by metamorphism of pre-existing igneous, sedimentary or other metamorphic rocks under high pressure and/or temperature -strength and resistance to weathering is associated with type of pre-metamorphic rock type -usually stronger and more resistant than the pre-metamorphic rock type, strength and resistance increases with degree of metamorphism -metamorphic fabric can form planes of weakness

Table A.3: Simplified geological time scale

Era	Literal Translation	Approximate Interval in Millions of Years
Cenozoic	Recent Life	65 to the present
Mesozoic	Middle Life	245 to 65
Paleozoic	Old Life	570 to 245
Proterozoic	Before Life	greater than 570

References: BCDOM, 1970; BCMELP, 1990; BCMEMPR (Highway Map) no date; Clague, 1989; Holland, 1964; Ryder, 1986; Tipper et al, 1981; Yorath, 1991

A2.3 Surficial Geology / Glacial Features / Permafrost

Table A.4: Brief description of surficial deposits

Surficial Deposits	Brief Description and Typical Characteristics
Morainal deposits (Till)	-deposited directly from, or by, glacial ice -generally compact, non-sorted and non-stratified sediment containing a wide range of particle sizes (gravel to clay) -geology of till varies greatly and is related to bedrock from where it was derived -higher-elevation tills tend to be more granular (more sand and gravel) than tills found in lowlands and on plateaus -tills cover level to moderately sloping surfaces above the valley floor -most extensive of all surficial material in province
Glacial fluvial deposits	-deposited by meltwater either in contact with glacial ice (e.g. kames and terraces), or beyond the glacial ice (outwash) -most deposits are well bedded -sand and gravel are dominant, some silt and clay may be present -generally well drained material -found in alpine settings, valley sides and valley bottoms
Glacial lake deposits	-deposited in the bottom of lakes that existed during, or shortly after, glaciation -most deposits are flat to gently dipping and well bedded -silt, fine sand and clay are dominant, sand and gravel occur as ancient lake deltas and beaches -if fine grained sediments dominate, deposits can be poorly drained
Glacial marine deposits	-deposited in salt water environments during or shortly after glaciation -some deposits occur on what is now exposed land, when the sea level was higher than present -most deposits are flat to gently dipping and well bedded -clay and silt are dominant, sand and gravel can occur as ancient beaches, spits and bars -if fine grained sediments dominate, deposits can be poorly drained
Colluvial deposits	-deposited by gravitational processes since glaciation -includes all forms of debris resulting from landslides, talus, and slope wash -occur wherever there are steeper slopes -unstratified mixture of many different particle sizes

continued...

continued...

Fluvial (alluvial) deposits	-transported and deposited by streams and rivers since glaciation -well bedded deposits -sand and gravel dominate, particle size depends upon on size (energy) of stream or river, minor silt can occur -can occur along streams and rivers (floodplains and terraces) or where streams emerge from steep valleys onto flatter ground (alluvial fans) -generally well drained
Recent lake and marine deposits	-deposited in the bottom of present day lakes and oceans -most deposits are flat to gently dipping and well bedded -silt, fine sand and clay are dominant -sand and gravel can occur in deltas, beaches, spits, and bars -if fine grained sediments dominate, can be poorly drained -generally soft deposits
Organic deposits	-accumulations of peat formed in depressions, margins of shallow lakes and other areas with high groundwater -abundant in the northern portion of the province (underlain by permafrost) and on the Queen Charlotte Islands -elsewhere restricted to relatively small poorly drained areas -highly compressible, very weak
Recent volcanic deposits	-lava, coarse pyroclastic material, layers of ash consisting of sand, silt and clay size particles -approximately 100 eruptions have occurred in British Columbia and southwestern Yukon in the past 1 million years -variable characteristics

For more detailed maps of the surficial geology of British Columbia, contact Maps BC (Ministry of Environment, Lands and Parks), Geological Survey Branch (Ministry of Energy, Mines and Petroleum Resources) Victoria, and the Geological Survey of Canada, Vancouver.

References: Clague, 1989; French 1989; Johnson, 1981; Prest et al, 1967; Ryder, 1986

A2.4 Precipitation / Climate / Biogeoclimatic Zones

Table A.5 Examples of climatic data

NANAIMO DEPARTURE BAY

49°13'N 123°57'W/O, 8m, 1913 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juill	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année
Temperature													
Daily Maximum (°C)	5.9	7.8	10.0	12.4	16.2	19.4	22.0	22.0	18.8	13.5	8.7	6.2	13.6
Daily Minimum (°C)	1.0	1.9	2.8	4.8	7.9	11.3	13.5	13.7	10.8	7.0	3.5	1.7	6.7
Daily Mean (°C)	3.5	4.9	6.4	8.5	12.1	15.3	17.7	17.9	14.8	10.2	6.0	4.1	10.1
Extreme Maximum (°C)	16.7	17.8	22.2	27.8	30.6	33.9	38.3	36.1	31.0	26.7	19.4	16.0	
Date	953/31+	963/09	941/28	934/23	956/30+	969/17+	941/16	939/08	988/02	952/05	949/03+	980/26	
Extreme Minimum (°C)	-13.9	-12.0	-8.3	-6.7	-1.1	1.7	4.4	1.1	1.1	-4.4	-17.0	-14.0	
Date	950/14	989/04	951/10	929/04	954/01	929/03+	929/23+	925/24	929/24	935/31	985/23	978/31	
Degree-Days													
Above 18 °C	N	0.0	0.0	0.0	N	13.5	36.9	36.5	5.9	0.0	N	N	N
Below 18 °C	N	361.2	362.4	287.5	N	91.3	42.5	39.6	104.4	240.7	N	N	N
Above 5 °C	N	30.4	53.2	103.5	N	312.2	397.4	399.9	291.5	163.1	N	N	N
Below 0 °C	N	0.7	0.2	0.0	N	0.0	0.0	0.0	0.0	0.0	N	N	N
Precipitation													
Rainfall (mm)	120.1	94.9	88.4	51.8	45.8	35.3	26.1	30.4	45.6	87.3	130.4	150.2	906.2
Snowfall (cm)	15.8	9.3	1.5	0.0T	0.0	0.0	0.0T	0.0	0.0	0.2	3.6	10.7	41.2
Precipitation (mm)	139.1	105.2	89.7	51.8	45.8	35.3	26.1	30.4	45.6	87.6	134.7	164.4	955.6
Extreme Daily Rainfall (mm)	67.1	55.0	45.2	35.3	32.5	32.3	37.1	52.1	54.6	63.0	60.7	92.2	
Date	958/22	983/10	971/11	969/03	948/27	971/24	935/30	920/27	953/29	921/28	954/17	937/28	
Extreme Daily Snowfall (cm)	66.0	42.7	21.6	1.3	0.0	0.0	0.0	0.0	0.0	6.0	20.3	45.7	
Date	935/20	923/14	913/23	968/11	990/31+	990/30+	990/31+	990/31+	990/30+	984/31	977/23	937/25	
Extreme Daily Pcpn. (mm)	91.4	55.0	45.2	35.3	32.5	32.3	37.1	52.1	54.6	63.0	60.7	92.2	
Date	935/20	983/10	971/11	969/03	948/27	971/24	935/30	920/27	953/29	921/28	954/17	937/28	
Month-end Snow Cover (cm)	1	0	0	0	0	0	0	0	0	0	0	N	
Days With													
Maximum Temperature >0°C	30	28	31	30	31	30	31	31	30	31	N	30	N
Measurable Rainfall	16	14	14	12	11	9	7	6	9	13	16	16	142
Measurable Snowfall	2	2	*	*	0	0	0	0	0	*	*	2	7
Measurable Precipitation	18	14	14	12	11	9	7	6	9	13	16	18	146

NELSON 2

49°30'N 117°17'W/O, 604m, 1955 to/à 1982

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juill	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année
Temperature													
Daily Maximum (°C)	-0.4	3.4	7.5	13.9	19.1	22.9	26.7	26.2	20.2	12.5	4.8	0.7	13.1
Daily Minimum (°C)	-5.3	-2.9	-1.3	1.9	5.7	9.5	11.8	12.1	8.0	3.7	-0.4	-3.9	3.2
Daily Mean (°C)	-2.8	0.3	3.1	7.9	12.4	16.3	19.3	19.2	14.1	8.2	2.2	-1.5	8.2
Extreme Maximum (°C)	9.4	12.2	18.3	28.3	32.8	35.0	38.3	38.3	33.9	23.3	15.6	9.4	
Date	974/16	968/29+	969/27+	977/25	958/26	974/17+	960/18	967/18	967/01	976/01	975/04	956/10	
Extreme Minimum (°C)	-25.6	-20.0	-15.0	-5.0	-1.7	0.5	4.4	1.1	-0.6	-5.6	-17.2	-29.4	
Date	969/01	956/16	976/04	979/01+	965/06	978/01	976/02	957/30	972/29+	971/29	955/17+	968/30	
Degree-Days													
Above 18 °C	0.0	0.0	0.0	0.0	1.3	N	64.1	N	4.1	0.0	0.0	0.0	N
Below 18 °C	646.4	499.8	465.0	302.3	173.5	N	23.6	N	122.0	304.4	476.4	601.6	N
Above 5 °C	0.2	0.7	11.2	92.5	230.9	N	443.5	N	272.2	105.4	8.2	0.1	N
Below 0 °C	105.3	32.9	10.7	0.0	0.0	N	0.0	N	0.0	0.2	17.6	68.0	N
Precipitation													
Snowfall (cm)	N	N	13.0	1.3	0.0T	0.0	0.0	0.0	0.0	0.1	N	N	N
Extreme Daily Rainfall (mm)	26.2	23.2	19.2	23.8	24.0	30.0	32.6	31.2	25.2	30.0	24.0	24.9	
Date	971/29	981/18	981/21	981/22	981/30	975/24	981/19	974/12	981/29	957/02	978/03	955/22	
Extreme Daily Snowfall (cm)	31.2	34.3	19.1	10.0	0.0	0.0	0.0	0.0	0.0	5.1	23.6	33.5	
Date	978/08	957/22	956/04	982/01	982/02+	982/30+	982/31+	982/31+	982/30+	958/12	971/02	965/26	
Extreme Daily Pcpn. (mm)	31.2	34.3	19.2	23.8	24.0	30.0	32.6	31.2	25.2	30.0	24.0	33.5	
Date	978/08	957/22	981/21	981/22	981/30	975/24	981/19	974/12	981/29	957/02	978/03	965/26	
Month-end Snow Cover (cm)	N	N	N	N	0	0	0	0	0	N	N	N	
Days With													
Maximum Temperature >0°C	15	24	30	30	31	N	31	N	30	31	27	20	N
Measurable Snowfall	N	N	3	*	0	0	0	0	0	*	N	N	N

Exerpt from the Environment Canada, Atmospheric Environment Service publication "Canadian Climate Normals (1961-1990): British Columbia (Environment Canada, 1993)

Table A.6: Brief description of the biogeoclimatic zones

Biogeoclimatic Zone	Brief Description
Alpine Tundra	-alpine zone, treeless region characterized by a harsh climate -associated with high mountains -long cold winters, short cool summers
Spruce-Willow-Birch	-subalpine zone with severe climate -common to northern portion of province -usually found below Alpine Tundra
Boreal White and Black Spruce	-common to northern valleys west of the Rocky Mountains and gently rolling topography of Interior Plains -long cold winters, short cool summers -ground remains frozen for much of the year
Sub-Boreal Pine-Spruce	-common to high plateaus of the west central interior -cold dry climate -rolling landscape, dotted with numerous wetlands
Sub-Boreal Spruce	-common to the central interior -primarily on gently rolling plateaus -climate is severe
Mountain Hemlock	-subalpine zone at high elevations along the Pacific Coast -adverse climate, short summers, high annual snowfall
Engelmann Spruce-Subalpine Fir	-subalpine zone at high elevations in the interior -severe climate with long cold winters and short summers -ground conditions can vary between wet and dry
Montane Spruce	-common to south-central interior at mid-elevations and on plateaus -winters are cold, summers are moderately short and warm
Bunchgrass	-common to lower elevations of the driest and hottest valleys of the southern interior -hot and dry climatic conditions
Ponderosa Pine	-common to a narrow band in the driest and warmest valleys of the southern interior -warm and dry climatic conditions
Interior Douglas-Fir	-common to rain shadows of the Coast and Columbia mountains -warm and dry conditions
Coastal Douglas-Fir	-common to east side of the Vancouver Island Mountains -mild Mediterranean type of climate prevails
Interior Cedar-Hemlock	-common to lower to middle elevations in the interior wet belts -winters are cool and wet, summers are warm and dry
Coastal Western Hemlock	-common to low elevations along the Pacific coast -abundant rainfall and mild temperatures

References: BCMOF, 1988; Environment Canada, 1993; Farley, 1979; Ryder, 1989; Schaefer, 1986

A2.5 Earthquake Activity

Table A.7: Approximate TNT (energy) equivalent of earthquake magnitudes

Magnitude	TNT Equivalent
3	179 kg
4	5.5 tonnes
5	910 tonnes
6	5,700 tonnes
7	181,000 tonnes
8	5,706,000 tonnes
9	181,999,000 tonnes

Earthquake magnitude is an objective measure of the amount of energy released by an earthquake. It is measured by an instrument known as a seismograph. Magnitude is usually expressed by the logarithmic, open ended Richter Scale. Every 1 level increase in the Richter scale is equivalent to a 10 times increase in the energy released by the earthquake. For example, a magnitude 7 earthquake is 100 times (10 x 10) as strong as a magnitude 5 earthquake.

Table A.8: Observations for some Modified Mercelli Scale earthquake intensities

Intensity	Observations
I - II	-barely noticeable
II - III	-feels like vibration from nearby truck
IV - V	-small objects upset; sleepers awakened
VI - VII	-difficult to stand
VII - VIII	-general panic; some walls fail
IX - XI	-wholesale destruction; large landslides
XI - XII	-total damage; waves seen on the ground

Earthquake intensity is a subjective measure of the effect of an earthquake on local residents and construction. Depends on magnitude, distance from epicentre, duration, type of ground, water table, type and quality of construction. It is determined by people's perception of the ground shaking and the damage. It is usually expressed by the Modified Mercelli Scale.

Note, earthquake magnitudes and earthquake intensities cannot be correlated.

Table A.9: Dates and magnitudes of some larger British Columbian recorded earthquakes

Year	Region	Mag.	Comments
1872	Washington-BC border	7.4	-widely felt in BC
1899	Yukon-Alaska border	8.0	-widely felt in northwest BC
1918	Vancouver Island	7.0	-widely felt, damage on west coast of Vancouver Island
1929	South of Qn Charlotte Isl.	7.0	-widely felt, minor damage
1946	Vancouver Island	7.3	-widely felt, most damaging earthquake in Western Canada
1949	Queen Charlotte Islands	8.1	-largest earthquake in Canada, one the world's great earthquakes, minor damage because of sparse population
1949	Washington	7.0	-much damage in Washington and felt in southwest BC
1958	Alaska-BC border	7.9	-damage in Alaska, widely felt in northwest BC
1964	Alaska	9.2	-tsunami damage on Vancouver Island
1965	Seattle area	6.5	-felt by most in the lower mainland
1970	South of Qn Charlotte Isl.	7.4	-felt widely
1976	Washington-BC border	5.4	-felt by most in the lower mainland
1976	West of Vancouver Island	6.8	-felt along west coast of Vancouver Island
1979	S. Yukon-Alaska border	7.5	-felt strongly in southern Yukon
1980	West of Vancouver Island	6.8	-felt along west coast of Vancouver Island
1986	Prince George area	6.0	-felt widely in the interior of BC

Table A.10: Brief description of natural hazards associated with earthquakes

Hazard	Brief Description and Some Impacts
Ground shaking	-vertical and horizontal movement of the ground as earthquake waves pass -depending upon magnitude and duration of ground motions, distance from epicentre and underlying geology, damage or collapse of structures can result -horizontal motions generally cause greatest damage -bedrock is more resistant to shaking than soil; coarse soils are more resistant to shaking than fine
Ground rupture	-the relative displacement of the ground surface, along the main fault of rupture -can be horizontal displacement, vertical displacement, or a combination of both -can also result in localized ground tilting -damage or collapse of structures can result
Liquefaction	-occurs when loosely packed, water-saturated sand loses its strength -often accompanied by cracks in the ground surface and small eruptions of sand (sandboils) -the liquefied mixture (like quicksand) may flow like a fluid -when a soil liquefies, it is unable to support the weight of any soil or structures above it, causing settlement and/or differential settlement -if the liquefied area is on a slope, a landslide may result.
Earthquake induced landslides and avalanches	-earthquakes increase gravitational affects on the slope which increase the probability of a landslides and snow avalanches -also includes submarine landslides -can impact people and property above, on, or below, the landslide
Earthquake induced waves and tsunamis	-earthquakes generate waves around lakes and reservoirs (seiches), and generate tsunamis in the marine environment -depending upon size of the wave, and the geometry and geology of the location where the wave reaches the shore, tsunamis can result in flooding, erosion and destruction
Regional tilting and subsidence	-regional tilting can cause flooding in low-lying areas, can change flow direction of gravity structures such as sewers

Table A.11: Factors affecting damage from an earthquake

Factor	Affect
Magnitude	-the larger the magnitude of an earthquake, the more damage that will result -a moderate earthquake, however, close to a populated area will result in more damage than a large earthquake centered offshore or in a remote area
Intensity	-the earthquake intensity generally decreases rapidly with distance from the epicentre
Duration of ground shaking	-the longer the shaking, the more damage the earthquake can cause -the duration of shaking depends on how the fault breaks during the earthquake, how large a segment of the fault moves, and the underlying geology.
Topography	-steeper topography is more likely to be affected by earthquake induced landslides
Geology underlying the site	-the geology underlying a site has a large influence on the amount of earthquake damage -in most cases, ground shaking on soil will be greater than shaking on rock -shaking will transform some loosely packed, water-saturated sediments, such as sand or poorly compacted fills, into a fluid mass that can no longer support buildings -landslides, especially in areas with marginally stable soil and steep mountainous rock slopes, often result from the ground shaking that accompanies an earthquake
Type, design and construction of a structure	-the type, design and construction of a structure determines how it behaves in an earthquake -generally single story, wood frame houses are relatively flexible and therefore less susceptible to earthquake damage than taller building and those constructed with structural brick -but unless bolted to its foundation, a flexible structure can be dislodged.
Time of day	-the time of day may not change the amount of damage incurred by a structure in an earthquake, but it can have a great impact on personnel injury and even death -during an earthquake, it's not who you know, it's where you are

Table A.12: Acceleration earthquake zones for Highway District Offices

REGION/District	Community	Acceleration Earth- quake Zone (Za)
Fraser Valley	Chilliwack	4
Howe Sound	North Vancouver	4
Lower Mainland	New Westminster	4
Nicola	Merritt	1
Okanagan Shuswap	Vernon	1
South Cariboo	100 Mile House	1
South Okanagan	Penticton	1
Thompson	Kamloops	1
Central Kootenay	Nelson	1
East Kootenay	Cranbrook	1
Kootenay Boundary	Grand Forks	1
Selkirk	Revelstoke	1
Central Cariboo	Williams Lake	1
Fort George	Prince George	0
Nechako	Vanderhoof	0
North Cariboo	Quesnel	0
North Peace	Fort St John	0
Robson	McBride	0
South Peace	Dawson Creek	0
Bulkley Nass	Smithers	1
Lakes	Burns Lake	1
Skeena	Terrace	2
Stikine	Dease Lake	N/A
Central Island	Nanaimo	4
North Island	Courtenay	6
South Island	Victoria (Saanich)	6

For other communities refer to National Building Code, 1990 or contact the Geological Survey of Canada, Sidney

References: Anglin et al, 1990; BCMEMPR, 1991; Lutenhauer et al, 1994; National Building Code, 1990; Nuhfer et al, 1993; Rogers, 1992; Rogers, 1994; State of Utah, 1992

A2.6 Volcanic Activity

Table A.13: Brief description of volcanic belts of British Columbia

Volcanic Belt	Brief Description
Garibaldi **Presumed status: active**	-extends approximately 200 km northward from the BC-Washington border -northward extension of the Cascade volcanoes (Mount St Helens, Mount Baker) -major volcanoes include Mount Meager, Mount Cayley and Mount Garibaldi -volcanoes can be either explosive or lava type -the central portion of the belt is most active -the last eruption was 2,300 years ago at Mount Meager
Anahim **Presumed status: inactive**	-extends across central BC from the coast to the Fraser River -activity becomes progressively younger from west to east -generally lava type volcanoes
Alert Bay **Presumed status: inactive**	-extends across the northern end of Vancouver Island -no volcanoes in past 10,000 years and volcanic activity is presumed ceased
Stikine **Presumed status: active**	-extends northward from the Skeena River to the BC-Yukon border -contains over 50 volcanic centres -volcanoes can be lava type to weakly explosive type -Tseax River Cone erupted about 200 years ago, Canada's youngest volcano
Wrangell **Presumed status: active**	- extends from the panhandle of Alaska, through the extreme northwest portion of BC into the Yukon -most volcanic activity ended about 200,000 years ago, but some recent activity has occurred; two events at 1,200 and 1,800 years before present -volcanoes tend to be explosive type

Table A.14: Possible volcanic hazard versus distance from volcano

Volcanic hazard	Frequency of relative impacts at distances kilometres from volcano					
	<10	10-30	30-100	100-500	500-1000	>1000
Earthquakes and ground deformation	Common	Common	Very rare			
Lava flows	Frequent	Common	Very rare			
Ejected material (projectiles)	Common					
Ash falls	Very frequent	Frequent	Frequent	Common	Rare	
Ash flows	Very frequent	Frequent	Rare	Very rare		
Landslides (other than debris flows)	Very frequent	Frequent	Very rare			
Debris flows	Frequent	Frequent	Rare	Very rare		
Tsunamis	Very frequent	Frequent	Common	Rare	Very rare	
Atmospheric effects	Common	Common	Rare	Very rare	Very rare	
Acid rains and gases	Frequent	Frequent	Rare	Rare	Very rare	Very rare

References: Clague, 1991; Hickson, 1992; Hickson, 1994; Nuhfer et al, 1993

APPENDIX B: PHYSIOGRAPHIC SUMMARY OF LANDSCAPES

Because many of the factors discussed in **Sections 2.2 to 2.6** are related to the physiography of the province, **Tables B.1 to B.18** in this appendix attempts to summarize these factors by **Physiographic Region** under the headings:

- **brief description**
- **bedrock geology**
- **surficial geology/glacial features/permafrost**
- **precipitation/climate/biogeoclimatic zones**
- **earthquake activity**
- **volcanic activity**

Obviously many generalizations have had to be made.

Western System

Table B.1: St. Elias Mountains

Brief description	-in the extreme northwestern part of BC -contains the highest summits, 4,600 to 5,500 m
Bedrock geology	-intrusive igneous rocks; folded and faulted sedimentary and volcanic rocks
Surficial geology/glacial features/permafrost	-morainal, glacial fluvial, colluvial and fluvial deposits -contains numerous glaciers, the largest in BC -widespread alpine permafrost
Precipitation/climate/ biogeoclimatic zones	-1,000-2,500 mm precipitation per year -long cold winters, short cool summers -Alpine Tundra, Spruce-Willow-Birch, Boreal White and Black Spruce
Earthquake activity	-major
Volcanic activity	-Wrangell Volcanic Belt, active

Table B.2: Queen Charlotte Mountains

Brief description	-comprises the western 75% of the Queen Charlotte Islands -highest summits are 1,100 m -includes the Queen Charlotte Ranges and the Skidegate Plateau
Bedrock geology	-folded and faulted volcanic rocks and flat lying volcanic rocks are dominant; some igneous intrusive rocks
Surficial geology/glacial features/permafrost	-morainal, glacial marine, colluvial, and organic deposits -no glaciers or permafrost
Precipitation/climate/ biogeoclimatic zones	-1,000-2,500 mm precipitation per year -cool temperatures throughout the year, cold temperatures at higher elevations -Mountain Hemlock, Coastal Western Hemlock
Earthquake activity	-major
Volcanic activity	-none

Table B.3: Vancouver Island Mountains

Brief description	-comprises most of Vancouver Island -highest summits are 2,000 m -includes the Vancouver Island Ranges, the Alberni Lowlands and the Estevan Coastal Lowlands
Bedrock geology	-folded and faulted volcanic rocks are dominant; igneous intrusive rocks are co-dominant; some folded and faulted volcanic and sedimentary rocks
Surficial geology/glacial features/permafrost	-morainal, glacial fluvial, colluvial, fluvial and organic deposits -a few glaciers -minor alpine permafrost
Precipitation/climate/ biogeoclimatic zones	->2,500 mm precipitation per year -cool temperatures throughout the year, cold at higher elevations -Mountain Hemlock, Coastal Western Hemlock
Earthquake activity	-major
Volcanic activity	-Alert Bay Volcanic Belt, inactive

Table B.4: Hecate Depression

Brief description	-lies between Coast Mountains and Queen Charlotte Mountains -generally below 500 m -includes the Queen Charlotte Lowlands
Bedrock geology	-flat or gently dipping sedimentary and volcanic rocks; igneous intrusive rocks along the mainland coast
Surficial geology/glacial features/permafrost	-morainal, glacial marine and marine deposits -no glaciers or permafrost
Precipitation/climate/ biogeoclimatic zones	-1,000-2,500 mm precipitation per year -cool temperatures throughout the year -Coastal Western Hemlock
Earthquake activity	-major
Volcanic activity	-none

Table B.5: Georgia Depression

Brief description	-lies between Coast Mountains and Vancouver Island Mountains -generally below 500 m -includes the Fraser Valley Lowlands and most of the east side of Vancouver Island (the Nanaimo Lowlands)
Bedrock geology	-flat or gently dipping and sedimentary rocks; igneous intrusive rocks along the mainland coast
Surficial geology/glacial features/permafrost	-morainal, glacial marine, fluvial and marine deposits -no glaciers or permafrost
Precipitation/climate/ biogeoclimatic zones	-1,000-2,500 mm precipitation per year in the north, 500-1,000 mm in the south -cool to mild temperatures throughout the year -Coastal Western Hemlock, Coastal Douglas-Fir
Earthquake activity	-major
Volcanic activity	-Alert Bay Volcanic Belt, inactive

Table B.6: Coast Mountains

Brief description	-extends the length of BC -highest summits are 2,500 to 4,000 m -dissected by many large river valleys, Skeena, Bella Coola, and Homathko -includes fiords along the coast, such as Douglas Channel and Knight Inlet, and includes the Hazelton Mountains
Bedrock geology	-igneous intrusive rocks are dominant; some folded and faulted volcanic and low grade metamorphic rocks
Surficial geology/glacial features/permafrost	-morainal, glacial fluvial , glacial marine, colluvial and fluvial deposits -contains numerous glaciers -widespread alpine permafrost
Precipitation/climate/ biogeoclimatic zones	-1,000->2,500 mm precipitation per year -cool to severe temperatures in the far north; cool temperatures in the south with cold temperatures at higher elevations -Alpine Tundra, Spruce-Willow-Birch dominate in the far north; Mountain Hemlock, Coastal Western Hemlock dominate in the south
Earthquake activity	-major
Volcanic activity	-Garibaldi Volcanic Belt, active; Stikine Volcanic Belt, active; Anahim Volcanic Belt, inactive

Table B.7: Cascade Mountains

Brief description	-extends into the State of Washington -contains mountains such as Mount Baker, Mount St. Helens, Mount Rainer and Mount Hood (all active volcanoes in the US)
Bedrock geology	-folded sedimentary and volcanic rocks; minor igneous intrusive rocks
Surficial geology/glacial features/permafrost	-morainal and colluvial deposits -a few glaciers -minor alpine permafrost
Precipitation/climate/ biogeoclimatic zones	-300-1,000 mm precipitation per year in the north; 1,000-2,500 mm in the south -short cool to warm summers, long cold winters -Mountain Hemlock, Coastal Western Hemlock dominate in the southwest; Engelmann Spruce-Subalpine Fir, Ponderosa Pine dominate elsewhere
Earthquake activity	-major
Volcanic activity	-Garibaldi Volcanic Belt, active

Interior System

Table B.8: Yukon Plateaus

Brief description	-a group of elevated plateaus extending into the Yukon -generally between 1,500 and 1,800 m -composed of a number of smaller plateaus and highlands
Bedrock geology	-folded sedimentary and volcanic rocks; some igneous intrusive rocks
Surficial geology/glacial features/permafrost	-morainal and organic deposits -no glaciers -sporadic discontinuous permafrost
Precipitation/climate/ biogeoclimatic zones	-300-1,000 mm precipitation per year -short cool summers, long cold winters -Spruce-Willow-Birch, Boreal White and Black Spruce dominate
Earthquake activity	-minor
Volcanic activity	-located between Stikine Volcanic Belt and Wrangell Volcanic Belt, both active

Table B.9: Stikine Plateaus

Brief description	-lie between the Coast Mountains and Kaska Mountains -a group of elevated plateaus, extending up to 2,300 m, individual mountains extending up to 2,800 m -composed of numerous smaller plateaus and highlands
Bedrock geology	-folded and non-folded sedimentary and volcanic rocks; minor igneous intrusive rocks
Surficial geology/glacial features/permafrost	-morainal, glacial lake, organic and recent volcanic deposits -no glaciers -sporadic discontinuous permafrost
Precipitation/climate/ biogeoclimatic zones	-500-2500 mm precipitation per year in the west, 300-1000 mm in the east -short cool summers, long cold winters -Engelmann Spruce-Subalpine Fir in the west, Spruce-Willow-Birch, Boreal White and Black Spruce in the east
Earthquake activity	-major
Volcanic activity	-Stikine Volcanic Belt, active

Table B.10: Skeena Mountains

Brief description	-bordered by Coast Mountains, Stikine Plateaus, Kaska Mountains and Interior Plateaus -highest summits are 2,300 to 2,500 m -includes the Nass Depression
Bedrock geology	-flat or gently dipping sedimentary rocks
Surficial geology/glacial features/permafrost	-morainal, colluvial and organic deposits -no glaciers -alpine permafrost
Precipitation/climate/ biogeoclimatic zones	-500-1,000 mm precipitation per year -short cool summers, long cold winters -Alpine Tundra, Spruce-Willow-Birch, Engelmann Spruce-Subalpine Fir dominate at elevation, Interior Cedar-Hemlock dominate in the valleys
Earthquake activity	-minor
Volcanic activity	-Stikine Volcanic Belt, active

Table B.11: Kaska Mountains

Brief description	-lies between the Stikine Plateaus, Skeena Mountains and the Rocky Mountain Trench -highest summits are 2,600 m -includes the Carrier and Omineca Mountains
Bedrock geology	-igneous intrusive rocks surrounded by folded and faulted volcanic and sedimentary rocks; low grade metamorphic rocks
Surficial geology/glacial features/permafrost	-morainal, colluvial and organic deposits -no glaciers -sporadic discontinuous permafrost in the north; alpine permafrost in the south
Precipitation/climate/ biogeoclimatic zones	-500-1,000 mm precipitation per year -short cool summers, long cold winters -Alpine Tundra, Spruce-Willow-Birch, Boreal White and Black Spruce dominate in the north; Engelmann Spruce-Subalpine Fir, Sub-boreal Spruce dominate in the south
Earthquake activity	-very minor
Volcanic activity	-Stikine Volcanic Belt, active

Table B.12: Interior Plateaus

Brief description	-includes the southern 2/3s of the interior of BC -generally rolling glaciated terrain -dissected by many large rivers, such as the Fraser and Thompson -composed of numerous smaller plateaus and highlands
Bedrock geology	-on the plateaus: flat or gently dipping volcanic and sedimentary rocks; minor igneous intrusive rocks -in the highlands: low grade metamorphic rocks are dominant; minor volcanic, sedimentary and igneous intrusive rocks
Surficial geology/glacial features	-morainal, glacial lake, fluvial lake and recent volcanic deposits -no glaciers -some alpine permafrost in the northern portion
Precipitation/climate/ biogeoclimatic zones	-300-1,000 mm precipitation per year in the north, drier to very dry in some locations in the south -cold winters, warm to hot summers -Sub-boreal Spruce, Sub-boreal Pine-Spruce, Montane Spruce dominate the north; Interior Douglas-Fir, Engelmann Spruce-Subalpine Fir, Montane Spruce, Ponderosa Pine, Bunchgrass dominate the south
Earthquake activity	-minor
Volcanic activity	-Anahim Volcanic Belt, inactive

Table B.13: Columbia Mountains

Brief description	-lies between the Interior Plateaus and the southern Rocky Mountain Trench -highest summits are 3,500 m -composed of the Cariboo, Monashee, Selkirk and Purcell Mountains separated by a series of valley lakes including Arrow, Slocan and Kootenay
Bedrock geology	-folded and faulted sedimentary and minor volcanic rocks; low to high grade metamorphic rocks
Surficial geology/glacial features/permafrost	-morainal, glacial fluvial, colluvial and fluvial deposits -some glaciers -discontinuous alpine permafrost
Precipitation/climate/ biogeoclimatic zones	-500-2500 mm precipitation per year, >2500 mm in isolated locations -warm summers, cool to cold winters, colder at higher elevations Alpine Tundra, Engelmann Spruce-Subalpine fir dominate at elevation; Interior Cedar Hemlock dominate in the valleys
Earthquake activity	-minor
Volcanic activity	-none

Table B.14: Rocky Mountain Trench

Brief description	-extends almost 1400 km from the 49th parallel to the BC-Yukon border -includes the western portion of the Laird Lowland in the north
Bedrock geology	-glacial sediments are dominant overlying folded sedimentary and minor volcanic rocks; sedimentary rocks in the Laird Lowland
Surficial geology/glacial features/permafrost	-glacial fluvial, glacial lake, fluvial, lake and organic deposits -no glaciers -widespread discontinuous permafrost in the far north; sporadic discontinuous permafrost in the north
Precipitation/climate/ biogeoclimatic zones	-300-500 mm precipitation in the north and south, 500-2,500 mm in the central portion -warm summers, cool to cold winters -Boreal White and Black Spruce, Spruce-Willow-Birch dominate the northern 1/3, Sub-boreal Spruce dominates the central 1/3; Interior Cedar-Hemlock, Interior Douglas-Fir, Ponderosa Pine dominate the southern 1/3
Earthquake activity	-minor
Volcanic activity	-none

Eastern System

Table B.15: Mackenzie Mountains

Brief description	-small area in the northeast portion of BC extending into the Yukon -includes the eastern portion of the Liard Lowland
Bedrock geology	-folded sedimentary and minor volcanic rocks
Surficial geology/glacial features/permafrost	-morainal, colluvial and organic deposits -no glaciers -some widespread and sporadic discontinuous permafrost
Precipitation/climate/ biogeoclimatic zones	-300-500 mm precipitation per year -short cool summers, long cold winters -Boreal White and Black Spruce
Earthquake activity	-very minor in BC portion, minor in the Yukon
Volcanic activity	-none

Table B.16: Franklin Mountains

Brief description	-small area in the northeast portion of BC extending into the Yukon -includes the Liard Plateau
Bedrock geology	-folded sedimentary and minor volcanic rocks
Surficial geology/glacial features/permafrost	-morainal, colluvial and organic deposits -no glaciers -sporadic discontinuous permafrost
Precipitation/climate/ biogeoclimatic zones	-300-500 mm precipitation per year -short cool summers, long cold winters -Spruce-Willow-Birch, Boreal White and Black Spruce
Earthquake activity	-very minor
Volcanic activity	-none

Table B.17: Rocky Mountains

Brief description	-extends almost the entire length of BC -highest summits are 2,500 to 3,500 m, relief of 1,200 to 1,500 m -includes the Rocky Mountain Foothills to the east
Bedrock geology	-folded and faulted sedimentary and minor volcanic rocks; low grade metamorphic rocks
Surficial geology/glacial features/permafrost	-morainal, glacial fluvial, colluvial, and fluvial deposits -contains many glaciers -sporadic discontinuous permafrost in the north, alpine permafrost in the south
Precipitation/climate/ biogeoclimatic zones	-500-2,500 mm precipitation per year -cool to severe temperatures in the far north; cool temperatures in the south with cold temperatures at higher elevations -Alpine Tundra, Spruce-Willow-Birch dominate the northern 1/3; Alpine Tundra, Engelmann Spruce-Subalpine Fir dominate the central 1/3; Alpine Tundra, Engelmann Spruce-Subalpine Fir, Interior Cedar-Hemlock dominate the southern 1/3
Earthquake activity	-very minor
Volcanic activity	-none

Interior Plains System

Table B.18: Alberta Plateau

Brief description	-in the northeastern portion of BC -generally flat to gently rolling, between 900 and 1,200 m elevation -physiographically part of the prairies
Bedrock geology	-flat to gently dipping sedimentary rocks
Surficial geology/glacial features/permafrost	-morainal, glacial lake, fluvial and organic deposits -no glaciers -sporadic discontinuous permafrost in the north
Precipitation/climate/ biogeoclimatic zones	-500-1,000 mm precipitation per year in the west, 300-500 mm in the east -short cool summers, long cold winters -Boreal White and Black Spruce
Earthquake activity	-none
Volcanic activity	-none

APPENDIX C: MORE INFORMATION ON NATURAL HAZARDS

C3.1 Landslides

References: BCMEMPR, 1993; Carson and Bovis, 1989; Chatwin et al, 1994; Clague, 1991; Cruden et al, 1989; Evans, 1992; Evans and Gardner, 1989; Evans and Savigny, 1994; Nuhfer et al, 1993; Rib and Laing, 1978; VanDine, 1992; Varnes, 1978.

C3.2 Snow Avalanches

References: BCMOF, 1992; Freer and Schaerer, 1980; McClung and Schaerer, 1993; Perla and Martinelli, 1978.

C3.3 Subsidence

For specific reference to the underground coal workings beneath the Nanaimo area, refer to Island Geotechnical Services, 1979.

References: Association of Engineering Geologists, 1987; Island Geotechnical Services, 1979; Johnson, 1981; Nuhfer et al, 1993; State of Utah, 1992.

Map C.1 , at the end of this appendix, shows the **Relative Tsunami Hazard Potential** along the coast of British Columbia. All low lying coastal areas are subject to some tsunami hazard potential. The more exposed coastal areas, especially at the heads of coastal inlets are subject to high tsunami hazard potential. The actual hazard depends on many factors including:

- **the location of the earthquake**
- **the magnitude of the earthquake**
- **the type of earthquake faulting**
- **the geometry of the geographic area**
- **the geometry of the shoreline**
- **the geology of the area**

References: Barlow, 1993; Environment Canada-BC Environment, 1991; Luttmerding et al, 1990; Nuhfer et al, 1993; Thurber, 1983.

C3.4 Flooding

Table C.1, at the end of this appendix, is the **Index of Designated Floodplain Areas in British Columbia**, as compiled by the Ministry of Environment, Lands and Parks, September, 30, 1994. These are areas which have been identified, mapped and designated as having a serious flood risk. The maps show the areas potentially affected by the "200-year flood". These maps **do not** consider:

- smaller tributary streams
- any downstream damming of the stream or river by a landslide or ice
- breaching of upstream natural dam, landslide dam or man-made dam (it is assumed that recently constructed dams are designed for a flood greater than the "200-year flood")

These maps depict dyked areas as potentially flooded lands. The individual maps also provide further information.

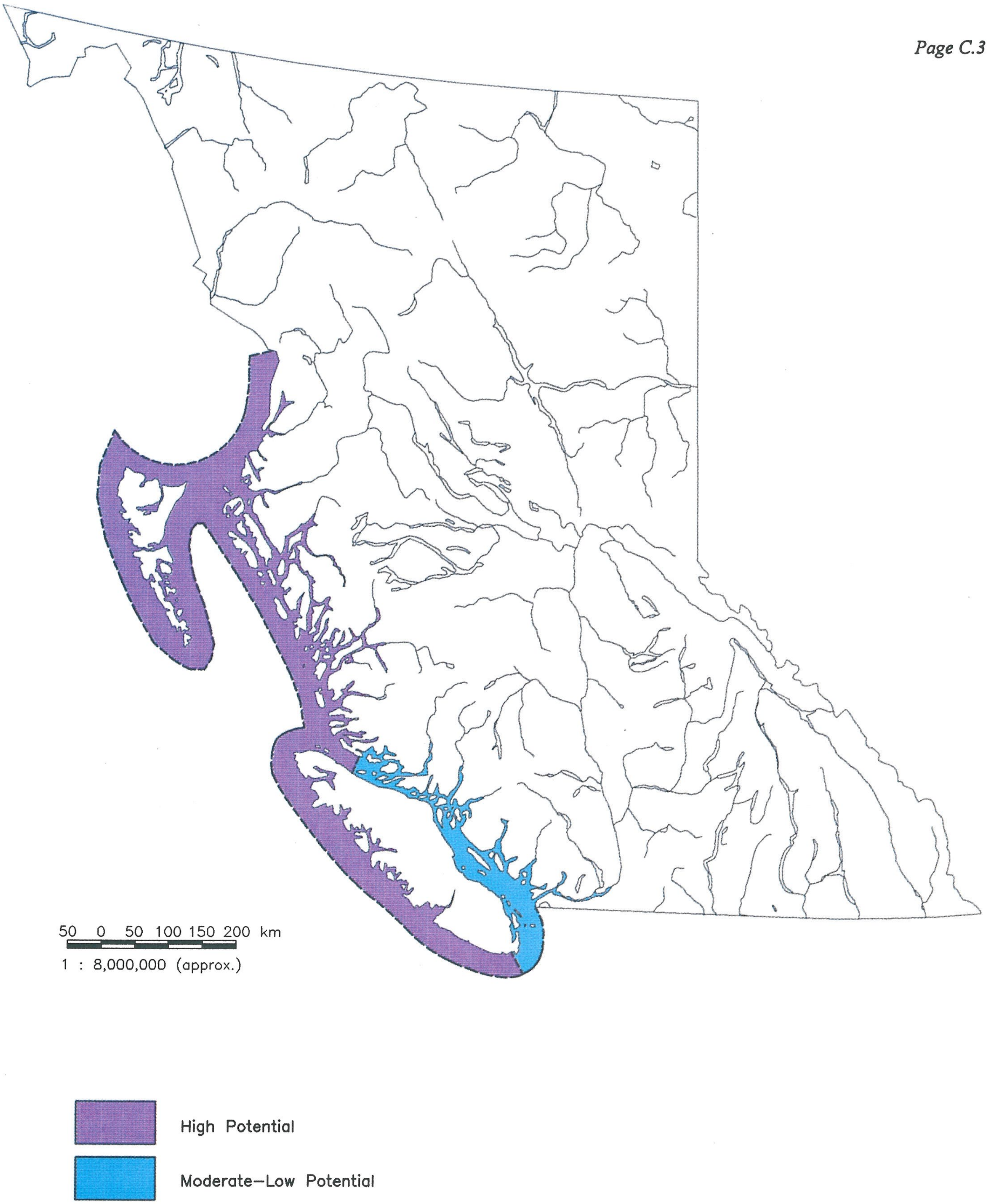
For more information, contact the Ministry of Environment, Lands and Parks, Water Management Division.

C3.5 Erosion

References: Clague, 1991, Nuhfer et al, 1993.

C3.6 Problem Soils

References: Buchanan and Haughton; 1980; Johnson, 1981.



MAP C.1 RELATIVE TSUNAMI HAZARD POTENTIAL

Table C.1

INDEX OF DESIGNATED FLOODPLAIN AREAS IN THE PROVINCE OF BRITISH COLUMBIA		
DESIGNATED AREA (Alphabetically)	DRAWING NUMBER	DESIGNATION DATE
Alouette and North Alouette Rivers	89-44 1&2	91/09/30
Alpha Lake* (see Whistler Area)	89-16 1 to 4	93/09/30
Alta Creek* (see Whistler Area)	89-16 1 to 4	93/09/30
Baker Creek* (see Fraser & Quesnel River)	89-43 1 to 5	92/09/30
Bear River at Stewart*	91-30 1&2	93/09/30
Beaver Creek - Beaver Falls to Meadows	88-35 1 to 5	90/03/31
Bella Coola River*	87-56 1 to 10	89/09/30
Birkenhead River (see Lillooet River)	88-44 1 to 11	90/09/30
Buck Creek (see Bulkley River at Houston)	85-14 1 to 3	87/12/03
Bulkley River (see Skeena & Bulkley Rivers at Hazelton	91-1 Sheet 1	94/09/30
Bulkley River at Houston (including Buck Creek)	85-14 1 to 3	87/12/03
Bulkley River: Quick Area*	86-23 1 to 4	88/09/30
Bulkley and Telkwa Rivers: Smithers - Telkwa	84-68 1 to 8	87/12/03
Campbell and Quinsam Rivers	88-28 1 & 2	90/03/31
Cheakamus River	85-15 1 to 3	87/12/03
Chemainus River	89-10 1 to 3	91/09/30
Chilliwack River: Vedder Crossing - Slesse Creek	A5283 1 to 6	87/12/03
Christina Lake	89-1 1 to 5	91/09/30
Coldwater River (see Nicola R. - Canford to Nicola L.)	87-22 1 to 7	89/09/30
Columbia Lake (see Kootenay R. at Canal Flats)	89-41 1 to 8	91/09/30
Columbia River: Columbia Lake to Windermere Lake	A5286 1 to 6	87/12/03
Columbia River at Golden	A5186 1 to 4	87/12/03
Columbia River at Revelstoke	5514 1 to 5	87/12/03
Columbia River: Windermere Lake - Radium	A5296 1 to 9	87/12/03
Copper River (see Zymoetz R.)	84-63 Sheet 1	87/12/03
Coquihalla River at Hope*	85-27 Sheet 1	88/09/30
Coquitlam River: Coquitlam Lake - Fraser River	5148 1 to 7	87/12/03
Courtenay, Puntledge and Tsolum Rivers	89-13 1 to 7	91/09/30
Cowichan Lake	84-33 1 to 6	87/12/03
Cowichan and Koksilah Rivers at Duncan	A5293 1 to 5	87/12/03
Crawford Creek: Alluvial Fan	86-4-3 Sheet 1	88/09/30
Dutch Creek (see Columbia R: Columbia L. to Windermere L)	A5286 1 to 6	87/12/03
Eagle River	A5187 1 to 7	87/12/03
Elk River near Elkford*	87-30 1 to 7	89/09/30
Elk River at Fernie	A5196 1 to 7	87/12/03
Elk River at Sparwood	A5196 1a & 2a	87/12/03
Englishman River	85-23 1 to 7	87/12/03
Erie Creek (see Salmo River)	90-32 1 to 9	91/09/30
Fraser River near Hope*	87-1 Sheet 1	88/09/30
Fraser and Nechako Rivers: Prince George Area	5419 1 to 4	87/12/03
Fraser and Quesnel Rivers at Quesnel*	87-43 1 to 5	92/09/30
Goat River at Creston	84-42 1 & 2	87/12/03
Granby River (see Kettle and Granby Rivers)	90-34 1 to 9	92/09/30
Green River (see Lillooet River)	88-44 1 to 11	90/09/30
Green River (see Whistler Area)*	89-16 1 to 4	93/09/30
Hirsch Creek (see Kitimat River)	A5328 1 to 11	87/12/03
Illecillewaet River (see Columbia River at Revelstoke)	5514 1 to 5	87/12/03
Kaslo River at Kaslo	5521 Sheet 1	87/12/03
Kettle and Granby Rivers	90-34 1 to 9	92/09/30
Kitimat River	A5328 1 to 11	87/12/03
Kitsumkalum River (see Skeena R.: Lakelse - Terrace - Usk)	5375 1 to 13	87/12/03

***Interim Designated**

INDEX OF DESIGNATED FLOODPLAIN AREAS IN THE PROVINCE OF BRITISH COLUMBIA		
DESIGNATED AREA (Alphabetically)	DRAWING NUMBER	DESIGNATION DATE
Koksilah River (see Cowichan River)	A5293 1 to 5	87/12/03
Kootenay River: Columbia Lake at Canal Flats	89-41 1 to 8	91/09/30
Kootenay River: Kootenay Lake - U.S. Border	A5278 1 to 6	90/09/30
Lakelse River and Lake	88-29 1 to 6	90/09/30
Leiner River (see Tahsis and Leiner Rivers)	89-15 1 & 2	92/09/30
Lillooet River	88-44 1 to 11	90/09/30
Little Slocan River (see Slocan River)	88-26 1 to 11	90/03/31
Mamquam River (see Squamish River)	5461 1 to 10	87/12/03
McKelvie Creek (see Tahsis and Leiner Rivers)	89-15 1 & 2	92/09/30
Millar Creek (see Whistler Area)*	89-16 1 to 4	93/09/30
Miller Creek (see Lillooet River)	88-44 1 to 11	90/09/30
Mission Creek	84-43 1 to 3	87/12/03
Nahounli Creek* (see Stuart River and Lake)	89-42 1 to 7	91/09/30
Nanaimo River	84-29 1 to 3	87/12/03
Nechako River (see Fraser R: Prince George area)	5419 1 to 4	87/12/03
Nechako River at Vanderhoof	5531 1 to 3	87/12/03
Necoslie River* (see Stuart River and Lake)	89-42 1 to 7	91/09/30
Nicomekl River (see Serpentine and Nicomekl Rivers)	91-5 1 to 14	94/09/30
Nicola River: Canford to Nicola Lake	87-22 1 to 7	89/09/30
Nicola River: Spences Bridge to Canford*	87-22 8 to 15	89/09/30
Nita Lake* (see Whistler Area)	89-16 1 to 4	93/09/30
North Alouette River (see Alouette River)	89-44 1 & 2	91/09/30
North Thompson River: Kamloops - Vavenby	A5302 2 to 48	87/12/03
Okanagan Lake: Westbank to Peachland	A5289 83 to 90	87/12/03
Okanagan River: Osoyoos to Penticton*	89-12 1 to 12	93/09/30
Osoyoos Lake* (see Okanagan River: Osoyoos to Penticton)	89-12 1 to 12	93/09/30
Otter Creek and Lake (see Tulameen River)	A5294 1 to 4	87/12/03
Oyster River*	5532 1 to 3	88/09/30
Peace River: B.C./Alberta Border to Site "C"	85-37 1 to 6	88/09/30
Pemberton Creek (see Lillooet River)	88-44 1 to 11	90/09/30
Puntledge River (see Courtenay, Puntledge and Tsolum R.)	89-13 1 to 7	91/09/30
Quamichan Lake (see Cowichan R.)	A5293 1 to 5	87/12/03
Quatse River*	89-7 1 & 2	94/09/30
Quesnel River* (see Fraser and Quesnel Rivers)	89-43 1 to 5	92/09/30
Quinsam River (see Campbell and Quinsam R.)	88-28 1 & 2	90/03/31
Ryan River (see Lillooet River)	88-44 1 to 11	90/09/30
Salmo River including Erie Creek	90-32 1 to 9	91/09/30
Salmon River: Salmon Arm - Spa Creek	89-14 1 to 6	91/09/30
Salmon River: Spa Creek - Falkland	89-14 7 to 14	92/09/30
Salmon River near Prince George*	86-1 1 & 2	88/09/30
Salmon and White Rivers	A5282 1 to 6	87/12/03
Serpentine and Nicomekl Rivers	91-5 1 to 14	94/09/30
Seymour River at Seymour Arm*	89-11 1 & 2	91/09/30
Shawnigan Lake*	A5250 1 to 3	88/09/30
Shuswap River: Mara Lake to Mabel Lake	A5241 1 to 17	87/12/03
Silverhope Creek (see Fraser R. near Hope)	87-1 Sheet 1	88/09/30
Skaha Lake* (see Okanagan River: Osoyoos to Penticton)	89-12 1 to 12	93/09/30
Skeena and Bulkley Rivers at Hazelton	91-1 Sheet 1	94/09/30
Skeena River: Lakelse - Terrace - Usk	5375 1 to 13	87/12/03
Slocan River	88-26 1 to 11	90/03/31
Somenos Lake (see Cowichan River)	A5293 1 to 5	87/12/03

*** Interim Designated**

INDEX OF DESIGNATED FLOODPLAIN AREAS IN THE PROVINCE OF BRITISH COLUMBIA		
DESIGNATED AREA (Alphabetically)	DRAWING NUMBER	DESIGNATION DATE
South Thompson River: Kamloops - Chase	5113 1 to 15	87/12/03
Squamish River: Howe Sound - High Falls Creek	5461 1 to 10	87/12/03
Stuart River and Lake at Fort St. James*	89-42 1 to 7	91/09/30
Tahsis and Leiner Rivers - Village of Tahsis	89-15 1 & 2	92/09/30
Telkwa River (see Bulkley and Telkwa Rivers)	84-68 1 to 8	87/12/03
Thompson and North Thompson Rivers Kamloops Area	5112 1 to 19	87/12/03
Toby Creek (see Columbia R.: Columbia L. to Windermere)	A5286 1 to 6	87/12/03
Tsloum River (see Courtenay, Puntledge and Tsolum Rivers)	89-13 1 to 7	91/09/30
Tulameen River at Tulameen	A5294 1 to 4	87/12/03
Vasseux Lake* (see Okanagan River: Osoyoos to Penticton)	89-12 1 to 12	93/09/30
Vedder River	85-53 1 & 2	87/12/03
Whistler Area*	89-16 1 to 4	93/09/30
Williams Lake	89-46 1 & 2	90/09/30
Zeballos River*	89-45 Sheet 1	92/09/30
Zymoetz (Copper) River	84-63 Sheet 1	87/12/03
Zymagotitz River (see Skeena River: Lakelse - Terrace - Usk)	5375 1 to 13	87/12/03

***Interim Designated**

APPENDIX D: GLOSSARY

Many of the following words and terms have meanings in addition to those provided. The meanings provided are those associated with geological hazards. If there are other words or terms used in this manual with which you are unfamiliar, please contact the Regional Geotechnical and Engineering Office, or Geotechnical and Materials Branch in Victoria.

Abandoned channel - A surface channel along which water no longer flows, such as on an alluvial fan or on a floodplain.

Active mitigation - A method of reducing the likelihood of occurrence of a hazard, or the consequences of a hazard, by methods that involve action, such as prevention or remediation of the hazard, or by designing protection to reduce the consequences. The opposite of passive mitigation.

Alluvial deposit - An accumulation of predominantly coarse grained soils, deposited during post glacial time by running water, such as a stream or river, in the bottom of the water course, on a floodplain or delta, or on a fan at the base of a mountain slope. The material is generally well sorted and stratified. Also referred to as a fluvial deposit.

Alluvial fan - A relatively flat to gently sloping landform composed of predominantly coarse grained soils, shaped like an open fan or a segment of a cone, deposited by a stream where it flows from a narrow mountain valley onto a plain or broad valley, or wherever the stream gradient suddenly decreases.

Alpine permafrost - A permafrost condition that occurs in mountainous areas and varies with altitude as well as latitude. At the 49th parallel alpine permafrost is found approximately 2100 m above sea level, while in northern British Columbia, it is found as low as 1200 m above sea level.

Annual probability of occurrence - The statistical chance or likelihood of a particular event occurring in any given year.

Avulsion - An abrupt change in the course of a stream whereby the stream leaves its old channel for a new one.

Backwater effect - An upstream increase in the level of a stream or river, produced when the water flow is slowed down by an obstruction, such as a dam, a larger river in flood or high tide.

Bank erosion - A loosening and wearing away of soil and rock by water from the edge of a body of water, usually resulting in an enlargement of the body of water.

Bed erosion - A loosening and wearing away of soil and rock by water from the bottom of a body of water, usually resulting in a deepening of the body of water.

Bedrock - A generally older, harder naturally occurring material that has undergone some rock-forming processes. From an engineering viewpoint, bedrock cannot be broken down by hand, or during one wetting and drying cycle.

Biogeoclimatic zone - A geographic area with relatively consistent characteristics of geography, climate, plant and animal life.

Bluff - A high, steep bank.

Bombshell appearance - The pitted land surface, most often resulting from piping and subsidence of soils.

Breach - A gap or break in a dam, dike or embankment, often resulting from overtopping and erosion by water.

Cat steps - see **Sheep tracks**

Chance of occurrence - see **Probability of occurrence**.

Channel bank erosion - A loosening and wearing away of soil and rock by water from the side of a channel, usually resulting in lateral shifting of the channel.

Channel bed erosion - A loosening and wearing away of soil and rock by water from the bottom of a channel, usually resulting in deepening of the channel.

Channel erosion - A loosening and wearing away of soil and rock by water flowing in a well-defined drainage course.

Channel scar - An arc-shaped landform resulting from water erosion of a channel bank.

Coarse grained soil - A textural term for soil in which sand and/or gravel predominate. The soil grains are gritty to the touch and large enough to be visible to the naked eye. Coarse grained soil can be further subdivided into fine sand, sand, coarse sand, gravel, pebbles, cobbles and boulders.

Collapse - A sinking or caving in of soil or rock at the surface, usually the result of natural underground erosion, or underground excavation.

Colluvial deposit - An accumulation of loose, heterogeneous mixture of soil and/or rock fragments deposited by any gravitational process, usually at the base of steeper slopes. The deposit is generally unsorted and unstratified.

Colluvial fan - see **Debris flow fan**.

Complex - A type of landslide movement that is best described by combination of two or more other types of landslide movement. For example a debris slide-debris flow is a complex type of landslide.

Conifer - Any of a large family of evergreen shrubs and trees, characterized by needle-shaped leaves and cones, such as pines, firs, hemlocks and spruces.

Consequence - An estimate of the impact of a hazard, the severity of the damage, or the loss to social, economic and/or resource values.

Creep - A slow, more or less continuous type of downslope landslide movement of soil and rock under gravitational stresses. It often occurs on an open slope.

Cut - An excavated slope from which material has been removed. Also refers to the material excavated.

Debris - An accumulation of loose, predominantly coarse grained soil and rock fragments, and sometimes with large organic material such as limbs and trunks of trees, that have become mixed together in an unsorted fashion. Sometimes the term is used to refer solely to organic material, as in "logging debris".

Debris fall - A type of landslide characterized by the free falling, leaping, bounding and rolling of predominately coarse grained soil and rock fragments.

Debris flow - A type of landslide characterized by water-charged, predominantly coarse grained soil and rock fragments, and sometimes large organic material, flowing rapidly down a pre-existing channel. Sometimes referred to as channellized debris flow, debris torrent, or mudflow.

Debris flow fan - A relatively steep sloping landform shaped like an open fan or a segment of a cone, deposited by a debris flow where it exits from a narrow mountain valley onto a plain or broad valley, or wherever the channel gradient suddenly decreases. Sometimes referred to as colluvial fan.

Debris slide - A type of landslide characterized by the relatively rapid downslope movement of predominantly coarse grained soil, rock fragments and overlying vegetation, in which the mass does not show backward rotation but slides or rolls downslope. Usually relatively thin, long and narrow.

Debris torrent - see **Debris flow**

Deciduous tree - Any of a large family of shrubs and trees, such as maple, birch, cottonwood and alder, whose leaves shed annually.

Delta - A low, nearly flat, alluvial landform deposited in deeper water at the mouth of a river, sometimes forming a triangular or fan-shaped plain, and crossed by a number of distributaries of the main channel.

Depression - A low lying area surrounded by higher ground, often poorly drained or having no natural outlet for surface drainage.

Differential settlement - Non-uniform or uneven lowering of different parts of an engineering structure, often resulting in damage to the structure. Among other reasons, it can occur when frozen ground melts.

Dip - A geological term for the angle that a planar feature, such as a bedding plane or fault plane, makes with the imaginary horizontal plane. The dip is measured in the vertical plane, perpendicular to the "strike" of the structure.

Discontinuous permafrost - A condition where permafrost exists along with patches or "islands" of unfrozen ground. Discontinuous permafrost occurs as intermediate zones between the northerly continuous permafrost and the southerly sporadic permafrost.

Driving force - A force composed of gravity, and possibly other external forces due to earthquakes, wind and/or human activities, that applies stresses to slope materials. If greater than the resisting force, a landslide will occur.

Drunken trees - A group of trees leaning in all directions. Drunken trees can occur on flat permafrost-rich terrain as well as on steep terrain influenced by landslides. Also referred to as jackstrawed trees.

Earth - Generic unconsolidated material overlying bedrock. Sometimes used synonomously with soil. With respect to landslides, earth refers to predominately fine grained soils (silt and clay).

Earth creep - A type of landslide characterized by the slow, more or less continuous downslope movement of fine grained soils.

Earth fall - A type of landslide characterized by the free falling, leaping, bounding or rolling of predominantly fine grained soil or blocks of fine grained soils.

Earth flow - A type of landslide, generally relatively large, characterized by the downslope flow of predominantly fine grained soils. The viscous-like movement is relatively slow.

Earth slump - A type of landslide characterized by the curved backward rotation in a mass of predominantly fine grained soils.

Earthquake - A shaking motion or trembling of the Earth caused when stress, built up within the Earth's crust, is released suddenly.

Earthquake zone - A geographic area in which, based upon past and predicted earthquake occurrence, the predicted peak ground acceleration and hence the earthquake hazard is similar. In Canada there are 7 zones (0 to 6), the higher the number, the more severe the potential earthquake hazard.

Epicentre - A point on the Earth's surface that is directly above where an earthquake occurred.

Era - A geologic time unit, shorter than an eon, into which geological time periods are grouped.

Erosion - A process or group of processes whereby surface soil and rock is loosened, dissolved or worn away, and moved from one place to another, by natural processes. Erosion usually involves relatively small amounts of material at a time, but over a long time can involve very large volumes of material.

Estuary - A landform at the seaward end, or the widened funnel-shaped tidal mouth, of a river valley where fresh water comes into contact with sea water and where tidal effects are evident.

Explosive volcano - An eruptive type of a volcano characterized by the energetic ejection of pyroclastic materials. Mount St Helens is an example of an explosive volcano.

Fall - A very rapid downward movement of a mass soil or rock that travels through the air by free fall, leaping, bounding or rolling, with little or no interaction between one moving unit and another.

Fault - A fracture or a zone of fractures, usually in rock, along which there has been movement relative to one another. An example of a very large fault is the San Andreas Fault in California.

Fetch - An area of open water over which the wind can blow with constant speed and direction, and thereby create a large wave system.

Fill - see **Made Ground**

Fine grained soil - A textural term for soil in which clay and/or silt predominate. The soil grains do not feel gritty to the touch and are too small to be visible to the naked eye.

Flood deposit - An accumulation of soil along a river or around a lake, deposited as the result of flooding. It is generally thickest near the river or the lake, and thins outwards.

Flood fringe - The strip of land on both sides of a river, and relatively far away from the river, where flood waters are relatively thin and move slowly. Flooding is less frequent and generally less severe.

Flooding - The covering or inundation of land with a high level of water.

Floodplain - A surface or strip of relatively flat land adjacent to a stream or river channel, constructed by the present stream or river, and covered with water when the water course overflows its banks.

Floodway - The strip of land on both sides of a river, and relatively close to the river, where flood waters are relatively deep and swift and have the potential to flood most frequently and cause the most damage.

Flow - A type of landslide movement that exhibits a plastic or semi-fluid motion similar to a viscous fluid. In most cases flow is accompanied by an abundant amount of water mixed with the material.

Flow line - see **Trim line.**

Fluvial deposit - see **Alluvial deposit.**

Fold - A curve or bend of a planar bedrock structure such as bedding planes, foliation or cleavage. A fold is usually a product of very large tectonic forces..

Fracture - Any break or discontinuity in a rock, whether or not displacement between the two sides has occurred. Fractures include cracks, joints, and faults.

Geological hazard - A naturally occurring or human accelerated geologic process that presents a potential risk to property and/or life. (See also Natural Hazard)

Glacial fluvial deposit - An accumulation of predominantly coarse grained soils deposited by meltwater from a glacier. The deposit is generally well sorted and stratified.

Glacial lake deposit - An accumulation of predominantly fine grained soils deposited in the bottom of a lake that existed during or shortly after glaciation. The deposit is generally well sorted and stratified.

Glacial lake silt - Predominantly silt-sized material that was originally deposited in a relatively quiet lake environment during or shortly after glaciation. Most deposits are flat to gently dipping, well sorted and stratified. This material is often susceptible to erosion and landslides.

Glacial marine deposit - An accumulation of predominantly fine grained soils deposited in the bottom of an ocean or salt water environment that existed during or shortly after glaciation. The deposit is generally well sorted and stratified.

Glaciation - The formation, movement, and recession of glaciers or ice sheets. In British Columbia, the last period of extensive glaciation ended approximately 10,000 years before present. Some remnant glaciers still exist today.

Ground heave - The vertical movement of soil or rock at the surface due to the expansion as water freezes and becomes ice.

Ground rupture - The relative movement along a line or series of lines at the Earth's surface, usually as a result of an earthquake.

Hazard - Something that presents a potential risk to property and/or life, such as a geological hazard or landslide hazard.

Headland - An irregularity of land that juts out from the coast or shore into a body of water. Usually composed of less erodible material. Similar to a promontory.

High frequency-low magnitude natural hazard - A natural hazard that occurs relatively often, but has relatively small impact, such as a snow avalanche or river erosion.

Hummocky ground - Very uneven ground surface, frequently characteristic of a landslide deposit.

Igneous rock - A rock or mineral that solidified from molten or partly molten materials (magma). A granite is an example of a coarse crystalline rock that cooled slowly beneath the Earth's surface. A basalt is a fine crystalline rock that cooled quickly at the Earth's surface (lava).

Infilling - A process where humans use a variety of materials to increase the building grade within a floodplain. As the area infilled increases, the potential flood level of future floods also increases.

Intense rainfall - see **Rainfall intensity**.

Intensity - A subjective measure of the effect of an earthquake on local residents and construction. The intensity depends upon on the earthquake magnitude, duration of shaking, type of ground, water table, type and quality of construction. It is determined by peoples' perception of the ground shaking and the resulting damage. It is usually expressed by the Modified Mercelli Scale.

Jackstrawed trees - see **Drunken trees**.

Karstification - The formation of karst features, such as caves and surface depressions, by the solution action of underground water in a region of limestone, gypsum or other bedrock.

Lake deposit - An accumulation of predominantly fine grained soils deposited in the bottom of a lake. The deposit is generally well sorted and stratified.

Landslide - The movement of a mass of soil, debris or rock down a slope. The term covers a wide variety of landforms all the result of gravitational forces.

Landslip - see **Landslide**.

Lava - Molten rock as it flows on the Earth's surface, as seen near the volcanos in Hawaii.

Leaning trees - A group of trees that are tilting in a similar direction, such as found on the backscarp of a landslide.

Levee - An embankment of sediment, bordering one or both sides of a channel, formed by material descending the channel, as in a debris flow.

Liquefaction - The change from a solid to a liquid state, usually in a sandy soil, as a result of increased pore water pressure and reduced effective stress, often the result of ground vibrations such as caused by an earthquake or heavy equipment.

Loss of ground - The removal of land or property by causes such as a landslide or erosion.

Low frequency-high magnitude natural hazard - A natural hazard that occurs relatively seldom, but has relatively large impact, such as an earthquake or volcano.

Made ground - An area artificially filled with earth materials and sometimes mixed with waste materials. Made ground is common in low lying areas and at many sanitary landfill sites.

Magma - A naturally occurring molten, mobile rock material, generated within the Earth, from which igneous rocks are derived.

Magnitude (earthquake) - An objective measure of the amount of energy released by an earthquake. It is measured by an instrument known as a seismograph and expressed by the logarithmic, open ended Richter Scale. Every 1 level increase in the Richter Scale is equivalent to a 10 times increase in the energy released. For example, a magnitude 7 earthquake is 100 times (10 x 10) as strong as a magnitude 5 earthquake.

Magnitude (of a landslide event) - An estimate of the volume of displaced material involved in a landslide.

Marine deposit - An accumulation of predominantly fine grained soils deposited in the bottom of an ocean or salt water environment. The deposit is generally well sorted and stratified.

Mass movement - Any movement of the Earth's surface, and includes landslides, snow avalanches, subsidence and erosion. A similar term to mass wasting.

Mass wasting - see **Mass movement**.

Mean annual precipitation - The total precipitation (rain and the water equivalent of snow) recorded per year and averaged over many years.

Metamorphic rock - A rock that has been changed from its original form by high temperature and/or pressure. Gneiss is an example of a metamorphic granite; slate is an example of a metamorphic shale.

Morainal deposit - An accumulation of a heterogeneous mixture of gravel, sand, silt and clay deposited directly from, or by, glacial ice. The deposit is generally unsorted and unstratified.

Mudflow - see **Debris flow**.

Natural hazard - Any hazard found in nature, typically biological, atmospheric and geological.

Normal maximum reservoir level (NMRL) - The maximum level to which the water in a reservoir will be raised, under normal operating conditions.

Organic deposit - An accumulation of organic material and decaying organic material, such as peat and muck. Organic deposits usually contain a large volume of water.

Organic soil - A soil that consists primarily of organic matter and decaying organic matter, such as peat and muck.

Overhang - A mass of rock or soil jutting out from a slope, especially the upper part, or edge, of an eroded bluff.

Pacific ring of fire - A term that refers to the relatively active tectonic zone that borders the Pacific Ocean. The active tectonism is evident by numerous earthquakes and volcanos that occur around the border.

Passive mitigation - A method of reducing the consequences of a hazard by methods that do not involve designed action. Examples include avoidance, land use regulations, and public education. The opposite of active mitigation.

Permafrost - The thermal condition in any soil or rock of temperatures persisting below 0^{o} C for at least 2 consecutive winters and the intervening summer. Water and ground ice may not be present. In British Columbia, permafrost is commonly found in peatlands and on north-facing slopes.

Physiographic region - A grouping of physiographic units into a larger geographic area with broad similar topographic features.

Physiographic system - A grouping of physiographic regions into a very large geographic area with broad similar topographic features.

Physiographic unit - A geographical area with similar topography and landform. Types of units include mountains, highlands, foothills, plateaus, lowlands, trenches, depressions, fiords, and plains.

Physiography - A description of the physical nature, such as topography and landform, of natural features.

Pipe - An elongated, tubular subsurface cavity in soil or rock formed by underground erosion. Pipes can vary in diameter from centimetres up to many metres.

Piping - Erosion of subsurface materials by percolating water, resulting in pipes, caves, collapse structures and subsidence.

Pistol butt trees - trees curved at the base due to slope movement during the period of growth.

Planar slide - A type of landslide movement in which the movement takes place on a well defined inclined plane. Similar to a translational slide.

Plane of weakness - A plane or zone (close series of planes) along which the shear strength of the rock or soil is low, or potentially low and movement may occur.

Precipitation - Water that falls to the surface of the Earth from the atmosphere as rain, snow, hail, or sleet. It is measured as a liquid-water equivalent regardless of the form in which it falls.

Probability of occurrence - The statistical chance or likelihood of a particular event occurring. Same as chance of occurrence.

Problem soil - Any of a number of soil types that commonly cause engineering problems for a variety of reasons. Examples of problem soils include glacial lake silt and organic soil.

Projectiles - Material that is ejected explosively from a volcano.

Promontory - A relatively high prominent projection or point of land jutting out boldly into a body of water beyond the coastline. Similar to a headland.

Rain on snow event - A rainfall than occurs when there is already snow on the ground. Depending on the temperature, the rain melts the snow and the resulting runoff can be substantially greater than that from just the rain.

Rainfall intensity - A relatively large amount of rainfall in a given period of time. For instance, 50 mm in 24 hours, or 10 mm in 1 hour.

Regional tilting - Tilting on a large regional scale, the result of an earthquake or a volcano.

Remobilize - To become mobile again, such as an old landslide deposit that starts to move again.

Reservoir - A natural or artificial storage place for water, such as a lake or pond, from which water may be withdrawn for power, irrigation, water supply, or flood control.

Resisting force - A force, primarily generated by the strength of the slope materials (cohesion and friction), and sometimes supplemented by human activities. If greater than the driving force, a landslide will not occur.

Retrogress - A characteristic of a landslide, in which the upper portion of the landslide continues to fail resulting in the top of the landslide moving up slope.

Return period - A statistical number representing the number of years between events of a similar type or magnitude. The inverse of the annual probability, chance or likelihood of occurrence. For instance, if the annual probability of occurrence is 1 in 200 (also expressed 1:200), the return period is 200 years.

Risk - The product of a hazard (as in geological hazard) multiplied by the consequence (as in impact on social, environmental and resource values) of that hazard occurring. If there is no hazard or no consequence, then there is no risk.

Rock creep - A type of landslide characterized by the slow, more or less continuous, downslope movement of a rock mass.

Rock fall - A type of landslide characterized by the free falling, leaping, bounding or rolling of a newly detached fragment of rock or block of rock from a near vertical slope.

Rock flow - A type of landslide characterized by the rapid downslope flow of a mass of rock. Rock flows are generally large magnitude events.

Rock mass - A mass of rock including the pieces of solid rock separated by all fractures or discontinuities. The strength of a rock mass is usually more dependent on the strength of the rock to rock contact along the fractures or discontinuities.

Rock slide - A type of landslide characterized by the downward, and usually sudden and rapid movement of detached fragments of bedrock sliding on an inclined planar surface of weakness, such as a surface of bedding, jointing, or faulting, or at the interface between soil and rock.

Rock slump - A type of landslide characterized by the curved backward rotation in a mass of rock.

Rock topple - A type of landslide, similar to a rock fall, but which involves the forward rotation of a mass of rock about a point below the displaced mass.

Rotational slide - A type of landslide movement in which the movement takes place on a well defined, curved shear surface, concave upward, producing a backward rotation in the displaced mass.

Sag pond - A small pond occupying an enclosed depression or "sag" formed by a change in the ground surface such as by a landslide.

Scarp - A steep surface on the undisturbed ground directly above a landslide and caused by the movement of the landslide.

Scour - The downward or lateral erosion by swiftly moving water or by a debris flow.

Sedimentary rock - A rock formed by the deposition of sediment, followed by lithification or other rock forming processes over a long period of time. Limestone, shale, sandstone and conglomerate are examples of sedimentary rocks.

Settlement - The subsidence of a structure, caused by compression or movement of the soil below the foundation.

Sheep tracks - A series of very long and narrow terraces, often discontinuous, that run parallel to the contour of a slope, usually produced by very local surficial slumping. Similar to terracettes and cat steps.

Sheet erosion - The removal of thin layers of surface material more or less evenly from an extensive area of gently sloping land, by broad continuous sheets of running water rather than by streams flowing in well-defined channels.

Slide - A type of landslide movement in which the soil or rock moves downslope relatively intact by sliding as opposed to flowing or falling. Also see planar slide and rotational slide.

Slope stability - The resistance of a natural or artificial slope, or other inclined surface, to failure by landsliding.

Snow avalanche - An avalanche consisting predominantly of snow, although considerable soil and rock material, and vegetative matter, may also be carried downward.

Snow avalanche area - A geographic area characterized by one or more avalanche paths.

Snow avalanche path - The entire path of a snow avalanche comprised of the starting zone, track and runout zone.

Snow avalanche runout zone - The deceleration and deposition area of an avalanche path.

Snow avalanche starting zone - The location at the top of a path where unstable snow fails and begins to move downslope.

Snow avalanche track - The portion of a snow avalanche located just below the starting zone, down which the snow travels before it comes to rest.

Snowpack - An accumulation of snow at higher elevations.

Soil - All unconsolidated earthy material overlying bedrock. Broadly classified by grain size into gravel, sand, silt and clay. From an engineering viewpoint, soil can be broken down by hand, or during one wetting and drying cycle.

Solifluction - The slow downslope viscous flow of water saturated soil and other unsorted surficial material.

Solifluction lobe - An isolated, tongue-shaped feature, formed by solifluction on certain sections of a slope showing variations in gradient. It commonly has a steep front and a relatively smooth upper surface.

Split tree - A tree that has been split by the relative ground movement beneath or on either side of the tree. Often the ground movement is the result of a landslide.

Sporadic permafrost - A condition where permafrost exists in widely spaced patches or "islands".

Spring runoff - High channellized surface flow, usually the result of snowmelt in the spring.

Starting zone - The area of a snow avalanche located at, or near the top, where the unstable snowpack breaks away from the underlying snow or ground surface.

Storm surge - An abnormal, sudden rise of sea level along an open coast during a storm, caused primarily by onshore winds or by a very low atmospheric pressure, resulting in water piling up against the coast.

Strike - A geological term for the direction, relatively to north, that a planar feature, such as a bedding plane or fault plane, makes with the imaginary horizontal plane.

Subsidence - The local or regional sinking or collapse of the land surface with little or no horizontal movement.

Surficial geology - The geology at the Earth's surface and can include both soil and rock.

Surge - In a debris flow, a pulse of material that descends the channel at one time.

Talus - Rock fragments of any size and shape, usually coarse and angular, derived from and lying at the base of a very steep, rocky slope.

Tectonic plate - The Earth's crust is made up of a number of independently moving segments, known as tectonic plates.

Tension crack - A fracture in the ground surface caused by tensile stresses, often found at the head of a landslide. Also referred to as a tension fracture.

Tension fracture - see **Tension crack**.

Terracettes - A series of very long and narrow terraces, often discontinuous, that run parallel to the contour of a slope, usually produced by very local surficial slumping. Similar to cat steps and sheep tracks.

Terrain stability - Slope stability from a regional perspective as opposed to the study of the stability of an individual slope.

Till - A heterogeneous mixture of gravel, sand, silt and clay, unsorted, unstratified, and often poorly unconsolidated, deposited directly by or beneath a glacier without subsequent reworking by meltwater.

Toe - The lower, usually curved, margin of the disturbed material of a landslide that has often overridden undisturbed terrain.

Topple - A type of landslide movement that involves the forward rotation of a mass of soil or rock about a central point below the displaced mass.

Training - An artificial channelization of a surface drainage course, such as a dike.

Translational slide - see **Planar slide**.

Transporting medium - The medium that supports the downslope movement in flow type landslides. Water and air are the most common transporting media.

Trim line - A line along a stream or river channel below which evidence of erosion by water and/or by a debris flow is readily apparent by the erosion of soil and rock and/or by the removal of vegetation, including moss. Similar to flow line.

Tsunami - A wave or series of waves generated by a large geological event such as an earthquake, volcano or large underwater landslide or a landslide into water. It is a Japanese word, literally translated as "harbour wave".

Unconsolidated - A soil that is loosely arranged, or whose particles are not cemented together.

Undercut - The void left by the natural or artificial removal of material at the base of a steep slope or bluff.

Underground working - The result of human endeavors underground, such as mining.

Volcanic belt - A geographic area characterized by more than one, and usually numerous, dormant and/or active volcanos.

Volcano - A vent in the surface of the Earth through which magma and associated gases and ash erupt.

Weathering - The destructive process or group of processes by which soil and rock, exposed to atmospheric agents at or near the Earth's surface, are changed in colour, texture, composition, physical properties, and/or form, with little or no transport of the loosened or altered material.

APPENDIX E: REFERENCES

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