HYDROLOGIC ASSESSMENT

Kenyon Creek Watershed
Sunshine Coast

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Client:
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EARTH WATER LAND

SUMMARY

The Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. to assess the cumulative hydrologic risk associated with present and proposed future harvesting and forest road construction in the Kenyon Creek watershed in the Halfmoon Bay area on the Sunshine Coast. As with many areas of coastal British Columbia, Kenyon Creek was affected by a series of intense atmospheric rivers in November 2021, and a flood in Kenyon Creek washed out Redrooffs Road near the mouth of the watershed. SCCF requested the assessment to determine whether or not their forestry activities had contributed to the damaging flood and to evaluate actions that they could take to manage hydrologic risk from forestry operations.

Analysis of precipitation totals measured during the November storms indicates that the storm precipitation over the period of November 13-15 was unexceptional for the area, with peak intensity on the order of a 1-in-5 to 1-in-10 year, 20% to 10% annual exceedance probability event; however, high water levels in Trout Lake, exacerbated by beaver activity, caused a culvert under Highway 101 to backwater and water flowed across the low divide from the lake, in the Milne Creek watershed, into Kenyon Creek. This extra water increased the size of the resultant flood. Finally, existing drainage structures on public roads that cross Kenyon Creek appear to have been undersized for expected, let alone augmented, flood magnitudes and frequencies.

Watershed Equivalent Clearcut Area (ECA) in Kenyon Creek is presently at 14% and will be 15% in 2023 if all currently planned blocks are harvested. At this level of ECA, it is unlikely that forest harvesting is having any detectable effect on peak flow magnitudes.

Road density, the length of road per unit area of watershed, is high for Kenyon Creek. This may also have been a factor in increasing peak flow magnitude; however, road density has been relatively constant in the Kenyon Creek watershed for decades, while beaver activity in Trout Lake is a relatively recent change. Larger storms in the past without beaver activity did not result in similar damage to roads.

Hydrologic risk from roads is a function of not only road density but the time over which roads remain active. SCCF can help to reduce the hydrologic risk from road density by building planned

roads as temporary forest roads, which are deactivated rapidly once they are no longer needed, and by evaluating what existing forest roads may not be needed in future and deactivating those roads.

SCCF should provide this report to BC Ministry of Transportation and Infrastructure (BC MOTI) and BC Hydro for their information so that they can make appropriate plans to manage and upgrade culverts and drainage structures on public roads and powerline access roads in the watershed.

CONTENTS

1.0 INTRODUCTION

The Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the cumulative hydrologic risk posed to downslope resources in the Kenyon Creek drainage from harvesting and road building in the community forest.

A series of atmospheric rivers affected the South Coast of BC in November 2021. During those atmospheric rivers and associated flooding, Kenyon Creek washed out the crossing on Redrooffs Road. This prompted SCCF to retain Statlu to evaluate the potential cumulative hydrologic effects of past, present, and proposed future land use, including forest harvesting and road building near Kenyon Creek, in order to guide future development plans.

Statlu's general assessment methods and rationale are described in Appendix 2, and commonly used terms are defined in Appendix 3. Hydrologic hazard assessment methods are described in Section 5 and Appendix 4. Additional water license information is presented in Appendix 5.

2.0 OVERVIEW OF SETTING AND DOWNSLOPE RESOURCES

Kenyon Creek is located in the Halfmoon Bay area of the Sunshine Coast, approximately 8 km west of Sechelt, in the Georgia Lowland of the Georgia Depression (Holland, 1976). Elevations within the watershed range from 0 m to 500 m above mean sea level.

2.1 Downslope Resources and Elements at Risk

2.1.1 Surface Water

Two domestic water licenses lie within the Kenyon Creek watershed. One is on Kenyon Creek, and a second is on Justine Brook, a small western tributary of upper Kenyon Creek north of Belair Road (Appendix 5). These are the only current water licenses within the watershed. Three abandoned water licenses that shared one point of diversion south of Leaning Tree Road and were used for irrigation, residential power, and domestic purposes are no longer active (iMapBC, 2022).

2.1.2 Groundwater

The West Sechelt aquifer (Aquifer ID #0562, identified as having moderate vulnerability and unknown productivity and developed in fractured crystalline bedrock) underlies the entire Kenyon Creek drainage as well as adjacent areas between Halfmoon Bay to the west and Sechelt to the east. (iMapBC, 2022).

There are many water wells in the lower part of the watershed near Highway 101, where rural residential development is concentrated along Birch Way, Belair Road, Leaning Tree Road, and Rocky Ridge Road (iMapBC, 2022). All of these wells are developed within the mapped extent of the West Sechelt aquifer.

2.1.3 Land

Private land in the Kenyon Creek drainage is extensive. Almost all of the land in the watershed near Highway 101 below about 150 m in elevation is private land. In total, this is approximately one-third of the land in the watershed.

Land within Sargeant Bay Provincial Park lies along the western edge of the watershed and bounds the private land on the west.

Crown forest land in the watershed is divided approximately equally between the Community Forest and BC Timber Sales (BCTS) chart area. The Community Forest lands are generally upslope of the BC Hydro transmission line right-of-way while the BCTS chart area is downslope of the BC Hydro line.

2.1.4 Fish

Fish species identified in Kenyon Creek include cutthroat trout, steelhead, and stickleback species. Fish habitat in the watershed is restricted due to both habitat quality and barriers to movement. Identified restrictions on fish include bedrock channel reaches, waterfalls, and highway culverts (Habitat Wizard, 2022).

2.1.5 Roads

Highway 101 crosses the watershed and closely parallels the main channel of Kenyon Creek to its east, crossing it just east of Trout Lake. Redrooffs Road crosses Kenyon Creek just upstream of the mouth, at an elevation of about 42 m a.s.l. Several other named private roads are in the watershed, but aside from Highway 101 and Redrooffs Road, only Belair Road and Leaning Tree Road cross the main channel of Kenyon Creek.

2.1.6 Utility Corridors

A BC Hydro electrical transmission line and associated access road crosses through the watershed from east to west, uphill of Highway 101.

2.1.7 First Nations

The entire watershed is within the territory (swiya) of the shíshálh Nation (shíshálh, 2022).

2.1.8 Other

Other downslope resources and elements at risk, including recreational, aesthetic, etc., are beyond the scope of this report to address.

2.2 Bedrock and Surficial Geology

The watershed is underlain by two types of igneous intrusive rocks. Late Jurassic diorite outcrops in the northern and eastern parts of the watershed, and mid-Cretaceous granodiorite is found in the western and southern parts of the watershed. The contact between the two units runs through the middle of the watershed, approximately parallel to the main channel of Kenyon Creek and Highway 101 (iMapBC, 2022).

Surficial materials in the watershed include organic sediments, glaciomarine raised beach sediments, till, and colluvium. The till has predominantly sandy textures with some silty patches, the colluvium consists of isolated patches of blocks and rubble, and the organic sediment is associated with small wetlands in bedrock hollows and is mucky to peaty in texture. The glaciomarine raised beach sediments are sandy to bouldery in texture, much like active beaches at sea level in the same region. In general, surficial material deposits in the Kenyon Creek drainage are thin. Bedrock outcrops on bluffs, ridges and knolls are prevalent through the watershed.

2.3 Weather and Climate

Climatic information is important for hydrologic studies because it describes general weather trends, including the frequency and intensity of precipitation and the timing of snowmelt, that in turn give clues about the timing of peak and low flows, the duration of wet and dry seasons, possible antecedent moisture conditions, and provide guidance for environmental shutdown of operations. Climate is difficult to describe in mountainous terrain because long-term weather stations are limited to valley bottoms in populated areas of the province.

The nearest station with long-term climate data (Environment Canada, 2022) is the Merry Island Lightstation, 4.5 km southwest of the watershed, at an elevation of 7 m a.s.l. Climate normal data is available for this station for the period 1981-2010. Mean annual precipitation was 1028 mm, with 23 cm (23 mm water equivalent) of snowfall and 1006 mm of rainfall. 70% of total precipitation fell in the hydrologic fall and winter months (October through March). Extreme daily rainfall intensity over the period of record was 78 mm/24 h. Daily average temperature ranged from 5.2°C in December to 18.2 °C in July and August; extreme temperature ranged from -12 °C to +32 °C.

I expect that Merry Island would be warmer and drier than the Kenyon Creek drainage due to its elevation and position offshore. I used ClimateBC (Wang et al., 2016) to model climatic conditions at two different elevations within Kenyon Creek's watershed (Table 1). The model output illustrates the expected increase in precipitation, snowfall, and runoff with elevation for Kenyon Creek.

Table 1: Representative Climatic Variables from ClimateWNA from the 1981 to 2000 interval (Wang et al., 2016).

Elevation of Representative Location (m asl)	Mean Annual PPT (mm)	Rainfall (mm)	Snowfall (cm)	Total Autumn Winter PPT	Reference ET (mm)	Notional Runoff (PPT - ET) (mm)
140 m	1203	1158	45	953	612	591
480 m	1836	1692	144	1466	597	1239

2.3.1 November 2021 Storms

The intensity of precipitation during the November 2021 storms varied from place to place. Table 2 lists precipitation recorded at Merry Island Lightstation and at Pender Harbour, the nearest active climate gauges, during mid-November.

Table 2: November 2021 Storm Precipitation by Location

Climate Station	Precipitation November 13 (mm)	Precipitation November 14 (mm)	Precipitation November 15 (mm)	Total Precipitation November 13-15 (mm)
Merry Island Lightstation	33.4	60.6	5.4	99.4
Pender Harbour	35.0	62.2	8.2	105.4

The IDF-CC 6.0 tool (Simonovic et al, 2022) suggests that the daily precipitation intensities for this storm were not exceptional: expected 24-hour, 2-year return period (50% annual exceedance probability; AEP) rainfall intensity for Kenyon Creek based only on historical data is about 55 mm, and 24-hour, 5-year (20% AEP) precipitation intensity is 68 mm. Even the three-day storm totals are not unusual; the AEP for the total storm precipitation, which fell over about a 48-hour period from midday on November 13 to midday on November 15, is about 10%, i.e., expected 48-hour, 1-in-10 year (10% AEP) precipitation intensity is 103 mm.

Possible reasons why Redrooffs Road was washed out when this was not an exceptional storm are discussed in Sections 4 and 6.

2.4 Hydrology

The nearest Water Survey of Canada stream gauge was located on Homesite Creek near Halfmoon Bay, approximately 7 km northwest of Kenyon Creek. This gauge (08GB010) was active from 1974 to 1981. Homesite Creek has a generally similar climate, topography, and watershed size to Kenyon Creek, and so I expect that Kenyon Creek's annual hydrograph is like that recorded at Homesite Creek.

Homesite Creek had a hydrograph characterized by episodic peak flows separated by short-duration periods of low flows from late fall through spring, followed by a summer and early low-flow period. No spring freshet flow is evident. This sort of hydrograph is characteristic of low-elevation coastal streams where not only peak flow but baseflow is entirely controlled by the timing and magnitude of rainfall events. Therefore, I expect that Kenyon Creek has a similar flow regime, with the largest peak flows in late fall (late October to early December) and a dry period in mid-June, July, August, and September.

I do not expect that snow or snowmelt make a significant contribution to streamflow in Kenyon Creek given the low elevation of the entire watershed and the close proximity to the Salish Sea.

3.0 REVIEW OF BACKGROUND INFORMATION

3.1 Aerial Photography

Statlu completed a review of historic aerial photography when assessing the adjacent Milne Creek Community Watershed for SCCF in 2019. The area of coverage of the historical photos reviewed for that assessment also included Kenyon Creek, given the scale of the photographs. Therefore, that air photo review is repeated here.

Land use, since 1947, was described by studying historic black and white aerial photography and digital imagery (Table 3). The oldest air photos do not capture the baseline condition of the watersheds but they are the earliest record available.

Table 3: Historic air photographs – Milne Community Watershed

Air Photo Numbers	Date	Observations
BC349:17-19 BC401: 29-30	1947	The road on the south side of Trout Lake is visible. It is hard to tell if it is paved, but it is most likely a gravel road because the alignment follows the modern day forestry road on the west side of the lake and the modern road is not paved. Much of the land is cleared or harvested. Cutblocks are evident because they have skid trails, yarding corridors, and roads. Some of the clearings are larger with more variable boundaries, suggesting that they are old fire scars. The area north of Trout Lake has been harvested but is revegetating with trees that are large enough to be visible on the photos.
BC1230: 96-98	1950	The area appears very similar to the 1947 condition.
BC2097: 27-30	1957	The powerline right-of-way is visible on the north side of Trout Lake. The highway on the south side of the lake now follows the modern alignment and is paved. There is new selective harvesting on the south side of the lake with yarding corridors visible between standing trees. A clearing is visible where a landfill operated, but features in the clearing are not discernible at the photo scale. All trees and ground cover were removed from the landfill, forming a rectangular clearing with an abrupt transition from clearing to forest.
BC5102: 020-021	1964	The watershed is similar to the 1957 photos. There is more residential and urban development visible at Halfmoon Bay, west of the watershed.
BC4426: 233-235 BC4426: 193-195	1967	A narrow road or trail is visible that starts on the east side of Trout Lake on the south side of the highway. Several log booms are visible in the water near Halfmoon bay. The forest road on the west side of Trout Lake (Trout Lake FSR) is wider than in earlier images. The landfill is in use.

Air Photo Numbers	Date	Observations
BC5758: 277-279	1975	The access road between the Trout Lake FSR and the landfill is hard to see despite the more detailed photos compared to the earlier sets. The forest in the watershed is noticeably taller with an even canopy on the north side of the lake. The topography has a hummocky surface form on both sides of the lake. Older cutblocks, north of the watershed, are greening up.
30BC80060:195-195	1980	A new cutblock north of the landfill is visible. Overall watershed condition is similar to 1975.
30BC85015: 193-195 30BC85015: 218-221	1985	The photos show greater detail than earlier sets. A new cutblock clearing is visible on the south side of the watershed. There is additional clearing near the landfill that might be to improve the nearby road that heads to the north. A new logging road on the east side of the watershed is visible.
30BC90014:185-187 30BC90014: 134-136	1990	The cutblock on the south side is still visible and is starting to green up, but branch roads are still visible. The access roads near the powerline are clearly visible. The landfill is now capped and is starting to green up. A few new cutblocks are visible to the east of the watershed.
30BC94079: 57-59 30BC94079: 120-122 30BC94079: 132-133	1994	The part of the watershed south of the highway is similar to the 1990 image. Harvesting to the east of the watershed is advancing along the mainline road. There is a new block to the west of the watershed. The landfill cover is much more vegetated than on earlier images.
FFC9700: 284	1997	Blocks surrounding the watershed are greening up. No new harvest is visible in the watershed. More residential and urban development is visible outside the watershed near Halfmoon Bay.
30BCC03039:83-85 30BCC03039: 99-101	2003	Vegetation is visible in the powerline right of way. No new development is visible in the part of the watershed south of the highway. The landfill is hard to see with the vegetation growing over it. Otherwise, the image is similar to 1997 image.
Google Earth digital imagery	2014	Three new cutblocks (or openings) are adjacent to the power transmission line right of way. Each block has roads. The landfill is identifiable by its mainly deciduous forest. The remainder of the watershed appears similar to the 2003 photos.

3.2 Other Reports and Assessments

In addition to the 2019 Milne Creek watershed assessment, Statlu has completed terrain stability hazard assessments for several cutblocks in the community forest, including Blocks HM50, HM65, HM68, and HM70, in and near Kenyon Creek. I used information and observations from these reports to inform my analysis of the Kenyon Creek watershed.

4.0 OBSERVATIONS

Drew Brayshaw, Ph. D., P. Geo. and Warren Hansen, RPF of SCCF made a field inspection of the Kenyon Creek watershed on February 23, 2022. We started at Redrooffs Road and proceeded through the watershed, stopping at Leaning Tree Road, Belair Road, and Trout Lake, and ending at Blocks HM50 and HM70. In total, we spent about 6 hours in the watershed. Weather conditions during the field assessment were sunny and dry, and the water level in Kenyon Creek was low, although water levels in Trout Lake were high, as discussed in Section 4.5.

4.1 Redrooffs Road

Redrooffs Road was washed out where it crosses Kenyon Creek during the November 2021 atmospheric rivers, about 400 m upstream of its mouth in Sargeant Bay. It had only been recently repaired at the time of our field visit in February. The repairs consisted of placing coarse rock fill and several culverts and then paving the road running surface. The new fill placed across the creek had effectively created a dam which formed a pond upstream of the road. The water level in the pond was up to about 3 m deep in places. Trees near the pond were dying because they had been flooded and their roots were under up to 1 m depth of water (Photo 1).

Photo 1: Ponding above Redrooffs Road

Several culverts had been placed in the repaired road fill. In total, we counted an 800 mm concrete pipe culvert at the base of the fill (which appeared to be the original culvert in place from before the washout, Photo 2), a new 1000 mm corrugated metal pipe culvert, and four separate new 600 mm black plastic pipe culverts. These latter five culverts are just below the asphalt of the road and discharge onto the top of the coarse rock fill (Photo 3).

Photo 2: Concrete culvert at base of Redrooffs Road fill

Photo 3: New metal and plastic pipe culverts

A 6 m high waterfall flows directly into the head of the pond by Redrooffs Road (Photo 4). Above this waterfall, Kenyon Creek flows over benchy bedrock steps. Sediment has deposited on the benches between the steps. On the steeper steps, Kenyon Creek has a bedrock channel and flows over bare rock and boulders. The November 2021 flood could not erode down through this bedrock so the high flows scoured moss and soil from each side of the channel on the steep steps, exposing additional bedrock. Wood pieces and cobble sized sediment were also moved by the flood and deposited on the steps, though the deposited sediment is mostly sand and gravel (Photo 5).

Photo 4: Waterfall upstream of Redrooffs pond

Photo 5: Sediment and wood deposited above waterfall

4.2 Leaning Tree Road and Belair Road

Leaning Tree Road and Belair Road are respectively about 1.7 km and 2.0 km upstream of Sargeant Bay. Both of these roads branch off Highway 101 and cross Kenyon Creek. These are the only public roads that cross Kenyon Creek upstream of Redrooffs Road, although some private roads on private land do cross Kenyon Creek between these public access points.

Both Leaning Tree Road and Belair Road cross Kenyon Creek on coarse rock fill placed over culverts. At Leaning Tree Road, there are two, side by side, 1000 mm diameter corrugated metal pipe culverts. Water was flowing through the coarse rock fill and not through the culverts during the field assessment, although it might flow through the culvert at higher flow. (Photo 6).

At Belair Road, a single 1200 mm culvert was about half full of water during our site visit (Photo 7). A metal grate is placed across the inlet of this culvert, presumably to prevent woody debris from blocking it.

Photo 6: Double culverts at Leaning Tree Road stream crossing

Photo 7: Single culvert at Belair Road

At both Leaning Tree Road and Belair Road, strand lines of sediment and wood showed that at previous high-water levels, likely associated with the November flooding, water had backed up upstream of both roads causing ponding (Photo 8). At both locations, ponding upstream of the roads had resulted in up to 1 m depth of water outside the stream channel banks for up to 100 m upstream of each crossing. Neither crossing appeared to have been overtopped by the flooding, but some of the coarse rock fill at Belair Road appeared to be newly placed, so this crossing may have been repaired after the November flood and before our site visit.

Photo 8: Strandline shows extent of ponding during flood upstream of Belair Road

Between the two crossings, and upstream and downstream of them, Kenyon Creek flows in a forested valley bottom about 50 m west of Highway 101. Unvegetated stream banks at bends of the channel expose silty till, and up to cobble sized sediment moves in the channel. We found one old crossing where an abandoned private road crossed Kenyon Creek on a log stringer bridge, about 350 m downstream of Leaning Tree Road (Photo 9). The log stringers on this bridge are decaying and turning into nurse logs, and it is likely that this whole structure will collapse into the stream within the next few decades. On these stream channel reaches, we saw recent bank erosion at bends and sediment deposition on point bars that was likely caused by high flows during the November storm, but no evidence of extensive overbank flow or overbank sediment deposition outside the active stream channel.

Photo 9: Collapsing log stringer private land bridge downstream of Leaning Tree Road

Along Highway 101 in this area, culverts are very widely spaced and small. Between Leaning Tree Road and Tapp Road, which is about 660 m south, we found only one culvert providing drainage under the highway. The culvert is a 500 mm diameter corrugated metal pipe culvert. The sediment under the outlet of this culvert was eroded (Photo 10), and the area near the inlet of the culvert, on the east side of the highway, had tussocks of living and dead vegetation that suggested it floods at high water, probably when the culvert backs up.

Photo 10: Erosion at culvert outlet between Leaning Tree Road and Tapp Road

4.3 Trout Lake

The water level in Trout Lake was very high at the time of our site visit, and it had flooded some low-lying areas near the lakeshore which appear as vegetated marshes in Google™ Street View images of Highway 101 taken in 2011.

A 1000 mm corrugated metal pipe culvert passes under Highway 101 from the easternmost end of Trout Lake. The inlet and outlet of this culvert were both completely underwater at the time of our assessment. A beaver had blocked the Trout Lake (western) side of the culvert with woody debris and mud (Photo 11), while the eastern side was not blocked (Photo 12). The valley bottom to the east of the highway was flooded, creating a long, narrow pond that extended almost as far east as the junction where the Carlson Forest Service Road joins the highway (Photo 13).

Photo 11: Beaver debris blocking culvert inlet at Trout Lake

Photo 12: East side of culvert under Highway 101 from Trout Lake

Photo 13: Ponding where water diverts across divide from Milne Creek to Kenyon Creek watershed east of Trout Lake

East of Trout Lake, Highway 101 crosses through a narrow, low-relief pass between the Kenyon Creek and Milne Creek catchments. The mapped location of the pass is about 170 m east of the east end of Trout Lake, or about halfway from the lake to the Carlson FSR. The original location and elevation of the drainage divide between these two catchments may have been modified by the construction of the highway; however, because of the low elevation of the pass and the placement of the culvert, it is clearly possible for water to flow out of Trout Lake at high water levels through the culvert and spill across the drainage divide, thereby flowing from the Milne Creek watershed into the Kenyon Creek watershed. This would reduce peak discharge in Milne Creek slightly and augment Kenyon Creek flows by the same amount, with the maximum contribution from Milne to Kenyon limited by the hydraulic head (water level above the top of the culvert inlet on the Trout Lake side) and the culvert's diameter.

The headwaters of Kenyon Creek downstream of the drainage divide are a series of narrow wetlands following the highway for approximately 650 m, after which the mapped main channel of Kenyon Creek flows to the highway from the west, out of Sargeant Bay Provincial Park. The low gradient and extensive vegetation of these wetlands undoubtedly reduce the flow velocity and discharge magnitude of any water diverted across the divide. Essentially, such water must be overflowing in sequence from wetland to wetland until it reaches Kenyon Creek's channel.

4.4 BC Hydro Power Line Right-of-Way and Carlson FSR

A small, triangularly shaped wetland is located upslope of Highway 101 and downslope of the Carlson FSR and BC Hydro transmission line right-of-way. This wetland has old stumps and snags in it and may have been created by past beaver activity (Photo 14). A stream flows from the western end of this wetland, down a short steep bedrock-controlled slope, onto level ground near the highway, then under the highway through a 600 mm CMP culvert, and into the wetlands in the headwaters of Kenyon Creek.

Photo 14: Wetland upslope of Highway 101 and downslope of Carlson FSR

The stream reach that flows down the steep slope below the outlet of the wetland was scoured to bedrock and had avulsed, creating two parallel channels. These channels coalesced at the bottom of the steep slope and sediment had deposited there, about 50 m from the highway culvert. There was no sedimentation at the inlet of the culvert. The outlet of the culvert deposits onto coarse rock that appears to be old highway fill before flowing into the wetlands of upper Kenyon Creek and had slightly eroded that fill (Photo 15).

Photo 15: Outflow of highway culvert coming from Carlson FSR

Two smaller, probably ephemeral streams flow from the forest upslope of the BC Hydro right-of way and across the right-of-way, then join and flow into the wetland. These streams are conveyed across the hydro right-of-way access road in very small (300 mm diameter) CMP culverts but flow under the FSR through larger, 600 mm diameter CMP culverts. At the time of my assessment, both stream crossings along the Hydro access road were eroded by flow that had exceeded the small culverts' capacity and run across the access road (Photo 16). There was no corresponding erosion of the FSR, indicating that the flow in these streams had not exceeded the capacity of the larger culverts.

Photo 16: Tiny culvert under BC Hydro access road

4.5 Blocks HM50 and HM70

We briefly inspected both Blocks HM50 and HM70 at the end of the day. These blocks are located along the edge of the watershed boundary. Block HM50 is on the Milne Creek side above Trout Lake and Block HM70 is on the divide with the Wakefield Creek drainage to the east. At the time of the February site visit, Block HM50 had been logged and Block HM70 had not been logged.

There are no continuous streams in either of these blocks. A short S4 stream in the northwestern corner of Block HM50 dewaters before it reaches the middle elevations of the block. An NCD stream in a slope hollow on the Wakefield Creek side of Block HM70 dewaters after about 50 m of surface flow. These streams showed no sign of unusual surface erosion or flooding as a result of the November 2021 floods.

I noted some ditch erosion and scour along roads in the bottom part of Block HM50, where water had overflowed the ditch onto roads and caused localized erosion of the road running surface. Sediment had been transported about 50 m downslope from the culverts on these roads and had deposited on the ground as the culvert discharge had dewatered.

Outside of and downslope of Block HM70, at the Carlson FSR near where it crosses out of Kenyon Creek watershed into the Wakefield Creek drainage, I saw a small pond on a level bench that the FSR crosses. A 600 mm CMP culvert is in place on the FSR at this pond, but there was no stream flow into or out of the pond at the time of our site visit and I observed no signs of recent erosion or sedimentation. I expect that the pond dewaters seasonally in the summer and fall.

5.0 HYDROLOGIC RISKS

Hydrologic assessment of the risks posed by logging identifies and characterizes potential sources of disturbances (either natural or human-caused) that can potentially affect hydrologic parameters of value. These risks result from the presence of the parameters of value and the likelihood (hazard) that natural and human-caused disturbances can affect those parameters of value. Risk assessment requires identification of risks, determination of the level of risk, evaluation of means to alter or reduce the risk, and evaluation of the acceptability of the unmodified and modified levels of risk.

Ultimately, determination of the acceptability of a particular level of risk is the responsibility of land managers.

With respect to the Kenyon Creek watershed, the identified hydrologic resources that I identified as potentially at risk include:

- Changes in the timing, duration, magnitude, or frequency of stream flows on streams with water intakes including peak flows (floods), low flows, and mean flows;
- Decreases in channel stability, both in the channel and on the fan of or in the channels of other alluvial streams, either due to increased sedimentation or to channel avulsion;
- Changes in water quality used for domestic water supply as a result of increased sedimentation or changes in stream temperature;
- Changes in channel pattern and riparian function along streams with alluvial channels and riparian vegetation;
- Changes to fish habitat resulting from the other changes.

The primary parameters of value (elements at risk) with respect to these risks include infrastructure (culverts and other drainage structures) on Kenyon Creek and its tributaries. Secondary parameters of value include fish and fish habitat in Kenyon Creek. Tertiary parameters of value are the water licenses on Kenyon Creek and Justine Brook. The ranking of these parameters of value is based on their perceived exposure and vulnerability to altered hydrologic processes. Infrastructure is ranked highest because the November flood damaged Redrooffs Road. Fish and fish habitat are ranked second because of the apparent low quality of the existing fish habitat (bedrock channels in the lower reaches near the ocean) and also because of barriers which appear to limit anadromous fish movement, such as the 6 m high waterfall above Redrooffs Road. I expect that fish in Kenyon Creek may move downstream from populations stocked into Trout Lake rather than upstream from the ocean. Water licenses are ranked third because they are located far downstream from planned forest activities (and thereby more likely to be affected by activities on private land or events on the highway than forestry activity) and because domestic usage of Kenyon Creek has decreased over time.

5.1 Changes in Timing, Duration, Magnitude, and Frequency of Stream Flow

The likelihood that logging will result in changes to the timing, duration, magnitude, or frequency of stream flows is proportional to the location, aspect, and elevation of proposed blocks and, most importantly, their areas relative to the drainage areas that they are located within as well as the length of road within each drainage.

Blocks HM50 and HM70 are the only SCCF blocks currently proposed within the Kenyon Creek watershed. Each block is partly within the Kenyon Creek watershed and partly within neighbouring watersheds. According to their most recent operating plan, BCTS is not planning any blocks in Kenyon Creek for at least the next four years. The hydrologic effects of Block HM50 on Milne Creek and Trout Lake have already been assessed by Statlu in the Milne Creek watershed assessment.

About 1.6 ha of Block HM50 and 5.5 ha of Block HM70 are within Kenyon Creek watershed. The total increase of harvested area within the Kenyon Creek watershed from these two blocks rounds up to 7.2 ha.

I evaluated the existing equivalent clearcut area (ECA), and the projected recovery due to regrowth over the period 2022 to 2025, in the Kenyon Creek watershed from provincial Vegetation Resources Inventory (VRI) data, using the same methods as detailed in the 2019 Statlu Milne Creek Watershed Assessment. I included the harvest of one block from 2020, CP A95107, with a total area of 7.2 ha, which is too recent to have been included in the VRI data. This block is just south of the BC Hydro right of way and the Carlson FSR.

The VRI data is not ideal for estimating the forest cover percentages of private land. I used Google™ Earth imagery from April 2021 to evaluate the average proportion of cleared area on private land within the watershed. Most of the private land in the watershed is variably forested, with only small areas around existing houses, and planned new building sites, completely denuded. By my estimate, this private land clearing accounted for an additional 26.5 ha of ECA.

5.1.1 Changes to Streamflows from Harvesting

Table 4: Area to Be Harvested Within Each Watershed

Watershed	Watershed Area (ha)	Equivalent Clearcut Area 2022 (ha)	Planned Harvest 2022-2025 (Blocks HM50 and HM70) (ha)	Recovery 2022-2025 (ha)	Equivalent Clearcut Area 2025 (ha)	ECA 2022 (%)	ECA 2025 (%)
Kenyon Creek	**419**	**59.6**	**7.2**	**3.4**	**56.3**	14.2	**15.2**

Watershed ECA levels in the 14% to 15% range indicate a very low likelihood of detectable changes to watershed hydrology. At this level of harvest, no detectable changes to peak flows, low flows, timing of flows, or duration of flows are expected as a result of the cumulative effects of forest harvest and private land clearing together.

5.1.2 Changes to Streamflows from Road Construction

Roads can also present a source of hydrologic risk. The risk from roads, exclusive of their potential to be a sediment source, is dependent on the road density (length of road relative to the size of the watershed, Appendix 4).

There are about 5.3 km of public and private (highways, other public roads, and private driveways) in the Kenyon Creek watershed. There are also about 6.4 km of resource roads, including forestry and BC Hydro powerline access roads, of which 2.9 km are retired roads which have been permanently or semi-permanently deactivated and 3.5 km are presently active. This includes built roads in Block HM50 and planned roads in Block HM70 within the Kenyon Creek watershed.

The total active road length within the watershed is therefore about 8.8 km. Since the watershed area is about 4.2 km², this means that the watershed's road density is 2.1 km/km². This is a relatively high road density and it is likely that at this road density value, there will be detectable effects to watershed hydrology, particularly increased peak flows. However, the road density has remained relatively constant for many years; there has been little change to the total road density over time for at least the last 15 years, judging by historic Google™ Earth imagery and aerial photography. Therefore, any effects of elevated road density are likely to be longstanding effects rather than new effects.

5.2 Changes in Riparian Function

No riparian logging is proposed for any of the blocks. Although Highway 101 parallels much of the main channel of Kenyon Creek, it is set back from the channel and a high proportion of mature riparian forest remains to contribute woody debris and shade to the channel. Accordingly, there is a very low likelihood of changes to Kenyon Creek's riparian function.

5.3 Changes in Channel Pattern or Channel Stability

The November 2021 flood had localized effects on stream channels in the watershed. Specifically, stream channel reaches in both the headwaters, and in the lower watershed near Redrooffs Road, were scoured by high flows, resulting in widening of the channel and coarsening of the bed sediment. These changes were confined to bedrock channel reaches, and alluvial channel reaches were not similarly affected. The undersized culverts at Belair Road and Leaning Tree Road that restricted water flow and ponded water upstream, as well as the low channel gradients and wetland areas, may have contributed to the relative stability of the main channel of Kenyon Creek in these alluvial reaches. Planned forestry activities are located far from streams and will present very low likelihood of changing channel pattern or channel stability.

5.4 Changes in Water Quality

Potential risks to water quality are primarily limited to increases in sediment transport at high flows and to potential sources of contamination from the road network, particularly from Highway 101. It is possible, for instance, that winter road maintenance may result in increased salinity in Kenyon Creek. Planned forestry activities are distant from Kenyon Creek and have a very low likelihood of altering water quality.

6.0 DISCUSSION

Kenyon Creek experienced a flood in November 2021. This flood scoured bedrock reaches of Kenyon Creek and its tributaries, caused ponding against culverts on Belair Road and Leaning Tree Road, and washed out Redrooffs Road.

The storm which produced this flood was not exceptionally large. The individual days of the storm had precipitation intensities below 20% AEP (1-in-5 year return period). The entire storm had an AEP of about 10%; such a storm could be expected, on average, about once a decade. Precipitation intensity, by itself, is not sufficient to explain why this storm damaged the Redrooffs Road crossing.

The Redrooffs Road crossing may have had undersized drainage structures. I do not know what was in place before the washout but it may have been a drainage structure as small as the 1000 mm diameter concrete culvert which is now in place at the base of the replacement fill. It may even have been the same concrete culvert.

I would expect that infrastructure such as a stream crossing on a local access public road would be built for a large, rare flood such as the 1% AEP (1-in-100 year) event, as per BC MOTI guidelines[1]. If this is the case, then a 1000 mm CMP culvert is significantly undersized for Kenyon Creek. The two upstream crossings at Leaning Tree Road and Belair Road have, respectively, double 1000 mm CMP culverts and a single 1200 mm CMP culvert. Kenyon Creek has about a 4.2 km^2 drainage area; it is possible to use regional hydrologic analysis to estimate the expected 1% AEP flood for a drainage of this size in the South Coast hydrologic region. Different methods give slightly different estimates, in the range of 17 m^3/s to 28 m^3/s, for the expected 1% AEP flood for a watershed of this size (Hassan et al., 2014; Obedkoff, 2003). An expected flood of this magnitude should require a bridge installation, not a culvert. The largest culvert typically installed without a site-specific engineering design, a 2000 mm CMP culvert, can pass a design discharge of about 6 m^3/s. Therefore, it seems that whatever drainage structure was previously in place on Kenyon Creek at Redrooffs Road was undersized for expected flood flows in this creek, and furthermore, the

[1] https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/highway-design-and-survey/tac/tac-2019-supplement/bctac2019-chapter-1000.pdf

upstream culverts at Leaning Tree Road and Belair Road, though they service smaller drainage areas, are also likely undersized.

The second factor which appears to have affected the November flood in Kenyon Creek is Trout Lake, the culvert there, and beaver activity. Beavers and wet weather have increased the water level of Trout Lake the point where some water backwaters through the Highway 101 culvert, crosses the divide from Milne Creek watershed, and flows into Kenyon Creek. As a result, the approximately 1.4 km^2 of the Milne Creek watershed upstream of Trout Lake contributes water to Kenyon Creek watershed. Although the size of the Highway 101 culvert restricts the total volume of water that crosses the divide, this still represents an up to one-third (33%) increase in the effective drainage area of Kenyon Creek due to the diversion. This causes larger floods in Kenyon Creek and proportionally smaller floods in Milne Creek.

Beaver populations have been expanding in southwestern British Columbia for many years as they re-establish themselves and recover from historical near-extirpation caused by trapping. In the early 2000s, beaver activity in Silver Creek Community Watershed near Powell River caused the effective drainage area of that watershed to increase from the previously mapped 40 ha to over 400 ha as a result of similar drainage diversions.

In determining the cause of the damaging flood which washed out Redrooffs Road at Kenyon Creek, it appears to be most likely that the combination of an undersized drainage structure at Redrooffs Road and an unusual cross-divide diversion of water from Trout Lake, caused by an unusually wet fall, a storm, and beaver activity, were to blame.

7.0 RECOMMENDATIONS

The replacement drainage structures at Redrooffs Road, and the existing drainage structures at Belair Road and Leaning Tree Road, all appear to be undersized for the calculated 1% AEP flood magnitude for Kenyon Creek. SCCF should provide this information to BC MOTI, who are responsible for the maintenance of these structures, so that they may incorporate it into plans to upgrade such drainage structures and therefore prevent future washouts.

The culvert under Highway 101 at Trout Lake is also a factor in the damaging Kenyon Creek flood. BC MOTI may wish to remove this culvert or to replace it with a more beaver-resistant design.

In addition to BC MOTI culverts, several of the culverts in place at stream crossings along the BC Hydro powerline access road are significantly undersized and had their capacity exceeded during the November storm. SCCF should provide this information to BC Hydro so that they can replace and upgrade their undersized culverts.

Road density, the length of road per unit area of watershed, is relatively high for the Kenyon Creek watershed as a result of the presence of Highway 101 and other public and private roads. It is likely that the hydrology of Kenyon Creek has been affected by the existing road density. The hydrologic risk from roads is a function not only of their length but also their lifespan. Thus, the risk is greatest from roads when those roads are relatively permanent or long-term installations, and least when roads are built temporarily and are permanently hydrologically deactivated after use. Just under half of all the forestry roads built within the Kenyon Creek watershed have already been deactivated and formally retired. SCCF should evaluate its existing and planned future roads within the Kenyon Creek watershed, prioritize deactivation of those roads which are no longer needed, and build temporary roads in future rather than roads intended for long-term use.

8.0 CONCLUSION

Sunshine Coast Community Forest retained Statlu to assess the cumulative hydrologic risk associated with present and proposed future harvesting and forest road construction in the Kenyon Creek watershed in the Halfmoon Bay area on the Sunshine Coast. As with many areas of coastal British Columbia, Kenyon Creek was affected by a series of intense atmospheric rivers in November 2021, and a flood in Kenyon Creek washed out Redrooffs Road near the mouth of the watershed. SCCF requested the assessment to determine whether or not their forestry activities had contributed to the damaging flood and to evaluate actions that they could take to manage hydrologic risk from forestry operations.

Analysis of precipitation totals measured during the November storms indicates that the storm precipitation over the period of November 13-15 was unexceptional for the area, with peak intensity on the order of a 1-in-5 to 1-in-10 year, 20% to 10% annual exceedance probability event; however, high water levels in Trout Lake, exacerbated by beaver activity, caused a culvert under Highway 101 to backwater and water flowed across the low divide from the lake, in the Milne Creek watershed, into Kenyon Creek. This extra water increased the size of the resultant flood. Finally, existing drainage structures on public roads that cross Kenyon Creek appear to have been undersized for expected, let alone augmented, flood magnitudes and frequencies.

Watershed Equivalent Clearcut Area (ECA) in Kenyon Creek is presently at 14% and will be 15% in 2023 if all currently planned blocks are harvested. At this level of ECA, it is unlikely that forest harvesting is having any detectable effect on peak flow magnitudes.

Road density, the length of road per unit area of watershed, is high for Kenyon Creek. This may also have been a factor in increasing peak flow magnitude; however, road density has been relatively constant in the Kenyon Creek watershed for decades, while beaver activity in Trout Lake is a relatively recent change. Larger storms in the past without beaver activity did not result in similar damage to roads.

Hydrologic risk from roads is a function of not only road density but the time over which roads remain active. SCCF can help to reduce the hydrologic risk from road density by building planned roads as temporary forest roads, which are deactivated rapidly once they are no longer needed, and by evaluating what existing forest roads may not be needed in future and deactivating those roads.

SCCF should provide this report to BC Ministry of Transportation and Infrastructure (BC MOTI) and BC Hydro for their information so that they can make appropriate plans to manage and upgrade culverts and drainage structures on public roads and powerline access roads in the watershed.

9.0 LIMITATIONS

The recommendations provided in this report are based on observations made by Statlu and are supported by information Statlu gathered. Observations are inherently imprecise. Conditions other than those indicated above may exist on the site. If such conditions are observed or if additional information becomes available, Statlu should be contacted so that this report may be reviewed and amended accordingly.

This report was prepared considering circumstances applying specifically to the client. It is intended only for internal use by the client for the purposes for which it was commissioned and for use by government agencies regulating the specific activities to which it pertains. It is not reasonable for other parties to rely on the observations or conclusions contained herein.

Statlu prepared the report in a manner consistent with current provincial standards and on par or better than the level of care normally exercised by Professional Geoscientists currently practicing in the area under similar conditions and budgetary constraints. Statlu offers no other warranties, either expressed or implied.

10.0 CLOSURE

Please contact me should you have any questions or if you require further clarification.

Yours truly,
Statlu Environmental Consulting Ltd.

Prepared by:	*Reviewed by:*
Drew Brayshaw, Ph. D., P. Geo *Senior Hydrologist*	Eryne Croquet, M. Sc., P. Ag., P. Geo. *Agrologist and Geoscientist*

DB/CC/EC/jb

Permit to Practice Number: 1000170

11.0 ASSURANCE STATEMENT – REGISTERED PROFESSIONAL

Note: This Statement is to be read and completed in conjunction with the Professional Practice Guidelines – Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector and is to be provided for Watershed Assessments or Hydrologic Assessments.

May 12, 2022
To: Warren Hansen, RPF
Sunshine Coast Community Forest
5710 Teredo St #213,
Sechelt, BC V0N 3A0

With Reference to the Kenyon Creek watershed the undersigned hereby gives assurance that they are a Professional Geoscientist, registered with Engineers and Geoscientists BC.

I, Drew Brayshaw, have signed, sealed, and dated this Hydrologic Assessment report in general accordance with the Joint Professional Practice Guidelines - Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector[2].

2022-05-12

[2] https://www.egbc.ca/getmedia/8742bd3b-14d0-47e2-b64d-9ee81c53a81f/EGBC-ABCFP-Watershed-Assessment-V1-0.pdf.aspx

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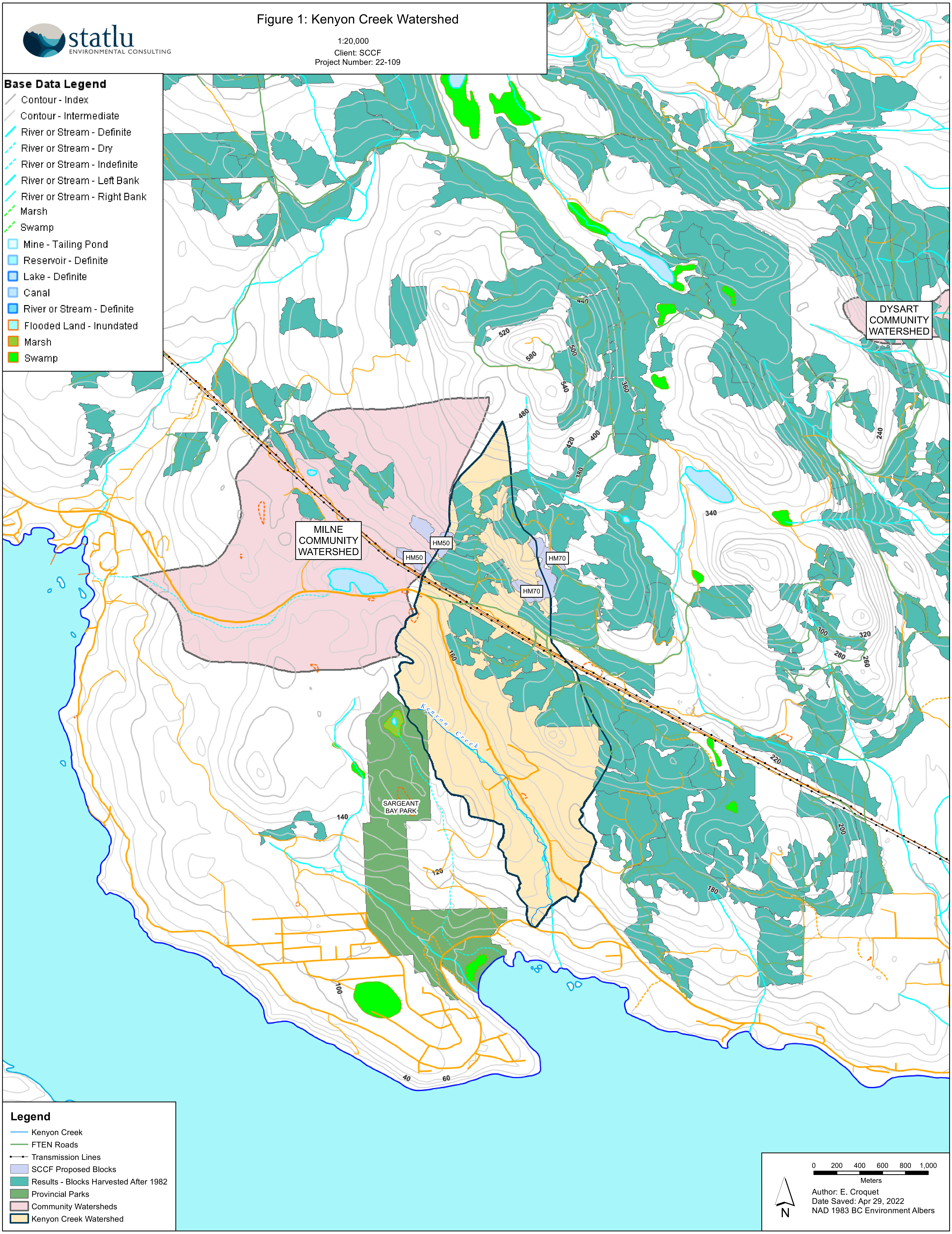
Figure 1: Kenyon Creek Watershed



APPENDIX 2: METHODOLOGY

The methods used in this assessment to evaluate and report on present or potential future geotechnical hazards, estimate their probability of occurrence, size and runout distance, and anticipate their probable consequences should they occur are based on accepted standards of professional geoscience current in the province of British Columbia. These methods follow the outline of recommended practice embodied in guidance documents, including:

- Draft Professional Practice Guidelines: Watershed Assessment And Management of Hydrologic and Geomorphic Risk in the Forest Sector (EGBC and APCFP, 2018)
- Guidelines for Professional Services in the Forest Sector – Terrain Stability Assessments (APEGBC, 2010); and
- Similar publications.

The methods include insights for improved practice gained from current publications in peer-reviewed scientific literature.

My assessment included a consideration of the background information available for the area, including the area's climatic condition, topographic features, vegetation, bedrock, and surficial geology. I obtained and reviewed overview images for the area, including some or all of Google™ Earth imagery, digital orthophotos, and/or historic aerial photography, to provide historical perspective to my ground observations.

The field traverse was located using a combination of results from overview observations, discussion with the forest professional, and professional experience to located features of interest. The field traverse passed through and beyond the area(s) of interest to include areas of steep or potentially unstable ground within and adjacent to the proposed blocks and roads.

The field traverse is augmented by observations of terrain in the general vicinity of the block(s), looking particularly for evidence of past natural or logging- or road-related instability, especially activity that might have occurred more recently than the date of the most recent imagery covering the area in question.

During my field traverse, I observed and recorded details of surficial material type, drainage, topographic expression and position, stream courses, vegetation, bedrock geology, and evidence of past instability. I considered the proposed development (logging and/or road building) as well as the proposed size and location of drainage structures and the resultant potential for changes in runoff and subsurface hydrology. I made note of existing patterns of windthrow, including whether or not past windthrow had resulted in local instability.

Based on my overview and field investigations, and my professional experience and judgment, I developed qualitative estimates of the likelihood of hydrologic risk for the polygons and road segments that I assessed, both for existing conditions, and for post-harvest or post-construction conditions assuming that the development occurred using the construction, harvest, and yarding methods proposed by forest professionals for the block(s) and/or road(s) in question. Where the post-construction or post-harvest likelihood of hydrologic risk was greater than low, I provided recommendations to mitigate the hazard.

I have evaluated the potential consequences of hydrologic risk and described those consequences to the best of my professional ability. Ultimately, the determination of acceptable risk is outside the scope of my assessment and must be made by forestry professionals and government land managers. This assessment is intended to provide information to assist those professionals with their decisions.

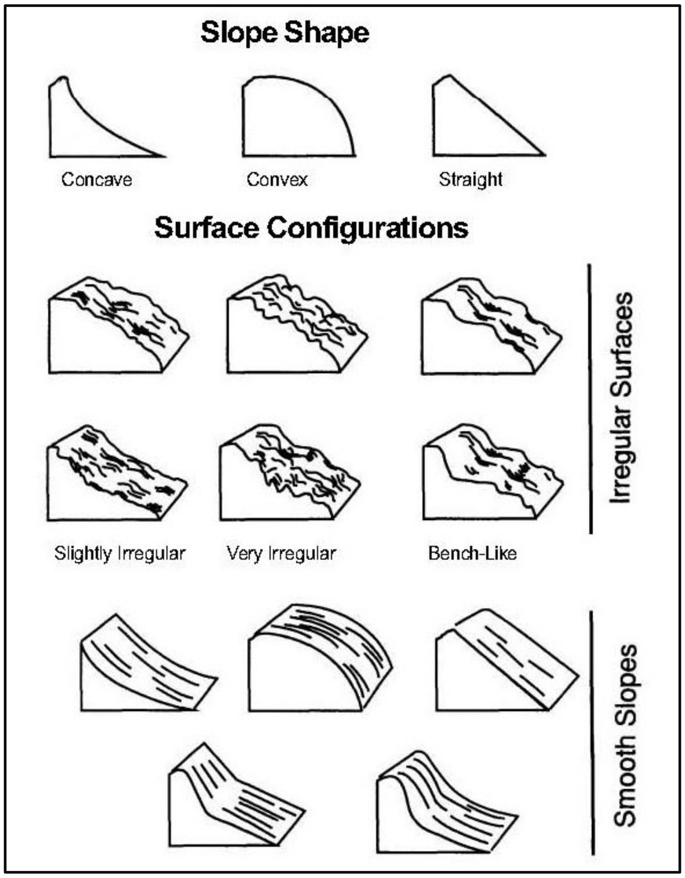
APPENDIX 3: DEFINITIONS

Statlu follows the Terrain Classification System for British Columbia, 2nd Version when describing terrain attributes (Howes and Kenk, 1997) and the Canadian System of Soil Classification, 3rd Ed. (SCWG, 1998) when describing soil drainage and forest soils.

Slope morphology: the shape of the slope, both along contour and in profile.

Term	Along Contour	In Profile
Concave	**The contour converges**	**Slope gradient decreases downslope**
Convex	**The contour diverges**	**Slope gradient increases downslope**
Irregular	**No pattern to slope changes**	**Slope changes gradient with no pattern**
Uniform/straight	**Consistent shape**	**Slope has consistent gradient**
	General Slope Descriptors	
Benched	**A series of flat bench tops broken by steeper steps between benches, similar to terraces but not formed by fluvial processes**	
Terraced	**Slope pattern of step-like forms composed of flat tops or treads separated by shorter, steep pitches (risers); formed by fluvial processes**	
Undulating	**An assemblage of multidirectional slopes; regular slope variation along contour**	

(From LMH 18)



Soil Drainage: the rate at which saturated surficial material reaches field capacity, the moisture content remaining after removal of water by gravity (usually 24 hours after saturation)

Soil Drainage Class	Description
Very rapid	**Water removed rapidly in relation to supply. Water source is precipitation.**
Rapid	**Water removed rapidly in relation to supply. Water flows downward if material is pervious. Water source is precipitation. Soils are generally coarse textured.**
Well-drained	**Water readily removed from soil. Water flows downward or laterally.**
Moderately well-drained	**Water is removed from soil somewhat slowly in relation to supply.**
Imperfect	**Water is removed from the soil slowly. The soil remains wet for a significant portion of the growing season. Soils may be mottled.**
Poor	**Water is removed so slowly in relation to supply that the soil remains wet when it is not frozen. Soils may be mottled or gleyed.**
Very Poor	**Water is removed so slowly in relation to supply that the water table remains at or near the surface for most of the time the soil is not frozen. Associated with wetlands.**

(From LMH 25)

Surface expression: the form and pattern expressed by a surficial material at the land surface. Figure B1 provides a general summary of terms commonly used to describe surface expression. In addition to common terms, we describe sediments thicker than approximately 5 m as "deep."

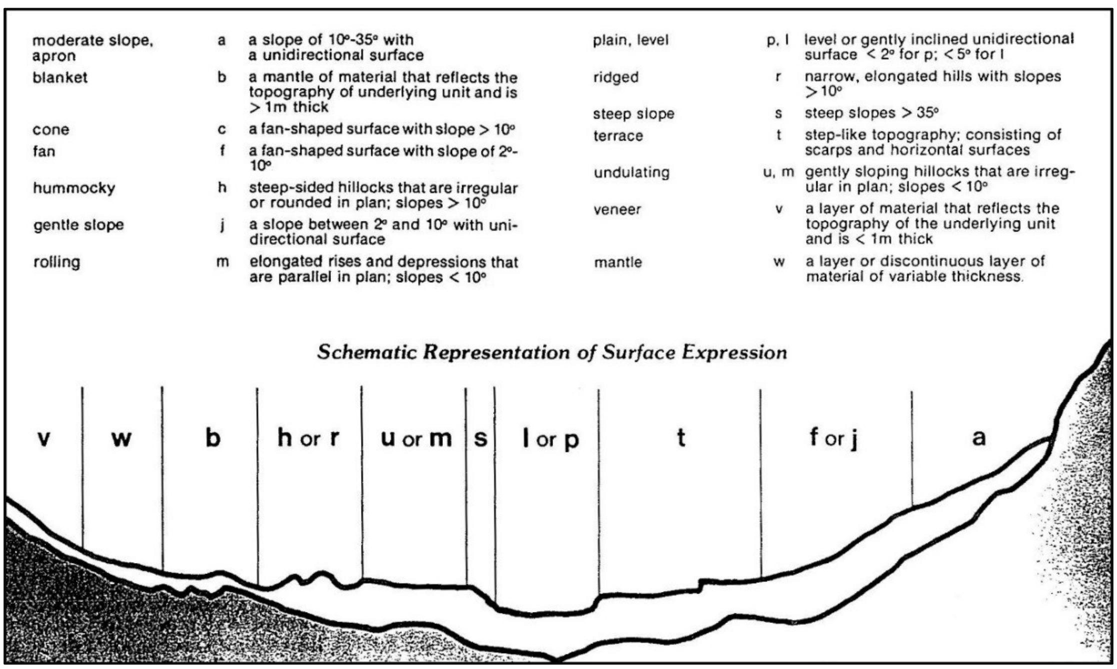


Figure B1: Common surface expression terms (Ryder and Howes, 1986)

Surficial materials: non-lithified, unconsolidated sediments that are classified by mode of deposition (*i.e.,* till, colluvium, glaciofluvial).

Surficial material texture: the size, shape, and sorting of particles in clastic sediments.

Single Particles		Mixtures	
Class Name	Particle Size and Shape	Class Name	Particle Size and Shape
clay	< 0.002 mm	gravel	> 2 mm, mix of round particles; pebbles, cobbles, boulders
silt	0.002 mm – 0.0625 mm	rubble	2 mm to 256 mm, mix of angular particles
sand	0.0625 mm - 2 mm	mud	mix of clay and silt; may include sand
pebbles	2 mm - 64 mm, round	angular fragments	> 2 mm, mix of angular particles; blocks and rubble
cobbles	64 mm - 256 mm, round	mixed fragments	> 2 mm, mix of round and angular particles
boulders	> 256 mm, round	diamicton	mix of materials with two or more distinct particle sizes
blocks	> 256 mm, angular		

Harvesting Methods

Harvesting systems include four phases: falling and bucking, yarding, loading, and hauling. Timber yarding methods have the most impact on terrain stability and are often modified to reduce the likelihood of increased post-harvest terrain instability (CSSP, 1995).

Ground-based yarding uses skidders, hoe forwarders, or other equipment to bring timber to the landing. Skidders drag timber on the ground, hoe forwarders carry timber or lift and swing it to a yarding or skidding corridor, landing, or roadside. Application of ground-based methods is limited by slope gradient, slope shape, soil sensitivity to erosion, and weather. Ground-based yarding with rubber tired or tracked machines is limited to slope gradients <40%. Restricted ground-based yarding uses ground-based machines on slope gradients between 40% and 60% by running machinery on cut and fill skid trails or from roads.

Cable yarding uses stationary yarders to move logs along cables from where they were felled to the roadside or landing. Cable yarding reduces soil disturbance and can be used on steep slopes. Skyline and highlead are two cable yarding methods.

Helicopter yarding is used to yard logs in sensitive or inaccessible terrain. Helicopters are used to fly logs from where they were felled to an accessible drop site. Helicopter yarding is both expensive and slow compared to other yarding methods.

Road Construction Terms

Conventional Construction: cut and fill is balanced; fill is sidecast on the downslope side of the road and will form a portion of the load-bearing road surface. Where conventional construction is described as a low-hazard option, other construction techniques that use more fill than cut, such as overlanding and full fill, are also low-hazard options unless otherwise specified.

Conventional Reconstruction: conventional reconstruction of an existing road consists of resurfacing the road, re-establishing a functional ditch line, and installing drainage structures with appropriate capacity and spacing**.**

Conventional Reconstruction with no sidecast is identical to regular conventional reconstruction, but prescribed in areas where existing roads cross steep slopes and where sidecast would result in oversteepened or unstable perched fills**.** Material which cannot be incorporated into the road surface during reconstruction operations must be endhauled to an appropriate spoil site.

Full Bench: the cut width is equal to the road width; none of the road prism is supported on fill. Sidecast may be hauled to a dump site, used for road ballast, or fully sidecast, as prescribed in the report and as defined below. Ditches are constructed on full bench road segments and where specifically recommended in the report.

Partial Bench (Sliverfill): 3/4 to full bench construction where fill is supported on rubbly material draped down hillslope. Used only in rock or coarse colluvium, or in locations where thin veneers of sidecast material will disperse downslope stably. Do not place material over organic material, soil, logs, etc.

Full Sidecast: Excavated material may be cast downslope but must not form a portion of the load-bearing road surface. Full bench with full sidecast is typically prescribed in locations where the slope is too steep for load-bearing fill to be stable but topographic features downslope of the road prism will capture and stabilize sidecast material.

No Sidecast: The sideslopes are too steep to support sidecast; therefore, all sidecast material must be hauled to a spoil site or spoiled in grade on adjacent road segments.

Keyed Fill: The ballast is composed of coarse pieces of angular rock placed on, and supported by, an excavated bench. The toe of the bench should be wide enough to support the lowest course of placed rock (generally 1.0 m to 1.5 m wide) and should be gently outsloped to facilitate drainage.

APPENDIX 4: HYDROLOGIC HAZARD AND RISK ASSESSMENT METHODOLOGY

Peak flow is the maximum flow rate that occurs within a specified period, usually on an annual or event basis. Generally, melting of the snowpack in spring and/or heavy rainstorms or rain-on-snow events generate peak flows. Tree removal and road building by forestry can affect peak flow timing and volumes. By removing trees, not only is more precipitation able to reach the ground and infiltrate the soil, but the timing of the delivery may be altered. Timber harvesting reduces interception and evapotranspiration, and increases the winter snowpack. This can result in an earlier and more rapid snowmelt, and higher flow resulting from the deeper snowpack. It can also result directly in higher runoff during rainfall events and/or higher groundwater levels. By changing the longwave and shortwave radiative balance, logging can also change the timing of snowmelt, although this depends on aspect and other shading as well as forest canopy removal.

Construction of logging roads can affect the pathway and the timing in which precipitation or snowmelt reaches the stream channel. Subsurface flow may be intercepted and directed down ditches as surface flow, reaching stream channels at an accelerated rate. Compacted surfaces of roads reduce infiltration, transferring surface flow to ditches, which also means that surface water reaches stream channels at an accelerated rate.

Cumulative hydrologic hazard is commonly expressed as the likelihood that logging will result in increases to peak flow magnitude or frequency. Cumulative hydrologic hazard is evaluated by considering the net area logged over time and determining the equivalent clearcut area (ECA) for each logged area, which consists of the initially clearcut area modified by a recovery term that accounts for the restoration of forest canopy, root structures, transpiration and interception as new trees grow. For instance, an area of 10 ha, originally clearcut, fully restocked, and with vigorous new growth 20 years old, might be calculated to have recovered 30% of the original hydrological effectiveness of the previous forest in terms of rainfall and snowfall interception and ground shading. The ECA is calculated as clearcut area times the recovery factor (percent clearcut minus percent recovered). In this example, the ECA is 10 ha * (100%-30%) = 7 ha. Therefore the 10 ha, 20-year-old block would be determined to be hydrologically equivalent to a 7 ha fresh clearcut. ECA is summed for each past block harvested in a watershed to determine cumulative hydrologic hazard. Intermediate categories of hazard (such as very low to low) are included in the table to indicate the range of watershed sensitivities, which depend on woody debris abundance, channel substrate, geology, hydrograph type (snowmelt or rainfall dominated) and other factors.

In addition to peak flow changes, cumulative hydrologic hazard can result in changes to mean annual or low flow, and to changes in the timing and duration of flow. Flow might become less variable if melt from different aspects and elevations is synchronized. The timing of low flow might be altered, and its duration lengthened, if snowmelt occurs earlier in the year. Conversely, by reducing transpiration, forest harvesting might increase low flow levels or decrease the duration of summer low flows.

<table>
<tr><th>ECA Range (% total watershed area)</th><th>Hydrologic Hazard</th><th>Qualitative Interpretation</th></tr>
<tr><td>0% to 15%</td><td>Very low.</td><td rowspan="2">Detectable changes to peak, mean and low flow will not occur</td></tr>
<tr><td>15% to 20%</td><td>Very low to low</td></tr>
<tr><td>20% to 25%</td><td>Low</td><td rowspan="2">Detectable changes to peak or flow are unlikely to occur. Small variations might be detectable using statistical analysis.</td></tr>
<tr><td>25% to 30%</td><td>Low to moderate</td></tr>
<tr><td>30% to 35%</td><td>Moderate</td><td rowspan="2">Detectable changes to peak flow might occur for some flow magnitudes and return periods. Flow durations might be altered.</td></tr>
<tr><td>35% to 40%</td><td>Moderate to high</td></tr>
<tr><td>40% to 45%</td><td>High</td><td rowspan="2">Detectable changes to peak flow frequency and magnitude will occur. Floods will become larger and more frequent. Low flows might increase or decrease. Mean annual flow might change.</td></tr>
<tr><td>45% to 50%</td><td>High to very high</td></tr>
<tr><td>50% or higher</td><td>Very high</td><td>Watershed hydrology will be significantly changed. Peak flow frequency and magnitude will undergo large changes. Floods will be much larger and much more frequent. Low flow and mean annual flow frequency and duration will change.</td></tr>
</table>

Risk is a function of hazard (the likelihood of an event) as well as the exposure of downslope or downstream resources to the event, and vulnerability of the downslope resources to the hazard, which together determine the consequences should the hazard occur. Land Management Handbook 56 (Wise et al. 2004) and the BC Ministry of Forests Forest Road Engineering Guidebook (2002) define risk as the product of the probability of hazard and consequence. Consequence further depends on the nature of the element(s) at risk, the exposure of those elements to the hazard, and the vulnerability of those elements to the hazard.

Statlu recognizes that the evaluation of the exposure and vulnerability of elements at risk to the identified hazards is difficult and may require specialized skills or additional information not available to professional geoscientists. Since the information is available or potentially available to land managers and statutory decision makers, we have concentrated on identifying and describing the geomorphic components of the consequence of hydrologic hazard, specifically their likelihood of reaching downstream identified elements and resources at risk. This is a partial risk analysis since it identifies the geomorphic components of a risk analysis without addressing the vulnerability of the elements at risk to the hazard.

As an example, consider a theoretical watershed of 1000 ha. The existing ECA is 150 ha, and another 100 ha are planned for logging, with associated road construction, which will raise the watershed ECA to 25%. The main stream in the watershed flows into a lake and has built a fan at its mouth; there are cabins on the lake, with a community water license intake near the head of the fan, and fish present in stream reaches on and near the fan, while higher stream reaches are too steep for fish habitat. Statlu estimates that the post-harvest hazard of peak flow changes is low, and that if changes to peak flow regimes do occur they are likely to be transient and persist for less than five years. Small changes to the timing of flow are likely: spring snowmelt may occur up to a week earlier, and the summer low flow period may be extended by a similar length of time, but summer low flows may be slightly higher for up to ten years due to reduced evapotranspiration. Changes to channel pattern in the stream and on the fan are unlikely and changes to water quality are unlikely if all roads are built as planned and incorporate site-specific erosion and sediment control measures, and if old roads are deactivated.

To extend this hydrogeomorphic analysis to a full evaluation of the consequence of the potential harvesting and road building and the resultant risk, requires information on the frequency of use, and designated flood construction level and flood control measures incorporated into the design of the cabins on the fan, the nature and frequency of use of the forest service roads by industrial and recreational traffic, the quality of riparian habitat, species present and seasonality of use of the fish stream by those species, the water diversion and treatment methods used at the water intake, and other information beyond the purview of geoscience but available or potentially available to land managers and statutory decision makers.

Broadly speaking, the qualitative estimations of probability determined by Statlu correspond to the following classes of consequence from the Forest Road Engineering Guidebook (Table A2). These correspondences are approximate and are provided only to help with decision-making.

Qualitative Probability of Consequence	Range of Quantitative Probabilities of Occurrence	Approximate Qualitative Consequence Class
Certain; Will Occur	>50%	Very High
Likely to Occur	25-50%	High
Probable; Could Occur	10-25%	Moderate
Unlikely to Occur	1-10%	Low
Remote or Will not Occur	<1%	Very Low

APPENDIX 5: DOWNSTREAM WATER LICENSE INFORMATION

License Number	Map Reference and Points Code	Stream	Use	Permitted Volume
C033771	92.G.041.4.3 H (PD45005)	Kenyon Creek	Domestic	2.273 m^3/day
C112814	92.G.041.4.3 J (PD73564)	Justine Brook	Domestic	2.273 m^3/day