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ENVIRONMENTAL CONSULTING

WATERSHED ASSESSMENT

Wakefield Creek – Sunshine Coast Community Forest

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EARTH WATER LAND

SUMMARY

Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the Wakefield Creek watershed, near Sechelt, BC. SCCF has forest development plans in the upper sub-basin of the watershed and requested a watershed assessment to assess the effects of the proposed development on watershed hydrology and to provide guidance for current and future forest management.

Wakefield Creek is a 13.5 km² watershed that flows from headwaters near Crowston Lake into the Salish Sea about 4 km west of Sechelt. Infrastructure including Highway 101, a power transmission line, and a gas pipeline cross the watershed. Much of the lower watershed consists of suburban and rural residential property on the western outskirts of Sechelt, while the upper watershed is part of the community forest. There are several water licenses on Wakefield Creek and its tributaries, and fish use at least the lower watershed, with scattered observations of fish presence in the headwaters as well.

SCCF is planning about 29 ha of logging in total, in two cutblocks, between 2024 and 2027, with no additional logging proposed until after 2030. Watershed equivalent clearcut area (ECA) is 291 ha (21.6% of watershed area) at present and would decrease to 250 ha (18.6% of watershed area) by 2030 if no additional logging occurs. If the proposed cutblocks are developed, watershed ECA in 2030 will be 279 ha, or 20.8% of watershed area. That is, the proposed amount of logging is somewhat less than the ongoing rate of hydrologic recovery, so overall watershed equivalent clearcut area will slightly decrease over the period from 2024 to 2030. This level of harvest will maintain low hydrologic risk to watershed resources at the watershed and sub-basin level.

The watershed has many roads, but a large proportion of the roads, particularly in the lower part of the watershed, are suburban, paved roads which have been constructed along with storm sewers and other measures to mitigate their hydrologic risks. These roads contribute to total watershed road length and road density, but not to active resource road length and density. The active road density in the watershed as a whole now is about 1.18 km/km² at present and will be marginally lower, 1.17 km/km², by 2030 after all planned road construction and deactivation has taken place. The active road density within the Upper Wakefield Creek sub-basin is currently higher, at

1.57 km/km^2, and will also decrease marginally to 1.56 km/km^2 by 2030. If SCCF were to deactivate an additional 0.4 km or more of presently active roads by 2030, active road density in the Upper Wakefield Creek sub-basin would be reduced to below 1.5 km/km^2. This level of active road density will maintain low hydrologic risk to watershed resources at the watershed and sub-basin level.

The largest single hydrologic issue that we observed in the watershed during our 2024 field inspection was the culvert under Norwest Bay Road. This culvert is misaligned because it is skewed at an angle to the trend of the stream channel, so that it directs water against the western streambank near the outlet. This misdirected water has caused bank erosion and a slump which caused trees and sediment to fail into the creek. Additionally, the culvert has an overhang at its outlet which appears to present a barrier to fish passage, and it appears to be undersized for present and expected future peak flows when compared to the Highway 101 culvert downstream. Statlu understands that this Norwest Bay Road culvert is the responsibility of the District of Sechelt and/or BC Ministry of Transportation and Infrastructure (MOTI). We recommend that SCCF pass this information to District of Sechelt and MOTI so that they can prioritize the replacement of the existing culvert with a properly aligned and sized drainage structure.

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1.0 INTRODUCTION

The Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the Wakefield Creek Watershed, near Sechelt, BC. SCCF has forest development plans in the upper sub-basin of the watershed and requested a watershed assessment to assess the effects of the proposed development on watershed hydrology and to provide guidance for current and future forest management.

2.0 OVERVIEW AND BACKGROUND

Wakefield Creek watershed drains the southern part of the Sechelt Peninsula and flows into the Salish Sea. The watershed lies about 4 km northwest of the District of Sechelt, in the Pacific Ranges of the Coast Mountains. The mouth of Wakefield Creek is directly north of Trail Islands, and 3.6 km west of Sechelt. Elevations in the watershed span from 0 m (sea level) at the mouth to 580 m at the height of land on the northwestern watershed divide. The watershed is 1342 ha (13.4 km^2) in extent.

2.1 Physiography

At the south end of the Sechelt Peninsula, the isthmus of Sechelt forms a connection between the Caren Range and the mainland. During the Pleistocene, glaciers flowing out of Salmon Inlet and Narrows Inlet coalesced and flowed down Sechelt Inlet, where they merged with the larger Georgia Lowland piedmont glacier. At glacial maximum, the thickness of glacial ice was much higher than the summits of the Caren Range and ice flowed over the ridge. Converging ice flow near Wakefield Creek watershed left rounded ridge tops and roches moutonnées with rounded northwestern sides and steeper southeast sides, and an overall northwest-southeast orientation of ridges and valleys.

The northwestern half of the watershed is above the elevation of the deep glaciogenic sediments and consists of bedrock knolls and ridges separated by narrower, parallel draws and valleys. In the southeastern half of the watershed, Wakefield Creek flows out of this bedrock-controlled area and onto the surface of the glacial deposits, first flowing across them, and then becoming progressively incised into them, eventually becoming deeply incised in a ravine to the south of Norwest Bay Road.

2.2 Surficial and Bedrock Geology and Hydrogeology

Ice advance and retreat created deep deposits of glaciofluvial sediments in the Sechelt area, with extensive Quadra Sands outwash deposits covered with a thinner, less permeable layer of till and glaciomarine sediments. These sediments can be found at different elevations in the watershed. Above 200 m in elevation, the only sediments present are thin soils derived from till and weathered bedrock. Below 200 m, the sediments are more complex because of the interaction of glaciers, ice-contact sediment deposition, sedimentation during deglaciation, and changing sea levels. The sediments are derived from till, glaciomarine, marine, glaciofluvial, and fluvial sediments (McCammon, 1977). The depth of the sediments found below 200 m in elevation is variable, with deep glaciofluvial sands and gravels next to bedrock outcrops.

Two aquifers underlie the Wakefield Creek watershed, the larger West Sechelt aquifer and the smaller Sechelt/Wakefield Creek aquifer. The West Sechelt aquifer is a bedrock aquifer that is approximately 56.8 km^2 in size and underlies the entirety of the Wakefield Creek watershed as well as additional areas outside the watershed on all sides (iMapBC, 2024). The Sechelt/Wakefield Creek aquifer is a confined aquifer comprised of glacial sand and gravel from the Quadra Sands lithostratigraphic unit. This aquifer is approximately 10.5 km^2 and underlies around 4.3 km^2 (32%) of the lower Wakefield Creek watershed (iMapBC, 2024). In the Wakefield Creek area, the Sechelt/Wakefield Creek aquifer sediments generally overlie the West Sechelt bedrock aquifer where both are present, but the contact is not necessarily a simple horizontal one. It is possible that water from the bedrock aquifer flows horizontally into the Sechelt/Wakefield Creek aquifer from the west/northwest near the western edge of their area of overlap, following the general trend of the topography.

Bedrock underlying the watershed is mapped as dioritic intrusive bedrock (iMapBC, 2024). Diorite is typically coarse-grained and can weather to grus. In general, intrusive bedrock is associated with good surface water quality and low turbidity in BC (Brown et al., 2011). Elevated levels of arsenic in groundwater in some areas of the Sunshine Coast are associated with Gambier Group volcanic and metasedimentary rocks, which do not outcrop in the Wakefield Creek watershed (Mattu and Schreier, 2000).

A subdivision to the north of and outside the Wakefield Creek watershed, on the shores of Snake Bay along Gale Avenue North, has been affected since it was developed by high artesian pressure in the groundwater underlying the subdivision, leading to sinkholes and uninhabitable homes[1]. The subdivision in question is outside of, and lies 1 km north of the mapped northern boundary of, the Sechelt/Wakefield Creek aquifer. Hence, nothing suggests that any water from Wakefield Creek that might recharge into the Wakefield/West Sechelt Aquifer, would flow across the hydrographic divide and reach Snake Bay near Gale Avenue North.

2.3 Hydrology

Wakefield Creek is not gauged. The nearest gauged stream with similar watershed characteristics is Roberts Creek, about 13 km to the southeast (Wateroffice, 2024). Roberts Creek watershed is larger than Wakefield Creek watershed (29.5 km^2 compared to 13.4 km^2) and has higher elevations, but both watersheds have south aspect and drain into the Salish Sea. In addition, they have similar bedrock and surficial geologies. The general shape of Wakefield Creek's hydrograph should be similar to that of Roberts Creek, although the magnitude of flow is greater in Roberts Creek.

The hydrograph for Roberts Creek (Figure 1) indicates that peak flows typically occur in the fall and early winter (November to January), when rain and rain-on-snow events are most common (Wateroffice, 2024). The summer low flows occur from June to September, with the lowest flows in August. The discharge declines rapidly in the spring and rises quickly again in the fall, following the precipitation patterns in the area. Because Wakefield Creek is a relatively small and low-elevation watershed, there is minimal contribution from snowmelt to the annual hydrograph, and no appreciable spring freshet.

[1] https://www.cbc.ca/news/canada/british-columbia/sechelt-sinkhole-nuisance-ruling-1.6770272

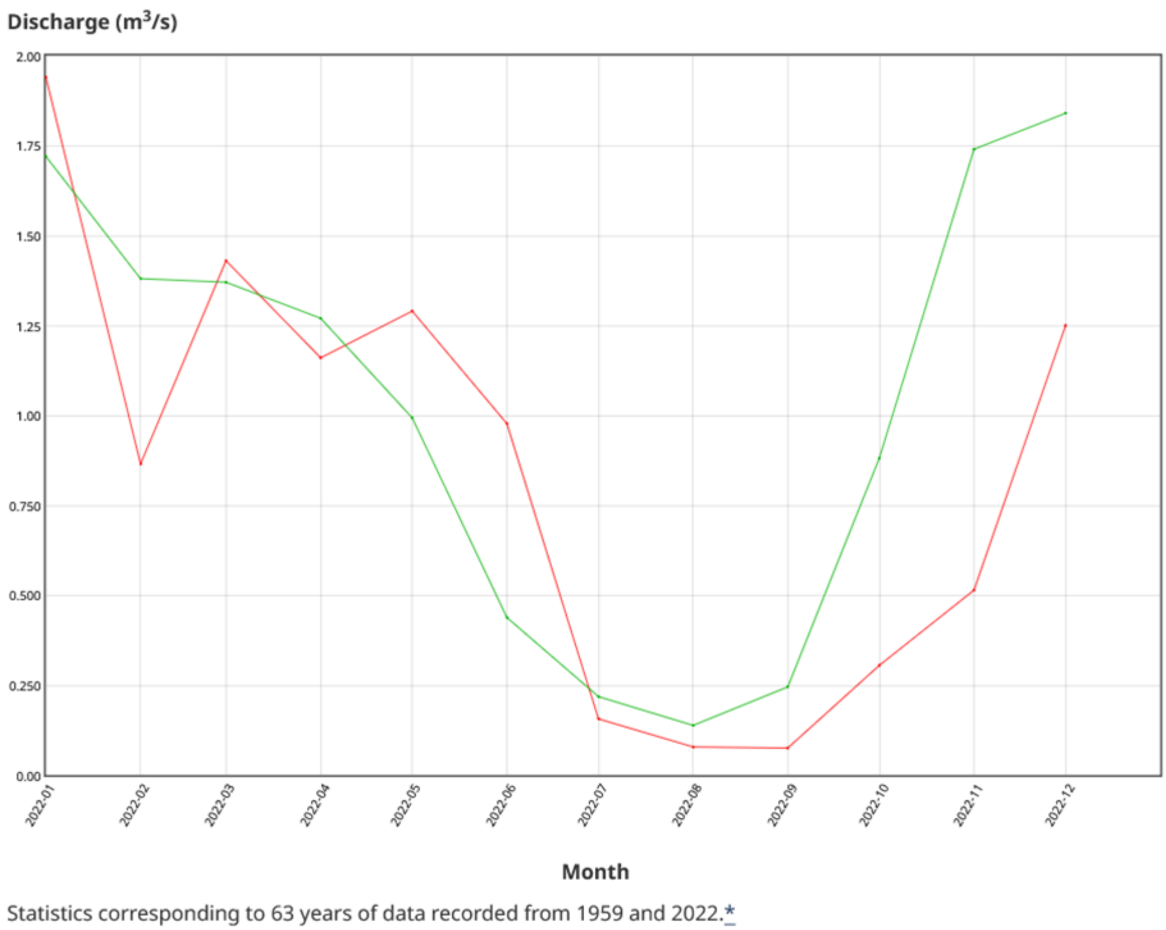

Figure 1: Hydrograph for Roberts Creek (08GA047) (Wateroffice, 2024), with the average annual trend in green and 2022 data in red.

2.4 Climate

The current climate in Wakefield Creek watershed, described using recent normals data from the ClimateNA model (Wang et al., 2016, Table 1), has warm summers and temperate winters, with some snow, particularly at higher elevations. Most of the precipitation occurs in winter. Precipitation increases significantly with elevation.

Table 1: Climate Conditions in Wakefield Creek watershed

Location	Elevation (m)	MAT* (°C)	MWMT (°C)	MCMT (°C)	MAP (mm)	PAS (cm)	Winter PPT (%)	ERef (mm)	Runoff (mm)	CMD (mm)
Headwaters	564	8.1	16.1	1.5	1912	161	80	596	1316	118
Crowston Lake	315	9.2	16.9	2.7	1496	75	80	606	890	158
Highway 101 Crossing	11	10.5	17.9	4.5	1073	27	80	610	463	216

**MAT - mean annual temperature, MWMT - mean warmest month temperature, MCMT - mean coldest month temperature, MAP - mean annual precipitation, PAS - precipitation as snow, Winter PPT - proportion of precipitation in autumn and winter, ERef - Hargreaves reference evapotranspiration, Runoff - notional runoff, CMD - climatic moisture deficit*

2.5 Climate Change

The climate is changing and this affects watershed hydrology. Understanding the changes is necessary in order to separate and distinguish climate change from the effects of forest management on hydrologic conditions in the watershed. Modeling climate change is useful for evaluating the direction and possible magnitude of trends in climate factors that affect streamflow in order to estimate changes in streamflow.

The Plan2Adapt tool provides a summary for of the projected climate changes for the regional districts in BC, including SCRD (Table 2) (PCIC, 2024). The tool uses a standard set of climate projection data to generate the output.

Table 2: Summary of Climate Change for the Sunshine Coast in the 2050s from Plan2Adapt

Climate Variable	Season	Projected Change from 1961-1990 Baseline	
		Ensemble Median	Range (10th to 90th percentile)
Temperature (°C)	Annual	+3.0 °C	+2.0 °C to +4.1 °C
Precipitation (%)	Annual	-1.0%	-5.0% to +3.4%
	Summer	-13%	-40% to +1.4%
	Winter	+0.97%	-4.0% to +5.4%
Precipitation as Snow* (%) *This variable may have a low baseline***.	Annual	-54%	-61% to -45%
	Winter	-56%	-59% to -45%

** These values are derived from temperature and precipitation.*
*** Percent changes from a low baseline value can result in deceptively large percent change values. A small baseline can occur when the season and/or region together naturally make for zero or near-zero values. For example, snowfall in summer in low-lying southern areas.*

The ClimateNA model (Wang et al, 2016) downscales and aggregates the results from 13 global circulation models (GCM) to evaluate potential future climate scenarios. The model uses Shared Socioeconomic Pathways (SSP) to approximate how different greenhouse gas emission scenarios, coupled with different mitigation strategies, will affect future climates. The SSP 5[2] scenario was used because it represents unrestrained growth with continued fossil fuel dependence (worst-case scenario). If less carbon and other greenhouse gases are emitted than modelled under this worst-case scenario, it is probable that the effects will be less severe than what is described here. The same locations in the watershed that were used to describe the current climate were used to model predicted climate changes (Table 3).

The temperature and precipitation will increase by 2040. Most of the expected increased precipitation will arrive in winter, with a corresponding decrease in summer precipitation. More of the winter precipitation will fall as rain, and less will fall as snow. That means that the summer drought will likely be longer and could result in lower and longer low flow conditions in Wakefield Creek relative to present conditions. The combination of lower flows in the summer and warmer air temperatures will result in warmer water temperatures and increased evapotranspiration. A hint of what this predicted change might look like occurred in 2023, when the Sunshine Coast Regional District imposed Stage 5 water restrictions in Sechelt and other nearby communities, then declared a local state of emergency[3] as a response to the ongoing drought.

Table 3: Expected change relative to current climate conditions in Wakefield Creek watershed – to 2040

Location	Elevation (m)	MAT* (°C)	MWMT (°C)	MCMT (°C)	MAP (%)	PAS (%)	Winter PPT (%)	ERef (%)	Runoff (%)	CMD (%)
Headwaters	564	8.9	17.6	1.5	1969	141	82	627	1342	145
Crowston Lake	315	10.0	18.4	2.7	1539	66	81	637	902	180
Highway 101 Crossing	11	11.3	19.4	4.6	1101	23	81	639	462	243

**MAT - mean annual temperature, MWMT - mean winter temperature, MCMT - mean summer temperature, MAP - mean annual precipitation, PAS - precipitation as snow, Winter PPT - proportion of precipitation in autumn and winter, ERef - Hargreaves reference evapotranspiration, Runoff - notional runoff, CMD - climatic moisture deficit*

[2] https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change
[3] https://www.cbc.ca/news/canada/british-columbia/sunshine-coast-drought-stage-4-restrictions-1.6960243

2.6 Watershed Resources

Resources in Wakefield Creek watershed include fish habitat, water resources, recreational trails, and forest resources. Trails in the mid-elevation part of the watershed are used for mountain biking, hiking, and dog walking. Some of the trails use old forest roads. The lower-elevation area of the watershed has mixed-use commercial and suburban/rural residential neighbourhoods.

Water license points of diversion in the Wakefield Creek watershed include water licenses on both Wakefield Creek and its tributaries. Domestic use, irrigation, and pond and aquaculture represent the three most common uses (WRBC, 2024 and Table 4). Five water licenses have been abandoned over time, and another two have been cancelled, but Table 4 includes these as well as the active licenses. The Sunshine Coast Regional District water mains supply most of the properties in Wakefield Creek with treated water, but in times of low availability and high demand on the SCRD water system, individual domestic licenses and wells can provide alternative water sources for license holders, even if they are also serviced by the water mains.

Table 4: Water Licenses in Wakefield Creek Watershed

POD Number	Status	Licence Number	Licence Status	PURPOSE	SOURCE	QUANTITY
PD45022	Active	C052734	Current	Domestic	Wakefield Creek	4.5461 m3/day
PD45033	Active	C050304	Current	Stream Storage: Non-Power	Cenci Creek	6167.4 m3/year
PD45033	Active	C050303	Current	Irrigation: Private	Cenci Creek	24669.6 m3/year
PD45021	Active	C065450	Current	Grnhouse & Nursery: Nursery	Addernac Creek	1659.031 m3/year
PD69376	Inactive	C108189	Cancelled	Domestic	Wakefield Creek	2.2731 m3/day
PD69376	Inactive	C108189	Cancelled	Irrigation: Private	Wakefield Creek	3700.44 m3/year
PD45037	Active	C070119	Current	Domestic	Pearl Creek	2.2731 m3/day
PD45051	Active	C025944	Current	Pond & Aquaculture	Derelys Creek	0.0283 m3/sec
PD45052	Active	C025944	Current	Pond & Aquaculture	Derelys Creek	0.0283 m3/sec
PD45049	Active	C025944	Current	Pond & Aquaculture	Derelys Creek	0.0283 m3/sec
PD45035	Active	C025944	Current	Pond & Aquaculture	Derelys Creek	0.0283 m3/sec
PD45031	Active	C121466	Current	Domestic	Lewarne Spring	2.2731 m3/day
PD45031	Active	C121466	Current	Domestic	Lewarne Spring	2.2731 m3/day
PD45047	Active	C025511	Current	Irrigation: Private	Derelys Spring	9867.84 m3/year
PD45047	Active	C025511	Current	Domestic	Derelys Spring	9.0922 m3/day
PD45029	Inactive	C026761	Abandoned	Domestic	Rigler Spring	2.2731 m3/day

POD Number	Status	Licence Number	Licence Status	PURPOSE	SOURCE	QUANTITY
PD45028	Active	C065433	Current	Domestic	Wakefield Creek	2.2731 m3/day
PD45027	Active	C039325	Current	Domestic	Wakefield Creek	2.2731 m3/day
PD45025	Inactive	C050120	Abandoned	Domestic	Wakefield Creek	2.2731 m3/day
PD45023	Active	C051841	Current	Domestic	Wakefield Creek	4.5461 m3/day
PD44990	Inactive	C028812	Abandoned	Domestic	West Wakefield Creek	2.2731 m3/day
PD44987	Inactive	F040878	Abandoned	Domestic	West Wakefield Creek	4.5461 m3/day
PD44997	Active	C039407	Current	Domestic	Wakefield Creek	2.2731 m3/day
PD44995	Inactive	C034759	Abandoned	Domestic	West Wakefield Creek	4.5461 m3/day

Fish have been observed from the mouth of Wakefield Creek up to Crowston Lake. Cutthroat trout, steelhead, sculpin, chum and coho salmon have all been observed in the creek (Habitat Wizard, 2024). A prominent waterfall downstream of Norwest Bay Road likely presents at least a partial barrier to anadromous fish passage, although there are historic records of steelhead and coho salmon as well as cutthroat trout upstream of the waterfall.

2.7 Land Use History

Wakefield Creek watershed is the traditional territory of the shíshálh people. A main settlement was at tewankw near Porpoise Bay within Sechelt Inlet, approximately 2 km downslope to the east. In 1986, the shíshálh First Nation regained self-government and are continuing to work with the Province of British Columbia to protect the environment[4].

Historic Indigenous land management practices are difficult to interpret from the air photo record because the earliest photo is from 1947, long after colonial land management practices left their mark on the landscape. The shíshálh people have a strong connection to the land (shíshálh, 2024). They carefully managed forest resources to care for cedar trees, for example. Therefore, the extent and age of forest cover in the Wakefield Creek area, both before 1850 and in the post-contact period without air photos between 1850 and 1947, likely reflected the effects of this forest management.

[4] https://en.wikipedia.org/wiki/Sh%C3%ADsh%C3%A1lh_Nation

The air photo record begins in 1947, but changes to the landscape, such as logging, began before that time. Logging in Wakefield Creek and adjacent watersheds likely began in the 1890s as horse and oxen logging on timber skid roads, then as railway logging, with the development of truck logging following in the 1920s and 1930s (Sunshine Coast Museum & Archives, 2024). A logging railway ran from Halfmoon Bay, north of Trout Lake, in the 1910s and may have extended into the Wakefield Creek watershed (Coast Reporter, 2022). The provincial VRI forest cover data records stand ages for various polygons within the watershed ranging from 0 to 191 years old as of 2023, but there is no distinct boundary age immediately apparent that might demarcate a time between younger logging disturbance and older fire history, unlike many other BC watersheds.

Table 5: Historic air photographs – Wakefield Creek watershed

Air Photo Numbers	Date	Observations
BC401:30-31 BC349:18-14	1947	Historic burning or land clearing for development is evidenced by areas with younger deciduous trees. A two-lane road parallels the coastline. Mason Road and Norwest Bay Road are present but appear unpaved. Some farms and smaller properties along Mason Road are cleared and have structures. Sechelt is minimally developed. There is visible sediment at sea level in Snake Bay and at the mouth of Wakefield Creek. Logging is observed between Crowston Lake and Milne Creek, as well as on summits in the Caren Range and near where Oracle Road and Page Road will intersect when they are built.
BC1230:97-94	1950	Development and road building appears similar to the previous images. Logging north of Norwest Bay Road near Mason Road is visible.
BC2097:14-18 BC2099:73-66	1957	The power transmission line corridor is now visible. Logging is observed to the east and the south of Crowston Lake, as well as near the bay north of Snake Bay. Logging roads are visible at the south end of Snake Bay and selective logging is seen. Logs are boomed in the bay, where an increased amount of sediment is visible. Sechelt is becoming more developed and more roads are connecting Sechelt Inlet. Properties are being developed near the mouth of Wakefield Creek.
BC5055:3-6 BC5055:29-26	1962	The watershed appears similar to the earlier images. The logged area south of Snake Bay is regrowing.
BC4427:33-35 BC4426:236-239 BC4426:194-191	1967	More logging is visible in the watershed, including one area south of the transmission lines off the Sunshine Coast Highway. The school on Mason and Norwest Bay Road is constructed, and some properties in the nearby area are being developed. The small gravel pit near the south end of Addernac mountain bike trail is now visible. A larger gravel pit is also visible off Wigard Road and Mason Road.
BC5758:249-251 BC5758:278-275 BC5760:146-148	1976	Wakefield Road has been built up to Norwest Bay Road. Jasper Road is built, and more development close to the lower end of the creek is visible. The large property north of Reeves Road has extended its cleared area up to the transmission lines. There is some development east of Kinnikinnick Park as well as a cut block west of the park, north of the current day golf club. More logging is visible in the upper watershed.

Air Photo Numbers	Date	Observations
BC80060:142-143 BC80060:182-179 BC80060:196-199	1980	Logging is visible off of the power lines right-of-way south of Crowston Lake, and selective logging occurred in between Norwest Bay Road and Sechelt. There are cutblocks observed north of Lub Lake (which is outside of the watershed) and at the farm property northwest of Kinnikinnick Park. Some properties have been cleared on Nickerson Road, Mason Road, and along Sechelt Inlet up towards Snake Bay.
BC85015:177-174 BC85015:195-199 BC85015:219-216	1985	The clearing north of Lub Lake that was observed in the 1980 imagery has been extended. There are cleared areas between Snake Bay and Pinniped Rock, as well as at Pinniped Rock, and some partial clearing south of Snake Bay where the selective logging was observed in the 1957 imagery. A large cutblock is logged north of Sargeant Bay, and pooled water is observed north of the cutblock along the transmission line right-of-way. Few logging roads were built north of the powerline right-of-way. More property clearing occurred on upper Mason Road and between Mason Road and Sechelt. A relatively large square building was constructed on the east side of the mouth of Wakefield Creek.
BCB90014:203-205 BCB90014:185-182 BCB90014:135-138	1990	Extensive logging has taken place throughout the watershed and to the north, east, and west. The logging road that connects to the top of Mason Road is built. Heritage Road is also built, with development noted north of this road. The golf course land has been cleared. The pipeline that runs next to the transmission line right-of-way is constructed.
BCB94079:8-3 BCB94079:63 BCB94079:57-60	1994	Logging that was observed around Wormy Lake in the 1990 imagery has been extended towards Snake Bay. South of Snake Bay, land has been cleared and farms have been developed. The golf course has been established. More land clearing is seen near Mason Road and near to the large property off of Reeves Road. Increased urbanization is noted between Mason Road and Nickerson Road, below the powerlines.
BCC03039:10-12 BCC03039:82-79 BCC03039:100-103	2003	More logging and land clearing is observed in several areas including Pinniped Point, near Trout Lake, north and west of the large property on Reeves Road (which was logged in the 1994 imagery), and near Wakefield Road.
Google™ Earth imagery	2004-2024	New cutblocks south of the powerlines and west of Crowston Lake, partly in and partly out of the watershed, were harvested between 2003 and 2006. One more cutblock southeast of Crowston Lake was harvested between 2006 and 2009, and several additional smaller blocks between 2009 and 2012. Several blocks near the watershed divide, but apparently mostly outside the watershed, south of the powerlines near Tapp Road and Cairns Creek were harvested in 2019, as well as a block north of the watershed divide near Wormy Lake. Revegetation in blocks harvested in the 1990s and early 2000s is well-advanced by the time the 2019 imagery was taken. No additional forest development is visible on imagery between 2019 and 2022. Flooding from beaver ponds is visible along Wakefield Creek under the power transmission line clearing and adjacent gas pipeline right-of-way on imagery with dates between 2009 and 2017, inclusive.

2.8 Previous Assessments

Wakefield Creek is not a designated fisheries watershed or community watershed and has not previously had hydrologic assessments performed.

3.0 ASSESSMENT METHODS

3.1 Rationale

The potential for forest harvesting and road building to affect watershed hydrology were assessed using the rationale of the Coastal Watershed Assessment Guidebook (2001) and Hudson and Horel (2007). This assessment method examines the cumulative effects of past and proposed future harvesting. The discussion of hydrologic risk follows the 2020 EGBC/ABCFP guidelines for watershed and hydrologic assessment. The assessment considers changes in forest cover, forest stand age, and forest species composition through the mechanism of equivalent clearcut area (ECA). It also considers hydrologic risk from roads, sedimentation hazards posed by road networks and landslides, changes to riparian forest, and changes in channel patterns. A detailed description of the rationale for assessment and the assessment methods used, particularly in the delineation of the transitions between rainfall and rain-on-snow zones, is presented below and in Appendix 4.

3.1.1 Peak Flow Generating Hydrologic Processes

The CWAP guidebook (2001) recommends using three elevation bands (sea level to 300 m, 300 m to 800 m, and 800 m and up) for evaluating hydrologic recovery, corresponding to the rainfall, rain-on-snow, and snowmelt-dominated portions of the watershed. Hudson and Horel (2007) discriminate between warm rain-on-snow and cold rain-on-snow because warm rain liberates more water from a snowpack than cold rain does. Millard (2012) questioned whether, for Coastal BC, it was appropriate to consider pure snowmelt floods at all or whether the rain-on-snow process should be evaluated at all elevations to represent worst-case conditions. For the purposes of this assessment, especially when considering the potential for rare flood-generating processes rather than typical conditions, I have considered the headwaters of the watershed above 300 m elevation as subject to warm rain-on-snow processes when evaluating hydrologic recovery, even though the average winter likely sees very few to no rain-on-snow generated floods in Wakefield Creek.

3.1.2 Age of Full Recovery

The provincial Vegetation Resources Inventory (VRI) dataset defines tree height and age for each forest cover polygon based on field surveys added to the database over time, with a projection date of 2022. It does not include recent events, such as logging or fire. To determine present ECA, the projections were extended to January 1, 2024, and all recent cut blocks were incorporated into the ECA calculations.

The age of full recovery is determined by looking at canopy dominant tree age, height, and historic forest disturbance from fire (Chart 1). Any disturbance within the historic period, whether from fire, logging, etc., is considered for hydrologic effects, but effects from before the historic period are considered to be natural.

Stands older than 104 years (harvested before 1920) were assumed to be fully hydrologically recovered. At least some of the watershed was harvested before the air photo record began in 1947, but, judging from the appearance of the stands on the 1947 imagery, that harvesting most likely occurred between 1920 and 1947, therefore stands older than that (age of disturbance before 1920) were likely not commercially harvested and are recovering from other processes such as fire or windthrow. More recent logging of second growth has also occurred and may have targeted stands that were originally logged before 1920. Stands with heights greater than 25 m were also assumed to be fully recovered.

3.1.3 Snow Depth and Recovery Thresholds

Wakefield Creek is entirely within Snowpack Zone 4 as defined by Hudson (2000) and has two elevation bands (Table 6). I used the Snowpack Zone 4 equation from Hudson and Horel (2007) to estimate the expected peak snowpack depth within the warm rain-on-snow elevation band (300 m to 800 m), using the median elevation of the zone (550 m) to estimate snowpack depth for the whole zone. The equation predicts a peak snowpack depth of 1.3 m. The height threshold for the start of recovery for young stands in rain-on-snow elevation bands is 0.5 m greater than the expected maximum snowpack depth at the same elevation (Hudson and Horel, 2007). Therefore, a threshold of 1.8 m was used to calculate the start of hydrologic recovery and resultant ECA in that elevation band.

Table 6: Elevation Bands, Flood Processes, and Peak Snowpack Depths

Elevation Band (m)	Flood Generating Process	Peak Snowpack Depth (m)
0-300	Rain	0
300-580	Warm rain-on-snow	1.8

3.1.4 Land Use Assumptions

Parts of the Lower Wakefield Creek sub-basin include developed lands adjacent to the lower reaches of the creek. These lands are used as rural residential, residential, agricultural, and gravel pits. Residential, agricultural, and gravel pit uses represent a permanent loss of forest cover. The VRI polygons classified as rural were assumed to be mostly permanently unforested, and the proportion of rural use for each polygon was used to calculate the ECA for that polygon. For example, a rural residential polygon with approximately 70% forest cover was assumed to have at least a 30% ECA. No recovery projection was applied to these polygons over the period of assessment.

3.2 GIS Analysis

GIS analysis was used to prepare the data for ECA calculation. The watershed was divided into elevation bands using TRIM contours as the input elevation. The watershed boundary and elevation bands were then intersected with the VRI data. The resultant attribute table was exported for ECA calculation using Excel. Block and road data, both existing and proposed, was intersected with the watershed boundary, and the resulting attributes were also exported for further analyses. SCCF provided GIS data that showed their proposed harvest and road building in the watershed. Blocks (proposed and harvested) and roads were clipped to the watershed boundary, so only those parts of each feature that lie within the watershed was considered in the ECA analysis.

3.3 Hydrologic Recovery of Unvegetated Polygons

Watersheds contain areas that will never become forested and thus do not count towards estimates of equivalent clearcut area; for example, unvegetated, unforested, or non-productive forestland with small trees such as wetlands or alpine forest. All forest cover polygons were reviewed so that all polygons describing non-vegetated and non-productive lakes, rivers, or bedrock outcrops were considered 100% hydrologically recovered. Areas temporarily deforested, even if by natural processes, such as patches with shrub vegetation, are considered to be hydrologically recovering in the same way as logged patches, and their effects are summed with logging to evaluate cumulative hydrologic effects. The power transmission and pipeline corridors were assumed to be permanently unforested, and no projected recovery was applied to them.

4.0 HYDROLOGIC RISK ASSESSMENT

Hydrologic risk is defined as the product of likelihood of occurrence of an event and the consequence, with respect to watershed values (EGBC/ABCFP, 2020). Hydrologic risk assessment is a partial risk analysis because it only considers the potential for damage of watershed values but does not consider vulnerability. For example, when fish habitat is the watershed value and partial risk assessment determines there is moderate hydrologic risk, it means that in fish habitat could be damaged or degraded by the proposed changes in the watershed, but it will not quantify the magnitude of the harm.

The watershed assessment method includes evaluation of the cumulative effects and the partial risk of past harvesting and road construction on watershed properties and hydrologic regimes. The assessment considers changes in forest cover, forest stand age, and forest species composition. It also considers hydrologic risk from roads, sedimentation hazards posed by road networks and landslides, changes to riparian forest, and changes in channel patterns.

Hydrologic partial risk assessment identifies and characterizes the risks posed by forest disturbance and 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 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 and statutory decision makers.

4.1 Risk Identification

With respect to Wakefield Creek watershed, identified hydrologic risks include:

- Changes in the timing, duration, magnitude, or frequency of stream flows, including peak flows (floods), low flows, and mean flows, that could result in changes to the amount of usable water for water licensees, reductions in flow or water level for fish, flooding of private property, or damage to infrastructure.
- Decreases in channel stability either due to increased sedimentation or to channel avulsion, that could result in sedimentation at water intakes or loss of riparian habitat;
- Changes in water quality as a result of increased sedimentation or changes in stream temperature that could adversely affect drinking water quality, fish, or fish habitat; and
- Changes in channel pattern and riparian function that could affect fish habitat;

The primary parameters of value (elements at risk) with respect to these risks include water supply and water quality for water users. Secondary parameters of value are fish and fish habitat. Tertiary parameters of value are transportation infrastructure in the watersheds, including highway, public roads, resource roads, mountain bike trails, bridges, and culverts that could be affected by increased peak flows. This ranking of risks is based on their identified sensitivity to potential changes and to their perceived significance. The watershed is not a designated community watershed but supports domestic, pond and aquaculture, and irrigation licenses, so effects on water quality are ranked highest. Changes to low flows will not affect transportation infrastructure, but could affect fish and fish habitat; therefore, fish habitat has a higher sensitivity to disturbance and is consequently the secondary parameter of value. The lower part of the watershed is a residential suburb of Sechelt, but most of the development is outside the floodplain of Wakefield Creek, and along with that development has come stormwater management infrastructure which helps to mitigate the risk of flooding to private property in the lower watershed. Consequently, flood risks to private property, though not unimportant, are ranked as the tertiary parameter of value because they are the least susceptible to disturbance of the parameters of value. Changes to water quality, or to the timing and duration of low flows, will not affect private property; only large destructive floods in excess of the design capacity of the stormwater infrastructure would.

5.0 FIELD OBSERVATIONS

Drew Brayshaw, Ph. D., P. Geo., and Carlie Chan, M. Sc., GIT, completed the field assessment with Warren Hansen, RPF, on April 17, 2024. It was sunny and warm during the assessment.

We started the assessment at the mouth of Wakefield Creek. Wakefield Creek flows under Highway 101 in a large corrugated metal pipe culvert and over bedrock before flowing into the Salish Sea at a small beach. Both sides of the mouth of the creek are developed. The property on the west side of the mouth of the creek has a seawall made of concrete lock blocks, while the property on the east bank of the creek has angular blocky rock riprap. Several logs are wedged across the creek, between the lock block wall and the rip rap, in a manner suggesting that they have deliberately been placed that way, possibly as a habitat feature, although I have not been able to find any specific documentation confirming that this is the case (Photo 1 in Appendix 1). The highway culvert has concrete baffles in it, which provide a fish ladder for fish swimming upstream (Photo 2).

Upstream of Highway 101, Wakefield Creek is in a ravine with sidewalls which progressively increase in height upstream to the waterfall. Bedrock is exposed in the channel bed and banks in a few places, and the channel has a step-pool morphology with lag boulders being the dominant clasts. An invasive species, English ivy, is extensive in the lowest part of the canyon and has overgrown woody debris jams and fallen logs. Based on my understanding of the speed of growth of this and other plants, and on the state of decay of the wood in the woody debris jams, it appears that it has been at least several years, and possibly more than a decade, since the wood which makes up the jams was moved by water (Photo 3).

The waterfall in Wakefield Creek is downstream of Norwest Bay Road and consists of a bedrock cascade. Above the waterfall, near Norwest Bay Road, the channel is low-gradient. Sand has deposited in the stream channel and makes up the banks of the channel upstream of the culvert (Photo 4). The culvert under Norwest Bay Road is a concrete pipe culvert, and is placed so that it is skewed to the west, opposite to the trend of the channel, which trends slightly east below the culvert. There is at least a half meter of drop below the culvert outfall into an eroded pool. On the west bank of the ravine sidewall just below the culvert, the bank has eroded and the erosion has caused bank slumping, with glaciomarine sediment and trees falling into the channel (Photo 5). Downstream of the eroded section at the outlet of the culvert, Wakefield Creek flows across private property in a stable channel with a mixture of grassed and forested banks.

Further upstream, where the power transmission lines and gas pipeline cross Wakefield Creek, a cleared farm and gravel pit are on a terrace top on the west side of the creek, south of the powerlines, while the areas to the east and north of the channel are forested. Wakefield Creek is incised in a broad low-gradient draw about 25 m to 30 m below the level of the terrace top. The surface of the terrace top is gravel, but the surficial material switches to a glaciomarine or glaciolacustrine layer of silt and clay about 20 m below the top of the terrace, so that surficial materials along the banks of the floodplain in the draw's bottom are fine-grained. Elk trails (and possibly past cattle or other livestock trails) crisscross the floodplain and expose this fine-grained sediment where they climb up the steep slopes of the draw sidewalls. The sidewalls and draw bottom are overgrown with Himalayan blackberry and other invasive species under the transmission line, but these species have not invaded the forest to the north and south of the cleared transmission corridor. In the channel of Wakefield Creek under the transmission lines, buried logs are visible in the channel and banks, and the bed is of gravel while the banks contain silt and clay (Photo 6). The channel meanders in the forest south of the transmission line, with one back-channel that has been abandoned by a meander cutoff and an active channel both having gravel beds and fine-textured banks (Photo 7). This area was previously dammed by beavers between approximately 2009 and 2017 as per the Google Earth imagery and discussion with locals. Once the dams were removed, vegetation has recolonized the flooded area, and it is likely that the visible buried logs were original vegetation from before the beavers, with sedimentation in the beaver dams depositing on top of them. To the west of Wakefield Creek, where the gas pipeline runs up onto the terrace top, off-road vehicles have left extensive rutting on the grassed pipeline right-of-way (Photo 8).

In the forested, headwater part of the watershed, Wakefield Creek has gravel-bed channels that are developed in till veneers over bedrock (Photo 9). The till has a bouldery sandy texture, and mobile sediment in the channels is largely coarse gravel sized with occasional bouldery lag sediment that has been winnowed from the overlying till (Photo 10). We followed the main channel of Wakefield Creek until we could locate the transition where the creek flows from the till-and-bedrock upper watershed out onto the deeper surficial materials of the lower watershed. Near the transition point, the surficial material exposed at the surface changes from the sandy bouldery till to fine-textured material with few stones, likely a glaciomarine deposit (Photo 11). We did not notice any alteration in streamflow in the channel at or below the sedimentary transition, and it appears that Wakefield Creek does not experience either substantial increase or decrease in flow as it runs out of the upper watershed and onto the deep deposit of sediments, so neither losing nor gaining water in interchange with the underlying aquifer.

Crowston Lake and another smaller, unnamed lake are in the headwaters of the watershed. Both of these lakes have standing dead trees in the water (Photo 12), which is often indicative of past increases in water level, such as might be caused by the construction of beaver dams or other structures. Along the shore of Crowston Lake near the outlet, I noted a vegetated berm parallel to the shoreline which I interpreted as an abandoned and overgrown beaver dam which was still affecting lake level. Roads reach the shores of both lakes, and we observed one paddler in Crowston Lake during our field visit.

In addition to active roads, old roads and trails crisscross the watershed. The condition of these roads and trails, and their connectivity to stream channels, varies. Mountain bikes trails that we observed had been constructed with bridges over streams and coarse rip-rap along stream banks (Photo 13) while on an old road used by ATVs as well as by bikes, a ford crossing had not been armoured (Photo 14). One crossing on an active but unmaintained (wilderness status) forest road near Crowston Lake had decaying wood from a collapsed wood box culvert in the channel of Wakefield Creek and had been driven across by vehicles accessing Crowston Lake (Photo 15). I understand that MoF is aware of this and plans to deactivate this road segment, remove the damaged culvert, and restore the stream in the near future, although plans to do so in 2024 appear to have been delayed (W. Hansen, p. comm. November 2024).

6.0 RESULTS

6.1 Sediment Source Survey

We did not observe any landslides, either during the field inspection, or on the historic air photos and imagery, with the exception of the slumped streambank at Norwest Bay Road. The upper watershed is mostly low-gradient, and it is unlikely that landslides would occur within it. In the lower watershed, the steepest slopes within the whole watershed are along the ravine of Wakefield Creek downstream of the waterfall. We did not notice any landslides or old landslide scarps in the area below the waterfall during our field inspection, but if older slides had occurred, it is likely that they would have been small (< 0.1 ha) and concealed by forest cover and hence not visible on the historic imagery. If any old slides did occur in the Wakefield Creek ravine, it is likely that the most recent one was before 1990.

In the absence of landslides, the primary natural sediment sources in the watershed are the channel bed and banks. We noticed meandering and abandoned cutoff channel downstream of the powerline right-of-way, and bank erosion at a stream bend upstream of the right-of-way; these are mentioned not to suggest that they are the only two such sediment sources but that they are characteristic of such sources.

The largest anthropogenic sediment source that we noted in the watershed was the bank slump below Norwest Bay Road (Photo 5), which appears to have been caused by the installation of the culvert under the road. The culvert is skewed at an angle to the natural trend of the creek, so that water coming out of it is directed against the western (river-right) bank of the creek, eroding the bank and apparently causing undercutting which in turn led the slump. The total volume of this slump is difficult to measure because some of it has been eroded and carried away by Wakefield Creek, and what remains is the woody debris and coarse fragment of the original deposit. The total volume of the original slump may have been about 20 m^3, but it could have occurred as a sequence of smaller slumps over time rather than in a single event.

In addition to the slump at Norwest Bay Road, anthropogenic sediment sources in the watershed consists of roads and trails. Many of the roads and trails contain sediment control measures such as bridges and drainage structures, but some of the old roads now used as ATV trails do not, and as described in Section 5.0, we noted one old failing drainage structure on an unmaintained road near Crowston Lake which was leading to both truck and ATV traffic driving through the stream. Ruts from mud bogging along the gas pipeline right-of-way were another obvious source of sediment production, but as these ruts were approximately 200 m away from the stream channel, and we did not observe any evidence of sediment transport from the rutted area to the stream channel by overland flow, it is much less likely that they were directly contributing sediment to the channel of Wakefield Creek.

We noted that the channel immediately upstream of Norwest Bay Road was accumulating fine sediment, but this accumulation is likely due to the effects of the road and culvert, and the removal of upstream beaver dams after 2017, rather than due to a specific source of upstream sedimentation. In the remainder of the watershed, we did not observe substantial aggradation or degradation of the streambed. The beach at the mouth of Wakefield Creek where it flows into the Salish Sea has not changed appreciably with respect to size or shape over the last few decades.

6.2 Riparian Assessment and Channel Conditions

In most of the watershed, riparian forest cover is largely intact, either because it is within the ravine of Lower Wakefield Creek or because it is mature second growth in the headwaters. Only the power transmission line and the adjoining gas pipeline right-of-way present substantial removals of the riparian forest along Wakefield Creek, and these removals are very small in terms of the total amount of riparian forest in the watershed. Invasive plants such as English ivy and Himalayan blackberry have colonized the riparian area of the lower watershed but are not affecting the essential hydrologic functions of the riparian forest: shade for temperature and a source of coarse woody debris to the stream channel.

The channel morphology along Wakefield Creek is controlled by the local terrain and topography. Headwaters channels in the watershed have riffles and pools with gravel beds and immobile lag stones winnowed from the overlying till. Where Wakefield Creek flows out from the headwaters and onto the deep sediments of the lower watershed, fluvially transported gravel in the stream bed overlies the cohesive fine-textured glaciomarine sediments that compose the banks, the channel decreases, and the stream meanders as its gradient decreases. Below Norwest Bay Road, the point where the stream flows over the waterfall demarcates a relatively stable knickpoint which represents the sum extent of upstream fluvial erosion over the Holocene. The channel between the base of this waterfall and the ocean, in the ravine, is bedrock-controlled and has abundant coarse woody debris and gravel to cobble-sized sediment, again with some lag boulders derived from the underlying bedrock.

6.3 Effective Clearcut Area

Table 7 lists both the present ECA as well as the projected recovery over the period 2023 to 2027 that would occur if no additional logging were to take place, computed in two 3-year increments for 2024 and 2027. This provides a baseline for considering the effects of proposed logging, as described in Section 7.

Table 7: Sub-Basin and Watershed Equivalent Clearcut Area, No Further Logging, 2024-2030

Watershed or Sub-Basin Name	Area (ha)	ECA (ha)			ECA (% watershed area)		
		2024	2027	2030	2024	2027	2030
Upper Wakefield Creek	753	171	155	139	22.7%	20.6%	18.5%
Lower Wakefield Creek	589	120	115	111	20.3%	19.6%	18.8%
Entire Wakefield Creek Watershed	1342	291	270	250	21.6%	20.1%	18.6%

6.4 Road Density

Table 8 lists the length of active road and resultant road density values for each watershed, with road lengths derived from SCCF's operational roads database and the provincial FTEN database and Digital Road Atlas. Because some segments of some roads appear in multiple sources of data, the data has been processed to address the overlap. Specifically, road length and status from SCCF's operational roads database has been considered first. The FTEN database includes some forest roads built or under permit to other forest licensees, so roads in the FTEN database and also not in the operational roads database have been added to the road lengths listed in Table 7. Likewise, the Digital Roads Atlas includes non-forest roads in the lower watershed, including suburban streets, Highway 101, and powerline and pipeline access roads. Finally, mountain bike trails that follow inactive roads were considered as roads, while purpose-built singletrack mountain bike trails through the forest were not.

The Digital Road Atlas includes urban and suburban paved roads (driveways, local, collector, and arterial roads in the MOTI classification system). Unlike the resource roads which are typically assessed as part of a watershed assessment for forestry, these roads are accompanied with a more substantial engineered drainage network, including drains, ditches, and most importantly, storm sewers, all of which are intended to manage runoff from precipitation and runoff falling onto or reaching the paved road network. The regional storm drainage network's extent and design parameters (sizing, connections, etc.) are shown on District of Sechelt's online webmap (Sechelt, 2024), and essentially runs parallel to Wakefield Creek and its tributaries and discharges directly into the ocean, rather than collecting water and discharging it into Wakefield Creek. Therefore, because these roads' drainage networks largely bypass Wakefield Creek rather than contributing to it, in Table 8, the DRA paved roads have been listed in the total road length and total road density columns but not in the active road length and active road density columns.

The road drainage network does not entirely bypass Wakefield Creek. Along the northeast side of Norwest Bay Road where it crosses Wakefield Creek, a drainage pipe discharges into a ditch which in turn flows into Wakefield Creek just upstream of the culvert under Norwest Bay Road. During the 2021 atmospheric river rainfall events, this ditch overflowed, and water flowed across Norwest Bay Road and eroded the road fill to the east side of the culvert. The damage to the road had been recently repaired during our spring 2024 site visit (Photo 16).

Table 8: Watershed Road Length and Road Density Values, 2024

Watershed or Sub Basin Name	Area (km^2)	Active Road Length (km)	Active Road Density (km/km^2)	Total Road Length (km)	Total Road Density (km/km^2)
Upper Wakefield sub-basin	7.5	11.8	1.57	11.8	1.57
Lower Wakefield sub-basin	5.9	4.0	0.68	20.7	3.51
Wakefield Creek Watershed	13.4	15.8	1.18	32.5	2.43

7.0 PLANNED FOREST DEVELOPMENT

SCCF has two engineered blocks in the Wakefield Creek watershed. Both blocks are in the Upper Wakefield sub-basin and are shown on Figure 1 in Appendix 1. These are the only blocks that SCCF is planning to harvest in the watershed between 2024 and 2030. Block HM66-1A is 17.3 ha in size and Block HM64 is 11.2 ha, for a total of 28.5 ha of harvesting planned for the watershed. For the purposes of this assessment, I assumed that both blocks would be harvested during the 2024 to 2027 interval. Table 9 updates the 2027 and 2030 values from Table 7 to include the effects of this planned logging. If harvesting of one or both blocks is delayed and occurs between 2027 and 2030, then the estimate of 2027 ECA will be lower than presented in Table 9, but the 2030 ECA will be unchanged because for calculation purposes no recovery of harvested blocks is projected through to 2030. This does not mean that no recovery will occur, only that it has not been included in the ECA estimates. Any recovery in the harvested blocks that does occur by 2030 will reduce actual watershed ECA below the values presented in Table 9.

Table 9: Planned Harvest and Post-Harvest Watershed ECA

Watershed or Sub-Basin Name	Area (ha)	Planned Harvest 2024 – 2027 (ha)	ECA (ha) after planned harvest		ECA (% watershed area)	
			2027	2030	2027	2030
Upper Wakefield Creek	753	29	184	168	24.4%	22.3%
Lower Wakefield Creek	589	0	115	111	19.6%	18.8%
Entire Wakefield Creek Watershed	1342	0	299	279	22.3%	20.8%

Approximately 1.3 km of new road will be built, and another 0.7 km of existing deactivated road will be reconstructed, in the Upper Wakefield sub-basin in order to access the planned blocks. All of the new construction and reconstruction, together with a small amount of existing road nearby, will be deactivated after the completion of harvesting and silvicultural obligations, resulting in a total amount of deactivation of approximately 2.1 km, and hence a net overall long-term decrease in active road length of 0.1 km. The resultant road length and road density values by 2030 are listed in Table 10.

Table 10: Watershed Road Length and Road Density Values, 2024

Watershed or Sub Basin Name	Area (km^2)	Active Road Length (km)	Active Road Density (km/km^2)	Total Road Length (km)	Total Road Density (km/km^2)
Upper Wakefield sub-basin	7.5	11.7	1.56	11.7	1.56
Lower Wakefield sub-basin	5.9	4.0	0.68	20.7	3.51
Wakefield Creek Watershed	13.4	15.7	1.17	32.4	2.42

8.0 DISCUSSION

The proposed development will maintain watershed equivalent clearcut area and active resource road density at levels below those where statistically detectable effects on watershed hydrology would be expected. Accordingly, the likelihood of alterations to existing watershed hydrology is low.

Past road development in the watershed has been extensive, both with respect to old forestry roads and with respect to suburban roads in the lower watershed. Many of the old forest roads have been retired or deactivated, while the suburban roads associated with residential and commercial development in the lower watershed has also seen the development of stormwater drainage systems which are intended to manage and mitigate the hydrologic effects of such development.

During our field assessment, we did not observe any evidence of watershed-wide hydrologic issues such as flooding or sedimentation driven by unsustainable land use changes. We did observe site-specific issues at individual locations, including invasive species colonizing the riparian areas along lower Wakefield Creek, bank slumping and sedimentation caused by poor culvert installation under Norwest Bay Road, localized aggradation and degradation driven by beaver dam building and removal between the power transmission lines and Norwest Bay Road, and a failing wood box culvert near Crowston Lake.

These localized issues can be dealt with individually, with varying degrees of difficulty and success. The invasive Himalayan blackberry and English ivy in the lower watershed have likely become endemic, as they have across much of southwestern British Columbia, and would be difficult to remove without sustained effort over a long time by local governments and community groups. The culvert under Norwest Bay Road is relatively new and likely has a long design life before it is scheduled for replacement, but in its current location and orientation, it presents both a barrier to fish passage and a downstream terrain stability and sedimentation hazard. The appropriate road managers (District of Sechelt and/or BC MOTI) should consider replacing it sooner rather than later. The damaged culvert near Crowston Lake can and will be fixed soon by MoF. Beaver activity has likely been historically been widespread throughout the watershed, based on evidence from the lakes and the powerline, and should be expected in the future as well, though its locus may vary over time.

8.1 Hydrologic Partial Risk Assessment

This assessment provides a partial risk assessment because some details related to exposure of elements at risk, vulnerability of those elements, and consequences are beyond the scope of this assessment. The resultant partial risk is a function not only of factors such as watershed ECA or road density but also of the time over which those indicators change. Watershed ECA levels depend on tree growth and integrate the effects of past disturbance as well as present and proposed future conditions. The partial hydrologic risk from harvesting and other disturbances will remain the same or decrease over time if there are no additional fires, insect infestations, or other unforeseen disturbances. The following tables summarize the hydrologic partial risk to the identified resources (see Section 4.1) in Wakefield Creek watershed.

Table 11: Hydrological Partial Risk Summary

Parameters of Value	Relevant Hydrologic Risks	Likelihood	Consequence	Partial Risk	Comments
Water supply and water quality	Damage due to increased peak flows	Low	Low	Very Low	ECA and road density are below the range where they should produce any statistically detectable alteration to existing peak flow regime.
	Damage due to longer and lower low flows	Low	Moderate	Low	Climate change might exacerbate length of low flows or reduce future low flows to even lower levels.
	Damage due to decreased water quality and increased fine sediment transport	Low	Moderate	Low	Fine sediment pulses associated with past beaver dam construction and removal have caused localized fine sediment accumulations near Norwest Bay Road.

Parameters of Value	Relevant Hydrologic Risks	Likelihood	Consequence	Partial Risk	Comments
	Damage due to increased water temperature	Low	Low	Very Low	The channel is narrow and shaded by riparian vegetation throughout most of its length and should be resistant to short-duration temperature swings. Long periods of warm air temperature may raise temperatures in Crowston Lake. Temperatures likely decrease downstream from Crowston Lake.
	Damage due to degraded riparian habitat	Low	Low	Very Low	Invasive blackberry and ivy in lower watershed may cause long-term degradation of riparian habitat by suppressing growth of new conifers which supply wood to channel. Presently wood is abundant.
	Damage due to increased coarse sedimentation from landslides	Very Low	Low	Very Low	No historic landslides noted except bank slump caused by Norwest Bay Road culvert. Ravine on lower Wakefield Creek below waterfall most likely site of any future landslides.
Groundwater supply and groundwater quality	Damage due to decreased recharge of groundwater	Very Low	Very Low	Very Low	Recharge to bedrock aquifer likely from Crowston Lake and unnamed lake. Direct recharge to surficial sediment aquifer unlikely due to capping layer of glaciomarine sediments. Possibly some discharge from bedrock aquifer into lower Wakefield Creek occurs below waterfall.
	Damage due to decreased water quality of groundwater	Very Low	Very Low	Very Low	Fine-textured glaciomarine layer provides seal for underlying aquifer and minimizes interchange with Wakefield Creek surface water.
Fish and fish habitat	Damage due to increased peak flows	Low	Low	Very Low	ECA and road density are below the range where they should produce any statistically detectable alteration to existing peak flow regime.
	Damage due to longer and lower low flows	Low	Moderate	Low	Climate change might exacerbate length of low flows or reduce future low flows to even lower levels.
	Damage due to decreased water quality and increased fine sediment transport	Low	Moderate	Low	Fine sedimentation near Norwest Bay Road associated with past beaver dam removal has not substantially degraded fish habitat. Culvert under Norwest Bay Road may be barrier to fish passage.

Parameters of Value	Relevant Hydrologic Risks	Likelihood	Consequence	Partial Risk	Comments
	Damage due to increased water temperature	Low	Low	Very Low	The channel is narrow and shaded by riparian vegetation throughout most of its length and should be resistant to short-duration temperature swings. Long periods of warm air temperature may raise temperatures in Crowston Lake. Temperatures likely decrease downstream from Crowston Lake.
	Damage due to degraded riparian habitat	Low	Low	Very Low	Invasive blackberry and ivy in lower watershed may cause long-term degradation of riparian habitat by suppressing growth of new conifers which supply wood to channel. Presently wood is abundant.
	Damage due to increased coarse sedimentation from landslides	Very Low	Low	Very Low	Bank slump caused by misaligned Norwest Bay Road culvert may have cause localized temporary degradation of fish habitat immediately downstream of Norwest Bay Road.
Infrastructure including roads, bridges, and culverts	Damage due to increased peak flows or coarse sedimentation	Low	Moderate	Low	The culvert under Norwest Bay Road is substantially smaller than the culvert under Highway 101 and may be undersized for present as well as future climatic conditions. If this culvert is replaced to address its misalignment, fish passage barrier effects and terrain stability effects downstream, there is opportunity to increase its size as well.
Private property including houses and buildings	Damage due to increased peak flows	Low	Low	Very Low	For almost all of its course near private property, the channel and channel-adjacent flood plain of Wakefield Creek is incised below the level of adjacent residential and rural developed properties, either in a ravine or below a terrace. Although property lines may extend to the creek in some places, the developed portions of properties are not at risk of flooding.

The risk scenario described in Table 11 evaluates partial risk under current climate conditions. If the climate changes in the manner summarized in Section 2.4, Wakefield Creek will likely have longer and more intense summer droughts due to increased air temperature, increased evapotranspiration, and decreased summer precipitation, as well as more frequent and larger fall and winter floods due to increasing fall and winter precipitation and more intense individual storms. The altered likelihoods of low flows and floods due to climate change will not likely alter the resultant risks in Table 11 except with respect to infrastructure, specifically with respect to the current Norwest Bay Road culvert. Replacing this culvert could maintain low future risk.

9.0 RECOMMENDATIONS

This report has few recommendations to make for Wakefield Creek, in part because the risks to Wakefield Creek are generally low and in part because the watershed assessment process is intended to guide forestry development, and much of Wakefield Creek watershed is suburban land outside the scope of forestry development and managed by different land managers.

The most substantial source of risk to Wakefield Creek that we noted in the watershed is the Norwest Bay Road culvert. This culvert is both misaligned and has an overhang at its downstream end which presents a potential barrier to fish passage. The misalignment of the culvert has caused terrain instability in the western bank immediately downstream because the flow of water from the culvert's outlet is directed against the bank rather than down the channel. The culvert also appears to be undersized for expected and future peak flows, because it is substantially smaller than the downstream culvert on Highway 101. This culvert is not the responsibility of SCCF, but our observations should be passed on to the responsible agencies, who appear to be District of Sechelt and BC Ministry of Transportation and Infrastructure, for their consideration.

Forestry activities are maintaining overall low to very low risk in Wakefield Creek watershed. The only site-specific issue that we noted in the part of the watershed that SCCF manages was the damaged wood box culvert near Crowston Lake, and I understand that this had already been identified as a problem and replacement has been planned by MoF.

Active resource road density in Upper Wakefield Creek sub-basin is about 1.57 km/km^2 at present, and will decrease marginally to 1.56 km/km^2 by 2030 following all planned road deactivation. The active resource road density for the whole watershed is lower (1.17 km/km^2) even though total road density is higher for the whole watershed (2.42 km/km^2) because most of the roads in the watershed are paved roads in the lower watershed that have been constructed with associated storm sewer infrastructure designed to mitigate their hydrologic effects. The BC Interim Assessment Protocol for Aquatic Ecosystems in British Columbia (BC CEF, 2020) uses 1.5 km/km^2 as an upper threshold for low likelihood of hydrologic effects, although this assessment protocol is intended as a preliminary approach that must be followed up with field assessment. Upper Wakefield Creek is slightly above this 1.5 km/km^2 threshold, and although our field assessment did not observe any indicators to suggest that road density was adversely affecting watershed or sub-basin hydrology, it would only take the deactivation of about an additional 0.4 km of presently active road to reduce the road density value in Upper Wakefield Creek below 1.5 km/km^2. Therefore, we suggest that SCCF re-evaluate their road use plans to determine if any additional active resource roads within their operating area could be deactivated. Hydrologic risk from roads is a function not only of road density but also of the time over which roads remain active.

10.0 CONCLUSIONS

Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the Wakefield Creek watershed, near Sechelt, BC. SCCF has forest development plans in the upper sub-basin of the watershed and requested a watershed assessment to assess the effects of the proposed development on watershed hydrology and to provide guidance for current and future forest management.

Wakefield Creek is a 13.5 km^2 watershed that flows from headwaters near Crowston Lake into the Salish Sea about 4 km west of Sechelt. Infrastructure including Highway 101, a power transmission line, and a gas pipeline cross the watershed. Much of the lower watershed consists of suburban and rural residential property on the western outskirts of Sechelt, while the upper watershed is part of the community forest. There are several water licenses on Wakefield Creek and its tributaries, and fish use at least the lower watershed, with scattered observations of fish presence in the headwaters as well.

SCCF is planning about 29 ha of logging in total, in two cutblocks, between 2024 and 2027, with no additional logging proposed until after 2030. Watershed equivalent clearcut area (ECA) is 291 ha (21.6% of watershed area) at present and would decrease to 250 ha (18.6% of watershed area) by 2030 if no additional logging occurs. If the proposed cutblocks are developed, watershed ECA in 2030 will be 279 ha, or 20.8% of watershed area. That is, the proposed amount of logging is somewhat less than the ongoing rate of hydrologic recovery, so overall watershed equivalent clearcut area will slightly decrease over the period from 2024 to 2030. This level of harvest will maintain low hydrologic risk to watershed resources at the watershed and sub-basin level.

The watershed has many roads, but a large proportion of the roads, particularly in the lower part of the watershed, are suburban, paved roads which have been constructed along with storm sewers and other measures to mitigate their hydrologic risks. These roads contribute to total watershed road length and road density, but not to active resource road length and density. The active road density in the watershed as a whole now is about 1.18 km/km^2 at present and will be marginally lower, 1.17 km/km^2, by 2030 after all planned road construction and deactivation has taken place. The active road density within the Upper Wakefield Creek sub-basin is currently higher, at 1.57 km/km^2, and will also decrease marginally to 1.56 km/km^2 by 2030. If SCCF were to deactivate an additional 0.4 km or more of presently active roads by 2030, active road density in the Upper Wakefield Creek sub-basin would be reduced to below 1.5 km/km^2. This level of active road density will maintain low hydrologic risk to watershed resources at the watershed and sub-basin level.

The largest single hydrologic issue that we observed in the watershed during our 2024 field inspection was the culvert under Norwest Bay Road. This culvert is misaligned because it is skewed at an angle to the trend of the stream channel, so that it directs water against the western streambank near the outlet. This misdirected water has caused bank erosion and a slump which caused trees and sediment to fail into the creek. Additionally, the culvert has an overhang at its outlet which appears to present a barrier to fish passage, and it appears to be undersized for present and expected future peak flows when compared to the Highway 101 culvert downstream. Statlu understands that this Norwest Bay Road culvert is the responsibility of the District of Sechelt and/or BC Ministry of Transportation and Infrastructure (MOTI). We recommend that SCCF pass this information to District of Sechelt and MOTI so that they can prioritize the replacement of the existing culvert with a properly aligned and sized drainage structure.

11.0 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.

12.0 CLOSURE

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DB/EC/js

Permit to Practice Number: 1000170

13.0 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.

December 4, 2024
To: Warren Hansen, RPF
Sunshine Coast Community Forest
213-5710 Teredo Street
Sechelt, BC V0N 3A0

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

I, Drew Brayshaw, Ph.D., P.Geo. have signed, sealed, and dated this Watershed Assessment report in general accordance with the Joint Professional Practice Guidelines - Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector[5].

2024-12-04

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

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Figure 1: Wakefield Creek Watershed

APPENDIX 2: PHOTOS

Photo 1: Wedged logs across stream at beach.

Photo 2: Concrete baffle fish ladder in Highway 101 culvert.

Photo 3: Overgrown woody debris jam in lower ravine below waterfall.

Photo 4: Sandy deposits in channel upstream of Norwest Bay Road.

Photo 5: Bank erosion and slump deposit where Norwest Bay Road culvert directs flow against bank.

Photo 6: Buried wood in channel in former beaver dam area under powerlines.

Photo 7: Back channel in forest downstream of powerlines.

Photo 8: ATV rutting in gas pipeline ROW.

Photo 9: Bouldery till making up bank of channel in forested upper watershed.

Photo 10: Mobile gravel and lag boulders in channel of Upper Wakeman Creek.

Photo 11: Glaciomarine or glaciolacustrine sediment with dropstones making up bank of channel at terrace edge.

Photo 12: Crowston Lake near outlet with standing dead trees and vegetated old beaver dam.

Photo 13: Bridge and coarse rock riprap on mountain bike trail in forest.

Photo 14: Ford on old road used as ATV trail with sediment entering stream.

Photo 15: Damaged wood box culvert near outlet of Crowston Lake.

Photo 16: Recently repaired damage to road fill over culvert, Norwest Bay Road.

APPENDIX 3: HYDROLOGIC RISK 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 effects are commonly expressed as the likelihood that logging will result in increases to peak flow magnitude or frequency. Cumulative hydrologic effects are 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 effects. Intermediate categories (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 effects 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.

ECA Range (percent of total watershed area)	Hydrologic Risk	Qualitative Interpretation
0% to 15%	**Very low**	**Detectable changes to peak, mean and low flow will not occur**
15% to 20%	**Very low to low**	
20% to 25%	**Low**	**Detectable changes to peak, mean or low flow are unlikely to occur. Small variations might be detectable using statistical analysis.**
25% to 30%	**Low to moderate**	
30% to 35%	**Moderate**	**Detectable changes to peak flow might occur for some flow magnitudes and return periods. Flow durations might be altered.**
35% to 40%	**Moderate to high**	
40% to 45%	**High**	**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.**
45% to 50%	**High to very high**	
50% or higher	**Very high**	**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.**

Risk is a function the likelihood of an event occurring and the exposure of downslope or downstream resources to the event, and vulnerability of the downslope resources, which together determine the consequences should the event occur. Land Management Handbook 56 (Wise et al. 2004) and the BC Ministry of Forests Forest Road Engineering Manual (2023) define risk as the product of the probability of hazard (likelihood of occurrence) and consequence. Consequence further depends on the nature of the element(s) at risk, exposure, and vulnerability.

Statlu recognizes that the evaluation of the exposure and vulnerability of elements at risk 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 consequences, 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.

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 likelihood 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 4: RATIONALE FOR HYDROLOGIC ASSESSMENT

Rationale for Assessment

Forest harvesting can affect hydrology in many ways. The assessment of hydrologic impacts in a CWAP focuses on the potential for:

- Changes to peak stream flows,
- Accelerated surface soil erosion,
- Accelerated landslide activity,
- Changes to riparian zones; and,
- Changes to channel morphology.

The following section describes the potential effects of changes to these five indicators resulting from forestry and forestry-related activities.

Changes to Peak Stream Flow

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.

Construction of logging roads can affect the pathway and the timing in which precipitation reaches the stream channel. Subsurface flow may be intercepted and directed down ditchlines 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.

Accelerated Surface Soil Erosion

Surface soil erosion is defined as the detachment, entrainment, and transport of individual sediment particles due to falling or running water, or wind. It is a function of surface cover, mineral soil type, slope gradient, slope length and shape, and rainfall intensity.

The principal effect of forest practices on surface soil erosion results from road building. Sediment generated from ditches, cut and fill slopes, and road surfaces is introduced to stream channels through ditches and at stream crossings. Higher road densities indicate higher potential for sediment delivery to streams. High quantities of sediment can clog ditches and stream channels, accelerate stream bank erosion, deposit fine sediments in reservoirs, cover fish spawning grounds, and reduce downstream water quality. Timber harvesting can also cause accelerated surface soil erosion due to exposing soil as a byproduct of removal of vegetation. However, roads, particularly old pre-*Forest Practices Code* roads that have not been deactivated, pipeline and powerline access roads, and other similar roads, are a far greater potential source of sediment than conventional harvesting done to current *Forest and Range Practices Act* (FRPA) standards.

Landslide Activity

Landslides are a natural process on steep terrain, and occur over time at a natural rate. Forest practices can accelerate this natural rate through road construction and logging on unstable or potentially unstable terrain.

The alteration of natural drainage patterns through road building can lead to unusual concentrations of water on hillslopes, road fillslopes, and road beds, leading to a higher likelihood of landsliding. Timber harvesting can alter slope hydrology. Removal of forest cover results in a reduction of transpiration and interception losses, leading to increased soil saturation, subsurface flow, and surface runoff. In addition, when trees are harvested, the roots of the stumps decay and begin to lose their soil binding strength, reducing their reinforcing capacity. This makes slopes more susceptible to landsliding until new growth re-establishes deep root systems.

The harvesting method can also lead to slope instability. Log yarding can disrupt natural pathways for water drainage, and create new pathways. Yarding logs across slopes and using heavy machinery can damage the soil surface and the roots that help hold the soil.

FRPA requires that logging not cause landslides, adverse gully processes, or fan destabilization. The frequency of landsliding from logged terrain has been reduced by identifying and avoiding harvesting on unstable slopes, and by applying mitigation measures that promote stability on harvested slopes.

Changes to Riparian Zone

The riparian area, or land adjacent to the high water line in watercourses and standing bodies of water, is important to stream ecosystems and stream morphology. Riparian areas help maintain water quality by controlling sedimentation, supplying nutrients and large woody debris, and maintaining stream channel morphology. Excessive harvesting within riparian areas can destabilize stream banks, increase bank erosion and stream sedimentation, diminish the supply of woody debris to the channel, and increase the size of sediment wedges of some stream reaches.

Changes to Stream Channel Pattern

Analysis of stream channel patterns can indicate that changes to sediment supply, riparian vegetation, or peak flow indices may have influenced a watershed because these variables influence changes to stream channel pattern. For instance, increased flooding can lead to increased bank erosion or overbank deposition as well as changes in bed material texture. Increased sediment supply can result in increased sediment deposition in-channel and a consequent widening of the channel or changes in the texture and composition of channel bedforms. Changes to riparian vegetation can change coarse woody debris inputs to the channel, altering the frequency and size of logjams as well as the bed texture.