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TERRAIN INVENTORY
FOR THE
CLAYOQUOT SOUND AREA

YEAR FOUR

for:

British Columbia Ministry of Sustainable
Resource Management

by:

MADRONE ENVIRONMENTAL SERVICES LTD.
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SUMMARY

This report is part of a terrain inventory conducted in the Clayoquot Sound area. To date, four years have been spent working on the inventory, and approximately 200,300 hectares have been mapped.

Work in Years One, Two, and Three (1996-99) was completed by Madrone Consultants Ltd. in partnership with EBA Engineering Consultants Ltd. and Hugh Hamilton Ltd. The inventory was completed under contract to the Ministry of Forests with funding from Forest Renewal British Columbia.

Work in Year Four (2002-03) was completed by Madrone Environmental Services Ltd. in partnership with Chartwell Consultants Ltd.; all under contract to the British Columbia Ministry of Sustainable Resource Management.

The main objective of the terrain inventory was to identify areas prone to geologic and geomorphic hazards, in particular, landslides, soil erosion, and sedimentation, as well as identify and characterize terrain conditions associated with these hazards. In addition, in Year Four sensitive soils were identified according to criteria previously established for the Clayoquot Sound area (Millard *et al.* 2002). This information can be used to designate soil reserves in the area.

A five-class Terrain Stability Classification system was used in which Class V terrain is the most unstable and Class I the least unstable. For this terrain mapping project, we utilized formal stability criteria based on the results of an extensive study of terrain attributes and past landsliding on logged terrain (Rollerson *et al.*, 1998).

In Year One, nine areas were mapped totaling 89,400 hectares, including Bedwell Sound, Bulson Creek, Catface, Flores Island, Fortune, Hesquiat Peninsula, Sydney River, Tofino Creek, and Tranquil Creek. In Year Two, five areas were mapped totaling 47,400 hectares, including Atleo, Hesquiat, Marble, Pretty Girl, and Ursus. In Year Three, two areas were mapped totaling 24,100 hectares, including Kennedy River and Muriel Ridge. The results of mapping in Years One, Two, and Three are presented in separate reports.

This report accompanies the maps produced for the Year Four portion of the multi-year project. In Year Four, three areas were mapped–Bedwell, Vargas Island, and Clayoquot River/Kennedy Lake–totaling 39,400 hectares. The report

includes a description of the physical environment of the area, mapping procedures, surficial materials present, terrain hazards identified, classification systems used, and management concerns for the project area. The maps and this report may be used to assist in development planning through the identification of unstable and potentially unstable terrain and sensitive soils prior to road construction and timber harvesting in an area.

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PROJECT INTRODUCTION

1.0 INTRODUCTION

Clayoquot Sound is an area of 2,546 km^2 (254,600 ha) located on the west coast of Vancouver Island. It is a landscape consisting of steep walled inlets, mountains, hills, lakes, and streams forming a highly rugged and spectacular area. Clayoquot Sound is famed for its scenery, recreational opportunities, wildlife viewing, and for its important place in native culture and history.

It is also famous as the site of conflicts between resource industries and those opposed to them. Clayoquot Sound has been the site of logging for decades, but in the early and mid 1990s, environmental and other groups have vociferously demanded the cessation or dramatic reduction in the rate of logging. World attention was focused on this conflict.

One outcome was the establishment of the Clayoquot Sound Scientific Panel for Sustainable Management in Clayoquot Sound (Anonymous 1995). The Panel's report recommended the best use of Clayoquot Sound's resources. That report has been touted as representing world class standards for resource management.

One of those standards was the recommendation that the area be mapped for terrain and terrain stability to enable resource management planners to identify and thereby avoid or specially manage potentially hazardous slopes. The past legacy of logging and landslides has contributed greatly to the conflict and left permanent scars on the landscape, as well as, the trust the public has toward the resource industry. We hope that accurate terrain and terrain stability mapping will assist resource managers in achieving their objectives in a way that will minimize the probability of future landslides, sedimentation, or soil erosion.

This report accompanies terrain and terrain stability maps produced in the Clayoquot Sound area. This submission represents the fourth part of a multi-year project to complete the terrain mapping for the entire Clayoquot Sound area (Figure 1). The terrain mapping forms one part of a larger endeavor to conduct resource mapping in the Clayoquot Sound area, which embraces the mapping of terrestrial ecosystems and hydroriparian corridors.

The objective of the terrain component of this project was to identify and map hazardous areas with respect to landslides and soil erosion prior to forest harvesting and to identify soils that will be sensitive to development in an area. Terrain is considered hazardous if it is prone to landsliding or if it is likely to

Figure 1

deliver sediment to streams following logging. Soils are considered to be sensitive for one of many criteria, including the inclusion in a fragile ecosystem or the likelihood that productivity will decline if disturbed.

Mapping has been completed at a scale of 1:20,000, Terrain Survey Intensity Level C (minimum of 35% polygons field checked). Three separate maps are provided for each of the areas, Bedwell, Vargas Island, and Clayoquot/Kennedy, showing terrain, terrain stability, soil erosion potential, landslide-induced stream sedimentation, and sensitive soils.

The terrain and terrain stability maps are based on air photo interpretation with field checking, primarily by foot traverse, supplemented with limited helicopter reconnaissance. The sensitive soils maps are produced by manipulating the terrain map data in ArcView.

The terrain, terrain stability maps, as well as derived maps depicting soil sensitivity can be used to plan road and cutblock locations, prioritize areas for further field review and to identify areas where increased intensity of watershed management is necessary. The maps should not be used for making site-specific decisions concerning logging or other development activities.

2.0 METHODS

Terrain mapping and the assessment of terrain stability, soil erosion potential, landslide-induced stream sedimentation, and sensitive soils involve four stages:

- Air photo interpretation and the delineation of terrain unit polygons (i.e., 'pre-typing').
- Field checking to confirm or modify labels and line work completed during Stage 1.
- Air photo correction, review, and monorestitution.
- Identification of sensitive soils in ArcView GIS.

Terrain stability mapping methodology follows the *Guidelines and Standards for Terrain Mapping in British Columbia* (Resources Inventory Committee 1996) and *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests 1999). The terrain classification used follows see *Terrain Classification Systems for British Columbia* (Howes and Kenk 1997).

2.1 Air Photo Interpretation

The first stage of mapping involved pre-typing/ interpretation of color air photos taken in 1996 at a scale of approximately 1:17,000. Full stereo coverage was obtained for the Year Four project areas. Air photos were organized by flight line, north arrows and project area boundaries were delineated on the photos, coordination points were identified, and "boxing" of the edges was completed to allow matching between adjacent photos and flight lines. Only every second photo was used for pre-typing.

Terrain polygons were delineated on the air photos with ink pens. Interpreting the terrain from air photos is an acquired skill, which relies on the interpreter's experience with the area and knowledge of glacial geomorphology. We rely on a three-dimensional view of the ground to interpret slope gradient, shape, position relative to the landscape, cover textures, and evidence of slope processes such as landslides, gullying, avalanche tracks, fan deposition, or avulsing channels. Lines are drawn around areas of relatively homogeneous terrain creating polygons that represent visible slope facets, distinct landforms or areas exhibiting certain processes such as gullying or snow avalanching. The minimum size of our polygons was 1 cm^2 or about 4 ha on a 1:20,000-scale map.

Although we attempt to distinguish "pure" map units containing only one terrain unit, in some cases, polygons include a mixture of terrain types, for example, colluvial veneers (*Cv*) and steep bedrock outcrops (*Rs*). Because it is impossible at this scale to map most individual outcrops, this was mapped as a complex of the two terrain units (e.g., *Cv/Rs*). In some cases, complexes of three units may appear. Where polygons contain complexes, we have rated the terrain stability of the most hazardous component.

Each polygon was assigned a terrain label following Howes & Kenk (1997) and a label for soil drainage (Table 1). Soil drainage class refers to the speed and extent to which water is removed from a soil in relation to additions.

Based on the pre-typing, areas were identified for field checking. These include landscape features of typically high terrain hazards, steep slopes, landslides, seepage zones, and areas where there was uncertainty in the terrain label.

Table 1. Soil Drainage Classification

Code	Definition
r	rapidly drained
w	well drained
m	moderately well drained
i	imperfectly drained
p	poorly drained
v	very poorly drained

2.2 Field Checks

The second stage of mapping involved the field inspection of a sample of polygons. As per the project contract, Terrain Survey Intensity Level C was required, with ground checking of a minimum of 35% of the polygons (BC Ministry of Forests 1999). Ground traverses were planned so that terrain identified during pre-typing was inspected and that the required number of polygons were ground checked (based on a preliminary estimation of average polygon size and project area size). Traverses were planned so that a maximum area of unstable or potentially unstable terrain was inspected. On the photos, we identified areas of access including non-deactivated logging roads and helicopter landing areas. The ruggedness and extensive forested cover in the Clayoquot Sound area restricts the number of appropriate landing spots. Nevertheless, by using a combination of a helicopter and trucks, we were able to meet these sampling requirements.

Once in the field, we dug soil pits or described soil in exposures created by windthrow, road cuts, gully sidewalls, and landslide scars. The location of each of the observation points was recorded on the air photo and later digitally captured during the monorestitution of the line work. The location of each plot is displayed on the terrain, terrain stability, and soils maps.

For each polygon inspected, one of three types of plots was made: detailed, reconnaissance, or visual. Information collected was recorded on terrain field cards. We used standard forms, a copy of which is included in Appendix II.

For a *detailed* plot, information for several terrain attributes was collected, including surficial material, texture, slope gradient, slope shape and position, soil drainage, vegetative cover, bedrock type and presence of outcrops, active geomorphic processes, and evidence of instability. Evidence of instability may include recent or historic landslide scars; tension cracks; or leaning, jackstrawed, fallen, or scarred trees. Interpretations of terrain stability and soil erosion potential were made and a rating for each of these was assigned. Seepage, an important factor in terrain stability, was assessed by the presence of hydrophytic vegetation such as devil's club (*Oplopanax horridus*) and lady fern (*Athyrium felix-femina*). Soil creep was assessed by the degree of tree-stem deformation (that was caused by creeping soil but not snow or other external factors) and the presence of fresh colluvium on the ground surface.

Information gathered for a *reconnaissance* plot includes surficial material, soil drainage, slope gradient, terrain stability, and soil erosion potential. *Visual* plots were recorded when nearby polygons were viewed from a vantage point. In most cases, information recorded for these plots was limited to surficial material and an interpretation of terrain stability. Visual plots were used only for obvious terrain features (i.e., easily identifiable across a valley or from a helicopter) and include floodplains, bedrock outcrops, and colluvial cones.

Preliminary fieldwork was conducted April 7-14, 2002 with two teams of two based out of Ucluelet. This work was truck access only and was therefore restricted to the southern half of the Clayoquot/Kennedy project area. Access to much of the roaded terrain in this area was limited because of deactivation (e.g., crossing structures removed, berms blocked access) and because of recent landslides intersecting roads, resulting in impossible or unsafe driving conditions

(Photo 1). The remainder of the fieldwork was completed June 26-July 4, 2002 with four teams of two based out of Tofino. Two trucks and a helicopter were used to complete this work.

Photo 1

Road recently fully deactivated in Clayoquot River/Kennedy Lake project area.

Numerous openings were available for helicopter landing sites including alpine areas, organic openings, bedrock outcrops, roads, and landslide deposition zones (Photo 2). For those areas inaccessible (e.g., lack of landing spots, treacherous slopes), the ground traverses for the Bedwell and Clayoquot/Kennedy project areas were supplemented with a low-level helicopter traverse. During these flights, inaccessible areas were inspected and oblique air photographs were taken of slopes not traversed. Landslides not inspected on the ground were viewed and initiation zone surficial materials were identified as best as possible.

The field teams faced many challenges along the traverses, including extremely dense vegetation, bedrock bluffs, wild animals, deep bedrock gorges, recent landslides with oversteepened unsafe slopes, and fast-moving watercourses. (Photo 3). Safety was always of the utmost importance.

Photo 2

Rocky ridgeline used for morning helicopter drop off in the Bedwell project area.

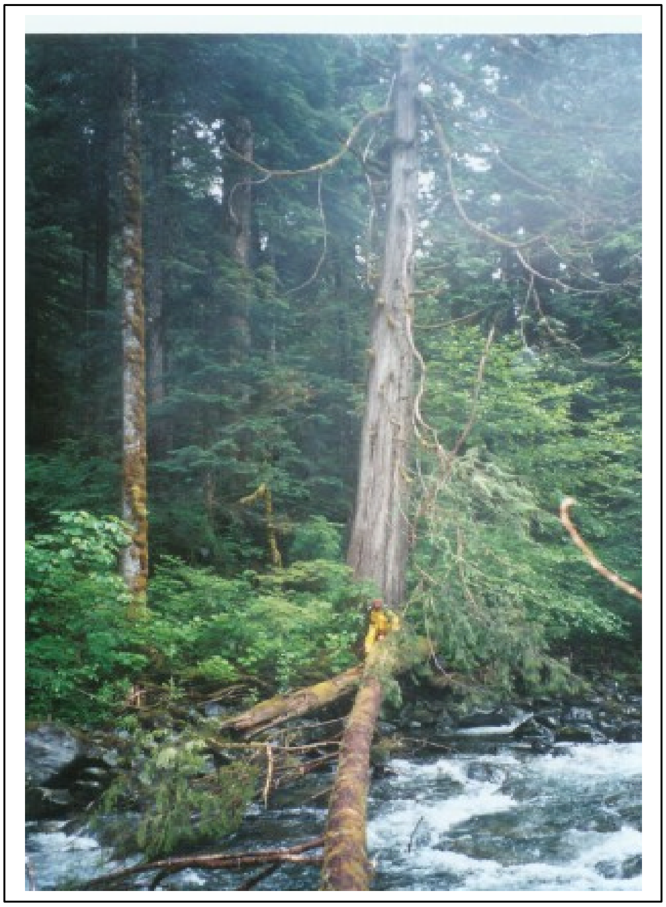

Photo 3

Finding a safe crossing of the larger creeks was often challenging.

Traverse maps (Figures 2a, 2b and 2c) show the spatial distribution of the ground traverses, as well as the mapped Class IV, and V terrain. The traverses were evenly distributed throughout the project area, and much of the unstable or potentially unstable terrain was inspected on the ground. Sampling intensity was low for terrain with steep bedrock slopes and moderate to high in all other areas. We reviewed the air photos after each traverse, to confirm that the terrain inspected along each traverse was representative of the surrounding terrain.

2.3 Air Photo Correction, Review, and Monorestitution

The final stage of mapping involved completing the labels for each polygon and adding, modifying, or deleting polygons and the associated label based on observations made during the fieldwork. During this stage, slope range (in degrees), terrain stability class (Table 3), soil erosion potential class (Table 4), and landslide-induced stream sedimentation interpretations (Table 6) were added to complete each polygon label. In addition, terrain labels or line work were corrected where necessary and information was added (e.g., surficial material texture) based on the field observations. In complex terrain (e.g., hummocky), two slope ranges may be assigned (e.g., 10-20, 30-35). Terrain stability, soil erosion potential, and landslide-induced stream sedimentation ratings are interpretations based on observations made. Details of these interpretations are described in Section 5.0.

With the line work and labels finalized, the mapping was reviewed in-house by Gordon Butt, *M.Sc., P.Geo.* Line work and labels were adjusted accordingly and the air photos were sent to Terry Rollerson, *P.Geo.*, of Golder Associates Ltd. for external quality control review. Upon approval of the mapping by the Mr. Rollerson, the edited line work was digitized using monorestitution software. This is a computerized process in which distortion and tilt in the photos are digitally corrected and line work is transferred to a 1:20,000-scale TRIM base. The final product is a planimetrically correct map showing the location of the polygon line work.

To ensure maximum accuracy, the control points were cascaded from the typed air photos to the original 1:60,000 photos used to generate the TRIM files. The cascade control was done under contract to Chartwell Consultants Ltd. At the same time, polygon labels were entered into a standardized terrain database and this information was linked to the digital maps for the final digital product of labeled terrain maps and terrain stability maps. A final step at this stage was to complete a final edit of the labeled polygons by comparing the work on the air photos to the terrain and terrain stability maps.

2.4 Identification of Sensitive Soils in ArcView GIS

Using the criteria established by Millard *et al.* (2002), a GIS analysis in ArcView was conducted and a layer of data generated identifying the two classes (Table 7) used for sensitive soils designation. The results of the analysis are presented on a separate map from the terrain and terrain stability maps and are discussed in this report in the details for each project area.

2.5 Reliability

The terrain maps are presented at a scale of 1:20,000 and are based on air photos with an average scale of 1:17,000. The air photo scale is suitable for the map scale produced, as polygon size and density represents the complexity of the landscape.

The mapping of surficial materials is based on experience in air photo interpretation, field observations, and knowledge of geomorphic processes and the Quaternary history of the Clayoquot Sound project area. Many of the slopes in the project area are covered with dense vegetation and are mantled by a complex of materials. Identification of the surficial material, along with deposit depth and material distribution, was based on evidence from the surface, shallow soil pits, soil exposed by windthrow, streams and riverbanks, gully sidewalls, and landslide scars. No subsurface drilling or boring was done.

The reliability of the mapping can be represented by the number of polygons field checked, the percentage of polygons checked, and the percentage of total area (in ha) checked. This information is summarized for the project area in Tables 8, 11, and 14. Visual plots supplement the detailed and reconnaissance plots and are not counted in the total number of polygons field checked. The field-checked values in all three of the sub-areas of this project fall well within the appropriate range for Terrain Survey Intensity Level C as defined in the *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests 1999) and they exceed the contractual requirement of a minimum of 35% of the polygons checked.

3.0 PHYSICAL ENVIRONMENT

3.1 Physiography

Clayoquot Sound is a complex region of inlets and bays set in a rugged area of western Vancouver Island. In his physiographic classification of British Columbia, Holland (1976) places the area in the Insular Mountains unit. The lowlands forming the western extremities of the area, including the Hesquiat Plateau, Vargas Island, and the Tofino-Ucluelet Lowlands, lie within the Estevan Coastal Plain. The more mountainous interior portions of the Sound are part of the Vancouver Island Ranges - a sub-unit of the Vancouver Island Mountains. Yorath and Nasmith (1995) recognize this area as the West Vancouver Island Fiordland physiographic subdivision - an apt term for this area of mountain ridges and sinuous fiords.

The Estevan Coastal Plain is a narrow strip of subdued terrain mostly less than 50 m in elevation stretching discontinuously along the west coast of Vancouver Island. For most of its length, it is less than 5 km wide, but at the Hesquiat Peninsula, it reaches 12 km in width. In places, it contains steep sided hills, which protrude above the surrounding plain; Radar Hill south of Tofino is one such example (Yorath and Nasmith, 1995). The plain is covered with glaciomarine/glaciofluvial sediments deposited during a time of raised sea levels at the end of glaciation in the form of shallow sea sediments or deltaic sequences of silts, sands, and coarser material. In places, local ice advances deposited tills stratigraphically above or in place of marine sediments. The coastline is mainly rocky with some intermittent crescent beaches formed between rocky headlands. The portion of the Estevan Coastal Plain between Tofino and Ucluelet is considered by Holland to be a remnant of a late Tertiary erosion surface.

The Vancouver Island Ranges physiographic unit of Holland (1976) forms the northwesterly trending backbone of the Island. Although not the tallest mountains on Vancouver Island, peaks in the map area typically reach over 1,500 m elevation. This unit contains numerous inlets or fiords that form deep cuts into the mountain range. They appear to be true fiords representing ancient river valleys that have been deepened and widened by glaciation during the Pleistocene Epoch. Characteristically, they have steep valley walls, which tend to drop directly into the inlet waters. Most follow bedrock structural features and trend north to northeast except for Sydney, the straightest of the inlets, which trends northwest by north. Several of the larger rivers have a distinct east-west trend in some reaches; good examples are the Megin, Bedwell, and Ursus Rivers.

3.2 Climate

Established climate stations that represent Clayoquot Sound are located at Ucluelet Kennedy Camp, Tofino Airport, and Estevan Point. All are located at elevations under 50 m and represent the climate of the Estevan Coastal Plain but not the Vancouver Island Ranges that form the main part of the Clayoquot Sound area. There are intermittent records from areas covering shorter time intervals (e. g., Henderson Lake, Clayoquot Lake), but long-term climatic data from the mountains are lacking.

The data we do have suggest strong orographic effects resulting in higher average and more intense rainfall in the mountains compared to the coastal plain - an effect that appears to disappear eastward of the main axis of the Vancouver Island Ranges.

Thus, the record of Henderson Lake (about 25 km east of Kennedy Lake and near the axis of the Vancouver Island Ranges) set rainfall records for Canada both for yearly precipitation (8123 mm in 1931) and for wettest month (2019 mm in December 1923); whereas, only about 35 km further east, Port Alberni shows a moderate 1886 mm yearly average.

The trend in rainfall intensity is apparently similar. The maximum 24-hour precipitation values at Tofino, Ucluelet, and Estevan are 184.2, 185.1, and 218.9 mm (Atmospheric Environment Service 1993a). In contrast, at the Brynmor Mines in the mountains behind Ucluelet, intensity records for B.C. were set for 2 hours (70.9 mm), 6 hours (139.4 mm), and 24 hours (489 mm) (Phillips 1990). The effect of orographic influence on precipitation is also noted in the “Landslide Inventory” (EBA 1997), which discovered that there was an increase in the landslide frequency with increasing distance from the sea in the Clayoquot Sound area.

Annual precipitation totals at Tofino, Ucluelet, and Estevan are 3285, 3356, and 3180 mm. Of this, about 10% to 15% falls as snow - a proportion that increases with elevation and distance from the coast (Atmospheric Environment Service 1993a). Above 300 m elevation, rain-on-snow events occur between October and April and may generate the highest instantaneous stream discharges of the year.

If the trends in monthly rainfall over the year at Tofino, Ucluelet, and Estevan are representative of the Sound, then there is a marked seasonality. About three-quarters of the total rainfall occurs in the six month period between October and March, inclusive. The ratio of highest monthly rainfall to the lowest is about 5.5.

The wettest months are November, December, and January. The relatively low rainfall period in the summer months come to an end in late September or early October. By the end of October, the area is typically buffeted by an unrelenting series of large low-pressure cyclonic systems moving on-shore from the Pacific. Each of these storms brings heavy precipitation and, commonly, strong winds.

We believe that embedded within these large storms are cells of highly intense rainfall that may generate large volumes of water in short time periods. One or more of these cells may be responsible for the astonishing records at Brynmor Mines. These cells may have a short life span as they travel across the landscape but could be highly influential in triggering clusters of landslides under certain circumstances. Furthermore, their localized distribution makes them difficult to detect in the sparse rainfall gauge network.

At Tofino Airport and Estevan Point, the annual average temperature is 9.0°C and 9.2°C - among the mildest in Canada. Winters are relatively mild, and climate stations in the lowland areas of the Clayoquot Sound area are frequently the warmest places in the country during January and February. Summers are correspondingly cool compared to more interior locations on Vancouver Island (for example, in Port Alberni, July daytime temperatures can be 15°C warmer than at Tofino). The lowlands and inlets are cooled by maritime winds, but more importantly, during July and August are commonly blanketed by morning advective fog, which may not disperse until mid-day. For example, at Tofino Airport, the months of July through October are the foggiest with an average of about 12 days per month (Atmospheric Environment Service 1993b).

The main effect of the mild temperatures is to minimize the depth and duration of snow packs at lower elevations where the ground is essentially snow-free all year. On average, Tofino and Estevan have only 12 and 13 days with measurable snowfall, and the corresponding figure for Ucluelet is 9 days (Atmospheric Environment Service 1993a). These values are also among the lowest in Canada. Both snowpack depth and duration increase with increasing elevation to the extent that in places along the eastern boundary of the project area, there is evidence of localized snow avalanche activity.

3.3 Hydrology

The Clayoquot Sound area contains several large rivers that drain the Vancouver Island Ranges. These rivers flow into the sea at or near the head of sheltered inlets, which deeply penetrate into the Fiordland region. Moyeha, Megin, Bedwell, Ursus, and Kennedy are the largest rivers draining large, highly mountainous catchment areas that extend well beyond the Clayoquot Sound project area. Sydney, Clayoquot, Tranquil, Cypre, and Bulson watersheds are smaller in size comprising areas mainly within Clayoquot Sound. These watersheds drain areas of intermediate relief with lower average elevations than the larger rivers. Tofino, Cotter, Watta, and Pretty Girl form smaller watercourses less than 5,000 ha.

There are no well-established stream gauging stations in the project area. The nearest and most representative are Sarita River, Carnation Creek, and the Ucona River (Laird in Madrone 1991). All three are located on the west coast of the Island; Sarita and Carnation to the south and Ucona, which drains into Gold River, is just to the north. Sarita and Carnation drain mainly forested, low elevation catchments. Sarita, with a catchment of 16,200 ha on moderate-relief terrain up to 950 m elevation, is probably representative of intermediate drainages in the project area such as the Megin and Bulson and, to a lesser extent, Clayoquot River, Ursus, Tranquil, and Sydney (although Ursus lacks lakes). The Ucona River drains 18,500 ha in mountainous terrain up to 1,800 m elevation. It therefore has a much higher snowpack contribution to streamflow. It is probably representative of the Moyeha and, to a lesser extent, the smaller Bedwell River and more subdued Kennedy River. Carnation is a well studied watershed of 10,100 ha of low elevation terrain (less than 700 m). It will be representative of watercourses such as the Cypre River. Table 2 lists the major drainages in the Sound and their similarity to gauged rivers.

Table 2. Major Drainages in the Clayoquot Area

Drainage	Approx. Area (km^2)	Max. Elevation	Lake(s)	Floodplain	Similarities To
Kennedy River	229	1515	Small	Yes	Ucona
Clayoquot	50	1300	Yes	Lower	Sarita
Tofino Creek	42	1360	No	Mid-valley	Sarita
Tranquil Creek	65	1200	Yes	Lower	Sarita
Bulson Creek	81	1400	Yes	No	Sarita
Bedwell River	212	1850	No	Lower	Ucona
Cypre River	58	1150	No	Lower	Sarita
Moyeha River	181	1800	No	Lower	Ucona
Cotter Creek	31	1500	No	Lower	Carnation
Megin River	254	1750	Yes	Lower	Ucona
Watta Creek	38	1450	Yes	Short	Carnation/
Sydney River	65	1200	Yes	Short	Sarita
Pretty Girl	45	1100	Yes	Lower	Sarita/

All the gauged drainages show the highest mean monthly discharges (and instantaneous flows) during the winter months, namely, between October and February. The Ucona River also shows high monthly discharges during the months of May and June reflecting the influence of snow melt from higher elevations. Because of its size, presence of late-lying and persistent snowpack, and heterogeneity of terrain, the Ucona shows less variation between the highest monthly discharge and the lowest monthly discharge. The Moyeha River can be expected to have a similar pattern.

The Sarita contains relatively little high elevation ground in its watershed, and, consequently, the main contribution to streamflow is rainfall rather than snow melt. Hence, the highest discharges are in the winter months with pronounced low flows in the summer and early fall period. The system is buffered to some extent by lakes and a relatively large area. The response of streamflow to storm precipitation is somewhat muted; although, protracted rainfall in a succession of winter storms may still produce large discharges. However, very low summer flows are characteristic and can be expected to occur in most of the medium sized and smaller drainages in the Clayoquot Sound area.

Carnation Creek contains lower elevations, and its hydrology is almost completely dominated by rainfall rather than snow melt. Lacking storage elements (e.g., lakes, extensive floodplains, and wetlands), its streamflow has a relatively fast response to storm precipitation (Hartman and Scrivener 1990).

We can expect streams such as Cypre, Watta, and Cotter to have similar responses.

With its rugged relief, steep slopes, and high precipitation, the Clayoquot Sound area is geomorphically active. Despite extensive forested cover, there is a high rate of sediment transfer from hillslopes to streams and rivers. Based on data from Carnation, Laird (Madrone 1991) has estimated that natural sediment yields in the Clayoquot Sound area watersheds will equal or exceed 0.5 tonnes/per ha/per year. Most of this sediment will be generated during the late fall and winter months associated with peak discharges. Although in the larger systems much of the suspended sediment yield will be contributed from bank and channel bed erosion, landslides reaching stream channels form an important local contribution. The landslide inventory (EBA 1997) confirmed that logging activity increases the rate of landslides over natural rates by a factor of nine. This will undoubtedly have a dramatic effect on sediment supply rates.

3.4 Glacial History and Surficial Materials

Much of the present appearance of the landscape is due to the glaciation during the Pleistocene Epoch of which the latest major glaciation, the Fraser (or Late Wisconsin), has left the most extensive and readily identifiable evidence. The Fraser Glaciation commenced about 29,000 years ago reaching its maximum extent about 15,000 years ago (Yorath and Nasmith 1995). Initially, the glacial advance on Vancouver Island consisted of alpine glaciers that in places expanded and coalesced into some of the larger valleys such as the Cowichan. By about 19,000 years ago, glacial ice of the Cordilleran Ice Sheet on the mainland began to cross the Georgia Trough and extended across Vancouver Island. In the project area, the main direction of ice movement was southwesterly (Alley and Chatwin 1979).

According to Holland (1976), the terrain below about 1,200 m was affected by ice of the Cordilleran Sheet. Mountain peaks above this elevation were sculpted by local alpine glaciers. In general, peaks above this elevation tend to be more rugged than lower peaks. In any case, it appears that the total thickness of ice was considerably lower here than in the interior of the Island and on its eastern side.

The thickness of the ice sheet was probably at least 1,555 m in the Beaufort Range (Fyles 1963) but was thinner on the west coast, probably dropping to 800 to 1,000 m. Clague *et al.* (1981) set the 500 m surface contour for ice thickness at the Fraser Maximum (14,500 to 15,000 years ago) just off-shore beyond the Estevan Coast Plain. Presumably, the ice extended as a shelf into the Pacific. The weight of the ice in the project area depressed the land by approximately 50 m relative to the sea level at the time compared to up to 120 m along the Georgia Straight shoreline (Yorath and Nasmith 1995). Clague *et al.* (1981) report maximum late Pleistocene marine transgression to be about 32 to 34 m at Hesquiat Harbour. The ice began to wane about 13,000 years ago and despite several small re-advances was essentially gone by about 10,000 years ago.

With the onset of deglaciation, a redistribution of many of the glacial materials began via fluvial and mass movement processes. In general, gullies are incised in bedrock on the upper slopes (these may be in part pre-glacial) and in morainal, colluvial, fluvial and glaciofluvial deposits on the lower and mid slopes. Sediment is entrained and transported downstream in the gullies to the streams in the area, where most of the material is sorted and deposited as fluvial sediments. Debris slides, debris flows, and debris torrents (i.e.: channelized debris flows and/or debris floods) that initiate on the upper or mid slopes rework the entrained materials and deposit them on the lower slopes in colluvial cones and fans and streams. This redistribution of material is ongoing throughout the area.

Evidence of glaciation lies in the shape of the valleys and fjords, presence of sharp aretes, striations and grooves in exposed bedrock, and in the nature of the surficial deposits throughout the project area. The accumulation, movement and later melting of glacial ice deposited extensive sediments on the landscape in the form of morainal (or till), glaciofluvial, and, to a lesser extent, glaciolacustrine deposits.

Throughout the project area, the dominant surficial materials are morainal deposits. These materials cover the hillsides, valley bottoms, and coastline but in places may be buried by colluvium, fluvial, or other sediments. Secondary surficial materials include fluvial, glaciofluvial, and marine sediments and organics, which typically occur along valley floors and the coastline.

In general, the surficial materials in the area are deposited as a blanket (greater than 1 m) on the lower and mid slopes and taper to a veneer (less than 1 m) on the upper slopes. Many of the bedrock-controlled slopes lack any surficial material or are covered by only a thin veneer (less than 0.25 m) of mineral or organic soil. The deepest deposits are on the valley bottoms. Many of the terrain polygons are a complex of more than one type of material or a combination of bedrock and one or more materials.

3.4.1 Till

Morainal deposits (tills) are most commonly present as a blanket on mid-slopes where the surface of the deposits more or less conforms to the shape of the underlying bedrock. These landforms are mapped as Mb but are often complexed with shallower deposits (morainal veneer or *Mv*), exposed rock, or colluvial deposits.

On lower-valley sides, it is not uncommon to find thicker morainal deposits in which the surface does not reflect the underlying rock surface. These deep deposits are prone to post-glacial gullying or incision by down-cutting streams or rivers. The erosional scarps along gully sidewalls or alongside creeks or rivers tend to be subject to debris slides and slumps. Morainal materials (till) are common on upper slopes where they tend to be thin in the form of veneers (*Mv*) and where they are usually complexed with colluvial veneers (*Cv*) or steep, exposed rock (*Rs*).

Tills in the project area are generally poorly sorted consisting of a wide range of particle sizes including gravel, rubble, and boulders usually set within a matrix of finer-textured material (most often silty sand or sandy silt). The coarse fragment content varies from about 30% up to 70% and in most cases the dominant clast is the local bedrock. In other parts of Vancouver Island (Alley and Chatwin 1979), clasts imported from the Jurassic Coast Intrusives can be found indicating that Cordilleran Ice overrode the Island at some point in the last glaciation, but we cannot confirm that such rocks are found in the Clayoquot Sound area (since there is intrusive bedrock on Vancouver Island, and these rocks are hard to distinguish visually from those of mainland origin).

Till in the area exhibits reddish-brown to pale yellow colors within 1.0 m of the surface. This color is a result of the soil-forming process of podzolization that has taken place in the Holocene epoch. At the base of this upper horizon, there is commonly a sharp discontinuity above a greyish colored, relatively consolidated material. Many people know this as “hardpan”. This represents either an unweathered counterpart to the overlying material or a basal till deposited under the ice during its expansion phase. In the majority of cases, there is no difference in clast or fines content between the upper and lower deposits suggesting that post-glacial weathering is responsible for the difference and that the discontinuity is due to the present extent of a weathering front. In some cases, a difference exists suggesting that they are different materials and that the lower unit is a basal till. In either case, the lower unit represents a relatively impermeable material such that most groundwater flow is perched on its surface and most flow is confined to the weathered zone. Numerous landslide scars expose the surface of the unweathered tills suggesting that they commonly function as failure planes in the development of debris slides. The maximum rooting depth corresponds to the depth of the weathered soil in most places, which, in general, is less deep in till-derived soils than in soils derived from colluvium.

Most tills have been consolidated to some degree even though weathering in the upper 1 m may have reduced this effect. In general, erosional slopes in till stand at steeper gradients than in other unconsolidated materials such as fluvial or glaciofluvial sediments. The same is true for road-cuts.

3.4.2 Colluvium

Colluvium is defined as material in which gravity is the dominant process in transport and deposition. Colluvial landforms can be landslide deposits or talus, or they can be mantles deposited over morainal blankets that in turn overlie rock.

Colluvium occurs on some of the steeper slopes throughout the region and at the base of bedrock outcrops where slow or rapid downslope movements are dominant processes. It is present as blankets or veneers (*Cb, Cv*). On slopes between 50% and 80% colluvium may be complexed with morainal deposits (*Cv/Mw or Mw/Cw*). Colluvium commonly consists of subangular to angular rubble or blocks loosely set in a matrix of silty sand. This material is generally moderately well to well drained depending on the texture of the matrix. Coarse-textured colluvium or talus may be rapidly drained. Active colluvial slopes are often subject to intermittent rockfall or rock slide deposition, which in places can represent a hazard to forest workers.

Colluvial fans and cones are also present in the project area. These are common at the mouth of gullies where there is an abrupt slope gradient change between the gully channel and the adjacent valley bottom. The aggradation of these fans and cones would primarily be a result of rapid mass movements, such as debris flows.

3.4.3 Glaciofluvial

Glaciofluvial (*FGj, FGp*) sediments are found along the valley floor of many of the rivers in the project area. These deposits consist of moderately well sorted and stratified gravels and sands laid down by meltwater from ice during deglaciation. They can be massive (no structure) or bedded, and contain lenses of silt in places. These sediments are moderately well to well drained, but when exposed in steep, natural erosional scarps, they are subject to rapid failure and constant ravelling.

3.4.4 Fluvial

Fluvial deposits (*Fp, FAp, Ff*) are post-glacial (Holocene) deposits associated with active rivers and streams. Extensive floodplain deposits are present in the Clayoquot Sound area alongside major rivers such as the Sydney, Bedwell, and Moyeha especially in their lower reaches. In general, these are well-sorted sediments but vary in their specific texture. In some places, floodplains contain well-sorted gravels with intercalated sands. In others, floodplains contain finer sediments with decreasing grain size towards the surface (representing flood-deposited silts). Fluvial deposits can be active or inactive depending on their position relative to the modern stream or river. The distinction between active and inactive is not defined in quantitative terms (Howes and Kenk 1997). We have mapped floodplains with vegetative evidence of recurrent floods (e.g., sparsely vegetated gravel bars) as active; otherwise we have assumed an inactive status. This we believe is consistent with the definition provided in Howes and Kenk (1997).

Fans are common features forming at slope breaks along stream channels. By definition, fans have slope gradients up to 15°, above which they are “cones”. These fans are not necessarily fluvial in origin: steep fans (10 to 15°) are likely to have been constructed by debris flows, wherease lower gradient fans reflect debris-flood or mainly fluvial deposition. Fans vary in their stability; stable fans have entrenched stream channels with no evidence of recent avulsion. Geomorphically active fans show evidence of recent and recurrent stream avulsion with poorly incised channels. Both active and inactive fans are present in the project area.

Most fluvial sediments are prone to erosion as they are water-laid and contain highly detachable particles. Because they are generally located on gentle slopes, erosion under natural conditions is mainly confined to channel banks; however, as in every surficial material, accelerated erosion is possible with poor road drainage management.

3.4.5 Marine

Marine (*Wv*, *Wp*) deposits are present in numerous places along the coastline in the project area. These recent deposits are composed of sands, silts, and clays and include active beaches, as well as, relict beach deposits. The most extensive areas of marine deposits can be found in the Kennedy Flats area (in the southern portion of Clayoquot Sound southwest of Kennedy Lake), and on the Hesquiat Peninsula (in the northern portion) where air photos reveal a succession of beach ridges formed as the land surface gradually rises above sea level. Both archaeological and geological evidence point to emergence of the land relative to the sea of about 2 to 4 m in the last 4,000 years (Clague *et al.* 1981).

3.4.6 Glaciomarine

Glaciomarine (*WGp*) sediments were deposited during the last deglaciation when sea level was higher and when fine silts and clays were released from the melting of floating ice and ice shelves. Because they were deposited in near-shore marine environments under conditions of decaying ice shelves, these sediments are commonly compact deposits containing occasional coarser fragments originating as drop-stones or ice-rafted rocks. Glaciomarine deposits are confined to those parts of the project area below 50 m in elevation. They are uncommon in the Clayoquot Sound area and have been sparingly mapped; however, they may be more extensive but buried under more recent (ie: post-glacial) fluvial or organic deposits. Further north in the Escalante River, there are extensive glaciomarine deposits buried by more recent marine deltaic sands and silts. These are difficult to detect except where they are exposed in terrace scarps. Glaciomarine deposits are also known to occur along the eastern shore of Fortune Channel where they are visible in gully sidewalls and road cuts.

Certain glaciomarine deposits in northern British Columbia are “sensitive” in that their particle structure is highly prone to sudden collapse and subsequent liquefaction. In 1994 near Terrace, a mudslide occurred in glaciomarine sediments on a very gentle slope (Geertsema, and Schwab 1995). Although there is no evidence that sensitive sediments occur in the Clayoquot Sound area, there is the possibility that they are present but so far undiscovered and warrants very careful treatment of glaciomarine sediments.

3.4.7 Organics

Organic (*Ov*, *Op*) materials are found mainly associated with wetlands throughout the project area. Most are located in bogs where centuries of waterlogging in acid soil conditions have created anaerobic environments and slowed decomposition. This in turn has resulted in the accumulation of peaty materials (Sphagnum moss species). Bogs are also common along the margins of lakes, most of which are in the very gradual process of becoming bogs entirely as the peat accumulation encroaches on the open water. Bogs occur where precipitation is the most important form of water input. Where groundwater is predominant, a different kind of wetland – a "fen" – tends to form. The organics accumulating in these environments are formed from forb vegetation (sedges and rushes) and non-sphagnum mosses. This results in organic material less raw and acid than bog organics. Fens can be transitional to bogs where both precipitation and groundwater are significant contributors or where groundwater is low in dissolved salts. Some wetlands in the Clayoquot Sound area form on moderate slopes that are subject to continuous saturation. Here, the organics form a blanket (*Ob*) over other materials.

Organic soils have extremely poor bearing strengths and therefore are generally avoided in road construction. In addition, many wetlands have disproportionately high biodiversity values in the predominantly forested Clayoquot Sound area that further reduces the desirability of development activity.

3.5 Bedrock Geology

The Clayoquot Sound area is a complex assemblage of formations created by the accretion of terranes[1], a number of intrusions, and, lastly, accumulations of sedimentary rocks. Much of our information comes from Muller (1977) and Massey *et al.* (1994).

The main structural feature in the Clayoquot Sound area is the West Coast Fault, which runs northwest-southeast, parallel with the west coast of the Island. This is a deep fault thought to be a continuation of the San Juan Fault to the south and separates the older rocks of the Wrangellia Terrane (the main structural unit of the Island) from the younger sedimentary and volcanic rocks of the Pacific Rim Terrane (Yorath and Nasmith 1995).

The oldest rocks in the Clayoquot Sound area are members of the Paleozoic Sicker Group, which in the area consist mainly of metamorphosed sedimentary rocks such as greywacke and argillite. These rocks occur both east and west of Bedwell Sound at its southern limit, between Bedwell Sound and Herbert Inlet,

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[1] Defined by Yorath (1990) as "part of the earth's crust which preserve geological rocks different from those of neighbouring terraines."

and at the head of Herbert Inlet. Volcanic rocks of the Sicker Group also occur in the Clayoquot Sound area but appear to be rare. Rocks of the Sicker Group underlie about 9,400 ha or 4% of the total land area in the Sound. According to the Landslide Inventory in the area (EBA 1997), ground underlain by the Sicker Group has experienced a disproportionate number of landslides, almost twice the average landslide frequency. The reason for this is not clear, but EBA suspects that the reason may be due to factors other than the bedrock geology *per se*.

The most common rocks in the Clayoquot Sound area are members of the West Coast Complex, a group of mainly crystalline intrusive rocks of unclear age. Muller regards them as Jurassic. According to Muller, they are genetically related to the Jurassic Island Intrusives, which are also termed the Island Plutonic Suite according to the B. C. Ministry of Energy, Mines and Petroleum Resources Open File 1994-6. These two groups together account for about 46% of the land area in the Clayoquot Sound area or about 100,000 ha. These rocks in general are hard and competent and weather to a gravelly, silty sand or sand. The Island Intrusives also have higher than average landslide frequencies although not quite to the same extent as the Sicker Group.

Triassic volcanics of the Karmutsen Formation are the second most common rocks in the Clayoquot Sound area underlying about 72,000 ha or 33% of the land area. These are basaltic lavas generally forming moderately hard, competent rocks. Karmutsen rocks are the most common rocks on Vancouver Island, forming the core of the Wrangellia Terrane, which is the underpinning of Vancouver Island as well as the Queen Charlottes.

Rocks of the Quatsino Limestone have been observed in places in Clayoquot Sound, including west of the Clayoquot Arm of Kennedy Lake, east of Clayoquot River, and northeast of Kennedy Lake.

The most recent rocks are those of the Cenozoic Carmanah Group. These are sandstones, siltstones, and conglomerates and mainly underlie much of the flat or undulating terrain in the Estevan Coastal Plain. These rocks are thought to be members of the Pacific Rim Terrane, which collided with the west coast of Vancouver Island in the Tertiary period.

4.0 GEOMORPHIC PROCESSES

4.1 Debris Slides and Debris Flows

Debris slides and debris flows are rapid downslope movements of soil and organic materials. These are shallow, translational landslides in which failure occurs in weathered soil overlying a relatively impermeable plane - usually parallel to the ground surface. The failure plane is most commonly either a rock surface or the top of unweathered till.

Debris slides are distinguished from debris flows by the mechanism of movement after failure. Debris slides, although usually initiating in soil, move as a non-coherent mass of mixed clastic and organic material. Debris flows, as their name implies, move in a slurry with rheologic properties. Debris flows can be confined where a sidewall or headwall slide delivers debris into a channel (gully) in which conditions are conducive to the initiation and maintenance of flow. Unconfined debris flows may also occur in the Clayoquot Sound area where sufficient moisture is available to sustain the mobilized debris as a flow. In general, flows travel considerably farther than debris slides although the differences are not consistent. EBA (1997) found it difficult to distinguish debris flows from debris slides on air photos and thus lumped the two processes together in their analysis. In our mapping, we also had difficulty distinguishing open-slope debris flows from debris slides. Many, if not most, debris slides develop into debris flows except in very coarse materials (T. Rollerson, 2003, *pers.comm.*). Debris slides, i.e. those with no evidence of channelized flows, are denoted -R”s, and debris flows are denoted -R”d.

Debris flows may entrain soil and organic material as they travel. In addition, the materials expand in failure. Consequently, their final mass at deposition may be substantially larger than at initiation. Because of their often great travel distances (especially in confined environments), they often have significant effects on downstream resources.

Debris slides and debris flows occur on moderately steep or steep hillslopes where the forces acting downward on a slab of soil (e. g., the slope component of gravity) exceeds the forces maintaining the slab in place (e. g., the shear strength of the soil and the resistance to sliding along the failure plane). The ratio of these forces is called the Factor of Safety (FS)[2]. Where the FS drops to 1.0, failure of the slab in question occurs.

Most or possibly all landslides occur in conditions of high soil moisture associated with storms with prolonged and/or intense precipitation. In some cases, high soil moisture develops after rain on snow events. Saturation of the soil decreases the shear strength of the soil and, through buoyancy, reduces the frictional resistance of the slab to sliding. Rainfall onto the ground surface under a forest is rapidly converted to subsurface flow (surface flow is less common). The water flowing underground is mainly concentrated in the upper 1 m of the soil perched above either a rock surface or an unweathered till horizon. The flow paths appear to be highly irregular following root pores, cracks, or other structural openings in the soil matrix. Much of the groundwater flows along or just above the interface between the mineral soil and the forest floor (e. g., Chamberlin 1972). Evidence of this anisotropic character of water flow can be observed in a road cutslope during a winter storm.

Hillslopes are highly variable, and within even a relatively uniform terrain polygon there will be a wide range of terrain microsites with different slope gradients, micro-catchment basins, groundwater flow regimes, soil depths, and soil shear strength. This spatial variability combined with the variability in soil moisture due to precipitation and flow paths makes it highly difficult to model and predict slope failures. Within any steep terrain polygon, the FS diminishes with increasing soil moisture, and failure will occur if and where the FS of the most sensitive microsite reaches 1.0.

Logging probably increases landslide frequency. EBA found in its landslide inventory that logged terrain was approximately nine times more prone to sliding than unlogged terrain. Part of the increase is associated with road construction due to oversteepened fillslopes, localized saturation of soils due to drainage concentration, and undermined cutslopes. EBA found that about 50% of the open-slope landslides in logged terrain were initiated in roads (most of this from road fills) and the remainder initiated on open slopes in clearcuts. The increased failure frequency in logged open-slope terrain units is may be due in part to the gradual elimination of root-strength contribution to shear strength (e. g., Zeimer and Swanston 1977) and possibly to the alteration of near-surface groundwater movement.

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[2] FS is the ratio of Forces Resisting Failure divided by the Forces Promoting Failure.

Given the difficulty of predicting landslides on this basis, a geo-statistical approach has been developed relating the failure frequencies to the attributes of terrain polygons. Results from the terrain attribute study (Rollerson *et al.* 1998) are available and have been used to develop our terrain stability criteria for terrain polygons. This procedure is more fully discussed in Section 5.1.

4.2 Slumps and slump/earthflows

Slumps are rotational failures. These are in contrast to shallow translational slides common in the Clayoquot Sound area. Many debris slides or flows may actually initiate as slumps, but due to the presence of a shallow failure plane, they rapidly convert to a translational form.

Slumps may be simple landslides with a single soil mass failing over a curved plane, or they may be complex with numerous discrete masses. Movement may take the form of pure backward rotation around a horizontal axis, or it may be complex with a translational component over a planar surface. Slumps, in contrast to debris slides and debris flows, usually occur in deep, cohesive soils such as those derived from deep, silty tills or fine-textured glaciomarine or glaciolacustrine deposits. In certain soils, movement disturbs the soil structure and causes the mass to liquefy. The resultant mass is then subject to earthflow, which together with the initiating slumping is called a rapid slump/earthflow. These processes may involve the rapid delivery of liquefied soil downslope. Most slumps are caused by the removal of toe-support in a deep cohesive soil. In nature, the most common example is the undercutting of banks by streams or rivers. Complex slumps have been a common event in post-glacial history along the major drainages although the scars remaining may be difficult to discern because of revegetation. Slumps and slump/earthflows are much less common in the Clayoquot Sound area than their translational counterparts, mainly because of the relative paucity of deep cohesive soils and widespread presence of failure planes close to the surface. The EBA report did not classify slumps separately in their inventory mainly because of the difficulty in distinguishing them from debris slides and debris flows on air photos.

In logging, road construction may accelerate the incidence of slumping because of the removal of toe support in cutslopes. Small-scale slumping of cutslopes is a common occurrence; this may lead to larger problems with drainage concentration if ditches are blocked. In some circumstances, road-induced slumping may cause large landslides with significant environmental impacts.

However, such events have not, to our knowledge, occurred in the Clayoquot Sound area. Clearcut logging alone probably has little effect on the process of slumping. The curved failure plane in slumps generally occurs beneath the tree rooting zone.

4.3 Rock Slides

Natural landslides in rock landforms can take the form of slides, topples, falls, lateral spreads and flows (Varnes 1996). In the Clayoquot Sound area, slides and falls are the most common, with some topple failures. Failures in rock usually occur along a structural weakness as in a joint or fault. Rock slides occur when a rock mass fails along a plane of weakness parallel or sub-parallel to the ground surface. Rockfall involves a "free-fall" from a steep rock escarpment. Both involve the rapid downslope movement of rock debris forming colluvial cones (talus), blankets or veneers (overlying the previous ground surface), or irregular landslide deposits (e. g., *Ch*). Rockfall or rock slides are most likely to occur in weathered rocks with pronounced and/or steeply dipping joints, faults, or bedding planes. High rainfall and seismic activity are two phenomena that contribute to the incidence of landslides (Howes 1981). Locally, frost action may promote slab failure along near-surface openings in rock.

EBA (1997) found only three rock slides (which they called rock avalanches) in the Clayoquot Sound area. The largest of these occurred in the upper Kennedy River where the deposit dammed the river forming a new lake. The EBA study also identified 55 rockfall sites as shown by the presence of a fresh detachment surface and rubbly or blocky deposits downslope.

We believe that logging has little or no effect on rock slide frequency except possibly for the effect of blasting during road construction. It is conceivable that diverted drainage can increase the water loading on a particular joint or set of joints such that failure occurs. Although we have observed localized slab failure above a road cut, there is no evidence that significant rock slides have resulted from road construction in the Clayoquot Sound area.

4.4 Gully Erosion

Gullies are erosional landforms created by the incision of streams into hillsides. They are produced by the progressive erosion of channels (degradation), sidewall erosion (including debris slides and minor rock slides or rockfall), and headwall retrogression. Many gullies have been formed by landslides or have been modified (eroded) by landslides (mainly debris flows) that initiate on their sidewalls and/or headwalls or adjacent slopes.

By definition, gullies contain streams, but the relationship between the erosive power of those streams and the size and morphology of gullies is complex. Some gullies are relict having been formed under conditions that differ from those of today. Such relict gullies may be relatively large with small streams or streams with low erosive power. Other gullies may also contain unusually small streams, but their morphology is more closely related to landslide history rather than stream erosion.

Certain gullies in the Clayoquot Sound area have developed along large joints or faults in the bedrock. These are usually straight-line features, many of which do not directly follow the fall line downslope. Joint-controlled gullies are typically in rock, and their size may not reflect the erosive power of their streams.

Post-glacial gullies are the most common. These have formed in glacial deposits, mainly till, within the past 13,000 years. We suspect that much of the gully erosion occurred in early post-glacial time when vegetative cover was less dense than at present.

Terrain polygons containing gullies have a higher landslide frequency than non-gullied polygons (Rollerson *et al.* 1998). In that study (including Clayoquot Sound), gullied terrain showed a mean landslide frequency of 0.17 landslides per ha compared to only 0.08 on uniform slopes.

Gullies contain sidewalls and headwalls, which are typically much steeper than adjacent open slopes. Most gullies also have stream flow and confined profiles; both conditions promote the development of debris flows. As noted earlier, debris flows travel farther and are more likely to deliver debris to larger streams in the valley bottom than debris slides on open slopes. In general, the larger and steeper the sidewalls/headwalls (except those in rock), the greater the probability for failure. Millard (1999) found that debris flows were more likely to initiate from headwall, rather than sidewall failures. The probability of flow initiation was also directly related to the size of the initiating failure.

Logging on gullied terrain can have a substantial impact on both soil erosion and landslide incidence. Tripp (1994) identified poor treatment of gullies as a major source of fisheries impacts in logged terrain in coastal British Columbia. Falling and yarding across gullies frequently damages vegetative and forest floor cover and causes disturbance of mineral soils on the sidewalls. This increases surface soil erosion and accelerates the natural delivery of sediment to the channel. Failure to remove logging slash in streams larger than 2 m to 3 m in width may result in accelerated channel or bank erosion, and consequently increased sediment production (Millard 1999).

4.5 Other Geomorphic Processes

Other processes occurring in the Clayoquot Sound area include slumps and slump/earthflows, soil erosion, piping, stream channel and bank erosion, soil creep, and windthrow.

4.5.1 Slumps and Slumps/Earthflows

Slumps are rotational failures. These are in contrast to shallow translational slides common in the Clayoquot Sound area. Many debris slides or flows may actually initiate as slumps, but due to the presence of a shallow failure plane, they rapidly convert to a translational form.

Slumps may be simple landslides with a single soil mass failing over a curved plane, or they may be complex with numerous discrete masses. Sliding may take the form of pure backward rotation around a horizontal axis, or it may be complex with a translational component over a planar surface. Slumps, in contrast to slides and debris flows, usually occur on deep, cohesive soils such as those derived from deep, silty tills or fine-textured glaciomarine or glaciolacustrine deposits. In certain soils, the action of the slump disturbs the soil structure and causes the mass to liquefy. The resultant mass is then subject to earthflow, which together with the initiating slumping is called a slump/earthflow. These processes may involve the rapid delivery of liquefied soil downslope. Most slumps are caused by the removal of toe-support in a deep cohesive soil. In nature, the most common example is the undercutting of banks by streams or rivers. Complex slumps have been a common event in post-glacial history along the major drainages although the scars remaining may be difficult to discern because of revegetation. Slumps and slump/earthflows are much less common in the Clayoquot Sound area than their translational counterparts, mainly because of the relative paucity of deep cohesive soils and widespread presence of failure planes close to the surface. The EBA report did not classify slumps separately in their inventory mainly because of the difficulty in distinguishing them from debris slides and flows on air photos.

In logging, road construction may accelerate the incidence of slumping because of the removal of toe support in cutslopes. Small-scale slumping of cutslopes is a common occurrence; this may lead to larger problems with drainage concentration if ditches are blocked. In some circumstances, road-induced slumping may cause large failures with significant environmental impacts.

However, such events have not, to our knowledge, occurred in the Clayoquot Sound area. Clearcut logging alone probably has little effect on the process of slumping. The curved failure plane in slumps generally occurs beneath tree rooting zone.

4.5.2 Surface erosion

The surface erosion of soils by water or wind can play a major role in geomorphology, but in the Clayoquot Sound area, it is relegated a secondary significance after landsliding. Gullies are created by stream erosion on hillslopes (or, they are landslide scars modified by stream erosion). Soil erosion may have been highly active on the landscape in early post-glacial times, but more recently, the dense vegetation and, more importantly, the extensive forest floors have minimized non-channelized surface soil erosion on open slopes.

The extensive forest floors in the Clayoquot Sound area are highly effective in preventing soil erosion. The porous layer of decomposing litter from the forest canopy readily allows infiltration of even the most prodigious rainfall intensities. Thus overland flow is generally uncommon under coniferous forests. Under certain circumstances, a limited amount of overland flow may occur where near-surface flow is concentrated or where the forest floor has been compacted. On certain steep forested slopes in the Clayoquot Sound area, it is not uncommon to find roots exposed above the ground surface. This reflects a lowering of the ground surface due to a combination of soil erosion and accelerated decomposition of the surface organics.

Only where the forest floor is removed does soil erosion become significant. This occurs in nature on landslide scars and windthrow pits and mounds. The former are more important in sediment movement as they are linear along the fall line and more commonly allow delivery of sediment to streams or rivers. Pits and mounds expose mineral soil to raindrop splash and overland flow. Where they occur on hillslopes, there may be a net downslope movement over time.

Logging increases erosion and sedimentation by exposing mineral soils. This is done in part by increasing the landslide rate above the natural one. Erosion is potentially increased by road and trail construction and by soil disturbance created by yarding, or forwarding (although the latter is most commonly done on gentle slopes where soil erosion is a low hazard). Roads are probably the most common culprit in increasing sedimentation rates in watersheds, and researchers have found, for example, that such rates are related to the road density (Reid and Dunne 1984). Erosion of landslide scars, both from clearcut open slopes and from roads, also increase sedimentation rates. Most of the increase will occur in the first few months after the event, then the rate of sediment transfer decreases if the scar remains inactive or unless the landslide occurred in deep materials and localized gullying of the scar follows the initial event. Exposure of mineral soils occurs to some extent in most clearcut blocks although the overall extent is usually limited. Gully sidewalls are particularly prone to exposure.

Soils most prone to soil erosion are those in which particles are easily detached from the matrix by the impact of raindrop splash and flowing water. These soils tend to be fine to medium sands with low clay content. Typically, poorly consolidated soils derived from glaciofluvial, coarse-textured glaciomarine and ablation tills have the highest susceptibility. Any fluvial deposit is subject to erosion and entrainment as well.

Long, steep, uniform slopes are most at risk because surface runoff will gain high velocities, and with it, high entraining powers. Broken slopes with plentiful surface irregularities are less prone to erosion as runoff is interrupted.

4.5.3 Piping

Piping refers to concentrated sub-surface flow through preferential pathways in the soil. Piping is perhaps the most important flow mechanism for groundwater in forested environments (e. g., Cheng 1975). Piping in till soils may play a role in landslide initiation where it contributes to localized saturation. Piping may also contribute to the retrogression of landslide headwalls on some steep slopes in the Clayoquot Sound area (although we have not confirmed it here). This process, in expanding gully systems, has been observed in other areas (e. g., Selby 1993).

In unconsolidated, coarse-textured sediments, piping can have different consequences. Under conditions of high groundwater flow, pipes can enlarge as particles along the walls of the pipe are entrained. The resulting expansion can trigger a massive collapse of material that, if near saturation, can create an earthflow. The authors have observed evidence for such events in Capilano Sediments in the Sechelt Peninsula, but we have not identified them in the Clayoquot Sound area. It is possible, however, that such piping failures have occasionally occurred in raised deltas or glaciofluvial deposits.

4.5.4 Soil Creep

Creep is the slow (usually imperceptible) downslope movement of soil (Selby 1993). On steep slopes (over 31°), it is intuitive to envisage the downslope movement of surface soils over time. Soil creep investigations (e. g., Terzaghi 1953) have usually focused on highly cohesive fine-textured soils, but there is little data on creep mechanisms in forested hillslopes.

Despite this, there is little doubt that creep does occur as indicated by stem deformations on conifers. Other phenomena such as snow loading, rolling debris, avalanches, rock slides, wind, and asymmetric branching can deform conifer stems. However, soil creep produces a distinctive curvature that extends over much of the stem (unlike snow loading that produces a basal “pistol-butting”). On most steeper slopes, it is typical to observe up to 10% of trees exhibiting such curvature.

Our observations of tree form and other visible indications of soil creep in the Clayoquot Sound area (eg: tree stem curvature) indicate that soil creep is discontinuous over time and space. We believe that on most forested slopes in Clayoquot Sound, soil creep is highly localized, only occurring in a certain location when the soil is at or near saturation. Soil creep may be induced or accelerated by the action of wind sway causing displacement in the rootwad.

4.5.5 Windthrow

Windthrow is the uprooting of trees by wind. Trees can also be snapped off in a related process termed windsnap. In the Clayoquot Sound area, both windthrow and, to a lesser extent, windsnap are common events. Most even-aged or discretely two-aged stands in the Clayoquot Sound area have likely developed after a windthrow event. The effects of windthrow on soil erosion have been discussed. It is possible that windthrow acts to trigger landslides. We have observed that a number of landslides have initiated from the boundary areas of logged clearcuts in the Clayoquot Sound area. These may have been induced by or followed windthrow along the timbered edges of the opening. It seems intuitively obvious that the uprooting of trees on steep, potentially unstable ground can trigger a landslide, however there is not universal agreement on this. However, the landslide frequency is higher on logged terrain where windthrow is generally not an issue.

5.0 INTERPRETATIONS FOR TERRAIN STABILITY, SOIL EROSION POTENTIAL, LANDSLIDE-INDUCED STREAM SEDIMENTATION, AND SENSITIVE SOILS

5.1 Terrain Stability

Each terrain polygon is assigned a terrain stability class. There are five classes, ranging from I through V. We have segregated the terrain stability ratings for clearcuts from those for roads based on the assumption that the two can, in certain terrain conditions, differ substantially.

The terrain stability classes generally reflect a qualitative measure of the probability that a landslide will occur. Thus, it is a measure of the hazard. It does not reflect the magnitude of the landslide nor does it reflect the probability that the landslide will deliver debris into a stream. This effect is commonly referred to as the consequence. Risk is a term that represents the interaction of hazard and consequence. We do not rank risk *per se*, but instead use a qualitative assessment of the probability that landslides will deliver debris into a stream is included in polygons rated IV or V (see section on landslide-induced stream sedimentation).

The criteria used for ranking terrain polygons for terrain stability class is summarized in Table 3. This set of criteria was developed by Mr. Terry Rollerson several years ago based on preliminary results of an extensive terrain attribute study carried out on the west coast of Vancouver Island (including Clayoquot Sound). Using these data, we hoped to provide stability rankings for terrain polygons in the most scientifically valid method possible.

Table 3. Terrain Stability Class Definition

3A. Clearcut Stability Criteria

Class	Slope	Natural Failures*	Gullies	Variations**
I	<19º (34%)	A	A	W, WG, L, or LG <5º (<9%)
II	20º-25º (36-47%) or >46º (>104%)	A	A	W, WG, L, or LG <5º-19º (9-34%)
III	26º-46º (49-104%)	A	A	W, WG, L, or LG 20º-25º (36-47%) Any concave slopes 19º-26º (34-49%) Any concave slopes >46º (>104%)
IV	26º-46º (49-104%)	A	P	W, WG, L, or LG >26º (49%) Imperfectly to poorly drained surficial materials on slopes >35º (>70%) (e.g., some lower slope stream escarpments)
V	Any naturally unstable slopes	P	A/P	

* A = absent; P = present

** W = marine; WG = glaciomarine; L = lacustrine; LG = glaciolacustrine

3B. Road Stability Criteria

Class	Slope	Natural Failures*	Gullies*	Variations**
I	<15º (<27%)	A	A/P	
II	15º-19º (27-34%)	A	A/P	W, WG, L, or LG <15º (<27%)
III	20º-30º (49-58%)	A	A/P	W, WG, L, or LG 15º-19º (27-34%)
IV	31º-40º (60-84%)	A	A/P	W, WG, L, or LG 20º-30º (36-58%)
V	>40º (84%)	P	A/P	W, WG, L, or LG > 31º (>60%) Any naturally unstable slopes

* A = absent; P = present

** W = marine; WG = glaciomarine; L = lacustrine; LG = glaciolacustrine

In polygons where the stability differs for clearcuts and roads, both stability rankings are presented with the road stability shown first (e. g., IVr IIIc). Where the stability class is the same for both, only one symbol is used (e. g., III). Notice that for roads, there is no parallel to the increased slope/decreased stability class as in clearcuts. Many polygons between 30° and 40° may receive a IVr for road development but IIIc for clearcuts.

The terrain attribute study generated a large database of terrain polygons with selected attributes (e. g., surficial geology, slope, shape, drainage, etc.) and their associated failure frequency. Thus, the study allows us to identify what proportion of a certain group of terrain polygons (e. g., all polygons with slopes 35° to 37°, straight, colluvial veneers over smooth rock, on northeast aspects) have experienced landsliding.

Looking at hillslope gradient alone, failure frequency is highest between 30° and 35° then decreases with both increasing and decreasing slope gradient. Thus, steeper slopes above 35°, according to this finding, have a lower failure frequency (and thus stability class) than slopes between 31° and 35°.

Note that slopes above 46° are ranked Class II with regard to clearcutting. The results of the terrain attribute study indicated low landside rates on these slopes suggesting that on terrain so steep, there is little soil mantle present in which failure can occur. Most of these polygons are predominantly bedrock.

The use of the terrain attribute study resulted in some decisions made about stability that were not entirely consistent with our judgement. Our mappers walked many slopes between 35° and 40° with morainal or colluvial blankets, which we deemed to be potentially unstable. Outside of the Clayoquot Sound area, most of us would have ranked such terrain as Class IV. For this project, we typed such polygons as Class IVr/IIIc because, according to the terrain attribute study, they have a lower failure frequency (<30%), which would equate to a ranking of low or Class III as tabulated in Appendix 1 of the 1995 edition of the Mapping and Assessing Terrain Stability Guidebook. Because we are still concerned about the stability of such polygons, in Years One, Two, and Three we modified the clearcut stability class and designated it as Class IIIc*. As described in the map legends and accompanying reports, IIIc* ranking is similar to IV and an on-site geotechnical assessment prior to any development is required. On the terrain stability maps, IIIc* was printed as IIIc'.

Consistency between the four years of the terrain inventory was important, and as a result, this designation of Class IIIc* was also used in Year Four. However, following the correlation of the Year Four air photo work by Mr. Rollerson and a conversation with Mr. Tom Millard, *P.Geo.*, Regional Research Geomorphologist of Ministry of Forests (pers. comm. Dec. 2002), we became aware that some users of the previous years' mapping were confused by the IIIc* designation. Therefore, it was agreed upon by Mr. Millard and Madrone that in order to prevent future confusion with the use of the Year Four terrain stability maps, Class IIIc* rankings have been automatically upgraded to Class IVc. With this upgrade, those polygons with road stability Class IVr were changed to Class IV. For practical reasons (including time constraints), these changes to Class IIIc* were not made on the air photos but were in the databases. Therefore, Class IIIc* appears on the final typed air photos but Class IV or IVc appear on the printed maps and in the digital files.

5.2 Soil Erosion Potential

We have used a five-class system to rank soil erosion potential. The classes are defined in Table 4.

Table 4. Soil Erosion Potential Classification

Class**	Rating	Description	Management Implications
VL	Very Low	Flat or gently sloping terrain, organic soils, floodplains	Low concern for sediment production. Disturbance of streams could initiate some bank and channel erosion.
L	Low	Gentle slopes. Short slopes	Erosion limited to channel and streambanks. Expect minor erosion of fines from ditch lines and disturbed soils. Exercise care not to channelize water onto more sensitive sites.
M	Moderate	Moderately steep and long slopes. Sediments high in silt or fine sands.	Expect some problems with disturbed sediments. Plan additional measures to reduce sediment production where entry into stream network is a potential.
H	High	Moderately steep slopes and highly erodible sediment textures.	Water management critical. Close attention to prevention of soil erosion such as grass/legume seeding is necessary.
VH	Very High	Steep slopes with highly erodible sediments. Active soil erosion or gullies present.	Very high concern. Remedial planning to control erosion is necessary.

** Modified from Schwab (1993).

The criteria for evaluating the soil erosion potential are shown in Table 5. The potential is defined as the susceptibility of the soil to erosion if the surface has been exposed in road construction or other disturbance. It assumes that the forest floor has been removed. The rankings range from VL (very low) to VH (very high). No actual measures of soil erosion are available, although on an aerial basis, we assume that soil erosion can range from 0 m^3 to as much as 50 m^3 per ha per year. The most extreme cases of soil erosion have been associated with steep gradient ditches alongside logging roads constructed in unconsolidated glaciofluvial sands.

The ratings in Tables 5A and 5B are for materials greater than 1 m deep with the exception of bedrock. For materials less than 1 m deep, see bedrock ratings in Table 5B. Except for the symbols for the soil erosion potential ratings (VL to VH), refer to Howes and Kenk (1997) for definitions of symbols used in Table 5A and 5B.

Table 5. Guidelines for Rating Soil Erosion Potential

Table 5A. This table is based on material texture vs. slope morphology on moderate slopes (16°-25°). Typical moisture conditions have been accounted for in the slope morphology.

Dominant Texture Decreasing Erodibility	Typical Material	Uniform			Ridge Crest	Scarp	Dissected -V	Irregular h, u, r, m	Single Gully
		Upper	Mid	Lower					
coarse z fine s	LG, W, WG, FG	M	H	VH	M	VH	VH	M	VH
m, c	W, WG, LG	L	M	H	L	H-VH	H	L	H
coarse s, xs, gs	C, F, FG, M	L	M	H	L	H-VH	H	L	H
dzs, dsz	M	L	M	H	L	H-VH	H	L	H
sg, sr, sx	C, F, FG, M	VL	L	M	VL	M-VH	M	VL	M

Table 5B. Special Cases

Material or Dominant Texture	Typical Landform	Rating
Bogs	Op, Ob	VL
a, b, x	Ck, Cb	L-M
Resistant bedrock	R	VL-L

How to Adjust the Tables for Special Circumstances:

Soil erosion potential ratings can be adjusted based on the following:

Slope Morphology:

Concave slope – increase rating by 1 grade from the equivalent uniform rating

Convex slopes – decrease rating by 1 grade from the equivalent uniform rating

Soil Drainage:

For slopes with abundant seepage, increase class up 1 grade

Slope Steepness:

For slopes >26°, increase rating by 1 grade

For slopes <16°, decrease rating by 1 grade

Definitions:

Concave: concave down slope and/or across slope

Convex: convex across slope and straight down slope

Slope morphology: polygon location in relation to the entire slope (i. e., ridge top to valley bottom

Uniform: slope straight in all directions

The interpretation of the table is self-explanatory. Table 5A pertains to slopes between 16° and 25°. The main criteria are dominant soil texture and slope morphology. Silts and fine sands are the textures deemed most susceptible to soil erosion. This is due to the ease of particle detachment under the entraining influence of raindrop splash or running water. Both finer and coarser textures are less susceptible. Clayey soils resist detachment due to cohesive forces acting between particles. Coarser textures contain particles large enough that they are difficult to entrain. Table 5B of the table pertains to special cases, namely bogs, very coarse substrates, resistant bedrock, and materials less than 1 m deep.
We have accounted for special circumstances by adjusting the potential rating up or down by one class depending on conditions in the polygon. These include slope morphology, soil drainage, and steepness.

As indicated above, surface cover is an extremely influential factor, but the classification system assumes no such cover. This is appropriate for road construction surfaces such as fill slopes, cutbanks, ditches, or running surfaces of roads. In addition, poor deflection in logging may result in extensive exposure of mineral soil resulting from scouring by logs during yarding or pulling stumps. Although Table 5 suggests increased concern for erosion with increased rating class, a reasonable standard of care for controlling erosion is necessary in all logging operations. An area subject to concentrated seepage or runoff during high rainfall renders all exposed mineral soil highly subject to erosion. It is believed by some that the most influential factor affecting sediment production in a watershed is the level of skill and care taken in logging operations (Rice and Gradek 1984).

5.3 Landslide-Induced Stream Sedimentation

Another interpretation shown on our maps is the landslide-induced stream sedimentation (LISS). This three-class system (Table 6) is used to qualitatively rate the probability that a slide initiating in any polygon will travel downslope and deliver debris to a stream, lake, or ocean identifiable on 1:20,000 scale air photos. Used together with the terrain stability class, this information gives an approximate picture of the risk of logging or road construction in that polygon. The LISS designation is only provided in polygons ranked Class IV or V for terrain stability.

Table 6. General Guidelines for Landslide-Induced Stream Sedimentation Classification

Class	Interpretation	Criteria
1	Low likelihood that a landslide originating in this polygon will reach a perennial watercourse. Post-event soil erosion of the landslide scar and deposition zone will result in no or limited stream sedimentation.	Downslope terrain is concave, irregular, or benchy. Downslope gradient <15º No air photo or field evidence of landslides entering watercourses.
2	Moderate likelihood that a landslide originating in this polygon will reach a perennial watercourse. Post-event soil erosion of the landslide scar and deposition zone will result in some additional stream sedimentation.	Downslope gradient 15º to 30º Limited air photo or field evidence of landslides entering watercourses.
3	High likelihood that a landslide originating in this polygon will reach a perennial watercourse. Post-event soil erosion of the landslide scar and deposition zone will result in additional stream sedimentation.	Downslope terrain is convex or uniform. Downslope gradient >30º Clear evidence of landslides entering watercourses is visible on air photos or in the field.

5.4 Sensitive Soils

In 1995, the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (Anonymous 1995) made several recommendations to maintain long-term ecosystem integrity at a watershed level. Among those was the need for the identification and delineation of sensitive soils so that reserves can be established in fragile or potentially fragile areas.

The identification of sensitive soils is a two-step process, involving (1) terrain and terrain stability map analysis and (2) field assessments. As part of this terrain inventory, we have conducted the map analysis and assigned each terrain polygon a qualitatively-defined sensitive soils class (Table 7). Just as terrain stability maps (typically 1:20,000 scale) are used to identify areas where a detailed terrain stability field assessment (e.g., 1:5,000 scale) is required prior to any development, the sensitive soils map have been created at 1:20,000 scale and can be used to identify areas where a detailed field assessment (1:5,000 scale) is needed to identify additional sensitive soils. Given that we were conducting field work for 1:20,000-scale maps it was not practical to collect data regarding sensitive soils at 1:5,000 scale.

The classification system has been created based on criteria established by Millard *et al.* (2002), following recommendations made by the Scientific Panel. The classes are outlined in Table 7.

Table 7. Sensitive Soils Classification

Class	Interpretation	Criteria
1	Confirmed sensitive soils. Reserve required.	Pure organics (e.g., Op, Ob) Bedrock complexed with organics only (e.g., Rh/Ox, Ov/Rs) Blocky or bouldery colluvium (e.g., aCk, bCb) Pure bedrock (e.g., Rs)**
2	Potential sensitive soils. Potential reserve. Detailed field assessment may be required to identify sensitive soils at a large scale (e.g., 1:5,000).	All other polygons not mapped as class 1.

**Although polygons mapped as pure bedrock units will have little to no soil, these polygons are included in Class 1 as there is value in identifying those polygons where harvesting is not feasible.

6.0 MANAGEMENT CONCERNS AND RECOMMENDATIONS

The main objective of this exercise is to provide a planning tool for resource managers to ensure that development activities do not accelerate the natural rate of sediment movement from hillslopes to stream channels. Clayoquot Sound is a geomorphically active area that has a relatively high natural rate of sediment movement. Landslides occur in undisturbed forests without any human influence. Windthrow of trees is a natural occurrence; where it occurs in riparian corridors, it may be associated with small landslides that deliver sediment directly to channels. Blockage of channel flows by windthrown trees or roots can also increase sediment yield. Stream and bank erosion also have natural rates, which in particular places and times, may also reach levels much higher than average historic ones.

While we should strive to minimize any change in the natural rate of sediment transfer, we should also be aware that it would be difficult and even unwise to attempt to reduce the rate of natural processes below their historic rate. To eliminate all landsliding would have undesirable effects. For example, a reduction in the rate of sediment transferred to streams would result in accelerated streambed degradation, possibly with the result of increased sediment delivery to valley bottom mainstems.

Landslides pose a risk to water quality, fish habitat, site productivity, and visual quality, and logging and related activities can affect the stability of a hillslope in several ways:

- Road construction can increase landsliding by diverting and concentrating water flows.

- Ground-based harvesting can lead to diverted flows and the saturation of areas of a hillslope that would not otherwise receive so much water.

- Where cut-and-fill construction crosses steep slopes, roads can create unstable fillslopes subject to failure when they saturate or when incorporated stumps and logs collapse.

- Cutslopes can undercut soil mantles above the slope, leading to debris slides.

- Timber harvesting may reduce the shear strength of the surface mantle of soil through the loss of root strength as tree roots rot.

- Timber harvesting may increase soil erosion and the subsequent transport of sediment downstream.

There are a number of measures that can be taken to minimize the effect of logging on terrain stability. The most effective measure is to avoid areas of high risk (i.e., consideration of both hazard and consequence). The primary objective of this mapping exercise is to allow areas of high hazard to be identified in the planning stages and thus be avoided or assessed thoroughly.

Class IV and V terrain should be closely inspected prior to any development. Terrain mapped as Class V generally has a high likelihood of instability, but this should be confirmed by field evaluation if development is proposed, since polygons may contain smaller areas that are stable.

Terrain within Class IV polygons is not all inherently unstable, but these polygons are likely to contain smaller areas that are. Thus, it may be possible to develop a portion of Class IV terrain, still avoiding the unstable components within the polygon. An on-site terrain stability field assessment by a qualified professional is required to ensure that such components will not be affected by the development and that the road design will not result in unstable fillslopes.

In general, it is not necessary to avoid Class III polygons in harvesting and road construction plans. However, a risk management approach is still necessary. Class III polygons may contain small areas of potential instability. Where the consequence of slope failure is significant, for example, above a steep gully leading down to a creek, extra care in hazard evaluation and monitoring of operations is warranted.

Besides avoidance of sensitive areas, there are other methods of minimizing or eliminating the effect of road construction and logging on terrain stability, and these are described below.

6.1 Roads and Road Construction

Road construction is the activity with the greatest potential to produce sediment. In the Clayoquot Sound area, as in many other areas in the coast, landslides initiating from roads have had a widespread and substantial impact on streams and fish habitat.

There are several ways to manage this impact. By far the most economical and environmentally sound way to minimize erosion and sediment production is simply to avoid building road in sensitive terrain. Our terrain/terrain stability maps provide an effective planning tool to accomplish this. Planners should attempt to minimize roads across steep hillslopes that are mapped as Class IVr, IV, Vr, or V areas, (keeping in mind that our 1:20,000 scale maps are designed for broad scale planning and not detailed lay-out). In many cases, the careful location of roads to avoid unstable areas not only minimizes the risk of landsliding but commonly avoids costly construction.

Reduction of the amount of road constructed will also greatly reduce site loss (from erosion and slope failures) on all terrain. Development plans which reduce the total length of active roads, with a judicial combination of conventional and unconventional harvesting methods (especially helicopter), will have a lower overall impact.

Where proposed roads cross terrain with potential stability problems (e. g., IIIr, IVr, IV, Vr, V), an on-site inspection by a qualified geoscientist or engineer is required. This investigation will assess the geological hazards and may indicate feasibility of construction. It will also determine the need for special construction methods or strategies: for example, special management of spoil, stabilization of cutslopes or fillslopes, scheduling constraints (e. g., avoid construction under conditions of high soil moisture), special blasting techniques, extra supervision, or final certification by a professional engineer. Another alternative is to plan for early retirement of the road to a permanent or semi-permanent deactivation or to call for seasonal deactivation prior to heavy fall rains. Full-bench construction, coupled with appropriate sidecast treatment such as full or partial end-haul, will reduce the hazard of fillslope failures on roads built on hillslopes greater than 60% to 70% (depending on terrain and material). Cutslope instability can be prevented by avoiding road construction across steep slopes with deep deposits. Where such conditions cannot be avoided, engineering support for cutslopes may be necessary.

Proper watershed management measures in road construction and maintenance will minimize the amount of sediment produced along roads. Careful water management is especially necessary during construction, when the potential for generating sediment is greatest. Appropriate drainage structures are necessary when pioneered roads cross watercourses. Near watercourses, sediment-laden water from ditches should not be allowed direct access to free-flowing streams.

Where high or very high soil erosion potential has been mapped, extra care is needed to protect soils from erosion. Special attention to stream crossing structures is always justified, especially in the flashy hydrologic regimes and copious stream flows found in the Clayoquot Sound area. In the past, inadequate cross-drain density, inadequately sized culverts or bridges, poor placement and poor construction of structures have caused damaging landslides. Culverts and bridges must be designed for the appropriate design flood, according to the relevant regulation. In addition to anticipated water flows, the design should also account for the passage of any future woody debris and bedload. Forest engineers should also be aware that upstream logging will probably change (if temporarily) the amount of woody debris and bedload transported by the stream.

Under the Forest Practices Code and as suggested in the Clayoquot Sound Scientific Panel for Sustainable Management (Anonymous 1995), all stream courses crossing the road must be culverted. Sizing of culverts has become rather routine, involving methods outlined in the *Forest Road Engineering Guidebook* (BC Ministry of Forests 1995b). These methods provide a means of estimating the sizing to convey 100-year floods based on cross-stream area. The estimates do not always take into consideration debris and bedload or potential debris flow activity.

Pipe culverts are routinely used to convey the water from small streams across roads on steep hillslopes, but in practice, they are placed at a gentle slope. Consequently, bedload may accumulate at the intake of the pipe thus reducing its capacity. The result may be a washed out culvert or diverted drainage across the road. Forest engineers must therefore be cognizant of these effects and understand where to modify routine procedures.

Forest roads must be planned, built, monitored, and deactivated with a view to minimizing an acceleration of sediment transfer. Proper planning, construction (including supervision), and deactivation of logging roads and skid roads can minimize water diversion or concentration problems. Planning includes the placement, spacing, and sizing of culverts. In addition to minimizing the effect of landslide initiation, there should be plans to minimize soil erosion. The application of appropriate mixtures of grass and legume seed on exposed surfaces, particularly fillslopes and ditches near stream crossings, should be routine. Hay bales, silt fences, gravel surfacing, and hydroseeding are some of the erosion-control products that should be available to operational managers. Emergency erosion control plans should be in place so that the necessary procedures can be promptly followed if sudden changes in weather occur.

Similarly, avoid allowing subgrade construction to extend too far ahead of the finished road, and ensure that, even at the pioneering stage, stream crossing structures allow the unimpeded passage of water. End-hauled material should be carefully placed away from sensitive terrain and should be seeded to minimize soil erosion. The road surface should also be properly ballasted with gravel or crushed rock.

6.2 Timber Harvesting

Clearcut logging should have a minimal effect on surface erosion providing extensive soil exposure does not occur and provided the forest floor remains intact. Blocks should be laid out to minimize poor deflection or ground-lead yarding. Better than average deflection or full suspension may be necessary in certain areas. Steeply graded back-spar trails (e.g., skid-trails running up and down the fall line) will create erosion, but this can be avoided with routine water bars and trail rehabilitation. Where soil exposure occurs after logging, the application of grass and legume seed is usually advisable.

Streamside management prescriptions have now become a routine procedure. On a block specific basis, these will specify how streams or gullies will be managed. Gully assessments will prescribe how to manage these active environments; prescriptions will range from the retention of large buffers to no buffer retention and “fall-and-yard-across”. The retention of buffers should be accompanied by a windthrow hazard assessment and, if necessary, prescription of treatments to reduce that hazard. In the past, in our opinion, too many buffers have suffered windthrow thereby negating any benefits and, in some cases, creating a more deleterious impact than if no buffer had been left.

Where buffers have not been prescribed, extra care is required for harvesting in, near, and/or across streams and gullies. Falling and yarding away is often desirable but not always feasible. Stream reaches in which such a prescription is mandatory must be clearly marked; those in which it may be acceptable to bridge leaning trees and yard across should also be identified. Two potential impacts should be recognized - damage to banks during cross-stream yarding and accumulation of logging slash in creek channels. Based on assessments of bank sensitivity and the potential for the stream to transport sediment and introduced debris, both impacts must be addressed in the streamside management prescription.

The loss of root strength after clearcutting an area is a temporary effect that diminishes as the forest regenerates. Prompt regeneration of fast-growing stock will reduce the window of vulnerability and reduce the likelihood that slope failures will occur resulting from root strength loss. However, a period of at least 30 years will pass before the slope approaches its previous stability, and landslides will still occur if the slope remains otherwise unstable. Maximizing deflection of cables and minimizing ground lead during yarding will minimize surface scour and prevent the creation of ruts where surface water can channelize.

In the Clayoquot Sound area, there is an opportunity for forest management to be a showcase of excellence. We hope that with these resource inventories we will make our contribution towards that goal.

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YEAR FOUR PROJECT AREAS

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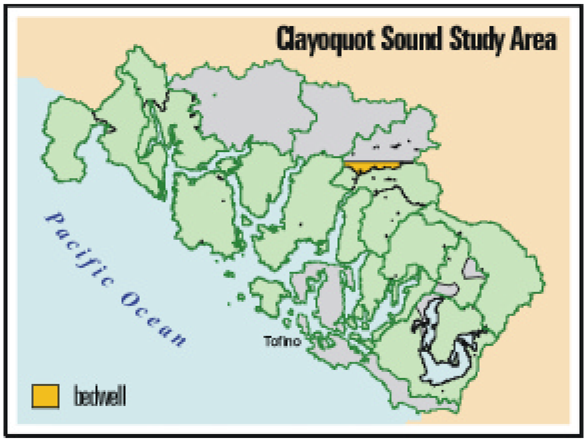
BEDWELL PROJECT AREA



BEDWELL PROJECT AREA

1.0 INTRODUCTION

The Bedwell project area is located 29 km north-northeast of Tofino, encompassing 1558 ha on 1:50,000-scale map sheets 92F.032 and 92F.042. The area is located approximately 3.5 km north-northeast of the north end of Bedwell Sound and the mouth of the Bedwell River (Figure 3). Both sides of Bedwell Sound were mapped as part of the Year One terrain inventory, including the Bedwell project area to the east and the Catface project area to the west. To avoid confusion between the two Bedwell mapping areas, the Bedwell area in Year One remains 'Bedwell' and the current mapping is referred to as 'Bedwell 2003' in the accompanying digital files and printed maps. For the purposes of this report, the current mapping is referred to simply as Bedwell.

1.1 Physiography

The Bedwell project area includes a narrow strip of land between the Ursus River watershed to the south (mapped in Year Two) and the Strathcona Provincial Park boundary to the north. The southern side of the project area follows the drainage divide between the Ursus and the Bedwell, and the north side is a straight boundary truncating several watersheds. The area includes the main Bedwell River stem along its lower reaches just upstream of the confluence with the Ursus River, Ursus Mountain (1440 m above sea level), Penny Creek on the west side of Bedwell River, and the headwaters of Sam Craig Creek, Blaney Creek, and Ashwood Creek, all of which flow north into Strathcona Park and join the west-flowing Bedwell River. The terrain in the area is generally rugged and steep with numerous bedrock bluffs (Photo 4).

1.2 Bedrock Geology

Bedrock in the project area is dominated by rocks of the Early Jurassic to Mid-Jurassic aged Island Plutonic Suite, including granodioritic intrusives. These rocks occur throughout the project area with the exception of a small area in the western portion. On the east side of the mainstem of the Bedwell River, there are basaltic volcanics of the Middle to Upper Triassic aged Vancouver Group of the Karmutsen Formation. In this area there are large bluffs and deep gullies entrenched in the bedrock (Photo 5). The gullies likely follow the scattered faults in the area.

Figure 3

Photo 4

Looking east towards Ursus Mountain in the western portion of the project area.

Photo 5

Large bedrock bluffs Typical of the Bedwell Area.

2.0 METHODS

2.1 Fieldwork

Fieldwork was completed in two days in June and July 2002. At this time, three teams led by Dave Bergman, Marian Oden, and Bryan Tasaka completed three foot traverses (Figure 2a) in the area; two in the western portion of the project area and one in the headwaters of Blaney Creek. Tofino was used as the base camp, and access to the project area was by helicopter. Landing spots included large bedrock outcrops and gravel bars along the Bedwell River.

The traverses were located in areas with Class IV and V terrain and operable timber. Within the project area, the lower slopes and valley bottom along the Bedwell River have been logged and well-established second-growth exists. Well-trodden trails were intersected on both sides of the river.

Sampling intensity was low for terrain with steep bedrock slopes, for terrain dissected by deep, closely spaced, ravines, and for terrain dominated by snow avalanche tracks with minimal operable timber. Ms. Oden viewed areas considered inaccessible (e.g., lack of landing spots, dangerous terrain) or inoperable during a helicopter overview flight on July 2, 2002. Sampling intensity was higher in all other areas. After close inspection of the air photos with the completion of each traverse, the terrain observed in the field was considered to be representative of the surrounding terrain.

2.2 Reliability

The reliability of the mapping can be represented by the number of polygons field checked, the percentage of polygons checked, and the percentage of total area (in ha) checked. This information is summarized for the project area in Table 8. Visual plots supplement the detailed and reconnaissance plots and are not counted in the total number of polygons field checked. These field-checked values fall well within the appropriate range for Terrain Survey Intensity Level C as defined in the *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests 1999) and they exceed the contractual requirement of a minimum of 35% of the polygons checked. In addition, 38% of the unstable or potentially unstable polygons and 45% of the area mapped as unstable or potentially unstable terrain was field checked, increasing the accuracy of the stability portion of the mapping (Table 9).

Figure 2a

Table 8. Summary of Reliability of Mapping-Bedwell Project Area

Total Mapped Area (ha)	Number of Terrain Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Field Checked	Percent of Area Field Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
1558	106	15	40	2	5	47	638	40%	41%	2.70

Table 9. Summary of Class IV & V Field Checked**-Bedwell Project Area

Total Class IV & V Area (ha)	Number of Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Checked	Percent of Area Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
794	55	15	20	1	0	21	354	38%	45%	1.35

** Includes Class IV, IVr, IVc, V, Vr, and Vc.

3.0 SURFICIAL MATERIALS

3.1 Colluvium (C)

Colluvium is the dominant surficial material in the Bedwell area and has been mapped throughout the project area, covering or partially covering 75 polygons or 2964 ha. There are three distinct types of colluvial deposits in the area, which are distinguished by the source and depositional environment. A colluvial veneer (*Cv*) or blanket (*Cb*) is common on the moderately steep to steep mid and upper slopes. These slopes are typically bedrock controlled, and the colluvium is a result of eroded bedrock raveling or falling downslope and weathering into a clast-rich mineral soil. The matrix texture of this material is commonly a silty sand (*zs*), and rubble-sized clasts (angular particles 2 mm to 256 mm) occupy 50% to 90% of the material volume. These soils are unconsolidated, highly permeable, and are often complexed with a morainal veneer or blanket (e.g., *Cv/Mv*).

There are a few scattered colluvial cones (*Cc*) in the area located at the base of bedrock bluffs and outcrops. These terrain features are comprised of rubble (*r*), blocks (*a*), or a combination of the two clast sizes (*x*). Coarse fragments occupy approximately 70% to 100% of the material volume, and fine sediments, where present, comprise an interstitial sandy or silty sandy matrix. These deposits are unconsolidated and highly permeable, and the depth of the material is estimated to range from 2 m to greater than 5 m on the lower end of the cone.

The third type of colluvial deposit is a product of rapid mass movements. The deposition zones of some of the debris flows and debris torrents in the area are colluvial cones or fans (*Cf*) formed by the chronic supply of material from landslides interspersed with fluvial deposition. The deposits are poorly sorted and are comprised of a mixture of fine and coarse fragments ranging in size from sand, silt, and clay to blocks and boulders. The shape of the coarse fragments ranges from angular to rounded. These deposits are common at the mouths of or along the lower reaches of gullies and creeks. Those fans that are derived predominantly from colluvial processes are labeled *Cf* and those that are derived predominantly from fluvial processes (but may include a lesser amount of colluvium) are labeled *Ff*. The material is unconsolidated and fairly permeable, and the depth of the deposits is estimated to range from 2 m to greater than 5 m.

3.2 Weathered Bedrock (D)

Weathered bedrock has been mapped as a minor component in three polygons, totaling 95 ha, in the project area. The bedrock in the area is a granodioritic intrusive. In places, the rock has weathered to a veneer or thin veneer and the material has not been removed by any geomorphic agent (e.g., water, gravity, or wind). The material is thick enough within a polygon (less than 1 m deep) for identification and mapping. The weathered bedrock in the area consists of unconsolidated rubble or blocks and is rapidly drained.

3.3 Fluvial Deposits (F)

Fluvial deposits have been mapped in five polygons (covering or partially covering 89 ha) along the Bedwell River and in one area along Penny Creek, a tributary stream west of the river. Several polygons in the valley bottom are a combination of fluvial and morainal materials (e.g., *Mj/Fja, Fp/Mb*) as the two materials grade into one another with indistinct boundaries. The fluvial sediments are highly permeable, and the depth of most of the deposits is estimated to range from 2 m to greater than 5 m. Within the floodplain of the Bedwell River, there are sections that periodically flood, and a significant amount of sediment is transported downstream. These fluvial deposits are considered to be active and are distinguished with an ‘A’ qualifier (*FAp*) (Photo 6).

Photo 6

Active floodplain of the Bedwell River with large gravel bar

3.4 Glaciofluvial Deposits (FG)

Glaciofluvial materials deposited by glacial meltwater rivers have been mapped along the Bedwell River valley bottom. These deposits have been mapped in 11 polygons and cover or partially cover 112 ha or 7% of the project area.

These deposits are poorly to well-sorted sandy gravels and mixed fragments. The material is non-cohesive and subject to ravel on steep slopes, and the poor cohesion renders it highly susceptible to erosion. The deposits are estimated to be 5 m to 10 m deep and are moderately well to well drained. These sediments are complexed with morainal, colluvial, fluvial deposits. In places, post-deglaciation incision and gully erosion through the deposits has resulted in moderately steep river banks (*FGk*) that are susceptible to failure, chronic ravelling, and erosion.

3.5 Moraine (M)

Morainal material, or till, is common throughout the project area, and it covers nearly 25% of the terrain. It is generally absent on the steeper slopes (greater than 35°) and blankets (*Mb*) the lower and mid slopes. Deeper deposits (*Mj*) have been mapped along the Bedwell River valley bottom. The surface expression of the thinner deposits (*Mv, Mb*) is a reflection of the profile of the underlying bedrock. Much of the terrain at higher elevations is bedrock controlled with numerous outcrops and bedrock hummocks. The till deposits in these areas typically mantle (*Mw*) the underlying irregular bedrock, with a till veneer (less than 1 m deep) on the steeper slopes adjacent to a deep pocket (1-3 m deep) of till in the troughs. The surface expression coincides with the irregularity of the bedrock.

Since the morainal material was deposited during glaciation, the upper meter has weathered. The weathered till has a sandy (*s*), silty sandy (*zs*) or sandy silty (*sz*) matrix texture and is fairly permeable. The unweathered material typically has a silty sandy texture and is generally highly consolidated and impermeable. The coarse fragments in both the weathered and unweathered zones are variable in size, and occupy 30% to 80% of the material volume. The clast roundness ranges from sub-angular to round.

The tills in this area are relatively compact and resistant to erosion in an undisturbed state. Upon disturbance (e.g., in road construction or in slope failure), the material loses much of its original strength.

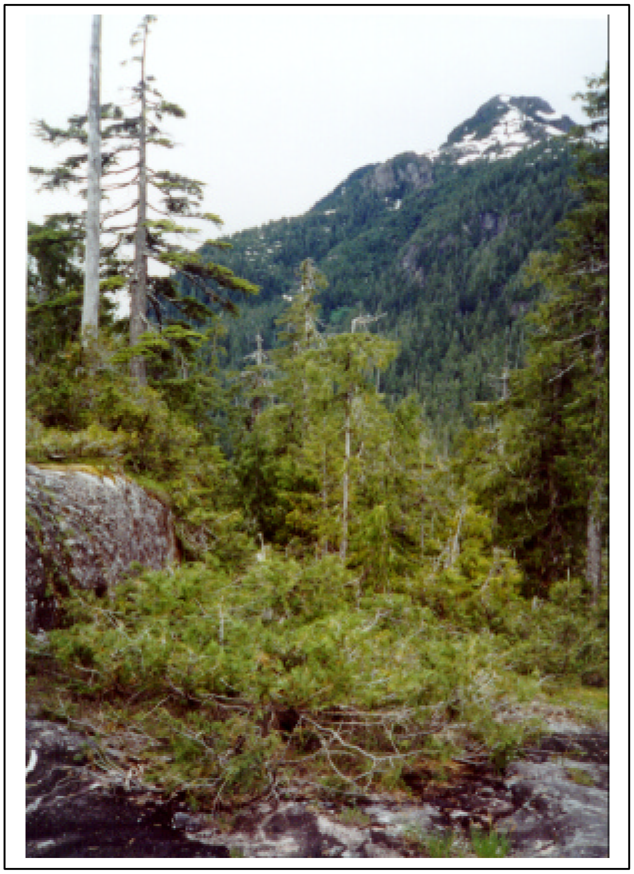
3.6 Organics (O)

Organic veneers have been mapped in four polygons, totaling 51 ha, on the west side of the Bedwell River. They likely occur in other areas but field checking is ordinarily needed to identify this type of soil. This surficial material is an accumulation of leaf litter, twigs, and branches. Also termed 'folisols', these soils are a very thin (*x*) or thin veneer (*v*) directly over bedrock. These organics can support the growth of large trees, and in the project area, they occur on moderately steep to steep, bedrock slopes and may be complexed with till or colluvium. The soil is well drained.

3.7 Bedrock Exposure (R)

Bedrock outcrops and rock covered by a thin mantle (up to 10 cm thick) of unconsolidated mineral or organic soil are common in the project area (Photo 7). There are a few areas where bedrock is the only component of a terrain unit, but in most polygons the bedrock is complexed with either till, colluvium, or organics. On many slopes, the bedrock is uniform and the surface expression is related to the slope gradient (*Rs, Rk, Ra*), but in many places, the bedrock is irregular and expressed as hummocks (*Rh*) or undulations (*Ru*). In the project area, bedrock has been mapped in 61 polygons and occurs in more than 69% of the area.

Photo 7
Bedrock exposure with thin material.



4.0 GEOMORPHIC PROCESSES

4.1 Snow Avalanches (-A)

Snow avalanching has been mapped in 9 polygons in the project area, affecting 333 ha or 21% of the area. This geomorphic process label is included in the polygons where the avalanches initiate as well as in the downslope polygons that are affected by the events. Snow avalanches play an important role in transporting entrained debris from the upper and mid slopes to lower and valley-bottom slopes.

4.2 Irregularly Sinuous Channel (-I)

The Bedwell River is a moderate-sized river that transports a significant volume of sediment. For its length within the project area, the river is irregularly sinuous with a single, well-defined channel. Along these reaches, the average channel gradient is less than 15°. These reaches consist primarily of fluvial deposits. There are several large gravel bars and the river has an active floodplain 50 m to approximately 500 m wide.

In places, the northern reaches of the river (that fall within the project area) have gully-like characteristics rather than river attributes with a moderately steep channel gradient (15° to 30°), well-defined sidewalls at least several meters high, and no floodplain. The channels are incised in shallow surficial material deposits, as well as bedrock.

This geomorphic process has been mapped for three polygons, covering 37 ha.

4.3 Rapid Mass Movement (-R)

Rapid mass movements occur frequently in the project area and have been identified in 34 polygons affecting 710 ha or 46% of the project area. Processes that have been identified include debris slides, debris flows, and debris torrents, and rock slides and rockfall.

4.4 Debris Slides (-R”s), Debris Flows (-R”d), and Debris Torrents (-R”t)

Debris slides, debris flows, and debris torrents are scattered throughout the area. They are primarily associated with gullies and affect approximately 7% of the terrain. Debris flows have initiated in polygons covering approximately 30 ha, debris torrents have initiated in polygons encompassing 13 ha, and debris slides have initiated in polygons covering 26 ha. Debris flows and debris torrents usually travel longer distances downslope than other types of slope failures, and this is evident by the fact that debris flows or torrents have affected downslope polygons equaling approximately 46 ha, while debris slides have not impacted downslope polygons.

Several of the larger slides have directly deposited material in sensitive fish-bearing creeks, while some have indirectly contributed sediment to these watercourses. A majority of the slope failures occurred in shallow soils and have scoured the transport zone to bedrock. Natural rehabilitation of these bedrock tracks will be a lengthy process.

Much of the terrain that is subject to these types of rapid mass movements is subject to more than one process (Photo 8).

Photo 8
Typical gully in Bedwell area. Water flow is subsurface here but there is evidence evidence that the channel is actively scoured by rapid mass movements, small snow avalanches, and peak flow discharge.

Many of the terrain labels are a complex of two or three processes, particularly in gullied terrain, where a distinction between a slide and a flow is sometimes difficult to identify. Within smaller gullies, it is sometimes difficult to determine after the fact if the surficial material slid down the gully or if it was saturated and flowed downstream. Furthermore, most debris torrents are triggered by debris slides so it is appropriate to include the initiation of both types of processes within a given gully system subject to a debris torrent. Where the mass movement transformed from a debris slide to a debris torrent is not always easily identified, particularly for those areas with air photo interpretation only. As a result, the label for a number of the polygons subject to rapid mass movements has a complex of subclasses.

Typical initiation zones for these types of slides include steep bedrock slopes with veneers of colluvium or till, or gully sidewalls composed of deep till deposits or colluvium undercut by fluvial action. Gully sidewall failures are more common than open-slope failures. Debris slides within gully systems commonly deposit in the channel and are later transported downstream. The volume of most of the debris slides is estimated to range from 50 m^3 to 1000 m^3.

The debris flows and debris torrents in the project area have initiated on mid or upper slopes in till or colluvium and quickly channelized into steep gullies. Many of the larger gully systems are inherently unstable and debris torrents occur frequently (on a geologic time scale), flushing out any material that may have accumulated between events. The volume of the debris torrents is estimated to range from 1000 m^3 to 5,000 m^3, depending on several factors including distance traveled to the deposition zone and the amount of material entrained in the transport zone.

For all three of these subclasses, the geomorphic process label is included in the polygons where the slope failure was triggered (*-R"d*), as well as the downslope polygons that were affected by the event (*-Rd*). The " symbol indicates the initiation zone of the rapid mass movement. In most places, an on-site symbol on the map is used to delineate the extent of the landslide.

4.5 Rockfall (-R"b) and Rock Slides (-R"r)

Rock slides and rockfall are similar geomorphic processes; the distinction being that rockfall involves falling, bouncing, and rolling of dislodged bedrock pieces, and rock slides involve the sliding of the pieces.

Rockfall is a common process throughout the steep, mountainous areas within the project area. This is partly a result of the prominence of bedrock at the surface and partly due to the highly fractured and jointed nature of the rock itself. Rockfall is initiated from approximately 32% of the slopes (or 497 ha) within the project area. The average rockfall event is small and travels a short distance. This is evident by the fact that only eight polygons (covering an area of 133 ha) downslope of the initiation of the events are affected by rockfall. Much of the rockfall occurs within gully systems where the material accumulates in the channel and is eventually transported downstream during episodes of high discharge. Rockfall accumulation in the form of cones or aprons at the base of bedrock outcrops and bluffs is less common.

Rock slides occur less frequently than rockfall in the area. This geomorphic process has been mapped in only two polygons, affecting less than 55 ha.

For both rockfall and rock slides, the geomorphic process label is included in the polygons where the failures were triggered, as well as the downslope polygons that were affected by them.

4.6 Gully Erosion (-V)

Gully erosion affects 29 polygons in the project area covering more than 570 ha or 37% of the area. Gullies are a significant conduit for transporting material downslope and play an important role in the supply of sediment to valley bottoms. In many places, the gullies are incised in bedrock. On the lower slopes and in places where the surficial materials are deep, gullies are incised several meters in surficial material. Along these reaches, the sidewalls are composed of steep surficial material that is susceptible to debris slides. The larger gullies are deep bedrock ravines that are incised more than 30 m and are usually located along fault lines.

5.0 INTERPRETATIONS FOR TERRAIN STABILITY, SOIL EROSION POTENTIAL, LANDSLIDE-INDUCED STREAM SEDIMENTATION, AND SENSITIVE SOILS

5.1 Terrain Stability

Terrain stability was rated for each polygon using the five-class system outlined in Table 3). Unstable or potentially unstable terrain, as identified by terrain stability Class IV, IVr, IVc, V, Vr, or Vc, has been mapped for 51% of the project area (794 ha). This is likely a result of the dominance of steep bedrock throughout the region. Polygons mapped as unstable or potentially unstable are not restricted to any one type of surficial material, drainage, slope morphology or position, and they include a wide variety of attributes and are present throughout the Bedwell project area.

Terrain stability was assessed with regard to both road construction and clearcut harvesting, and if the stability class differs between the two activities, two classes are presented. Subscript ‘r’ is used for the stability class related to road construction and subscript ‘c’ is used for the stability class related to clearcut harvesting (e.g., IVr, IIIc). In the Bedwell project area, more than half (approximately 53%) of the terrain in the area has separate stability classes for road construction and for clearcut harvesting. Within the 53% of the terrain that has a single stability class, 23% is rated as Class IV and 20% is rated as Class V.

Many unstable slopes have a gradient range of 25° to 40° and consist of deposits of till and colluvium. This type of terrain, particularly along streams and creeks, has been subject to rapid mass movements. In contrast, extremely steep slopes (>35°) on competent bedrock with little or no overlying surficial material are relatively stable. It is likely that development in the form of road construction or timber harvesting will aggravate existing instability or promote additional landslides on Class V terrain.

Terrain stability *Class IV* has been mapped throughout the area and has a similar spatial distribution within the project area as the Class V terrain. The terrain attributes are similar to those of Class V but with less evidence of active instability. Terrain units in Class IV should be treated with a similar level of caution as those in Class V, as their potential instability renders them sensitive to disturbance. The designation of Class IV does not preclude road construction or timber harvesting in the entire polygon. If roads must traverse the polygon, alignments must be carefully placed to avoid potentially unstable areas, and special construction techniques will likely be required on some or all road segments.

Terrain stability *Class III* is not restricted to any one type of surficial material, soil drainage, slope morphology or position and includes a wide variety of attributes. Active geomorphic processes in these polygons include snow avalanching, rockfall, and gully erosion. Slope gradients commonly range from 15° to 30°. Class III terrain is evenly distributed throughout the project area. Class III polygons should be interpreted as potentially containing some inclusions of unstable terrain. In general, these polygons are less problematic than those of Class IV or Class V. Evidence of actual or historical instability is lacking. The designation of Class III does not preclude road construction or timber harvesting in most areas within the polygon but does indicate that increased levels of attention in planning, engineering, and maintenance are necessary, relative to Class I and Class II terrain. Slope failures can occur in Class III terrain, and attention to specific road location is warranted. Inadequate or failed drainage systems on roads can initiate landslides.

Terrain stability *Class II* and *Class I* polygons are minimal in the Bedwell project area. Slope gradients commonly range from 0° to 20°. Active geomorphic processes include irregularly sinuous channels, snow avalanching, and rockfall. Class II and Class I polygons have a relatively low inherent instability and display no evidence of historic or active slope failures. Planning and engineering do not require special precautions, except those consistent with sound watershed management.

5.2 Soil Erosion Potential

The rating of soil erosion potential is based on several terrain attributes, including surficial material texture, slope gradient, slope morphology, and slope position (refer to Tables 4 and 5). In many cases, slopes with a high terrain stability hazard rating also have high or very high susceptibility to erosion. Gullied polygons tend to have higher erosion ratings due to the presence of steep gully sidewalls, which are formed by erosion, in contrast to constructional, open slopes. In addition, polygons containing smooth slopes of deep surficial deposits may be more subject to erosion than irregular slopes with numerous bedrock outcrops or benches.

Very High (VH) soil erosion potential has been mapped for only one polygon in the Bedwell project area. The polygon delineates an erosional slope in glaciofluvial sands and gravels, 16 ha. High (H) soil erosion potential has been mapped for several polygons, all of which have either a IV or V terrain stability class rating. These polygons are associated with sandy and/or silty morainal, glaciofluvial sediments, and colluvial deposits on steep slopes. Moderate (M) and Low (L) soil erosion potential have been mapped throughout the area. Very Low (VL) soil erosion potential has been mapped in 70 polygons or 9% of the project area. Six polygons have been assigned a Very Low (VL) soil erosion potential rating, and these are all hummocky or undulating bedrock slopes.

5.3 Landslide-Induced Stream Sedimentation

All polygons with terrain stability Class IVc, IVr, IV, Vr, or V (51% of the terrain) were assigned a rating for landslide-induced stream sedimentation (LISS). Polygons with terrain stability ratings of Class I, II, or III were not assigned a value of LISS. In polygons that include areas with different LISS ratings, the more conservative rating (higher number) is assigned. This interpretation is a general guideline for the likelihood that a landslide initiated in a given polygon will deliver sediment to a downslope stream, lake, or ocean. The results are presented in the following Table 10.

Table 10. Assigned Landslide-Induced Stream Sedimentation Ratings – Bedwell

LISS Class	# of polygons with LISS assigned	Area covered (ha)	% of total polygons	% of total area	% of polygons with LISS assigned	% of area with LISS assigned
1	5	136	5	9	17	10
2	14	209	13	13	26	25
3	36	449	34	29	57	65

5.4 Sensitive Soils

Sensitive soils identified in the Bedwell project area are limited in number. Six polygons have been mapped as Class 1 (confirmed sensitive soils; reserve required) covering 46 ha or 3% of the area (Figure 4). The polygons delineate pure bedrock outcrops on upper slopes. The remaining polygons have been mapped as Class 2, indicating no reserve required or the potential for sensitive

Figure 4

soils in the area. A detailed field assessment (1:5,000 scale) may be necessary to determine whether or not a reserve is required to protect and preserve any sensitive soils within a given terrain polygon mapped as Class 2.

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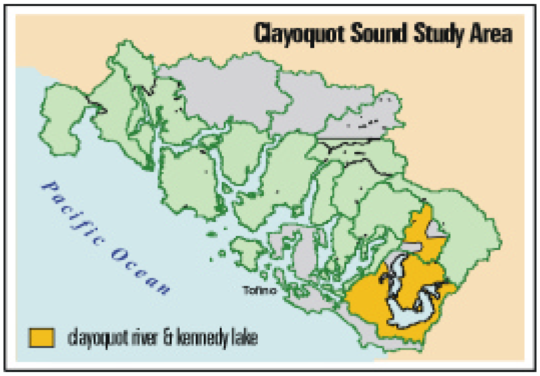
CLAYQUOT RIVER/KENNEDY LAKE PROJECT AREA



CLAYOQUOT RIVER/KENNEDY LAKE PROJECT AREA

1.0 INTRODUCTION

The Clayoquot River/Kennedy Lake project area encompasses 34,569 ha on seven 1:50,000-scale map sheets, including 92F.023, 92F.012, 92F.013, 92F.014, 92F.002, 92F.003, and 92C.093. The area includes the majority of the Clayoquot River watershed, the majority of the Kennedy Lake watershed, the lower reaches of the Kennedy River, and the area known as Kennedy Flats (Figure 5).

This project area is surrounded by watersheds mapped in the previous years' terrain inventory. Kennedy River project area (Year Three) is immediately to the north and east. Tofino Creek (Year One), Marble (Year Two), and Muriel Ridge (Year Three) project areas are adjacent to the west. Edgematching was necessary in all of these areas and in many places; the same air photos with the previous years' typing were used for the Clayoquot/Kennedy work.

1.1 Clayoquot River Physiography

The Clayoquot River watershed is characterized by steep slopes, extensive bedrock outcrops, and many active geomorphic processes (Photo 9). Rockfall, rock slides, gullying, debris slides, debris torrents and flows, and snow avalanches are all common in the headwaters of the Clayoquot River, resulting in an abundance of colluvium. Till deposits are essentially absent in this portion of the project area.

Photo 9
View down valley of the Clayoquot River watershed. Clayoquot Lake and Kennedy Lake can be seen in the distance.

Figure 5

The valley bottom along the headwaters of the river is wide and gentle to moderately sloping, and there are several small lakes. A few of the lakes occupy large bedrock depressions carved by ice, while others were created by the encroachment of colluvial fans on the valley floor, eventually impounding the Clayoquot River. Other lakes in the area include Norgar Lake (369 m above sea level) towards the headwaters of the Clayoquot River (Photo 10) and Clayoquot Lake (15-20 m asl) located approximately 1.5 km upstream of the mouth of the Clayoquot River.

Photo 10
Norgar Lake towards the headwaters of the Clayoquot River.

The mid and lower valley of the Clayoquot River is characterized by steep sidewalls, extensive bedrock outcrops, and active geomorphic processes. Rockfall, rock slides, gullying, debris slides, and debris torrents and flows are common in the area. Till deposits are abundant on the lower slopes as a blanket and taper to a veneer on the mid and upper slopes. Colluvium varies in depth, and is several meters deep at the base of large bedrock bluffs. Glaciofluvial deposits have been mapped in a few areas. Extensive fluvial deposits are present on the wide floodplain. Organics have been mapped in a few isolated places within a hanging valley.

The tributary valleys generally have a steep gradient as well as steep sidewalls. Soils are shallow and bedrock exposures are common. Colluvial deposits dominate the surficial materials, with till deposits restricted to the lower slopes along the lower reaches of the valleys.

Elevations in the Clayoquot River watershed range from 4 m asl at the mouth of the river to 1484 m asl at Steamboat Mountain in the northeastern portion of the project area.

1.2 Kennedy Lake Area Physiography

Kennedy Lake is a large U-shaped lake, with the Kennedy River flowing into the northern end of the east arm and the Clayoquot River flowing into the northern end of the west arm (referred to as Clayoquot Arm). The 'U' of the lake is separated by a large wide peninsula with a broad ridgeline and broad hanging valleys. Small lakes dot the ridgeline.

Steep slopes characterize the majority of the Kennedy Lake study area, with gentle slopes dominating the southwestern portion. The elevation in the area ranges from sea level along the lower reaches of the Kennedy River to Mount Maitland (1200 m asl), located between the Kennedy River to the east and the Sand River to the west. Other peaks in the area include Mount Dawley (723 m asl) and Salmonberry Mountain (714 m asl), both located on the southeast side of Kennedy Lake.

Throughout much of the area, the steep terrain is associated with the many bedrock outcrops and bluffs. However, the mid and lower reaches of several of the creeks and rivers, including the Sand River, are incised in deep till colluvial, and glaciofluvial deposits. These oversteepened slopes are inherently unstable.

Rockfall, rock slides, gullying, debris slides, and debris flows and torrents are geomorphic processes common to the area. This area has been heavily logged, and although these processes occur naturally in the study area, most of the debris slides, debris torrents, and debris flows that have occurred are logging related. These events transfer large volumes of material from the upper slopes to the lower slopes and valley bottoms, creating a complex of colluvial cones and fans. These processes are common in the Sand River watershed, upslope of Highway 4 on the southeast side of Kennedy Lake, and on the steep slopes west of Muriel Lake.

From Kennedy Lake, the lower reaches of the Kennedy River flow west and northwest to Kennedy Cove along Tofino Inlet. Kennedy Flats is located west and southwest of the lake. Pacific Rim National Park and Long Beach are immediately to the southwest of Kennedy Flats.

The gentle slopes of Kennedy Flats (Photo 11) in the southwestern portion of the study area are a reflection of a raised sea level during glacial times. Deep marine deposits blanket the area. Scattered bedrock knobs protrude above these gentle slopes, and till deposits and colluvium are common on the steeper, higher elevation slopes (maximum of 250 m asl). Till deposits were also observed on the gentle slopes in throughout the area. Organics are common in this area and have been extensively mapped in association with the marine materials, reflecting the poor to imperfect drainage conditions of the fine sediments. Several low-gradient streams dissect Kennedy Flats, including Lost Shoe Creek (flows west-southwest into Florencia Bay), Staghorn Creek (flows northeast into Kennedy Lake) (see photo 12 on the following page), Sandhill Creek (flows west into Wickaninnish Bay), and Kootowis Creek (flows west into Grice Bay).

Photo 11

Kennedy Flats, with Kennedy Lake on the right, Long Beach on the left, and Highway 4 in the center-left.

Photo 12
Staghorn Creek, a low-gradient stream on Kennedy Flats. Evidence of stream restoration work is visible in the foreground

1.3 Bedrock Geology

The bedrock geology in the Clayoquot/Kennedy project area is a complex of varying bedrock types. The area is dominated by volcanics and includes sedimentaries, and intrusives.

Clayoquot River is underlain primarily by basaltic volcanics of the Middle to Upper Triassic aged Vancouver Group of the Karmutsen Formation. Sedimentaries of the Middle to Upper Triassic Vancouver Group (including limestone) have been mapped and were observed towards the headwaters of the river (Photo 13). Volcanics of the Middle to Upper Devonian aged Sicker Group have been mapped on the west side of the lower reaches of the Clayoquot River.

Photo 13

Limestone outcrop and rubble beside Norgar Lake.

Muriel Ridge and the northern part of Kennedy Flats are underlain by bands and intrusions of granodioritics of the Island Plutonic Suite (Early to Middle Jurassic), intrusives of the Westcoast Crystalline Complex (Paleozoic to Jurassic), volcanics of the Sicker Group, and basaltic volcanics of the Karmutsen Formation.

The Sand River area is underlain by intrusives of the Clayoquot Plutonic Suite (Paleocene to Eocene), calc-alkaline volcanics of the Lower Jurassic aged Bonanza Group, sedimentaries of the Vancouver Group, and volcanics of the Karmutsen Formation.

The southern part of Kennedy Flats and the south and east side of Kennedy Lake is underlain by volcanics of the Sicker Group, basaltic volcanics of the Vancouver Group of the Karmutsen Formation, sedimentary rocks of the Mississippian to Lower Permian aged Buttle Lake Group, intrusives of the Clayoquot Plutonic Suite, sedimentary rocks of the Vancouver Group, volcanics of the Bonanza Group, and calc-alkaline volcanics of the Paleocene to Eocene aged Flores volcanics.

2.0 METHODS

2.1 Fieldwork

Fieldwork was completed over a period of sixteen days in April, June, and July, 2002. In April, 14 truck traverses were completed by two field teams led by Dave Bergman, Marian Oden, and Heather Stewart. In June and July, twenty-seven ground traverses with access by truck and/or helicopter were completed by four field teams led by Dave Bergman, Jason Hindson, Marian Oden, Brian Roberts, and Bryan Tasaka (Figure 2b). Ucluelet was used as the base camp for the truck work in April. Tofino was the base camp for the June-July trip.

Traverses were concentrated in areas with Class IV and V terrain. Sampling intensity was low for terrain with steep bedrock slopes, for terrain dissected by deep, closely spaced, ravines, and for terrain dominated by snow avalanche tracks with minimal operable timber. Ms. Oden viewed areas considered inaccessible (e.g., lack of landing spots, dangerous terrain) or inoperable during short helicopter overview flights on June 30 and July 3. Sampling intensity was higher in all other areas. After close inspection of the air photos with the completion of each traverse, the terrain observed in the field was considered to be representative of the surrounding terrain.

2.2 Reliability

The reliability of the mapping can be represented by the number of polygons field checked, the percentage of polygons checked, and the percentage of total area (in ha) checked. This information is summarized for the project area in Table 11. Visual plots supplement the detailed and reconnaissance plots and are not counted in the total number of polygons field checked. These field-checked values fall well within the appropriate range for Terrain Survey Intensity Level C as defined in the *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests 1999) and they exceed the contractual requirement of a minimum of 35% of the polygons checked. In addition, 42% of the unstable or potentially unstable polygons and 52% of the area mapped as unstable or potentially unstable terrain was field checked, increasing the accuracy of the stability portion of the mapping (Table 12).

Figure 2b

Table 11. Summary of Reliability of Mapping-Clayoquot/Kennedy Project Area

Total Mapped Area (ha)	Number of Terrain Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Field Checked	Percent of Area Field Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
34569	1445	24	509	95	26	630	17829	42%	52%	1.75

Table 12. Summary of Class IV & V Field Checked**- Clayoquot/Kennedy Project Area

Total Class IV & V Area (ha)	Number of Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Checked	Percent of Area Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
11644	658	18	226	67	0	293	6541	45%	56%	0.85

** Includes Class IV, IVr, IVc, V, Vr, and Vc.

3.0 SURFICIAL MATERIALS

3.1 Anthropogenic (A)

Anthropogenic material is applied to materials that are modified by humans such that their original physical properties (e.g., structure, cohesion, compaction) have been significantly altered. In the Clayoquot/Kennedy project area, this material has been mapped in four polygons, covering or partially covering 45 ha. One 5 ha polygon is associated with a landfill on the southern side of Kennedy Flats. Here the material overlies marine sediments. The other three polygons are associated with deep glaciofluvial deposits that have been extensively used as gravel pits. The glaciofluvial gravels have been excavated, reworked, and piled (*FGj//Ah*).

3.2 Colluvium (C)

Colluvium is a common material in the project area, covering or partially covering 615 polygons (43% of the total) or 10,820 ha (31% of the total). There are three distinct types of colluvial deposits in the area, which are distinguished by the source and depositional environment. A colluvial veneer (*Cv*) or blanket (*Cb*) is common on the moderately steep to steep mid and upper slopes. These slopes are typically bedrock controlled, and the colluvium is a result of eroded bedrock raveling or falling downslope and weathering into a clast-rich mineral soil. The matrix texture of this material is commonly a silty sand (*zs*), and rubble-sized clasts (angular particles 2 mm to 256 mm) occupy 50% to 90% of the material volume. These soils are unconsolidated, highly permeable, and are often complexed with a morainal veneer or blanket (e.g., *Cv/Mv*).

There are a few scattered colluvial cones (*Cc*) in the area located at the base of bedrock bluffs and outcrops. These terrain features are comprised of rubble (*r*), blocks (*a*), or a combination of the two clast sizes (*x*). Coarse fragments occupy approximately 70% to 100% of the material volume, and fine sediments, where present, comprise an interstitial sandy or silty sandy matrix. These deposits are unconsolidated and highly permeable, and the depth of the material is estimated to range from 2 m to greater than 5 m on the lower end of the cone.

The third type of colluvial deposit is a product of rapid mass movements. The deposition zones of some of the debris flows and torrents in the area are colluvial cones or fans (*Cf*) formed by the chronic supply of material from mass movements interspersed with fluvial deposition. The deposits are poorly sorted and are comprised of a mixture of fine and coarse fragments ranging in size from sand, silt, and clay to blocks and boulders. The shape of the coarse fragments ranges from angular to rounded. These deposits are common at the mouths of or along the lower reaches of gullies and creeks (Photo 14). Those fans that are derived predominantly from colluvial processes are labeled *Cf* and those that are derived predominantly from fluvial processes (but may include a lesser amount of colluvium) are labeled *Ff*. The material is unconsolidated and fairly permeable, and the depth of the deposits is estimated to range from 2 m to greater than 5 m.

Photo 14

Cross-section at field plot #TD1046 of colluvial fan/cone complex formed by debris torrents.

3.3 Weathered Bedrock (D)

Weathered bedrock has been mapped as a minor component in sixteen polygons, totaling 229 ha, in the project area. In these areas, the bedrock has weathered to a veneer or thin veneer and the material has not been removed by any geomorphic agent (e.g., water, gravity, or wind). The material is thick enough within a given polygon (less than 1 m deep) for identification and mapping. The weathered bedrock in the area consists of unconsolidated rubble or blocks and is rapidly drained.

3.4 Fluvial Deposits (F)

Fluvial deposits are common along the valley bottoms and mouths of the larger creeks in the project area. These deposits have been mapped in fifty-five polygons (covering or partially covering 6,642 ha) in the project area (19%). One of the polygons is 5,487 ha in size, encompassing much of the gently-sloping Kennedy Flats area, and the deposits are complexed with marine sediments. In that area, fluvial deposits were observed along existing and relict floodplains and are not as extensive as the marine deposits.

In the mid and lower reaches of the main valleys there are well-developed floodplains (*Fp*) consisting primarily of sandy gravels with boulders and sub-rounded clasts. In places on Kennedy Flats, pure sands have been deposited (Photo 15). In general, coarser sediments are in the upper valleys, and the average clast size decreases downstream. The exception to this is at the confluences with the tributaries, large gullies, and creeks. These side valleys supply sediment continuously, and those that are subject to debris flows periodically supply a large volume of sediment of all sizes. Since deglaciation, the creeks and rivers have eroded the glacial sediments in the upper valleys and deposited these in the mid and lower valleys, burying other glacial deposits. The fluvial sediments are highly permeable, and the depth of most of the deposits is estimated to range from 2 m to greater than 10 m.

Photo 15

Exposure of sandy fluvial deposits on Kennedy Flats.

Within the floodplains, there are sections that periodically flood, and a significant amount of sediment is transported downstream. These fluvial deposits are considered to be active and are distinguished with an 'A' qualifier (*FAp*). Many of the deposits are located at the mouths of the many rivers and streams in the area (*Ff, Ft*). Some of the polygons in the valley bottoms are a combination of fluvial and morainal materials (e.g., *Mj/Fj*, *Fj/Mb*), as the two materials grade into one another with indistinct boundaries.

The fluvial sediments are highly permeable, and the depth of most of the deposits is estimated to range from 2 m to greater than 8 m.

3.5 Glaciofluvial Deposits (FG)

Glaciofluvial materials deposited by large glacial meltwater rivers have been mapped in 23 polygons and cover or partially cover 796 ha in the project area (2%). They have been observed and mapped as a massive deposit in the southern end of the project area, at the mouths of some of the rivers, and as terraces on some of the valley mid slopes (Photo 16).

Photo 16

Cross-section of glaciofluvial deposit in the Sand River drainage. Bedding planes are easily visible.).

These deposits are poorly to well sorted sandy gravels and mixed fragments. The material is non-cohesive and subject to ravel on steep slopes, and the poor cohesion renders it highly susceptible to erosion. The deposits are estimated to be 5 m to 30 m deep and are moderately well to well drained. This material is complexed with morainal deposits, fluvial sediments, and organics in many of the polygons. In places, post-deglaciation incision and gully erosion through the deposits has resulted in oversteepened banks (*FGks/Mks-V*) that are susceptible to failure, chronic ravelling, and erosion.

3.6 Lacustrine (L)

Lacustrine materials are sediments associated with the settling of sediment suspended in lakes, underwater gravity flows, or washing from wave sediments. They are limited in extent in the Clayoquot/Kennedy project area and have been mapped in only three polygons. All have been identified along the Kennedy Lake shoreline. One polygon is sandy gravels subjected to washing by wave action (*sgLAj-U*). These gravels are well drained with terrain stability Class I. The other two are complexed with marine sediments (*gsLp//mWp*). These have been rated terrain stability Class I, with soil drainage of imperfect to well.

Glaciolacustrine (*LG*)

Glaciolacustrine sediments have been mapped in only two polygons in the project area. The deposits include visible bedding planes consisting of fine silt, and clay, with a minor component of sand in one deposit. The material is likely a result of temporary ice damming during glaciation along the Clayoquot River. Both occurrences have been complexed with till and fluvial sediments (*dszMw//smLGjp/gFfp*). The average depth of the material is greater than 3 m and may be as deep as 15 m. The material is imperfectly to well drained. Both have an assigned terrain stability Class II.

3.7 Moraine (M)

Morainal material, also known as till, is the dominant surficial material in the Clayoquot/Kennedy project area. Till deposits have been mapped in 1023 polygons (71% of the total), covering or partially covering 16,144 ha (47% of the total area).

In general, till deposits are absent on the steeper slopes (greater than 35°) and blanket (*Mb*) the lower and mid slopes. Deeper deposits (*Mj, Ma*) are present primarily in the valley bottoms and are extensive across the Kennedy Flats area. The deposits are dissected by major and minor creeks, and in places, stream erosion has resulted in oversteepened banks (*Ms*) susceptible to failure. The tills in this area are relatively compact and resistant to erosion in an undisturbed state.

Upon disturbance (e.g., in road construction or in slope failure), the material loses much of its original strength. The surface expression of the thinner deposits (*Mv*) reflects the shape of the underlying bedrock. Much of the terrain at higher elevations is bedrock controlled with numerous outcrops and bedrock hummocks. The till deposits in these areas typically mantle (*Mw*) the underlying irregular bedrock with a till veneer (less than 1 m deep) on the steeper slopes, adjacent to a deep pocket (1-3 m deep) of till in the troughs (Photo 17). The surface expression coincides with the irregularity of the bedrock.

Photo 17

Mantle of till visible between two bedrock outcrops.

Many of the polygons delineating till deposits are complexed with other materials such as colluvium (*Mb/Cv*) or with bedrock exposures (*Mv/Rk*).

Since the time of deposition during glaciation, the upper meter of the material has weathered and is fairly permeable (Photo 18). The unweathered material is generally highly consolidated and impermeable. The coarse fragments in both the weathered and unweathered zones are variable in size and occupy 30% to 80% of the material volume. The matrix texture of the till ranges from clay-rich (*c*) to sandy (*s*). The matrix texture is a clayey silt (*cz*) with minor sand (*s*). The clast roundness ranges from sub-angular to round.

Photo 18

Exposure of highly consolidated till. Weathered zone is clearly visible over the unweathered zone.

3.8 Organics (O)

Two types of organics occur in the project area and have been mapped in 46 polygons covering 1,095 ha. One type is associated with bogs and wetlands, and is common on gentle slopes throughout the southwestern portion of the project area. The areas are very poorly to imperfectly drained, and typically the material has accumulated over another surficial material. Organics have been mapped as homogenous units or as a complex with morainal, fluvial, or marine deposits.

The other type of organics is folisols. This surficial material is an accumulation of leaf litter, twigs, and branches. These soils are a very thin (*x*) or thin veneer (*v*) directly over bedrock. These organics can support the growth of large trees, and in the project area, they occur on moderately steep to steep bedrock slopes and may be complexed with till or colluvium. This type of organic soil is ordinarily well to rapidly drained.

3.9 Bedrock Exposure (R)

Bedrock outcrops and rock covered by a thin mantle (up to 10 cm thick) of unconsolidated mineral or organic soil has been mapped as a terrain component in more than 840 polygons (58%) or 11,739 ha (34%). In many places, pure bedrock has been mapped but in most polygons, bedrock is complexed with a deposit, most commonly till or colluvium. On many slopes, the bedrock is uniform and the surface expression is related to the slope gradient (*Rs, Rk, Ra*), but in many places, the bedrock is irregular and expressed as hummocks (*Rh*) or undulations (*Ru*).

3.10 Marine (W)

Marine sediments were observed in or interpreted to be present in 82 polygons (6%) covering or partially covering 8,027 ha (23%). The associated soil drainage ranges from very poor to well. The material has been extensively mapped in the low-elevation Kennedy Flats area where much of the terrain was underwater at some stage during recent glacial and deglacial periods. The material was observed in many places as pure silt (Photo 19), pure sand, or silt with minor clay and sand components. Where undercut by a stream, the material is prone to slumping and slow mass movements. Marine sediments were also mapped in low-lying areas along Kennedy Lake (current elevation of 4 m asl). In many places the material is complexed with morainal, fluvial, glaciofluvial deposits or bedrock.

Photo 19
Exposure of bedded silty marine sediments on Kennedy Flats.

4.0 GEOMORPHIC PROCESSES

4.1 Snow Avalanches (-A)

Snow avalanching has been mapped in 62 polygons in the project area, affecting 1672 ha or 5% of the area. The process is common in the Clayoquot River watershed and affects little of the terrain outside of this watershed. This geomorphic process label is included in the polygons where the avalanches initiate as well as in the downslope polygons that are affected by the events. Snow avalanches play an important role in transporting entrained debris from the upper and mid slopes to lower and valley-bottom slopes.

4.2 Slow Mass Movement (-F)

This geomorphic process has been mapped in two polygons in the Kennedy Flats area. Subclasses associated with these processes are a slump in surficial material (-*u*) and a slump-earthflow (-*x*). Both events have occurred in deep marine sediments and are presently or have been historically undercut by a stream. These unstable areas were observed on the ground (Photo 20) and although the mapped areas affected are small (total of 12 ha), these events have likely occurred elsewhere in these extensive fine sediments in the area. Both polygons have been mapped as terrain stability Class V.

Photo 20

Debris slump in marine sediments as evidenced by the lean in the trees on the right-hand side of the photo.

4.3 Irregularly Sinuous Channel (-I)

Many of the creeks in the project area are large and transport a significant volume of sediment. This geomorphic process has been mapped for nineteen polygons, covering 6,127 ha. One of the polygons is a large delineation of terrain on Kennedy Flats where there are several small creeks. In many places the creeks or too small to delineate as separate polygons and were therefore included in a much larger polygon.

The mid and lower reaches of the large creeks have well-defined main channels that are irregularly sinuous (no meanders), with a channel gradient of less than 15°. There are numerous large gravel bars throughout the area and back channels on the larger creeks. These reaches consist primarily of fluvial deposits. The upper reaches of many of these creeks have gully characteristics rather than river attributes with moderately steep channel gradients (15° to 30°), well-defined sidewalls at least several meters high, and no floodplain. The channels are incised in shallow or deep surficial material deposits, as well as bedrock.

The Clayoquot River is a moderate-sized river that transports a significant volume of sediment. For much of its length, the river is irregularly sinuous with a single, well-defined channel. Along these reaches, the average channel gradient is less than 15°. These reaches consist primarily of fluvial deposits. There are several large gravel bars and the river has an active floodplain 20 m to approximately 300 m wide.

4.4 Rapid Mass Movement (-R)

Rapid mass movements occur frequently in the Clayoquot/Kennedy project area and have been identified in 374 polygons (26%) affecting 7,419 ha (21%). Landslides have *initiated* in 247 of the 374 polygons. Approximately 52% of those initiation polygons are located in logged areas and the landslide initiation is believed to be a result of logging in the area, including clearcutting, road location, or road construction techniques.

In order to distinguish between natural landslides and logging-related landslides, an additional character or subtype was created for this project and added to the terrain symbol for the initiation of a rapid mass movement (-*R*”). For a road-related landslide, subtype ‘1’ was added to the symbol (e.g., -*R1”s*), for a clearcut-related landslide, subtype ‘2’ was added to the symbol (e.g., -*R2”s*), and if there are landslides within a polygon that initiated from both roads and open slopes within a clearcut area, the subtype '3' was added (e.g., -*R3"s*). If there is no subtype number, the landslide occurred naturally. This additional symbology is used only for the polygon containing the initiation zone.

Logging-related landslides are densely spaced in several areas, including the slopes above Muriel Ridge, the southeastern slopes above Highway 4, the Sand River watershed, and the east side of Clayoquot Arm. Many of these have advance rehabilitation and are well vegetated (Photo 21).

Photo 21

Side valley on east side of Clayoquot Arm. Old road-related landslides are visible as linear strips of dense alder. Small more recent landslides are visible in places on the mid and upper slopes.

Types of rapid mass movements identified in the Clayoquot/Kennedy project area include debris slides, debris slumps, debris flows, debris torrents, rockfall, and rock slides. Much of the terrain that is subject to these types of rapid mass movements is subject to more than one process. The terrain labels are typically a complex of two or three processes, particularly in gullied terrain, where in places it is difficult to make a distinction between a debris slide and a debris torrent. After an event has occurred within smaller gullies, it is sometimes difficult to determine if the surficial material slid down the gully or if it was saturated and flowed downstream. The initiation point of a debris torrent is not always easily identified, particularly for those areas with air photo interpretation only. As a result, the label for a number of the polygons subject to rapid mass movements has a complex of subclasses.

For all of the subclasses identified in the area, the geomorphic process label is included in the polygons where the process initiated (-*R"s*), as well as the downslope polygons that were affected by the event (-*Rs*). The " symbol indicates the initiation zone of the rapid mass movement. In most places, an on-site symbol on the map is used to delineate the extent of a landslide.

4.5 Debris Slides (-R"s) and Debris Slumps (-R"u)

Debris slides, both natural and logging related, are common in the project area. Natural slides have occurred on both open slopes and along sidewalls of the many creeks and rivers in the area. In the harvested areas it is not easily known which, if any, of the slides pre-date harvesting and road construction, therefore, slides in logged areas were considered to be logging related.

Debris slides have initiated in 168 polygons (12% of total) that delineate 3,617 ha (10% of the total area). Of the 168 polygons, 129 are considered to be logging related. Twenty-nine debris slides are related to clearcutting. Roads have triggered 47 debris slides. A combination of both road construction and harvesting in a given polygon have triggered 55 debris slides.

Typical initiation zones for natural failures include steep bedrock slopes with veneers of colluvium or till, stream banks, or gully sidewalls composed of deep till deposits or colluvium undercut by fluvial action. Gully sidewall failures are more common than open-slope failures. Debris slides or slumps within gully systems commonly deposit in the channel and are later transported downstream. The volume of most of the debris slides is estimated to range from 50 m^3 to 1000 m^3. Debris slides have affected 51 polygons downslope that delineate 833 ha.

Debris slumps are uncommon and have been identified in only a few polygons. All have occurred in marine sediments.

4.6 Debris Flows (-R"d) and Debris Torrents (-R"t)

Debris flows and debris torrents have occurred throughout the project area. One or the other has initiated in 67 polygons (5% of the total) that delineate 1541 ha (4% of the total area). Following Howes and Kenk (1997), a debris torrent is distinguished from a debris flow in that it is a slide channelized down a steep, well-defined stream channel. Debris flows and torrents usually travel longer distances downslope than other types of slope failures, and this is evident by the fact that debris flows or torrents have affected downslope polygons equaling approximately 782 ha.

The debris flows in the project area have initiated on mid or upper slopes in till or colluvium and many have flowed into creeks or gullies, triggering a debris torrent (Photo 22). Many of the larger gully systems are inherently unstable, and debris torrents may occur relatively frequently (on a geologic time scale), flushing out any material that may have accumulated between events. The volume of the debris torrents is estimated to range from 1000 m^3 to 10,000 m^3, depending on several factors, including distance traveled to the deposition zone and the amount of material entrained in the transport zone.

Photo 22

View is downslope of a recently scoured channel by a debris flow/torrent down a shallow gully.

4.7 Rockfall (-R”b) and Rock Slides (-R”r)

Rockfall is a common process throughout the steep, mountainous areas within the project area. This is partly a result of the prominence of bedrock at the surface and partly due to the highly fractured and jointed nature of the rock itself. Rockfall is initiated from within 76 polygons (5%) that encompass 2265 ha (7% of the total area). The average rockfall event is small and travels a short distance. Much of the rockfall occurs within gully systems where the material accumulates in the channel and is eventually transported downstream during episodes of high discharge. Rockfall accumulation is also common at the base of bedrock outcrops and bluffs in the form of cones and aprons.

Rock slides occur less frequently than rockfall in the area. This geomorphic process has been mapped in 26 polygons, affecting 645 ha.

4.8 Washing (-W)

Washing is the modification of a surficial material by wave action, resulting in the removal of fines from the material. This geomorphic process has been mapped in one polygon along Kennedy Lake where waves have removed the silts and fine sands leaving a sandy gravely beach. This process likely occurs elsewhere along the lake but it was assigned with confidence only to the polygon where it was observed in the field.

4.9 Gully Erosion (-V)

Gully erosion affects 174 polygons (12%) in the project area affecting more than 2,847 ha or 8% of the total area. Gullies are a significant conduit for transporting material downslope and play an important role in the supply of sediment to valley bottoms. In many places, the gullies are incised in bedrock. On the lower slopes and in places where the surficial materials are deep, gullies are incised several meters in surficial material. Along these reaches, the sidewalls are composed of steep surficial material that is susceptible to debris slides. The larger gullies are deep bedrock ravines that are incised more than 30 m and are usually located along fault lines.

In numerous polygons, this geomorphic process has been complexed with the initiation of rapid mass movements and with snow avalanching.

5.0 INTERPRETATIONS FOR TERRAIN STABILITY, SOIL EROSION POTENTIAL, LANDSLIDE-INDUCED STREAM SEDIMENTATION, AND SENSITIVE SOILS

5.1 Terrain Stability

Terrain stability was rated for each polygon using the five-class system described in Table 3. Unstable or potentially unstable terrain, as identified by terrain stability Class V, Vr, Vc, IV, IVr, or IVc, has been assigned to 658 polygons (46%) that delineate 11644 ha (34% of the total project area). Polygons mapped as unstable or potentially unstable are not restricted to any one type of surficial material, drainage, slope morphology or position, and they include a wide variety of attributes. Unstable or potentially unstable terrain has been mapped throughout the Clayoquot/Kennedy project area.

Terrain stability *Class V* has been mapped for 39 polygons that encompass 666 ha (2% of the total area). All polygons include an active geomorphic process and most polygons have multiple processes affecting the terrain. The processes include rapid and slow mass movements and gully erosion. Surficial materials include till, glaciofluvial sediments, colluvium, and marine deposits.

Terrain stability *Class Vr* has been mapped for 16 polygons that encompass 407 ha (1% of the total area). This terrain has a similar spatial distribution within the project area as the Class V terrain and similar terrain attributes. Class Vr has been mapped with Class IIc, IIIc, and IVc. Terrain stability Class Vc has not been assigned in the project area. It is likely that development in the form of road construction or timber harvesting will aggravate existing instability or promote additional landslides on Class V terrain.

Terrain stability *Class IV* has been mapped for 404 polygons that encompass 7,371 ha (21% of the total area). This terrain has a similar spatial distribution within the project area as the Class V terrain. The terrain attributes are similar to those of Class V but with less evidence of active instability. Terrain units in Class IV should be treated with a similar level of caution as those in Class V, as their potential instability renders them sensitive to disturbance. The designation of Class IV does not preclude road construction or timber harvesting in the entire polygon. If roads must traverse the polygon, alignments must be carefully placed to avoid potentially unstable areas, and special construction techniques will likely be required on some or all road segments.

Terrain stability *Class IVr* has been assigned to 198 polygons that encompass 3,181 ha (9% of the total area). Surficial materials include till, glaciofluvial sediments, colluvium, weathered bedrock, and marine sediments. Geomorphic processes occur in approximately half of the Class IVr polygons and include gully erosion, rapid mass movements, snow avalanching, and rockfall. This terrain stability class is assigned to polygons in which timber harvesting is unlikely to affect slope stability, but standard road construction (i.e., balanced cut-and-fill design) across the terrain may initiate significant instability along large sections of a road. If road construction is planned across this terrain, a detailed terrain stability field assessment should be conducted, and alternative construction techniques (e.g., full-bench construction with end-hauling or engineered fillslopes) can be recommended. This terrain stability class has a similar spatial distribution within the project area as that of Class IV and Class V terrain. Class IVr has been mapped with Class IIc and IIIc.

Terrain stability *Class IVc* has been assigned to 4 polygons that encompass 63 ha (less than 1% of the total area). Surficial materials include till and colluvium, with bedrock exposures. This class has been mapped with terrain stability Class Vr.

Terrain stability *Class III* has been mapped for 250 polygons covering 3,463 ha (10% of the total area). This type of terrain is not restricted to any one type of surficial material, soil drainage, slope morphology or position and includes a wide variety of attributes. Active geomorphic processes in these polygons include snow avalanching, rock slides, rockfall, gully erosion, and the transport and runout zones of rapid mass movements. Class III terrain is evenly distributed throughout the project area. These polygons should be interpreted as potentially containing some inclusions of unstable terrain. In general, these polygons are less problematic than those of Class IVc, IVr, IV, Vr, or V. Evidence of actual or historical instability is lacking. The designation of Class III does not preclude road construction or timber harvesting in most areas within the polygon but does indicate that increased levels of attention in planning, engineering, and maintenance are necessary, relative to Class I and Class II terrain. Slope failures can occur in Class III terrain, and attention to specific road location is warranted. Inadequate or failed drainage systems on roads can initiate landslides on these slopes.

Terrain stability *Class II* has been assigned to 302 polygons, encompassing 10,526 ha (30% of the total area). This high occurrence is a result of the extensive gentle terrain on Kennedy Flats. Terrain stability *Class I* has been assigned to 107 polygons encompassing 1,504 ha (4% of the total area). Active geomorphic processes include rockfall, irregularly sinuous channels, and the runout zones of snow avalanches and rapid mass movements. Class II and Class I polygons have a relatively low inherent instability and display no evidence of historic or active slope failures. Planning and engineering do not require special precautions, except those consistent with sound watershed management.

5.2 Soil Erosion Potential

The rating of soil erosion potential is based on several terrain attributes, including surficial material texture, slope gradient, slope morphology, and slope position (Tables 4 and 5). In many cases, slopes with a high terrain stability hazard rating also have high or very high susceptibility to erosion. Gullied polygons tend to have higher erosion ratings due to the presence of steep gully sidewalls, which are formed by erosion, in contrast to constructional, open slopes. In addition, polygons containing smooth slopes of deep surficial deposits may be more subject to erosion than irregular slopes with numerous bedrock outcrops or benches.

Very High (VH) soil erosion potential has been mapped for only 8 polygons covering 115 ha (less than 1% of the project area). This has been mapped on moderate to steep slopes with sandy tills, glaciofluvial deposits, and marine deposits. High (H) soil erosion potential has been mapped for 311 covering 5,458 ha polygons (16% of the area). These polygons are associated with sandy and/or silty morainal and glaciofluvial sediments on steep slopes. Moderate (M) soil erosion potential has been mapped in 501 polygons covering 7,754 ha (22% of the area). Low (L) soil erosion potential dominates the landscape in the project area and has been mapped in 551 polygons encompassing 14,267 ha (41% of the area). Very Low (VL) soil erosion potential has been mapped in 37 polygons (824 ha; 2% of the area). Polygons with a Very Low (VL) soil erosion potential are associated with bedrock, organics, and blocky colluvial deposits.

5.3 Landslide-Induced Stream Sedimentation

All polygons with terrain stability Class of IVc, IVr, IV, Vr, or V (34% of the terrain) were assigned a rating for landslide-induced stream sedimentation (LISS). Polygons with terrain stability ratings of Class I, II, or III were not assigned a value of LISS. In polygons that include areas with different LISS ratings, the more conservative rating (higher number) is assigned. This interpretation is a general guideline for the likelihood that a landslide initiated in a given polygon will deliver sediment to a downslope stream, lake, or ocean. The results are presented in Table 13.

Table 13. Assigned Landslide-Induced Stream Sedimentation Ratings – Clayoquot/Kennedy

LISS Class	# of polygons with LISS assigned	Area covered (ha)	% of total polygons	% of total area	% of polygons with LISS assigned	% of area with LISS assigned
1	235	3,851	16	11	36	33
2	152	2,970	11	9	23	26
3	271	4,804	19	14	41	41

5.4 Sensitive Soils

Sensitive soils identified in the Clayoquot/Kennedy project area are limited in number. Thirty-five polygons have been mapped as Class 1 (confirmed sensitive soils) covering 722 ha or 2% of the area (Figure 6). The polygons delineate pure bedrock outcrops on upper slopes, pure blocky colluvial deposits, and pure organics. The organics are scattered on Kennedy Flats.

The remaining polygons have been mapped as Class 2, indicating no reserve required or the potential for sensitive soils in the area. A detailed field assessment (1:5,000 scale) may be necessary to determine whether or not a reserve is required to protect and preserve any sensitive soils within a given terrain polygon mapped as Class 2.

Figure 6

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VARGAS ISLAND PROJECT AREA

VARGAS ISLAND PROJECT AREA

1.0 INTRODUCTION

The Vargas Island project area encompasses approximately 3250 ha including Vargas Island, located 4 km due west of Tofino on the west side of Father Charles Channel, and a small area on the Esowista Peninsula, located 6.5 km southeast of Tofino and 5 km west-northwest of the Tofino Airport (Figure 7). Vargas Island is covered by 1:50,000-scale map sheets 92E.020, 92E.030, 92F.011, and 92F.021. The small area on the Esowista Peninsula is covered by map sheets 92F.001 and 92F.011.

The topography in the area is characterized by gently rolling and undulating terrain with only three small areas on Vargas Island reaching above 30 m above sea level. With the exception of these hills, Vargas Island and the peninsula polygons were likely submerged for long periods of time during the last glacial period when sea level was an average of 50 m above its present-day level. The terrain on the island is dominated by marine sediments, extensive organic areas, with several large sandy beaches.

Bedrock geology of Vargas Island and the portion of the Esowista Peninsula underlying the project area is dominated by rocks of the Triassic to Cretaceous aged Pacific Rim complex, particularly undivided volcanics. The northeastern tip of Vargas Island is underlain by Paleozoic to Jurassic aged rocks of the Westcoast Crystalline Complex. Bedrock outcrops are common along the shoreline around the island and comprise the few hills in the project area.

Figure 7

2.0 METHODS

2.1 Fieldwork

Fieldwork was completed in two days in June and July 2002. At this time, three teams led by Dave Bergman, Marian Oden, and Bryan Tasaka completed three foot walking traverses (Figure 2c) in the area, all concentrated in parts of the island with some relief. Two traverses were completed in the northern quarter of the island and one in the southern quarter. Tofino was used as the base camp, and access to the island was by helicopter. Landing spots included large organic openings in the interior of the island, rocky outcrops on the south shore, and beaches on the west coast. The two polygons on the Esowista Peninsula were ground checked in July, as part of a truck traverse in the Kennedy Flats area.
The traverses on Vargas Island were located on the steeper slopes. Two of the three polygons in the project area that are rated higher than Class III were ground checked. The remainder of the 47 polygons on the island have been given a Class I, II, or III rating.

Travel on the island was slow and arduous because of extremely dense vegetation throughout much of the area (Photo 23) and as a result, spatial coverage for two of the three traverses was below average. The field team on the southern traverse had the benefit of boardwalks and well-established trails (Photo 24). However, after close inspection of the air photos with the completion of each traverse, the terrain observed in the field was considered to be representative of the terrain conditions present on the island.

Figure 2c

Photo 23

Dense vegetation typical of Vargas Island

Photo 24

Southern Vargas Island.

2.2 Reliability

The reliability of the mapping can be represented by the number of polygons field checked, the percentage of polygons checked, and the percentage of total area (in ha) checked. This information is summarized for the project area in Table 14. These field-checked values fall well within the appropriate range for Terrain Survey Intensity Level C as defined in the *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests 1999) and they exceed the contractual requirement of a minimum of 35% of the polygons checked. In addition, 66% of the unstable or potentially unstable polygons and 80% of the area mapped as unstable or potentially unstable terrain was field checked, increasing the accuracy of the stability portion of the mapping (Table 15).

Table 14. Summary of Reliability of Mapping-Vargas Island Project Area

Total Mapped Area (ha)	Number of Terrain Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Field Checked	Percent of Area Field Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
3250	47	69	20	1	0	21	2926	45%	90%	0.65

Table 15. Summary of Class IV & V Field Checked-Vargas Island Project Area**

Total Class IV & V Area (ha)	Number of Polygons	Average Polygon Size (ha)	Number of Polygons Field Checked				Area Field Checked (ha)	Percent Polygons Checked	Percent of Area Checked	Field Checks Per 100 ha
			Detailed	Recce	Visual	Total				
40.6	3	14	2	0	0	2	33	67%	81%	0.06

** Includes Class IV, IVr, IVc, V, Vr, and Vc.

3.0 SURFICIAL MATERIALS

3.1 Colluvium (C)

Colluvium has been mapped in four polygons in the project area, covering or partially covering approximately 50 ha. The colluvium in the area was observed on the few slopes in the area that are greater than 20°. The slopes are bedrock controlled, and the colluvium is a result of eroded bedrock raveling or falling downslope and weathering into a clast-rich mineral soil. The matrix texture of this material is commonly a silty sand (*zs*), and rubble-sized clasts (angular particles 2 mm to 256 mm) occupy 50% to 90% of the material volume. This material is 0.5 m to 2 m deep, unconsolidated, highly permeable, and complexed with a morainal veneer (*Cv/Mv*) or bedrock (*Cv//Rsk*).

3.2 Weathered Bedrock (D)

The only weathered bedrock mapped in the project area is presented as the third component in one polygon (33 ha), although it is likely more prevalent than has been mapped. The material is complexed with hummocky, undulating bedrock and till. This polygon was field checked.

The local bedrock has weathered to a thin veneer and this weather zone has not been removed by any geomorphic agent (e.g., water, gravity, or wind). The material is thick enough within the polygon (less than 1 m deep) for identification and mapping.

3.3 Eolian (E)

Eolian sediments have been mapped in three polygons on Vargas Island, covering or partially covering 80 ha. These wind-deposited sediments are present along the west coast of the island adjacent to existing beaches. They are predominantly sands in the form of dunes (*Ehr*). Finer silts may also be present. The material is well-sorted and unconsolidated, and the soil is well to rapidly drained.

3.4 Fluvial Deposits (F)

Fluvial sediments have been mapped in one polygon on the island, partially covering 5 ha. They are complexed with marine muds near the mouth of a stream flowing southwest into Ahous Bay on the west side of the island. The deposits are considered to be active and are distinguished with an ‘A’ qualifier (*FAp*).

3.5 Moraine (M)

Morainal material, or till, is a common deposit on Vargas Island, covering or partially covering nearly 32% of the project area. It is complexed with marine sediments across the majority of the island and the boundary between the two materials was not identified. Till and marine sediments likely grade into one another throughout the island.

Where the elevation increases to more than 50 m above sea level, the till deposits overlie bedrock or are complexed with the scattered colluvial deposits. The texture of the till deposits in the project area ranges from diamictic-sandy-silt to silty-sandy-diamictic to silty-clayey-silt. Coarse fragments occupy 30% to 60% of the material volume. The clast roundness ranges from sub-angular to round. The till in this area is relatively compact and resistant to erosion in an undisturbed state.

3.6 Organics (O)

Organics are a dominant feature of the island and have been mapped extensively across the wide-ranging undulating topography. The material has been mapped in ten polygons, covering or partially covering more than 2240 ha or 69% of the project area. The material is associated with bogs and wetlands. The organic textures of fibric, mesic, or humic represent the proportion and degree of composition of the material.

The soils are very poorly to imperfectly drained, and typically the material has accumulated over another surficial material. Organics have been mapped as homogenous units or as a complex with morainal or marine deposits.

3.7 Bedrock Exposure (R)

Bedrock is exposed along the Vargas Island shoreline and is associated with the few hills in the area. These exposures have been mapped in a number of polygons and are complexed with till and colluvium. In several places, the surficial material only partially covers the bedrock. No pure bedrock polygons have been mapped. In general, the bedrock in the area is highly irregular and the resulting surface topography is hummocky (*Rh*) and undulating (*Ru*).

3.8 Marine (W)

As a result of the predominance of low elevation terrain on Vargas Island, marine sediments have been mapped extensively in the area, including the majority of

the project area located on the Esowista Peninsula. These materials are unconsolidated and have a variety of textures, including pebbles, sand, clay, and silt (Photo 25). Marine muds (combination of silt and clay) have been mapped in a few tidal areas where mud flats were visible where air photos were taken.
The materials are complexed with till and organics, and along the shoreline, have been mapped as a mantle over hummocky or undulating bedrock. The depth of the material on the island is estimated to range from 0.5 m up to 5 m. The soil is poorly to well drained.

Photo 25
Exposure of silty sands on
Southern Vargas Island.

4.0 GEOMORPHIC PROCESSES

4.1 Irregularly Sinuous Channel (-I)

This geomorphic process has been assigned to only one polygon in the project area, affecting 5 ha. The polygon is on the west side of the island where a stream flows southwest into Ahous Bay. The stream flows through marine deposits and an active fluvial plain is also identified in the polygon. The channel gradient is less than 15°.

4.2 Gully Erosion (-V)

Gully erosion has been mapped in one polygon (18 ha) in the northeastern corner of Vargas Island. Surficial materials in the polygon have been identified as colluvial deposits (0.5-2 m) with bedrock outcrops. The gullying is shallow with incision in bedrock less than 10 m. No sidewall instability was observed in the area. However, because of the steep gradients in the area (up to 35°), the polygon has been mapped as Class IV.

5.0 INTERPRETATIONS FOR TERRAIN STABILITY, SOIL EROSION POTENTIAL, LANDSLIDE-INDUCED STREAM SEDIMENTATION, AND SENSITIVE SOILS

5.1 Terrain Stability

Terrain stability was rated for each polygon using the five-class system described in (Table 3). Potentially unstable terrain has been mapped for three polygons in the Vargas Island project area, affecting a total of 41 ha (1% of the total area). Terrain associated with these Class IV and IVr polygons includes colluvial deposits up to 2 m deep, till veneer, and bedrock. Slope gradients range from 20° to 35° and exceed 35° in places. Soils are well to rapidly drained.

No evidence of instability was observed in the polygons but the slope gradients and the presence of gully erosion in one of the polygons resulted in the potentially unstable ratings.

The remainder of the project has been mapped as Class I, II, or III, with the majority of that as Class I or II.

5.2 Soil erosion potential

The rating of soil erosion potential is based on several terrain attributes, including surficial material texture, slope gradient, slope morphology, and slope position (refer to Tables 4 and 5). As a result of the predominantly gentle terrain in the project area, soil erosion potential ratings include Very Low (VL), Low (L), and Moderate (M), with only one polygon receiving a High (H) rating. This polygon is a diamictic-sandy till (with bedrock) on slopes exceeding 30°. The deposit has been mapped as a veneer and therefore erosion would be limited. No polygons were assigned a Very High (VH) soil erosion potential rating.

5.3 Landslide-Induced Stream Sedimentation

The polygons with terrain stability Class of IV or IVr were assigned a rating for landslide-induced stream sedimentation (LISS). Polygons with terrain stability ratings of Class I, II, or III were not assigned a value of LISS. This interpretation is a general guideline for the likelihood that a landslide initiated in a given polygon will deliver sediment to a downslope stream, lake, or ocean.

Of the three polygons mapped as potentially unstable terrain, 2 of the polygons have a low likelihood of delivering a landslide to a watercourse (Class 1) and one polygon has a high likelihood (Class 3). The polygon with the Class 3 rating is located along the northeastern shore of Vargas Island and includes Rassier Point overlooking Maurus Channel and Meares Island to the east. The polygon slopes steeply (>25°) into the ocean and the stability rating is IVr IIIc. If a road failure occurred in this polygon it would directly enter the ocean.

5.4 Sensitive soils

Sensitive soils identified in the Vargas Island project area are limited in number. Three polygons have been mapped as Class 1 (confirmed sensitive soils) covering 14 ha or <1% of the area (Figure 8). The polygons delineate pure organics.

The remaining polygons have been mapped as Class 2, indicating no reserve required or the potential for sensitive soils in the area. A detailed field assessment (1:5,000 scale) may be necessary to determine whether or not a reserve is required to protect and preserve any sensitive soils within a given terrain polygon mapped as Class 2.

Figure 8

6.0 SUMMARY

The Year Four Clayoquot Sound project area contains a fair number of areas with significant terrain stability and soil erosion potential hazards. These hazards must be addressed when the area is subject to further timber harvesting and road construction. Proposed development of Class IVc, IVr, IV, Vc, Vr, or V areas should be subject to a detailed on-site terrain stability field assessment completed by a qualified professional experienced in terrain stability and soil erosion hazard assessment. Measures can be taken to minimize the effects of timber harvesting on slope stability. Where road construction and/or timber harvesting is planned for areas of moderate risk for terrain stability or erosion, a high level of watershed management is warranted. Water diversion can, under certain circumstances, initiate landslides on unstable ground some distance downslope. It is therefore imperative that roads and harvesting operations do not divert water out of established channels where unstable ground exists downslope.

7.0 LIMITATIONS

This mapping is based on air photo interpretation with field checking. The terrain unit boundaries should not be considered to be precise. If logging or road construction encroaches on Terrain Stability Class IVc, IVr, IV, Vc, Vr, or V or terrain with Very High (VH) soil erosion potential, a detailed field check is warranted. This mapping is intended to assist in planning but does not take the place of site-specific work.

Prepared by:

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Appendix I

Clayoquot Year Four
Terrain Photo Inventory by Project area

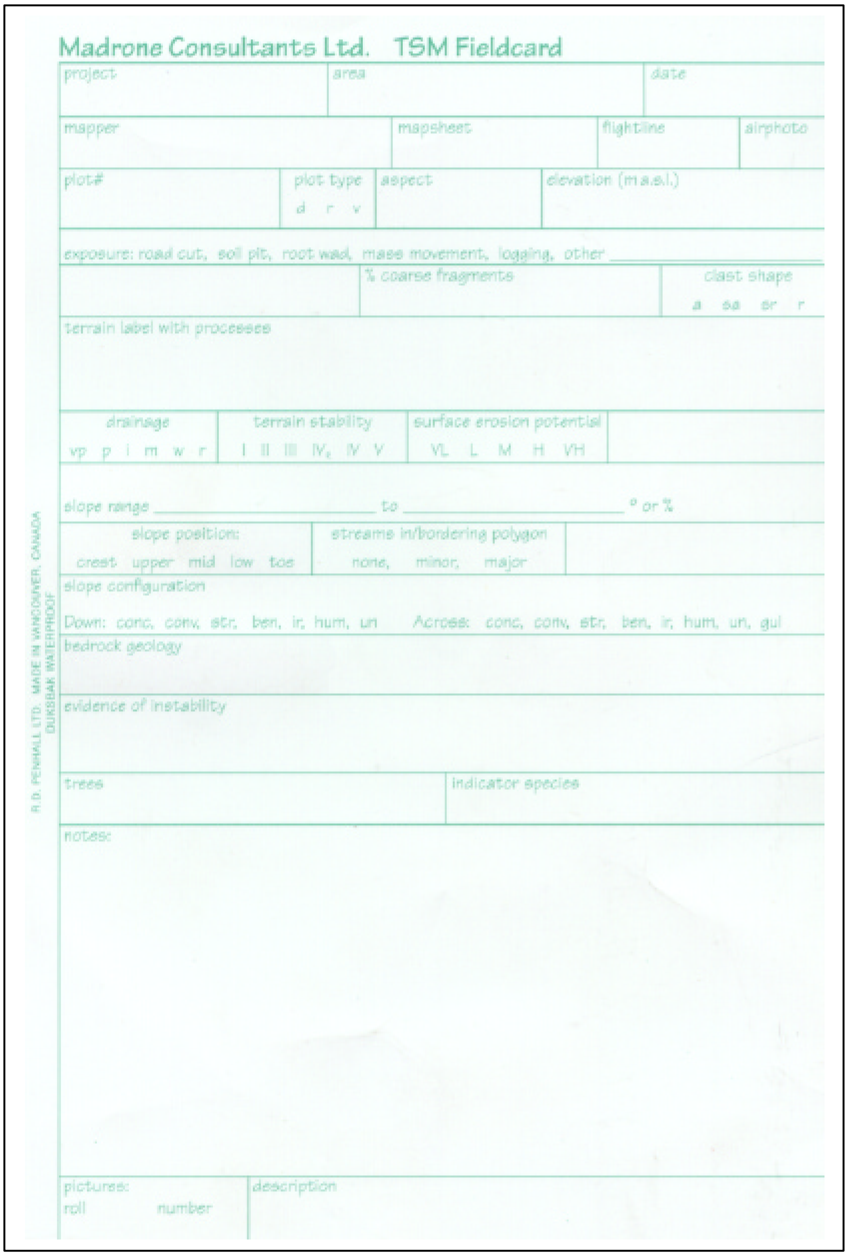
Bedwell 2003
30BCC 96005, #017-005
30BCC 96007, #017-005

Clayoquot River/Kennedy Lake
30BCC 96008, #147-151
30BCC 96008, #178-173
30BCC 96009, #019-014
30BCC 96009, #084-091
30BCC 96009, #129-123
30BCC 96009, #188-199
30BCC 96010, #030-017
30BCC 96005, #144-160
30BCC 96005, #111-094
30BCC 96005, #053-067
30BCC 96004, #198-185
30BCC 96003, #170-158
30BCC 96004, #135-143
30BCC 96010, #122-116

Vargas Island
30BCC 96009, #058-063
30BCC 96009, #155-149
30BCC 96009, #168-171
30BCC 96005, #136-137
30BCC 96005, #118-116

Appendix II

Field Data Form



Madrone Consultants Ltd. TSM Fieldcard

project
area
date
mapper
mapsheet
flightline
airphoto
plot#
plot type
d r v
aspect
elevation (m a.s.l.)
exposure: road cut, soil pit, root wad, mass movement, logging, other ____________
% coarse fragments
clast shape
a sa sr r
terrain label with processes
drainage
vp p i m w r
terrain stability
I II III IV, IV V
surface erosion potential
VL L M H VH
slope range ____________ to ____________ ° or %
slope position:
crest upper mid low toe
streams in/bordering polygon
none, minor, major
slope configuration
Down: conc, conv, str, ben, ir, hum, un Across: conc, conv, str, ben, ir, hum, un, gul
bedrock geology
evidence of instability
trees
indicator species
notes:
pictures:
roll number
description

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