Geomorphological/Hydrological Assessment of the Central Coast Plan Area

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Riparian Decision Tool
Technical Report #1

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Prepared for the Joint Solutions Project
reporting to the Central Coast Land and Resource Management Plan by:

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1. INTRODUCTION

This report is designed to summarize geomorphological and hydrological information of the Central Coast Plan Area (Figure 1). For the report, fourteen study areas and fifty-six sub-areas have been delimited in the Plan Area. For each study area and sub-area, data on stream density and landslide frequency have been collected and statistically analyzed. The overall purpose is to assess whether there are critical geomorphological or hydrological differences amongst the different physiographic/ecological regions of the Central Coast Plan Area. This information will be put to use in developing the "Decision Tool" for riparian zone management in the Central Coast Plan Area. In other words, regional differences will be factored into the management prescriptions found in the Decision Tool.

The goal of the Decision Tool is to improve protection of riparian zones over what is currently afforded under the regulations of the Forest Practices Code. The Decision Tool is based on the principles of ecosystem management as applied at the watershed scale, here defined as ranging from 10,000 ha to 100,000 ha. Accordingly, the study areas and sub-areas delimited in this report incorporate this required scale range.

2. CENTRAL COAST PLAN AREA

In order to assess whether there are critical geomorphological or hydrological differences amongst the different regions of the Central Coast Plan Area, it is necessary to first delineate the different regions.

Using Holland's (1976) physiographic zone classification, the Plan Area primarily consists of two major physiographic subdivisions in the Western System: the Coastal Trough (in particular, the Hecate Lowland and Milbanke Strandflat regions), and the Coast Mountains (in particular, the Pacific Ranges and Kitimat Ranges). The northeast corner of the Plan Area also includes a small portion of the Interior Plateau (in particular, the Nechako Plateau region), a major physiographic subdivision of the Interior System.

The physiographic zone boundaries delineated by Holland (1964) closely parallel the ecological sub-units outlined by Pojar et al., (1999). The **Hecate Lowland** ecological sub-unit is essentially identical to the Hecate Lowland physiographic region. The **Outer Coast Mountains** ecological sub-unit includes a significant portion of the Coast Mountains physiographic region. The **Inner Coast Mountains** ecological sub-unit is comprised of both the Coast Mountains and Nechako Plateau physiographic regions. The Nechako Plateau region was not distinguished from the Coast Mountains in this classification system. Pertinent features of these three ecological sub-units are discussed in the report by Pojar et al., (1999). This ecosystem sub-unit classification system was followed to delineate the different regions of the Plan Area. Within each region, study area locations were then chosen.

3. SELECTION OF STUDY AREAS

In order to accommodate the required scale range (10,000 ha – 100,000 ha), a nested study design was chosen. The size of the large study areas was set at 90,000 ha. This size was chosen for the simple reason that it could be subdivided into 9 equal 10,000 ha sub-areas.

To choose study area locations a grid was overlaid on the Plan Area. The size of each grid cell was commensurate with the largest scale of interest in this study (~90,000 ha). The southwest corner of each grid cell was numbered and, using a randomly generated number table, study grid cells (henceforth referred to as study areas) were then selected. Several factors were considered when selecting study areas. First, the number of study areas in a given region needed to be proportional to its size. For example, the Outer Coast Mountain region is the most areally extensive in the Plan Area. Therefore that region has more study areas than the other two regions. Secondly, if the selected study area corresponded to a zone dominantly ice-covered, it was discarded. Overall, fourteen study areas were selected: three in the Inner Coast Mountain region, four in the Hecate Lowland region, and seven in the Outer Coast Mountain region.

In order to delineate study sub-areas, a 3x3 grid was overlain on each study area and numbered (as shown below). Using a random number generation table, strings of 4 random digits were picked to select 4 sub-areas within each study area.

1	2	3
4	5	6
7	8	9

Figure 1 illustrates the Central Coast Plan Area, the 3 regions, and the location of the 14 study areas and their associated sub-areas (labeled A through D).

4. AVAILABLE DATA RESOURCES

The available data sources in the Central Coast Plan Area consist of:

- 1:250 000, 1:50 000, and 1:20 000 topographic maps
- 1:250 000 geological maps (specifically produced by the Land Use Co-ordination Office for the Central Coast LRMP)
- 1:50 000 digital watershed atlas
- ~1:50 000 air photos (flown between the years 1984-1988) with individual landslides mapped

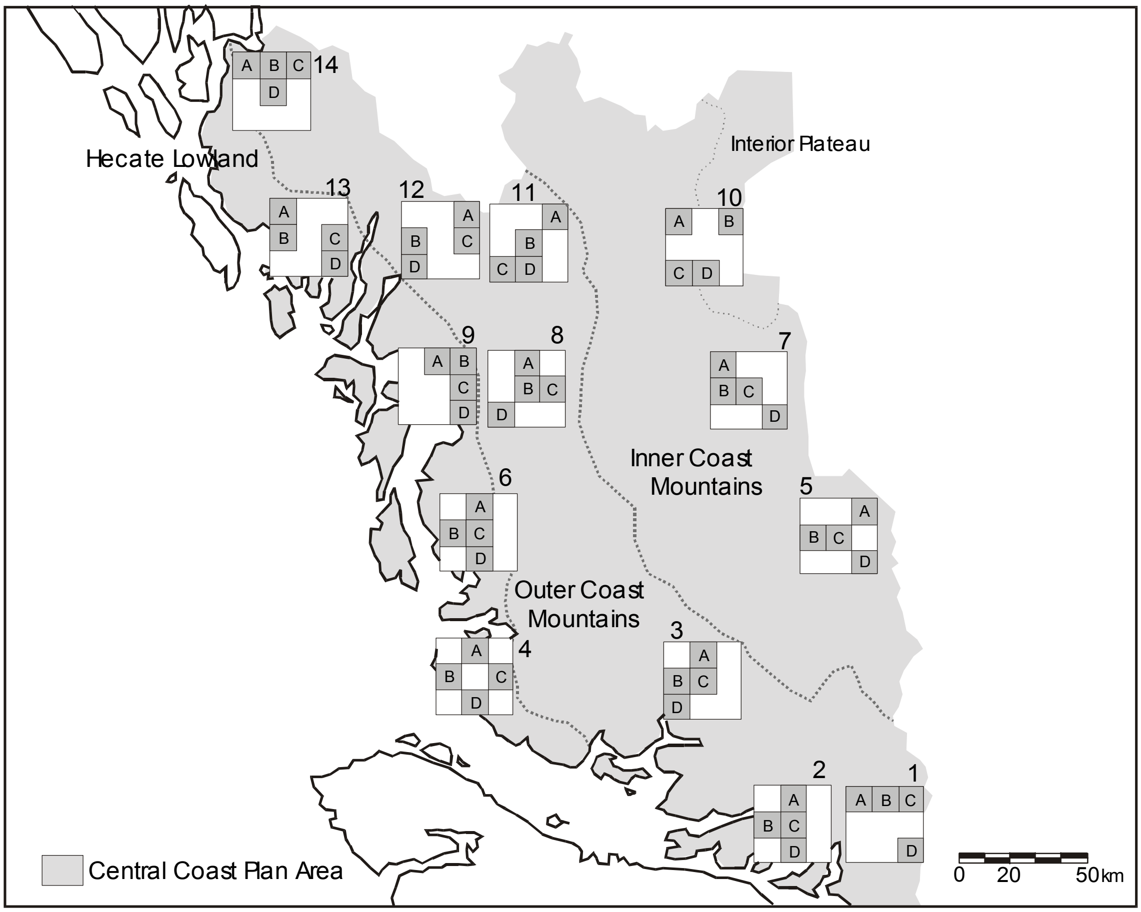

Figure 1. Study Areas & Sub-Areas in the Central Coast Plan Area

From these sources the following information was extracted or derived for each study area and sub-area:

- Dominant geology
- Total number of landslides
- Landslide density
- Total number of landslides in operable areas (here defined as lands likely accessible for forest harvesting)
- Drainage density (derived from digital watershed atlas)
- Length of all valley flat streams (measured off 1:250 000 topographic maps)
- Percentage of valley flat streams

Table 1 summarizes the data extracted or derived for each study area/sub-area.

Table 1. Available Geomorphological/Hydrological Data

A. Outer Coast Mountain Region

Study Area	Sub-Area	Dominant Geology*	Total # Landslides	Landslide Density	# of Landslides in Operable	Drainage Density (km/km^2)	Length of Valley Flat Streams (km)	% of Valley Flat Streams per area
1		All	1560	1.73	1110	0.606	125.50	23
	A	All	46	0.46	25	0.495	13.75	28
	B	All	164	1.64	61	0.657	15.75	24
	C	All	202	2.02	154	0.511	16.50	32
	D	All	121	1.21	72	0.649	5.25	8
2		All	510	0.57	430	0.688	108.50	18
	A	All	96	0.96	89	0.640	16.75	26
	B	All	62	0.62	56	0.585	3.00	5
	C	All	21	0.21	21	0.750	8.00	11
	D	All	2	0.02	2	0.464	7.50	16
3		All	1600	1.78	908	0.671	210.50	35
	A	All	148	1.48	97	0.572	25.00	44
	B	All	226	2.26	126	0.974	48.50	50
	C	All	327	3.27	186	0.574	18.00	31
	D	All	88	0.88	56	0.590	10.75	18
8		All	2581	3.25	1830	1.093	158.25	18
	A	All	281	3.60	148	0.811	20.00	32
	B	All	236	2.36	146	1.300	28.75	22
	C	All	138	1.42	69	0.891	12.25	14
	D	All	433	4.47	295	1.234	22.50	19
11		All	3594	3.99	2032	0.867	170.75	22
	A	All	417	4.17	234	1.044	20.75	20
	B	All	390	3.90	229	0.990	41.50	42
	C	All	475	4.75	309	1.122	22.25	20
	D	All	305	3.05	219	0.775	11.00	14
12		All	5836	6.48	2638	0.721	140.50	22
	A	All / HGM	274	2.74	0	0.561	20.00	36
	B	All	533	5.33	229	0.816	18.50	23
	C	All / HGM	748	7.48	286	0.927	15.50	17
	D	All	359	3.59	148	0.394	2.50	6
14		All	3712	4.74	1272	0.817	141.50	22
	A	All	457	5.22	203	0.700	16.00	26
	B	All	362	5.03	128	0.642	11.00	24
	C	All	142	1.57	48	0.908	20.75	25
	D	All	558	6.16	99	0.751	16.25	24

B. Inner Coast Mountain Region

Study Area	Sub-Area	Dominant Geology*	Total # Landslides	Landslide Density	# of Landslides in Operable	Drainage Density (km/km^2)	Length of Valley Flat Streams (km)	% of Valley Flat Streams per area
5		Mix	1276	1.42	365	0.581	231.00	44
	A	All	121	1.21	18	0.568	29.25	51
	B	HGM / LGM	307	3.07	87	0.738	24.25	33
	C	HGM	178	1.78	76	0.819	45.25	55
	D	All	108	1.08	40	0.572	14.50	25
7		All / TMV	1343	1.49	461	0.657	98.00	17
	A	TMV	200	2.00	37	0.742	13.25	18
	B	TMV	87	0.87	7	0.499	10.50	21
	C	TMV / All	108	1.08	19	0.841	11.75	14
	D	All	145	1.45	51	0.715	9.25	13
10		TMV	1442	1.60	787	0.709	398.75	62
	A	TMV	319	3.19	224	0.780	38.75	50
	B	TMV	58	0.58	58	0.819	65.50	80
	C	TMV	285	2.85	107	0.619	16.25	26
	D	TMV	74	0.74	54	0.614	50.50	82

C. Hecate Lowland Region

Study Area	Sub-Area	Dominant Geology*	Total # Landslides	Landslide Density	# of Landslides in Operable	Drainage Density (km/km^2)	Length of Valley Flat Streams (km)	% of Valley Flat Streams per area
4		AII	298	0.47	298	0.519	64.50	20
	A	AII / BUI	92	0.96	92	0.547	8.25	16
	B	AII	1	0.01	1	0.656	16.50	36
	C	BUI	72	0.94	72	0.250	4.00	21
	D	AII	0	0	0	0.259	2.00	12
6		AII	875	1.21	823	0.631	156.75	34
	A	AII	103	1.22	103	0.757	23.25	36
	B	AII	13	0.16	13	1.003	19.00	24
	C	AII	59	0.82	59	0.600	7.50	17
	D	AII	16	0.27	16	0.558	8.00	24
9		AII	1209	1.85	1086	1.006	119.50	18
	A	AII	40	0.73	40	1.023	8.50	15
	B	AII / BUI	323	3.44	287	1.113	36.25	35
	C	AII	119	1.73	93	1.165	17.75	22
	D	AII	120	1.97	120	0.758	8.00	17
13		AII	1451	2.10	1194	0.917	62.75	10
	A	AII	353	3.70	231	0.660	15.25	24
	B	AII	65	0.74	44	0.991	10.50	12
	C	AII	250	2.81	194	1.076	14.00	15
	D	HGM	252	3.04	201	0.940	0.00	0

*Geology Legend:

AII = Acidic to Intermediate Intrusive Rocks (granite to quartz diorite)
HGM = High Grade Metamorphics (schist-gneiss-amphibolite-migmatite grade; silicious sediments and volcanics)
LGM = Low Grade Metamorphics
TMV = Tertiary to Mesozoic Volcanics (rhyolitic to basaltic flows, breccia, tuff and minor sediments)
BUI = Basic to Ultra Basic Intrusives (diorite-gabbro-ultrabasic)

5. LANDSLIDES

5.1 Methodology

Table 1 summarizes the total number of landslides in each study area and study sub-area, landslide density, and the total number of landslides found in operable areas. This information was derived from an extensive mid-coast mapping project funded by the provincial government as part of the central coast LRMP process. Air photo identification of landslide headscars, landslide initiation zones, and landslide runout zones was carried out by JM Ryder and Associates Ltd. Old landslides (reforested but still distinct) were counted as well as new, bare slides. It is important to note that, due to the scale of the air photo survey, many of the smaller landslides were likely not visible (Brardinoni, 2001).

During the air photo analysis, detailed information was collected regarding landslide type. After landslide headscars were individually marked on the air photos, terrain polygons were constructed to delineate the initiation and run-out zones. The polygons were labeled with processes and process sub-classes according to the BC Terrain Classification System (Howes and Kenk, 1997). Table 2 lists the different rapid mass-movement sub-classes mapped in the study areas and sub-areas.

Table 2. Mapped Geomorphic Processes (and sub-classes)

Terrain Polygon label	Description
R”s	Rapid mass movement* (debris slides)
R”sV	Rapid mass movement (debris slides) and Gully Erosion
R”sdb	Rapid mass movement (debris slides, debris flows, and rock fall)
R”sd / R”ds	Rapid mass movement (debris slides and debris flows)
R”sdV / R”dsV	Rapid mass movement (debris slides and debris flows) and Gully Erosion

* Rapid mass movement = rapid downslope movement by falling, rolling, sliding or flowing of dry, moist or saturated debris derived from surficial material and/or bedrock (Howes and Kenk, 1997).

Some caution was taken interpreting this information. Four different terrain mappers worked on the Plan Area air photos. As different terrain mappers may give greater emphasis to different rapid mass-movement sub-classes, consistency is a concern. However, if one combines categories such as R”sd and R”ds (as in Table 2) this risk becomes slight. More importantly, a substantial number of landslides were simply noted on the air photos but not included in terrain polygons or given terrain labels. It was beyond the scope of this project to look at all the individual landslides and label them.

As a number of the study areas/sub-areas include substantial amounts of ocean area, comparing landslide frequency values (e.g., total # of landslides) among the study sites may be misleading. The landslide data should ideally reflect the area of ‘dry’ land in each study area/sub-area. In order to accomplish this, the map areas occupied by the ocean (and lakes) were measured and then subsequently subtracted from each study area/sub-area. Landslide density values (number of landslides per square kilometre of dry land) were then calculated for each study area/sub-area (Table 1).

The ocean/lake areas were measured off the 1:250 000 topographic maps using a dot planimeter. It is worth noting that this method does not account for the total surface area. In map areas where the relief is greater, the total surface area will be greater. It is beyond the scope of this report to calculate true surface areas. However, for *average* terrain gradient up to 25° (46%) the error remains less than 10%.

5.2 Geology

The study areas situated in the Outer Coast Mountains are dominated by acidic to intermediate intrusive rocks (AII). In addition, 2 of the 28 sub-areas found in this region include substantial amounts of high-grade metamorphic rocks.

The Hecate Lowland region is also dominated by acidic to intermediate intrusive rocks (AII), with secondary amounts of basic to ultra basic intrusive rocks and minor amounts of high-grade metamorphics.

While a greater mix of rock types exists in those study areas situated in the Inner Coast Mountain region, the dominant rock type appears to be Tertiary to Mesozoic Volcanics

(TMV). However, there are also acidic to intermediate intrusive rocks and minor high-grade and low-grade metamorphic rocks present.

5.3 Landslide Types

As discussed in Section 5.1, a substantial number of the landslides identified on the air photos were not assigned a geomorphic process and/or sub-class (e.g., a landslide type). As a result, no formal statistical analysis (based on different landslide types) could be carried out. However, qualitative comments can be made.

In general, landslide activity in the Hecate Lowland region is dominated by debris slides and debris flows (R”s or R”sd). This is not surprising, considering the typical terrain found there. The topography is rough but there is little relief (Pojar et al., 1999). In this subdued topography small, shallow, individual landslides are typically found. R”sd type landslides, by definition, are often linked to gully systems/stream channels. R”s type landslides may or may not enter stream channels or gully systems, and therefore the terrain designation can not be used as a diagnostic tool to determine connectivity to streams.

The Outer Coast Mountain and Inner Coast Mountain regions are typically low in R”s type landslides and are dominated by R”sd or R”sdV type landslides. In this more extreme terrain, gully sidewall debris slides commonly occur. The majority of these landslides enter larger gully systems/stream channels and may trigger debris flows (hence the R”sdV or R”sd terrain designation).

There are two exceptions to this generalization. Study area 10 (Inner Coast Mountains) and study area 14 (Outer Coast Mountains) both contain a substantial number of R”s type landslides (i.e., debris slides). Study area 10 is situated in and adjacent to the Nechako Plateau region where the terrain is gentler than is typical for the Inner Coast Mountain region. As it more closely resembles the terrain found in the Hecate Lowland region, it is not surprising that debris slides are more common. Study area 14 is situated right on the break between the Hecate Lowland and Outer Coast Mountain regions. As such, this study area is comprised of typical Hecate Lowland terrain as well as typical Outer Coast Mountain terrain. The fact that debris slides are relatively common in this study area can presumably be attributed to the presence of typical Hecate Lowland topography.

We can approximate regional trends in landslide occurrence if we average the landslide density values per study area and sub-area (Table 3).

Table 3. Average Landslide Density Values within each Region

	Study Areas		Study Sub-Areas	
	Average Landslide Density	Standard Error of the Mean	Average Landslide Density	Standard Error of the Mean
Outer Coast Mountain	3.22	0.67	2.85	0.37
Inner Coat Mountain	1.50	0.05	1.65	0.27
Hecate Lowland	1.41	0.36	1.41	0.31

For the Outer Coast Mountain region the average landslide density value for the study sub-areas is less than that for the study areas by 11%. It is possible that the selected sub-areas may be more stable than the overall study areas. In the Inner Coast Mountain region we have the reverse position (+ 10%).

The average landslide density values per study area and per study sub-area are greatest in the Outer Coast Mountain region. This is expected, as landslide occurrence is highly correlated to slope steepness and relief. The Outer Coast Mountain region is rugged, with oversteepened valley walls. In contrast, the gentler terrain found in the Hecate Lowland region yields the smallest average landslide density values per study area and per study sub-area.

There are also differences in average landslide density values between the Outer Coast Mountain and Inner Coast Mountain regions. These differences are likely related to a combination of climatic and terrain factors. Due largely to orographic effects, mean annual precipitation values systematically decrease from the coast to the interior. As abundant precipitation can lead to high pore water pressures in soils and ultimately slope destabilization, it is a common landslide trigger. In addition, while both regions are very rugged, the Outer Coast Mountain region contains minimal intermediate hillslopes (Pojar et al., 1999). In contrast, the Inner Coast Mountain region contains a significant amount of intermediate hillslopes (Pojar et al., 1999) which, presumably, are less prone to failure. Lower precipitation values combined with these gentler, intermediate hillslope gradients likely result in lower average landslide density values in the Inner Coast Mountain region.

Tertiary to Mesozoic volcanics are dominant in the Inner Coast Mountain region whereas acidic to intermediate intrusive rocks are found in the Outer Coast Mountain region. Soils derived from intrusive rocks are typically coarser textured and, as a result, are better drained and less prone to failure than soils derived from volcanic rocks. This appears to conflict with the fact that more failures are seen in the Outer Coast Mountain region, which is dominated by intrusive rocks. This may be related to the climatic factors discussed above. This may also be explained by considering where the landslides occur in the landscape. In the Inner Coast Mountain and Outer Coast Mountain regions landslides typically occur on steep rock slopes covered with a discontinuous veneer of colluvium. Here, slope steepness is likely the primary factor contributing to failure, and soil texture (typically coarse) is less of a concern.

5.4 Data Analysis and Results

5.4.1. Landslide Density

Nested Anovas were performed on untransformed landslide density values[1] to compare values both inter- and intra-regionally.

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[1] With the exception of drainage density, the variables listed in Table 1 are not normally distributed.

Table 4. Nested Anova – Landslide Density Values

Variance Components	Df Effect	MS Effect	Df Error	MS Error	F	P
Region (R)	2	12.722	42	1.344	9.466	0.00040
Study Sub-Areas (within R)	11	7.213	42	1.344	5.367	0.00003

From Table 4 it is apparent that significant differences exist among the different regions. In addition, significant differences exist among the study areas nested within the regions. Within each region, single factor Anovas were performed in order to further investigate the behaviour of landslide density values within study sub-areas.

Table 5. Single Factor Anova – Landslide Density Values

A. Hecate Lowland Region

Source of Variation	SS	Df	MS	F	$P_r > F$
Study Sub-Area	12.639	3	4.213	4.914	0.019
Error	10.288	12	0.857		
Total	22.927	15			

B. Inner Coast Region

Source of Variation	SS	Df	MS	F	$P_r > F$
Study Sub-Area	0.576	2	0.288	0.293	0.7529
Error	8.855	9	0.984		
Total	9.431	11			

C. Outer Coast Region

Source of Variation	SS	Df	MS	F	$P_r > F$
Study Sub-Area	66.130	6	11.022	6.204	0.0007
Error	37.308	21	1.777		
Total	103.438	27			

For both the Hecate Lowland and Outer Coast Mountain regions, the null hypothesis is rejected at the $\alpha = 0.05$ level, though the Outer Coast Mountains supports $\alpha = 0.01$. Therefore within each of these regions there are significant differences in landslide densities within the study areas (based on their sub-area values) and, in the Outer Coast Mountains, the result is highly probable. For the Inner Coast Mountain region, the null hypothesis is accepted. Within this region there are no significant differences in landslide densities among the study areas. Due to the relatively small sample sizes involved these results are not definitive.

5.5 Landslides in Operable Area

Many of the landslides identified on the air photos originate in the inoperable regions of the study areas and sub-areas. As this report is concerned with riparian zone management in headwater streams, it is important to consider landslide occurrences in strictly the operable zones of the study areas and sub-areas.

Table 1 shows the total number of slides found in the operable zone of each area or sub-area. The percentage of landslides that are in the operable areas is typically less than 55% for the Inner Coast Mountain region (see Table 6). In study areas and sub-areas situated in the Hecate Lowland region the majority of landslides (greater than 80%) originate in operable areas. This is due to the simple fact that there is considerably less inoperable land in the region. The Outer Coast Mountain region falls in between these two extremes, with the percentage of landslides originating in operable areas ranging from 34% to 84%.

Table 6. Percentage of Landslides Originating in Operable Areas

Study Area	Sub-Area A*	Sub-Area B*	Sub-Area C*	Sub-Area D*	Total Study Area*
Outer Coast Mountain Region					
1	51	37	76	60	71
2	93	90	100	100	84
3	66	56	57	64	57
8	53	62	50	68	71
11	56	59	65	72	57
12	0	43	38	41	45
14	44	35	34	18	34
Hecate Lowland Region					
4	100	100	100	0	100
6	100	100	100	100	94
9	100	89	78	100	90
13	65	68	78	80	82
Inner Coast Mountain Region					
10	70	100	38	73	55
7	19	8	18	35	34
5	15	28	43	37	29

* all values in percentages

Operable landslide density values were not calculated for each study area/sub-area for two major reasons. First, in order to calculate operable map areas, operability lines would need to be transferred by hand from the 1:60 000 air photos to the topographic maps. The errors associated with physically transferring operability lines would be significant. Second, both logged and unlogged areas were found within the operable areas. Presumably the tabulated landslide frequencies may have been influenced by logging in some areas more than in other areas. Quantifying this influence was beyond the scope of this report.

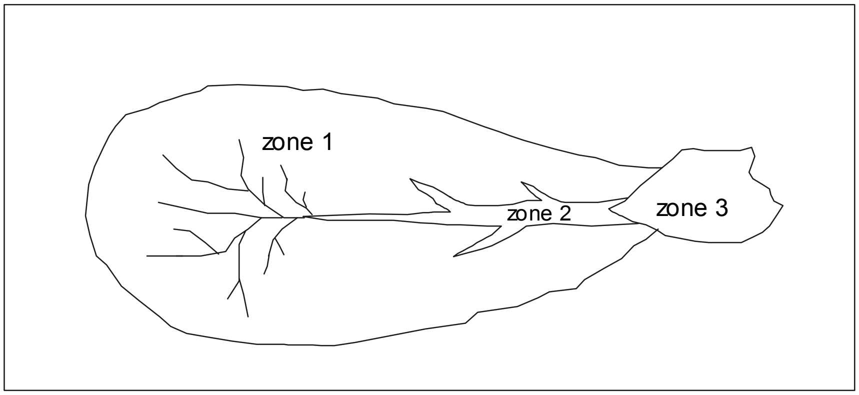
6. DRAINAGE DENSITY

6.1 Methodology

For every study area/sub-area, the total lengths of all streams and side channels (expressed in km) were extracted from the digital watershed atlas. These stream lengths were then divided by the dry land area (km^2) in order to determine drainage density (defined as the total length of stream channels per drainage area). The methods involved in calculating dry land areas were discussed in section 5.1. Again, this method does not account for true surface area.

The drainage density values extracted from the digital watershed atlas do not differentiate between larger, valley-flat rivers and steeper headwater streams. In order to focus on smaller headwater streams, a zonation approach to classifying streams (Church, 1983) was adopted. This approach does not specifically distinguish between “fish-bearing” and “non-fish bearing” streams. Any channel in a fish-bearing watershed capable of transporting water, sediment, or organic debris over ecologically relevant time scales has the potential to influence aquatic habitat. A zonation approach to classifying streams is simply based on position within the watershed.

The **origin zone (zone 1)** is the upland area where the cumulative length of channels comprises the bulk of the whole drainage system (see Figure 2). Material is being delivered to the system directly from hillslopes along the stream. The processes associated with this recruitment of sediment impose different conditions on the channel than we find downstream. The episodic recruitment of sediment everywhere along the channel means that there is no organized decrease in sediment size down the system.



based on Church, 1992

Figure 2. Schematic Representation of the Different Zones of a Drainage Basin (Note: Channels are shown in only a portion of zone 1)

The **transport zone (zone 2)** is situated in major valleys. Here water and sediment arrives from the adjacent upland and is transferred through the system. This zone is quite spatially limited in the landscape but exceedingly important, as major channel processes occur here. At the end of the system is the **deposition zone (zone 3)**. The system is organized to transfer water and sediment from the upland to the deposition zone. In the Central Coast region, deposition zones would be alluvial fans or river deltas.

In order to focus on zone 1 streams, zone 2 and zone 3 stream lengths were measured with a ruler off the 1:250 000 topographic maps. These stream lengths were then subtracted from the total stream length values (previously extracted from the digital watershed atlas). As the digital watershed atlas is at a scale of 1:50 000, it can be argued that measuring the zone 2 and zone 3 stream lengths off 1:50 000 topographic maps would be preferable. However, the main difference between the 1:50 000 topographic maps and the 1:250 000 topographic maps is that more headwater streams are included at the 1:50 000 scale. The larger, valley flat streams are depicted at both scales.

There is a question of how appropriate it is to combine data from different map sources (e.g. topographic maps vs. digital watershed atlas). In order to investigate this issue, one study area was selected from each region. For each of the selected study areas (and their sub-areas) total stream lengths (zones 1, 2 and 3) were measured off the 1:250 000 topographic maps. These measured values were then compared to the total stream length values extracted from the digital watershed atlas (see Table 7).

As expected, the total stream length values measured off the 1:250 000 topographic maps were considerably less than the total stream length values extracted from the digital watershed atlas. This is most likely attributed to the absence of zone 1 streams on the 1:250 000 topographic maps. There is no indication that the same discrepancy exists with the zone 2 or zone 3 stream lengths. In addition, there is no way to isolate zone 2 and zone 3 stream lengths in the digital watershed atlas in order to formally compare the values. Therefore, the zone 2 and zone 3 stream lengths measured off the topographic maps were subtracted from the total stream length values extracted from the digital watershed atlas. Zone 1 drainage density values were then calculated (Table 8).

Table 7. Comparison of Stream Lengths: 1:250 000 Map to Digital Watershed

Study Area	Sub-Area A	Sub-Area B	Sub-Area C	Sub-Area D	Total Study Area
Study Area 1 – Outer Coast					
Stream Length off Map (km)	18.5	39.5	19.0	23.0	246.5
Stream Length off Digital Atlas (km)	49.5	65.7	51.1	64.9	545.7
% of Digital Stream Length found on Map	37%	60%	37%	35%	45%
Study Area 6 – Hecate Lowland					
Stream Length off Map (km)	23.2	20.5	9.2	11.8	189.8
Stream Length off Digital Atlas (km)	63.9	79.9	43.1	33.1	457.5
% of Digital Stream Length found on Map	36%	26%	21%	35%	41%
Study Area 5 – Inner Coast					
Stream Length off Map (km)	46.0	40.2	56.2	38.5	367.2
Stream Length off Digital Atlas (km)	56.8	73.8	81.9	57.2	523.0
% of Digital Stream Length found on Map	81%	55%	69%	67%	70%

Table 8. Drainage Density Values (Zone 1 Streams only)

Study Area	Sub-Area A	Sub-Area B	Sub-Area C	Sub-Area D	Total Study Area
Outer Coast Mountain Region					
1	0.358	0.500	0.346	0.596	0.467
2	0.472	0.555	0.670	0.389	0.568
3	0.322	0.489	0.394	0.483	0.437
8	0.555	1.012	0.765	1.001	0.894
11	0.836	0.575	0.900	0.665	0.677
12	0.361	0.631	0.772	0.369	0.565
14	0.517	0.489	0.679	0.572	0.636
Hecate Lowland Region					
4	0.460	0.421	0.197	0.227	0.417
6	0.482	0.765	0.495	0.423	0.415
9	0.868	0.727	0.907	0.627	0.823
13	0.500	0.871	0.919	0.940	0.826
Inner Coast Mountain Region					
10	0.392	0.164	0.456	0.109	0.266
7	0.610	0.394	0.723	0.622	0.548
5	0.276	0.496	0.366	0.427	0.324

6.2 Data Analysis and Results

6.2.1 Drainage Density

Drainage density values derived from the provincial digital watershed atlas are presented in Table 1. Nested Anova tests were performed to compare the drainage density values both inter- and intra-regionally.

Table 9. Nested Anova – Drainage Density

Variance Components	Df Effect	MS Effect	df Error	MS Error	F	P
Region (R)	2	0.02478	42	0.02926	0.847	0.43589
Study Sub-Areas (within R)	11	0.14898	42	0.02926	5.092	0.00005

From Table 9, it is apparent that no significant differences exist among the different regions. However, significant differences do exist among the study areas nested within the regions.

Within each region, single factor Anovas were performed in order to further investigate the behaviour of drainage density characteristics within study sub-areas. For the Inner Coast Mountain region, the null hypothesis was accepted ($F_{2,9} = 0.077$, $p = 0.9264$). Therefore within this region, there are no significant differences in drainage density among the study areas (based on their sub-area values). For the Outer Coast Mountain and Hecate Lowland regions, the null hypothesis was rejected at the level $\alpha = 0.01$

(respectively: $F_{6,21} = 4.56$, $p = 0.0041$; $F_{3,12} = 7.21$, $p=0.0050$). Within these regions there are significant differences in drainage density among the study areas.

6.2.2 Drainage Density (zone 1 streams only)

It is important to point out that the zone 1 drainage density values were calculated by dividing the total length of zone 1 streams by the entire drainage area (i.e., zones 1, 2 and 3). Therefore the zone 1 drainage density values do not represent the actual density of streams in zone 1. Rather, the zone 1 drainage density values are simply a measure of the relative lengths of zone 1 streams. We can approximate regional trends in zone 1 stream lengths if we average the zone 1 drainage density values per study area and sub-area (Table 10).

Table 10. Average Zone 1 Drainage Density Values

	Outer Coast Mountain	Inner Coast Mountain	Hecate Lowland
Average zone 1 Dd per study area	0.606	0.379	0.620
Average zone 1 Dd per study sub-area	0.581	0.420	0.614

From Table 10 we can infer the relative lengths of zone 1 stream channels. For example, the Inner Coast Mountain region has the lowest average zone 1 drainage density values per study area and study sub-area. Therefore the Inner Coast Mountain region has the least amount of zone 1 stream channels (by length). As stated previously, the actual drainage density within zone 1 is not known, as it was not possible to calculate zone 1 map areas. An argument can be made that the area drained by zone 1 streams comprises the bulk of any drainage basin. Only the areas of channels and floodplain are apt to be directly drained to zone 2 and zone 3 streams, so the adjustment to calculate actual zone 1 drainage density values would be minor.

Nested Anova tests were performed in order to compare the zone 1 drainage density values both inter- and intra-regionally (Table 11).

Table 11. Nested Anova – Drainage Density (zone 1 streams only)

Variance Components	Df Effect	MS Effect	df Error	MS Error	F	P
Region (R)	2	0.147816	42	0.022185	6.663	0.00307
Study Sub-Areas (within R)	11	0.123901	42	0.022185	5.585	0.00002

Based on study sub-area values, it appears that significant differences exist among the different regions. Significant differences also exist among the study areas nested within the regions.

Within each region, single factor Anovas were performed in order to further investigate the behaviour of zone 1 drainage density characteristics within study sub-areas. For all regions, the null hypothesis was rejected at the level $\alpha = 0.05$ (Outer Coast Mountains:

$F_{6,21} = 4.23$, p = 0.006; Inner Coast Mountains: $F_{2,9} = 5.11$, p = 0.033; Hecate Lowland: $F_{3,12} = 8.14$, p = 0.003). In other words, within each region there are significant differences in zone 1 drainage density values among the study areas (based on their sub-area values).

6.3 Selected Drainage Basins

In order to further investigate hydrological conditions between different regions, individual drainage basins were selected. Within each region one watershed was delineated and streams were classified based on the zonation approach outlined in section 6.1 (see Table 12). For every zone, stream lengths were measured off the 1:250 000 topographic maps.

Table 12. Stream Lengths by Zone

A. Phillips River

Zone	Stream Length(km)	% of Entire Length
1	54.75	45
2	50.75	42
3	16.00	13
Entire Basin	121.50	100

B. Johnstone Creek

Zone	Stream Length(km)	% of Entire Length
1	11.75	49
2	9.00	38
3	3.00	13
Entire Basin	23.75	100

C. Frontier Creek

Zone	Stream Length(km)	% of Entire Length
1	30.50	48
2	26.25	42
3	6.50	10
Entire Basin	63.25	100

The Phillips River Drainage Basin is located in study area 1 (Outer Coast Mountain Region). The Johnstone Creek watershed is located in study area 6 (Hecate Lowland Region). Frontier Creek watershed is located in study area 5 (Inner Coast Mountain Region). For all three drainage basins, zone 1 stream lengths are the greatest, closely followed by zone 2 stream lengths. The actual difference in stream lengths between these two zones is likely much larger than is represented in Table 12. This is related to the fact that many zone 1 streams are not represented on the 1:250 000 topographic maps. Based on the selected drainage basins, the relative stream length proportions (by zone) are very similar between the three regions. Whether these basins are truly representative of their regions is unknown. It is beyond the scope of this report to increase the sample size in order to formally investigate this relation.

7. DISCUSSION

Geomorphological and hydrological data from the Central Coast Plan Area have been summarized and assessed in order to determine whether significant differences exist between the three distinct physiographic/ecological regions (following Pojar et al., 1999).

Regional differences regarding geology and typical landslide types were qualitatively discussed. Due to limitations in the source data it was not possible to formally investigate the differences between landslide types. However, formal statistical analyses on more general landslide data were performed. Significant differences were found when comparing landslide density values both inter- and intra-regionally (based on study sub-areas nested within study areas). Within each region, single factor Anovas were performed in order to further investigate the behaviour of landslide density values between study areas. In the Outer Coast Mountain and Hecate Lowland regions, significant differences in landslide densities exist among the study areas (based on their sub-area values). Within the Inner Coast Mountain region, there are no significant differences in landslide densities among the study areas.

Landslide occurrences in the operable zones of the study areas and sub-areas were next examined. The Hecate Lowland region has very few landslides originating in the inoperable region, due to the simple fact that there is minimal inoperable terrain in this region. The Inner Coast Mountain region had the greatest percentage of landslides originating in the inoperable zone. As discussed previously, deriving operable landslide densities was not possible due to the complexity of calculating operable map areas.

A number of issues need to be addressed concerning the landslide data. First, no minimum landslide size cutoff was established during the actual air photo mapping. Any slide detectable using stereoscope binoculars was inventoried. Certainly, the air photo scale (1:60 000) and dense forest cover limited identification of the smaller landslides. An estimate of the minimum landslide size mapped is not feasible, considering factors such as air photo distortion. In addition, large deep seated landslides were not differentiated from the shallow landslides.

The landslide density data do not discriminate between logged and unlogged areas. The landslide densities may have been influenced by logging in some areas more than in other areas. This influence would be strongest when considering operable landslide densities (as discussed in section 5.5).

Avalanches and the presence of glaciers were not discussed in the report. Snow avalanches (which are widespread in the Coast Mountains) and glacial processes could be significant factors contributing to sediment and debris delivery to the streams. The influence of avalanche activity relative to landslide activity is not quantified. Similarly, the potential influence of glacial processes on sediment delivery to streams is beyond the scope of this report.

Nested Anova tests were performed on the drainage density values derived from the provincial digital watershed atlas. No regional differences were discerned, but significant differences were found to exist intra-regionally. Within each region, single factor Anova tests were then performed in order to investigate the behaviour of drainage density characteristics among study areas (based on their study sub-area values). Significant differences were discerned within the Outer Coast Mountain and Hecate Lowland regions.

In order to focus on the headwater streams, a zonation approach to classifying streams was adopted (Church, 1992). Drainage density values based solely on zone 1 (headwater) stream lengths were calculated by subtracting zone 2 and zone 3 stream lengths from the total stream length values. As stated in section 6.2.2, the zone 1 drainage density values are a measure of the relative lengths of zone 1 streams rather than a measure of the actual density of streams within zone 1. Nested Anova tests were performed on the zone 1 drainage density values. Significant differences were discerned both inter- and intra-regionally.

The Inner Coast Mountain region has the lowest zone 1 drainage density values, while the Hecate Lowland region has the highest. This trend was also apparent (although not as strong) in the actual (i.e., all zones) drainage density values. This could be related to climatic factors. As stated previously, annual precipitation values systematically decrease from the coast to the interior. Drainage density is broadly correlated with mean annual precipitation (Knighton, 1998). Another factor to consider here is that the Inner Coast Mountain study areas contain substantial numbers of glaciers. It is unknown how the digital watershed atlas represents the drainage network in these ice dominated areas. Unfortunately, it was beyond the scope of this report to account for the ice-dominated areas in the drainage density calculations.

8. CONCLUSIONS AND RECOMMENDATIONS

- *Regional differences are detected in landslide activity.* These differences are expressed at both the local (i.e. study sub-area) scale and the larger (i.e. regional) scale. This implies that, if riparian management prescriptions are to be tailored to varying land situations, they need to be adjusted both to regional conditions and to variations in the intensity of processes within relatively small subregions.

- *The average landslide density values per study area and per study sub-area are greatest in the Outer Coast Mountain region, and lowest in the Hecate Lowland region.* Management practices in the Outer Coast Mountain region should have a strong focus on ways to minimize the direct and/or indirect effects of landslides on the riparian zone.

- *No significant regional differences are detected in drainage density values.*

- *The results discussed in this report are limited by the nature of the available data.* Specifically, further analysis of typical landslide types between the different regions is hindered by the incomplete nature of the landslide database. In addition, the available hydrological data are very general. While inter- and intra-regional differences were discerned, it is difficult to say how the results would be incorporated into a watershed-level riparian management decision tool.

- *Watershed-level management should incorporate data collection/experimental designs that will enhance present databases.* Management practices rely upon the current knowledge framework. Currently, the lack of data in the Central Coast is a major limiting factor in creating better management practices.

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