CHAPTER 1
SLOPE MOVEMENT PROCESSES AND CHARACTERISTICS

by

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1.1 SLOPE MOVEMENT TYPES AND PROCESSES

The mechanics and rates of slope movement are controlled by many factors: slope gradients, overburden depth, structural rock properties, water content and soil pore water pressure, and certain engineering properties of overburden and weathered rock, such as cohesion and coefficient of friction. Geomorphic, hydrologic, and vegetative factors determine the occurrence, frequency, and relative importance of such processes in an area.

1.1.1 Classification

Six dominant groups of landslide processes are encountered on steep forested terrain in the Pacific Northwest: falls, creep, slumps and earthflows, debris avalanches and debris flows, debris torrents and bedrock failures. These groups have been categorized according to depth of movement, rate of initial failure, failure mechanics, and water content of the moving material. As well, each category is distinguished by zone of initiation (slope source) rather than by transportation and deposition zones, and by composition of its material.

The terms "soil" and "overburden" refer to any surficial material overlying bedrock, and include alluvial/fluvial sands and gravels, marine and lacustrine silts and clays, colluvium and rock fragments, weathered bedrock, and glacial till. The term "debris" refers to any mixture of soil, rock and organic material incorporated into a landslide mass. "Debris flows" are rapid downslope movements of a mass of predominantly soil and organic debris mixed with water. Within the Pacific Northwest the rapid downslope movement of channelized floods of water with high concentrations of soil, rock and organic debris are called "debris torrents."
1.1.2 Description of Forest-Landslide Categories

**Falls**

Movement takes place mainly through the air by free-fall, leaping, bounding, or rolling. Falls are very rapid to extremely rapid mass movements (from meters/minute to meters/second).

**Creep**

The slow downslope movement of overburden. Rates of movement are very slow (centimeters/year) to extremely slow (millimeters/year).

**Slumps and Earthflows**

These often involve combined processes of earth movement (rotation of a block of overburden over a broadly concave slip surface, or slump), and result in the downslope transport of the resulting mass, either by
a flow or a gliding displacement of a series of blocks (earthflow). Creep activity is a common precursor to slumps and earthflows. Rates of movement range from extremely slow (millimeters/year) to rapid (meters/second).

**Debris Avalanches and Debris Flows**

Debris avalanches are rapid, shallow landslides from steep hillslopes. Movement begins when overburden slides along bedrock or along other layers within the overburden having higher strength and lower permeability. If enough water is present, debris avalanches become debris flows. This results in the rapid downslope transport of a slurry of soil, rocks, and organic material (collectively called debris) directly to the valley floor and occasionally to stream channels. Debris avalanches typically begin on open slopes or within shallow hillslope depressions where groundwater is concentrated. Debris flows commonly follow existing drainageways or linear slope depressions created by past landslide activity, although not necessarily. Debris flows tend to increase in volume downstream. Rates of movement range from rapid (meters/minute) to extremely rapid (meters/second).
Debris Torrents

Where debris avalanches and debris flows enter steep gullies and canyons during high flow periods, debris torrents or debris floods occur. These torrents involve the rapid movement of large volumes of water-charged soil, rock, and debris. Rates of movement are very high (meters/second) and damage can be extensive.

Bedrock Failures

Bedrock slumps typically occur as a displacement of one or more blocks, which rotate backward along a curved basal shear surface which may cross several rock units. Movement rates are extremely slow (millimeters/year) to moderate (meters/day) and take place well beneath the surface of the earth.

Bedrock slides typically occur as movements along a planar or nearly straight basal shear surface which follows a structural discontinuity within or at the boundary of rock units. Movement rates of bedrock slides range from rapid (meters/minute) to extremely rapid (meters/second) and are usually initiated below the surface.
1.2 THE GENERAL DYNAMICS OF LANDSLIDES

1.2.1 Mechanics of Movement

The infinite slope model is a common framework for discussing the mechanisms and complex relationships between the factors active in development of landslides on steep forested slopes. Although this model applies predominantly to shallow planar slides, it is useful in illustrating the mechanics of more complex failures. It describes the stability of a block of material in terms of the ratio between its shear strength, or resistance to sliding along a surface of failure, and the downslope gravity or shear force. This ratio defines the "Factor of Safety" of the block. As long as the shear strength exceeds the pull of gravity, the Factor of Safety is greater than 1 and the block of material will remain in place. By analogy, the block becomes a surrogate of the material and terrain conditions prevailing in an area. Landslides result from changes in the "Factor of Safety" of a block of overburden in the vicinity of failure.

The geometrical relationship of the forces acting on a small block are shown below.

![Diagram of force acting on a vegetated slope](image)
Increases in shear force or the pull of gravity on a block result from increased sliding surface inclinations, such as those produced by undercutting slope, or from increased weight of the block of rock or overburden. Shear force can also be influenced by:

| **WIND FORCES** transferred to the surface through the stems and root systems of trees |
| **HORIZONTAL ACCELERATIONS** produced by earthquakes and blasting |

Three principal forces are active in maintaining shear strength. These are:

| **COHESION** or the capacity of particles to stick or adhere together |
| **FRICTIONAL RESISTANCE** between individual particles and between the overburden mass and the sliding surface |
| **RESISTING FORCE** generated by the anchoring and reinforcing effect of tree roots, provided the failure surface is within the rooting depth of vegetation |

Shear strength can be significantly reduced by:

- **presence of zones of weakness** in overburden or underlying bedrock produced by bedding surfaces, fractures and joints, and local layers of silt and clay;
- **removal of downslope support** of the mass, as a result of undercutting, commonly by stream cutting or roads;
- **development of a temporary water table** above a potential failure surface; and
- **progressive creep** producing a strain-dependent drop in strength.
1.2.2 Factors Affecting Slope Stability

Undisturbed, steep mountain slopes have adjusted to the various forces acting on them and have developed a delicate “static equilibrium” between gravitational forces tending to pull the overburden materials downslope and the various resisting forces comprising shear strength. Slopes in such a state are highly sensitive to modifying factors which change the developed strength/stress relationships over geologic time. The table below lists these modifying factors for both shear strength and gravitational force in terms of their influence on the Factor of Safety at a site. Road construction and logging activities strongly influence these factors by undercutting of hillslopes, increasing surface weight, altering surface and subsurface drainage, and reducing short-term anchoring and reinforcing effects of tree roots.

Texture and mineralogy (both of which govern cohesion), angle of internal friction, water content of overburden, pore water pressure, and gradient of the potential sliding surface are controlling factors in determining the stability of a steep forested slope. These controlling factors are interactive, and the importance or effectiveness of each in controlling the type and degree of instability is dependent on local geologic, vegetative, and hydrologic conditions.

Factors modifying slope stability

<table>
<thead>
<tr>
<th>Increasing Gravitational Force (Shear Stress)</th>
<th>Reducing Shear Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inherent</strong> (internal)</td>
<td><strong>Inherent</strong> (internal)</td>
</tr>
<tr>
<td>1. composition (increased weight)</td>
<td>1. composition (reduce cohesion, reduce internal friction angle)</td>
</tr>
<tr>
<td>2. structure (downslope dip of fractures and beds)</td>
<td>2. structure (downslope dip of beds and joints)</td>
</tr>
<tr>
<td>3. slope geometry (increased gradient)</td>
<td>3. slope geometry (increase gradient, concave slopes, slope depressions)</td>
</tr>
<tr>
<td><strong>External</strong> (variable)</td>
<td><strong>External</strong> (variable)</td>
</tr>
<tr>
<td>1. undercutting (increases local gradient, removes lateral support)</td>
<td>1. weathering (disintegration, clay alteration, permeability)</td>
</tr>
<tr>
<td>2. surcharging (increased surface load)</td>
<td>2. intergranular forces (pore water pressure)</td>
</tr>
<tr>
<td>3. shocks and tilting (earthquakes, blasting)</td>
<td>3. vegetation removal (loss of anchor and reinforcing effects of roots)</td>
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<tr>
<td>4. lateral pressure (frost wedging, heaving)</td>
<td></td>
</tr>
<tr>
<td>5. wind stress (prying, loosening, lateral pressure from swaying trees)</td>
<td></td>
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</tbody>
</table>
Influence of Geologic Conditions

1) Overburden Materials

Non-cohesive (coarse-textured materials low in clay-sized particles)
- Colluvium
- Sands
- Gravels
- Weathered surface of most tills
- Residual soils

Cohesive (fine-textured materials)
- Lake silt/clay
- Marine silt/clay
- Some residual soils and tills

Debris avalanches and debris flows dominate in non-cohesive materials. Slope angle is a major indicator of the stability of these sites. Slopes at or above the angle of internal friction of the overburden material indicate a highly unstable natural state even in the absence of excess water. The development of a temporary perched water table or the disturbances produced by timber harvest and road construction greatly increase the probability of failure of such slopes.

Stability in cohesive materials is controlled largely by clay mineralogy and moisture content of overburden. When they are dry, clayey materials have high shear strength with high cohesion and angle of internal friction (>30 degrees or >58%). Increased water content mobilizes the clay as it is absorbed into the clay structure. Thus, clay-rich materials have a high potential for accelerated deformation and ultimate failure in the presence of excess water. Under these conditions, failures do not depend directly on sliding surface gradient as in shallow, cohesionless materials, but may develop in slopes with gradients as low as 2-3 degrees (about 5%), with creep, slump and earthflows being the dominant processes.

2) Bedrock

- Silt/claystones
- Mudstones
- Soft shales
- Graywacke
- Sandstone
- Welded ash-tuff
- Serpentine-rich rocks

Under moist upper mid-latitude climatic conditions, many materials are susceptible to rapid weathering: medium- to fine-grained sedimentary rocks (siltstones, mudstones, claystones, poorly indurated shales, sandstone, graywacke); welded ash and tuff; and serpentine-rich rocks. Such materials develop a high degree of
cohesion and mobility. They are prone to slope movements of the 
creep, slump and earthflow types.

- **Granite/diorite**
- **Hard sedimentary**
- **Metamorphic rocks**

On slopes underlain by more resistant coarse-grained intrusives (granites and 
diorites), hard and dense sedimentary and metamorphic rocks (massive shale, 
graywacke, sandstone and conglomerate, greenstone and limestone/marble), shallow overburden derived from these rock types are usually coarse grained and low in clay-sized particles. Such materials have low cohesion and are most likely to develop slope movements of the debris avalanche and debris flow types.

- **Andesite and basalt**

Fine-grained andesite and basalt flow rock also develop thin, coarse-textured overburden on steep surfaces, with resultant debris avalanche and debris flow failures. On flat-lying surfaces underlain by such rocks, deep weathering is common due to retained water, and slumps and earthflows are the dominant types of slope movements. On near-vertical outcrops of this rock, rockfalls are most common.

3) **Structure and Stratigraphy**

(Internal character of the rock)

- **Highly jointed or fractured bedrock slopes**

Highly jointed or fractured bedrock slopes with principal joints and fracture surfaces parallel to or dipping with the slope provide little mechanical support to overlying materials and create avenues for concentrated subsurface water movement. Jointing also provides avenues for deep penetration of surface and ground water. This results in the development of springs at remote sites on the slope, and of excess hydrostatic pressures locally because of confining rock and overburden layers. At near-surface locations, joint and fracture planes are ready-made zones of weakness that
• Dipping bedding surfaces

Parallel (less stable)

Perpendicular (more stable)

• Alternating bedrock units (Stratigraphy)

Resistant Basalt

Weathered Volcaniclastics

provide potential failure surfaces along which overlying materials can slide.

Downslope dipping surfaces between units with different composition, permeability, or degree of alteration serve as boundaries to subsurface water movement, as layers restricting penetration and development of root systems, and as potential surfaces of failure. Conversely, horizontal bedding surfaces and those dipping into the slope frequently produce natural buttresses that may actually increase stability of slopes locally. Care must be taken in assessing the stabilizing influence of horizontal and in-dipping bedding surfaces, however, because jointing, which is always present to some degree, frequently crosscuts the bedding planes. When this happens, it becomes the major determinant of a slope’s ultimate stability.

Flat-lying, resistant rock units capping incompetent rock, commonly play an important role in shaping complex slump and earthflow features. Steep headwall scarps of slumps and earthflows usually occur at these contacts. Water is frequently trapped and transported laterally along bedding surfaces and joints or within more permeable rock units and fed directly into more incompetent materials, where failures occur.
Shallow, linear depressions or "swales" on hillslopes are common points of origin for debris avalanches and debris flows. Such linear depressions are created by the weathering of bedrock along zones of weakness. Subsequent and recurring slope processes result in periodic stripping and infilling of these swales. Converging flows of groundwater into these depressions during periods of storm precipitation or rapid snowmelt cause the buildup of temporary perched water tables. Later generation of pore-water pressures in the in-fillings of the depressions reduces the strength of the material and greatly increases the instability of the site.

In local areas, subsurface water accumulation in these depressions may be substantially augmented by seepage from downslope-dipping bedrock units and joint systems. Midslope springs are indicative of this type of augmented flow and may be important indicators of potential failure sites. Jointing also conducts surface water considerable distances downslope under confined conditions, resulting in the local buildup of excess hydraulic head and the explosive failure of overburden.

Deep gullies and canyons (V-notch drainages) dissecting the slope frequently serve as collectors of debris avalanche and debris flow material from adjacent hillslopes. They also tend to have very steep, unstable side slopes with frequent rockslides and small debris avalanches that dump additional soil, rock and organic debris directly into these confined channels. If the quantities of debris are large enough, or if flows are too small to mobilize debris initially, temporary dams may develop. During major storms, these dams may fail, producing
large volume, high velocity debris torrents. Torrents may also be produced during high-flow periods by the mobilization of stored channel materials. In general, debris torrent activity increases with increasing gully density.

**Influence of Vegetation**

Tree cover influences the amount and intensity of rainfall reaching the surface, the amount of water stored in the overburden, and the strength developed along a potential failure surface.

- **Interception**
  The direct effect of interception on the water budget in the overburden material is probably not large, especially in areas of high total rainfall or during large storms, when most slope movements occur. Small storms, where interception is effective, probably have little influence on total subsurface water available for activating slope movements.

- **Evapotranspiration**
  In areas of low rainfall (<750 mm), the effect of evapotranspiration is much more pronounced, but it is particularly dependent on region and rainfall. For example, in areas characterized by warm, dry summers, evapotranspiration significantly reduces the degree of saturation resulting from the first storms of the fall recharge period. This effect diminishes as subsurface water deficit is satisfied. Once the overburden material is recharged, the effects of previous evapotranspirational losses become negligible. Conversely, in areas of continuous high rainfall or those with arid or semi-arid climates, evapotranspirational withdrawals are probably negligible during the time period when most landslides occur.

- **Depth of evapotranspirational withdrawals**
  Depth of evapotranspirational withdrawals is important, also. Deep materials may require substantial recharge of the groundwater deficit, delaying or reducing the possibility of saturated conditions necessary for major landslide-pro-
ducing events. Shallow materials, however, recharge rapidly, possibly becoming saturated and reaching an unstable state during the first major storm.

- **Root systems**

  Root systems of trees and other vegetation may increase the shear strength of unstable overburden by anchoring through the mass into fractures in bedrock, providing continuous long-fiber binders within the overburden (a fiber reinforcing effect) and tying the slope together across zones of weakness or instability. In shallow materials, all three effects may be important. In deep materials, the anchoring effect of roots becomes negligible, but pore water pressures and soil strength parameters remain important. In some extremely steep areas, root anchoring may be the dominant factor in maintaining slope equilibrium of an otherwise unstable area.

**Influence of Hydrologic Conditions**

- **Recharge of subsurface water**

  Recharge of subsurface water is the result of water entering the overburden materials. It is influenced by vegetation cover, management practices, and shape of terrain, as well as by soil physical processes affecting water movement.

- **Discharge rate of water**

  The discharge rate of water from unstable overburden is probably the most significant hydrologic factor affecting slope movement. If subsurface flow rate is less than infiltrating rates (from rainfall and/or snowmelt) for extended periods of time, a perched groundwater table will form within the overburden. The height and persistence of the perched water table above an impermeable layer depends largely on rainfall or snowmelt intensity, duration, and antecedent conditions,
infiltration rate at the site, slope gradient, subsurface configuration of the bedrock, and flow rate within the overburden. Because the infiltration rate often does not limit recharge of unstable slopes (infiltration rate is more than able to absorb incident rainfall), the subsurface flow rate becomes the controlling hydrologic variable during most rainfall and snowmelt periods.

1.2.3 Factors Affecting Downslope Transport

Once failure occurs, movement of materials downslope is determined largely by the morphology of the hillslope and associated flow path.

• **Open slope** *(debris avalanches and debris flows)*

  On the open slope *(outside of a confining drainage)*, large failure volumes, steep hillslope gradients, and unobstructed flow paths generally encourage greater transport distances and greater impact in the deposition zone. Sharp reductions in gradient caused by intervening bedrock benches, valley floor interception, or the buttressing effect of trees standing within the flow path can cause rapid deposition and significantly limit landslide runout.

• **Channelized** *(debris torrents)*

  The channelization of landslide materials, such as in a gully, provides an established, less obstructed flow path and may significantly increase velocity of movement, distances traveled, and volumes of debris delivered to the valley floor and associated channel systems. Once landslide debris becomes channelized, fluidity increases due to converging groundwater and surface water flows. The volume of materials transported also increases as a result of in-
increased channel erosion and mobilization of debris temporarily stored on and adjacent to the channel banks. Much of this stored debris is the direct result of local slumping of channel banks and deposition from earlier landslide activity.

The gradient of the channel controls the rate at which landslide debris is transported and the dominance of erosion or deposition processes during a particular flow event. Scouring and mobilization of debris in and adjacent to the channel generally occur at gradients above 10 degrees (about 18%). Major velocity reductions and significant deposition of materials occur when channel gradients drop below 7 or 8 degrees (12 to 16%).

Preliminary research on landslide transport distances suggests that behavior of channelized landslides is determined by a combination of geomorphic and hydrologic factors, including junction angle, channel gradient, and magnitude of stream discharge. Channelized landslides that reach tributaries at a low angle of incidence (70-90 degrees) tend to deposit debris at the tributary junction. At this point, channel gradients are decreasing, channel widths are increasing, and an abrupt change in flow direction occurs. How long this deposit remains in place is a function of the drainage area above the deposit and the volume of flow in the tributary at the time of deposition. It is possible that during major storm flows, the deposit may be almost immediately remobilized. Channelized landslides that enter tributaries at a high angle of incidence tend to travel farther initially and may pass through several tributary systems before final deposition occurs. In small first- and second-order channels with gradients greater than 10 degrees (about 18%), scouring and lateral erosion dominate, resulting in a major portion of the mobilized material originating in this portion of the flow path. Below that gradient, erosion rates are reduced. Significant deposition begins below 8 degrees (14%). As debris flows into larger, higher-order channels, deposition and erosion are reduced as magnitude of the streamflow increases.
Further Reading for Chapter 1


CHAPTER 2
A TECHNIQUE FOR
STABILITY HAZARD ASSESSMENT

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2.1 GENERAL PROCEDURE FOR RECOGNIZING UNSTABLE TERRAIN AND IDENTIFYING AREAS AFFECTED BY LANDSLIDES

Steps for identifying both potential and existing landslide areas are outlined on page 24. After following these steps, the user should be able to recognize that a landslide problem may exist within a specific development area. Having recognized the problem, the user should seek the expertise of a specialist for further analysis of the problem, assessment of risk, and recommendations for control and correction.

The procedure for recognizing unstable terrain involves:

<table>
<thead>
<tr>
<th>Part A:</th>
<th>an office evaluation of existing information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part B:</td>
<td>a field evaluation</td>
</tr>
<tr>
<td>Part C:</td>
<td>a simple method of assessing stability hazard</td>
</tr>
</tbody>
</table>

2.2 PART A: OFFICE EVALUATION OF EXISTING DATA

Information used in a landslide evaluation may come from single or multiple sources including maps, reports, and aerial photographs. The table below identifies the kinds of information one can expect to obtain from these various sources. A data card for this exercise is presented on pages 22 and 23.
<table>
<thead>
<tr>
<th>MAP/MAP TYPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPOGRAPHIC MAP</td>
<td>indicates slope gradient, terrain configuration, drainage pattern.</td>
</tr>
<tr>
<td>TERRAIN MAP</td>
<td>identifies material, depth, geological processes, terrain configuration, surface and subsurface drainage, slope gradient (also called surficial geology or Quaternary geology maps).</td>
</tr>
<tr>
<td>BEDROCK MAP/REPORT</td>
<td>identifies bedrock type, surface and subsurface structure, surficial cover (overburden), age.</td>
</tr>
<tr>
<td>SOIL MAP</td>
<td>identifies surficial material (overburden) type, drainage, limited engineering characteristics, soils characteristics, vegetation cover.</td>
</tr>
<tr>
<td>FOREST COVER MAP</td>
<td>identifies surface vegetation, topographic features, surface drainage pattern, soil drainage character.</td>
</tr>
<tr>
<td>AIR PHOTO REVIEW</td>
<td>identifies vegetation cover, topography, drainage pattern, soil drainage character, bedrock geology, surficial geology, landslide type and relationship to other factors.</td>
</tr>
<tr>
<td>RESEARCH STUDIES</td>
<td>may provide information on all of the above, plus quantitative data on controlling factors and possibly local stability risk assessment.</td>
</tr>
</tbody>
</table>
### Slope Stability Map Data

- **Rating on Slope Stability Map**: No Data Available
- **Recommended Land Use**: ____________

### Landslide Data Derived from Resource Maps/Air Photos

1. **Identify if Landslides Present** (check box)
   - [ ] Landslide(s) occur in area/similar terrain nearby
   - [ ] Landslide(s) impacted a stream

2. **Identify source of data** (check box)
   - Forest Inventory Map
   - Terrain Map
   - Soil Map
   - Landslide Inventory Map
   - Bedrock Geology Map

3. **Identify Type of Landslide** (check box)
   - Fall
   - Creep
   - Slump
   - Earthflow
   - Debris Avalanche/Flow

4. **Describe Character of Landslide initiation Site**

   - **Slope Angle**: ____________ (°) ____________ (%)
   - **Location**: Gully
   - **Material Type**: Till
   - **Weathered rock (residual soil)**
   - **Other**:
   - **Drainage**: Rapid/Well
   - **Land use**: Natural

### Physical Character of Study Area

1. **Identify Source of Data** (check box)
   - Forest Inventory Map
   - Terrain Map
   - Soil Map
   - Landslide Inventory Map
   - Bedrock Geology Map

2. **Slope Angle**: ____________ (°) ____________ (%)
   - **Shape**: Concave
   - **Depth**: Shallow (<3 m)
   - **Texture**: Coarse-Grained
   - **Drainage**: Rapid/Well

3. **Overburden**
   - **Type**: Till
   - **Material**: Weathered Rock (Residual Soil)
   - **Other**:
   - **Other**:
   - **Depth**: Deep (>3 m)
   - **Texture**: Fine-Grained
   - **Drainage**: Moderately Well-Imperfect

4. **Bedrock**
   - **Type**: Intrusive
   - **Specific Type**:
   - **Structure**: Bedded
   - **Stratigraphy**: Massive, hard beds overlying softer rock
   - **Dissected by Gullies**: (check if yes)
   - **Other**:

### Summary

- **Field Check Required**: Yes

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Office data card (information derived from existing sources)
Site Information

Site Name: Identify the site by geographic name, drainage basin, cut block number, etc.
Map Sheet Number: Indicate topographic number and name
Map Sheet Scale: Enter map scale

Slope Stability Map Data

If no slope stability map is available – check box [✔]
Slope stability rating: Enter rating of the area from the map
Recommended land use: Many slope stability maps are accompanied by legends that detail different land use practices in landslide prone terrain; note any of these recommendations made for the area of concern.

Landslide Data from Resource Maps/Air Photos

1. Indicate if landslides have occurred in area/near the area after review of all resource maps and air photos – check box [✔]; also indicate if these landslides have entered a creek – check box [✔]
2. Source of Data: check box(es) [✔] to indicate source of information used to determine landslide activity.
3. Check box(es) [✔] to indicate type of landslides in area; use definitions provided in Section 1.1.2 (p. 3-5).
4. Describe the Character of Landslide Initiation Site (where the landslide started):
   Slope Angle: enter slope angle in degrees or percent
   Location: check box [✔]; use definitions provided in Section 1.2.2 (p. 12 and 15)
   Material Type: check box [✔]; use definitions provided in Section 2.3 (p. 50-51)
   Drainage: check box [✔]; use definitions provided in Section 2.3 (p. 68)
   Land Use: check box [✔]; natural refers to forested

Physical Character of the Study Area

1. Source of Data: Check box(es) [✔] to indicate source of information used to determine character of area
2. Slope angle: enters slope angle in degrees or percent
3. Overburden:
   Material Type: check box [✔]; use definitions provided in Section 2.3 (p. 50-51)
   Depth: check box [✔]
   Texture: check box [✔]; use definitions provided in Section 2.4.2 (p. 75)
   Drainage: check box [✔]; use definitions provided in Section 2.3 (p. 68)
4. Bedrock:
   Type: for specific types use rock classification chart in Section 2.3 (p. 63)
   Structure: check box(es) [✔]; use definitions provided in Section 2.3 (p. 64)
   Stratigraphy: check box(es) [✔]; use definitions provided in Section 2.3 (p. 65)
   Steep Outcrops: check box [✔] if these are present

Summary

Summarize the information available; indicate if a field check is required.

Explanation notes of office data card
Flow diagram of procedures for recognizing unstable terrain
2.2.1 Maps and Reports

There are several types of geological, geotechnical, and biophysical maps and reports from which data can be extracted for a landslide evaluation. These include topographical maps, terrain (surficial geology) and soil maps and reports, slope stability maps, landslide inventory maps, forest cover maps, and bedrock maps and reports. The maps vary from large to small scale (e.g., 1:10 000 to 1:100 000) and the reports, which may accompany these maps, can be regional or site specific.

In British Columbia, information from terrain classification (Appendix 2) and mapping is used as a basis for deriving slope stability classes (Appendix 3) with regards to forest activity. These classes are portrayed on stability maps (e.g., page 96).

The types of information available from maps and reports listed in the table below and on page 27 note the various agencies or locations where the maps and reports may be obtained.

<table>
<thead>
<tr>
<th>Information Available from Maps and Reports</th>
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<tbody>
<tr>
<td>Information type</td>
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<tr>
<td>------------------</td>
</tr>
<tr>
<td>SLOPE</td>
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<td>LANDSLIDE</td>
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<td>BEDROCK</td>
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<tr>
<td>GEOLOGIC HISTORY</td>
</tr>
</tbody>
</table>

- Data may be obtained from a map.
- Data may be obtained from a report (if available).
- Data may be obtained from a map and a report (if available).
- These reports only discuss large rock failures.
2.2.2 Limitation of Map and Report Data

**QUALITY AND SCALE** of photographs and experience of the mapper strongly influence the reliability of data. An experienced mapper and good quality photographs result in a more accurate map.

**A FIELD CHECK** is a prerequisite for final judgment, no matter how detailed a photo interpretation may be. Areas mapped strictly from air photographs are generally less reliable than those that have been field checked.

**INFORMATION** that can be obtained from these sources is presented at a regional scale (e.g., 1:100 000) and should not be used inappropriately in a detailed landslide evaluation study (e.g., at a scale of 1:20 000). For example, a 1:50 000 terrain map may indicate that a certain type of material occurs on a particular slope (e.g., till). At this scale of data presentation, however, local variations in material type may occur on this slope (e.g., 15% of the slope may be made up of lacustrine silt).

**FINITE BOUNDARIES** in mapping terrain, soils, and bedrock conditions must be drawn for some conditions that do not have finite boundaries. Thus, there is a certain degree of error built into these maps, even the most detailed. For example, groundwater levels can transgress different types of material.
### Sources of Maps/Reports

<table>
<thead>
<tr>
<th>Source of data</th>
<th>Topo</th>
<th>Terrain</th>
<th>Soil/Soils</th>
<th>Slide Inventory</th>
<th>Bedrock</th>
<th>Forest Cover</th>
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<td>Maps B.C. (Ministry of Environment)</td>
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- Map/report available

#### 2.2.3 Air Photograph Analysis

Careful study of a given area of terrain with the aid of oblique photographs and vertical stereo pairs can yield significant information on landslide type and frequency, and the effects of management practices. A review of recent and past air photographs of the area should be undertaken whenever possible, as older slides may not be evident on more recent photographs. The table on page 28 outlines the various agencies or locations where aerial photographs and other remote imagery can be obtained.

Features discernible on air photographs can help users identify landslide type and develop a reasonable assessment of overburden characteristics. These, in turn, provide a means for estimating the landslide hazard at a site.
### Sources of Remote Imagery

<table>
<thead>
<tr>
<th>Source of data</th>
<th>Aerial Photos</th>
<th>EOSAT (LANDSAT)</th>
<th>SLR</th>
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<td>Maps B.C., Ministry of Environment</td>
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<td>EROS Data Center, Sioux Falls, SD</td>
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<tr>
<td>Earth Observation Satellite Co. Landau, MD</td>
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<td>Washington State, Department of Natural Resources</td>
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<tr>
<td>(Photo Sales Division)</td>
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<tr>
<td>Oregon State, Department Natural Resources</td>
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</table>

Air photographs can also be a valuable aid in identifying “potential” landslide terrain. A skilled air photograph interpreter can identify numerous ground conditions (type of material, drainage, and so forth) indicative of potential or developing hazards by observing various elements on the photograph.

A number of features discernible on air photos also aid in the identification and interpretation of landslide processes. Some of these are: scarps, irregular or hummocky topography below scarps, bare linear tracks oriented downslope, fresh rock exposures, and fresh rock accumulations at the slope base. Air photograph examples and a list of basic features useful for identifying landslide types and terrain that may be potentially unstable are outlined on the following pages.
Features of rockfalls or sediment falls

**AREAS** of steep rock outcrop with large blocks or boulders, or of talus deposits (fans or cones) resting at the foot of the slope.

**RECENT** rockfall at the above sites may be indicated by fresh rock accumulations at the base of the slope or exposed rock on the rock face (both would have a light tone on the photo).

**ESCARPMENTS** of unconsolidated sediments with large coherent blocks of sediment at the base of the escarpment.

*Rock cliffs A subject to rockfall processes. Note fresh accumulation of large rock blocks at the base of the slope (talus deposit).*
Features of bedrock landslides

**HEADWALL** and sidewall scarps that are straight or concave.

**TOPOGRAPHY** below scarp may consist of large blocks of bedrock, or irregular mounds made up of large bedrock fragments.

**SURFACES** may display tension fractures, benches and ponded water.

**STREAMS** at base of landslide may be displaced laterally towards opposite valley sidewall.

**OLDER** bedrock landslides may display some of the above features, but they are not as sharply defined.
Terrain susceptible to bedrock instability

Steep bedrock slopes (cliffs or escarpments) that exhibit the following features are common sites of rockfall or deep-seated bedrock landslides. Wet sites are particularly prone to failure.

**ALTERNATING** parallel dark and light bands on hillslopes and straight, nearly parallel ridges or escarpments usually indicate the presence of tilted, interbedded sedimentary and volcanic rocks.

**NARROW**, linear, intersecting features (joints) highlighted by darker photo tones than surrounding areas.

**DARK-TONED**, narrow linear or curvilinear lines (faults, scarps) interrupted by standing water (ponds, lakes); or curvilinear lines creating a banded pattern on the photograph (folds or benches).

**NARROW** linear features on cliffs or steep hillslopes with a distinct tonal difference from the surrounding area (tension fractures).

*Escarpment consisting of volcanic flow rocks*
Features of slumps and earthflows in overburden

**HEADWALL** and sidewall scarps that are straight or concave. Scarps may be rectangular or horseshoe-shaped.

**TOPOGRAPHY** below scarp may consist of a large intact block or series of blocks with scarps, or chaotic irregular-shaped mounds and hummocks, or mixes of both.

**SURFACES** of slumps and earthflows may display tension fractures, benches and small scarps, and ponded water (sag ponds).

**STREAMS** along the base of these landslides may be diverted laterally towards the opposite site of the valley.

**OLDER** landslides may display some of the above features but they are not as sharply defined.

*Slump in glaciolacustrine materials, Fraser River, B.C. Note headwall scarp (arrows) and bench-like topography downslope (A).*
Terrain susceptible to slumps and earthflows

Slumps and earthflows commonly occur in exposed lake and ocean bottom sediments (silt, clay); in wind-blown deposits of silt and fine sand (loess), and fine-textured till; and in residual overburden derived from fine-grained sedimentary or volcanic rocks. Features that aid in the identification of these materials are outlined below.

Slumps and earthflows typically occur at escarpments undercut by streams and ocean waves, and in moderate to steep slopes. Wet or poorly drained locations on these slopes are particularly sensitive to these processes. Shallow drainage channels appear as narrow, linear features above steep pitches, whereas seepage sites tend to be irregularly shaped patches. The photo tones of both features contrast sharply with the surrounding area.

- FINE-TEXTURED LAKE, OCEAN BOTTOM, AND WIND-BLOWN SEDIMENTS

**FLAT** or undulating surface topography.

**GENERAL** absence of surface drainage and local ponded water with associated organic deposits (bogs).

**SMALL STREAMS** or gullies with steep sideslopes and flat bottoms (U-shaped profiles).

**DISSECTED AREAS**, with connected gullies forming intricate feather-like (pinnate) drainage patterns.

**UNIFORM**, drab, dark gray photo tones over broad areas.
• FINE-TEXTURED RESIDUAL OVERBURDEN

REGIONAL TOPOGRAPHY of low, softly rounded hills and rounded ridge tops.

TREE-LIKE DENDRITIC drainage patterns with local springs and ponds.

HILLSLOPES with lobate bulges, terracettes, swales and short, shallow, intermittent gullies.

VEGETATION cover of trees interspaced by open prairies indicating local surface disruption.

Raised marine silts, northern Vancouver Island, B.C. Note flat topography (A), absence of surface drainage and escarpment along shoreline (potential site for failure).
Features of debris avalanches, debris flows and debris torrents

**BARE**, narrow, linear tracks in forested terrain oriented downslope; denuded gullies and canyons.

**DEPOSITION** of material at slope toe, or some distance downslope in fan-shaped or hummocky forms.

**OLDER TRACKS** indicated by vegetation differences (species type or age – see page 71).

**SNOW AVALANCHES** and debris flow tracks may be separated by their point of origin (alpine zone vs below treeline).

**ORIGINATE** in gullies and canyons displaying steep, unstable side slopes and steep channel gradients or steep open slopes.

Oblique photo of debris avalanches, Vancouver Island, B.C. Note bare linear tracks in contrast to an older revegetated track (arrow).
Terrain susceptible to debris avalanches, debris flows, or debris torrents

Debris avalanches and flows develop on steep slopes and in coarse-grained, low cohesion overburden. Debris torrents (debris floods) result from rapid discharge of debris-laden water from confining gullies during high-flow periods. Failures that indicate terrain susceptible to these processes are:

**STEEP**, smooth, slopes (>26°); lighter tone, irregular or narrow linear patches indicate wet sites and are prone to failure.

**SHALLOW OVERBURDEN** indicated by frequent bedrock outcrops and minor surface irregularities.

**SLOPES DISSECTED** by gullies or canyons; usually indicated by linear features whose tone contrasts with the nearby area.

**DEBRIS FANS** and cones at foot of the slope.

*Forest, steep, gullied (arrows) slopes overlain by shallow overburden*
2.2.4 Sources of Support Research

Published reports from various public and private research organizations charged with developing knowledge of landslide processes and the influence of management practices on them are excellent sources of technical information. The output of public agencies is generally available through government publications or as reprints from professional journals obtained from the particular agency involved. The output from universities, government departments and private organizations may appear as internal reports, or consultation reports, or in professional journals available from departments, companies or authors. Several federal agencies in British Columbia and the U.S. Pacific Northwest have active slope stability research programs and are primary sources for most available research information.

2.2.5 Office Assessment

A preliminary slope stability assessment may be made on the basis of the information collected on the office data card.

STEP ONE: Review slope stability map data

If the area in question has a moderate to high slope stability rating:

- Seek outside expertise of a specialist; or
- Proceed to Section 2.3 (field evaluation).

If no stability maps exist for the area, proceed to Step 2.
STEP TWO: Review resource map/air photo data for landslides

If the resource data indicate that landslides have occurred in or near the area of concern in similar terrain:

- Seek outside expertise of a specialist; or
- Proceed to Section 2.3 (field evaluation).

If the resource data indicate no landslides have occurred in or near the area of concern, proceed to Step 3.

STEP THREE: Review physical character of the area as established from the resource map/air photo data

If there is sufficient information available, review the physical character of the area for the presence of indicator factors, (as reviewed in Section I), such as slope angle, character of overburden, moisture status, and presence of geological processes that can influence slope stability. A simple guide is presented below, although it can and should be adjusted according to the various regions in the Pacific Northwest.

If the area consists of non-cohesive\(^1\), shallow (<3 m in depth), coarse-textured materials on slopes >33 degrees (>65%), or on slopes >20 degrees (>36%) that are wet\(^2\) or dissected by gullies:

- Proceed to Section 2.3 (field evaluation).

\(^{1,2}\) For definitions of these terms, refer to Section 2.4.1, pages 75 and 80.
If the area consists of cohesive,\textsuperscript{3} deep (>3 m), fine-textured materials on slopes >30 degrees (about >58\%), or on slopes >10 degrees (18\%) that are wet or exhibit progressive deformation:

- Proceed to Section 2.3 (field evaluation).

If there is insufficient resource data available to assess the site:

- Proceed to Section 2.3 (field evaluation).

\textsuperscript{3} For a definition of this term, refer to Section 2.4.1, page 75.
2.3 PART B : FIELD EVALUATION

An integral part of the procedure for recognizing unstable terrain is being able to identify and interpret certain "indicators" of controlling and contributing factors in the slope stability model described in Chapter 1. This requires a working knowledge of how these factors operate and interact, and sufficient knowledge at the site to discover what kinds of indicators of instability are present. The resulting information can be integrated with support data to provide a final stability assessment. Some of the field information can be obtained from air photo analysis. This may be all that is required for general planning.

2.3.1 General Procedure

Six major groups of known characteristics should be investigated to supply information adequate to characterize unstable conditions on forested watersheds. These are:

1) Landform
2) Overburden
3) Geological Processes on the Slope
4) Bedrock Lithology and Structure
5) Hydrology
6) Vegetation

For each of these groups, there are diagnostic indicators which identify factors controlling stability. A data card has been developed for compiling information according to these six topics (pages 42-43). The information provided on the data card, in turn, can be used for the stability hazard assessment outlined on pages 74-83.