A Forest Engineering Analysis of Landslides in Logged Areas on the Queen Charlotte Islands, British Columbia

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ABSTRACT

FERIC conducted a synoptic survey of 102 landslides on the Queen Charlotte Islands, 97 of which originated within logged areas, to supplement the Fish/Forestry Interaction Program's air photo landslide survey and to provide forest engineering input into the interpretation of probable causes and possible preventative measures. Ninety landslides were selected from Rood's (1984) population and 12 more recent failures were added to provide information on fresh landslides. Sample landslides were not chosen randomly so statistical inferences were not made from the survey data.

Thirty-one landslides initiated from logging roads, almost all in road fill slopes. The principal factors in road-related landslides appeared to be overloading of steep slopes with fill or sidecast material and inadequate control of road drainage, usually in combination. Road engineering and construction practices contributed to stability problems to some extent, but insufficient maintenance of road drainage systems, particularly on inactive logging roads, was considered to be the most significant factor in road-related failures. In the opinion of the authors, the frequency of road-related failures could be substantially reduced by improving the level of road maintenance, including putting roads to bed.

Specific causes for landslides that initiated within clearcuts but away from roads could rarely be identified. In particular, the role of yarding disturbance (gouging soils and uprooting stumps) as a failure mechanism could not be reliably distinguished from indirect logging factors (tree removal and root deterioration) or natural factors (storm and seismic activity). However, the yarding process probably accelerated landslide activity at critical points where poor deflection generated severe yarding disturbance on sensitive slopes. Reducing the frequency of this type of landslide would require maximizing available deflection through careful field layout and the use of mobile yarding systems, and minimizing the occurrence of difficult yarding situations such as that through or over major gullies.

PREFACE

A series of storms struck the Queen Charlotte Islands, British Columbia, during October and November of 1978, and triggered a large number of landslides. Many of the failures occurred in logged terrain and carried debris into important salmon-spawning streams. The B.C. Deputy Ministers of Forests and Lands, and Environment and Parks, and the Federal Deputy Minister of Fisheries and Oceans recognized the need to develop strategies that would minimize fishery and forestry management conflicts and impacts in this and other areas subject to intense mass wasting. In early 1979, the ministries established the Technical Advisory Committee on Fish/Forestry Interactions to investigate the problem on the Queen Charlotte Islands. Members included district, regional, and headquarters staffs of the three ministries.

The Technical Advisory Committee submitted its report to the deputy ministers in April 1980. Among its recommendations was the call for establishing a high-priority research program to investigate several aspects of the problem. Under joint funding by the two provincial and one federal agency, the Fish/Forestry Interaction Program (FFIP) was initiated in 1980. A Steering Committee of senior officials of the Ministry of Forests and Lands, Ministry of Environment and Parks, and Department of Fisheries and Oceans--later expanded to include the Canadian Forestry Service and FERIC--provided overall direction for FFIP. The Technical Advisory Committee was retained, and reported to the Steering Committee; and a program manager was hired to administer the research, and reported to the Technical Advisory Committee.

The following objectives were adopted for the program:[1]

(1) Provide documentation on the severity and extent of natural and logging-induced mass wasting and to evaluate the potential impact of this material on fish habitat and forest site productivity;

(2) Investigate the feasibility of rehabilitating stream and forest sites following damage by mass wasting and evaluate the effectiveness of suitable techniques;

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[1]Poulin, V.A. 1981. Fish/Forestry Interaction Research Program, Queen Charlotte Islands 1981 working plan. Unpublished draft report prepared for Fish/Forestry Interaction Program, September, 1981.

(3) Assess the use of alternative silviculture treatments for maintaining and improving slope stability by means of establishing thrifty root systems; and

(4) Investigate the feasibility and success in reducing mass wasting through the use of alternative logging methods, including skylines, helicopters, and improved logging planning.

The Technical Advisory Committee asked FERIC to participate in FFIP by conducting the alternative logging studies component (objective 4) of the program.

From the outset, FERIC believed that any effective approach to reducing logging-induced landslides depended upon careful and thorough logging planning and field engineering. This required forest engineers with a working knowledge of basic slope stability and mass wasting processes; an understanding of how logging and road-building affect mass wasting; an ability to recognize potentially unstable conditions in the field; and a sound understanding of the operating principles and characteristics of road-building machinery, and conventional and alternative cable yarding systems. Local information was lacking when FFIP began, so FERIC identified and conducted four studies to achieve the goals of the alternative yarding studies component of FFIP:

1. review of pertinent literature, to determine what information was available, and interviews with industry and agency staff, to become familiar with the specific problems of the Queen Charlotte Islands;

2. synoptic survey of landslides in logged areas of the Islands, to: identify common types and causes of landslides; identify common terrain features which could aid in early recognition of unstable sites; and suggest possible ways to reduce the frequency of such failures in the future;

3. series of studies of conventional and alternative cable yarding systems, to: describe system productivity; investigate how and where yarding disturbance is generated; and experiment with yarding techniques designed to minimize yarding disturbance in specific situations; and

4. study of two representative steep-slope areas, including ground-mapping, to: determine the type and quality of information forest engineers need for planning operations on steep slopes; and demonstrate the benefits and disadvantages of various cable yarding options and techniques through a series of map layouts.

All four studies have been completed. This paper presents the results of the second study, landslide survey. Reports describing the results of the other three studies are currently being prepared.

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- and finally, the managers, engineers, foremen, and crew of the forest companies on the Islands for their assistance, encouragement, discussion, and reviews of the information presented in this and other FERIC reports.

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1 INTRODUCTION

This is the second of four reports prepared by FERIC for the Fish/Forestry Interaction Program (FFIP). It presents the results of a synoptic field survey of 102 landslides on the Queen Charlotte Islands, 97 of which originated within logged areas. Its primary objectives were to:

1. apply forest engineering expertise to identifying and documenting possible logging- and road-related factors that contributed to landslide initiation in logged areas of the Islands;

2. suggest possible forest engineering, logging, and road construction and maintenance practices that could reduce landslide frequencies on logged terrain; and

3. identify terrain features that forest engineers could use to recognize failure-prone sites in the field, prior to road construction and logging.

1.1 Background

Information on mass wasting processes and impacts on the Queen Charlotte Islands was scarce and localized when FFIP was initiated. Alley and Thomson (1978) had prepared an overview of mass wasting processes on parts of Graham Island, and Wilford and Schwab (1982) and Schwab (1983) had examined mass wasting processes and storm impacts on logged and unlogged terrain in the Rennell Sound area of western Graham Island. As well, some forest companies had begun to survey landslides on their operating areas.

One of FFIP's stated objectives was to ".....provide documentation of the extent and severity of mass wasting impact on fish habitat and forest site productivity" (Poulin 1984). FFIP, therefore, initiated a two-stage air photo survey to expand the base of mass wasting information for the Queen Charlotte Islands. The first phase, covering the entire Islands, was a comprehensive overview based on small-scale (1:50 000) aerial photography.[2] In the second phase, 1:10 000 air photos were used to provide more detailed information about mass wasting on a number of selected watersheds (Rood 1984). Rood's survey recorded 4 times as many failures on logged areas as on unlogged areas, and indicated that the frequency of failures on steep logged terrain could be as much as 34 times higher than on comparable unlogged terrain. This study was designed to investigate reasons for the increase and identify ways to reduce it.

Before landslides were selected for field inspection, the literature was reviewed to establish what logging- and road-related factors have been identified or implicated as landslide-triggering agents (Sauder [1986]). Those associated with logging in general--and yarding in particular--include the following (Bishop and Stevens 1964; Swanston 1969, 1974; O'Loughlin 1972; Burroughs and Thomas 1977; Rice 1977; Ziemer and Swanston 1977; Gray and Megahan 1981; Wilford and Schwab 1982):

- Yarding--the process of moving logs from stump to landing--may contribute to failure initiation directly by damaging or dislodging stumps and roots, or by gouging the soil and channelling surface or seepage water onto unstable slopes.

- Slash and debris may accumulate in gullies and create debris jams that eventually give way, producing debris torrents.

- Tree removal alone may reduce slope stability for several years following logging. Studies have shown that tree roots can provide substantial mechanical support to slopes. After cutting, tree roots decay and mechanical strength declines. This trend is eventually reversed as the new crop grows. Also, decreases in transpiration and increases in soil moisture levels following cutting may increase the likelihood, or prolong the period, of soil saturation and peak stress.

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[2]Gimbarzevsky, P. 1983. Mass wasting on the Queen Charlotte Islands: a regional overview. Unpublished draft report prepared for Fish/Forestry Interaction Program, November, 1983.

- Cutblock orientation may expose boundary trees to windthrow, which may in turn trigger slope failures.

The factors associated with road construction and recognized as potential failure-triggering mechanisms include (Gonsior and Gardner 1971; Swanston 1971, 1974; Swanson and Dyrness 1975; Rice 1977):

- Road bed excavation may undercut and remove mechanical support for unstable, upslope soil masses.

- Blasting, building fills, sidecasting waste materials, and not compacting fill slopes may overload soil masses.

- Intersecting natural drainage paths and concentrating or redirecting road drainage onto marginally stable slopes may trigger failures.

2 STUDY METHODS

Given the size and biogeoclimatic variability of the study area, the availability of Rood's (1984) large data base, and the fact that the sample landslides were to be chosen from Rood's data, a randomized, statistically valid survey design was not considered necessary to satisfy the goals of this study. Rather, the need to establish a selection process and criteria that would provide data on a cross-section of landslides within logged areas was felt to be more important. Therefore, sample sites were selected nonrandomly and no attempt was made to sample the different types of failures in proportion to their frequencies of occurrence.

2.1 Selection Process and Criteria

A two-stage selection procedure was used. First, a subsample of the 27 watersheds examined by Rood was chosen, providing a reasonable cross-section of the Island's geologic and climatic conditions, timber harvesting practices, and ages of cutblocks.

Next, a subsample of Rood's landslide population was chosen from each of the selected watersheds. Sample landslides were chosen from Rood's base maps and photo-measurement summaries before they were located and examined in the field. The candidate landslides were selected to represent a range of sites, failure types, and land-use practices. The following selection criteria were applied:

1. Only landslides that appeared to originate within clearcuts were considered.

2. Landslides that appeared to deliver large volumes of debris into stream channels were given the highest priority for examination, followed by those covering the largest areas.

3. Sampled landslides were distributed among various topographic settings (open-slope, open-slope-into-gully, and within-gully) and according to apparent relationships to various land-use practices (roads, within-clearcuts, and near clearcut boundaries).

4. Finally, other landslides were selected to cover a range of types, sizes, ages, and other features found in a particular drainage. For example, a summer storm triggered several failures in early August of 1983 on northern Moresby Island. Several of these failures were added to the survey to provide data on fresh landslides.

2.2 Survey Methods

In addition to recording features to define a landslide's relationship to logging activities, the field surveys also recorded physical dimensions and descriptions (lengths, widths, depths, and slopes), and soils, topographic, geologic and vegetative characteristics (see Appendix 1 for field forms). Data collection methods, terminology, and descriptions were taken from the handbook, "Describing Ecosystems in the Field" (Walmsley et al. 1980). FERIC retained Rood's (1984) format for describing landslides so that data from the two surveys would be compatible. Landslide type was classified according to identification criteria and definitions of slope movement processes from Alley and Thompson (1978) and Varnes (1978). Thus, slope failures were categorized in the field by slope movement process (debris slides, flows, or torrents) and topographic setting (open-slope, open-slope-into-gully, or within-gully). Gully failures were further described according to whether they initiated at headwalls or on sidewalls.

Landslides were surveyed from deposition zone to initiation zone. Traverses were extended beyond initiation or deposition zones to include nearby relevant features (e.g., roads, tailhold stumps, slope depressions, or major slope breaks).

The landslide's position in relation to yarding patterns and truck roads was considered after the physical survey was completed. A landslide was classified as "road-related" if its headscarp was between the top of the cutbank and the bottom of the fill or sidecast slope. (It was assumed that the landslide had originated in the prism rather than moved into it as a result of retrogressive failure.) A landslide was classified as "clearcut-related" if its initiation zone was within a clearcut, but not in contact with a road prism.

The final stage of the field survey was to determine if any of the natural and logging-related factors identified in the literature review might have contributed to the failure's initiation. Each landslide's particular characteristics were carefully evaluated, but, of necessity, the process involved subjective judgment. The survey team was guided by Varnes' (1978, p. 26) observation: "Seldom, if ever, can a landslide be attributed to a single definite cause", which he expanded with a citation from Sowers and Sowers (1970, p. 506):

> In most cases a number of causes exist simultaneously and so attempting to decide which one finally produced failure is not only difficult but also incorrect. Often the final factor is nothing more than a trigger that set in motion an earth mass that was already on the verge of failure.

Evidence of yarding disturbance, such as gouging of soil or uprooted stumps, could be lost if a slope fails after it is logged. To compensate for this, cable deflection was measured in cases where yarding difficulties and consequent yarding disturbance were suspected in the vicinity of a landslide's initiation zone. The technique, described in more detail in Sauder [1986], consisted of surveying and plotting the ground profile of a yarding road from the tailhold stump to the landing (i.e., a deflection line was run). It established whether a yarding road passed near or through the initiation zone and determined the clearance between the cables and the ground at the point of failure.

Landslides originating within 30 m of the base of a fill slope were carefully examined for evidence of redirected road drainage. If enough evidence was found to suggest that road drainage had influenced the failure, it was treated as road-related; if not, it was treated as clearcut-related.

2.3 Data Analysis

Data were grouped and analyzed according to failure type (debris slide, flow, and torrent) to identify common attributes and characterize sites in logged areas where failures occur. Parameters of interest included ranges and modal values of initiation slopes, topographic position and location, surficial geology, bedrock, terrain, and site moisture features. To document and describe failure mechanisms, a similar procedure was used to examine road-related and within-clearcut failures. Landslides were grouped and analyzed by source (road or within-clearcut), location within the road prism if road-related, landslide type and location, and topographic and site characteristics. (Refer to the tables in Appendix 3.)

3 RESULTS AND DISCUSSION

A total of 102 landslides in 11 watersheds were surveyed between April and September 1983 (Figure 1). Ninety were chosen from Rood's (1984) survey and 12 were more recent failures, most of which occurred during a storm in early August 1983. Appendix 2 cross-references landslides examined by Rood (1984) and FERIC.

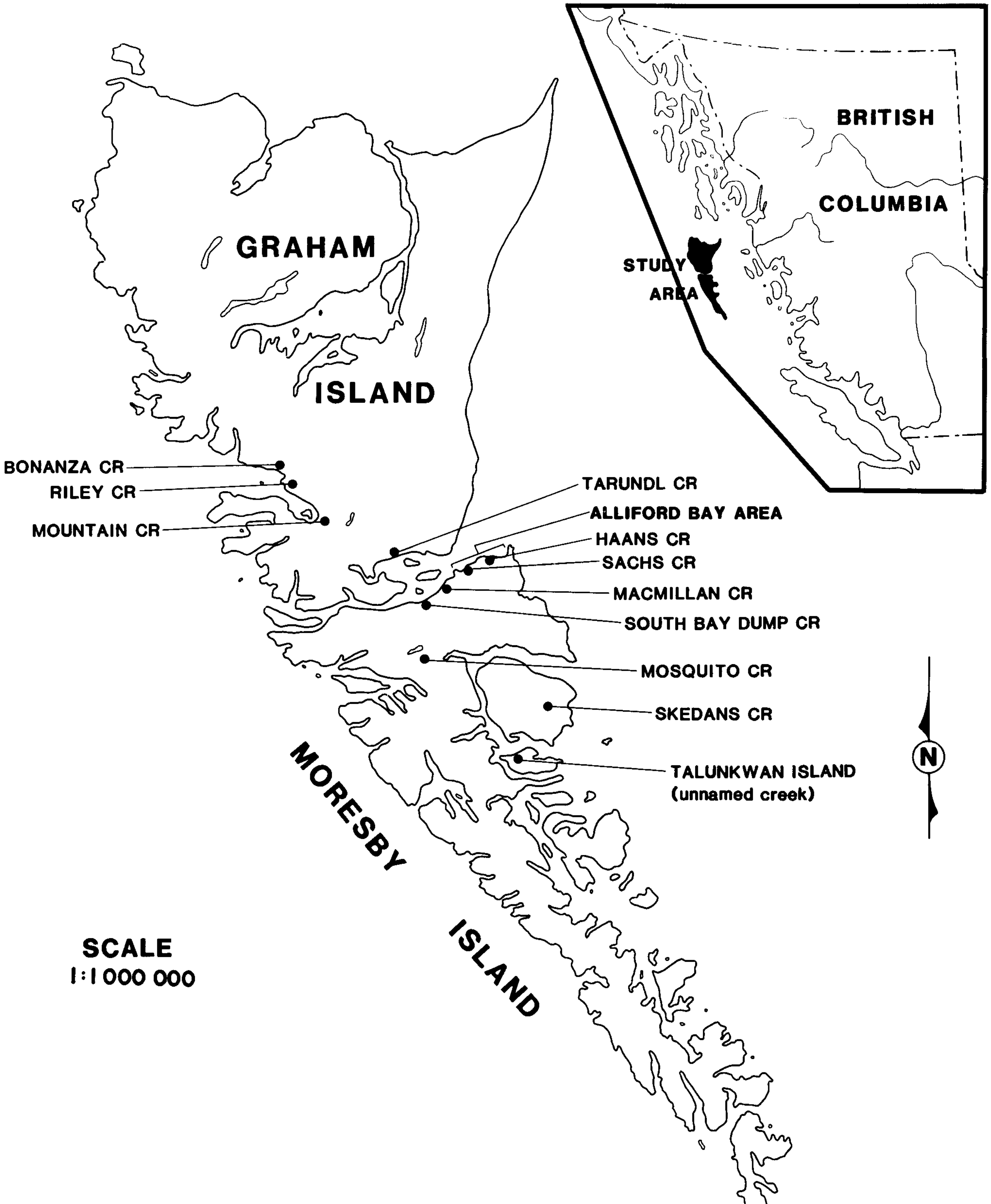

FIGURE 1. Location of study streams on the Queen Charlotte Islands.

The sample landslides occupied two physiographic regions (the Skidegate Plateau and the Queen Charlotte Ranges) (Holland 1976) on Graham, Moresby, Louise, and Talunkwan islands, and were distributed over seven geologic formations. Two volcanic formations (Yakoun and Masset) and three sedimentary formations (Kunga, Haida, and Honna) were well represented among the sample failures, while the Karmutsen (volcanic) and Skidegate (sedimentary) formations and some plutonic bodies were sampled less intensively (Sutherland Brown 1968). Summaries of these and other physical characteristics including failure type, topographic features and areas and volumes are presented in Appendix 3.

Of the 102 landslides FERIC examined, 77 were classified as debris slides, 14 as debris torrents, and 11 as debris flows. Forty-three occurred on open slopes, 22 initiated on open slopes and entered gullies, and 37 originated within gullies. Five failures in gullies or narrow channels originated well outside the boundaries of logged areas and appeared to be unrelated to logging or road-building. Of the 97 failures that developed within clearcuts, 31 were associated with roads and 66 with clearcuts (Table 1). Twenty-five of the 31 road-related failures were debris slides, two were debris flows, and four were debris torrents. Among the clearcut failures, 51 of 66 were debris slides, 8 were debris flows, and 7 were debris torrents.

Rood's (1984) air-photo survey, which examined 530 slope failures in logged areas, provides a better basis for establishing representative proportions of landslides by type and source on the Queen Charlotte Islands.[3] He recorded 463 debris slides and 67 debris flows (torrents). A total of 239 landslides originated on open slopes and 291 initiated within gullies. Ninety-seven failures were road-related (74 open-slope debris slides, 14 within-gully debris slides, and 9 debris torrents), and 433 failures were clearcut-related (165 open-slope debris slides, 210 within-gully debris slides, and 58 debris torrents).

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[3]Definitions of landslide type vary between Rood (1984) and this report. For purposes of comparison, Rood's debris slide encompasses both debris slide and debris flow as defined in this report, and his debris flow is equivalent to this study's debris torrent.

TABLE 1. Summary of slope failures by within-clearcut, road-related, and other categories[a]

	Within clearcuts	Roads	Other	Totals
Riley Creek	6	6	-	12
Bonanza Creek	6	6	-	12
Talunkwan Island	7	5[b]	1	13
Tarundl Creek	1	1	-	2
Mountain Creek	1	-	-	1
Mosquito Creek Tributary	1	-	-	1
MacMillan Creek	5	5	-	10
South Bay Dump Creek	9	4	-	13
Sach's Creek	22	3[b]	3	28
Haans Creek	4	-	-	4
Alliford Bay and vicinity	2	-	1	3
Skedans Creek	2	1	-	3
	66	31	5	102

[a]The proportions of road- and clearcut-related failures in the sample do not indicate actual relative frequencies for either individual drainages or the Queen Charlotte Islands as a whole.
[b]One failure in each of these drainages may have been related to yarding as well as to roads.

Appendix 4 describes 15 surveyed landslides in detail. These examples illustrate how slope failures were examined and indicate some of the problems and uncertainties involved in trying to determine their possible causes and means of prevention.

3.1 Landslide Types and Their Terrain Features

3.1.1 Landslide types

Characteristic site descriptions were compiled from the sample for four categories of landslides: debris slides on open slopes; debris slides and flows within gullies; debris flows; and debris torrents.

3.1.1.1 Debris slides on open slopes

Open-slope debris slides generally exhibited the classic features of translational movement described by Swanston (1974) and Varnes (1978). Fifty-one open-slope and open-slope-into-gully debris slides were examined.

Debris slides initiated on slopes with gradients ranging from 35 to 140% (19-54°); the majority started on slopes between 70 and 90% (35-42°). Slopes in the transport zone ranged from 17 to 114% (10-49°), while those of the deposition zone were 0-75% (0-37°). Debris slides starting on open slopes steeper than 90% appeared to be smaller than those starting on gentler slopes. Soils on very steep slopes were typically very shallow (often 10 cm or less) and not well developed, perhaps indicating a higher natural rate of erosion and mass wasting.

Open-slope debris slides occurred on all slope shapes (convex, straight, and concave), but convex slopes dominated the sample (30 of 51). Convex and straight slopes were characteristically composed of colluvial veneers (less than 1 m deep) over bedrock, which usually formed the failure surface. In a few cases, where highly weathered bedrock lay under the surficial deposits, the failure extended into the bedrock. Failures sites on concave slopes were characterized by blankets of colluvial or morainal deposits (deeper than 1 m). Landslides on morainal deposits usually failed along the interface between weathered and unweathered till.

Failures on convex and straight slopes were usually closely associated with depressional sites and/or seepage zones. Subsurface seepage was present in the headscarps of all concave open-slope failures, most of which occurred within or immediately below recognizable slope depressions.

3.1.1.2 Debris slides within gullies

Twenty-six debris slides initiating on gully sidewalls or headwalls were examined. Debris slides within gullies fell into two distinct classes:

1. Fairly large, discrete failures, similar in most respects to debris slide scars on open slopes.

2. Very small, shallow scars scattered along the sidewalls of gully systems. These appeared to be more frequent than the larger, discrete failures.

The first category of gully-controlled debris slide, the larger failure, usually initiated at or near the slope break marking the top of the gully headwall or sidewall, commonly in thin layers of colluvium derived from bedrock weathered _in situ_. Slopes in the initiation zones ranged from 65 to 145% (33-55°), and slopes in the transport zone reflected the oversteepened sidewall gradients, ranging from 48 to 110% (26-48°). The transport zone was usually very short. Debris from sidewall failures usually formed steeply sloping aprons adjacent to or encroaching on the gully channel.

The second category of gully-controlled debris slide, the small, shallow scar, appeared to continue to contribute sediment to the gully channel from secondary erosion processes such as ravelling, surface wash and possibly frost action, long after initial failure of a small soil mass. Many of these failures were probably yarding scars. Such scars are of concern because they appear to revegetate very slowly and generate sediment continually.

Almost all gully sidewall failures were on straight slopes and did not occur in recognizable slope depressions. Subsurface seepage was evident in the headscarps of about half of these slides. A few gully-wall debris slides that developed within deep morainal blankets were on lower receiving slopes and showed substantial seepage in their upper regions.

3.1.1.3 Debris flows

Eleven debris flows were surveyed, of which nine initiated on open slopes and two within gullies.

The debris flows occurred on gentler slopes than debris slides did. Slopes in the initiation zones of debris flows ranged from 45 to 80% (24-39°), with most (8 of 11) starting on slopes of 45-60% (24-30°). Transport zone slopes ranged from 30 to 55% (17-29°), and slopes in deposition zones were 0-20% (0-11°).

Seven debris flows initiated on convex slopes, although all slope shapes were represented. The failure surface was almost always at an interface of weathered and compact morainal materials, within a depressional site that transmitted subsurface flow. The seepage flow was usually heavy, even in the driest part of the year.

3.1.1.4 Debris torrents

Debris torrents by definition (Varnes 1978) occur in steep-walled, high-gradient gully systems, but may start as debris slides or flows outside the gully. (Of 14 torrents examined, 5 apparently were triggered by debris slides that originated outside the gully channel.) The channels of debris torrents were characterized by V-shaped gullies, at least 3 m deep, with sidewall and channel gradients of 60%+ and 40%+, respectively. Most torrented gullies were carved into bedrock which was usually soft, very weathered, and/or highly fractured. Surficial materials on the steep sidewalls were either thin layers of colluvium or thin organic mats directly on bedrock. Channel gradients ranged from 32 to 63% (18-32°), although most of the torrents were restricted to a narrower range of 40-50% (22-27°). Channel depth (vertical distance from top of sidewall to channel base) ranged from less than 3 m to more than 30 m.

The sidewalls of torrent-scoured gullies were often marked by small debris slides or flows.

3.1.2 Key terrain features

3.1.2.1 Terrain features of landslides on open slopes

Open slope landslides in the sample usually occurred on slopes steeper than 70%, in linear slope depressions, and/or at major slope breaks. Many open-slope failure sites exhibited more than one of these recognizable characteristics.

Slopes over 70%: Most of the road-related failures attributed in this survey to overloading, as well as many of the within-clearcut failures, initiated on slopes steeper than 70% (35°). The landslides had several common features:

- Initiation sites were often relatively dry.

- Soils usually consisted of shallow colluvial veneers over bedrock, normally less than 50 cm and often less than 25 cm deep.

- Small rock outcrops were sometimes present above or beside the headscarp.

- The sideslope was smooth and uniform for 20 m or more below the initiation point (not broken, benchy, or irregular).

- Failures occurred on mid- to upper slopes, usually on shedding positions such as convex ridges and spurs, or long uniform slopes below ridges or slope breaks.

It is not suggested here that slopes over 70% cannot be logged safely, or that all slopes of less than 70% are more stable. Several roads in this survey were still intact on slopes steeper than 70%, while many of the large failures initiated on much gentler slopes. However, the general observation corresponds with Swanston's (1969, 1970) findings in Maybeso Valley, southeast Alaska, in which the majority of slope failures initiated on slopes between 30 and 40° (58 and 84%) and most frequently around 37° (75%). Thus, areas having slopes over 70% have to be carefully engineered to minimize landslides, particularly those that are road-related.

Examples 1 and 2 in Appendix 4 describe failures on slopes greater than 70%.

(Linear) slope depressions: Most of the open-slope landslides away from roads began in shallow but noticeable slope depressions above or surrounding the failure sites. These depressions were often characterized by:

- relatively straight to slightly concave profiles;
- slopes of 40% (22°) and steeper;
- widths of less than 10 m to more than 50 m;
- apparent upslope extensions above the failure sites, often for distances of 30 m or more;
- noticeably greater moistness than surrounding higher ground; and
- slightly finer mineral soil textures than were found on surrounding slopes, and frequently black muck soils produced by the high contents of incorporated organic matter.

Because these depressions were obviously zones of slope drainage, plant associations indicative of locally higher moisture regimes were also a characteristic. Post-logging vegetation usually indicated relatively moister conditions in slope depressions associated with failure sites. For example, sedges, liverworts, and hellebore could be found within a depression, while huckleberry was the dominant ground cover on the relatively drier ground to either side.

Two general forms of slope depressions were distinguishable:

1. long, well-defined depressions with parallel lateral margins, usually on straight, uniform slopes. Landslides usually began in the middle and upper thirds of these depressions.

2. short, well-defined depressions, usually on concave slopes, with lateral margins diverging upslope. These funnel-shaped depressions appeared to receive and concentrate slope drainage, becoming noticeably wetter toward their outlets. Often a well-defined gully began at or near the outlets of these depressions. Failures usually developed in the lower third or at the outlet. Examples 6 and 15 in Appendix 4 are typical of this situation.

Surficial materials were variable. On gentle slopes linear depressions were often underlain by morainal blankets, whereas on steeper slopes a colluvial veneer over bedrock was more typical.

A general observation was that the wetter the site, the gentler the slope on which a failure may occur. Several failures in linear depressions occurred on slopes of 30-35% (17-19°). These were usually lower-slope receiving positions with strongly concave profiles. On steeper slopes, the failure depressions tended to have straight profiles.

Obviously not every slope depression is a potential failure site. However, the field engineer should watch for these slope depressions when locating roads through landscape units where stability problems are anticipated, particularly if the depressions lead into gullies downslope. (See following comments on gullies.)

Major slope breaks: Most open-slope landslides in the survey occurred in or near zones of major changes in slope angle. The minimum slope change was about 10%; more frequently it was 20% or more. Slope breaks ranged from sharp to gradual.

Landslides usually started right at the edge of the break if the slope break was sharp. On more gradual convex slope changes, landslides tended to initiate below the break where slopes were often steeper than 70% (35°) (but gentler on moister sites) and soils were thinnest. Slope breaks were often bedrock-controlled, with shallow soils below the break and slightly deeper soils on the gentler slopes above. Usually the slope below the break was relatively steep and uniform for a considerable distance downslope (see Example 9, Appendix 4). Rock outcrops were present at or near the break in many cases, especially where slopes were steeper than 70%.

Landslides on concave slopes usually initiated on the steeper slope just above the slope break. Among the landslides surveyed, slopes were generally 50% or more in the initiation zone and ranged from 30 to 40% below the slope break. These were generally moist to wet receiving sites at lower-slope positions. It was not uncommon to see seepage exiting as surface flow (discharge sites) at nearby areas along the slope break. Soils were deep and often underlain by morainal blankets.

Some failures initiated below the slope break. Usually these occurred in recognizable slope depressions in which seepage was discharging above the headscarp (see Example 12, Appendix 4).

3.1.2.2 Terrain features of landslides in gullies

The existence of a gully is evidence that a site is experiencing a high rate of natural erosion. Thus it is not surprising that the gullies of this survey appeared to be more sensitive to disturbance by logging and road building than were surrounding open slopes. Most gullies within the clearcuts examined showed some degree of renewed or ongoing erosion activity, as a result of yarding as well as natural forces. Yarding with partial suspension through gullies seemed to cause some surface soil disturbance, mostly in the form of small sidewall scars, almost regardless of available deflection. Fully half (19 of 37) of the within-gully landslides surveyed were of this type. It could not be determined by the authors if sidewall disturbance increases the risk of debris torrents occurring.

The banks of some V-shaped gullies in unlogged areas were unvegetated or covered only with mosses. These were usually very moist to wet sites, often associated with small sidewall failures. Whether these features indicate a higher-than-average potential for debris torrents to occur after such gullies are logged is unknown, but it is likely they are more sensitive to yarding disturbance than are fully vegetated gullies with stable banks.

Gully headwalls appeared to be zones of high landslide activity in logged areas. Often debris slides from headwalls appeared to trigger debris torrents. The headwall areas of gullies were usually concave, water-collecting sites, ranging from small depressions to very large bowls. Slopes were generally steep (70%+) toward the back of the headwall.

In numerous cases, one or more recognizable linear depressions draining into a gully headwall area were found above the actual headwall itself. Small failures in some of these depressions may have triggered debris torrents in the gullies below.

3.2 Landslides Associated with Roads

3.2.1 Probable failure mechanisms

Almost all road-associated landslides in the sample initiated within road fills. The major factors in these failures were the overloading of steep slopes with fill or sidecast material during construction; and/or poor road drainage control, causing road water to be directed onto fill slopes. (Usually the two factors were in combination.) A few landslides that developed below logging roads may have been influenced by the concentration of road drainage onto unstable slopes downhill. Cutbank slumps resulting from undercutting or oversteepening slopes were common in some areas. However, they were not sampled by Rood (1984) because they were almost always less than 200 m^2 in area, the minimum size that could be reliably distinguished from the 1:10 000 air photos.

3.2.1.1 Overloading steep slopes

Fill-slope failures starting on slopes steeper than about 70% usually had the following characteristics:

- Roads were three-quarter to full-bench cuts, usually in rock. Waste material was sidecast onto steep sideslopes.
- Slope shape was (often strongly) convex.
- Failures initiated on the steepest portion of the convex slope, usually where slopes exceeded 70%.
- Failures occurred on mid- to upper slopes.
- Failure sites were well to rapidly drained.
- Surficial materials were usually coarse- textured, noncohesive, and shallow (colluvial veneers).

- Signs of linear slope depressions or water inputs (road drainage and seepage) were lacking.

Overloading of steep slopes with sidecast material appeared to be the dominant factor in such landslides. Examples 1 and 2 in Appendix 4 illustrate failures of this type.

3.2.1.2 Road drainage onto fill slopes

Road-associated failures on sideslopes of less than 70% usually occurred at sites where breakdowns in the road drainage network redirected road water onto fill slopes. These landslides seemed to occur most frequently in slope depressions where fills were built to maintain road alignment. It was concluded that these failures involved overloading in combination with excess soil moisture as a result of poor drainage practices.

Examples 3 and 4 in Appendix 4 describe this type of failure.

3.2.1.3 Altering natural slope drainage patterns

Alteration of natural slope drainage patterns as a result of road construction is often cited as a failure-triggering mechanism, but it is poorly documented in the literature and difficult to prove. However, the possibility cannot be ruled out, and in this survey it was suspected to be a contributing factor in some landslides (e.g., Example 5, Appendix 4). In other cases, the landslide's close proximity to a logging road was thought to be coincidental and not linked to road drainage (e.g., Example 6, Appendix 4).

3.2.1.4 Undercutting steep slopes

Cutbank failures usually occurred as small slumps, the result of steep slopes being undercut. While of minor importance in directly causing site loss or damage to streams, cutbank slumps may indirectly contribute to larger, more damaging failures by plugging ditches and diverting ditch water onto fill slopes.

3.2.2 Aspects of engineering, construction and maintenance associated with landslides from logging roads

Road design and location, construction practices, drainage control, and maintenance all contributed to road-related failures in the sample, but they were not of equal importance. Road maintenance for drainage control stood out as the crucial factor in many of the road-associated failures investigated.

3.2.2.1 Road location

Minor changes in road locations might have made construction easier and perhaps lessened the risk of failure in some cases by reducing excavations or placing roadbeds on gentler slopes. It was concluded, however, that simply altering road locations alone would not necessarily have prevented any of the landslides examined. Construction and maintenance practices and road drainage were overriding factors.

3.2.2.2 Road construction practices

Sidecasting waste material onto steep slopes and into gullies was the principal construction practice contributing to road-associated landslides. Most of these construction-related failures occurred on older roads built with bulldozers or line shovels. It has been suggested by industry and agency personnel on the Queen Charlotte Islands that the frequency of road-associated landslides has decreased since hydraulic excavators were introduced to the Islands in the mid-1970s. In building roads on steep slopes, bulldozers and line shovels have limited ability to control sidecast or to use excavated soil and rock to finish the roads. By comparison, hydraulic excavators are better able to strip away overburden and separate soil materials to produce clean, well-formed subgrades; they can control placement of soil material more readily to reduce sidecast and build more stable fills; and they can easily dig ditches in non-rock subgrades during the subgrade construction phase.

However, there are several factors in addition to the construction machinery that may contribute to an apparent reduction of landslides from recently built roads:

- New roads appear to be narrower, built on better subgrades, and better ditched than old roads, and more attention seems to be given to road drainage requirements. The better quality of construction may be due in part to the hydraulic excavator's abilities, but it also indicates greater awareness and attention to matching construction methods to site condition.

- Fewer roads appear to have been built on sensitive slopes in recent years.

- Industry and agency personnel have gained experience at recognizing and avoiding failure-prone sites, and at scheduling construction during dry weather.

- Not enough time has elapsed yet to establish a true long-term failure frequency for excavator-built roads.

- Recently built roads are generally in active use and are adequately maintained.

3.2.2.3 <u>Road drainage control</u>

With the general exception of fill slope failures on very steep (70%+) slopes, most of the road-associated landslides in the sample were traced to problems in the road drainage network. Both construction and maintenance factors contributed to these failures. The major construction factors included:

- ditches that were sometimes absent or formed by the ballast layer;

- culverts that were spaced too far apart or poorly located; and

- culverts that were too small.

In some cases, mostly on roads built by bulldozers, ditches were absent and road drainage flowed directly into the sidecast or fill slope. This was not a problem where the roadbed was fully on bedrock. On non-rock subgrades, however, ditches were sometimes formed from ballast rather than cut into the subgrade. This practice caused water to pond in the ditch, saturating rather than draining the subgrade.

In general, culverts were spaced too far apart and allowed ditches to collect too much water. Often ditches on steep gradients were deeply cut by water and culvert inlets were plugged with sediment and debris. Culverts were usually installed only at well-defined water courses, and were not large enough to accommodate peak stream flows as well as ditch flows.

The wide culvert spacings may have contributed to off-road failures by collecting drainage from large areas and concentrating it onto small slope areas.

3.2.2.4 Road maintenance practices

In this sample, inadequate control of road drainage appeared to be the single most important factor influencing road-associated landslides. Although construction factors were also involved (see above), most fill slope failures were attributable to problems with road drainage, which occurred because of inadequate road maintenance.

Both frequency and techniques of road maintenance contributed to road drainage breakdowns. Typically, blockages in ditches or culverts by logging debris or cutbank slumps diverted drainage onto the road surface and eventually onto fill slopes where failure occurred. In some cases, ditches and culverts apparently were not cleaned out following logging, but more often they were plugged with debris that had sloughed off the cutbanks sometime after cleaning.

Only a few road-associated landslides in the sample occurred on active roads (roads being used for hauling), which might suggest that active roads are maintained adequately during periods of use. However, most of these roads were built within the last few years, so the benefits of new construction practices and shorter time of exposure to climatic events cannot be separated from those of more frequent maintenance.

Most road-associated landslides occurred on temporarily inactive or abandoned roads. The low frequency or complete lack of road maintenance, rather than its timing or technique, was the primary concern with respect to these failures. In general, post-logging maintenance on inactive roads was not sufficient to keep ditches and culverts in functional condition, and many inactive roads were not maintained at all. Most drainage-related landslides appeared to occur as a result of gradual deterioration--rather than sudden failure--of the ditches and culverts.

Several of the landslides examined occurred on roads that had been put to bed. Usually culverts had been removed and open cross-ditches installed in their place, and occasionally additional cross-ditches had been installed at points where there had been no culverts. Failures from these roads occurred for essentially the same reasons as for roads that had not been put to bed: ditches became plugged and diverted water out onto the road surface and fill slopes; cross-ditches were breached by running water and failed to carry all ditch flow off the road; and surface flows from several sources collected into small natural drainages which were not capable of handling the increased volumes.

3.2.2.5 Road drainage and off-road landslides

Several of the off-road landslides examined for possible road drainage influences had the following characteristics: the failure occurred on steep slopes below a slope break, occasionally in a small depression, and in shallow soils; the road was located on the gentler slope ("bench") a short distance above the initiation zone; and there was usually no evidence to indicate that the road had directed additional water onto the failure site.

Many of these situations, it appears, were coincidental. First, within-clearcut landslides on steep convex slopes and at slope breaks were found throughout clearcut areas and not just near roads. Second, from an engineering point of view a bench is a good place for a road location. In fact, it is usually necessary to build roads close to convex slope breaks to obtain adequate deflection for uphill yarding. Excavation volumes are reduced and the benches are potentially good landing sites. Therefore, while it was difficult to completely dismiss road influences in such failures, there was reason to believe that roads were not directly responsible for all of them.

3.2.3 Preventing road-associated landslides

Many road-associated landslides on the Queen Charlotte Islands could be prevented. Effective prevention must combine all aspects of road engineering, construction, and maintenance. No one factor by itself will ensure stability of a road.

3.2.3.1 Road engineering

Many landslides might be prevented if forest engineers could identify potential failure sites before road locations and setting boundaries were finalized. Early recognition offers the best opportunity and maximum flexibility for coping with these areas. Potential failure sites identified during field reconnaissance should be treated as control points when roads and setting boundaries are subsequently located.

Attention to terrain detail is essential if these sites are to be recognized. Descriptions of some characteristic failure sites are given in Section 3.1.2, Key Terrain Features. These descriptions can apply to very small landscape features, in some cases perhaps no more than 10 m across. Thus, although it is neither practical nor possible to pinpoint all potential failure sites in a development area, it is possible to inspect road locations carefully.

While these descriptions are not complete and are not substitutes for local experience, they may provide a base on which to build experience. An engineer and a terrain specialist who are thoroughly familiar with a particular area should be able to refine these descriptions considerably. Another way to identify failure sites and causes is to inspect new landslides regularly as they occur.

It may be possible to avoid some sensitive areas by adjusting road locations and grades, but in most cases not all such areas can be avoided. This is particularly true in the development of steep, difficult terrain, where a few key control points (landing sites, rock bluffs, creek or gully crossings) usually restrict road location options. When an engineer finds it necessary to locate a road across problem sites, he must pass on his findings and involve the construction supervisor in developing appropriate construction methods. In turn the construction supervisor must know where the problem sites are and what must be done, and discuss them with the road-building crew.

3.2.3.2 Road construction

Observations made in this survey suggest that the frequency of construction-related landslides on the Queen Charlotte Islands has decreased since hydraulic excavators were introduced in the mid-1970s. Even if this is true, credit should also go to the development of road-building techniques that are well-suited to the excavator's work abilities on steep slopes, and to the greater awareness of engineers, supervisors, and operators of why landslides occur and how they are affected by road construction.

To the authors of this report, the quality of construction in recently built roads and the trend toward increasing use of log--rather than metal--culverts are encouraging signs. Log culverts are more versatile than metal culverts because they can be built with local materials to whatever size the situation calls for (they are, in fact, generally overbuilt), and the original channel slope can be retained.

Even on newer roads, however, there appears to be a general lack of culverts. Although the concept of maintaining natural slope drainage patterns is well known, culverts are still not installed frequently enough during road construction, and the metal culverts that are installed are often too small.

3.2.3.3 Road maintenance

Improved standards of road maintenance, especially on inactive roads, can achieve a substantial reduction in the frequency of road-associated landslides. The authors of this report are convinced that the quality of road construction governs the risk of slope failure in the short term, but maintenance standards determine the road's stability in the long term. For example, most of the road-associated landslides in the sample were attributed to inadequate maintenance and not to construction. Also, even if new roads are better built, the extensive network of old roads that remains will continue to be a source of landslides.

Road maintenance, however, cannot be entirely separated from road location and construction. Initial decisions about where a road is to be sited and how it is to be built must also consider its maintenance requirements. However much maintenance may ameliorate location- or construction-related problems, it cannot correct them.

In general, active roads in this survey appeared to be adequately maintained, although berms were often left along road edges after grading. This contributed to at least one landslide in the sample, where road drainage was concentrated onto a fill slope. Berms should be broken down or breached frequently to permit surface runoff to flow off the road quickly.

Active haul roads require more intensive maintenance than inactive roads and obviously receive higher priority, particularly during wet weather. Inactive logging roads on steep-slope areas of the Queen Charlotte Islands, however, must also be maintained or put to bed. This survey indicates that inactive roads need a higher level of attention than they now normally receive. Since most road-related landslides appear to involve breakdowns in road drainage systems, maintenance activities must concentrate on keeping ditches and culverts clean of debris so they can handle normal storm runoff. The ditches and culverts of both active and inactive roads should be checked regularly during winter months and any blockages removed.

This increased maintenance will place extra demands on available equipment and manpower, particularly during wet weather when both active and inactive roads need more attention. If demands on maintenance resources to service active roads do not permit inactive roads to be inspected regularly and cleaned when required, then inactive roads should be put to bed. This raises two issues: 1) when to put a road to bed, and 2) how to do it.

The question of when to put a road to bed must consider: any potential stability problems; the need to keep a road open for purposes other than logging; and the ability of the operator to maintain it adequately after logging is completed. Other factors--the cost of maintenance versus the cost of putting a road to bed, the risk and consequences of landslides, access for protection and silvicultural activities, access to the public, and whether there are alternative methods for reducing landslide risk--must also be addressed. Whatever decision is made, it should be reviewed if any of these factors change.

Equally important is the question of how a road should be put to bed. This survey recorded failures on roads that had been put to bed, and in some cases the way it was done contributed to the failures (e.g., cross ditches draining onto road fills). In other cases, the techniques used to direct road drainage permanently off the road and onto stable sites were not sufficient to handle the accumulations of water, debris, and sediment.

In many cases a road may be put to bed and yet still remain accessible for small vehicles, whereas a road that has washed out is usually not passable.

On the abandoned roads examined, the principal technique for putting roads to bed was to pull out old culverts and replace them with cross ditches. Occasionally water bars were installed in places where there had been no culverts, but this appeared to be the exception rather than the rule. Generally, cross ditches and water bars were too far apart.

More effort must be made to determine what techniques are appropriate for putting roads to bed on the Queen Charlotte Islands. There are probably several approaches and methods that would be applicable to the Islands for different conditions, but there is still considerable scope to improve the use of standard techniques such as cross ditching.

3.3 Landslides Associated with Yarding

3.3.1 Probable failure mechanisms

No published evidence could be found by the authors of this report that clearly shows yarding disturbance is capable of triggering landslides. Nor was it possible to define specific reasons for most of the within-clearcut landslides not associated with truck roads. Probably the combined effects of several processes--tree root deterioration, climate, and yarding disturbance--are needed to reach failure point, but this study could not resolve these complex interactions.

It was hoped in this study to determine whether yarding itself could trigger slope failures by damaging or uprooting stumps or by gouging the soil. Landslides have been known to occur during active logging operations (E. Runtz, pers. comm. 1985) but such occurrences have not been reported or analyzed in the literature. In this study, yarding events at failure sites had to be reconstructed through the use of indirect evidence such as deflection analysis, extent and severity of yarding disturbance, and local topography. On the basis of this evidence, it was concluded that yarding disturbance was probably a contributing factor only in a limited number of the landslides examined.

3.3.1.1 Yarding disturbance

Within-clearcut failures, for which yarding was suspected as a potential triggering agent, had one or more of the following in common:

- evidence of moderate to severe yarding disturbance (scraping, gouging, and damaged stumps);

- reduction in deflection at or near the point of initiation (topographic obstacles such as ridges, benches, or knolls); and

- yarding along shallow depressions in combination with limited deflection.

Most within-clearcut failures on open slopes occurred on steep (greater than 70%), usually shedding (convex) slopes, and were associated with a pronounced break in slope. Soils were usually shallow at these sites, and rock exposures were common in the vicinity of the headscarp.

Yarding disturbance, whether associated with failures or not, was also generally more extensive and severe at these sites, reflecting the role of convex slope breaks as topographic obstacles to yarding. The frequency of landslides at sites of heavy disturbance may be partly coincidental in this sample, but it was high enough convince to the authors that yarding can indirectly induce some landslides.

Mechanical damage to stumps, root systems, and soil structure as a result of logs ploughing and scraping the ground or striking stumps seems to be the most likely cause of yarding-related landslides. In some circumstances yarding may trigger a landslide directly, perhaps when a stump is completely uprooted. More probably, however, yarding damage lessens the composite shear strength (soil plus root systems) to the point where further losses in strength (e.g., by root decay) or increases in stress (e.g., by heavy rainfall) eventually lead to failure.

In addition to the type of disturbance, the severity of yarding disturbance must also be considered. Light scraping of the ground surface during yarding is inevitable because one end of the turn is normally in contact with the ground at all times, but it may not be sufficient to cause significant damage to root systems. Gouging, however, probably does damage roots and alter soil hydrology, and may therefore be significant to yarding-related landslides. Gouging indicates either that there is not enough clearance to lift the front ends of the logs off the ground because of poor deflection, or that heavy turns have been yarded.

Very few landslides seem to occur during actual logging operations, which suggests that yarding damage to stumps and root systems is seldom sufficient to trigger landslides directly. The well-documented time lag of several years between logging operations and peak failure frequency is usually cited to support tree root deterioration as a factor in slope failure. More probable is that this time lag represents the combined effects of yarding disturbance and decay on root systems. Insufficient information is available to distinguish between these effects, and in any event their relative importance probably varies considerably within a clearcut.

3.3.1.2 "Pulled" tailhold and guyline stumps

Few if any of the landslides examined could be attributed to "pulled" tailhold or guyline stumps. The sample of landslides at clearcut boundaries was too small to determine whether pulled tailholds or some other factor (such as windfall) contributed to the initiation of these landslides.

3.3.1.3 Redirection of slope drainage by yarding roads

None of the landslides examined appeared to be influenced by the interception and redirection of subsurface flow along yarding gouges onto marginally stable slopes. However, others have identified evidence of this mechanism on the Queen Charlotte Islands (D. Wilford, pers. comm. 1986).

3.3.2 Operational factors in yarding-associated landslides

3.3.2.1 Yarding through gullies

On the basis of the survey, it appears that yarding over gullies with partial suspension will cause some sidewall disturbance regardless of deflection, although disturbance will be more severe if deflection is poor. Yarding-associated landslides in gullies ranged from yarding scars that remained barren because of ravelling and surface erosion, to debris slides probably initiated by the damage or uprooting of stumps along gully sidewalls. Gully-wall failures typically occurred: when yarding was done across or through gullies; and where deflection at or in the gully was poor, such as at crests of sidewalls and headwalls, and at ridges and corners within gullies.

Extensive yarding disturbance and numerous, widely distributed landslides typically were found in gullies intersected by several yarding roads (or fewer, but more heavily used ones) having generally poor deflection. Yarding disturbance was localized but often more severe in gullies where deflection was generally satisfactory except at a few hangup points (often the crest of the sidewall nearest the landing) which interfered with yarding.

It appeared that the upper reaches of sidewalls and headwalls were susceptible to gouging when the yarding direction was approximately perpendicular to the main axis of the gully (cross-slope yarding). Under these circumstances, stumps at the lip of the gully were heavily damaged and often uprooted.

Yarding parallel to the main gully axis (either uphill or downhill) usually disturbed sidewalls extensively. In heavily disturbed gullies, sidewalls were often bare. Bends and spurs were badly gouged, as was the top of the slope where the yarding road exited the gully, but most of the disturbance consisted of heavy scraping. Exposed stumps were often uprooted along the sidewall and deposited, along with a heavy load of slash, in the gully channel.

Not all of the disturbed area on the sidewalls of logged gullies was necessarily caused by yarding. In some gullies it appeared that the original ground cover was sparse prior to logging, and freeze-thaw cycles and ravelling had kept the areas open. Several of the steep-walled, V-notch gullies had bare areas of sidewalls that could not be attributed to yarding disturbance alone.

3.3.2.2 Yarding over open slopes

Most within-clearcut landslides on open slopes probably resulted from the cumulative effects of several destabilizing influences working over time--topography (steep slopes and slope drainage patterns), climate, and logging (tree removal and yarding disturbance). However, despite this qualification, the authors of this report still consider yarding disturbance to be a contributing factor in a few open-slope landslides. As with gullies, these failure sites were characterized by poor deflection and occurred either at steep, convex slope breaks where hangups would occur more frequently, or in shallow slope depressions where ground-lead yarding prevailed.

3.3.3 Preventing yarding-associated landslides

Much still has to be learned about within-clearcut landslides before it can be said with confidence that their frequency may be reduced by adopting specific logging or yarding practices. Until the mechanisms by which yarding activities actually cause slope failures are better understood, it is assumed that yarding-related landslides are linked (at least indirectly) to severe yarding disturbance and that the probability for a slope failure occurring increases as the proportion of ground severely disturbed on a setting increases.

The following discussion summarizes the factors involved in generating yarding disturbance and the opinions of the authors of the solutions that have been proposed to reduce landslides associated with yarding.

1. Deflection (ground clearance) and yarding direction are more important to reducing yarding disturbance than the logging system being used. With the exception of helicopter logging, all cable systems are dependent upon adequate deflection to perform efficiently (Sauder [1986]). If the frequency of within-clearcut landslides is to be significantly reduced, emphasis should be placed on ensuring that deflection is adequate regardless of which logging system is used.

2. Backspars will not solve all deflection-related problems nor can they be used in all areas. As examples in Appendix 4 illustrate, the longer the yarding distance the less a backspar of a given height improves deflection and ground clearance. Limits to backspars height are imposed by stand height and quality and crew safety, and there may not be any trees suitable for backspars even if their use could improve yarding conditions. Although backspars may be effective at shorter yarding distances, this would imply narrower road spacings and more roads. The benefits of backspars in possibly reducing clearcut landslides would have to be weighed against the added risk of more road landslides.

3. Landing location on steep, landslide-prone slopes is of critical importance, especially where standard tower set-ups are planned. The engineer usually determines where the landings will be located, checks deflection, and locates the cutting boundaries in relation to the landings. It is always worthwhile to have the flexibility to change landing sites once the timber is felled, but in general the landing locations specified by the engineer should be adhered to unless a clearly superior location is evident. This should minimize potential yarding difficulties as a result of poor deflection if the block has been properly laid out.

4. Yarding across gullies with partial suspension is likely to disturb gully walls extensively even where deflection is good. Minimizing disturbance to gully systems may require yarding patterns that reduce log transport over gullies. Mobile yarders may be preferable in gullied terrain to allow yarding away from gullies, rapid set-up changes, and use of available deflection to best advantage.

4 SUMMARY AND CONCLUSIONS

4.1 Summary

FERIC surveyed 102 landslides, 97 of which initiated within logged areas, on the Queen Charlotte Islands to determine reasons for their occurrence and to suggest engineering and operational measures might reduce their frequency. The sample was not randomly collected and consisted of 77 debris slides, 11 debris flows, and 14 debris torrents. The following general descriptions of these failure types and the topographic situations in which they were concentrated are based on the sample:

- Open-slope debris slides developed on steep (70%+), convex or uniform slopes covered with colluvial veneers over bedrock. They often occurred in shallow, linear slope depressions or seepage zones, and often initiated at or below convex breaks in slopes of 20% or more. Debris slides in gullies were commonly small sidewall failures or scars.

- Debris flows occurred in wet depressional sites and deep morainal deposits on moderate to steep (45-60%, or 24-31°), uniform or concave slopes.

- Debris torrents occurred in steep-gradient V-notch gullies, but frequently were triggered by large debris slides or flows that initiated on open slopes adjacent to the gullies.

Thirty-one of the surveyed failures originated on or near logging roads, and 66 began off-road but within logged areas, compared with 97 road-related and 433 clearcut-related failures in Rood's (1984) survey. Almost all of the road-associated failures in this study's sample initiated in fillslopes. The major factors contributing to these failures appeared to be overloading of steep slopes and inadequate control of road drainage, usually in combination. Both road construction and road maintenance practices created conditions that ultimately lead to road failures. Construction-related factors included sidecasting of waste material, inadequate ditching, and too few culverts.

Most of the examined failures occurred on older roads built with bulldozers and line shovels. Hydraulic excavators have been credited with helping to reduce the frequency of road-related failures since they were introduced in the mid-1970s. This reduction, if real, probably reflects other factors as well as superior work ability, including: 1) increased awareness of the consequences of building roads on steep slopes, leading to improved construction practices; 2) improved ability on the part of industry and agency personnel to recognize and avoid sensitive sites; 3) fewer roads being built on sensitive slopes in recent years; 4) still too soon for failures to develop on newer, excavator-built logging roads; and 5) a higher proportion of recently built roads still in active use and thus better maintained than older or inactive roads.

The survey indicated that inadequate maintenance leading to breakdowns in the road drainage network was the most important factor in road-related failures. Maintenance levels on active roads appeared to be sufficient to control failures during the period the road was in use, but the high incidence of failures on inactive or abandoned roads suggested that the general level of maintenance applied to these roads was not enough to keep ditches and culverts functioning properly. Instances of poor cross-ditching practices (either poorly installed or located) which appeared to contribute to some road-associated landslides were also noted.

Reasons for within-clearcut and boundary failures were more difficult to specify. Yarding disturbance, particularly severe gouging and damaged stumps at points of poor deflection, was suspected as a significant influence in a number of within- clearcut failures. Windthrow and pulled stumps were likewise regarded as possible factors. However, the effects of these three factors could not be isolated from other influences such as root decay, high rainfall, and seismic activity.

The incidence of road-related failures may already have decreased since excavators were introduced to the Queen Charlotte Islands, but greater emphasis on road drainage control and maintenance can probably reduce it further. It is not clear to what extent within-clearcut failures might be reduced by replacing conventional highlead and grapple-yarding systems with alternative cable yarding systems. More careful layout to optimize deflection may do more to reduce the frequency of yarding-related failures than switching to alternative, generally more complex cable systems.

4.2 Conclusions

The following conclusions are based on the results of the survey:

1. Inadequate control of road drainage and overloading steep slopes with sidecast are the primary causes of road-related failures, with road drainage the predominant factor. Road drainage appears to influence some off-road failures as well, but the frequency of this type of failure relative to on-road failures could not be determined from this limited sample.

2. Yarding probably contributes to the initiation of slope failures where poor deflection over a topographic barrier (bench, ridge, or knoll) results in severe disturbance in the form of deep gouges and damaged or uprooted stumps. However, it is not clear what proportion of within-clearcut failures can be attributed to yarding and yarding disturbance. It was not possible to distinguish the influences of logging-related factors (yarding disturbance, tree root deterioration) from the influences and natural factors (storm and seismic activity).

3. Redirection and channelling of slope drainage along yarding gouges did not appear to influence any of the failures visibly, although it has been recognized on the Queen Charlotte Islands by others.

4. Failures developing at clearcut boundaries seemed to occur less frequently than failures within clearcuts. The relative frequency of failures initiated by pulled tailhold stumps as compared to windfall-induced failures could not be determined.

5. Most failure sites appear to have a few key features that may help the engineer to identify potentially unstable sites during field layout. Typical failure sites are: 1) gullies on steep slopes, particularly their headwall regions; 2) uniform or convex slopes steeper than 70%; 3) slope depressions with indications of wetter site moisture regimes than in surrounding areas; and 4) major convex or concave slope breaks.

6. The frequency of road-related failures can be reduced substantially on new roads. Improved road location through early recognition of potentially unstable sites (e.g., gully headwall areas) may reduce failure frequency to some extent, but improved construction practices in the short term and more consistent maintenance in the long term will provide the greatest reduction from newly constructed roads.

7. On older roads, a reduction in failure frequency will depend on a higher level of road maintenance, including adequately putting abandoned roads to bed.

8. Not all potential problem areas will be recognized before construction or logging begins. The ability to modify logging plans at all stages of operations is therefore essential to deal with these sites when they are identified, as well as to allow better alternatives than those originally proposed for implementation.

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APPENDIX 1.

FIELD SURVEY FORMS

A1.1 Original field form developed by J. Schwab, Ministry of Forests and Lands, Smithers, B.C.

A1.2 Revised field form developed by E.A. Sauder, FERIC, Vancouver, B.C., and L. Beaven, FFIP, Queen Charlotte City, B.C.

ORIGINAL FIELD FORM

MASS WASTING DATA CARD

MINISTRY OF FORESTS

J.W. Schwab
Research Section,
Bag 5000, Smithers, B.C.
May, 1983

Card No.__________ Collector _________________ Air photo No ____________

Cordinates X ____________ Y ___________

Physiographic Region _______________________ Watershed ______________________

Operation ________ Road No. __________ Landing No. _________ Area No. _______

Slope Movement Process ____

Size (meters)

(Total) Length _____ Width _____ Depth _____ Vol. _____ M^3% organic _____

(Scour) Length _____ Width _____ Depth _____ Vol. _____ M^3% organic _____

Stream length travel: incipient _____ 1st _____ 2nd _____ 3rd ____ 4th _____

Volume deposit in stream ________(M^3).% organic ______ Stream order ______

SITE DESCRIPTION: Open slope ______ Gully ______ Open Slope into Gully ______

Aspect: N, NE, E, SE, S, SW, W, NW, Elevation ____________M.

Macro Position: apex __ face__ upper__ mid__ lower__ valley floor__ plain ____

Micro Position: crest __ upper__ mid__ lower __ Toe __ depression __ level ____

OPEN SLOPE:

Slope shape: Convex ______ Concave ______ Straight ______ Complex ________

(Complex): faceted ______ benchy ______ irregular _____ dissected ________

Slope gradient: origin ________transport __________ deposition ____________

Slope length: above _________ transport __________ deposotion ____________

GULLY: Gully in: rock ______________ surficial material _________________

Failure location: Headwall __ Sidewall __ Channel __ open slope into gully ___

Slope gradient: Headwall _____ sidewall _____ channel ______. ______. _______

origin __________ transport __________ deposition _________

Gully shape: 1, 2, 3a, 3b, 4, 5, channel depth _________________

TERRAIN: Surficial material __________ Derived from ________ Depth ________

Terrain Classification ______________________________

Terrain unit area __________ ha. Hazard class __________ system __________

Gully density: No. __________ Area ______________ (ha.)

Gully spacing: close ________ wide ________ rare ________ absent ________

Historic movement No. ______________ Area __________ Process ________

No. failure remain in unit __________. No. pass out side unit __________

Comments:

SOIL: Soil classification ________________ texture ________________

Primary structure: kind ________________ grade ________________

Rooting depth ______________ Effective rooting depth ______________

Describe effective rooting zone (size, abundance, AND orientation of roots).

Bedrock formation: ____________________ type ____________________

Structure: Bedded, Foliation, Jointing, Massive. Weathering depth _____ cm.

Dip: parallel, subparallel, horizontal, into, out.

Intensity of structure (cm): <5, 5-30, 30-90, 90-300, 300+

Consistency: extremely soft, very soft, av., hard, very hard, extremely hard.

DRAINAGE: up-slope drainage length _________________________ m

Drainage area (ha) <.5, .5-1, 1-2, 2-5, 5-10, 10-20, 20+

Surface seepage (y,n), subsurface seepage (y,n) depression (y,n)

Piping: (y,n) No. ____________ size __________ cm located ____________ .

Impermeable layer (describe) ________________________________ .

Drainage class: rapidly drained, well drained, moderately well drained, imperfectly drained, poorly drained, very poorly drained.

Soil perviousness: rapidly, moderately, slowly.

Comments:

Shear surface (y,n): Soil layer ___ surficial material ___ on rock ___ in rock ___

Describe ____

Vegetation: Ecosystem Association ________________ Subzone ____________

Tree species ________________ % Crown closure ________________

Shrubs __________________ % cover. Herbs __________________ % cover

Ecological moisture regime (BCFS) ______________________________ .

LAND USE:

Natural __________ Road __________ Clearcut __________ Other __________

Date of slope failure __________ Time of failure __________

ROAD:

Construction: Backhoe ______ Shovel ______ Cat ______ Other __________

Construction date: __________ Time to Fail __________

Failure located: Prisim __________ Cutslope __________ Sidecast __________

Down slope __________ Upslope ______ __________ __________

Sidecast/fill: est vol. __________ m^3, Slope angle __________

Ditches (y, n) In fill __________, In bedrock __________

Ditch conditions describe: __________

Culvert discharge (y, n) Metal __________ wood __________

Comments:

Clearcut: Date of felling __________ Yarding __________ Time to fail __________

Located: boundary ___ upper ____ mid. ____ lower ____ gully_____ open slope ___

Yarding system: highlead ______ grapple ______ drop line ______ skyline ______

Deflection: Good ____ Fair ______Poor ______ Height: Tower ____ Tailblock ____

Yarding disturbance:

Uprooted stumps ________ No. ________Gouging ________ channelized water________

Debris deposits: Clean ________ light __________ mod. __________ heavy ________

Comments:

Triggering Events (attach details)

Climate __________

Wind __________

Seismic __________

Other __________

Sketch Profile:

REFERENCE

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Date:_______________

REVISED FIELD FORM

Page

MASS WASTING DATA CARD: FERIC/FFIP

1. Watershed Name:_______________

Air Photo No._______________ Failure I.D. No._______ Collector_______

Co-ordinates: X_______ Y_______ Weather_______________

Operation_______________ Road No._______ Landing No._______ Area No._______

---

2. Slope Movement Process:_______________

Cause of Failure: Road Construction - Road Maintenance - Yarding - Timber Edge - Othe

---

3. Size (all measurements in metres):

SLOPE (%/)	ZONE	LENGTH	WIDTH	DEPTH	ESTIMATED VOLUME
	Above Origin				
	Headwall				
	Scour				
	Slope at Side (H.W.)				
	Transportation				
	Deposition				
	Total				
	Stream Length Impacted				
	Estimated Volume Entering Stream				
	Estimated Volume of LOD on Bank				
	Estimated Volume of LOD in Stream				

---

4. Site Desc'n. ( ): Open Slope_____ Gully_____ Open Slope Into Gully_____

Aspect: Az._______ Elevation at Top of Failure_______m.

Macro Position_______________ Meso Position_______________

Associated With: Depression_______ Major Ground Break_______ Other_______

---

5. Open Slope: Failure Exposes: Rock_____ Surf. Mat.: Cons._____ Uncons._____

Slope Shape: Convex_______ Concave_______ Straight_______ Complex_______

(Complex: Faceted_______ Benchy_______ Irregular_______ Dissected_______

---

6. Gully: Gully exposes ( ): rock _____ surf. mat.: cons. _____ uncons. _____

Failure exposes ( ): rock _____ surf. mat.: cons. _____ uncons. _____

Failure location ( ): Headwall _____ Sidewall _____ Channel _____

Open Slope into Gully _____. Comment _____

Slope of Sidewall _____ % Channel _____._____._____.

Gully Profile ( ): 1 _____ 2 _____ 3a _____ 4 _____ 5 _____. Gully X-Section: m m

---

7. Terrain: (at point of failure)

TEXTURE	GENETIC MATERIAL	QUALIFYING DESCRIPTION	SURFACE EXPRESSION	DEPTH (cm)	MODIFYING PROCESS
.					
.					
.					
.					

Evidence of Historical Movement: Y/N _____

Indication of slope instability: Y/N _____

---

8. Unconsolidated Material: Primary Structure: Gr ___ Cl ___ Kind ___ Text. _____

Secondary Structure: Gr ___ Cl ___ Kind ___ Text. _____

Presence of: Mottles: Y/N Where? _____

Gleys: Y/N Where? _____

Rooting Depth: _____ cm. Effective Rooting Depth: _____ cm.

Roots: Original cond.; Sheared Off; Exposed; Debarked;

Depth of organic layer: _____ cm.

---

9. Bedrock: Formation: _____. Type: _____

Depth of Weathering: _____ cm. Intensity of Weathering: 1 2 3

Structure: Bedded _____ Jointed _____ Massive _____ Faulted _____

Pressure of Intrusions: Hydro Thermal; Dykes; Sills; None;

Dip: _____° _____ Az. Strike (if discernable): Az _____

Int. of Str.: -5, 30, 90, 300, 300+. Competence of Structure ( ): L M H

10. Drainage

Presence of (Y/N): Surface Drainage _____ Subsurface Seepage ______

Piping _____. No./m^2 within failure Zone _____ Size _____ cm.

Location: ____

Drainage Collecting Area Length (Above failure) ____________m

Impermeable Layer: _____. Permeable Layer: _____ Depth: _________ cm.

Drainage of Uncons. Material ( ): Rapid _____ Moderate _____ Poor _____.

____

Perviousness of Uncons. Mat. ( ): Rapid _____ Moderate _____ Poor _____.

____

Drainage Area Increase: Y/N: ______. Reason _______________________________________

---

11. Shear Surface ( ): Surficial Mat.: Cons. _______ Uncons. ________

On Rock _______ In Rock _______ Soil Layer _______. ___________________________

Smooth, Rough, Other: ____

---

12. Vegetation: (Original) Stand Species ___________________________% cover.

Regeneration Species ____________________ % cover. Ht. ____________m.

Natural _______ Planted _______ None _________

Shrubs: Species ________________________ __________% cover.

Herbs: Species ________________________ __________% cover.

Presence of (Y/N): Moss _________ Grass __________

Ecological Moisture Regime (BCFS): _________________

Evidence of Deer Browse (Y/N): _____. ____

---

13. Land Use (at Init.): Natural ____ Road ____ Clearcut ____ Other _______

Estimated Time of Failures: Yr. ________ Mo. ______________. ____________________

---

14. Road: Const. Method ( ): Backhoe _____ Shovel _____ Cat _____ Other _____

Failure Location ( ): Prism _____ Cutslope _____ Sidecast _____ Downslope ________

Upslope _____. ______________________________________

Sidecast/Fill Failure: Est. vol. failed ________m^3. Slope Angle: ________/_________

Ditches (Y/N): Presence _____. Size: x m.Type: Excavated - Filled

Constructed in: Bedrock _____ Surficial Material ______ Fill ______

Culverts: Failure occurred at point of culvert discharge? (Y/N) __________

Metal (Y/N) _______ Dia. _______cm. Wood (Y/N) _______ Size _____cm

Culvert Condition: Maintained _____ Plugged _____ Cross Ditching _____ Size ____X____

Surfacing Material, same as ( ): local bedrock, or _____ imported ______

Road Construction on: Bedrock _______ surficial material _______ fill >2m __________

Distance and Grade to Nearest Culvert: _________m _________%, N/A

Reason for Failure: ____

---

15. Clearcut: Location of Failure in setting: Boundary __________ Upper __________

Mid __________ Lower __________ Gully __________ Open Slope _____________.

Yarding System ( ): Highlead _____ Grapple _____ Skyline _____ Other ____________

Deflection ( ): Good _____ Fair _____ Poor _____. Ht. of: Tower ____m Tailhold ____m.

Yarding Disturbance (Y/N): Soil Compaction or Dist. _____ Upr. stumps_____ Gauging____

Water Channelization _____. Presence of Windfall Uprooted Stumps _______________.

Logging Debris ( ): around initiation zone: Light _____ Mod. _____ Heavy _______

in gully bottom: Light _____ Mod. _____ Heavy _______

Reason for Failure: ____

---

16. Probable Contributing Environmental Factors:

Weather: ____

Windthrow: ____

Other: ____

Sketch longitudinal profile, plan and cross-sections of failure.

MASS WASTING DATA CARD--OFFICE INFORMATION: FERIC/FFIP

17.

Physiographic Region: ____________________ Watershed No. ____________

Date of Failures: Yr. ________ Mo. ____________ Day ______

Terrain unit area: ________ha. Hazard Class ________ System ________

Gully Density (No.): ________/ha. Gully Spacing ( ): Close _____ Wide ______

Rare _____ Absent _____

Presence of Historical Failures (from aerial photos) (Y/N): ________

No.: ______ Area: ______ha. Process: ________________________

Soil Classification: ____________________ System: ______________ Yr. _____

Drainage Area: based on (Y/N): Photo ___ or Map ___ Scale: 1: __________

Area: ________ha.

Ecosystem Association: __________________ Subzone: ________________

Road Construction Method ( ): Backhoe ____ Shovel ____ Cat ____ Other _____

Road Construction Date: Yr. ________ Mo. ____________ Day ______.

Felling Period: (month & Year) ____

Yarding System ( ): Highlead ____ Grapple ____ Skyline ____ Other _________

Yarding Period: (month & Year) ____

Probable Contributing Factors:

Seismic: ____

Other: ____

APPENDIX 2.

CROSS-REFERENCE INDEX FOR PHOTO-SURVEYED AND GROUND-SURVEYED LANDSLIDES

(FERIC 1986; ROOD 1984)

TABLE A2.1. Cross-reference index for FERIC (1986) and Rood (1984) landslide surveys

WATERSHED	FERIC LAND-SLIDE NO.	ROOD (1984) LANDSLIDE NO.
South Bay	1	FF8285-L13-116/115 - #2
Dump Creek	2	FF8285-L13-116/115 - #3
	3	FF8285-L13-116/115 - #4
	4	FF8285-L13-116/117 - #4
	5	FF8285-L13-116/115 - #6 & #7
	6	FF8285-L13-116/115 - #10 & #11
	7	FF8285-L13-116/115 - #10A
	8	FF8285-L13-116/115 - #13 & #15
	9	FF8285-L13-116/115 - #17 & #19
	10	FF8285-L13-117/116 - #7
	11	FF8285-L13-117/116 - #7A
	12	FF8285-L13-116/115 - #11
	13	FF8285-L13-117/116 - #17
Sach's Creek	1	FF8285-L13-123 - #3
	2	FF8285-L13-123 - #5
	3	FF8285-L13-124/123 - #4
	4	FF8285-L13-125/124 - #1
	5	FF8285-L13-125/124 - #2
	6	FF8285-L14-111/112 - #2
	7	FF8285-L13-111/112 - #3
	8	FF8285-L13-111 - #10
	9	FF8285-L13-111 - #11
	10	FF8285-L13-111 - #12
	11	FF8285-L13-111/112 - #12 ?
	12	FF8285-L13-112/113 - #3
	13	FF8285-L13-113 - #1
	14	FF8285-L13-113/114 - #7
	15	FF8285-L13-113/114 - #8 ?
	16	FF8285-L13-114/115 - #3
	17	FF8285-L13-114/115 - #4
	18	FF8285-L13-114/115 - #6
	19	FF8285-L13-114/115 - #13
	20	FF8285-L13-114/115 - #14
	21	FF8285-L14-115/116 - #1A & #1B
	22	FF8285-L14-115/116 - #5 & #6
	23	FF8285-L14-115/116 - #7 (A,B, & C)
	24	FF8285-L14-114/115 - #15
	25	FF8285-L15-122/123 - #1
	26	FF8285-L15-122/123 - #24
	27	FF8285-L15-122/123 - #25
	28	FF8285-L15-122/123 - #29

WATERSHED	FERIC LAND-SLIDE NO.	ROOD (1984) LANDSLIDE NO.
MacMillan Creek	1	*
	2	*
	3	FF8285-L12-84 - #1
	4	FF8285-L12-84 - #2
	5	*
	6	FF8285-L13-118 - #1
	7	FF8285-L13-118 - #2
	8	FF8285-L13-118 - #3
	12	FF8285-L13-120/119 - #1
	13	FF8285-L13-120/119 - #5 (119/118)?
	14	FF8285-L13-120/119 - #7 (119/118)?
Tarundl Creek	1	FF8286-La-69/68 - #1
	2	FF8286-La-69/68 - #2
	3	FF8286-La-69/68 - #3
Mountain Creek	1	(?) - #16
Mosquito Creek Trib.	1	*
Talunkwan Island	1	FF8285-L25-A71/94 - #10
	2	FF8285-L25-94/95 - #1
	3	FF8285-L25-94/95 - #2
	4	FF8285-L25-94/95 - #28
	5	FF8285-L25-94/95 - #32
	6	FF8285-L25-94/95 - #39
	7	FF8285-L25-94/95 - #41
	8	FF8285-L25-94/95 - #53
	9	FF8285-L25-94/95 - #61
	10	FF8285-L25-94/95 - #62
	11	FF8285-L25-A71/94 - #2
	12	FF8285-L25-A71/94 - #9
	13	FF8285-L25-94/95 - #10
Bonanza Creek	1	BC81059-142/143 - #1
	2	BC81059-142/143 - #3
	3	BC81059-143/144 - #2
	4	BC81059-143/144 - #2
	5	BC81059-196/195 - #2
	6	BC81059-196/195 - #3a
	7	BC81059-197/196 - #8
	8	BC81059-197/196 - #11
	9	BC81059-197/196 - #27
	10	BC81059-197/196 - ? (South of #32)
	11	BC81059-222/223 - #2
	12	BC81059-222/223 - #4

WATERSHED	FERIC LAND-SLIDE NO.	ROOD (1984) LANDSLIDE NO.
Riley Creek	1	*
	2	*
	3	*
	4	*
	5	*
	6	*
	7	*
	8	*
	9	*
	10	*
	11	*
	12	*
Skedans Creek	1	New
	2	New
	3	New
Haans Creek	1	New
	2	New
	3	New
	4	New
Alliford Bay	1	New
	2	New
	3	New

* corresponding number unknown
? correlation uncertain

APPENDIX 3.

SUMMARIES OF PHYSICAL CHARACTERISTICS OF SURVEYED LANDSLIDES

TABLE A3.1. Summary of landslides by watershed and geologic formation

GEOLOGIC FORMATION	Riley Creek	Bonanza Creek	Talunkwan Island	Tarundl Creek	Mountain Creek	Mosquito Creek Trib.	MacMillan Creek	South Bay Dump Creek	Sach's Creek	Haans Creek	Alliford Bay	Skedans Creek	Totals
	WATERSHED												
- Karmutsen	-	-	-	-	-	1	-	-	-	-	-	-	1
- Kunga	-	7	-	-	-	-	2	-	-	-	-	1	10
- Yakoun	12	-	-	-	-	-	-	-	10	-	-	2	24
Queen Charlotte Group:													
- Haida	-	-	-	-	-	-	7	3	4	-	1	-	15
- Honna	-	-	-	-	-	-	1	10	14	4	2	-	31
- Skidegate	-	-	-	2	-	-	-	-	-	-	-	-	2
Masset:													
- Tartu Facies	-	5	-	-	-	-	-	-	-	-	-	-	5
- Dana Facies	-	-	13	-	-	-	-	-	-	-	-	-	13
Post-Tectonic Plutons	-	-	-	-	1	-	-	-	-	-	-	-	1
	12	12	13	2	1	1	10	13	28	4	3	3	102

TABLE A3.2. Summary of landslides examined by slope movement process and by watershed

	DEBRIS SLIDES	DEBRIS TORRENTS	DEBRIS FLOWS	TOTALS
Riley Creek	10	1	1	12
Bonanza Creek	11	1	-	12
Talunkwan Island	10	3	-	13
Tarundl Creek	2	-	-	2
Mountain Creek	1	-	-	1
Mosquito Creek Tributary	1	-	-	1
MacMillan Creek	7	1	2	10
South Bay Dump Creek	11	-	2	13
Sach's Creek	18	4	6	28
Haans Creek	4	-	-	4
Alliford Bay & vicinity	-	3	-	3
Skedans Creek	2	1	-	3
	77	14	11	102

TABLE A3.3. Summary of landslides examined by topographic setting and by watershed

	OPEN SLOPE	OPEN-SLOPE INTO GULLY	GULLY	TOTALS
Riley Creek	9	1	2	12
Bonanza Creek	3	3	6	12
Talunkwan Island	3	5	5	13
Tarundl Creek	2	-	-	2
Mountain Creek	1	-	-	1
Mosquito Creek Tributary	1	-	-	1
MacMillan Creek	4	3	3	10
South Bay Dump Creek	5	3	5	13
Sach's Creek	10	3	15	28
Haans Creek	4	-	-	4
Alliford Bay & vicinity	-	2	1	3
Skedans Creek	1	2	-	3
	43	14	37	102

TABLE A3.4. Distributions of debris slides, flows and torrents by area and volume classes.

SIZE CLASS (ha)	DEBRIS SLIDES		DEBRIS TORRENTS		DEBRIS FLOWS	
	NO.	SIZE RANGES	NO.	SIZE RANGES	NO.	SIZE RANGES
<0.15 ha	57	0.008-0.144 ha 7-996 m³	6	0.018-0.129 ha 18-2 000 m³	5	0.040-0.124 ha 314-782 m³
0.15 - 0.30 ha	13	0.150-0.279 ha 137-1 800 m³	1	0.150 ha 450 m³	4	0.164-0.279 ha 1 066-3 075 m³
0.30 - 0.45 ha	4	0.301-0.423 ha 490-3 010 m³	1	0.333 ha 197 m³	2	0.406-0.430 ha 1 206-2 138 m³
0.45 - 0.60 ha	1	0.576 ha 3 060 m³	1	0.546 ha 1 211 m³	- -	- -
>0.60 ha	2	0.995-0.401 ha 2 806-2 986 m³	5	0.756-1.655 ha 1 168-4 658 m³	- -	- -
Ranges	77	0.008-1.401 ha 7-3 010 m³	14	0.018-1.655 ha 18-4 658 m³	11	0.040-0.430 ha 314-3 075 m³

APPENDIX 4.

DETAILED DESCRIPTIONS OF REPRESENTATIVE LANDSLIDES DESCRIBING POSSIBLE FAILURE MECHANISMS AND PREVENTATIVE MEASURES

INTRODUCTION

The following examples are presented to help the reader understand the procedures applied in this study to the analysis of landslides, particularly in evaluating possible road- and yarding-related factors that may have contributed to a failure. Alternative methods or approaches that might have prevented the failure were evaluated in much the same way as forest engineers consider and evaluate other control points affecting road construction or yarding.

The examples are separated into the following categories:

A. Road-Associated Landslides

1. Overloading Steep Slopes
   Example #1
   Example #2

2. Road Drainage Directed Onto Fill Slopes
   Example #3
   Example #4

3. Altering Natural Slope Drainage Patterns
   Example #5
   Example #6

B. Logging-Associated Landslides

1. Yarding-Associated Failures in Gullies
   Example #7
   Example #8
   Example #9

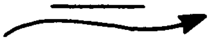
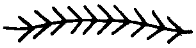
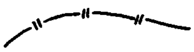
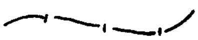
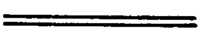
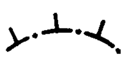
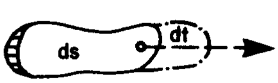
2. Yarding-Associated Failures on Open Slopes
   Example #10
   Example #11

3. Within-Clearcut Failures Not Related to Yarding
   Example #12
   Example #13

4. Failures Occurring Near Clearcut Boundaries
   Example #14
   Example #15

Symbols Used for Landslide Descriptions

LEGEND:

	Perennial Creek
	Gully (may be shallow)
	Intermittent Creek
	Spring
	Wet, saturated ground (free water present)
	Timber type boundary
	Other boundary (e.g., fillslope)
	Soil type boundary
	Gully edge/breakover
	Roads
	Rock outcrop
	Headwall (rock) scarp
	Waterfall
	Water collecting area
	Depression
	Earthflow boundary
	Active headwall
	Old mass movement - stable
	Debris slide: ds Debris torrent: dt

LEGEND:

Channel depositional zone

Shallow debris slide/avalanche

Watercourse bank failure

Debris jam

Logs interfering with water flow

Logs not interfering

Undisturbed stump

Yarding disturbed stump (including "hit" tailholds, guylines, etc.), stump remains in place

Stump uprooted by yarding disturbance

Windfall

Upturned root wad

Windfall tree (roots & log)

Ploughing by yarded logs

Exposure of mineral soil >25 cm

Exposure of mineral soil >5 cm

Removal of surficial organic layer

Rock outcrop disturbed by yarding

—R-R-R-R— Rock exposed by yarding

L.O.D. Large organic debris

SOILS:

v	Veneer; less than 1 m deep
b	Blanket; greater than 1 m deep
Cv,Cb	Colluvial veneer, colluvial blanket
Mv,Mb	Morainal veneer, morainal blanket
O	Organic
R	Rock
Rw	Rock (weathered)
Rv	Revegetated (mosses, grass, ferns, legumes)
Rs	Restocked (shrubs, trees, regeneration)

s,S	Sitka spruce	*Picea sitchensis*
h,H	Western hemlock	*Tsuga heterophylla*
c,C	Western redcedar	*Thuja plicata*
y,Y	Yellow-cedar	*Chamaecyparis nootkatensis*
d,D	Red alder	*Alnus rubra*
a,A	Sitka alder	*Alnus sitchensis*
	(e.g., s = immature, S = mature)	

⊖	Logged (year logged)
⊕	Logged and burned
⊗→	Photopoint (arrow indicates direction)

OTHER:

A	Active (recent: <2 years)
D	Dormant

e.g. 8 6 3

- 8 — Age classes: 1 - 9
- 6 — Height classes: 1 - 7 BCFS Inventory
- 3 — Stand density: 1 - 3

EXAMPLE #1: DEBRIS SLIDE/TORRENT

1.	Landslide Description	
	a. Location	South Bay Dump Creek, northern Moresby Island
	b. Landslide Type	Open-slope debris slide, entering gully and becoming a debris torrent
	c. Landslide Number	FF8285-L13-117/116, #4 (Rood 1984)
	d. Location of Initiation Zone	Road fill slope
2.	Physical Dimensions	
	a. Area	~ 1.0 ha
	b. Volume	3000 m^3
	c. Slope Gradient Near Initiation Zone	36° (73%)
	d. Slope Shape Near Initiation Zone	Strongly convex above the initiation zone and slightly concave through it
3.	Site Characteristics	
	a. Surficial Materials	Thin, sandy-gravelly colluvial veneer over bedrock
	b. Site Drainage	Shedding position, rapidly drained
	c. Failure Surface	Bedrock
	d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation: pebble/cobble conglomerate, weakly bedded, highly jointed and moderately weathered
4.	Suspected Cause or Contributing Factors	Overloading steep slopes by side-casting waste material when building the road.

Although much larger than average, this landslide was typical of failures caused by sidecasting excess soil and rock on oversteepened slopes when building logging roads.

Description

This large failure, shown in Figure A4.1, originated in the fill slope of a road about 40 m below the crest of the ridge, crossed a lower road and entered a gully on the lower slope. Once in the gully, the failure continued on as a debris torrent and probably reached South Bay Dump Creek.

The drainage area upslope of the initiation zone was small since it was near the crest of the ridge. No surface or subsurface water was evident in the headwall and scour zones of the slide scar at the time it was examined.

The failure originated at a large rock cut on a level to slightly rolling road which was fully benched on rock and ballasted with local material. No ditch was built in the cut, but the road was slightly insloped, draining water away from the sidecast slope. The road was apparently built by a bulldozer.

The failure occurred sometime after the area was logged (at least a year after the road was built) but the precise date is not known.

Factors Contributing to Failure

This failure typifies landslides that were considered to be caused principally by overloading. The principal features of the failure site were very steep slopes (>75%), highly weathered bedrock, and shallow noncohesive soils, coupled with sidecasting of excess material. The failure probably occurred during wet weather, but the available evidence indicated that surface drainage from the road and surrounding area was not a contributing factor.

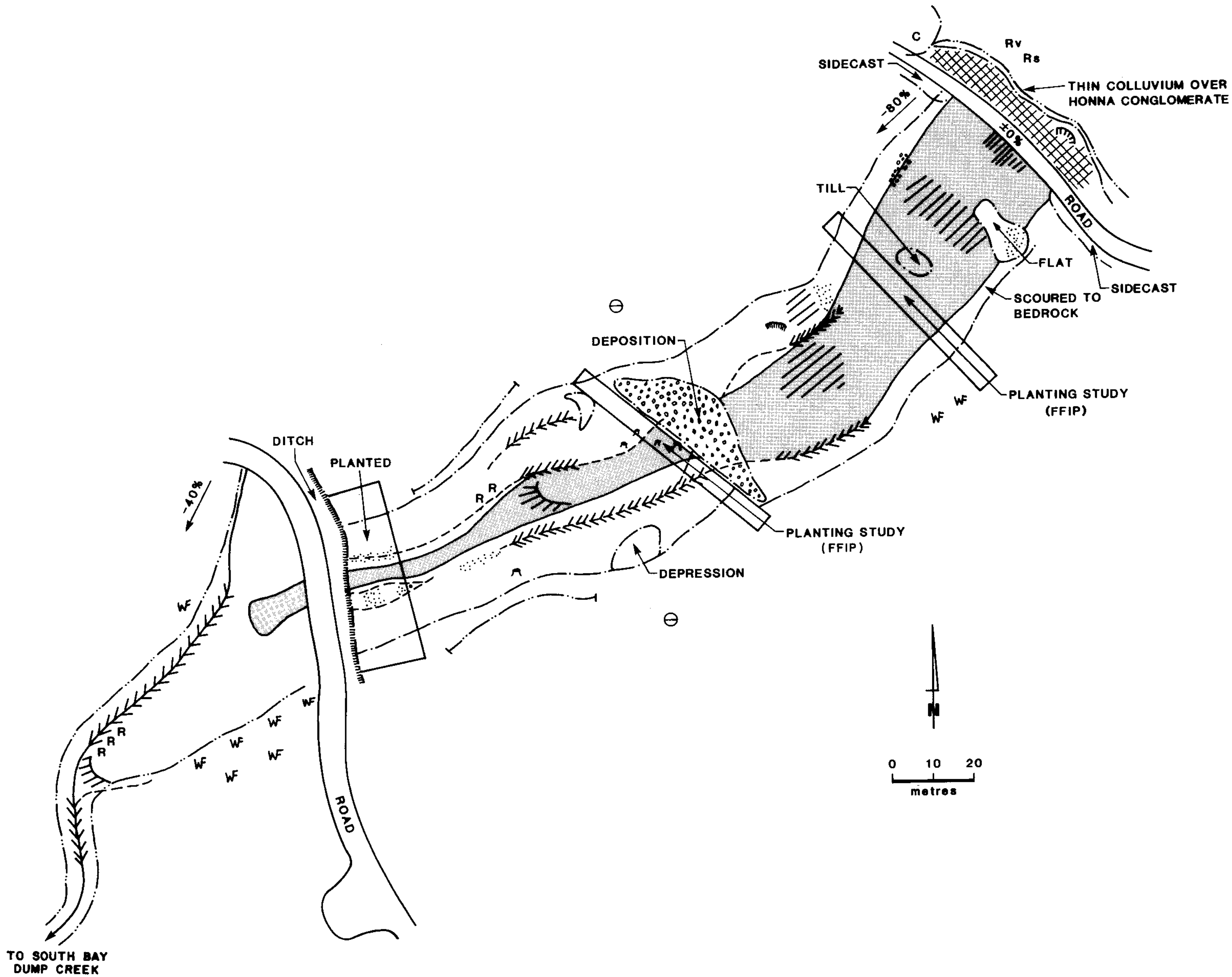


FIGURE A4.1. Diagram of Example #1, South Bay Dump Creek. (Failure #4, L13-117/116)

Suggestions for Prevention

This failure could possibly have been prevented by either relocating the roads onto gentler slopes further up the hill, or by end hauling the excess rock to a stable dumping site. On the basis of the surveys an alternative location above the existing road could have been reached without affecting landing locations. More detailed engineering would be required to determine whether the revised location would have created other stability problems.

Another alternative would be to pull back the sidecast with a backhoe after construction, but given the size of the rock cut and the steep slopes it is doubtful whether enough of the waste material could have been recovered for this technique to have been effective.

Careful blasting and end hauling of waste may reduce the risk of such failures, but to what degree is unknown. While end hauling is often cited as a technique to prevent fillslope failures, it may not be sufficient or necessary in all situations. Assuming that a similar road would be built with a backhoe today, then excess material could be carried to other stable locations by: walking the backhoe; using a front-end loader; or casting the material out over the sideslopes to disperse it, rather than piling it on the outer edge of the subgrade.

In situations similar to this example, it is preferable to examine alternative route locations first before committing expensive construction techniques with an undetermined chance of success.

Important features that may aid in identifying similar sites are:

- very steep slopes (70%+)
- thin soils (possibly with rock outcrops visible)
- noncohesive soils (from surficial geology maps)
- bedrock characteristics (local experience with this rock formation).

EXAMPLE #2: DEBRIS SLIDE/TORRENT

1.	Landslide Description	
	a. Location	South Bay Dump Creek, northern Moresby Island
	b. Landslide Type	Open-slope debris slide into gully
	c. Landslide Number	FF8285-L13-116/115, #17 (Rood 1984)
	d. Location of Initiation Zone	At the base of a long, steep slope of sidecast material
2.	Physical Dimensions	
	a. Area	0.58 ha
	b. Volume	1914 m^3
	c. Slope Gradient Near Initiation Zone	40° (85%)
	d. Slope Shape Near Initiation Zone	Uniform through and above the initiation zone
3.	Site Characteristics	
	a. Surficial Materials	Shallow, sandy-loamy colluvial veneer over bedrock
	b. Site Drainage	Shedding position, rapidly to well drained
	c. Failure Surface	Within the colluvial layer
	d. Bedrock Geology (from Sutherland Brown 1968)	Honna formation: pebble/cobble conglomerate; jointing, weathering, and bedding not visible in initiation zone
4.	Suspected Cause or Contributing Factors	Overloading steep slopes by sidecasting waste material from a rock pit

This landslide was also considered typical of failures caused by overloading steep slopes with waste material.

Description

This failure, shown in Figure A4.2, appeared to consist of two events: an initial, probably small failure which originated in waste material stored at the side of the road, leading downslope into a larger debris slide originating on a bench above the headwall of a gully complex (Figure A4.2b). The lack of road debris in the initiation zone of the lower failure suggested that the upper failure occurred before, and possibly triggered the lower one. The combined failures extended down from the road fill, across the bench and into a side channel of a large gully, and reached the main gully (Figure A4.2a).

The upper failure was confined almost entirely to the sidecast material and colluvial layer. The lower failure at the base of the sidecast slope extended down to a smooth bedrock base.

No surface or subsurface drainage was evident in the road cut or in the headwall of the slide, but surface water appeared in the scour zone near the base of the steep straight slope and increased in volume within the gully.

The slide was located near the middle of a 70-m section of road which had been quarried for ballast material. Waste material from the pit had been piled on the outer road edge. The road was fully benched on bedrock and drained water away from the failure site. It is not known what construction machinery was used, but presumably the ballast material and waste rock was handled by a front-end loader.

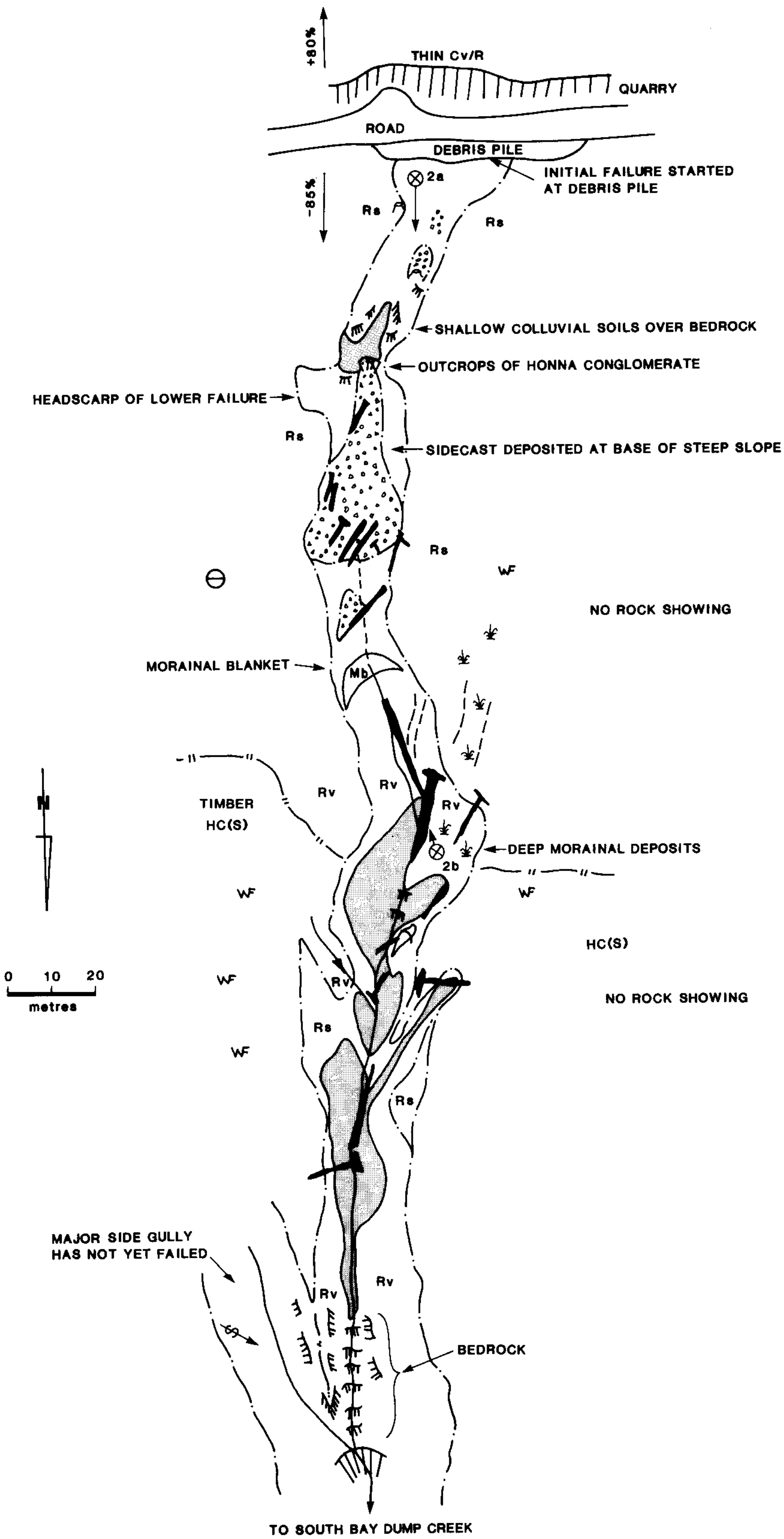


FIGURE A4.2. Diagram of Example #2, South Bay Dump Creek. (Failure #17, L13-116/115)

FIGURE A4.2a. Looking down from road, Example #2.

FIGURE A4.2b. Sidecast from road enters initiation zone of lower failure, Example #2.

Factors Contributing to Failure

As in Example #1, it appeared that sidecasting large volumes of waste rock onto steep slopes was primarily responsible for this landslide. This failure has the same features as Example #1: 1) steep slopes (about 85%); 2) shallow, noncohesive soils; 3) an initiation zone that is not depressional; 4) seepage from upslope areas that was intercepted by the road cut and drained away from the failure site; and 5) a large volume of fill that was placed on a steep sidehill.

Suggestions for Prevention

Like Example #1, this slide might not have occurred if the road could have been located to avoid the steep slope, or if the waste material had not been sidecast. The first option, relocating the road, did not seem to be a feasible alternative in this case. Steep slopes continued for some distance above and below the road. The slope below the road was, in fact, slightly steeper than the existing location.

The second alternative, minimizing sidecast, was the most practical solution in this case. Despite the very steep sideslopes, the road bed itself appeared firm and stable, with no tension cracks or other signs of settlement evident in the road surface. The failure was confined entirely to the waste piles. Sidecasting of excess grade rock may have triggered the slide, but judging by the volume of sidecast it seems more likely that most of the waste material came from the quarry.

Sidecasting could have been minimized by either end hauling waste rock or by excavating the quarry progressively, temporarily storing waste on the outer edge of the road, and then backfilling as sections of the quarry were completed. Backfilling would have been a cheaper alternative than end hauling. Given the long working face presented by this quarry, backfilling was a feasible alternative. A backfilling operation could have been done in conjunction with or immediately following ballasting operations. Care would have to be taken to ensure that the front-end loader could retrieve stored waste rock from the edge of the road without pushing too much over the road edge.

The selection of this particular site for a rock pit might be questioned. Short-hole lifter quarries often create substantial amounts of waste material.

The best way to prevent failures on oversteepened slopes is not to build roads on them. This failure illustrates a case where opportunities to relocate the road were limited, and alternative locations were not better than the one chosen. Under these circumstances, prevention of failures depends upon careful construction practices and minimization of sidecast. One alternative is to end haul waste material. However, this is an expensive option, and there is no guarantee that it will prevent such failures. Another, better option in this case would have been progressive backfilling as the quarry was excavated.

EXAMPLE #3: DEBRIS SLIDE/TORRENT

1.	Landslide Description	
	a. Location	South Bay Dump Creek, northern Moresby Island
	b. Landslide Type	Open-slope debris slide/debris flow entering a gully in lower reaches
	c. Landslide Number	FF8285-L13-116/115, #10 & #11 (Rood 1984)
	d. Location of Initiation Zone	Road fill slope
2.	Physical Dimensions	
	a. Area	0.28 ha
	b. Volume	3075 m^3
	c. Slope Gradient Near Initiation Zone	27° (50%)
	d. Slope Shape Near Initiation Zone	Slightly convex to straight
3.	Site Characteristics	
	a. Surficial Materials	Rubbly-textured colluvial blanket (1.5 m) underlain by silty-gravelly morainal blanket
	b. Site Drainage	Moderately to rapidly drained linear slope depression (100 m+ in length), with substantial seepage
	c. Failure Surface	Surface of morainal deposit
	d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation (possibly): moderately weathered, bedded and heavily jointed siltstone/sandstone.
4.	Suspected Cause or Contributing Factors	Inadequate road drainage (both construction and maintenance) causing saturation of fill slope

This failure is a good example of the type of landslide that results when fills built on steep slopes are not properly drained.

Description

A diagram of the failure is shown in Figure A4.3. Figure A4.3a shows the initiation zone and Figure A4.3b is a view of the failure looking down the slide path from the road.

The failure started in a road fill which was built across a shallow slope depression. It travelled about 130 m (horizontal distance) downslope from the road and entered South Bay Dump Creek.

The road crossed the slope depression right at the breakover from gentler (30-40%) slopes above, to steeper (50%) slopes below, at the head of a shallow but well-defined gully. The natural drainage area for the depression extended at least 100 m upslope of the road. It was expanded by the road ditch network because the road climbed at 10-15% and the next culvert, which was almost plugged with sediment, was 70 m uproad (Figure A4.3d).

The road, probably built with a bulldozer, had a till layer base. During construction the colluvial material had been scraped off and piled beside the road, then levelled or pushed over the bank. At the time of the first inspection, during a period of dry weather in May 1983, heavy seepage was observed at the colluvium/till interface (in the road cutbank). The ditch, which had filled in with sediment and was overgrown with horsetails and sedges, had been formed with ballast and was not cut below subgrade level. Since the road was built on impermeable till, road drainage flowed through the ballast layer and into the fill material. On a subsequent inspection in February 1984, water was observed flowing out of the headscarp at the contact between the ballast layer and the morainal deposit (Figure A4.3c).

Factors Contributing to Failure

Three factors probably contributed to this failure: 1) construction of a deep fill within a drainage depression on a moderate to steep slope; 2) high site moisture levels draining over a compact, impermeable morainal deposit; and 3) inadequate allowance for road drainage during construction and after logging.

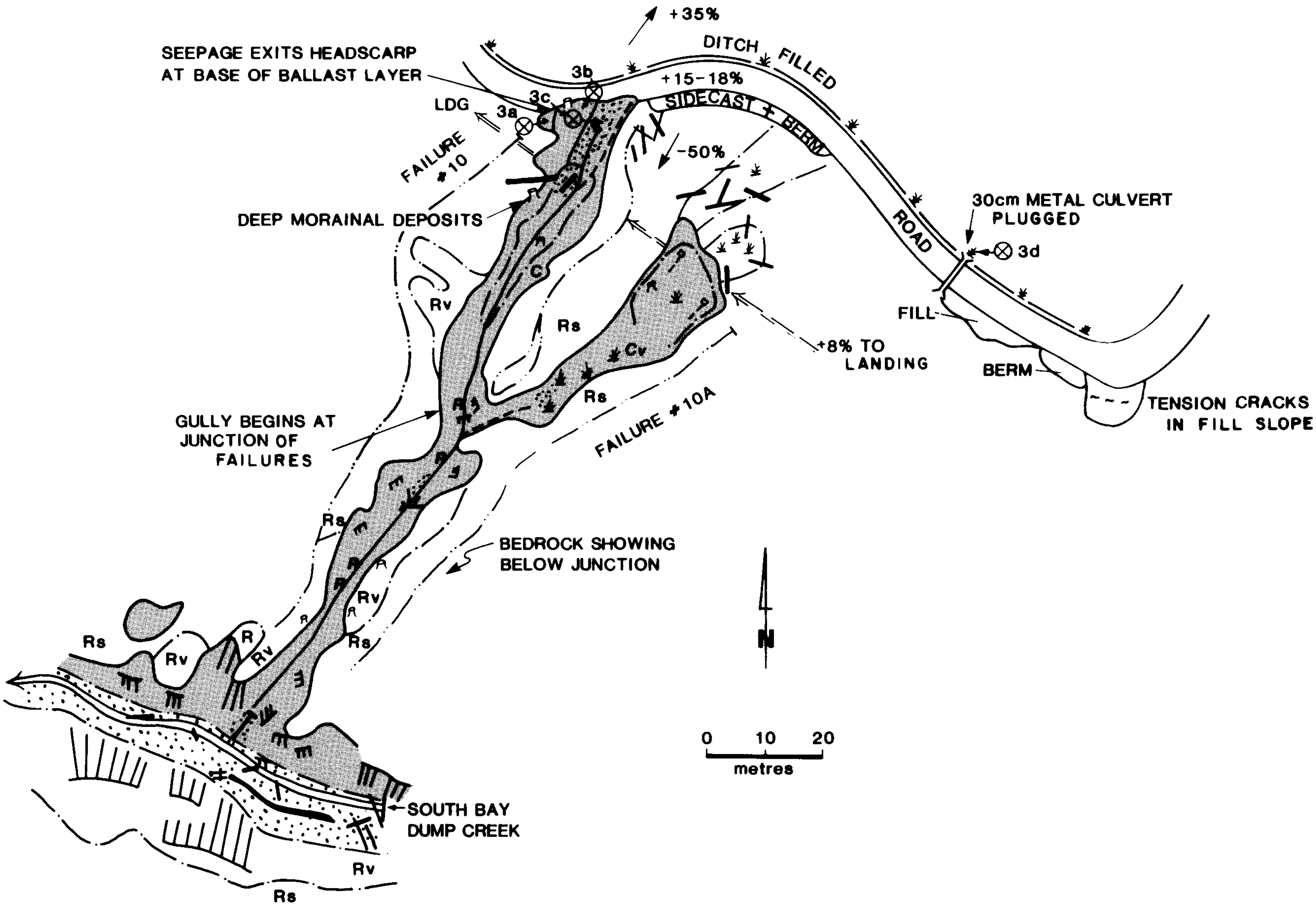


FIGURE A4.3. Diagram of Example #3, South Bay Dump Creek. (Failure #10, L13-116/115)

FIGURE A4.3a. Initiation zone, Example #3.

FIGURE A4.3b. Looking down slide channel, Example #3.

FIGURE A4.3c. Water flowing out of headscarp at the base of the ballast layer, Example #3.

FIGURE A4.3d. Culvert inlet almost plugged with debris and sediment, Example #3.

Suggestions for Prevention

This failure illustrates the importance of controlling road drainage both in the short and long terms. A fill can stand on a 50% sideslope if it is properly built. The key is to keep water out. This requires planning and installing an adequate drainage system in the first place, and adequate maintenance afterward to ensure the ditch and culverts function properly.

In this case the ditch was formed by the ballast layer rather than dug below the level of the subgrade. This allowed water to flow through the ballast layer and into the fill slope. A proper ditch should have been excavated into the morainal material at the base of the cutbank, to drain water away from the subgrade. Also, more culverts should have been installed in the road segment above the failure site, to avoid concentrating large volumes of seepage water.

It should be noted that it is difficult to excavate a proper ditch with a bulldozer, which probably explains why it was built with road ballast. This type of situation is less likely to occur now that most subgrade is built with excavators.

After a road is built, the ditches and culverts must be cleaned periodically. Judging by the condition of the ditches and the culvert uproad, this was not done, and sediment and vegetation eventually choked most of the ditch and clogged the one culvert in the vicinity of the failure. Cutbanks in zones of heavy seepage are prone to constant sloughing; consequently, ditches in such areas require continual cleaning. Backsloping the cutbanks and grass seeding will reduce sloughing, but it is not usually a practical measure if the ground slope exceeds about 40%. Therefore, putting the road to bed, is probably worthwhile, even if the road is only inactive temporarily. A series of cross-ditches, still passable to pickup trucks, would likely suffice, but their bases should extend into the morainal material below the subgrade.

EXAMPLE #4: DEBRIS SLIDE/TORRENT

1.	Landslide Description	
	a. Location	Bonanza Creek, western Graham Island
	b. Landslide Type	Open-slope debris slide entering gully and becoming a debris torrent
	c. Landslide Number	Not known
	d. Location of Initiation Zone	Road fill slope
2.	Physical Dimensions	
	a. Area	0.17 ha
	b. Volume	1000 m^3
	c. Slope Gradient Near Initiation Zone	35-39° (70-80%)
	d. Slope Shape Near Initiation Zone	Convex (at major slope break)
3.	Site Characteristics	
	a. Surficial Materials	Gravelly colluvial veneer overlying thin (10 cm) layer of compact, silty-clayey moraine or heavily weathered bedrock
	b. Site Drainage	Receiving area: moderately well to well-drained; large bowl-shaped depression
	c. Failure Surface	Smooth morainal or bedrock material
	d. Bedrock Geology (from Sutherland Brown 1968)	Kunga formation: reddish brown siltstone, bedded, extensively jointed and highly weathered
4.	Suspected Cause or Contributing Factors	Diverting road and slope drainage via a cross ditch onto a large fill built on steep slopes

This failure was triggered by overloading steep slopes with fill material and subsequently draining water into the fill.

Description

The failure, shown in Figure A4.4, began in a road fill and travelled about 75 m (horizontal distance) down an open slope, across a small bench, and into a gully where it became a debris torrent. Slopes above the road were about 20% and below the road, between 70 and 80%. The road crossed the base of a large depressional area. The length of drainage-collecting slope above the failure was not estimated. The drainage area was increased by the road ditch network which drained into the failure site from both sides. Subsurface seepage was evident along the rock surface and around tree roots in the failure zone, but there was no sign of piping.

The road was built on bedrock. Ditches were formed from ballast, but no culverts were installed in the vicinity of the failure. A cross-ditch, installed after logging was completed, drained ditch water onto the fill slope. The ditches were cleaned sometime after the slide had occurred, so their condition prior to failure could not be properly assessed.

Factors Contributing to Failure

As in Example #3, both construction technique and road drainage contributed to this failure. The road was built on the edge of a major slope break, and waste material was sidecast onto the steep slope below, overloading the slope. Ditch water was then diverted onto the fill slope by a cross-ditch, saturating the fill and eventually causing failure.

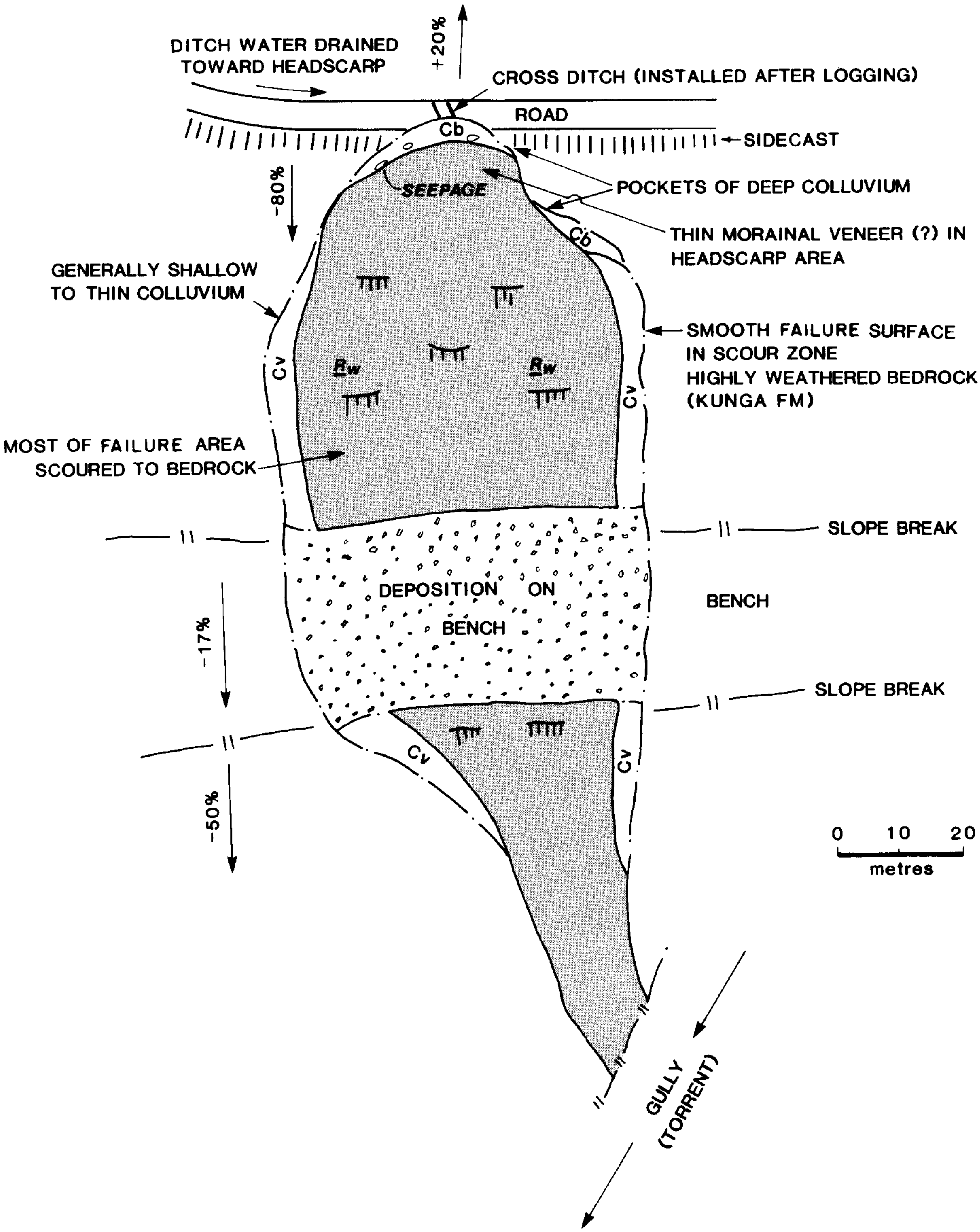


FIGURE A4.4. Sketch of Example #4, Bonanza Creek.
(Failure #1, BL 81059-142/143)

Suggestions for Prevention

This example illustrates several possibilities for avoiding failures of this type.

First, the road was located too near the edge of the bench. If it had been set back a bit further from the slope break, most of the sidecast would have stayed on the bench. The bench was wide enough to have moved the centreline uphill without appreciably affecting grade or alignment.

Alternatively, the excess rock could have been hauled back to a more stable dump site. Since there were no suitable dumping sites close at hand, however, it would have been cheaper and probably just as effective to relocate the road in this case.

In addition to minimizing sidecast, closer attention to road drainage was also needed. At least 200 m of road drained onto the site. More culverts should have been installed during construction at identifiable points of natural slope drainage. When the road was abandoned after logging, it should have been cross-ditched more frequently to avoid concentrations of surface water, and the cross-ditches should have avoided large fills.

EXAMPLE #5: DEBRIS SLIDE

1.	<u>Landslide Description</u>	
	a. Location	Skedans Creek, Louise Island
	b. Landslide Type	Open-slope debris slide
	c. Landslide Number	N/A (new failure)
	d. Location of Initiation Zone	Near a slope break approximately 60 m below a logging road
2.	<u>Physical Dimensions</u>	
	a. Area	~ 0.1 ha
	b. Volume	600 m^3
	c. Slope Gradient Near Initiation Zone	38° (78%)
	d. Slope Shape Near Initiation Zone	Convex through and above initiation zone
3.	<u>Site Characteristics</u>	
	a. Surficial Materials	Silty-sandy colluvial veneer overlying thin (10 cm) morainal veneer over bedrock
	b. Site Drainage	Depressional site; moderately to rapidly drained; surface flow and subsurface seepage evident
	c. Failure Surface	Surface of morainal veneer
	d. Bedrock Geology (from Sutherland Brown 1968)	Yakoun formation (possibly): competent; some jointing but no bedding; fine-grained (probably volcanic); moderately weathered at surface
4.	<u>Suspected Cause or Contributing Factors</u>	Concentration and redirection of drainage water from upper road, in combination with high rainfall and possibly earlier earthquake

This failure, not included in Rood's survey, is an example of the indirect impacts roads can have on slope stability.

Description

Example #5, indicated by arrows in Figures A4.5a and A4.5b, is one of three failures that occurred simultaneously on a setting that had been recently felled but not yarded. The landslide initiated on an open slope approximately 60 m below a road (Branch L460) and 30 m below a sharp slope break, and travelled about 200 m downslope before depositing debris in a larger, flat-bottomed gully. The failure site was slightly depressional. Both surface drainage and subsurface seepage were evident at and above the slide headscarp. The drainage area above the initiation zone was increased by ditches along the upper road. The failure is believed to have occurred on August 2, 1983. Events leading up to the occurrence of this and the adjacent two failures are reasonably well known. The upper road was built in the early summer of 1983 and falling had been completed in July 1983. The area was to be yarded to the upper and lower roads. Because of the general convex shape of the slope, deflection was limited in both directions across a band in the upper centre part of the sideslope, so a number of trees were left standing for backspars. Yarding was scheduled to begin in September of 1983.

An earthquake of magnitude 5.1 on the Richter scale was recorded on July 31, 1983, in addition to two others that occurred on July 6 (mag. 2.7 and 4.0) (E.A. Sauder, pers. comm.).

On August 2, 1983, an intense storm accompanied by strong winds passed through the area. A total of 41 mm of rain fell at Sandspit during the 24-hour period.

FIGURE A4.5a. Aerial view of Example #5. Note upper road, locations of three failures and backspar trees, and gullied terrain.

FIGURE A4.5b. Looking upslope to the three failures.

FIGURE A4.5. Example #5, Skedans Creek.

Factors Contributing to Failure

The fact that these failures occurred during a major storm suggests that heavy rainfall was the principal triggering factor. In addition, a sediment trail leading from the upper road toward the failure zone suggests that additional water had been drained by the upper road into the slope above the failure zones. Inspection of the upper roads showed that water had flowed along the road surface (see Figure A4.5a), finally breaching a berm at a point immediately above the three failures. Ditches were plugged with sediment and debris.

The degree to which other factors may have contributed to the failures is not clear. The earthquake of July 31 may have had some effect but this cannot be proven. Clearly, tree root deterioration as a result of clearcutting was not a factor, as the area had been felled only a month previously. The possibility of wind-induced dynamic loading as a contributing factor in conjunction with high soil moisture levels cannot be ruled out. Several of the trees reserved for backspars blew down, although these were located well below the initiation zone.

Suggestions for Prevention

Example #5 illustrates the importance of maintaining natural slope drainage patterns. A combination of excessive soil moisture levels and steep slopes is generally recognized as the most effective triggering mechanism of slope failures. The extensive network of subparallel gullies (visible in Figure A4.5a), steep slopes, and shallow soils, as well as the signs of old failures, all indicate that the sidehill was naturally unstable.

Engineers must recognize the potential for a road system to alter slope drainage patterns and, especially if slopes below a road are known to be unstable, design drainage networks that will not impose additional stresses on off-road areas. In this example, water was drained away from its natural drainage point (down the large gully to the left of the failure) and released instead onto the open slope above the three new failures. Areas such as this probably require closer culvert spacings, with culverts installed in most recognizable drainage areas (slope depressions as well as small creeks and gullies).

It is usually difficult to tell how culverts and ditches on a newly built road will perform until after the first major storm. If possible, roads should be examined during and following periods of heavy rainfall to assess the adequacy of ditching and culverts. Deficiencies should be corrected as early as possible.

Road grading is also important. The road surface should be sloped a little to enable the water to drain off. Berms should not be left beside the road edges where they can prevent surface runoff from reaching the ditch.

EXAMPLE #6: DEBRIS SLIDE/TORRENT

1. <u>Landslide Description</u>

a. Location	South Bay Dump Creek, northern Moresby Island
b. Landslide Type	Open-slope debris slide entering gully
c. Landslide Number	FF8285-L13-116/115, #13 (Rood 1984)
d. Location of Initiation Zone	Approximately 20 m below toe of road fillslope

2. <u>Physical Dimensions</u>

a. Area	0.022 ha (including adjacent failure)
b. Volume	120 m^3 (including adjacent failure)
c. Slope Gradient Near Initiation Zone	22° (40%)
d. Slope Shape Near Initiation Zone	Concave to straight through initiation zone, changing to convex at gully headwall

3. <u>Site Characteristics</u>

a. Surficial Materials	Sandy-silty colluvial veneer overlying dense, silty-clayey morainal veneer
b. Site Drainage	Imperfectly to poorly drained receiving site; at base of long, funnelling depression leading into gully headwall
c. Failure Surface	Morainal veneer
d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation (possibly): Highly weathered, heavily jointed and fractured siltstone; harder and more competent at one-metre (+) depth

4. <u>Suspected Cause or Contributing Factors</u> — Not believed to be related to or caused by road drainage

This landslide is probably clearcut- rather than road-related, but the latter could not be entirely ruled out because of the proximity of the failure to a logging road.

Description

This landslide, shown in Figure A4.6, initiated as an open-slope failure at the toe of a distinctly concave slope and about 40 m above the breakover into the gully headwall. The sideslope in the vicinity of the headscarp was about 40%. The failure was located within a well-defined slope depression, which was clearly a receiving site (Figure A4.6a). The depression narrowed rapidly from the base of a steep (50%+) sidehill into the head of the gully about 60 m downslope. A relatively straight and uniform slope about 150-200 m in length appeared to drain into the depression. Lateral boundaries of the upslope drainage area were indistinct. Colluvial deposits at the base of the sidehill were deeper than at the edge of the bench. Within the depression the ground was spongy and sedges and horsetail were evident.

The shape of the failure conformed to that of the depression: wide at the (roughly) semicircular headscarp and narrow where it exited into the gully channel. Seepage was flowing out of the headscarp and continued as surface flow into the gully.

The road was built on the inside edge of the bench, about 20-30 m above the failure headscarp. It had a level to rolling grade and was built on a subgrade of colluvium excavated from the inside bank. No rock or morainal material was exposed on the cutbank within the depression area, although rock outcropped at the margins of the depression. The road section within the depression was not ditched. There was evidence that water occasionally flowed across the road, but mostly it seemed to pass through or under the ballast. As the road dropped away to either side, additional water was not diverted into the depression.

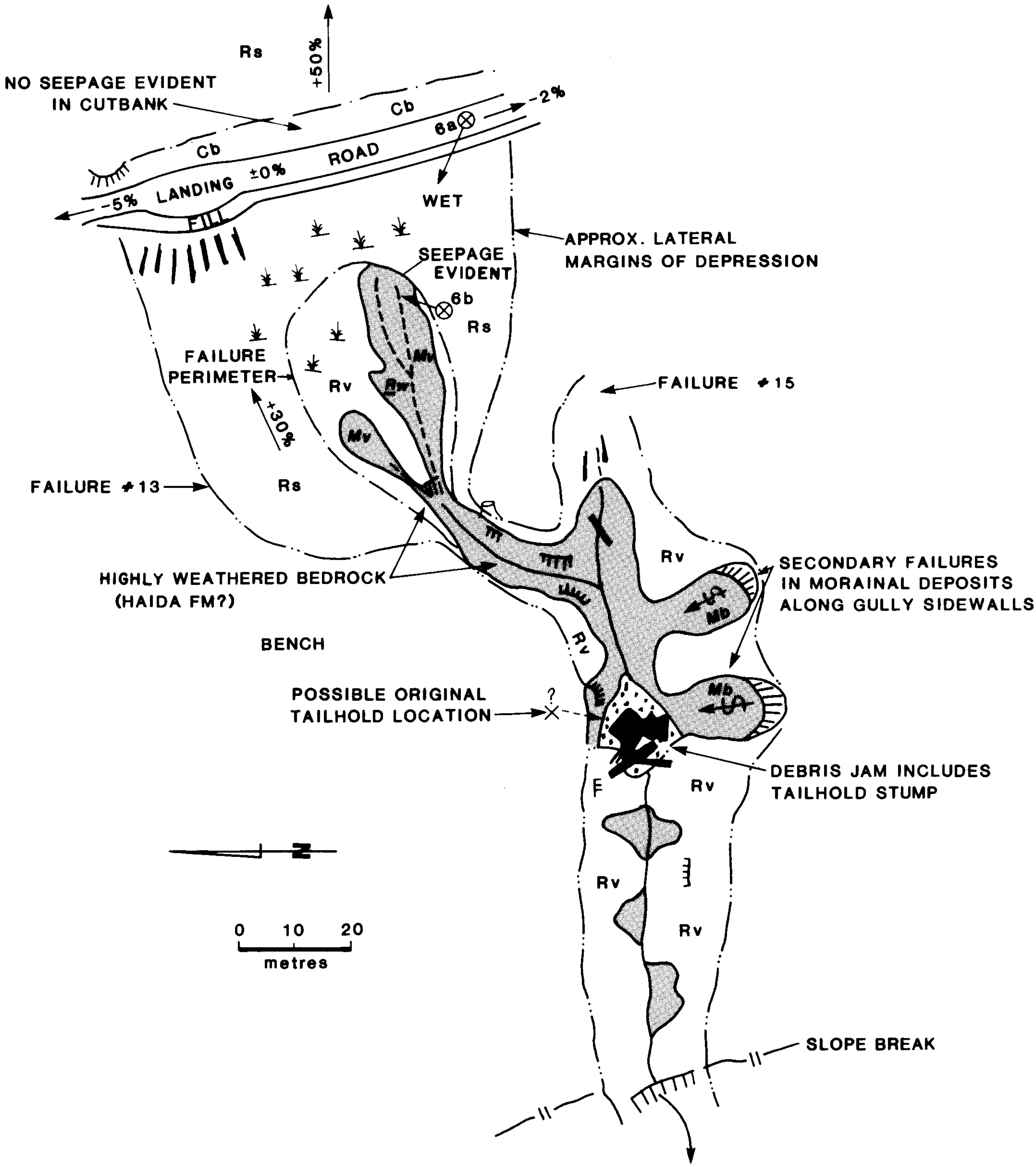


FIGURE A4.6. Sketch of Example #6, South Bay Dump Creek. (Failure #13, FF8285-L13-116/115)

FIGURE A4.6a. Bowl-shaped depression below road (the slide area is light yellow, covered with grasses and sedges), Example #6.

FIGURE A4.6b. Headscarp area of Example #6.

Factors Contributing to Failure

The high site moisture regime is clearly an important--perhaps the dominant--feature of this failure site. Given the relatively large upslope drainage area, the abrupt slope reduction, and the funnelling effect of the local topography, the site is wet and probably saturated for prolonged periods during wet weather. Vegetative indicators support this view.

There is no evidence to indicate that the road was a contributing factor. It does not appear to have contributed more water to the depression, the road fill is small and still intact, and it does not impinge on the initiation zone.

Suggestions for Prevention

It may not be possible to prevent this type of failure. From an engineering point of view the road was in the right place to cross the depression, along the inside edge of a gentle bench; the outer edge was too dissected for a road. The road also appeared to be stable and well built. The surface was firm and there was no sign of slumping or tension cracks in the fill. The road skirted the wettest ground by staying high, and the fact that the road remains stable suggests this was a good location. It lacked a culvert and ditches, but it is not evident that the lack contributed to the failure.

Prevention of this type of failure depends upon locating the road in the right place, which in turn depends upon early recognition of potentially unstable sites during layout. This failure site has several important indicators: 1) a long, steep upslope area breaking abruptly onto a narrow, gentle bench; 2) well-defined topographic confinement on the bench area, concentrating subsurface seepage into a small outlet zone; 3) the presence of a deep, steep-walled gully below the outlet zone; and 4) plants (visible now), indicating a high site moisture regime within the depression. (Presumably, other equally useful indicators would have been present prior to logging.)

EXAMPLE #7: DEBRIS SLIDE ON GULLY SIDEWALLS

1. <u>Landslide Description</u>

a. Location	Sach's Creek, northern Moresby Island
b. Landslide Type	Debris slides on gully sidewalls
c. Landslide Number	FF8285-L14-111/112, #10 (Rood 1984)
d. Location of Initiation Zone	Gully sidewalls

2. <u>Physical Dimensions</u>

a. Area	0.034 ha (combined area)
b. Volume	340 m^3 (combined volume)
c. Slope Gradient Near Initiation Zone	35° (70%) (average sidewall gradient)
d. Slope Shape Near Initiation Zone	Straight and uniform from crest to channel

3. <u>Site Characteristics</u>

a. Surficial Materials	Sandy-gravelly colluvial veneer overlying silty-sandy, compact morainal blanket
b. Site Drainage	Imperfectly to moderately drained receiving slope
c. Failure Surface	Within morainal deposits
d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation (possibly): bedrock not visible in gully

4. <u>Suspected Cause or Contributing Factors</u> — Yarding disturbance

Example #7 is a series of debris slides and yarding scars illustrating the effects of log movement across steep gully sidewalls.

Description

Figure A4.7 shows a diagram of the sidewall failures, the location of one of the yarding roads through the gully, and the available deflection at the failure points. Figure A4.7a looks north toward the landing and Figure A4.7b shows one of the small failures on the east sidewall.

The failure consists of a series of small, shallow debris slides and yarding scars along both sides of the gully. Extensive scarring on the west side has created a continuous open patch approximately 60 m long. Two smaller scars are located on the east sidewall. Collectively, the failures covered 0.034 ha and entrained an estimated 340 m^3 of debris.

Seepage was visible along the morainal surface in part of the initiation zone (near the crest) on the west sidewall and in the two failures on the east sidewall. Most of the exposed area on the west sidewall was created by yarding disturbance rather than mass wasting, while the failures on the east sidewall were small debris slides. Frost action and ravelling has probably slowed revegetation of these disturbed areas. Several yarding roads crossed the gully. Deflection through the gully was fair to poor. On the yarding road illustrated in Figure A4.7, deflection at the headscarp of the largest failure on the west sidewall was only 4%. Several stumps above this point were heavily scarred by logs (Figure A4.7c), and stumps on the sidewalls were uprooted during yarding and deposited in the gully channel.

Factors Contributing to Failure

Two logging-related factors account for the extensive scarring and consequent mass wasting in this gully: 1) several yarding roads crossed the gully; and 2) deflection was poor.

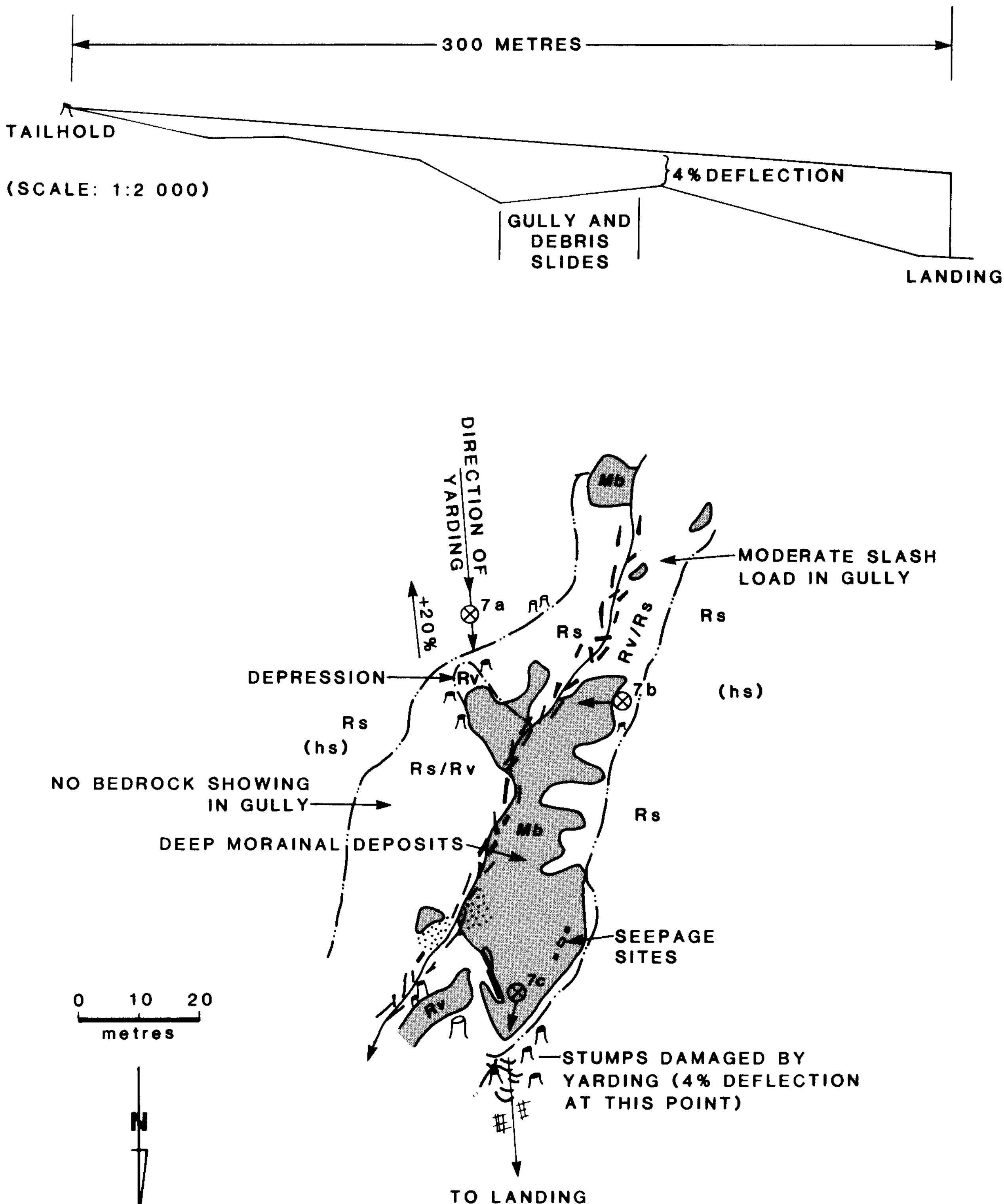


FIGURE A4.7. Example #7, Sach's Creek

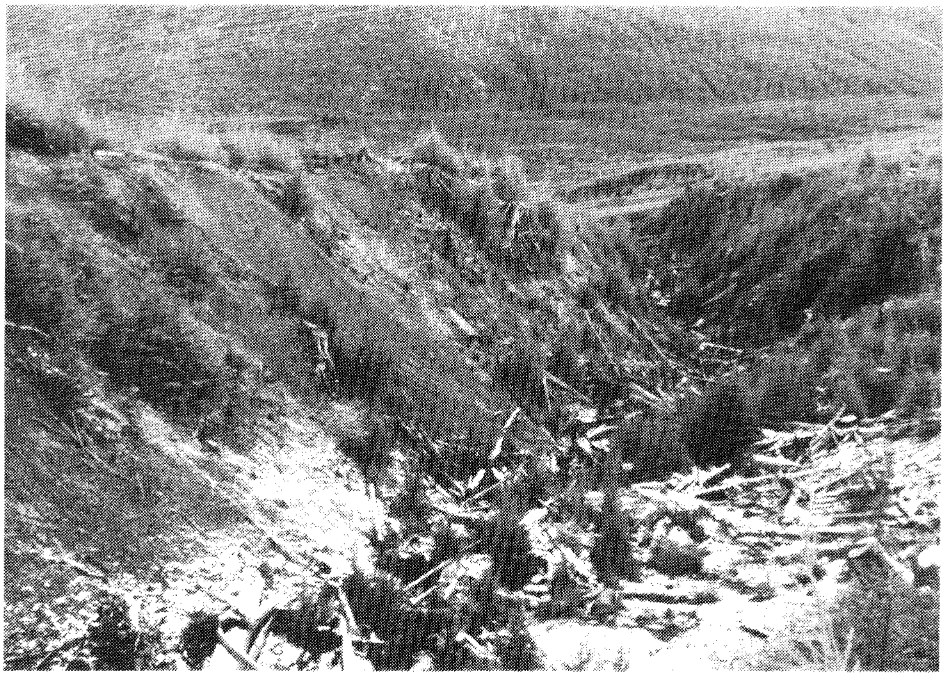


FIGURE A4.7a. Looking along the yarding road toward the landing (not visible), Example #7.

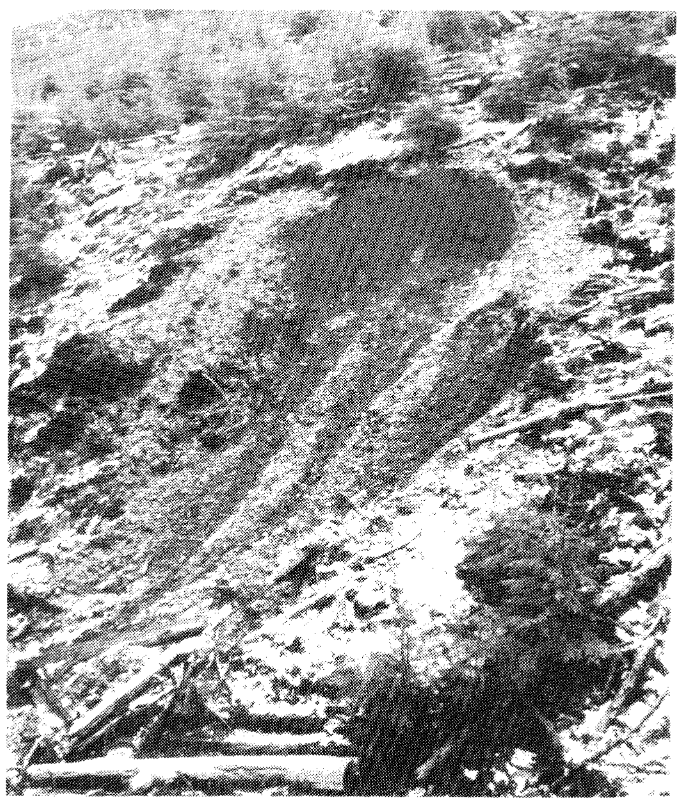


FIGURE A4.7b. Small failure on east sidewall, Example #7.

FIGURE A4.7c. A stump on the west sidewall damaged by yarding, Example #7.

Suggestions for Prevention

Prevention of such failures depends on reducing the number of yarding roads within the gully (or eliminating cross-gully yarding entirely), improving deflection, or both.

This was a difficult area to lay out because of the straight slopes and long yarding distances. There were two possibilities for reducing yarding distance: move the existing lower road further uphill; or put in a road above the gully either to split the yarding or to yard up, rather than down, the gully. Options for redesigning yarding patterns to yard away from, rather than over, the gully would depend upon the choice of road locations.

An alternative to altering road locations would be to improve deflection through the gully by using backspars at the falling boundary. However, the long yarding distances (300 m) involved here would call for high backspars.

Even a 15-m backspar would provide only 5% deflection (as compared to 4% for a stump-rigged tailhold) and would increase clearance from the chord to the ground by only 4 m (from 12 to 16 m) in the headscarp area. Yarding distances would have to be shortened substantially to favour the use of backspars.

Since the opportunities for improving deflection are limited, layout modifications emphasizing yarding away from gullies would probably be more effective. Additional roads and landings may be required. The gentle sideslopes make layout changes feasible, although any changes would have to be compatible with development of the surrounding slopes both above and below the bench. Also, it would still be necessary to remove any trees that fell into the gully, so some yarding disturbance to the sidewalls would probably still occur.

EXAMPLE #8: DEBRIS SLIDE/DEBRIS TORRENT

1. <u>Landslide Description</u>	
a. Location	Riley Creek, western Graham Island
b. Landslide Type	Debris slide in gully, becoming debris torrent
c. Landslide Number	Not known
d. Location of Initiation Zone	Near gully headwall
2. <u>Physical Dimensions</u>	
a. Area	0.333 ha
b. Volume	650 m^3
c. Slope Gradient Near Initiation Zone	52-55° (130-142%) (headwall area) (31° [60%] sideslope adjacent to gully)
d. Slope Shape Near Initiation Zone	Convex above headwall area
3. <u>Site Characteristics</u>	
a. Surficial Materials	Rubbly-silt loam colluvial veneer over bedrock
b. Site Drainage	Moderately well-drained; failures occurred immediately below a slope depression
c. Failure Surface	Bedrock
d. Bedrock Geology (from Sutherland Brown 1968)	Yakoun formation: massive to slightly jointed, moderately weathered, greenish, fine-grained with white phenocrysts; volcanic
4. <u>Suspected Cause or Contributing Factors</u>	Severe yarding disturbance

In this example, yarding disturbance probably aggravated conditions on a marginally stable site, resulting in a debris slide some time after logging.

Description

Figure A4.8 shows a sketch of the failure, with details of yarding disturbance in the vicinity of the headscarp. There are two discrete headscarps: the first just above the crest of the east sidewall; and the second very close to the first, at the gully headwall. The failures, treated as a single event, triggered a debris torrent that may have reached Riley Creek.

About 60 m of upslope length drained into the initiation zone of the east headscarp, which was situated immediately below a slope depression. Subsurface water was flowing out of both headscarps.

Yarding gouges in the depression above the east (right) headscarp indicated that deflection was poor across the headwall area. Yarding direction was almost perpendicular to the long axis of the gully. The landing was about 60 m to the west of the gully. The tailhold stump was not found.

Factors Contributing to Failure

The failure occurred sometime after logging and therefore was not triggered by yarding. This failure might have occurred even if the area had not been disturbed, but severe yarding disturbance could have accelerated it, perhaps by damaging root systems and loosening the soil mass.

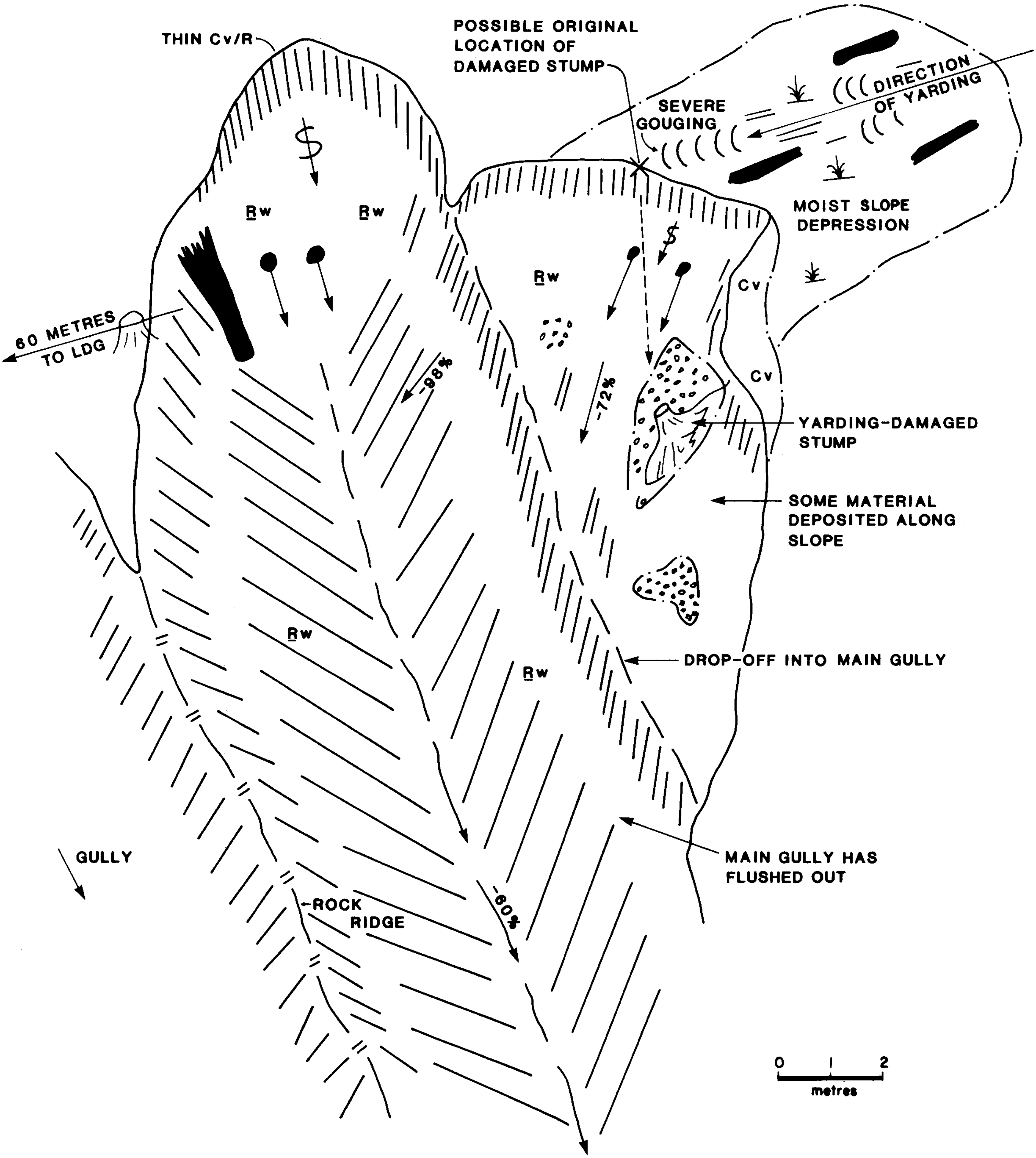


FIGURE A4.8. Example #8, Riley Creek.

Suggestions for Prevention

It is difficult to determine if modified yarding techniques could have prevented this landslide. Given its physical characteristics, the site was probably a sensitive area with little capacity to absorb additional stresses. In contrast to Example #7, the sideslopes were steep and the road was in a good location to develop the entire hillside. The steep slopes limited opportunities for moving road locations to improve yarding conditions. Reducing yarding disturbance on this site would therefore have to have been achieved by either a change in yarding patterns to yard away from the gully, or the use of backspars and shorter yarding distances to improve deflection. These options were not investigated in detail.

EXAMPLE #9: DEBRIS SLIDE IN SHALLOW GULLY

1.	Landslide Description	
	a. Location	MacMillan Creek, northern Moresby Island
	b. Landslide Type	Debris slide within a shallow gully
	c. Landslide Number	FF8285-L14-84, #1 (Rood 1984)
	d. Location of Initiation Zone	Within-clearcut
2.	Physical Dimensions	
	a. Area	0.126 ha
	b. Volume	290 m^3
	c. Slope Gradient Near Initiation Zone	33° (65%)
	d. Slope Shape Near Initiation Zone	Convex
3.	Site Characteristics	
	a. Surficial Materials	Rubbly, silty-sandy colluvial veneer overlying clayey-sandy morainal blanket
	b. Site Drainage	Moderately well-drained over impermeable till
	c. Failure Surface	Morainal blanket
	d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation, near contact zone with Kunga formation: soft, heavily weathered and highly jointed black argillite, bedding parallel to slope
4.	Suspected Cause or Contributing Factors	Yarding disturbance due to poor deflection in the gully headwall region

As in Example #8, gouging near the initiation zone of this failure suggests that the site was locally affected by yarding logs through the failure zone.

Description

A diagram of the failure, along with details of yarding patterns, is shown in Figure A4.9 (see also Figure A4.9a). This failure differs somewhat from the previous two examples: it occurred in a shallow gully; it initiated in the headwall area rather than on the sidewalls; and the yarding direction was uphill and slightly across the gully, rather than downhill (see Figure A4.9b).

A noticeable break in slope across the sidehill, at the same elevation as the headwall, produced a convex slope into the gully. The failure originated at this break. The average sideslope was 40% above the break and 65% below it. The area was generally depressional and received seepage from the uniform slope above, which flowed out of the headscarp along the top of the till layer.

Minor gouging was visible on the slope break above the gully headwall, but yarding disturbance may have been severe below the break. Deflection was very poor over the entire length of the gully. As Figure A4.9 shows, the yarding direction was nearly parallel to the long axis of the gully and a yarding road extended up the channel and through the middle of the headwall. A stump-rigged tailhold was located at the top of the gully sidewall. There was no ground clearance on the back third of the yarding road. At the headwall area, in the middle third of the yarding road, clearance between the chord and the ground was only about 6 m, yielding only 3% deflection. This would not have been sufficient to lift the front end of logs clear of the ground, so ground-lead conditions must have prevailed at the headwall. Although the evidence was lost with the slide, this probably caused severe scraping and gouging on the steep slope below the break.

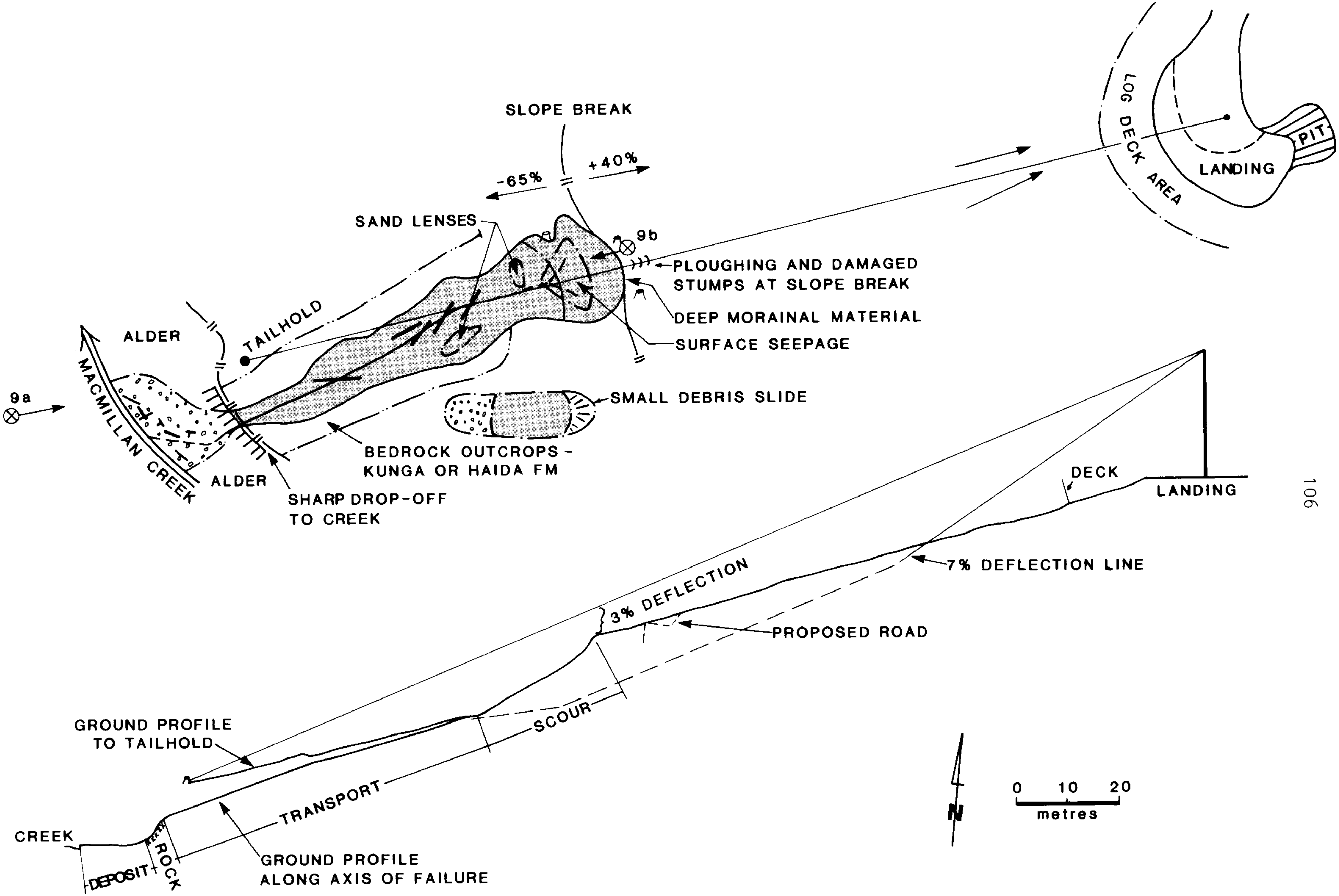


FIGURE A4.9. Example #9, MacMillan Creek.

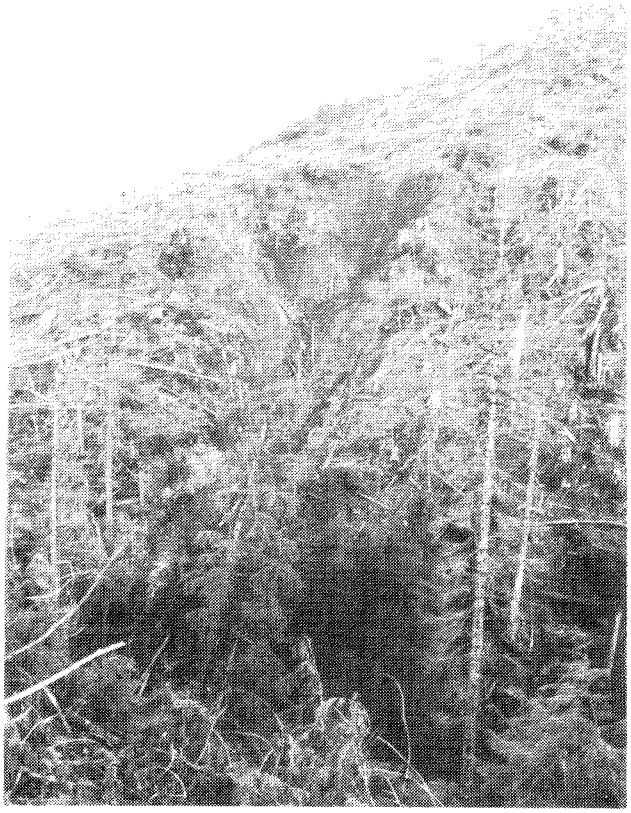


FIGURE A4.9a. A view of Example #9 from the west side of MacMillan Creek. Landing is at upper right and tailhold is at lower left.

FIGURE A4.9b. Looking down the slide scar from the headscarp, Example #9.

Factors Contributing to Failure

Moderately long yarding distances (190-200 m), smooth, uniform slopes, and a sharp break about 100 m from the landing provided poor deflection beyond the slope break.

The failure is thought to have occurred sometime after logging. As in Example #8, the extent to which yarding disturbance may have affected the site's stability is unknown. The severity of disturbance would have depended in part on the size of the timber, the size of the turns, and the number of turns that passed over the site. Analysis of yarding conditions at the headwall indicates that severe disturbance probably occurred and yarding was likely a contributing factor in this failure.

Suggestions for Prevention

If the current road location was not changed, a backspar at least 10 m tall would be needed to provide 6% deflection at the gully headwall. Even this would only provide 11 m of clearance, which would not be sufficient to eliminate yarding disturbance at the break. In a concurrent study of yarding operations, Sauder [1986] has shown that topographic obstacles such as slope breaks are usually disturbed by yarding, regardless of available deflection. Backspars may improve yarding productivity by reducing the frequency of hangups, but they cannot be guaranteed to reduce yarding disturbance in all situations.

There was probably greater potential to reduce yarding disturbance on this site by revising logging layouts rather than by using backspars. Another alternative would have been to move the road location downhill, shortening the yarding distance and improving deflection by bringing the yarder closer to the slope break. A road location about 20 m above the headwall area would have provided excellent lift and would also have left an area below the road on which to deck the logs. Also, by shortening the yarding distance to about 100-110 metres, it might have been possible to log the area with mobile yarding cranes, which would have provided more flexibility for adjusting yarding directions.

A key point in this and the other yarding examples is that, to develop logging layouts and yarding patterns that reduce disturbance to sensitive sites, it is first necessary to recognize such sites on the ground.

EXAMPLE #10: OPEN-SLOPE DEBRIS SLIDE

1.	Landslide Description	
	a. Location	Riley Creek, western Graham Island
	b. Landslide Type	Open-slope debris slide
	c. Landslide Number	Not known
	d. Location of Initiation Zone	Within-clearcut
2.	Physical Dimensions	
	a. Area	0.097 ha
	b. Volume	512 m^3
	c. Slope Gradient Near Initiation Zone	33° (65%)
	d. Slope Shape Near Initiation Zone	Convex (at minor slope break)
3.	Site Characteristics	
	a. Surficial Materials	Gravelly-silt colluvial veneer (with scattered deeper pockets) over bedrock
	b. Site Drainage	Moderately to well-drained
	c. Failure Surface	Bedrock
	d. Bedrock Geology (from Sutherland Brown 1968)	Yakoun formation: massive to weakly jointed, moderately weathered to a depth of 10 cm, greyish, fine-grained, possibly andesitic
4.	Suspected Cause or Contributing Factors	Possibly yarding disturbance in combination with natural factors

Yarding disturbance above the headscarp, while not extensive, may have contributed to this failure.

Description

Figure A4.10 shows a sketch of the failure and Figure A4.10a is a view of the failure from the landing.

The failure originated on the steepest part of a convex-shaped open slope in a deep pocket of colluvium that filled in a shallow trough in the bedrock surface. Soils along the slope break to either side of the failure were shallower. Ground slope was 57% above and 65% below the break. A slope 100 m in length drained into the failure site. Subsurface seepage was present in the headscarp.

Factors Contributing to Failure

As the diagram shows, a yarding road crosses right through the slide initiation zone at an acute angle to the slide axis. Several scarred stumps were found above the initiation zone. The landing was about 100 m downhill (Figure A4.10b). Although a deflection line was not run, it was clear that deflection was poor above the slope break.

The presence of yarding disturbance in the headscarp area suggests that yarding, while probably not the triggering event, weakened a marginally stable site. Logs dragged through the site may have dislodged stumps located in the initiation zone. Unlike the earlier examples, however, disturbance did not appear to be very severe.

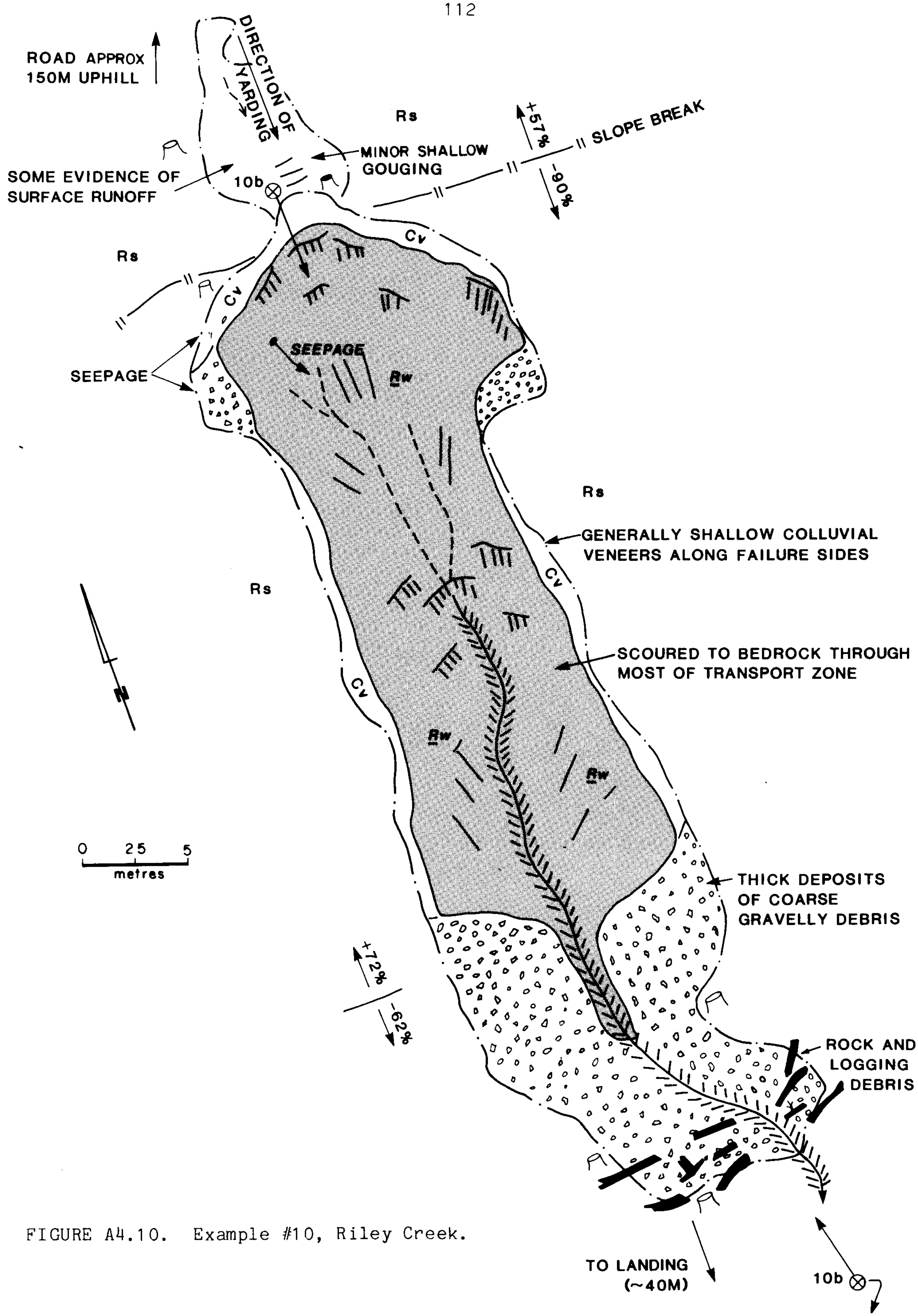


FIGURE A4.10. Example #10, Riley Creek.

FIGURE A4.10a. A view of Example #10 from lower road.

FIGURE A4.10b. Looking down Example #10 from the headscarp. The truck is parked at the landing.

Suggestions for Prevention

Alternatives for reducing disturbance include changing road locations and yarding patterns, or using backspars to improve deflection. Changing road and landing locations would be difficult, given the generally steep sidehills in the area, and in fact the road was in a good location. On steep sidehills it is more important to locate the roads in the right places and accept some difficult yarding, than to design a road system that will provide uniformly good yarding.

Even when a break in slope is small (in this case from 57% above the break to 65% below), deflection past the break is lost quickly when the sidehill is steep and the break is a long way from the landing. It might have been desirable to move the cutting boundary closer to the landing, perhaps to the slope break where the failure initiated. This would have improved downhill yarding, but it would have been necessary to review the entire layout to see if the timber above a revised cutting boundary could be yarded uphill. The benefits of less yarding disturbance on this particular site would have to have been weighed against potential problems created elsewhere.

Backspars might have improved clearance over the headscarp area, provided tailholds were not too far behind the slope break. However, it is more difficult to control turns when yarding downhill.

EXAMPLE #11: OPEN-SLOPE DEBRIS SLIDE

1. <u>Landslide Description</u>

a. Location	Haans Creek, northern Moresby Island
b. Landslide Type	Open-slope debris slide
c. Landslide Number	New
d. Location of Initiation Zone	Within-clearcut

2. <u>Physical Dimensions</u>

a. Area	0.111 ha
b. Volume	311 m^3
c. Slope Gradient Near Initiation Zone	32° (62%)
d. Slope Shape Near Initiation Zone	Convex

3. <u>Site Characteristics</u>

a. Surficial Materials	Veneer of organic matter (<30 cm) overlying highly weathered bedrock or possibly morainal veneer
b. Site Drainage	Poor; very wet receiving slope above headscarp
c. Failure Surface	Bedrock and/or morainal veneer
d. Bedrock Geology (from Sutherland Brown 1968)	Honna formation: sandy-gravelly conglomerate, heavily weathered and jointed; bedding, dip and strike not discernible

4. <u>Suspected Cause or Contributing Factors</u> — Possibly yarding disturbance in combination with high site moisture levels and steep slopes

This failure occurred during a rainstorm in August 1983. As in Example #10, yarding disturbance in the headscarp area suggests that logging may have affected this landslide.

Description

Figure A4.11 illustrates the failure and the direction of yarding. A deflection line was run and is shown in the figure.

The failure occurred just below the break on a convex slope. Sideslope was 46% above the break and 62% below. Debris travelled 55 m downslope and stopped on a lower road. No debris entered Haans Creek. The landslide originated in a depressional site with a visible drainage-collecting area upslope and subsurface seepage in the headscarp. The layer of weathered bedrock appeared to be transmitting a considerable volume of seepage flow.

An old, small failure was visible immediately above the headscarp of this one (Figure A4.11b). This earlier failure occurred in a pocket of colluvium, was approximately 3 m wide by 10 m long, and deposited debris just above the slope break. The headscarp of the new failure (this example) was less than 5 m downslope from the toe of the old slide deposit. When examined in February 1984, seepage was exiting the headscarp of the old failure, flowing on the surface for several metres before disappearing and then reappearing in the new failure headscarp.

The recent failure is known to have occurred in August 1983, several years after the area had been logged. The previous failure occurred before the area was logged, shown by the way fallen trees had been bucked. A yarding road passed through the initiation zone of the new failure at about 45° to the long axis of the landslide, resulting in scraping and gouging down to the surface of the weathered bedrock. Yarding direction was downhill.

The ground profile along the yarding road shows that deflection was fair in the headscarp area (see Figure A4.11). Clearance between the chord and the ground was 13 m, giving about 6% deflection. The profile, viewed along the yarding road, indicates there was not an abrupt change of slope at this point because the yarding road crossed the slope break at an angle.

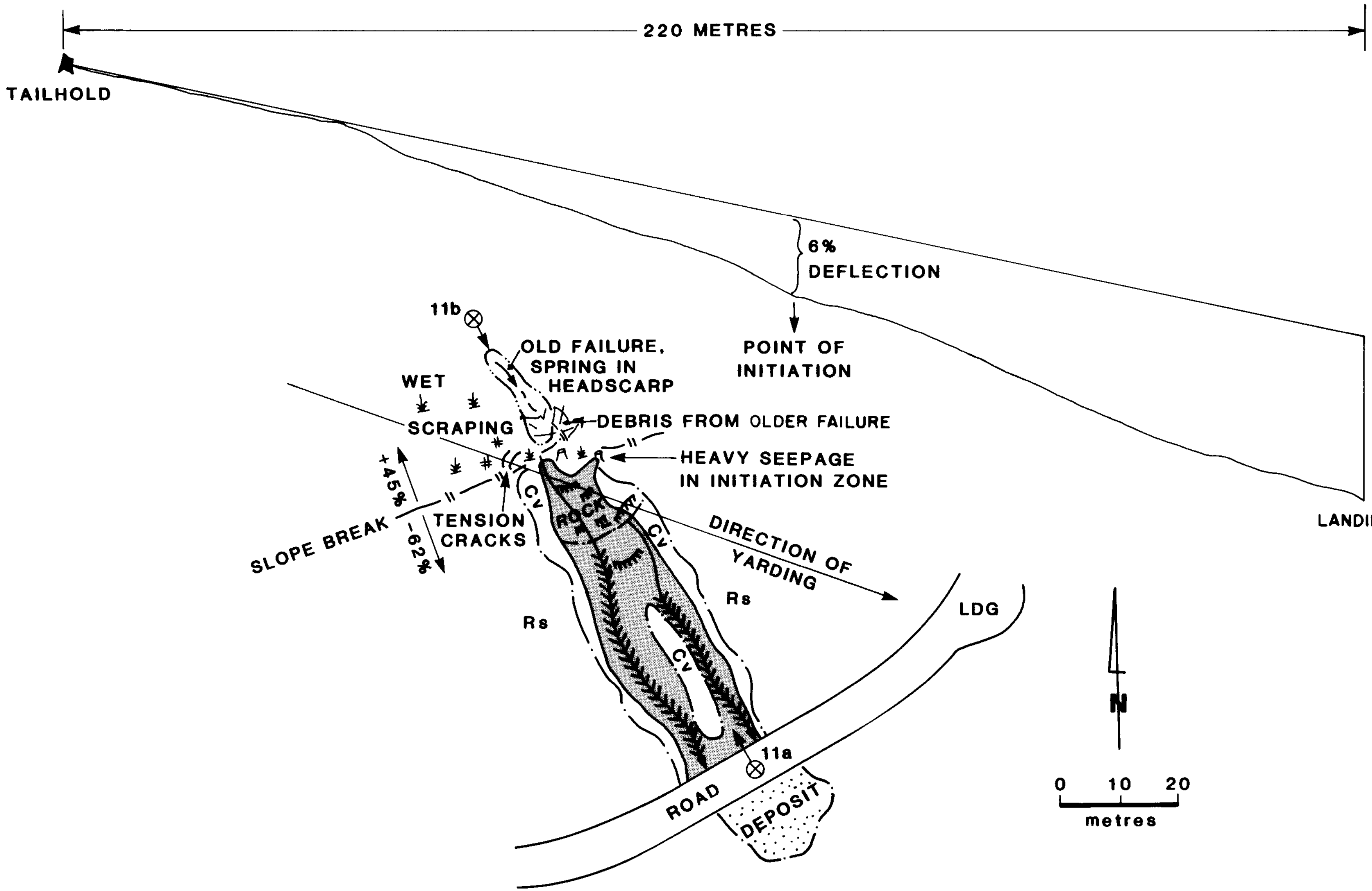


FIGURE A4.11. Example #11, Haans Creek.

FIGURE A4.11a. Example #11 viewed from the road.

FIGURE A4.11b. Looking down the small older failure above Example #11. The new failure (not visible) initiated just below the deposition zone of this failure.

Factors Contributing to Failure

A combination of site wetness and steep slopes appear to make this a naturally sensitive site. Heavy rainfall was probably the triggering event, but the possibility that yarding disturbance may have upset the balance of stability cannot be ruled out.

Suggestions for Prevention

It is difficult to propose changes to yarding systems or patterns that would have prevented this failure. Deflection through the failure zone was at least adequate; yarding disturbance above the headscarp was not severe; ground clearance was sufficient to avoid serious and consistent hangups; and a time lapse of several years occurred between logging and failure.

A key feature of the site's potential in stability was the presence of the old failure. It was too small to show on air photos, but was identifiable on the ground. Although it would probably not have influenced logged layout in this case, it would be an important indicator for a road location survey.

EXAMPLE #12: OPEN-SLOPE DEBRIS SLIDE

1. Landslide Description	
a. Location	MacMillan Creek, northern Moresby Island
b. Landslide Type	Open-slope debris slide
c. Landslide Number	FF8285-L13-118, #2 (Rood 1984)
d. Location of Initiation Zone	Within clearcut, at concave slope break
2. Physical Dimensions	
a. Area	0.120 ha
b. Volume	288 m^3
c. Slope Gradient Near Initiation Zone	17-24° (30-45%)
d. Slope Shape Near Initiation Zone	Concave
3. Site Characteristics	
a. Surficial Materials	Organic veneer overlying dense, sandy-clayey, probably morainal veneer
b. Site Drainage	Poor; discharge site
c. Failure Surface	Surface of morainal deposit
d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation (possibly): soft, highly weathered sandstone; bedding and jointing not discernible
4. Suspected Cause or Contributing Factors	Possibly root deterioration in combination with natural factors

Example #12 was classified as an open-slope failure occurring within a clearcut, due to unknown causes.

Description

Figure A4.12 shows logging details of the failure. Figure A4.12a shows the failure, looking upslope from the deposition zone.

The failure occurred in a depressional area on a concave slope of 30-35% below the break and 40-45% above. It was approximately 100 m long and deposited debris on a wide gentle bench well away from the creek.

Slope drainage discharged onto the ground surface in several small depressions across the slope break, including at the failure site. Grasses, sedges, hellebore, and skunk cabbage were common. The slope depression in which this failure occurred could be traced about 40-50 m uphill to an abrupt contact with a long, steep (55%) slope. Seepage first appeared on the ground surface about 15 m downslope from this break, which marked an abrupt change from very wet soils on the gentle slopes and much drier soils on the steep slope. The original timber stand composition reflected this change: large hemlock and spruce occupied the steep slopes, while smaller yellow-cedar, redcedar, and hemlock occupied the gentle, wet slopes.

When the failure was re-examined in February 1984, a tension crack 30-40 cm wide had opened across the slope depression of this slope break. Tree roots had pulled free across the crack (see Figure A4.12b).

As Figure A4.12 shows, a yarding road crossed the failure about 15 m downslope of the initiation zone, but, except for one small gouge, there was no evidence of yarding disturbance. Nor were the lateral margins of the slope depression scarred. The yarding direction was predominantly cross-slope and uphill, which--combined with fair to good deflection (7% where the yarding road crossed the scour zone)--should have provided a favourable lead for yarding logs. Also, only a few turns would have been yarded over the failure site, because it was in the back third of the yarding road.

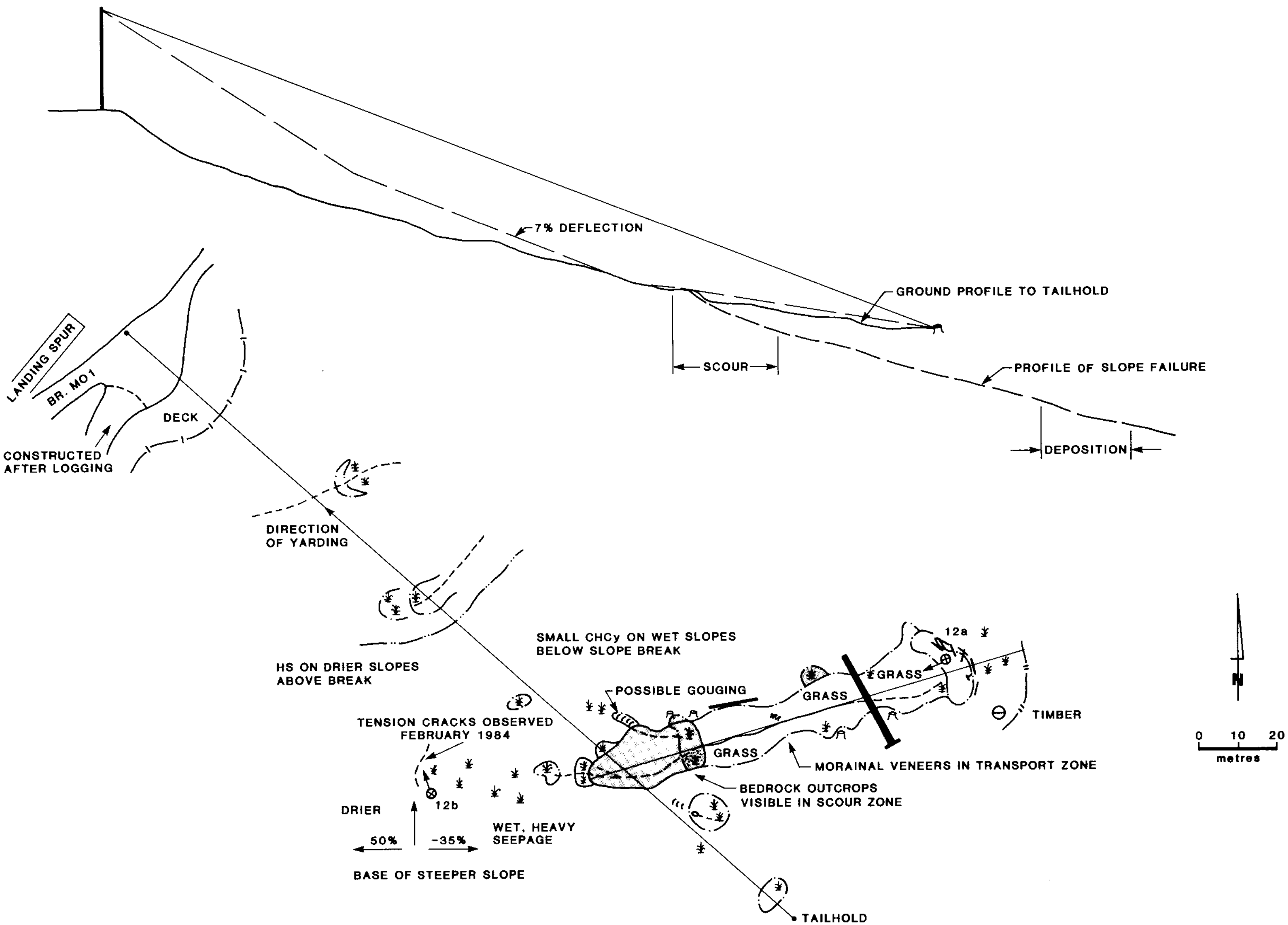


FIGURE A4.12. Example #12, MacMillan Creek.

FIGURE A4.12a. A view of Example #12, looking upslope from the deposition zone.

FIGURE A4.12b. Tension crack forming at the base of the steep hill side, above Example #12.

Factors Contributing to Failure

Yarding conditions were favourable, as the lack of yarding disturbance indicates. There is little reason to believe that yarding disturbance contributed significantly to this failure. A combination of natural factors and possibly root decay probably triggered this failure.

Suggestions for Prevention

No definite suggestions for preventing this particular failure can be recommended, since all logging factors appear favourable. The site features should warn engineers of potentially sensitive conditions--concave slopes at lower-slope positions, with abundant evidence of seepage discharge. This example shows that landslides can occur even on moderate (30-35%) slopes if conditions are unfavourable. When such sites are encountered, the engineer should lay the area out to ensure that deflection is adequate across the slope and that yarding roads avoid slope depressions where possible. As well, the use of backspars and scabline systems should be considered, if necessary, to minimize yarding disturbance. These measures cannot guarantee that failures will not occur, but they might reduce the likelihood of gouging and hangups and so reduce instability.

EXAMPLE #13: DEBRIS SLIDE/TORRENT ORIGINATING ON AN OPEN SLOPE

1. Landslide Description

a. Location	Above Alliford Bay Road near Sach's Creek, northern Moresby Island
b. Landslide Type	Open-slope debris slide entering a gully and triggering a debris torrent
c. Landslide Number	New
d. Location of Initiation Zone	Within-clearcut

2. Physical Dimensions

a. Area	0.952 ha
b. Volume	1368 m^3
c. Slope Gradient Near Initiation Zone	28° (54%)
d. Slope Shape Near Initiation Zone	Convex through and above initiation zone

3. Site Characteristics

a. Surficial Materials	Sandy colluvial veneer overlying sandy morainal blanket, with rock outcrops above headscarp
b. Site Drainage	Moderately to well-drained
c. Failure Surface	In morainal blanket in the upper part and on smooth outsloping bedrock in lower part of initiation zone
d. Bedrock Geology (from Sutherland Brown 1968)	Honna formation: Highly weathered and jointed, soft conglomerate with indistinct bedding

4. Suspected Cause or Contributing Factors	Heavy rainfall, possibly root deterioration, in combination with other site factors.

This failure extends almost 1 km to the beach at Skidegate Inlet. It was classified as an open-slope clearcut failure, due to unknown causes.

Slide Description

The failure, shown in Figure A4.13, started on a logged open slope, entered a gully about 20 m downslope, and was confined to a steep, V-notch gully through its transport zone (Figure A4.13a). The torrent affected more than 900 m of gully channel. Debris was deposited at the gully outlet (Figure A4.13b).

A sharp slope break was located 25 m above the headscarp. Slopes were 27% above the break and 54% below the break and into the initiation zone.

The failure began in a slope depression that extended up to the slope break and beyond. An old slide scar was visible above the initiation zone of this failure. A small amount of surface flow was evident above the headscarp 2-3 weeks after the failure had occurred, and subsurface seepage was heavy. When inspected in February 1984, seepage was flowing out of the initiation zone and along the rock surface. Despite the apparent wetness of the area, water flow in the gully was small. A nearby gully, which did not fail, had a substantially greater flow.

There was no sign of yarding disturbance around the initiation zone. Yarding direction was almost at right angles to the main axis of the failure (cross-slope yarding). Yarding roads must have passed above the slide and through its initiation and scour zones, but deflection at the slide site, which was midway along the yarding roads and about 100 m from the landing, was considered good. Regeneration on this clearcut was at least 10 years old.

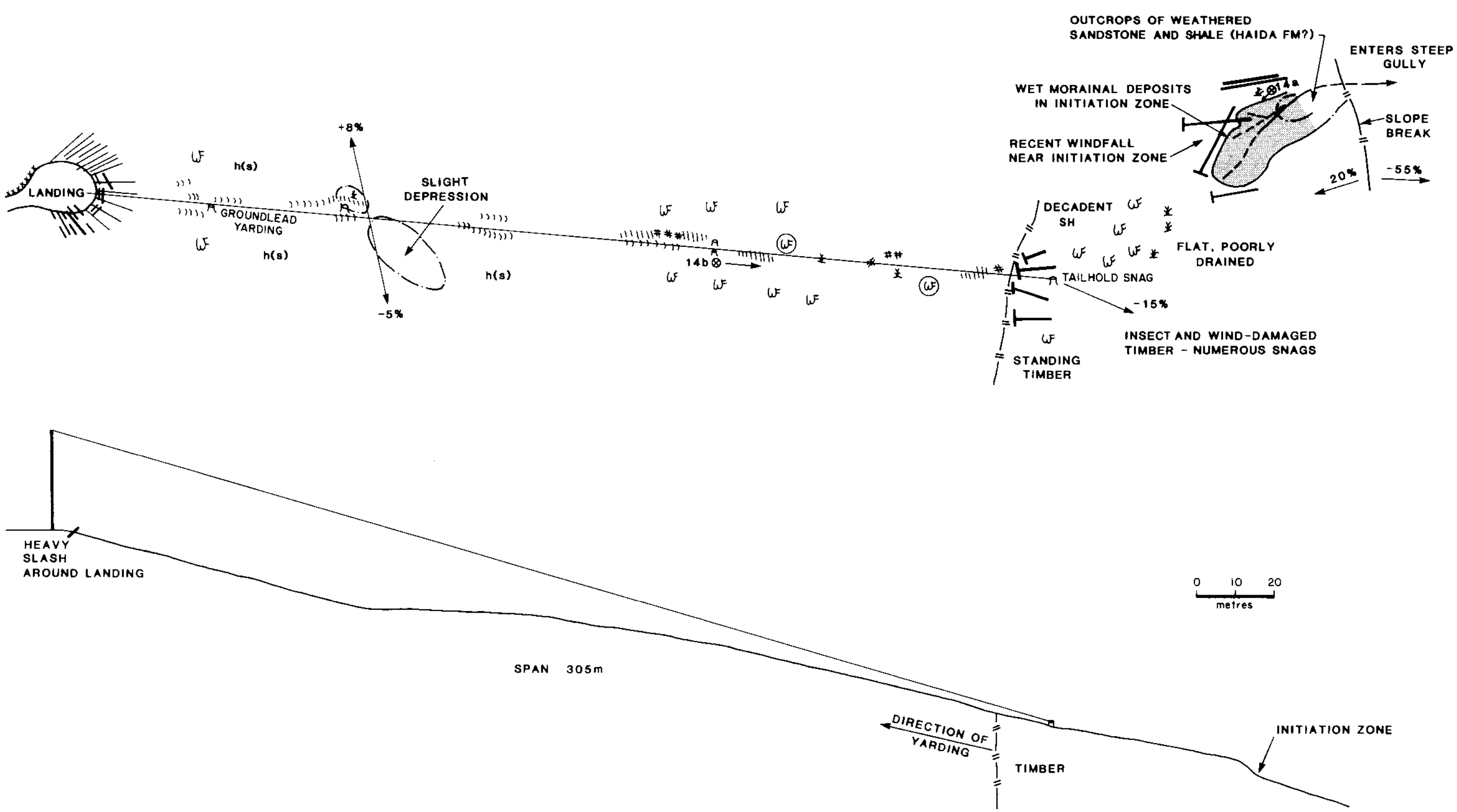


FIGURE A4.13. Diagram of Example #13, Alliford Bay Road near Sachs Creek.

FIGURE A4.13a. Looking across the clearcut to the initiation zone of Example #13.

FIGURE A4.13b. Looking down the gully channel, Example #13.

Factors Contributing to Failure

This failure was triggered by heavy rainfall during August 1983. An earthquake on July 31, 1983, may have contributed to the failure as well, although there is no evidence to suggest that it did. The lack of yarding disturbance and the 10-year lag between logging and failure indicates that yarding probably played a minor part at most. Root deterioration, combined with high rainfall, may have been an additional factor.

Suggestions for Prevention

Although much larger than other similar landslides, this failure was typical of most of the clearcut failures examined, in that there was no evidence to suggest that yarding contributed to its occurrence. It appears that this failure could not have been prevented by using alternative cable logging systems or by modifying yarding techniques (e.g., use of backspars to increase deflection). To prescribe specific prevention techniques, potential failure sites must be reliably identified during field reconnaissance; and while this may be possible in some cases (see examples #10 and #11), for many clearcut failures it does not seem feasible.

EXAMPLE #14: DEBRIS SLIDE/TORRENT ORIGINATING IN A WINDFALL AREA

1.	Landslide Description	
	a. Location	Vicinity of Alliford Bay, northern Moresby Island
	b. Landslide Type	Open-slope debris slide entering a gully and triggering a debris torrent
	c. Landslide Number	New
	d. Location of Initiation Zone	Open slope
2.	Physical Dimensions	
	a. Area	1.032 ha
	b. Volume	1168 m^3
	c. Slope Gradient Near Initiation Zone	36° (73%)
	d. Slope Shape Near Initiation Zone	Convex
3.	Site Characteristics	
	a. Surficial Materials	Organic veneer overlying sandy colluvial veneer, over dense, impermeable silty-sandy morainal blanket
	b. Site Drainage	Poor; at base of large depressional area
	c. Failure Surface	Morainal blanket
	d. Bedrock Geology (from Sutherland Brown 1968)	Haida formation (possibly): not visible in initiation zone
4.	Suspected Cause or Contributing Factors	Heavy rainfall, combined with loss in root strength over several years due to extensive blowdown?

This failure initiated in a stand of insect- and wind-damaged timber below a clearcut and scoured more than 2 km of gully channel. It was treated as a clearcut boundary failure.

Description

Figure A4.14 shows a diagram of the initiation zone and the clearcut area extending to the landing (see also Figure A4.14a). The failure originated on an open convex slope at the toe of a short steep (73%) pitch, about 50 m downslope of a tailhold stump, itself 15 m inside the timbered leave strip below the clearcut. The slope broke over to a gentle 20% sideslope above the headscarp. The initiation zone was at the base of a large depressional area that extended past a logging road more than 300 m upslope. Extensive insect and windthrow damage in the leave strip extended into the initiation zone (Figure A4.14b).

Factors Contributing to Failure

The failure occurred during a heavy rainfall in August 1983, several years after logging. Gradual root deterioration, combined with heavy rainfall, may have been the major contributing factors. Crown Forest Products recorded 65 mm of precipitation in 24 hours at its weather station, and the Department of Transport weather station at Sandspit, 35 km to the east, recorded 41 mm from the storm. The leave strip, including the gully headwall area, had suffered extensive blowdown since the area was logged.

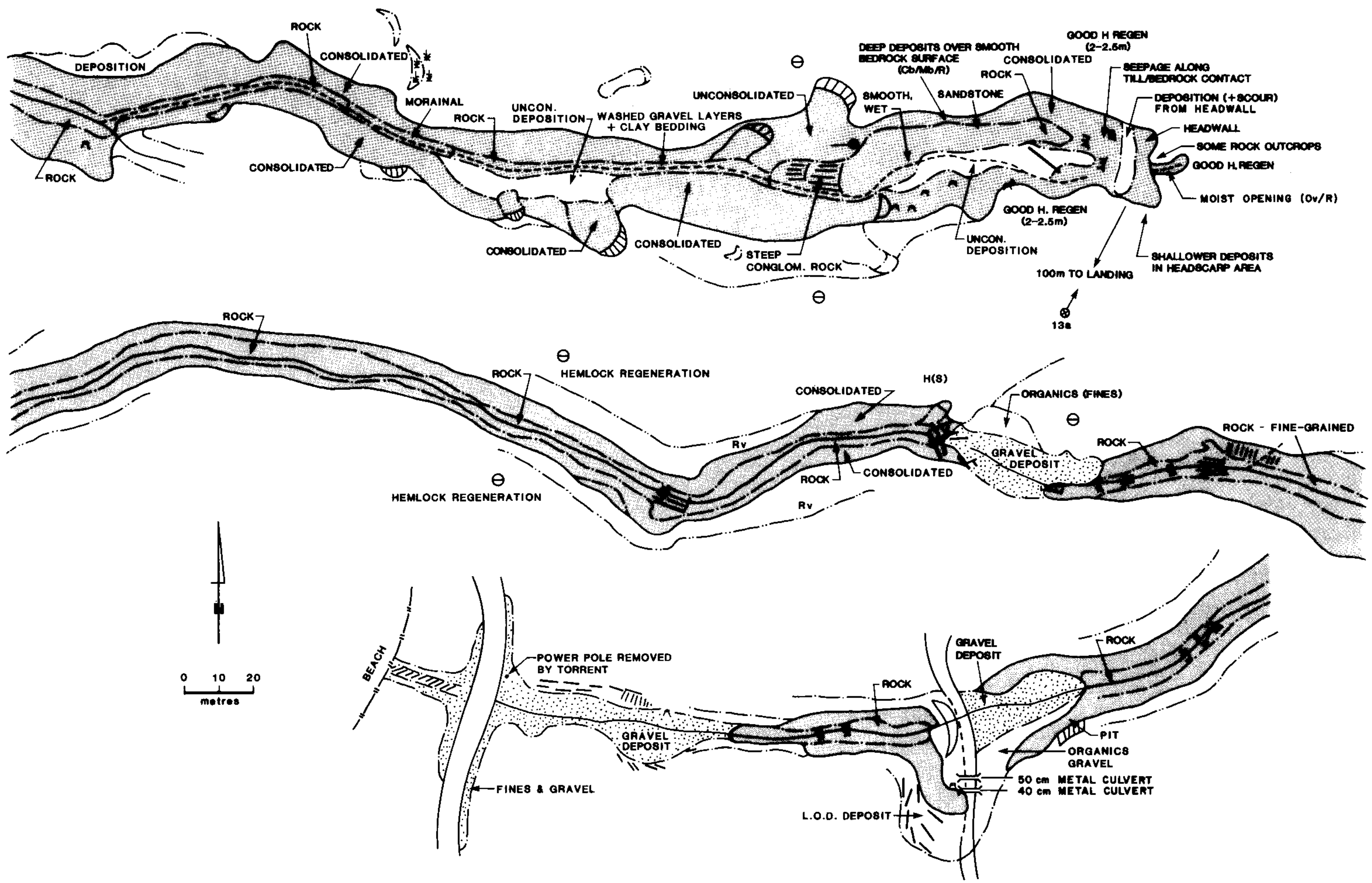


FIGURE A4.14. Diagram of Example #14, in Vicinity of Alliford Bay.

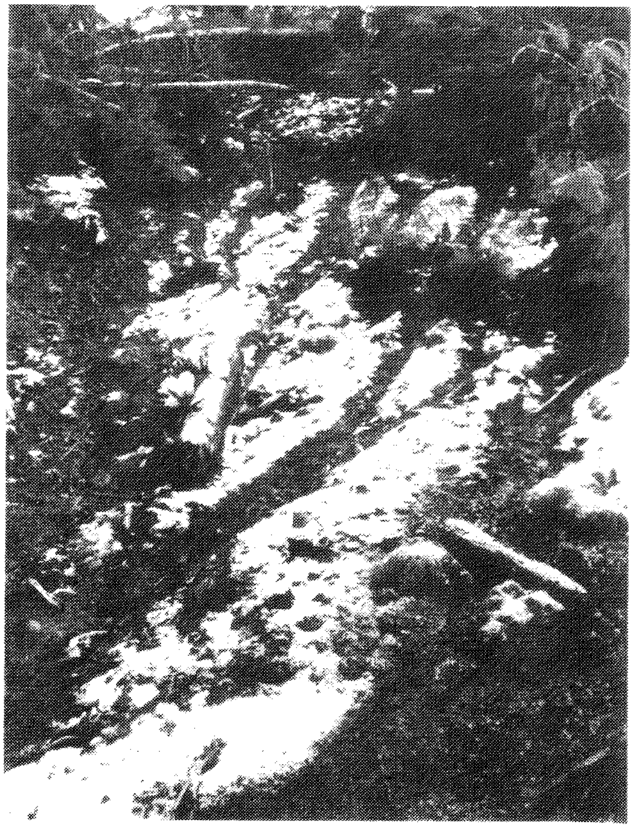


FIGURE A4.14a. The initiation zone of Example #14.

FIGURE A4.14b. Decadent insect- and wind-damaged stand in the initiation zone of Example #14.

Suggestions for Prevention

A combination of several factors probably influenced this failure: 1) the cutblock layout exposed the leave strip to excessive winds; 2) the boundaries were not windfirm; 3) insect damage may have weakened the stand and made it more susceptible to wind damage; and 4) there were unusually high winds. Because of the Islands' frequent high winds, establishing windfirm cutting boundaries is difficult and some blowdown can be expected along most boundaries. Without enough local experience, the authors of this report are unable to recommend revised cutblock patterns or identify better windfirm boundaries.

The decision to leave timber standing in the headwall region of a gully, where it will be exposed to storm winds when adjacent slopes are logged, is open to question. This practice invites windthrow in sensitive areas. An alternative approach in some situations might be to fell all tall trees in the headwall zone, yarding them out (or simply leaving them if yarding disturbance would be serious) and allowing smaller understory trees and saplings to remain, providing a network of live roots. Such a policy would have to be coupled with closer attention to cutblock layout and clearer guidelines for identifying windfirm sites.

EXAMPLE #15: DEBRIS SLIDE ORIGINATING AT A CLEARCUT BOUNDARY

1.	Landslide Description	
	a. Location	Talunkwan Island
	b. Landslide Type	Open-slope debris slides
	c. Landslide Number	FF8285-625-94/95, #1 & #2 (Rood 1984)
	d. Location of Initiation Zone	Clearcut boundary
2.	Physical Dimensions	
	a. Area	0.104 ha (combined)
	b. Volume	613 m^3 (combined)
	c. Slope Gradient Near Initiation Zone	40-45° (85-100%)
	d. Slope Shape Near Initiation Zone	Uniform to convex
3.	Site Characteristics	
	a. Surficial Materials	Rubbly-sandy colluvial veneers overlying denser colluvial blanket or bedrock
	b. Site Drainage	Rapidly drained shedding sites
	c. Failure Surface	Colluvium and bedrock
	d. Bedrock Geology (from Sutherland Brown 1968)	Masset formation (Dana facies): greenish, blue-grey breccia and massive, fine-grained volcanics
4.	Suspected Cause or Contributing Factors	Yarding disturbance on very steep slopes

Example #15 describes two adjacent debris slides.

Description

Figure A4.15 is a diagram of both failures. One failure initiated on open slopes on each side of a narrow rocky spur that jutted out into the clearcut. Failure #1 started at the base of a rock wall on a straight slope within a bowl-shaped area, and deposited debris on an upper road (Figure A4.15a). Failure #2 started on a convex slope, carried further downslope, crossed the upper and lower roads, and entered a creek. Some water was observed flowing on exposed rock nearby, but no surface or subsurface seepage was evident in the headscarp of either failure. A slope about 200 m long, from the crest of the ridge down to the failure sites, drained through the initiation zones.

The area was logged by highlead and the backline was stump-rigged. As a result, deflection at the backline was poor.

Factors Contributing to Failure

There was no evidence to suggest that yarding was particularly difficult near the clearcut boundary, but the failures might have removed any signs that were present. Tailhold stumps may have been pulled out or loosened during logging. Windfall at the upper boundary was slight and did not seem to be a factor in these failures. However, the failures are believed to have occurred several years after logging, so root deterioration is a possible logging-related factor, in combination with steep slopes and perhaps other factors.

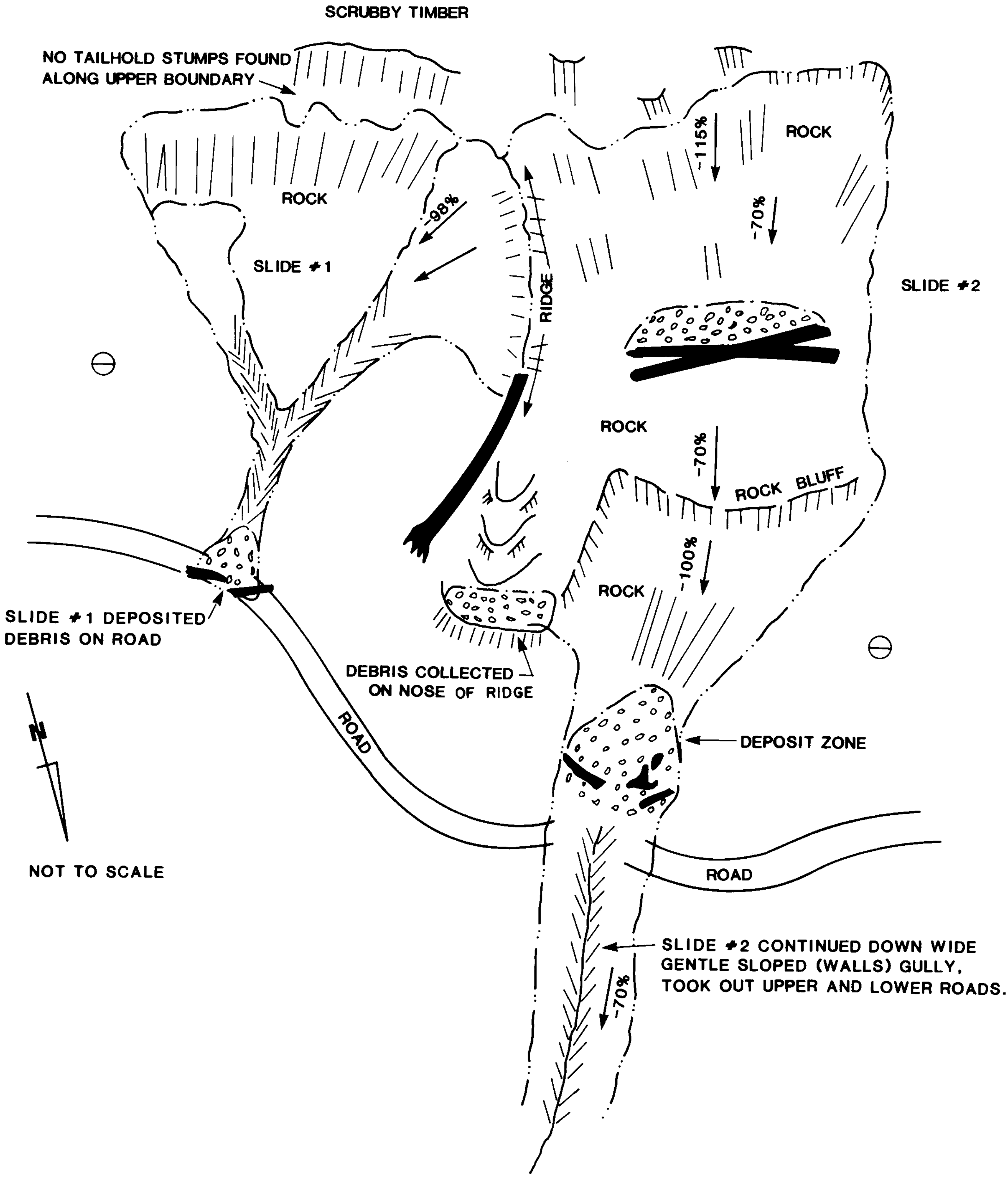


FIGURE A4.15. Example #15, Talunkwan Island

FIGURE A4.15a. Looking down Failure #1.

Suggestions for Prevention

It may not be possible to prevent failures when very steep slopes such as these are logged. The recommendations for logging are, therefore, very limited. In this case, the initiation zone occurred at a natural slope break that was a good location for the cutting boundary and apparently windfirm. Ground clearance at the back end would have been insufficient to avoid some yarding disturbance, even if backspars had been used. The timber was scrubby on the rock bluffs above, so trees suitable for backspars were scarce.

The failures might not have occurred if the cutting boundary had been located further downhill, but some merchantable timber would have been isolated. No general guidelines can be suggested for evaluating trade-offs of this sort. Decisions should be made on-site and should take into account: the likelihood that timber left will successfully prevent the failure from occurring; the value of the isolated timber; and the consequence to other resource values if a failure does occur.