1.0 Introduction

1.1 Background

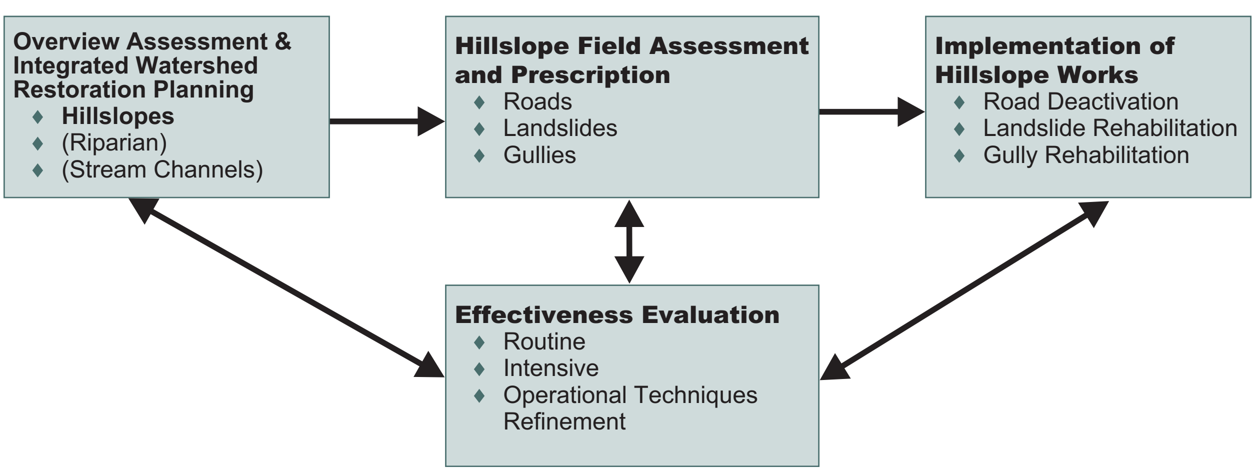
Watershed restoration began in British Columbia in the 1980's. The effort was prompted, in part, as a result of studies such as the Fish/Forestry Interaction Program that indicated logging-related landslides had caused severe degradation of fish habitat. Hillslope restoration treatments were developed to mitigate these impacts to both fish habitat and forest sites. In 1994, under the provincial Forest Renewal Plan, watershed restoration gained greater prominence with the establishment of the Watershed Restoration Program (WRP). The primary goal of watershed restoration is to accelerate the recovery of degraded environmental resources in watersheds by re-establishing pre-logging conditions, or to mitigate impacts where rehabilitation is not feasible. Restoration work within impacted watersheds is generally intended to proceed in a systematic and logical sequence beginning with overview inventories and risk assessments, followed by detailed assessments and treatment prescriptions, to implementation of prescriptions, and concluding with evaluations of treatment effectiveness. Figure 1.01 shows the main stages of hillslope restoration. A significant benefit of this work is the accumulation of experience that will contribute to better operational practices and to more sustainable forest management.

This document is based on a compilation of practical experience gained from completed watershed restoration projects. The hillslope restoration methodologies discussed have been enhanced through the province-wide practical experience of the writers and reviewers. As such, this compilation is considered to represent the current best management practices for hillslope restoration in BC.

1.2 About This Handbook

This handbook has been written and reviewed by practising professionals and technicians to provide technical guidance to forest workers engaged in any of the various aspects of hillslope restoration throughout BC, whether projects are funded by outside sources or carried out in

Fig. 1.01 *Main stages of hillslope restoration.*



conjunction with current forest development. The term 'hillslope restoration' in this document refers to any rehabilitation work undertaken generally upslope of the riparian zone.

Any persons wishing to familiarize themselves with hillslope restoration methodologies or upgrade their knowledge of currently accepted hillslope restoration techniques should find this document valuable as a reference.

The individual stages of hillslope restoration are addressed in Sections 2 to 9; with overview planning and inventory in Section 2; field assessments and prescriptions in Sections 3 to 7; implementation of works in Section 8; and effectiveness evaluation in Section 9. A Glossary of relevant technical terms and an Annotated Bibliography of references precede the Appendices at the back of this handbook.

1.3 Slope Stability, Erosion, and Sedimentation Risks in Hillslope Restoration

Reducing the risks of landslides, erosion, and sedimentation in sensitive aquatic environments such as fish habitat or community water supplies, are fundamental objectives of hillslope restoration. An understanding of mass wasting, erosion and stream processes is necessary to develop effective restoration prescriptions. This section provides an overview of these processes in the context of hillslope restoration and provides links to other sections of this handbook.

1.3.1 Slope Stability

Reducing the risk of landslides to downslope and downstream resources and values requires consideration of both the likelihood of an event (also termed the 'hazard') and the expected consequences. Landslide processes vary depending on the type of material and the mechanism of movement.

Hillslope stability is related to a large number of factors including bedrock geology, slope angle, surficial material(s), moisture conditions and vegetation present on the slope. The likelihood of a road-related landslide depends on this inherent hillslope stability, as well as the road locations and construction techniques used. On clearcut slopes, loss of root strength may result in a significant reduction in slope stability. In addition, the logging techniques used on steep slopes or in gully systems may reduce slope stability. For any hillslope restoration activities, the landslide hazards must be considered before field crews and equipment are deployed. The consequences of a landslide event depend, in part, on its severity, which is directly related to its size (volume or magnitude), runout distance (its length from the initiation point to the deposition area), and impact to downslope resources. For road fill failures, an evaluation of hillslope geometry and composition may be useful for prediction of severity and runout distance.

Landslides are classified depending on the type of material involved in the slide and the mechanism of landslide movement (Varnes, 1978). Different landslide types often require different considerations during assessment for road deactivation or hillslope rehabilitation. Figure 1.02 contains the landslide classification framework developed by Varnes. Although this framework has been updated recently e.g. (Cruden and Varnes, 1996), this older version is useful for operational purposes.

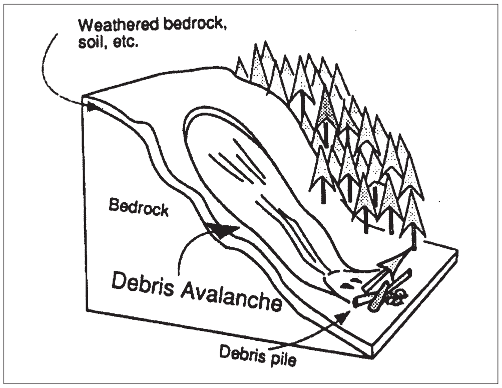
TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly Course	Predominantly Fine
FALLS			Rock fall		Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Few Units	Rock slump	Debris slump	Earth slump
			Rock block slide	Rock block slide	Rock block slide
	TRANSLATIONAL	Many Units	Rock slide	Rock slide	Rock slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Earth flow	Debris flow	Earth flow
			(except creep)	(soil creep)	
COMPLEX			Combination of two or more principal types of movement		

Fig. 1.02 *Landslide Classification System (after Varnes, 1978).*

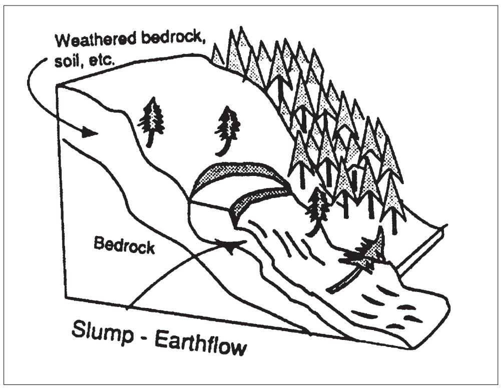
In this table, debris is material that contains greater than 50% coarse sand or larger fragments with organic material (woody debris). Earth contains predominantly sand, silt, and/or clay. Bedrock can be intact rock or previously weathered material.

In coastal areas of the province, common landslide types include debris slides and debris flows. Channelized debris flows (or debris torrents) and debris floods may be common in gullied terrain. In interior areas, earth slides, earth flows, earth slumps and earth block slides are more common. Rockfalls and rockslides can occur in any area of bedrock exposed or near surface. The speed and size of a landslide is often related to its mechanism of movement. Figure 1.03 summarizes many of the characteristics of forest landslide categories (after Chatwin et al, 1994).

Fig. 1.03 Forest-related landslide types (after Chatwin et al, 1994).

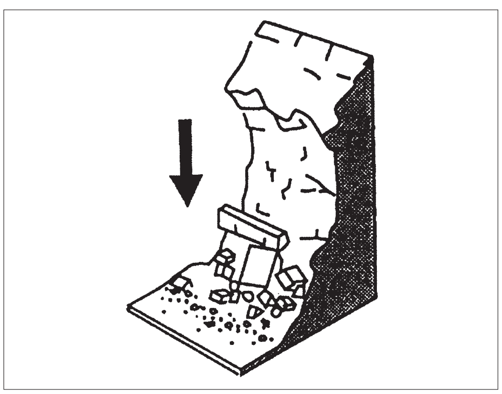


Debris Slides (also known as debris avalanches) are rapid, shallow landslides from steep hillslopes. Movement begins when overburden slides along bedrock or along overburden layers that have higher strength and lower permeability (such as dense glacial till). If enough water is present, debris slides become debris flows. **Debris Flows** are the rapid downslope flow of debris over considerable distance. Debris flows are more common in areas with pre-existing hillslope drainage paths or linear slope depressions created by past landslide activity. Debris flows are rapid (metres/min) to extremely rapid (metres/second).

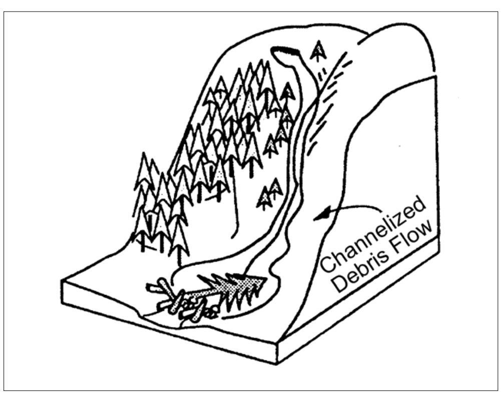


Earth Slumps and **Earth Flows** often involve the combined processes of earth movement e.g. (rotation of a block of overburden or soil over a broadly concave slip surface, or a slump) and result in the downslope movement of the block, either by a flow or through a gliding displacement of a series of blocks.

Creep activity is a common precursor to earth slumps and earthflows. Rates of movement range from extremely slow (millimetres/year) to rapid (metres/second).



Debris Falls, **Earth Falls**, and **Rock Falls** occur when the movement of the material takes place mainly through the air by free-fall, leaping, bounding, or rolling. Falls are very rapid to extremely rapid mass movements (from metres/min to metres/second). Debris falls and rock falls may present a safety hazard along older unstable road cuts or landslide headscarps.



Channelized Debris Flows (sometimes referred to as Debris Torrents) occur when debris slides or flows enter steep gully channels and canyons during high flow periods. These channelized debris flows involve the rapid movement of large volumes of water-charged soil, rock, and debris. Rates of movement are very high (metres/second) and damage can be extensive. Channelized debris flows can affect aquatic resources, and in some cases, may present a safety hazard in fan areas.

In hillslope restoration, work to prevent landslides is often carried out along the road corridor and within clearcut areas. Figure 1.04 contains information on the types of landslides that occur within these areas and the typical restoration activities that may be carried out. Note that for road corridors, the emphasis is on the prevention of landslides, while in clearcut areas the emphasis is on rehabilitation (or in some cases, stabilization to prevent further landslides and reduce erosion at the same location).

Hillslope Location		Landslide Type	Restoration Activity
Forest Roads	road cut	Slumps, Slides, Rockfalls	Road Deactivation (Sec. 3)
	road fill	Slides and Flows	Road Deactivation (Sec. 3)
Open Slopes	General	Slides and Flows	Revegetation, Bio-Stabilization (Sec. 4 and 6)
	Gully	Slides, Channelized Flows	Woody Debris Cleaning, Revegetation, Bio-Stabilization (Sec. 5 and 6)

Fig. 1.04 *Landslide Types and Restoration Techniques for Hillslope Rehabilitation*

1.3.2 Erosion and Sedimentation

Erosion is the wearing away of the land surface by the action of gravity, running water, wind, ice or other geological processes. Sediment generated by erosion is generally transported from a source area to a depositional area. Although erosion is a natural process, it may be accelerated by human activity. When determining the risk from erosion and sedimentation to an area, the erosion potential and the downslope or downstream connectivity to resources such as fish habitat or community water supplies must be considered.

Erosion in B.C is predominantly related to water, although in some regions erosion by wind and frost action may be significant. Erosion by water on a hillslope can occur in several different ways that may act separately or in conjunction with one another. In this discussion, soil erosion is considered to involve independent particle erosion as opposed to mass movements discussed in Section 1.3.1.

Rain splash erosion is the most basic form of water erosion and results when soil particles are dislodged and lifted into the air upon impact by raindrops. The level of erosion is dependent on the intensity and kinetic energy of the rainfall and the cohesion of the soil. Once dislodged, the soil particles may be easily washed from the slope as **sheet erosion**.

Fig. 1.05 *Rilling developed on fine-grained soil, Prince George area.*

Fig. 1.06 Headwall and transport zone of gully system well exposed after logging.

Sheet erosion acts in a generally uniform manner along the slope. **Rill erosion** may develop when runoff coalesces or merges into small channels or rills (see Figure 1.05). Erosion is concentrated at these sites due to the attendant increase in flow velocity and may result in processes such as downcutting of the channel base, undercutting of the sidewalls and 'headcutting' at the top of the rill. With continued erosion, rill erosion may develop into **gully erosion**. Gully erosion processes are similar, although on a larger scale, to rill erosion (see Figure 1.06). Large gullies can move considerable amounts of material in a very short time especially where they cross easily erodible materials. Gullies may also promote mass wasting (debris torrents) when sidewall or headwall erosion reduces slope stability. When flow in a gully is more or less continuous throughout at least part of the year, the flow is considered a stream and the erosion processes are those of **stream channel erosion**. Erosion occurs on the streambed through downcutting and along the streambanks by undercutting. Sloughing may occur within any channelized surface flow and result in streambank and channel bottom erosion.

Other types of water erosion include **solution** (erosion of soluble rock, such as limestone, when dissolved by acidic waters) and **groundwater piping** (the dislodgement and transport of soil particles by groundwater where it exits the ground to become surface water). Both processes may lead to collapse or subsidence of the ground surface.

The erosion of an area depends on several factors relating to soil, slope, vegetation, climate and erosion control practices. The Universal Soil Loss Equation (USLE) is one example of many methods that may be used to calculate erosion (soil loss). With the USLE, soil loss is the product of these factors:

$$X = R \times K \times L \times S \times C \times P$$

Where:

X = Soil Loss
R = Rainfall factor
K = Soil Erodibility index
L = Slope Length factor
S = Slope Gradient factor
C = Cropping or Vegetation factor
P = Erosion Control Practices factor

Rainfall factor (R) is based on the sum of storm energy and intensity and will generally be specific to a given region or area. Soil Erodibility index (K) provides an estimate of how erodible the local soil is and, therefore, will be site specific. In general, soils with low cohesion (e.g. sandy soils derived from fluvial or glaciofluvial deposits) will have a high index, while soils with high cohesion (e.g. silty or clayey soils derived from basal tills) will have a lower index. Slope Length factor (L) is determined by the length of the slope at a specific slope gradient. This slope gradient defines the Slope Gradient factor (S). Together, these factors (LS) may be considered the 'Topographic' factor. Long steep slopes will be more susceptible to erosion than short gentle slopes. Topographic factor will depend on site conditions; however, it may be possible to alter Topographic factor by treatments such as resloping or terracing. Cropping or Vegetation factor reflects the cover provided by vegetation or other material (e.g. mulch, erosion control matting): a higher cover yields a lower Cropping factor. Appropriate revegetation treatment can lead to a reduced Cropping factor. Erosion Control Practices factor is dependent on the application of non-vegetative erosion control practices such as installation of check dams or silt fencing, surface roughening, etc. Any such treatments can reduce this factor.

Erosion control for hillslope restoration (i.e. reduction of Soil Loss) will, therefore, benefit from any treatments that will aid in reducing Topographic factor (LS), Cropping factor (C) and/or Erosion Control Practices factor (P).

Hydraulic connectivity refers to the "connection" of hillslope areas to larger creeks or streams beyond the toe of the hillslope. In areas of direct hydraulic connectivity, any sediment that reaches a hillslope creek is transported directly downstream at a significant gradient (i.e. greater than 5 %) to locations where it may result in adverse effects to water quality or aquatic resources. For areas with no connectivity, the hillslope stream must flow into a swamp or lake and trap sediment where water quality or aquatic resources are not a specific concern, or it must terminate before connecting with any stream reaches that have water quality or aquatic resource values. Indirect connectivity may occur where the hillslope stream flows through a lower gradient reach (typically less than 5 % gradient for a minimum length of 100 m) before connecting with any stream reach with water quality or resource values.