Report

BC Timber Sales
Kootenay Business Area

Hydrologic Assessment of Areas of Interest, Perry Ridge

Project: 2012-8170.000

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Mr. George Edney, R.P.F.
Planning Officer
BC Timber Sales, Kootenay Business Area
1907 Ridgewood Road,
Nelson, B.C., V1L 6K1

Re: Final Report, Hydrologic Assessment of Areas of Interest, Perry Ridge

Dear Mr. Edney:

Summit Environmental Consultants Inc. is pleased to provide you with the final report for the above-noted study.

The results indicate that hydrologic risks are generally low and those that are "moderate" may be mitigated by appropriate planning and due care during development.

It has been a pleasure working with you and the BCTS team on this project.

We trust that this completes the assignment to your satisfaction. Please do not hesitate to call or e-mail us to discuss aspects of the project.

Yours truly,

Prepared by:

Summit Environmental Consultants Inc.

Polar Geoscience Ltd.

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1 Introduction

1.1 BACKGROUND

BC Timber Sales (BCTS), Kootenay Business Area, is proposing to extend forest development in the central part of Perry Ridge, approximately 16 km southwest of Slocan, B.C. (Figure 1-1). The proposed development currently consists of six areas-of-interest (1, 3-6 and A) from Operating Plan #7, which are located southwest of Timber Sale Licence (TSL) A80073 (harvested 2010-2012) (Figure 1-2).

Summit Environmental Consultants Inc. (Summit) previously prepared a hydrologic assessment for three of the four TSL A80073 blocks (Summit 2009) which involved field assessment, ECA analysis and preparation of recommendations to minimize risk.

The new proposed development falls within six small unnamed watersheds that drain the west side of the ridge (Figure 1-2). The development area would be accessed via the Little Slocan and Perry Ridge Forest Service Roads (FSRs) and approximately 8 km of new mainline and branch roads.

Perry Ridge has been a focus of considerable attention since the 1990s when plans for logging were announced and the Perry Ridge FSR was constructed. Numerous investigations and assessments have been conducted on Perry Ridge, commissioned both by Provincial agencies and private stakeholders. This work has addressed hydrology, terrain hazards and ecological concerns both on and downslope of the ridge. BCTS is aware of the issues raised over the years and is committed to minimizing risks associated with forest development. As a result, BCTS has adopted a phased approach to forest development planning on Perry Ridge whereby general areas-of-interest (AOIs) for harvesting are first identified. Following various assessments and review of their respective recommendations (in Phase 1), these AOIs are refined and block boundaries are drafted and field marked. Subsequent assessments of the specific (field-marked) blocks (in Phase 2) are then conducted to provide additional site-specific guidance to further minimize risks associated with forest development.

This report summarizes the Phase 1 hydrologic assessment of the proposed forest development.

1.2 OBJECTIVES

The overall objective of the Phase 1 hydrologic assessment is to evaluate the suite of potential hydrologic risks associated with the proposed development (i.e. AOIs 1, 3 - 6 and A, and associated roads) and to provide guidance to BCTS to minimize such risks.
The risks evaluated include:

1. Sediment delivery risk;
2. Peak flow risk;
3. Channel stability risk; and
4. Riparian function risk.

The assessment included both office and field components. In the office, the main goal was to gain a thorough understanding of the proposed development area by reviewing existing reports, topographic and terrain maps, aerial photographs and other information. Discussions were held with staff from BCTS, Sitkum Consulting Ltd. and study team members who have previous experience on Perry Ridge immediately to the northeast of the AOIs.

The office component also involved an Equivalent Clearcut Area (ECA) review, which included:

1. Identifying and defining the watersheds potentially affected by harvesting of the AOIs;
2. Calculating the existing and future ECAs for each watershed assuming that the proposed harvesting of the AOIs takes place; and
3. Commenting on the projected future ECAs, and providing recommendations, in light of field observations.

The field component involved a review of hydrologic and watershed conditions within and downslope of the AOIs, and included:

1. Documenting the general drainage conditions within and downslope of the AOIs, with specific attention paid to the largest stream (Stream #3);
2. Assessing the potential for forest development (i.e. roads and cut blocks) to alter the flow regime, channel stability, sediment delivery, and riparian function; and
3. Providing recommendations to revise the proposed harvesting plans, if necessary, in order to minimize the risk of drainage problems associated with the AOIs.

The Phase 1 assessment (this report) is intended as an initial overview, with Phase 2 assessment work intended to provide site-specific information at a later date.

1.3 STUDY TEAM

The Phase 1 hydrologic assessment was prepared by Summit in collaboration with Polar Geoscience Ltd. Staff from both firms have prior experience at Perry Ridge and were responsible for the previous hydrologic assessment of TSL A80073 (Summit, 2009). Summit has also communicated and shared information with Sitkum Consulting Ltd (Sitkum). Sitkum is responsible for a concurrent terrain stability assessment for the new roads and preparation of road construction prescriptions.
Project Area Characteristics

2.1 LOCATION

The proposed development consists of AOIs 1, 3-6 and A (Figure 1-1) that are located near the centre of Perry Ridge. The AOIs fall within six small, unnamed watersheds which drain the west side of the ridge. Timber is planned to be harvested using a clearcut with reserves harvest system, with random skidding to in-block roads and trails and log decking along roads. Riparian reserve areas and wildlife tree reserves have not been identified at this stage. About 8 km of new permanent mainline road and temporary branch roads will be constructed.

2.2 PHYSIOGRAPHY

Perry Ridge is located within the Selkirk Mountains, which are characterized by strongly glaciated mountain ranges and deep valleys with rivers and lakes (Holland 1976). The ridge trends southwest to northeast and has a rolling upland surface approximately 25 km long, bounded by the steep valley sides of the Slocan River valley on the east and the Little Slocan River valley on the west. As highlighted in Figure 1-2, the watersheds containing the AOIs are generally characterized as having gentle terrain on the upland directly above steep gullied terrain (i.e. "gentle-over-steep"). This configuration presents a unique set of potential drainage and slope stability issues that have been the subject of considerable study (Jordan et al. 2010). The streams flow out of the upland area, down the confining gullies and across their lower gradient fans onto the Little Slocan River valley bottom. Total relief of the watersheds draining the proposed development area is about 1,280 m, with elevations ranging from 680 m to about 1,960 m.

2.3 BEDROCK AND SURFICIAL GEOLOGY

Perry Ridge is generally underlain by granitic rock (BCGS 2005) which is frequently exposed on the upland surface and on the valley sides. Generally, the granitic bedrock is slightly weathered and widely to densely fractured. Rates of water infiltration into the bedrock are inferred to be generally low.

Comprehensive surficial geology mapping of the proposed development area on Perry Ridge is not available. According to Summit (2009), the upland surface is characterized as having a discontinuous layer of colluvium and/or till over bedrock. Based on field observations during the current assessment, these materials are up to 2 m thick and are generally coarse textured.

1 To facilitate discussion of these unnamed watersheds, we have arbitrarily named them Streams #1-6, from southwest to northeast (Figure 1-2).
Bedrock is commonly exposed along the Little Slocan River valley side, however colluvium is present in rock clefts and where there are local areas of gently sloping terrain. Talus slopes of blocky colluvium are found below cliffs.

At the bottom of the Little Slocan River valley side, the surficial deposits consist of blocky colluvium (from rockfall) and alluvial and colluvial deposits, which form fans or aprons (Photo 17). The main Little Slocan River valley near the project area has glacial till and outwash and modern alluvial deposits.

### 2.4 TERRAIN STABILITY

As noted above, Sitkum Consulting Ltd. is currently conducting a terrain stability assessment for the proposed mainline and branch roads (Robertson pers. comm. 2012). The following discussion provides some general context to this assessment.

According to Sitkum (2008 a), terrain stability mapping of Perry Ridge in the proposed development area was completed by Wehr (1985 and 1996) and Chatwin (1998). The mapping generally indicates that “potentially unstable” terrain is located directly upslope of the gullies and “unstable” terrain is located within the gullies. “Stable” terrain is generally found on the upland and on the Little Slocan River valley bottom.

In 1999, an overview risk assessment of road building and harvesting on Perry Ridge was completed (VanDine et al. 1999). The study evaluated the risk to watersheds at the north end of the ridge, well beyond the AOIs, but nevertheless in similar terrain. While VanDine et al. (1999) identified evidence of old debris flows and landslides, some possibly attributable to forest fires 80-100 years ago, they concluded that the rate of geomorphic activity along Perry Ridge was relatively low.

Robertson (pers. comm. 2012) has noted evidence of occasional natural rockfall events and landslides in the steep bedrock-controlled gullies below the upland. Evidence of debris flows and debris floods have also been noted in the steep gully for Stream #3 below the upland surface. Some debris flow deposits have mature conifer trees growing on them, suggesting these deposits are more than 100 years old.

### 2.5 CLIMATE

The climate normals for the project area have been estimated using Climate WNA (Wang et al. 2012), an on-line program which provides site-specific climate estimates from nearby stations with adjustments for location and elevation, over the 1981 to 2009 period. The project area has a cool moist climate, with an average annual temperature of about 3.3 °C and about 1,013 mm annual precipitation. Average monthly temperatures range from about -5 to -8 °C in winter and 7 to 15 °C in summer. The months with highest precipitation are November through January, with about 110-120 mm per month. About 70-90 mm of precipitation per month falls from February to October. The maximum depth of the winter snowpack averages about 2 m deep according to records from the Koch Creek snow survey site to the west (Ministry of Environment 2012a). The pattern of lower branches on mature trees in the project area provides supporting evidence of an average maximum snowpack depth of about 2 m.
Ongoing climate change has the potential to affect the hydrology of the project area over the next several decades. Based on a compilation of climate model results (Schnorbus et al. 2011), the following general climate changes are predicted to occur in the B.C. Interior, including the project area:

- Higher temperatures in all seasons (approximately 1.5 °C to 2.5 °C), with the largest temperature increases projected for the winter season.
- Annual precipitation is projected to increase modestly. Although precipitation projections have considerable uncertainty, it is suggested that increased precipitation (10-15%) will occur in the winter, spring and fall. Summer precipitation is likely to decrease.
- The proportion of rainfall versus snowfall is generally expected to increase, as freezing levels generally rise.
- As a result, snow accumulation is projected to modestly increase at high elevation, and decrease at low elevation.

These predictions of climate change rely on the available climate modelling and statistical analyses, which is a developing science. While the general trends are supported by modelling different scenarios, the amount of change cannot be known with precision at the different locations and elevations.

### 2.6 HYDROLOGY

The project area has a nival (snowmelt-dominated) hydrologic regime. Although there are no direct streamflow records in the project watersheds, seasonal streamflow gauging was previously conducted on the east side of Perry Ridge (Chatwin 1999). The hydrographs indicate that the melt of the winter snowpack generates streamflow that starts rising in mid-April, peaks in late May, and recedes thereafter. This annual hydrologic pattern is typical of many southern interior streams. Peak flows in the project area are normally associated with rapid spring snowmelt during hot spells, which may be intensified by rainfall. Summer and fall rain events are generally associated with only minor flood peaks. In most of the six project area streams, flows likely cease altogether by mid to late summer due to lack of rain and relatively dry soil conditions.

With climate change (Schnorbus et al. 2011), changes in rainfall and snowpack dynamics may cause the following hydrologic changes:

- A small increase in the total annual stream discharge associated with the small increase in annual precipitation;
- Earlier onset and shorter duration of the spring freshet;
- A small increase in discharge over spring and early summer;
- Lower late summer and early fall flows; and
- Higher late fall and winter flows.
2.7 WATER USE AND FISH PRESENCE

The proposed AOIs are located within the small watersheds associated with Streams #1 to 6 that flow seasonally to the Little Slocan River (Figure 1-2). According to provincial records, there are no water licences for the extraction of surface water nor are there any known fish populations in the six watersheds (B.C. Ministry of Environment, 2012a, b). The nearest water licences on the Little Slocan River are about 25 km downstream, below the confluences with several other large tributaries, and near the confluence with the Slocan River. There are, however, fish populations upstream and downstream of the six project streams in the Little Slocan River and Upper Little Slocan Lake. Fish inventories indicate the potential presence of the following species: Bull trout, Prickly Sculpin, Large-scale Sucker, Brook Trout, Kokanee, Mountain Whitefish, Northern Pikeminnow, Peamouth Chub, Pygmy Whitefish, Rainbow Trout and Redside Shiner (Ministry of Environment 2012b).

Other large alpine-sourced streams enter the Little Slocan River upstream and downstream of Streams #1-6 and strongly affect the flow regime and the amount of sediment transported. The headwaters of the Little Slocan River are in the Selkirk Mountains generally north of the project area. Robertson Creek joins the river above the project streams and Bannockburn Creek joins just below the project streams (Figure 1-1). There are also many smaller tributaries, including the six project area streams. Bannockburn Creek has a large, high elevation contributing area and forms the main water and sediment source for the Little Slocan River.

The total drainage area for the Little Slocan River above Upper Little Slocan Lake is about 130 km² and includes much high elevation, steep land with high seasonal snowpack and bare rock and talus slopes. The project area includes about 16.8 km² or about 13 % of the total watershed area. The project streams flow about 1.5 to 2.2 km (horizontal distance) from the edge of the upland (with proposed harvest) to the Little Slocan River.

No bedload deposits from Stream #3 are indicated at the confluence with the Little Slocan River, based on interpretation of the aerial photographs. Bannockburn Creek transports a lot of gravel and sand material into Little Slocan River, with gravel lateral bars and a single thread channel below the confluence.

Given their small sizes and contribution areas, the seasonal nature of stream flow, and the low amounts of transported sediment, the six project area streams tend to have a limited effect on the Little Slocan River. Instead, the large contribution areas, the perennial stream flow and the large volumes of transported sediment from the main tributaries tend to dominate the Little Slocan River upstream and downstream of the project area streams.

2.8 WATERSHED CHARACTERISTICS

There are seven key factors that affect hydrology and channel response in the area of proposed forest development. By understanding the suite of factors, it is possible to make sound inferences on the current
Study Area Characteristics

and likely future state of streamflows and channel conditions under changing conditions (forest development and climate change). These factors are:

1. *Climate*, which varies spatially in response to elevation, aspect, topography, prevailing winds, and other factors and which may change over time;
2. *Topography*, which influences precipitation patterns, how connected the hillslopes are to the stream network, and aspect, (which in turn affects snow accumulation and melt patterns);
3. *Hypsometry*, or distribution of elevations, which influences the patterns of snow accumulation and melt;
4. *Watershed routing efficiency*, which describes the efficiency by which surface runoff and shallow groundwater flow are routed to the stream network. Surface runoff rates may be reduced by areas of standing water (lakes and wetlands) or may be increased by high stream densities and high road network densities (road surfaces and ditches). Groundwater flow rate is affected principally by subsurface characteristics (surficial materials and bedrock geology and structure) and the water table elevation differences;
5. *History of natural forest disturbance*. In watersheds with a history of natural forest disturbance (e.g. wildfire, windthrow, insect infestations, tree diseases), there is a likelihood that the watershed will be more resilient to subsequent hydrologic changes. In watersheds with natural disturbance, there have been previous episodes of loss of forest cover, deeper snowpacks and higher runoff, which have conditioned the channels through armouring due to somewhat higher stream flows;
6. *Extent and location of forest harvesting, as indicated by the ECA*. This affects several hydrologic processes including snow accumulation, snow melt and evapotranspiration; and
7. *Channel sensitivity*. This is an inherent characteristic of a stream which controls its susceptibility to disturbance.

Controlling factors 2, 3 and 4 (noted above) are generally constant over time and are a function of watershed characteristics. Controlling factors 1, 5, 6 and 7 tend to vary with time. Factor 1 has been discussed in Section 2.5. Factors 2, 3 and 4 are summarized below. Factors 5, 6 and 7 will be discussed in regard to the proposed road construction and harvesting.

With respect to factors 2, 3 and 4, the watersheds draining the AOIs have considerable relief and are dominated by gently rolling terrain above steep gullies. In terms of the water routing efficiency (from the land surface to the stream network), there are two flow components to consider: surface flow and groundwater flow. The rate of surface flow tends to be directly proportional to such factors as drainage density, which for the project area is relatively high, and inversely proportional to the amount of storage (e.g. lakes and wetlands) in the watershed, which is relatively low (i.e. less than a few percent of the watershed area). Furthermore, the project area watersheds are characterized by relatively thin, coarse-grained soils above low permeability bedrock. The rate at which shallow groundwater drains to the stream network is therefore relatively high. As a result, the watersheds generally have a high watershed routing efficiency, which tends to limit the capacity of the watersheds to attenuate peak flows in spring, resulting in relatively rapid streamflow response to snowmelt and/or rainstorms.
The project area upland and gully slopes are generally highly coupled\(^2\) with the stream network; however, very little slope erosion was noted except at natural treefall locations.

The forests in the project area watersheds consist of mature Engelmann spruce / subalpine fir, larch, cedar and hemlock (Photos 24 and 25). With respect to controlling factor 5 (noted above), there is some evidence of natural localized blow-down and wildfire (i.e. charred stumps) in the watersheds. While the hydrologic recovery from these events that occurred many decades ago is effectively 100%, it is likely that the watersheds have to some degree become more resilient to hydrologic changes from loss of forest cover. For example, in some streams, channels that have been subject to a history of flood events can form a coarse armour layer that restricts sediment entrainment and channel adjustment by subsequent flows.

Controlling factor 6 - the extent of forest harvesting (as indexed by the ECA), is discussed in Section 4.0 with respect to the project area watersheds. Section 5.0 summarizes channel conditions in the watersheds and identifies channel sensitivity (factor 7).

As shown in Figure 1-2, the four smallest watersheds (Streams #1, #2, #5 and #6) have limited upland areas, generally shallow gullies, and relatively small fans. The two larger watersheds (Streams #3 and #4) drain considerably larger areas of the upland surface via dendritic pattern stream networks. The majority of the proposed development area is located on the upland surface in the Stream #3 and #4 watersheds. As a result, much of the focus of this Phase 1 assessment is on these two streams and their watersheds.

\(^2\) A highly coupled hillslope would have sediment from slope erosion directly enter the channel. A partially coupled slope would have a portion of the sediment deposit on the valley flat and some enter the channel. A decoupled slope would have the sediment interrupted by the valley flat and none would enter the channel.
This Phase 1 hydrologic assessment included both office and field components. The office work included a review of the background reports, aerial photography and topographic and geological mapping for the proposed development area. Much of the available background information is focussed on the populated valley on the east side of Perry Ridge, several kilometres northeast of the project area.

ECAs were calculated for each of the six watersheds, with the points of interest assumed at the mouth of each stream where it joins the Little Slocan River.

A field reconnaissance was completed on October 4, 2012 following a relatively warm and dry summer. The reconnaissance was led by Joe Alcock, P.Geo. of Summit in the company of Dan Upward, RPF and Charlene Strelaeff, RPF of BCTS. The weather during the field reconnaissance was cool, clear and dry, with little rainfall in the preceding weeks. Streamflow of less than 5 L/s was observed along the upper reaches of Stream #3, but otherwise the streams were dry. Visibility was good since leaf drop in deciduous stands had begun.

Although the centerline of the proposed access road was field flagged, no roads or trails have yet been constructed to access the AOIs. Therefore, the area was accessed by helicopter. The group landed near the upper edge of AOI #6 and traversed by foot along portions of the flagged road alignment and through AOIs #6, #4, #5 and #1 within the watersheds of Stream #3 and #4 (Figure 1-2). During the traverse, watershed and stream network characteristics were noted and photographed (Photographs 1 – 25 in Appendix B), particularly in the vicinity of the proposed AOIs and along the flagged road alignment.

Portions of the watersheds that were not reviewed during the traverse were observed from the helicopter and photographs were taken to document general watershed characteristics and indicators of channel conditions and hillslope processes (e.g., avalanches, rockfall).

The Little Slocan FSR is located on the south side of the Little Slocan River valley and provides access to the lower parts of the project watersheds. The focus of these observations was on Streams #3 and #4, which have well-defined stream channels. The other streams are poorly defined on the valley bottom and while they were not inspected in detail, are thought to flow sub-surface for at least part of the year.
4

Projected Equivalent Clearcut Areas

4.1 CURRENT AND FUTURE EQUIVALENT CLEARCUT AREAS

The six watersheds in which the AOIs are located are essentially undeveloped. Only the Little Slocan FSR and other roads cross through the downstream portions of the watersheds. Therefore, the current ECAs for the watersheds above their points of interest (at the Little Slocan River) are effectively about 0.2 to 2% due to the FSR and other road rights-of-way.

Watershed areas were delineated based on provincial 1:20 000 scale TRIM mapping, and refined based on a review of recent aerial photographs, and the results of our field reconnaissance. Projected ECAs were calculated above the point of interest for each stream using the proposed AOI areas and locations provided by BCTS and assuming that the blocks will be clearcut harvested. Projected watershed ECAs are reported in Table 4-1. The ECAs of new road rights-of-way outside of the AOIs but within the watersheds were also accounted for by applying a 25 metre harvested strip along the road center line. The projected ECAs reflect conditions immediately post-harvest, do not consider any wildlife tree or riparian retention areas, and do not account for any forest regeneration. Therefore, the values are considered conservative (i.e. over-estimates) of future ECAs.

Table 4-1 Summary of Watersheds and Proposed Areas of Interest for Harvesting

<table>
<thead>
<tr>
<th>Watershed / Stream</th>
<th>Watershed Area (ha)</th>
<th>Proposed Areas of Interest (AOI)</th>
<th>Permanent Road Outside of Blocks (ha)</th>
<th>Projected Total ECA (%)</th>
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<tr>
<td>ID</td>
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<td>ID</td>
<td>Area (ha)</td>
<td></td>
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<tr>
<td>#1</td>
<td>57</td>
<td>AOI #5 (portion)</td>
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<td>#2</td>
<td>90</td>
<td>AOI #5 (portion)</td>
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<td>0.5</td>
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<td>642</td>
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<tr>
<td>#4</td>
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<td>AOI #1</td>
<td>46.3</td>
<td>3.8</td>
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<tr>
<td>#5</td>
<td>116</td>
<td>AOI A (portion)</td>
<td>13.9</td>
<td>1.5</td>
</tr>
<tr>
<td>#6</td>
<td>160</td>
<td>AOI A (portion)</td>
<td>17.0</td>
<td>0.9</td>
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<tr>
<td>Total</td>
<td>1,315</td>
<td>-</td>
<td>254</td>
<td>12.5</td>
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</table>

The six watersheds are each of about 650 ha or less in area, with existing small ECAs and moderate proposed ECAs up to about 25.6%. ECA is a general index value of potential watershed effects from...
changes to rainfall and snowpack melt due to reduced canopy. The Interior Watershed Assessment Procedure (IWAP) (Ministry of Forests 1999) indicates that the use of ECA is most suitable for watersheds between 500 and 50,000 ha in area, and watersheds below 500 ha were better assessed through detailed field assessment. Therefore, the ECAs in the watersheds #1, 2, 4, 5 and 6 are provided for reference only.

4.2 DISCUSSION OF PROJECTED EQUIVALENT CLEARCUT AREAS

The hydrologic effects of forest harvesting have been the subject of much research in B.C. over many decades. The reader is referred to Winkler et al. (2010) for a recent comprehensive discussion of the effects of forest disturbance on hydrologic processes and watershed response in B.C.

Many watershed evaluations in the B.C. Interior have used a threshold ECA of 25 – 30%, below which the potential to detect hydrologic change is low. However several sources of uncertainty complicate the application of this simple index. According to Winkler et al. (2010) these include:

- The hydrologic function of growing forests varies according to species composition, tree spacing, climatic characteristics, and site topography;
- Hydrologic processes are strongly dependent upon the weather patterns (depth of snowpack, rainfall rate and total), which often overshadow effects of forest canopy changes; and
- Simple indices such as ECA cannot account for the complex linkages between forest stands, hill slopes, and entire watersheds.

The projected ECAs for the project area watersheds range from 6.1% to 25.6%. For five of the watersheds, projected ECAs are below the 25% threshold and are not anticipated to result in detectable changes to the hydrologic regime. Watershed #3 has a projected ECA marginally over 25%. Such ECAs are generally low and harvesting is not expected to have detectable effects on the hydrologic regime in the project area watersheds or downstream.
5 Observed Channel Conditions

The channel conditions for the project area streams are described below. Where warranted, recommendations are presented in Section 7 to promote maintenance of natural channel conditions and to minimize potential effects of harvesting.

The largest watershed potentially affected by the proposed development is that for Stream #3, which drains about 642 ha above the Little Slocan River. Given that the majority of the development falls within this watershed, it was a primary focus of the Phase 1 assessment. Since fewer observations were made of the other five streams, these have been grouped together for discussion purposes.

5.1 STREAM #3

The headwaters of Stream #3 are located on rolling forested terrain on the upland (Figure 1-2). Soils on the upland are generally thin and discontinuous and are composed of thin colluvium and till deposits over granitic bedrock. The overall channel pattern reflects bedrock control (Photos 4 to 9). Over the upland, the mainstem channel is generally 2 to 4 m wide and up to 1 m deep, with tributaries considerably smaller. Cobbles and boulders and some sand form the bed and banks of the mainstem and tributary channels. Naturally-supplied large woody debris (LWD) from blow-down is common. LWD is a key element responsible for natural stream channel processes. Although LWD may be responsible for causing local stream bank erosion as a result of tree blowdown and flow re-direction, LWD also forms jams which retain some sediment and help regulate sediment transport.

Stream #3 descends from the upland and flows into a deep bedrock-controlled gully down to the valley bottom (Photo 9). Based on the aerial photographs, ground photographs by Sitkum Consulting Ltd., and observations from helicopter, the gully is lined by a narrow deciduous riparian zone which has evidence of snow avalanche activity. Bedrock cliffs and steep side-slopes along the gully are prone to rockfall and occasional shallow natural landslides. These colluvial processes and the bedload transport from upstream supply the gully with coarse sediment and woody debris, which is eventually carried to the bottom end of the gully. On the more gentle gradient sections at the bottom end of the gully, some woody debris jams were noted. These jams tend to trap sediment and govern bedload movement. Release of this sediment and woody debris may occur if either the jams deteriorate or if they are destabilized by floods. If a large release occurs, a debris flow or flood may be possible. Evidence of such episodic natural events was noted during the Sitkum field review (Robertson, pers. comm. 2012).

Beyond the gully, Stream #3 flows over the eastern portion of its fan before flowing into the Little Slocan River (Photo 17). The fan is approximately 20 ha in area, with the outer edge near the river. On the date of the review, this portion of the stream channel was dry, presumably because any water was flowing subsurface through the coarse-textured fan materials. Although evidence suggests the fan is subject to some modern fluvial processes near the existing channel (e.g. flooding, erosion and occasional debris flows), the main part of the fan was likely formed during post-glacial times by mass movement processes and flood
events during a time of high sediment transport and water flow and has changed little since. Gradients on the fan range from about 20% at the apex to less than 10% near the Little Slocan River.

On the fan, the channel width ranges from about 5 – 7 m, and the depth up to about 1.5 m. The bed materials consist of boulders and cobbles near the fan apex with some fining in sediment texture towards the mouth. Evidence of flooding, erosion and deposition are widespread on the fan near the channel (e.g. levees, buried woody debris, side-channels) (Photos 18, 19 and 20). Much of the fan has been logged (in Tree Farm Licence #3 and on the private land), and dense patches of shrubs and trees occupy the Stream #3 riparian zone over the fan.

The Little Slocan FSR crosses Stream #3 at road km 17.5 on the lower portion of the fan. The crossing consists of three corrugated metal pipe culverts of different sizes (Photos 18 and 20). The culvert inlets were damaged and evidence of previous machine excavation of the channel was noted both at the crossing and upstream. BCTS staff indicate that a secondary channel was excavated to the west of the main channel (date unknown) to provide relief from flooding at the main road crossing (St. Thomas pers. comm. 2012). Although this overflow channel was not identified in the field, it was reported to cross the FSR at about road km 18.

5.2 OTHER PROJECT AREA STREAMS

In addition to Stream #3, five other streams and many non-classified drainages (NCDs)3 drain the proposed AOIs. Tributaries of Stream #4 on the upland were observed in the field, and the other four streams (#1, #2, #5, and #6) were reviewed from the air and by aerial photography. These small, seasonally-flowing streams occupy small upland draws or shallow gullies that have relatively low rates of bed-load movement (as evidenced by moss growth on in-channel cobbles and boulders) (Photos 10 and 11).

Similar to Stream #3, the five minor streams descend through bedrock and colluvium-lined gullies, ultimately reaching the valley bottom (Photos 2, 22 and 23). At that point, these minor streams flow across small fans or valley deposits. Only some streams have evidence of seasonal surface flow upstream of the FSR (Photo 21). Other streams appear to infiltrate into the surficial deposits and have poorly defined channels downstream. No recent evidence of stream crossing issues was noted along the FSR in association with these minor streams. (It should be noted that on the available topographic maps, the stream location symbols are inferred and not field verified, and therefore the streams may not actually be present).

In the upland area, many NCDs are present in and below the proposed AOIs and along the proposed road. The NCDs show evidence of seasonal or intermittent water flow across the land surface. The surface flow is generally discontinuous as the flow is routed into coarse-grained soils. There is little evidence of channel formation, and limited or no alluvium (Photos 13 and 14). NCDs often have adjacent moisture-loving plants and trees growing nearby.

3 A non-classified drainage is defined as a water feature with no continuous channel bed, and with no evidence of either scour or mineral alluvial deposits, over a distance of 100 m (B.C. Ministry of Forests 1998).
5.3 CHANNEL SENSITIVITY

The six project streams were evaluated in terms of channel sensitivity\(^4\) in order to assess the potential for changes from possible peak flow and sediment delivery changes. Streams #3 and #4 were observed in the upland, gully and fan sections. The other stream locations were observed from air and through aerial photographs, and the channel sensitivity in the different sections was inferred.

Stream #3 on the upland is considered to have a low to moderate channel sensitivity to future disturbance, based on the cobbles and boulders forming the bed and banks and the bedrock outcrops along the channel. Where natural blowdown into the channel had occurred, some minor lateral erosion around the obstructions was observed. Stream #3 within the steep gully has a low channel sensitivity as it is mainly bedrock controlled. Where Stream #3 crosses its fan, the channel is moderately sensitive to future disturbance, given that the channel bed and banks are composed of boulders and cobbles near the apex and finer sediment lower on the fan, with evidence of some previous lateral erosion, abandoned channels and previous flood deposits near the modern channel.

Streams #1, #2, and #4, #5 and #6 are considered to have low sensitivity on the upland, in the steep gullies, and over their mainly inactive fans.

5.4 POST-HARVEST OBSERVATIONS OF TIMBER SALE LICENCE A80073

As noted above, four blocks were harvested between 2010 and 2012 as part of Timber Sale Licence A80073. The location of these blocks is directly north of the current AOIs (Figure 1-1) in an area of similar terrain, surficial deposits and runoff. The blocks were clearcut using ground-based methods with random skidding. During our review from helicopter, we noted some evidence of soil disturbance from the random skidding and other areas with intact forest floor. However much of this disturbed soil is decoupled from the stream network and poses a low risk of sediment delivery. One road section and nearby ditches were observed on the ground during a helicopter stop-over. The road and ditches were constructed in silty and sandy surficial materials, and had a minor amount of local surface erosion that is typical for newly constructed roads. A minor number of blow-down of trees had occurred along the edges of blocks after harvesting.

\(^4\) Channel Sensitivity is defined as the potential for channel changes due to peak flow or sediment input changes. Sensitivity is a function of both natural stream characteristics and the level of existing watershed disturbance. For example, a stream channel comprised of coarse-grained alluvial material with a healthy riparian buffer is less sensitive to increased peak flows than a stream with sand and gravel alluvial banks with minimal riparian cover, or a channel with significant sediment build-up due to upslope erosion.
6 Risk Analysis

6.1 PARTIAL RISK ANALYSIS FRAMEWORK

The main objective of the Phase 1 hydrologic assessment is to evaluate the risks of the proposed forest development in the six AOIs and provide recommendations to minimize any associated risks to the streams. In order to objectively assess risks and provide qualitative risk levels (i.e. high, moderate and low), we adopted a hydrologic partial risk analysis framework that is based on the landslide partial risk analysis framework described by Wise et al. (2004). The comprehensive framework, definitions, and methodology used in this analysis are documented in Appendix A. Briefly, the partial risk analysis involves determining the combined probability of the occurrence of a specific hazardous event and the probability of that event affecting a specific element. The following equation provides the general framework:

\[ P(\text{HA}) = P(H) \times P(S:H) \]

where,

- \( P(\text{HA}) = P(\text{Hazardous and Affecting Event}) = \text{probability of occurrence of a specific hazardous event (e.g., sediment into a stream) and that event affecting a specific element.} \)
- \( P(H) = P(\text{Hazardous Event}) = \text{probability of occurrence of a specific event and that event being a hazard to a specific element.} \)
- \( P(S:H) = \text{probability of a spatial effect of the specific event on the specific element if the event occurs (e.g., the probability of the specific sediment event reaching or otherwise affecting the specific element at risk).} \)

Using the information collected during the office and field components of the Phase 1 hydrologic assessment, the risks to watershed values were assessed and analyzed at a watershed level based on professional experience, and organized as follows:

- Sediment delivery risk\(^5\);
- Peak flow risk;
- Channel stability risk; and
- Riparian function risk.

\(^{5}\) For the partial risk analysis, we did not assess landslides (which are part of the terrain stability assessment) but surface erosion from roads.
6.2 PARTIAL RISK ANALYSIS RESULTS

A summary of the assigned risks based on the Phase 1 assessment is provided in Table 6-1. Overall, the risks are deemed either nil or Low in all watersheds.

The overall sediment risk (from point sources) is low throughout all watersheds. Likewise, the overall sediment risk associated with roads is low in all project area watersheds where roads are proposed. In spite of the conservative assumption that new roads will initially have moderate rates of erosion (based on observations of nearby roads previously built to access A80073), their location on the upland surface largely decouples them from the elements at risk downstream.

In spite of the relatively high watershed routing efficiency in all project watersheds, the relatively low ECAs that are proposed result in a low overall peak flow risk in all watersheds. Given that the channel stability risk is strongly dependent upon the peak flow risk, channel stability risks associated with the proposed development are also low in all watersheds, including stream #3, despite its fan having moderate channel sensitivity.

In all watersheds except #3, the riparian function risk has been deemed low. The riparian function risk for watershed #3 is rated moderate based on the apparent proportion of the stream network (on the upland) where harvesting may encroach on riparian zones. It is important to note that this rating is based on map information and is subject to revision as harvest plans are refined and site-specific ground observations are made.

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6 This Phase 1 assessment is based on interpretation of topographic, stream and reconnaissance terrain maps, a helicopter overview and limited ground observations. As a result, the hazard/risk ratings are based on conservative assumptions that may be subject to revision as additional information becomes available from the Phase 2 assessment.
## Table 6-1  Summary of the Risk Analysis for the Six Project Area Watersheds with Development of the AOIs.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Stream #1</th>
<th>Stream #2</th>
<th>Stream #3</th>
<th>Stream #4</th>
<th>Stream #5</th>
<th>Stream #6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P(H)</td>
<td>P(S:H)</td>
<td>Risk [R(S)]</td>
<td>P(H)</td>
<td>P(S:H)</td>
<td>Risk [R(S)]</td>
</tr>
<tr>
<td>Sediment delivery (point sources)*</td>
<td>-</td>
<td>-</td>
<td>nil</td>
<td>-</td>
<td>-</td>
<td>nil</td>
</tr>
<tr>
<td>Sediment delivery (roads)</td>
<td>-</td>
<td>-</td>
<td>nil</td>
<td>-</td>
<td>-</td>
<td>nil</td>
</tr>
<tr>
<td>Peak flow</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Channel stability</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Riparian function</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Notes:
1) Refer to Appendix A for full definitions and methodology used to derive risk ratings.
2) Cells marked with "-" are not applicable (e.g. the watershed may not have roads, and therefore the risk from roads is nil).
   Mod. = Moderate
* = Excludes landslides
6.3 RISK MITIGATION

The main goal of this risk analysis is to provide general recommendations to mitigate potential negative hydrologic impacts of harvesting the AOIs on the project watersheds and downstream resources. This section includes watershed-level and stand-level recommendations to minimize near-future impacts on water resources (as well as other non-timber values). These recommendations apply throughout the project area watersheds and should be considered in future planning and operations.

6.3.1 Watershed Level Planning

Impacts of forest harvesting on non-timber values (including water resources) can be minimized by the following practices:

- Maintain a diversity of forest cover types and minimize reforestation delays through prompt planting of seedlings and through retention and protection of advanced regeneration which has the necessary form, vigour and number of stems per hectare to release;
- Minimize ground-based harvest on steep or gullied terrain that is highly coupled to the stream network;
- Minimize road length, road density, and the number of stream crossings wherever possible;
- Provide seasonal deactivation and water control for inactive temporary roads and trails and permanent deactivation when temporary roads or trails are no longer needed;
- Maintain natural drainage patterns and decrease the rate of direct ditch runoff to the stream network by avoiding long ditches and instead promoting local infiltration into the ground. Also, avoid the conversion of sub-surface flow to surface flow by minimizing road cuts; and
- Ensure that the drainage network on permanent roads can accommodate any changes in flow that may result from harvest effects and climate change.

Based on the current and projected ECAs, watershed characteristics (i.e. watershed routing efficiency), and channel characteristics (i.e. channel sensitivity), it is recommended that the maximum ECA for the Stream #3 watershed be kept at or below 25% to maintain a low peak flow risk. Given the limited upland area in the remaining five watersheds, ECAs are unlikely to increase much beyond the currently proposed levels.

6.3.2 Stand Level Retention

Tree retention within cutblocks using wildlife tree retention areas is a way to reduce the hydrological effects of harvesting. Retention could include:

- stands both in riparian reserves and in wildlife tree retention areas;
- live understory vegetation;
- large live and dead trees; and
- live vegetation within riparian reserve zones and (if feasible) riparian management zones, where the trees would be wind-firm.
6.3.3 Riparian Zones

Functioning riparian zones are important to minimize harvest impacts. Except where there are special circumstances, harvest in riparian reserve zones in Watershed #3 should be avoided. Furthermore, we recommend considering the entire riparian management zone of all streams as a riparian reserve zone and seeking opportunities to increase the size of the riparian reserve zone, but only if it is suitable to enhance the protection of watershed values. Blow-down is a potential issue. In order to mitigate blow-down, blocks should be planned with recognition of the local wind patterns and velocities and forest managers should consider feathering or topping of trees along block boundaries.

6.3.4 Harvest Operations

With harvest, surface soil disturbance to the watershed can be minimized during road construction and forest harvesting through use of suitable practices, which will result in less potential for sediment generation and less road restoration work required later.

For hydrologic purposes, it is important that non-merchantable trees (fine and coarse woody debris) be retained in cutblocks as much as possible and be left dispersed across the site rather than hauled to burn piles (Klenner 2006). This woody debris will delay surface runoff by slowing snow melt, reducing wind speed, maintaining soil moisture and aiding in site regeneration (Winkler et al. 2007). It will also reduce the potential for surface water erosion.

6.3.5 Roads

Three distinct classes of road are planned: temporary; short term permanent; and long term permanent. All road construction should be accompanied by erosion and sediment control plans developed by a Qualified Professional. Such plans should address road construction, maintenance, and deactivation.

Seasonal deactivation (e.g. establishing waterbars, cross ditch backup of key culverts, seeding of exposed soils) for all classes of road should be completed before spring freshet. All roads and trails should be inspected seasonally and after major precipitation or snowmelt events by a Qualified Professional.

For temporary and short term permanent roads, when all activities requiring the road are complete, then full rehabilitation (e.g. culvert removal and cross ditch installation) and slope recontouring (with revegetation and drainage control), should be completed to maintain natural surface and near-surface drainage patterns (Winkler et al. 2007). If this is done before spring break-up, it also reduces the amount of potentially erodible material available prior to peak flows.

For long term permanent roads, seasonal deactivation should be completed but no full rehabilitation or recontouring can be planned due to the continued requirement for access.

Any sediment risk associated with roads in Watersheds #3 to #6 can be minimized by ensuring the road alignments are set back from the stream network as much as possible in order to “decouple” the road prism sediment from the stream network. Where this is not possible, measures should be considered to minimize
sediment production (i.e. using rock ballast for sub-grades, and capping road surfaces with appropriate granular materials). Furthermore, in order to minimize sediment delivery to streams, drainage along roads should be conveyed (using culverts or cross-ditches) into vegetated areas for infiltration. Where this is not possible, check dams and sediment collection basins (sumps) may be constructed along ditch alignments to capture the transported sediment. If particularly erosive materials are discovered during road building (i.e. along the cutslope and/or ditch line), site-specific erosion control measures should be implemented. This may include installation of coarse rock or riprap (typically underlain by geotextile), installation of a rolled erosion control blanket product or hydraulically applying an appropriate seed/mulch/tackifier mix under the direction of a Qualified Professional.

Where Stream #3 crosses the Little Slocan FSR at 17.5 km, there have been previous culvert blockages and stream erosion of the road. The crossing may be undersized for the flood volumes and the type and volume of coarse sediment transport. This crossing site should be reviewed by a Qualified Professional and a re-construction prescription prepared and implemented.

### 6.3.6 Reforestation

To accelerate hydrologic recovery in the watershed, it is important that re-forestation be initiated as soon as possible after harvest. Site preparation should be conducted in a manner that considers the potential for increased runoff, groundwater levels and surface erosion.

Following reforestation, regularly scheduled silviculture surveys should be completed in the watershed to assess regeneration progress. The surveys would be used to develop prescriptions to address any plantations which have slow recovery.
Conclusions and Recommendations

7.1 CONCLUSIONS

The proposed development area has a gentle-over-steep topographic setting, with the upland slopes highly coupled to the stream networks.

The project area watersheds have a nival hydrologic regime, where peak flows commonly occur in late May/early June. Summer and fall rainstorms produce only minor flood peaks. Flows in the six project area streams generally cease by mid to late summer.

There are no fish populations or water licences in the six streams draining the proposed development. The six streams drain into the Little Slocan River. The Little Slocan River upstream and downstream of the six streams, and Upper Little Slocan Lake just downstream, are fish-bearing. Other large alpine-sourced tributary streams join the Little Slocan River upstream and downstream of the project area streams and strongly affect the flow regime and the amount of sediment transported. Water intakes are present near the confluence of the Little Slocan and Slocan Rivers about 25 km downstream, downstream of other large tributaries.

The projected ECAs for watersheds #1, #2, #4, #5 and #6, including proposed harvest areas and roads, range from 6.1% to 20.3%. Watershed #3 will have a projected ECA of 25.6%. These ECAs are low and are not expected to result in observable changes to the peak flow regime.

The four smallest watersheds (Streams #1, #2, #5 and #6) have limited upland areas, bedrock-controlled gullies, and relatively small fans at the valley bottom above the Little Slocan River. The two larger watersheds (Streams #3 and #4) have a dendritic pattern stream network draining the upland surface. Most of the proposed development is located on the upland surface in the watersheds of Streams #3 and #4.

The upland and gully portions of Stream #3 have low to moderate channel sensitivity to future disturbance, based on its response to previous natural flooding and treefall. On its fan, Stream #3 is moderately sensitive to future disturbance.

Streams #1, #2, #4, #5 and #6 have generally low sensitivity in the upland and gully sections. The smaller creeks generally infiltrate into their beds before reaching the FSR and have low to moderate sensitivity where there is still a channel or fan.

Large portions of the watersheds and proposed harvest areas are drained by seasonal NCDs which do not have significant channel formation or sediment transport.

A partial risk analysis of the proposed forest development was completed, using objective methods, in order to provide Phase I recommendations to mitigate potential negative hydrologic impacts on the six streams related to harvesting. The suite of risks evaluated includes:
The Phase 1 hydrologic assessment included a partial risk analysis based on map interpretation, helicopter overview and brief field review. In Phase 2, with further detailed on-site hydrologic, slope, surficial deposit and sediment transport information, the risk levels may be revised.

The assigned risks are summarized in Table 6-1. Overall, the risks are evaluated as either nil or Low in all watersheds.

The overall sediment risk from point sources is low throughout the six watersheds. Likewise, the overall sediment risk associated with roads is low in the four watersheds with proposed roads. While it has been conservatively assumed that new roads will initially have moderate rates of erosion, their location on the upland largely decouples them from the elements at risk downstream.

While the project watersheds have relatively high watershed routing efficiency conditions, the relatively low ECAs from proposed harvest result in a low overall peak flow risk in all watersheds. Since the channel stability risk is strongly dependent upon the peak flow risk, channel stability risks associated with the proposed harvest are also low in all project area watersheds, including stream #3, despite its fan having moderate channel sensitivity.

The riparian function risk has been evaluated as low in all watersheds except #3. The riparian function risk for watershed #3 is rated as moderate based on where proposed harvesting may impact riparian zones. This rating is based on available harvest plans and is subject to revision. Application of the risk mitigation practices outlined would appreciably reduce the sediment delivery and riparian function risk for the project area streams.

### 7.2 RECOMMENDATIONS

The following recommendations are provided:

1) General recommendations for risk mitigation are presented in Section 6.0, including

- Watershed level planning;
- Stand level retention;
- Implementation of riparian zone management areas and reserves;
- Harvesting operations sensitive to site conditions;
- Road construction and seasonal deactivation including provision of water and sediment control, and later permanent deactivation of short term permanent roads and trails; and
- Prompt reforestation.
It is recommended that an erosion and sediment control plan should be developed for the new roads.

2) Upgrade the culvert crossing for Stream #3 at Little Slocan FSR. The crossing site should be assessed by a Qualified Professional and a prescription prepared and implemented.
References


Appendix A - Risk Analysis

PARTIAL RISK ANALYSIS FRAMEWORK

The following partial risk analysis framework is based on the concepts outlined by Wise et al. (2004); however, it has been customized to address hydrologic risks. The framework is outlined as follows:

In the context of this hydrologic assessment, a Partial Risk Analysis approach was used. Partial Risk Analysis considers the effects of a specific hazard on a specific element, but it does not explicitly evaluate the vulnerability of the element $V(L:T)$. Such an evaluation is beyond the scope of this analysis, and requires obtaining detailed information on the elements at risk (e.g. water quality, fisheries).

$$P(HA) = P(H) \times [P(S:H) \times P(T:S)]$$  \hspace{1cm} [Equation A.1]

Where:

$P(HA)$ = $P$(Hazardous and Affecting Event) = probability of occurrence of a specific hazardous event (e.g., sediment into a stream) and that event affecting a specific element.

$P(H)$ = $P$(Hazardous Event) = probability of occurrence of a specific event and that event being a hazard to a specific element.

$[P(S:H) \times P(T:S)]$ = probability of the specific event reaching or otherwise affecting the specific element, where:

$P(S:H)$ = probability of a spatial effect of the specific event on the specific element if the event occurs (e.g. the probability of the specific sediment event reaching or otherwise affecting the specific element at risk).

$P(T:S)$ = probability of temporal effect of the specific event on the specific element, given a spatial effect (e.g., the probability of the specific element occupying that location when the sediment event occurs).

For a stationary specific element at risk, $P(T:S) = 1$, therefore $[P(S:H) \times P(T:S)] = P(S:H)$. If it is certain a specific event will reach or affect a stationary specific element at risk, then $[P(S:H) \times P(T:S)] = 1$, and Equation A.1 is reduced to $P(HA) = P(H)$. In this case, Equation A.1 is also reduced to $P(HA) = P(H)$. However, in the case where there is some uncertainty that a specific event will reach or affect a specific stationary element at risk, $P(S:H) < 1$. Therefore Equation A.1 is reduced to:

$$P(HA) = P(H) \times P(S:H)$$  \hspace{1cm} [Equation A.2]

Since all elements at risk in this project are associated with the stream network (which is stationary), we have conservatively assumed throughout the risk analysis that $P(T:S) = 1$. (This assumes that fish are present and/or water intakes are used throughout the year). Therefore, $P(HA)$ was evaluated based on Equation A.2 and assigned relative ratings that vary depending on the element at risk.
Definition of Risk Ratings
This section outlines the ratings used to assess the risks associated with proposed development in the watershed. The types of risk summarized in this section are:

- Sediment delivery risk;
- Peak flow risk;
- Channel stability risk; and
- Riparian function risk.

In this section, these risks are evaluated using a consistent framework (outlined above and summarized by Equation A.2). The results are presented in one of three risk categories (low, moderate, and high).

The risk analysis is based on the current conditions in the watershed and is intended to guide forest management in the near future.

The results of a risk analysis allow land managers to consider the types of risk and the risk rating, in order that the risk can be assessed as acceptable, tolerable or unacceptable for the type of land development being undertaken. Land managers should consider implementation of those practices which lower the hazard and therefore the risk.

Sediment Delivery Risk
The risk to fish habitat and/or water quality from sediment delivery is based on the probability of sediment entering the stream network and affecting downstream fish or fish habitat and/or water quality. The main sources of mobile sediment evaluated include:

1) point sediment sources (i.e., stream crossings or road fill-slope failures); and
2) non-point sediment sources (i.e, sediment delivery from roadside ditches).

Only those sources that are classified as development-related were included in this analysis.

Point Sediment Sources
With respect to point sediment sources, the elements at risk are fish and fish habitat, as well as water quality, in the stream network downstream of the project area watersheds. Equation A.2 provides the framework for assessing the risk of point sediment sources. In the case of point sediment sources, \( P(H) \) is based on the likely stream-crossing or road fill erosion or characteristics (e.g., size or magnitude and level or frequency of activity) while \( P(S:H) \) is based on the degree of coupling between the sediment source and streams with fish and fish habitat, or water intakes. \( P(H) \) was rated according to Table A.1, which is based on the estimated annual probability of an event occurring and the estimated magnitude of the event. \( P(S:H) \), which describes the degree of coupling, was rated according to Table A.2. The matrix used to rate \( P(HA) \), which is the combined probability of an event (e.g. sediment delivery event occurring and that event reaching and affecting fish and fish habitat), is presented in Table A.3.

Landslides were not included in the point sediment source assessment.
### Table A.1
Rating table for $P(H)$ associated with the risk of sediment delivery from point sediment sources.

<table>
<thead>
<tr>
<th>Estimated magnitude</th>
<th>Estimated frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (areas prone to erosion &gt; 1,500 m²)</td>
<td>High: Annual probability &gt;1/100 per annum; (likelihood of an event within 20 years is probable)</td>
</tr>
<tr>
<td>Moderate (areas prone to erosion 500-1500 m²)</td>
<td>Moderate: Annual probability 1/500 to 1/100 per annum; (likelihood of an event within 20 years is not likely but possible)</td>
</tr>
<tr>
<td>Low (areas prone to erosion &lt;500 m²)</td>
<td>Low: Annual probability &lt;1/500 per annum; (likelihood of an event within 20 years is remote)</td>
</tr>
</tbody>
</table>

Adapted from Wise et al. (2004)

### Table A.2
Rating table for $P(S:H)$ associated with the risk of sediment delivery from point sediment sources.

<table>
<thead>
<tr>
<th>$P(S:H)$ Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>Sediment source is highly coupled with the stream network and is likely to deliver sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Sediment source is partially coupled with the stream network. Mitigating factors are present to limit the delivery of sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Sediment source is not coupled with the stream network and is not likely to deliver sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
</tbody>
</table>

### Table A.3
Rating matrix for $P(HA)$ associated with the risk of sediment delivery from point sediment sources.

<table>
<thead>
<tr>
<th>$P(H)$ Rating</th>
<th>$P(S:H)$ Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>High (H) Moderate (M) Low (L)</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate (M) Moderate (M) Low (L)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low (L) Low (L) Low (L)</td>
</tr>
</tbody>
</table>

Note: The ratings for $P(HA)$ assume $P(T:S) = 1$.

### Roads

With respect to point and non-point sediment sources from roads, the elements at risk include the stream network where fish, fish habitat and/or water intakes are located. Equation A.2 presents the framework for assessing the risk. In the case of roads, $P(H)$ is based on the potential for road surface erosion (which
depends on the road characteristics), while \( P(S:H) \) is based on the potential for delivery of sediment from roads to the stream network where fish, fish habitat and/or water intakes are located. \( P(H) \) was rated according to Table A.4, and is based on the estimated annual sediment production from roads [as outlined in B.C. Ministry of Forests (MOF) (1999)]. \( P(S:H) \) was rated according to Table A.5, which is adapted from B.C. MOF (1999). The rating for \( P(HA) \), which is the combined probability of erosion potential and delivery potential to the stream network, is based on the matrix presented in Table A.6.

**Table A.4** Rating table for \( P(H) \) associated with the risk of sediment delivery from roads.

<table>
<thead>
<tr>
<th>( P(H) ) Rating</th>
<th>Sediment production class</th>
<th>Annual sediment production: range (m³/km of road length)</th>
<th>Road description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>4-6</td>
<td>&gt;30</td>
<td>Severe erosion, gullying, and/or total washout; access generally difficult with a 4x4 vehicle.</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>3 to 30</td>
<td>Moderate erosion (typical of erodible materials, average maintenance, high use roads).</td>
</tr>
<tr>
<td>Low</td>
<td>1-2</td>
<td>&lt;3</td>
<td>Light erosion (typical of well armoured, low-use roads).</td>
</tr>
</tbody>
</table>

Adapted from B.C. MOF (1999).

**Table A.5** Rating table for \( P(S:H) \) associated with the risk of sediment delivery from roads.

<table>
<thead>
<tr>
<th>( P(S:H) ) Rating</th>
<th>Sediment delivery class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>3-4</td>
<td>Road-related sediment source is highly coupled with the stream network and is likely to deliver sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
<td>Road-related sediment source is partially coupled with the stream network. Mitigating factors are present to limit the delivery of sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>Road-related sediment source is not coupled with the stream network and is not likely to deliver sediment downstream where fish, fish habitat and/or water intakes are located.</td>
</tr>
</tbody>
</table>

Adapted from B.C. MOF (1999).

**Table A.6** Rating matrix for \( P(HA) \) associated with the risk of sediment delivery from roads.

<table>
<thead>
<tr>
<th>( P(H) ) Rating</th>
<th>( P(S:H) ) Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>High (H)</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low (L)</td>
</tr>
<tr>
<td></td>
<td>Moderate (M)</td>
</tr>
</tbody>
</table>

Note: The ratings for \( P(HA) \) assume \( P(T:S) = 1 \).

**Peak Flow Risk**

This section summarizes the risk of forest development on the peak flow regime within the mainstem channels of the study watersheds, which is relevant because increased peak flows can alter channel stability. Equation A.2 provides the framework for assessing the risk of forest development on the peak flow regime. In the case of peak flows, \( P(H) \) is associated with the level of forest development (i.e., ECA), while
P(S:H) is associated with the watershed routing efficiency (Table A.8). P(H) was rated based on current ECA according to Table A.7. The ECA ranges are based on a combination of research results and watershed assessment experience throughout B.C. The ranges have been subject to much debate over the years since research findings are inconsistent and vary based on a multiplicity of local factors (Pike et al., 2010). Although there seems to be general consensus that hydrologic effects are not typically noticeable below an ECA of about 25%, there is simply no general consensus on the hydrologic effects at higher ECAs. As a result, the “moderate” and “high” ratings are defined largely by professional judgement. P(S:H), which is based on the watershed routing efficiency, is rated according to the watershed characteristics presented in Table A.8. The rating for P(HA), which is the combined probability of ECA-related effects and watershed routing efficiency, is based on the matrix provided in Table A.9.

### Table A.7
Rating table for P(H) associated with the risk of forest development to the peak flow regime.

<table>
<thead>
<tr>
<th>P(H) Rating</th>
<th>Current Overall ECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Greater than 40%</td>
</tr>
<tr>
<td>Moderate</td>
<td>Between 25% and 40%</td>
</tr>
<tr>
<td>Low</td>
<td>Less than 25%</td>
</tr>
</tbody>
</table>

### Table A.8
Rating table for P(S:H) associated with the risk of forest development to the peak flow regime.

<table>
<thead>
<tr>
<th>P(S:H) Rating (Watershed Routing Efficiency)</th>
<th>Lakes &amp; wetlands</th>
<th>Groundwater</th>
<th>Stream network</th>
<th>Road network</th>
<th>Hill slopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Few or no lakes or wetlands, affecting less than ¼ of the watershed.</td>
<td>Soils are shallow and/or impermeable, with little loss of surface water to groundwater.</td>
<td>Extensive channel network, resulting in rapid routing of precipitation or snowmelt from headwaters to mainstem. Headwater channels are well defined and relatively large.</td>
<td>Roads extend the drainage network significantly, and cutbanks intercept subsurface flow, affecting a large part of the drainage basin (i.e. greater than 1/3 of the basin area).</td>
<td>Terrain is generally steep (&gt;70%) to moderate (50-70%) slopes</td>
</tr>
<tr>
<td>Moderate</td>
<td>Lakes and wetlands may be present, but only cause attenuation of peak flows from ½ to ¾ of the watershed.</td>
<td>Limited areas of deep, permeable soil. Significant losses of surface water to ground-water may affect parts of the watershed, but not all.</td>
<td>Relatively extensive channel network with few/no discontinuities. Headwater reaches are well defined.</td>
<td>Road network extends the drainage network to a degree. Cutbanks intercepting subsurface flow are common, but the area upstream is small (i.e. &lt; 1/3 of basin area).</td>
<td>Terrain is generally moderate (30-50%), with local areas of moderately steep (50-70%) and gentle (5-30%) slopes.</td>
</tr>
<tr>
<td>Low</td>
<td>Frequent lakes and wetlands within the watershed, causing attenuation of peak flows from more than ½ of the watershed.</td>
<td>Soils may be permeable and deep, resulting in significant losses of surface water to groundwater, having much the same effect as lakes and wetlands.</td>
<td>The stream network may be discontinuous in places, with much of the headwaters unchannelized or drained by indistinct channels.</td>
<td>Road network does not extend the drainage network significantly. High, long cutbanks are rare, and the basin area upstream of existing cutbanks where subsurface flow is likely captured is small.</td>
<td>Terrain is generally gentle (5-30%) to moderate (30-50%) slopes.</td>
</tr>
</tbody>
</table>
Table A.9  
*Rating matrix for P(HA) associated with the risk of forest development to the peak flow regime.*

<table>
<thead>
<tr>
<th>P(H) Rating</th>
<th>P(S:H) Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>High</td>
</tr>
<tr>
<td>High (H)</td>
<td>Moderate</td>
</tr>
<tr>
<td>High (H)</td>
<td>Low</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Low</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low</td>
</tr>
</tbody>
</table>

Note: The ratings for P(HA) assume P(T:S) = 1.

**Channel Stability Risk**

In this section, the element at risk (from watershed development) is channel stability within the mainstem channels of the project area watersheds. Equation A.2 provides the framework for assessing the risk to channel stability. In the case of channel stability, P(H) is associated with the existing level and type of development and disturbance in the watershed, while P(S:H) is associated with channel characteristics, particularly channel sensitivity. P(H) was rated according to Table A.10, and is based on P(HA) for peak flows (which takes into account ECAs and watershed routing efficiency), and evidence of direct disturbance to the channel or riparian zone. P(S:H) is rated according to Table A.11, which considers the sensitivity of the channel. The rating for P(HA), which is the combined probability of indirect and direct impacts on the channel and the inherent sensitivity of the channel to direct and indirect impacts, is based on the matrix provided in Table A.12.

**Table A.10  
Rating table for P(H) associated with the risk to channel stability.**

<table>
<thead>
<tr>
<th>P(H) Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>P(HA) for peak flows rated as “high” and/or major anthropogenic impacts to the channel or riparian zone.</td>
</tr>
<tr>
<td>Moderate</td>
<td>P(HA) for peak flows rated as “moderate” and/or moderate anthropogenic impacts to the channel or riparian zone.</td>
</tr>
<tr>
<td>Low</td>
<td>P(HA) for peak flows rated as “low” and/or little or no evidence of direct anthropogenic impacts to the channel or riparian zone.</td>
</tr>
</tbody>
</table>

**Table A.11  
Rating table for P(S:H) associated with the risk to channel stability.**

<table>
<thead>
<tr>
<th>P(S:H) Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Channel may be stable or unstable and has a high sensitivity to future direct disturbance.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Channel may be stable or unstable and is moderately sensitive to future direct disturbance.</td>
</tr>
<tr>
<td>Low</td>
<td>Channel is currently stable and is generally not sensitive to future disturbance.</td>
</tr>
</tbody>
</table>

**Table A.12  
Rating matrix for P(HA) associated with the risk to channel stability.**

<table>
<thead>
<tr>
<th>P(H) Rating</th>
<th>P(S:H) Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>High</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low</td>
</tr>
</tbody>
</table>

Note: The ratings for P(HA) assume P(T:S) = 1.
Riparian Function Risk

In this section, the element at risk (from harvesting in the watershed) is riparian function along the stream networks in the study watersheds. Equation A.2 provides the framework for assessing the risk to riparian function from harvesting in the watershed. In the case of riparian function, $P(H)$ is based on how the riparian harvesting is conducted (e.g., by maintaining buffers or not), while $P(S:H)$ is based on the proportion of stream length where riparian disturbance occurs. $P(H)$ was rated according to Table A.13, and is based on existing conditions of the riparian zone. These conditions reflect both the degree of historic riparian disturbance as well as recovery since the disturbance. $P(S:H)$ is rated as outlined in Table A.14 based on the proportion of channel length that has evidence of riparian disturbance. The rating for $P(HA)$ is based on the matrix presented in Table A.15.

**Table A.13** Rating table for $P(H)$ associated with the risk to riparian function.

<table>
<thead>
<tr>
<th>$P(H)$ Rating</th>
<th>Description of riparian conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Logged to bank; stabilizing vegetation present</td>
</tr>
<tr>
<td>Moderate</td>
<td>Partial buffer; intact banks</td>
</tr>
<tr>
<td>Low</td>
<td>Extensive buffer; selective harvesting; natural conditions; little or no disturbance</td>
</tr>
</tbody>
</table>

**Table A.14** Rating table for $P(S:H)$ associated with the risk to riparian function.

<table>
<thead>
<tr>
<th>$P(S:H)$ Rating</th>
<th>Proportion of channel length with riparian disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Moderate</td>
<td>20-50%</td>
</tr>
<tr>
<td>Low</td>
<td>&lt;20%</td>
</tr>
</tbody>
</table>

**Table A.15** Rating matrix for $P(HA)$ associated with the risk to riparian function.

<table>
<thead>
<tr>
<th>$P(H)$ Rating</th>
<th>$P(S:H)$ Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H)</td>
<td>High</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low</td>
</tr>
</tbody>
</table>

Note: The ratings for $P(HA)$ assume $P(T:S) = 1$. 


Appendix B - Site Photographs
Perry Ridge Hydrologic Assessment – Phase 1

Photo 1: Bedrock outcrop and bedrock thinly covered by colluvium or till, with sparse forest.

Photo 2: West face of upland showing bedrock-controlled slopes, large old gullies in bedrock, cliffs and rockfall areas, and deciduous patches in gully bottoms.

Photo 3: Typical gravelly silty sand till exposed on root ball from windfallen tree.
Photo 4: Tributary stream in shallow gully with stable channel with boulders and large woody debris.

Photo 5: Tributary stream (top) entering Stream #3 (bottom) with stable channels with boulders and large woody debris.

Photo 6: Stream #3 with stable channel banks, mossy boulders and large woody debris.
Photo 7: Stream #3 with recent bank erosion and imbricated cobbles.

Photo 8: Stream #3 with colluvial channel boulders and LWD from treefall.

Photo 9: Stream #3 near top of gully, with angular colluvial boulders and large woody debris from treefall.
Perry Ridge Hydrologic Assessment – Phase 1

Photo 10: Tributary stream in shallow gully with stable channel with boulders and large woody debris. Some bedload transport of pebbles and cobbles occurs.

Photo 11: Tributary to Stream #4 in topographic hollow, with stable channel with boulders and large woody debris.

Photo 12: Non-classified drainage track with erosion pit from surface flow during 2012 Freshet. A cobble lag has developed.
Photo 13: Non-classified drainage which exits gully above and crosses bench in foreground. The field flagging indicates a CSP will be installed under the road at this location.

Photo 14: Non-classified drainage with evidence of minor erosion and transport. One metre long shovel for scale.
Photo 15: Old gravel pit along Little Slocan FSR, east of Stream #3. The pit was excavated into bouldery gravels, part of glacial outwash and/or old colluvial fan deposits.

Photo 16: Detail of old gravel pit, showing moist slope, possibly from shallow soil water drainage.

Photo 17: Base of upland face showing fan from Stream #3 in right centre..
Photo 18: Stream #3 above Little Slocan River FSR, with two of the three large diameter culverts pictured. The boulders and cobbles in stream bed are loose and not imbricated.

Photo 19: On Stream #3, a cut in levee shows boulders, gravel and buried log, about 50 m above FSR.

Photo 20: Outlets of Stream #3 culverts below Little Slocan FSR, showing pile of boulders which may be from clean-out of the culvert inlet area.
Perry Ridge Hydrologic Assessment – Phase 1

Photo 21: Small stream course (probably Stream #4) which crosses the Little Slocan FSR east of the Stream #3 crossing.

Photo 22: Small alluvial/colluvial fans from streams draining the west upland face, outside the project area.

Photo 23: Right bottom corner of photo shows the bottom of the valley side with the Little Slocan FSR. Some land clearing has occurred in the valley bottom.
Photo 24: Typical Engelmann spruce, subalpine fir forest over central part of Perry Ridge. Some groups of dead, gray trees are visible.

Photo 25: Lower density forest stand in headwaters area of Stream #3, with deciduous brush ground cover and large woody debris.