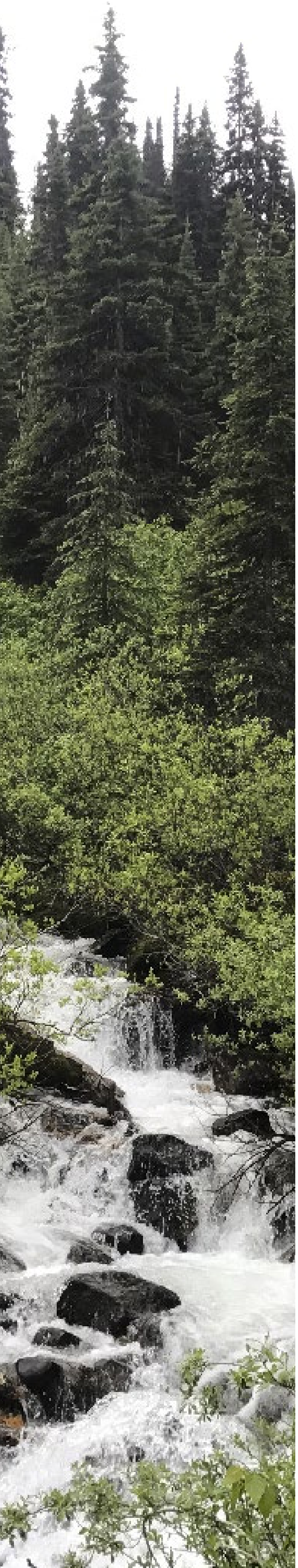


BC TIMBER SALES CHINOOK BUSINESS AREA

MT. ELPHINSTONE SOUTH WATERSHED ASSESSMENT: PHASES 1 & 2 (VOLUME 1)

Polar File: 740102
DRAFT REPORT
MARCH 2023

CONFIDENTIALITY AND © COPYRIGHT

This document is for the sole use of His Majesty the King in the Right of the Province of British Columbia as represented by the Ministry of Forests (the Province). The document contains proprietary and confidential information that shall not be reproduced in any manner or disclosed to or discussed with any other parties without the express written permission of the Province. Information in this document is to be considered the property of Province in accordance with Canadian copyright law. This report was prepared by Polar Geoscience Ltd. for the account of BC Timber Sales, Chinook Business Area. The material in it reflects Polar Geoscience Ltd.'s best judgement, in the light of the information available to it, at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Polar Geoscience Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

STATEMENT OF LIMITATIONS

This report incorporates and is subject to the following general conditions:

1. Use of report: This report pertains to a specific location or area and a specific scope of work. It is not applicable to any other locations nor should it be relied upon for types of development other than to which it refers.
2. Soil, surficial material and/or rock descriptions: Classification and identification of soils, surficial materials, and rocks are based upon commonly accepted methods employed in geoscience practice. This report relies work conducted as a part of previous investigations of subject area. The present report represents the current information available; it is valid for the condition of the study area as of the date of the information, verified by observations on the date of the associated field review. If further information or observations become available, the interpretations and conclusions contained within this report may require updating. Polar does not warrant conditions represented herein as exact but infers accuracy only to the extent that is common in geoscience practice.
3. Surface water and groundwater conditions: Surface water and groundwater conditions that are mentioned in this report are those observed or inferred at the times recorded in the report. These conditions vary with location, time, development activity, and in response to local meteorological conditions. Interpretation of water conditions from observations and records is judgmental and constitutes an evaluation of circumstances as influenced by geology, meteorology, and development activity. Deviations from these observations may occur during the course of development activities. Where surface water or groundwater conditions encountered during development are different from those described in this report, qualified professional(s) should revisit the site and review recommendations in light of actual conditions encountered.
4. Standard of care: Services performed by Polar for this report have been conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this report. No warranty or guarantee, express or implied, is made concerning the results, comments, recommendations, or any other portion of this report.
5. Environmental and regulatory issues: Unless stipulated in the report, Polar has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development at the subject location.
6. Implementation reviews: This report provides input to BC Timber Sales Forest Professionals as part of their Watershed Risk Management Framework. Unless indicated otherwise, Polar has not been requested to, nor is responsible for, implementation (field) reviews following submission of this report to confirm whether any or all recommendations outlined in this report are effectively implemented.

HARDCOPIES

Several pages of this report have been formatted for tabloid (11 x 17) sized paper. If hardcopies are desired, we recommend that all pages be printed "actual size". If tabloid pages are reduced to fit smaller format paper, the presented information may be illegible.

SUGGESTED CITATION

Polar Geoscience Ltd. (Polar). 2023. Mt. Elphinstone South Watershed Assessment: Phases 1 & 2. Prepared for BC Timber Sales, Chinook Business Area. Polar File No. 740102.

polargeoscience ltd.
1005 Balsam Place
Squamish, BC, V8B 0W1
(604) 815-4548
www.pgeo.ca

March 7, 2023
Polar File: 740201
BCTS File: 10005-40/PD21TBF001

Mr. Pierre Aubin, RPF
Practices Forester
BC Timber Sales, Chinook Business Area
7077 Duncan Street
Powell River, BC, V8A 1W1

Dear Mr. Aubin:

Re: **MT. ELPHINSTONE SOUTH WATERSHED ASSESSMENT: PHASES 1 & 2, DRAFT REPORT**

Polar Geoscience Ltd. (Polar) is pleased to provide this draft report on the above-noted study. The report summarizes our key findings and provides recommendations to mitigate potential adverse hydrologic effects from future forest development in the Mt. Elphinstone South assessment area. Please contact me if you have any questions.

Polar Geoscience Ltd.

Robbie Johnson, BSc, MASc, GIT
Project Hydrologist

Lars Uunila, MSc, PGeo (BC), PGeol (AB), PH, CPESC, CAN-CISEC, BC-CESCL
Senior Hydrologist & Geoscientist

Engineers and Geoscientists BC
Permit to Practice: ___________

WATERSHED OR HYDROLOGIC ASSESSMENT ASSURANCE STATEMENT: REGISTERED PROFESSIONALS

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 (Joint Practices Board, 2020) and is to be provided for watershed assessments or hydrologic assessments when requested by a client.

Client: Mr. Pierre Aubin, RPF
Practices Forester
BC Timber Sales, Chinook Business Area
7077 Duncan Street
Powell River, BC V8A 1W1

Date: March 7, 2023

With reference to the following assessment area: Mt. Elphinstone South

The undersigned hereby gives assurance that he/she is a Registered Professional:

Name	**Professional designation/associations:**
Lars Uunila	• Professional Geoscientist (P.Geo.), *Engineers & Geoscientists British Columbia* • Professional Geologist (P.Geol.), *Association of Professional Engineers and Geoscientists of Alberta* • Professional Hydrologist (P.H.), *American Institute of Hydrology* • Certified Professional in Erosion & Sediment Control (CPESC), *Envirocert International, Inc.* • Canadian Certified Inspector of Sediment & Erosion Control (CAN-CISEC), *CISEC, Inc.* • BC Certified Erosion and Sediment Control Lead (BC-CESCL), *Erosion & Sediment Control Association of BC* • Member, Canadian Water Resources Association

I/we have signed, sealed and dated the attached ☒ **watershed assessment report**, or ☐ **hydrologic assessment report** in general accordance with the Joint Professional Practices Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector (Engineers and Geoscientists British Columbia and Association of British Columbia Forest Professionals, 2020) and the scope of work in Section 3.0 of that document.

Signature & seal:

EXECUTIVE SUMMARY

BC Timber Sales (BCTS), Chinook Business Area (TCH) is planning forest development within its Crown land tenure in the southern portion of the Elphinstone operating area on the southern slopes of Mt. Elphinstone near Gibsons, BC. This area lies within the catchments of eight streams (hereafter referred to as the assessment area). From east to west, these include: Chaster Creek, End/Walker Creek, Smales Creek[1], Higgs Brook, Slater Creek, Molyneux Creek, Joe Smith Creek and Clough Creek[2]. Although BCTS' Forest Stewardship Plan (FSP #672) does not have watershed assessment requirements for this area, multiple downstream values have been identified and both local government and the public have expressed concern over these values. As such, a multi-phased watershed assessment was initiated by BCTS beginning in summer 2020. The principal objectives of the assessment are to review the current conditions within each of the assessment watersheds, identify the potential hydrogeomorphic hazards and risks from future forest development within BCTS' Chart on downslope watershed values, and provide risk management options to reduce, mitigate or avoid such risks within the context of the projected effects of climate change. It is important to recognize that the scope of the assessment is intended to provide BCTS with watershed-level guidance on how to proceed with forest development planning in order to minimize hydrogeomorphic risks; it does not review site-specific forest development plans. Such plans are the focus of subsequent assessments.

Within the assessment watersheds, the following downslope/downstream potential elements-at-risk were identified: human safety, private property, transportation infrastructure, utilities, water rights & use, and fish and fish habitat. Peak flows, low flows, aquifer recharge, sediment yields, channel destabilization, and water contamination by pollutants are the principal hazards under review. Based on the characteristics of the assessment watersheds and the research literature, the likelihood of the above-noted hazards under current levels of forest development (or disturbance) are provided. In order to minimize incremental increases in the above-noted hazards with future forest development, a number of recommendations have been identified for BCTS' consideration. These include recommendations on opening size, retention and overall extent of harvesting (i.e., equivalent clearcut area) to minimize risk which incorporate a degree of conservatism beyond what previous assessments have identified in the assessment area. This is considered prudent within the context of climate change and the values present downstream. Recommendations are also identified to minimize sediment and riparian risks, which along with hydrologic risks, are intended to minimize risks on stream channels and the values present.

---

[1] Also locally known as Elmer Creek.

[2] Also referred to as Clough Brook.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

1.1. BACKGROUND AND OBJECTIVES

BC Timber Sales (BCTS), Chinook Business Area (TCH) is planning forest development within its Crown land tenure in the southern portion of the Elphinstone operating area (also referred to as BCTS Chart) on the southern slopes of Mt. Elphinstone near Gibsons, BC (MAP 1). This area falls primarily within Sunshine Coast Regional District (SCRD) Electoral Areas D (Roberts Creek) and E (Elphinstone) as well as small portions of Areas F (West Howe Sound) and G (Gibsons) (FIGURE 1.1, MAP 1). It also lies within the catchments of eight streams (hereafter referred to as the assessment area). From east to west, these include: 1) Chaster Creek, 2) End/Walker Creek, 3) Smales Creek[3], 4) Higgs Brook, 5) Slater Creek, 6) Molyneux Creek, 7) Joe Smith Creek and 8) Clough Creek[4]. Prior to advancing forest development plans for the Elphinstone operating area, BCTS retained Polar Geoscience Ltd. (Polar) to conduct a watershed assessment of the eight streams.

The principal objectives of the watershed assessment are to review the conditions within each of the stream catchments, identify the watershed values[5] present and their sensitivity to disturbance, and analyze the potential hydrogeomorphic hazards (Section 3) and risks that forest development in the assessment area may pose to watershed values. Although a review of specific harvest plans is beyond the scope of this report, the assessment is intended to provide guidance and management options to reduce, mitigate or avoid risks as forest development planning advances.

This assessment consisted of Phase 1 in 2020-2021, and Phase 2 (2021-2022). This report summarizes both Phases 1 and 2 and provides findings and recommendations for consideration in BCTS' forest development planning process. A third phase of assessment involves site-level reviews of specific block and road plans, once confirmed.

---

[3] Also locally known as Elmer Creek.

[4] Also referred to as Clough Brook.

[5] Watershed values include the specific or collective set of natural resources and human developments in a watershed that have measurable or intrinsic worth. Values can include human life and bodily harm, aquatic and terrestrial habitat, and public and private property (including buildings, structures, lands, resources, recreational sites, transportation systems and corridors, utilities and utility corridors, water supplies for domestic, commercial, industrial, or agricultural use). Refer to Section 5 for further details.

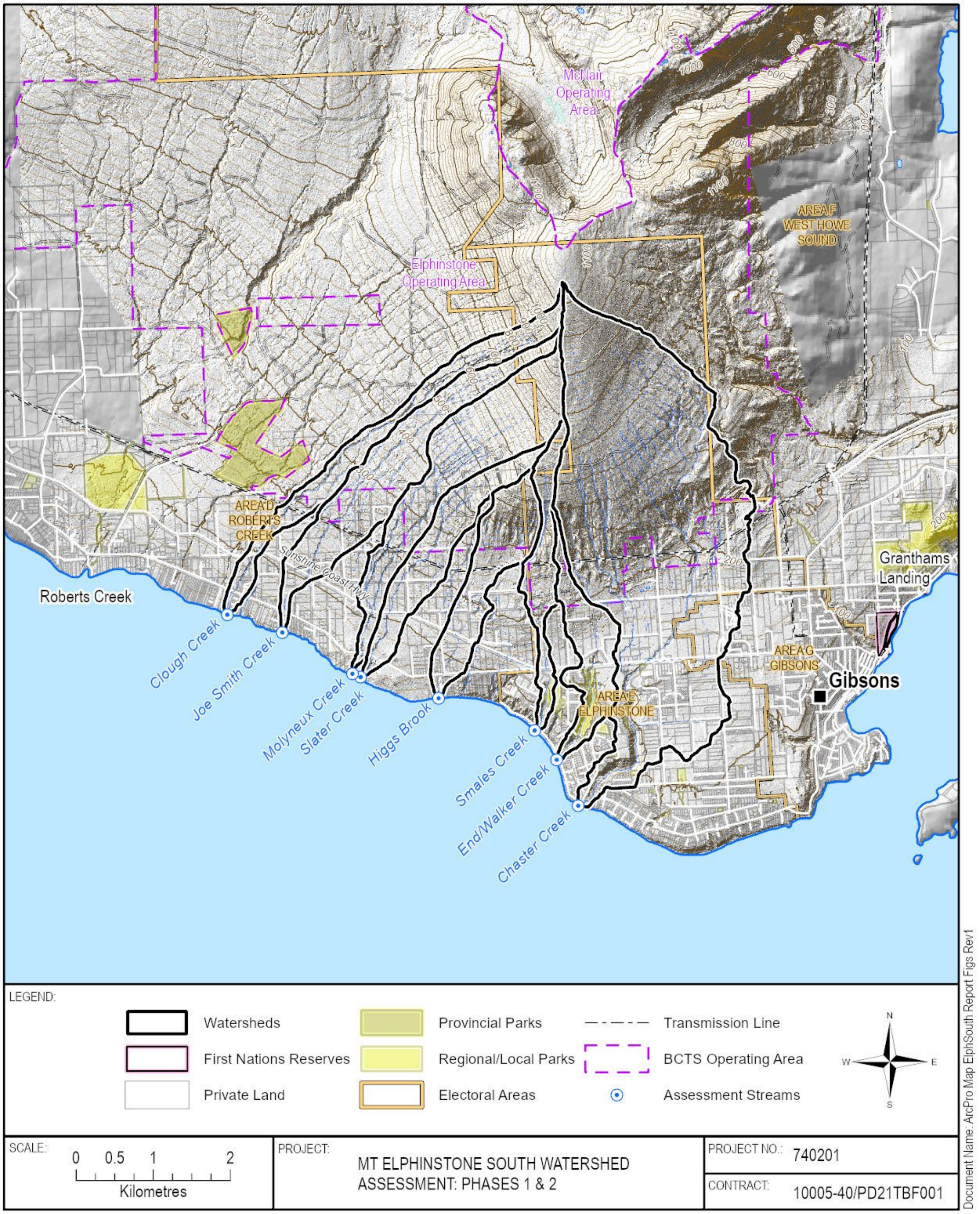


FIGURE 1.1 *Location of the assessment area comprised of eight stream catchments near Gibsons, BC. Refer to MAP 1 for additional detail.*

The general approach and the specific tasks completed to achieve the study objectives are outlined in Section 2. The approach aligns with BCTS' *Watershed Risk Management Framework (WRMF)* (Polar, 2022). The WRMF was developed to meet the current standards of professional practice as outlined in the *Joint Professional Practices Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector* (Engineers and Geoscientists British Columbia and Association of British Columbia Forest Professionals, 2020). These guidelines govern watershed assessments and management in BC through the *Forest and Range Practices Act*, the *Private Managed Forest Land Act*, the *Lands Act*, *Professional Governance Act* as well as bylaws of the Engineers and Geoscientists British Columbia (EGBC) and the Association of BC Forestry Professionals (ABCFP).

Under the *Joint Professional Practice Guidelines*, this report consists of watershed assessments of eight stream catchments in the Elphinstone operating area. These catchments fall within an urban-interface area with highly utilized groundwater resources along the lower slopes (MAP 1). As a result, the assessment considered potential forest development effects on both surface water and groundwater resources in the assessment area. However, this overview assessment is not a detailed groundwater investigation.

1.2. PLANNED DEVELOPMENT

BCTS is currently drafting plans for forest development in the assessment watersheds. These plans have not been confirmed and are contingent in part on the findings of this assessment. As such, analysis of hazards and risks associated with specific blocks or roads is beyond the scope of this report.

1.3. ASSESSMENT TEAM

The contract for this assessment was managed by Pierre Aubin, RPF, Practices Forester of BCTS TCH (Powell River) and Tom Johnson, RPF, Woodlands Manager of BCTS TCH (Chilliwack). Key members of the technical team included:

- Lars Uunila, MSc, PGeo, PGeol, PH, CPESC, CAN-CISEC, BC-CESCL (Senior Hydrologist & Geoscientist of Polar) served as Project Manager and Lead Author;
- Robbie Johnson, MASc, GIT (Hydrologist) served as Project Hydrologist and Contributing Author;
- Derek Brzoza, AScT (Senior Hydrologic Technician) served as Field Technician;
- Russell Thorsteinsson, RPF of Forsite Consultants Ltd.[6] served as Field Technician;

---

[6] Currently with the Canadian Forest Service.

- Jeremy Hachey, RPF (Forest Analyst of Forsite Consultants Ltd.) provided spatial data analysis and supported the operational-level hydrologic recovery modelling; and
- Dr. William Floyd, PhD, RPF, Research Hydrologist for the Coast Area Research Section, BC Ministry of Forestry, served as an External Reviewer of the assessment report.

All comments from reviews are greatly appreciated and were taken into consideration in preparation of this report. However, all analyses and conclusions remain the sole responsibility of the authors.

2. RISK ASSESSMENT METHODOLOGY

2.1. RISK ASSESSMENT FRAMEWORK

This section highlights the key components of the assessment. Watershed assessments generally characterize a watershed, identify past impacts (both natural and development-related), current condition (i.e., sensitivity), and any drivers of its future state (e.g., climate or land use change). Within this context, the first two steps of a risk assessment are performed to understand the potential impacts of forest development. Risk assessment refers to the overall step-by-step process of: 1) risk identification, 2) risk analysis, and 3) risk evaluation.

In the first step, risk identification, potential sources of risk and their consequences are identified and characterized. During the second step, the level of risk associated with one or more watershed processes or events is described either qualitatively or quantitatively based on an evaluation of the likelihood of occurrence and the severity of the consequences. The third step of a risk assessment is the responsibility of forest managers (i.e., BCTS forest professionals) and involves risk evaluation. In this step, the results of the risk analysis are compared against the organization's risk tolerance criteria. This step weighs the anticipated outcomes of forest development against the identified risks, and risk treatment measures available, to determine if they are acceptable, tolerable, or unacceptable.

2.2. RISK ANALYSIS

Since 2020, a standardized approach has been mandated for assessing hydrologic and geomorphic risks in watersheds in BC (Engineers and Geoscientists BC and ABCFP, 2020). The methodology and terminology used in this report are consistent with Engineers and Geoscientists BC and ABCFP (2020). As outlined by Engineers and Geoscientists BC and ABCFP (2020), the term "risk" is defined as *the chance of injury or loss, expressed as a combination of the consequence of an event and the associated likelihood of occurrence*. In this case, an "event" may be a hydrologic or geomorphic (i.e., hydrogeomorphic) process such as a landslide, debris flow, debris flood or flood, that has a potential for causing harm in terms of human injury, damage to property, the environment, quality of life, or other value. A harmful event may also be associated with watershed processes that result in an insufficient water supply or degradation in quality of water relied upon by humans and/or aquatic organisms.

Consequence refers to the likelihood of damage or losses to some value in the event of a specific hazardous event. Consequences can be expressed qualitatively (i.e., using a defined rating scheme) or quantitatively (e.g., by estimating the cost of damage). Analysis of consequence includes evaluation of the spatial and temporal exposure (i.e., is the element at a location and at a time when it could be affected by the hazard?) as well as the vulnerability of the value deemed to be at risk (i.e., element-at-risk).

The general risk framework adopted from Wise et al. (2004) is summarized as:

$$\mathbf{R(S) = P(H) \times [P(S{:}H) \times P(T{:}S)] \times V(L{:}T)} \qquad \text{[Equation 2.1]}$$

Where:

R(S) = Specific risk to a specific element from a specific event.

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

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

> **P(S:H)** = probability of a spatial effect of the specific event on the specific element if the event occurs (e.g., the probability of the specific landslide reaching or otherwise affecting the specific element at risk).
>
> **P(T:S)** = probability of temporal effect of the specific event on the specific element, given a spatial effect (e.g., the probability of the specific element occupying that location when the landslide occurs).
>
> **V(L:T)** = vulnerability of the element, given a temporal effect. This accounts for the probability of loss of life or the proportion of loss, or damage to, property, the environment or other things of value.

Based on the information requirements of BCTS, this hydrologic assessment utilizes a qualitative partial risk[7] analysis approach. Partial Risk Analysis considers the effects of a specific hazard on a specific element, but it does not explicitly evaluate the vulnerability of the element **[V(L:T)]**. Such an evaluation is beyond the scope of this assessment, and requires obtaining detailed information on the elements at risk. Therefore, we have conservatively assumed that **V(L:T)** = 1, meaning that if an element is affected by an event, total loss will occur. The Partial Risk Analysis is summarized by Equation 2.2.

$$\mathbf{P(HA) = P(H) \times [P(S{:}H) \times P(T{:}S)]} \qquad \text{[Equation 2.2]}$$

Where:

P(HA) = P(Hazardous and Affecting Event) = probability of occurrence of a specific hazardous event and that event affecting a specific element.

---

[7] Partial risk refers to the likelihood of occurrence of a hazardous event and the likelihood of it affecting the site occupied by a specific element. Partial risk analysis is often used when it is sufficient to know whether or not a hazardous event or change to watershed process will reach or affect a watershed value. The extent of harm to the value of interest (i.e., vulnerability) is not investigated. A partial risk analysis is often the first level of investigation by a Specialist since the vulnerability of specific values (e.g., water supply infrastructure, fish and fish habitat, etc.) often requires assessments by other Specialists (e.g., engineers, biologists, foresters, etc.) who tend to have greater knowledge of the elements-at-risk.

For a stationary specific element at risk, **P(T:S)** = 1, therefore **[P(S:H) x P(T:S)] = P(S:H)**. If it is certain a specific event will reach or affect a stationary specific element at risk, then **[P(S:H) x P(T:S)]** = 1, and Equation 2.2 is reduced to **P(HA) = P(H)**. In this case, Equation 2.1 is also reduced to **R(S) = P(HA) = P(H)**. However, in the case where there is some uncertainty that a specific event will reach or affect a specific stationary element at risk, P(S:H) < 1. Therefore Equation 2.2 is reduced to:

$$\mathbf{R(S) = P(HA) = P(H) \times P(S{:}H)} \qquad \text{[Equation 2.3]}$$

Since all elements at risk in this study are associated with the stream network (which is stationary), we have assumed throughout the risk analysis that P(T:S) = 1. Therefore, P(HA) and R(S) were evaluated based Equation 2.3 and assigned relative ratings that vary depending on the element at risk. Furthermore, the following scenarios are normally considered: 1) the current state; 2) the projected future state due to climate change; 3) the projected future state following forest development; and 4) the projected future state due to climate change and future forest development[8]. In this case, without block-specific harvest plans the latter two scenarios are not explicitly assessed; nevertheless, an effort is made to provide context on the anticipated risks under these scenarios (i.e., describe under what circumstances risks may increase or decrease).

The likelihood of hazard occurrence under each scenario is assigned qualitative ratings from very low to very high (TABLE 2.1). These ratings are associated with expected annual probabilities of occurrence, Pa (i.e., likelihood of hazard in a single year), or probabilities over a given period, Px[9]. For this assessment, the range in probabilities assigned to each hazard rating is based on the BCTS Watershed Risk Management Framework (Polar, 2022). It is the responsibility of the forest manager (i.e., BCTS) to understand and accept the rating definitions used herein as they are not set by any regulatory or professional body.

The level of risk under each of the scenarios noted above takes into account the likelihood of hazard occurrence and the likelihood of it affecting the location occupied by a specific element-at-risk. The latter is ranked qualitatively as:

- **High**: it is probable that the hazard will adversely affect the element-at-risk;
- **Moderate**: it is possible that the hazard will adversely affect the element-at-risk; or
- **Low**: it is unlikely that the hazard will adversely affect the element-at-risk.

---

[8] In each case, the potential reduction in risk as a result of the implementation of control measures or other hazard mitigation is also considered.

[9] The probability of occurrence over a specified number of years (Px) is based on (Wise et al., 2004) as follows:

$$Px = 1 - (1-Pa)^x$$

where,

Px = Probability of at least one event over the specified number of years
Pa = Annual probability of occurrence
x = Number of years

For each hazard, risks are assigned based on the qualitative partial risk matrix presented in TABLE 2.2.

TABLE 2.1 *Definitions used for likelihood of hazard occurrence (from Polar, 2022).*

Rating for likelihood of hazard occurrence	**Description**	**Range of annual probabilities of occurrence, Pa**		**Range of probabilities of occurrence over a 10-year period, P_{10}**		**Range of probabilities of occurrence over a 20-year period, P_{20}**	
		(decimal)	**(%)**	**(decimal)**	**(%)**	**(decimal)**	**(%)**
Very high	**Imminent**, the event or sustained change to the watershed process would almost certainly occur.	>0.10	>10%	>0.65	>65%	>0.88	>88%
High	**Likely**; the event or sustained change to watershed process will probably occur.	0.01-0.10	1.0%-10%	0.096-0.65	9.6%-65%	0.18-0.88	18%-88%
Moderate	**Possible**; the event or sustained change to watershed process could occur.	0.001-0.01	0.10%-1.0%	0.010-0.096	1.0%-9.6%	0.02-0.18	2.0%-18%
Low	**Unlikely**; the event or sustained change to watershed process might occur.	0.0002-0.001	0.02%-0.10%	0.002-0.01	0.20%-1.0%	0.004-0.02	0.40%-2.0%
Very low	**Remote**, the event or sustained change to watershed process is only a remote possibility.	<0.0002	<0.02%	<0.002	<0.20%	<0.004	<0.40%

TABLE 2.2 *Qualitative partial risk matrix.*

		Likelihood of hazard occurrence				
	Partial Risk ↘	**Very high**	**High**	**Moderate**	**Low**	**Very low**
Likelihood of hazard affecting the location occupied by a specific element-at-risk	**High**	Very high	Very high	High	Moderate	Low
	Moderate	Very high	High	Moderate	Low	Very low
	Low	High	Moderate	Low	Very Low	Very low

As a last step, the potential reduction in partial risk following implementation of risk control measures is evaluated and reported.

2.3. KEY TASKS

This watershed assessment combines an office-review with the findings of ground-based reviews. In Phase 1, the key objectives were to:

1. Identify the principal streams and their respective catchments (i.e., the assessment watersheds) where forest development is being considered;
2. Characterize the assessment watersheds;
3. Identify watershed values along each main stream in the assessment area (i.e., potential elements-at-risk);
4. Identify potential hydrogeomorphic risks[10] posed by future forest development in the assessment area;
5. Provide preliminary recommendations to BCTS to avoid, minimize or mitigate hazards and risks during the forest development planning process.

In order to meet the Phase 1 objectives, the following tasks were conducted:

1. Compilation and review of background reports and information. This included, but was not limited to, the following consulting reports: Waterline (2013), Madrone (2015), and Statlu (2018);
2. Compilation and review of GIS/mapping information, including high-resolution LiDAR data[11], which was used to characterize the topography, identify streams, refine drainage areas[12] and estimate tree heights.
3. Operational-level (i.e., detailed) hydrologic recovery (i.e., ECA) modelling. Based on recommendations from Dr. William Floyd, PhD, Research Hydrologist for the Coast area Research Section within the BC Ministry of Forestry, ECAs were calculated using an

---

[10] An evaluation of water quality parameters such as Nitrate, Phosphorous or pH levels was considered beyond the scope of this assessment.

[11] LiDAR data for the assessment area was sourced from the Province of BC and Sunshine Coast Regional District (SCRD).

[12] Stream alignments and drainage areas presented on legacy base mapping were inaccurate in several locations and are a potential source of confusion when referencing previous studies. In addition, there are inconsistencies with stream names. For example, Madrone (2015) refers to Joe Smith Creek at the location where Sunshine Coast Regional District mapping and Provincial water licence database identifies Molyneux Creek; we have adopted the latter naming convention for this report. An effort was made in this assessment to utilize LiDAR data to properly identify streams and their drainage areas. Nevertheless, there may be some inaccuracies given the complex drainage patterns in urbanized areas (MAP 1). One example of altered drainage patterns exists along Smales (also known as Elmer) Creek near the Sunshine Coast Highway (101). At the highway, flows from Smales Creek are conveyed largely to the east along 500 m of highway ditch to McComb Brook, a tributary of End/Walker Creek. Some portion of Smales Creek runoff also appears to be conveyed westward along the highway ditch system towards Whittaker Creek, where it may have contributed to the Whittaker Creek washout on February 1, 2020.

adapted approach from Hudson and Horel (2007) (William Floyd, pers comms., 2023). Rather than stratifying the assessment area into elevation bands based on the dominant runoff-generating process, as proposed in Hudson and Horel (2007), Dr. Floyd suggests applying a single rain-on-snow hydrologic recovery curve across all elevations. The rationale being that rain-on-snow can occur across all elevations, and is often responsible for producing some of the largest peak flows. As such, mitigating the potential effect of forest harvest on peak flows should be targeted towards mitigating effects on the dominant ***flood***-generating process rather than the dominant ***runoff***-generating process. ECAs were calculated for overall watershed area, as well as above points-of-interest (POIs) within each of the assessment watersheds. The principal inputs to the ECA model are median forest canopy heights projected on an annual basis for 2021-2071 (i.e., 50 years) using provincial tree growth modelling (i.e., SiteTools). The data used in the analysis, and ECA assumptions and methodology are provided in APPENDIX B.

4. Review of available digital imagery including 2018 Sunshine Coast Regional District Orthophotos, 2019 Planet Labs (Blackbridge) imagery, GoogleEarth and ESRI imagery of various years to 2021;
5. Review of available historical air photos obtained from the UBC Air Photo Library, including the years 1947, 1957, 1964, 1967, 1976, 1982, 1990, 1994, 1998, 2003 and 2005 (TABLE 2.3).
6. Ground-based review on August 24-27, 2020 was performed by Lars Uunila and Derek Brzoza of Polar. The Phase 1 review covered Crown land and publicly accessible areas in the assessment watersheds (FIGURE 2.1); and
7. Synthesis of information collected during Phase 1.

Phase 2 was initiated in Summer 2021. The goals of Phase 2 were to communicate with surface water licensees and stakeholders in the assessment watersheds and confirm stream channel conditions and the elements-at-risk. The key tasks in Phase 2 included:

1. Identification of property owners downstream of BCTS' Chart in the assessment watersheds, including those who hold water rights on the assessment streams;
2. Engagement by BC Timber Sales with property owners to request permission to enter their properties to access assessment streams and to meet on-site to discuss issues and concerns;
3. Ground-based review on July 12-16, 2021 was performed by Lars Uunila of Polar and Russell Thorsteinsson, RPF of Forsite Consultants Ltd. (FIGURE 2.1). The Phase 2 review focused on reviewing stream conditions and elements-at-risk along the lower portions of the assessment streams, and included several on-site meetings with property owners to gain further insight on local water-related issues and concerns. APPENDIX C summarizes our notes on this review. APPENDIX E provides a catalogue of photographs along the assessment streams.

4. Synthesis of information collected during Phase 2; and
5. Preparation of the Phase 1 and 2 report.

TABLE 2.3 *List of historical air photos reviewed by year (roughly organized north to south and west to east):*

Year	Flight Line	Photos
1947	BC349	112-110
	BC349	96-102
	BC349	11-7
1957	BC2392	21-19
	BC2392	98-103
	BC2393	21-14
	BC2099	59-50
	BC2099	21-29
1964	BC5102	74-76
	BC5102	37-32
	BC5102	26-29
1967	BC4426	247-249
	BC4427	42-47
	BC4427	63-57
	BC4427	73-79
	BC4427	265-260
	BC4427	88-86
1976	BC5758	270-268
	BC5758	256-259
	BC5758	237-233
	BC5758	222-227
	BC5758	219-217
1982	BC82003	86-88
	BC82003	93-91
	BC82003	55-59
	BC82003	14-10
	BC82002	242-248
	BC82002	237-231
	BC82002	216-218
1990	BCB90014	149-150
	BCB90014	173-170
	BCB90014	212-217
	BCB90014	236-230
	BCB90045	13-6
	BCB90045	42-35
	BCB90045	46-48
1994	BCC94151	47-50
	BCC94151	17-10
	BCC94145	130-138
	BCC94145	102-91
	BCC94145	67-79
	BCC94145	43-32
	BCC94145	11-22
1998	BCB98008	190-191
	BCB98008	209-205
	BCB98008	225-230
	BCB98007	223-229
	BCB98007	246-239
	BCB98008	245-240
	BCB98007	252-254
2003 & 2005	BCC03039	70-68
	BCC03039	20-25
	BCC05026	156-150
	BCC05026	178-185
	BCC05143	181-174
	BCC05143	182-185

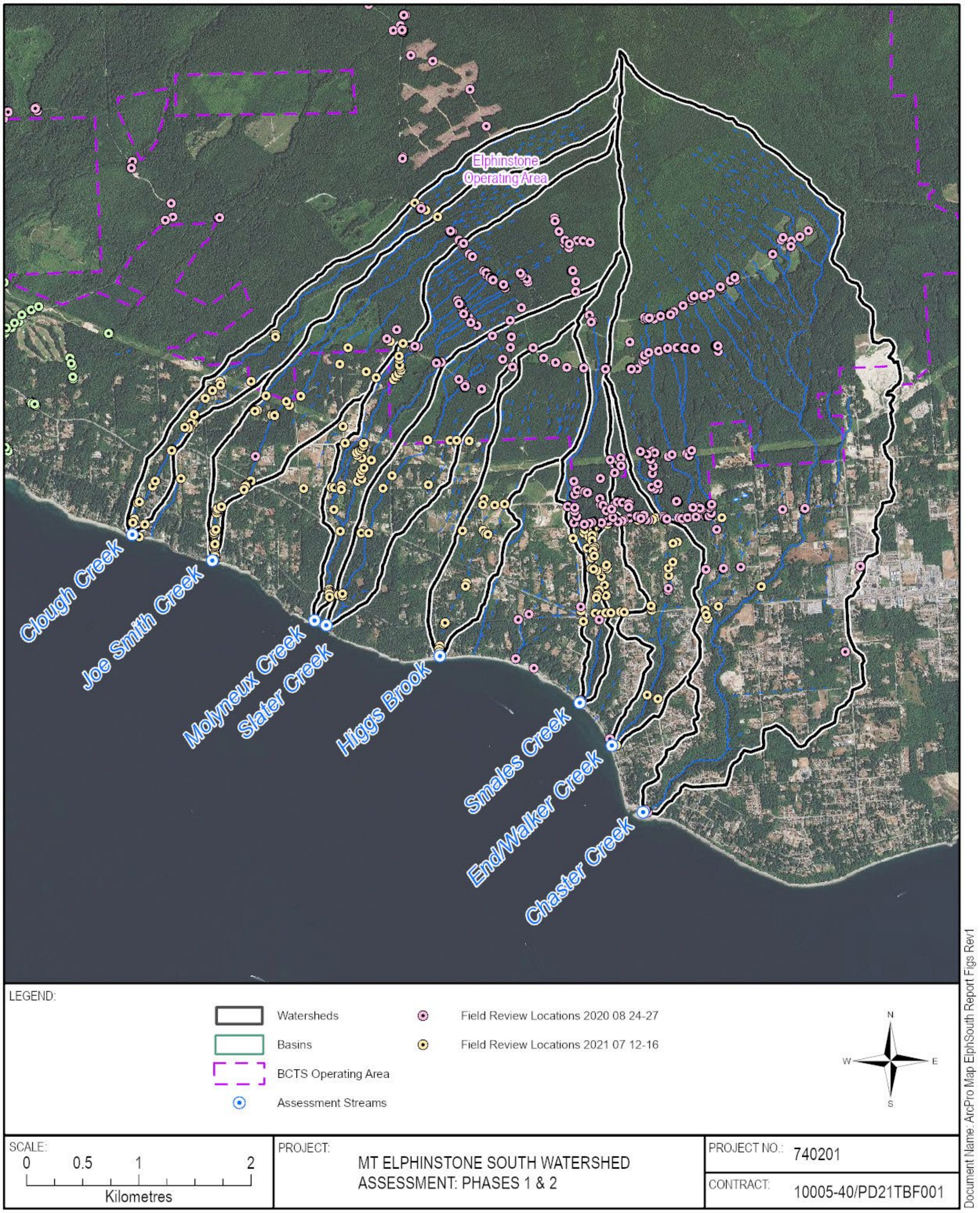


FIGURE 2.1 *Locations reviewed during the Phase 1 field review on August 24-27, 2020 and Phase 2 field review on July 12-16, 2021.*

3. OVERVIEW OF HAZARDS

As noted above, hydrogeomorphic hazards may be associated with sustained changes to watershed processes or conditions (Green, 2005). However, these do not in themselves present risks until they are identified as having the potential to harm specific value(s). The watershed processes or characteristics typically of concern are outlined below. The following section is intended as background on the types of hydrogeomorphic hazards that are typically reviewed in watershed assessments. Details on the current state of the science on these topics are provided. This data is in large part taken from literature from the Pacific Northwest and is generally applicable to the assessment area.

3.1. STREAMFLOW REGIME

The collective timing and volume of water that flows in a stream is considered its flow regime. Changes to a stream's flow regime can affect downstream ecosystems, private land, and infrastructure that is vulnerable to damage from floods or high water (Poff et al., 1997; PCIC, 2017). Stream systems in British Columbia are often broadly classified into pluvial[13], nival[14], or hybrid[15] hydrological regimes (Trubilowicz and Moore, 2017; Winkler et al., 2010b).

In assessing the streamflow regime, the focus is on identifying the likelihood and/or degree to which the baseline (or, pre-disturbance) hydrologic regime[16] (e.g., peak flow and/or low flow magnitude and frequency) has changed in response to watershed disturbance (e.g., timber harvesting, road building and/or other land use). Increases in peak flow magnitude and/or frequency, for example, can affect channel stability and channel destabilization can in turn result in increased sediment impacts, which may affect downstream elements-at-risk (depending on the sensitivity of those elements).

Runoff Generation Potential

The potential for a change in the streamflow regime is derived through consideration of runoff generation potential (RGP). Runoff generation potential (RGP), also referred to as flood response potential (Green, 2005), describes the propensity or rate at which precipitation and/or snowmelt

---

[13] Pluvial refers to rainfall-dominated streamflow typical of lower elevation coastal watersheds.

[14] Nival refers to snowmelt-dominated streamflow typical of coastal high elevation or interior watersheds that are snow-covered for much of the winter.

[15] Hybrid refers to a mixed system where both rainstorm and snowmelt process regularly affect peak flows, which can occur throughout the winter or spring.

[16] The baseline (or pre-disturbance) hydrologic regime refers to conditions under mature/old growth forest. It may include projected effects of climate change if long-term risks are being analyzed.

are converted to surface runoff and ultimately streamflow within a given spatial area of interest (i.e., drainage area or catchment). A high runoff generation potential corresponds to a relatively rapid runoff generation, whereas a low runoff generation potential corresponds to relatively lower rates of runoff generation. Physical characteristics that affect runoff generation include, but are not limited to, vegetation (e.g., forest type), soil type, geology, stream density, presence of lakes and wetlands, surface water and groundwater interaction, and physiography.

Meteorological factors affecting RGP include the type of precipitation; rainfall/snowmelt intensity, amount and duration; distribution of rainfall over the stream catchment, antecedent precipitation (as rain and as snow stored on the ground), and melt factors such as wind, humidity, radiation and temperature, and other conditions that affect evapotranspiration such as temperature, wind, relative humidity and season.

In coastal watersheds, such as the assessment area, the mechanism of runoff generation varies by elevation. In general, rainfall is the dominant runoff mechanism at lower elevations; however, rainfall can occur across all elevations. A transient snow zone exists at mid-elevations (i.e., from approximately 300 to 1,200 m) where snow is limited in extent and may melt more than once each winter. In this zone, runoff is typically generated either from rain or from rain-on-snow. Above approximately 1,200 m the snowpack is seasonal, where snow accumulation and melt are the dominant hydrologic process, although rain-on-snow can still occur. However, there are effectively no areas above 1,200 m in the assessment area. In terms of peak flows, rain-on-snow is considered the dominant peak flow generation mechanism in the assessment area. This is in large part due to the possibility for rain to occur across all elevations, and for snow to be present, on occasion, down to sea level. These events are often responsible for producing some of the largest peak flows. Assuming the presence of a snowpack, rain-on-snow runoff is often most severe when warm temperatures, strong winds, and intense rainfall, potentially associated with an atmospheric river (AR), coincide. As elevation increases, there is a greater probability there will be snow on the ground when it rains.

Physiographic factors that influence RGP include slope aspect, slope gradient and elevation. While elevation is generally a factor in snow accumulation and the volume of water available for runoff, the energy balance at the stand level influences the rate of snowmelt contributions to runoff. Hillslope gradient and hillslope aspect, collectively known as topographic exposure, are important factors controlling insolation (i.e., solar radiation at the ground surface) and thus net radiation available for snowmelt. In general, for snowmelt-dominated regimes, south aspects are more likely to see earlier and more rapid snowmelt (and runoff) than north aspects. Differences in solar radiation across aspect plays a lesser role in snowmelt during rain-on-snow events; however, given the typically deeper and longer lasting snowpack on northern aspects[17], there is

---

[17] This issue is not widespread in the assessment area given the absence of north aspects.

an increased probability for rain-on-snow on north-facing slopes. Topographic exposure does, however, play an important role during rain-on-snow events in controlling wind and wind-driven rain, whereby more rapid snowmelt rates can be expected on windward aspects.

There are many processes and events that can affect the water balance at the site-level and the flow regime at the watershed-level. The presence of forests controls several hydrological processes. The forest canopy intercepts a portion of rain or snow preventing it from reaching the ground. Some of this intercepted precipitation may evaporate or sublimate depending on weather and atmospheric conditions (e.g., temperature, solar radiation, humidity and wind speed). Given the moist climate (i.e., high humidity) of the assessment area, intercepted snow losses via sublimation are expected to be minimal, whereas meltwater drip from the canopy to the forest floor is expected to account for the greatest loss of intercepted snow (Storck et al., 2002). This is particularly the case at low and mid-elevations where winter temperatures hover above and below freezing.

If the precipitation is in the form of snow, once it reaches the ground, it may accumulate, sublimate to the atmosphere, or melt. Melt water and precipitation in the form of rain that reaches the ground may evaporate near the soil surface or be drawn up through the soil by trees and vegetation to be subsequently released through transpiration. The collective process of evaporation and transpiration is termed evapotranspiration. The remaining liquid water may infiltrate into the soil depending on antecedent soil moisture conditions, with any excess water moving downslope through surficial soils as shallow groundwater flow, eventually feeding streams or entering a deeper groundwater system. Runoff on the surface of forest floors is rare due to high soil porosity[18]. Exceptions to this can occur if soils are compacted by heavy equipment (e.g., along roads and trails) (Wondzell and King, 2003); however, such effects generally make up a small proportion of the watershed area and are localized[19].

The effects of forestry on the key hydrological processes and the flow regime of streams have been studied extensively in watersheds in BC, the Pacific Northwest, and elsewhere in North America. While the research results vary, there is general consensus that the removal of forest cover typically increases the amount moisture at the site-level, often resulting in increased annual water yields at the watershed scale. The effect of harvesting on peak and low flows, however, is more nuanced. The following sections provide a brief review on how forest harvesting in areas similar

---

[18] Dunnean, or saturation-excess overland flow, can occur when groundwater levels rise to the surface; however, Hortonian, or infiltration-excess overland flow is uncommon on undisturbed forest floors.

[19] It is important to recognize that avoidance of such impacts is a BCTS management objective as stated under Section 4.2.1 (Soils) of BCTS' Forest Stewardship Plan No, 672. https://www.for.gov.bc.ca/ftp/TCH/external/!publish/FSP/PowellR/FSP/FSP%20Extension/BCTS%20SCNRD%20FSP%20672%20-%20Consolidated%20-%2020221021_draft.pdf

to the assessment watersheds can affect hydrological processes and how these in turn affect peak flows, low flows and aquifer recharge.

When logging occurs in forested watersheds, the hydrological processes (i.e., water balance) at the site-level changes, primarily due to altered interception of rain and snow, changes to Evapotranspiration (ET) and altered energy sources for snow melt. These changes in turn may induce changes to peak flows and low flows downstream. An increased magnitude or frequency of peak flows can affect sediment mobilization, water quality and stream channel stability. Changes in frequency and magnitude of low flows (especially during drought) may affect water supplies for human use as well as instream flows and water quality (e.g., water temperature) for fish.

RGP is influenced by forest cover disturbance, which may be a result of logging, insect infestation, and/or wildfire. These factors can be quantified by Equivalent Clearcut Area (ECA)[20]. Land use, including forestry, may affect runoff generation potential by affecting site-level water balance following deforestation or reforestation, by changing drainage patterns and rates of flow through road construction, and by affecting soil permeability along roads or areas trafficked by heavy equipment (i.e., soil compaction). Forestry effects are a function of several factors, including area harvested and recovered (i.e., ECA); size, shape and orientation of individual forest openings, silvicultural system (e.g., clearcut, selective harvest) and method of harvesting (e.g., ground, cable-based, or air).

When snowmelt is the dominant flood generating process, a greater emphasis is put on the level of disturbance above the snowline. In cases where rain or rain-on-snow is dominant, the overall level of disturbance or level of disturbance within the rain-on-snow or rain zone, respectively, may provide a better indication of RGP.

3.1.1. Effects of Forestry on Peak Flows

Peak flow refers to the maximum rate of discharge during a period of interest. It is of concern since its magnitude, frequency and duration can influence sediment mobilization, water quality (e.g., turbidity) and stream channel stability as well as pose hazards to property and infrastructure (e.g., water intakes and stream crossings). Typically, flows near or above “bankfull flow” are of interest as they are capable of mobilizing coarse-textured bedload (e.g., gravel, cobbles, boulders) along alluvial and semi-alluvial stream channels (Copeland et al., 2000). Bankfull flow usually occurs on

---

[20] Equivalent clearcut area (ECA) is a commonly used index of the extent of forest disturbance and regrowth in a watershed (Winkler et al., 2010b). The ECA of a clearcut is derived by reducing the total area cut by recovery, which is estimated from relationships between snow accumulation and melt or precipitation interception and crown closure (Winkler and Roach, 2005) or tree height (Hudson and Horel, 2007). The cumulative ECAs for all openings are summed to provide an ECA for the entire catchment (Winkler et al., 2010b).

average every 1.0 to 2.5 years (Grant et al., 2008), with 1.5 years being the representative average of many streams (Leopold, 1994).

Peak flow hazard refers to the likelihood and/or degree to which the baseline or pre-disturbance peak flow magnitude and frequency has or could change in response to watershed disturbance, specifically forest development (e.g., timber harvesting and road building); however, other land uses or natural disturbances that affect the forest land base are also considered. In simple terms, the peak flow hazard refers to the likelihood that flooding along a particular stream or stream reach will become measurably more severe or frequent under 1) current conditions, and then 2) following forest development or other disturbance, relative to baseline conditions. In the case of the assessment streams, baseline refers to mature/old growth conditions. Current conditions are not necessarily natural, but rather have been influenced by past forest disturbance in the upper portion of the watersheds and increased urbanization over many years in the lower elevations of the watersheds. Future conditions include the cumulative effects from historical disturbances and potential future development.

Changes in the energy balance[21] and snowmelt associated with the loss of forest cover has been found to be a dominant process responsible for increased peak flows in watersheds where snowmelt is a principal driver of runoff (Green and Alila, 2012), and may also be a factor in the timing and magnitude of low flows in summer. The change in net radiation following forest cover loss is positively related to the solar radiation received at the stand level. As such, snow depth in forest openings is generally greater than under forests, especially in the late fall and early winter. The removal of trees not only eliminates interception losses through evaporation and sublimation, but also eliminates transpiration losses[22]. Both result in a net increase in the proportion of precipitation (both rain and snow) that reaches the ground surface. In areas subject to rain-on-snow, meltwater drip from the canopy is one of the dominant processes responsible for creating the large difference in snowpack between forested and open areas (Storck et al., 2002). Forest openings are also exposed to much higher turbulent energy fluxes associated with wind. Such increased turbulent energy fluxes can result in significantly higher water inputs at the stand level during rain-on- snow events (Floyd, 2012; Marks et al., 1998; Marks et al., 2001).

Increased precipitation at the ground surface increases the net water available for infiltration[23] and ultimately streamflow at the watershed-scale. While this may be undesirable with respect to peak

---

[21] Loss of forest cover is associated with increases net radiation that is the result of the conversion from longwave-dominated snowmelt beneath the forest canopy to shortwave-dominated snowmelt in harvested areas (Green and Alila, 2012).

[22] These losses are reduced over time as forests are re-established and mature (i.e., hydrologically recover).

[23] Before precipitation can induce subsurface water movement, any saturation deficit must be replenished. Usually, the soil saturation deficit is greatest in early fall and largely disappears after the first fall storms (Madrone, 2015).

flows, it may be beneficial in increasing streamflow during low flow periods, assuming any net increases in runoff are effectively captured in storage (e.g., groundwater / aquifer storage) and are later released as baseflow.

Given the physical limits of a forest canopy's interception capacity, a smaller proportion of rainfall during a given storm will be intercepted from higher magnitude, intensity, and duration storms relative to storms of smaller magnitude, shorter duration and lower intensity. In other words, during smaller rainfall events, a forest canopy may be able to intercept a majority of the rainfall; however, once a canopy's interception capacity is exceeded, any additional rainfall inputs will reach the ground surface. Although, interception from the forest canopy may have little or no influence on large and extreme rainfall events, this does not necessarily translate to no influence on large peak flow events (described below).

Where precipitation falls as snow, the elimination of the forest canopy may promote a deeper snowpack, which represents an increase in the bulk volume of water available for melt. Snow that accumulates in forest openings is at relatively greater exposure to winds and solar radiation than in forested areas, the former factor being important in causing snowmelt during rain-on-snow events (Floyd, 2012). Therefore, during rain-on-snow events snowmelt is expected to be much greater in open areas relative to forested areas, particularly those areas subject to wind.

Synchronization of runoff within a catchment is directly related to peak flows, and is strongly associated to catchment-wide RGP and the natural or development-related factors that affect RGP. Synchronization occurs when forest disturbance (e.g., forest harvesting and road construction) alters the rate and timing of snowmelt or storm runoff at different locations within a watershed so that there is an increase in the amount of water that is conveyed to a stream over a given period. The synchronization of hydrological processes is commonly attributed to increases in the magnitude of peaks flows (Moore and Wondzell, 2005). Synchronization of runoff during rain or rain-on-snow events is common on the west coast of BC when entire catchments are at or are approaching saturation, whereby, the entire catchment area is simultaneously producing runoff. Synchronization of snowmelt typically only occurs at higher elevations in coastal BC.

Previous reviews have found that logging can increase the magnitude and frequency of peak flows in pluvial, nival, or hybrid hydrological regimes, albeit with a high amount of variability (Hudson, 2001; Whitaker et al., 2002, Schnorbus and Alila, 2004; Moore and Wondzell, 2005; Alila et al., 2009; Winkler et al., 2010b; Winkler et al., 2015; Stednick and Troendle, 2016; Winkler et al., 2017). Frequency-based studies[24] in snow-dominated watersheds suggest by comparing pre- and post-

---

[24] Frequency-based studies evaluate how forest harvesting has affected the frequency of a flood event of a given magnitude, or conversely, how harvesting has affected the magnitude of a flood event of a given frequency. Rather than pairing events by equal storm input, as is done in conventional paired watershed studies, floods are paired by equal frequency.

harvest flood frequency curves, that removal of forest cover can affect floods of all magnitudes and frequencies (Alila et al., 2009; Green and Alila, 2012; Yu and Alila, 2019). Green and Alila (2012) found that harvesting 33-40% of catchments ranging in size from 3 to 37 km^2 caused 20-year return period peak flow events to double in frequency and larger 50-year events to become 2- to 4-times more frequent. Yu and Alila (2019) evaluated the effect of harvesting on peak flows in the Camp Creek watershed in interior BC. They found that at 24% ECA, peak flow magnitudes associated with the 2- to 100-year return period events increased by 31% to 10%, respectively. Such an increase in magnitude translates to an increase in frequency of three to four times. Despite, However, the frequency-based studies discussed above were conducted in purely snowmelt-driven hydrologic regimes. As such, outcomes from these studies may not be applicable to the rain/hybrid hydrological regime of the assessment area. The master's research of Rong (2017) evaluated the effect of forest harvesting on floods across three study sites in the Pacific Northwest (Coyote Creek, Fox Creek, and the H.J. Andrews Experimental Forest) using a frequency-based approach. Similar to nival hydrologic regimes, Rong (2017) found that harvesting in rain-on-snow (i.e., hybrid) hydrologic regimes can increase both small and large peak flows; however, there was considerable variability between watersheds and study sites. Increases in peak flow means and variability around the mean varied from 9% to 86% and 3% to 154%, respectively, for catchments subject to 100% clear-cut. Catchments subject to 25% to 30% harvest experienced smaller increases in the mean (5% to 35%) and the variability around the mean either increased or decreased (-9% to 52%). The range in responses was attributed to differences in watershed characteristics, where lower relief catchments with drier and warmer climates were considered more sensitive to forest harvesting.

Grant et al. (2008) conducted a state-of-the-science synthesis on the effects of forest harvesting on peak flows in the Pacific Northwest, by compiling and evaluating the results from a number of relevant studies in the area. They found the effect of harvesting in the rain-on-snow (i.e., transient snow) zone was detectable when forest harvest exceeded approximately 20% of the catchment area. Peak flow risks in purely snowmelt regimes are also generally considered low when less than 20% of the catchment area is subject to clearcut (Pike et al., 2010a). As such, 20% ECA is often considered a threshold beyond which increases in peak flows can generally be detected. In the synthesis of Grant et al. (2008), harvest effects could only be detected in rain-dominated zones when harvest on average exceeded 46% of the catchment area. Chapman's (2003) review of rainstorm-driven peak flows in seven watersheds on Vancouver Island suggests that logging effects in rain-dominated watersheds on the south coast of BC are small because rainstorm-driven floods in the region are often a combination of long-duration rainfall followed by intense storms that overwhelms any potential water reduction that might be due to canopy interception and evaporation[25]. Jones (2000) evaluated the effect of forest harvest on peak flows in the HJ Andrews Experimental Watershed in Oregon. The five Andrews study catchments ranged in size from 13

---

[25] This concept does not apply to rain-on-snow events. Chapman's (2003) analysis did not distinguish between rain-only and rain-on-snow events.

ha to 101 ha and were subject to either 100% clearcut[26], 50% selection cut, or 25% patch cut. The authors reported an increase for winter rain-on-snow peak flows of 31% for Andrews 1 (100% clearcut, no roads), 26% for Andrews 3 (25% patch-cut with roads), 26% for Andrews 6 (100% clearcut, roads), 30% for Andrews 7 (50% selection cut, no roads), and no change for Andrews 10 (100% clearcut, no roads). These results highlight the high variability in response to rain-on-snow events.

It is important to recognize that the work of Chapman (2003), Jones (2000) and studies synthesized by Grant et al. (2008) did not evaluate how the frequency distribution of peak flows was affected by forest harvesting. Moreover, these studies, in large part, evaluated the effect of forest harvesting on peak flows by applying an analysis of variance or analysis of covariance, which are statistical approaches designed for analyzing means (i.e., averages) and not extremes (i.e., peak flows). There have since been calls to abandon this approach to evaluate the effect of forest harvesting on peak flows (Alila et al., 2009).

Alila and Green (2014) propose in their comment on Birkinshaw (2014) that larger and more frequent floods can be expected with logging even in rain-dominated watersheds. They propose that following the removal of forest cover, the likelihood of saturated antecedent soil conditions due to reduced evapotranspiration is increased. Under such conditions, even medium-sized rainstorms have the potential to trigger relatively large floods. This was demonstrated by Kim et al. (2019), who found that a 7-year precipitation event falling on saturated soils could generate a 100-year flood, whereas a 200-year precipitation event falling on unsaturated soils may only result in a 15-year flood event. This same concept can be extended to watersheds that experience rain-on-snow, whereby forest openings (i.e., logged areas) generally have more snow on the ground and melt faster than under forested conditions (Storck, et al., 2002), particularly when subject to high winds (Floyd, 2012). As such, there is an increased likelihood that medium sized rainstorms falling on deeper snowpacks in forest openings could result in an increased frequency of large flood events.

In addition to the effect of forest cover removal on peak flows, roads can alter how runoff is conveyed to streams by intercepting shallow groundwater along road cuts. Pike et al., (2010a) notes, however, that in most studies involving road-only treatments, roads did not appear to have a measurable effect on peak flows. Moreover, due to relatively rapid preferential flow[27] and high drainage density in many coastal watersheds, shallow groundwater and surface water flow rates are often similarly rapid, such that road-related effects (e.g., interception of shallow groundwater

---

[26] This extreme level of harvest across an entire catchment is an exception and uncommon in practice in BC.

[27] Preferential flow refers to rapid shallow groundwater flow through preferential flow pathways. These pathways typically occur above low permeability soils/surficial materials (i.e., basal till), and through macropores (e.g., from decaying roots, cracks in the soil, and worm/insect holes).

flow and conveyance as ditch flow) on drainage patterns and rates are also expected to be small (Hudson and Anderson, 2006).

3.1.2. Effects of Forestry on Low Flows

During the summer months, high human demand for water resources coincides with naturally occurring low flows (Bradford and Heinonen, 2008), which are being exacerbated by climate change. In addition to direct water withdrawals and climate change, the timing and magnitude of low flows can also be impacted by land use activities such as logging (Smakhtin, 2001). Despite the summer low flow period being a critical period for the management of water resources, it remains an understudied topic (Moore and Wondzell, 2005). Earlier research specific to BC reviewed the effects of forest harvesting on the low flow hydrology in snowmelt-dominant catchments (Pike and Scherer, 2003)[28]. Pike and Scherer's (2003) review identified eight studies in watersheds with predominantly coniferous forests in the Pacific Northwest. Of these eight studies, four identified an increase in low flow volumes and four identified no statistical change in low flow volumes following logging. The increase in low flow is associated with the elimination of interception and transpiration losses and a net increase in soil moisture, which may contribute to groundwater recharge. Measurable effects, however, were found to last only 5-8 years (Keppler and Ziemer, 1990; Pike and Scherer, 2003; Surfleet and Skaugset, 2013), after which time re-establishing vegetation appears to consume and transpire any net increases in soil moisture. In some cases, where dense deciduous stands become established in forest openings, particularly near riparian areas, there is the possibility that transpiration rates exceed those of the original conifer stands.

We recognize that there are two primary components of the forest which can influence low flows - the riparian area and the upland forest. The research of Hicks et al. (1991) looked at the colonization of riparian areas by deciduous species following stream-side harvesting and suggested that evapotranspiration rates by such colonizing species could exceed those of the pre-harvest (mature) stand and result in reduced runoff during the low flow period. Moore (2004) compared transpiration rates between young (40-year-old) and old-growth (450-year-old) Douglas-fir stands and found that the riparian area[29] in the younger stands used 3.3 times more water than that of the old stands during the growing season. As a result, logging particularly in riparian areas has the potential to decrease summer low flows in the long-term (Hicks et al., 1991).

---

[28] This work is applicable because in the Pacific Northwest, both rainfall-dominant and snowmelt dominant hydrological systems experience a period of low flows during the late summer and fall. In addition, previous reviews on the effects of forest harvesting on streamflow in both snowmelt systems (Pike and Scherer, 2003) and rainfall dominant systems (Austin, 1999) contained similar findings, suggesting similarity between these different systems for the low flow period (i.e., they are largely driven by groundwater processes).

[29] Riparian forests contained approximately 36% and 7% deciduous species in the young and mature forest, respectively. Riparian areas were defined as the vegetation 50 m on each side of the stream. Stream size was not described in the study although the study watersheds are 96 ha and 60 ha, so the principal streams are expected to be relatively small.

Austin (1999) examined the streamflow response to forest harvesting in both snowmelt- and rainfall-dominant hydrological systems. Austin (1999) evaluated streamflows of 28 different watersheds: 16 exhibited an increase in low flow volumes, 10 did not exhibit an increase in low flows, and two identified a decrease in low flows. The studies reviewed by Austin (1999) along with those of Keppler and Ziemer (1990), Pike and Scherer (2003), and Surfleet and Skaugset (2013) broadly demonstrated that low flows tend to be either unaffected or increased by forest harvesting. It is important to recognize that observed effects of forest harvesting were relatively short (i.e., a few years), and that there are few studies that consider the longer-term forest harvesting effects on low flows. Two such studies that examined longer-term forest harvesting effects on low flows are that of Perry and Jones (2017) and Segura et al. (2020), summarized below.

The work of Perry and Jones (2017) was conducted using a paired-watershed approach with long-term streamflow data for eight small (9-101 ha) headwater catchments in Oregon with rainfall and hybrid hydrologic regimes. Each catchment had been subject to forest harvesting in the 1960s-1980s, with four subject to 100% clearcut, one subject to 100% basal area removal in two passes 10 years apart, one subject to 50% removal by thinning, and two subject to 25-30% patch cut. In each catchment, Douglas-fir was the primary species planted post-harvest. It is important to note that these experimental watersheds are relatively small and harvest at such levels is remarkably high, with exception of the 25-30% patch cut. As a result, the research findings reflect an extremely high level of harvest that is uncommon in current forest management in BC[30]. Perry and Jones (2017) concluded that conversion of mature and old-growth mixed conifer forests to Douglas-fir plantations produced summer streamflow surpluses for 10 to 15 years post-harvest, similar to that previously reported in the literature. However, after 15 years of plantation growth, relatively high rates of summer evapotranspiration by young (25-40 years old) Douglas-fir relative to mature and old-growth forests were associated with observed summer streamflow deficits up to approximately 50%. It is important to emphasize that these results were identified in relatively small watersheds subject to 100% basal area removal. Amongst the range of silvicultural treatments that Perry and Jones (2017) reviewed, summer streamflow deficits were not observed under two scenarios. The first scenario involved selective harvest of 50% of the overstory canopy across the entire study catchment. The second scenario involved 30% canopy removal with 2- to 3-ha patch cuts. The authors conclude based on their observations combined with soil moisture dynamics in canopy gaps from Gray et al. (2002), that persistent summer streamflow deficits are not anticipated in openings up to 8 ha. These results suggest that for the conservation of summer streamflows in headwater catchments, that forest managers should consider alternative silvicultural systems such as limiting the size of forest openings and/or selective harvest.

---

[30] Although it is not uncommon for watersheds to be comprised nearly entirely of second growth stands (i.e., nearly the entire watershed area has been harvested at some point), harvest is typically staggered over many years rather than occurring all at one time.

More recently, Segura et al. (2020) evaluated long-term effects of forest harvesting on low flows in the Alsea Watershed Study in Oregon, USA. The study watersheds share a similar size (75 ha – 311 ha) and forest type as the assessment watersheds. Outcomes from this study are therefore applicable to the assessment area. Segura et al. (2020) compared differences in streamflow response for a reference watershed with mature/old (90- to 170-year-old) Douglas fir forest relative to the Deer Creek and Needle Branch Creek treatment watersheds. The Needle Branch Creek watershed was subject to 100% clearcut over ten years (17% clearcut in 1956 and 82% clearcut in 1966) and the Deer Creek watershed was subject to 25% patch cut in 1966. The authors found that by 2006 (40 to 53 years post-treatment) daily summer[31] streamflow was 50% less in the Needle Branch watershed relative to the watershed containing mature/old forests. Roughly 40 to 51 years after the Deer Creek watershed was subject to 25% patch-cut, mean daily summer streamflow was 14% lower than in the reference watershed. The reduction in low flows following harvest is thought to be due to higher evapotranspiration rates associated with the younger plantation forests relative to the old/mature forest.

Additionally, Segura et al. (2020) examined how clearcut harvest with a 15 m riparian buffer[32] affects streamflow in subsequent plantation forests. Harvesting (with riparian buffers) nearly 100% of the 40- to 53-year-old forest in the Needle Branch Creek watershed caused marginal increases in streamflow, which only persisted for two years before dropping to below pre-harvest levels. Despite a marginal increase in streamflow immediately following harvesting, streamflow deficits were still greater (i.e., lower streamflow) relative to the old/mature forest. The authors theorize that the relatively short-lived increase in streamflow is a result of high evapotranspiration rates associated with the riparian buffer and rapidly regenerating plantation and higher stand density of young relative to older mature forests. As such, Segura et al. (2020) conclude that rotations of young (i.e., 40- to 50-year-old) Douglas fir plantations can result in a persistent decrease in low flows. This research suggests that young regenerating forests can have potentially adverse effects on low flows for many years, and highlights the importance of having a mix of forest age distributions in a watershed.

3.1.3. Effects of Forestry on Groundwater/Aquifer Recharge

Water balance changes following logging at the site-level (i.e., cutblock) potentially can affect groundwater recharge; however, the linkages are complex and difficult to quantify, in part because the time-scales of the hydrologic processes above and below the ground surface are often orders of magnitude different (Smerdon et al., 2009). Moreover, quantifying changes in groundwater can be difficult, although inferences can be made based on changes to the water table, water yield, and/or base flow (Pike et al., 2010a). Research on the interaction between forest activities and groundwater is rather limited, particularly for deeper/confined aquifers. However,

---

[31] June 1 to September 15.

[32] The species composition of the riparian buffer is unknown.

Smerdon et al., (2009) conducted a review on the topic with a focus on British Columbia. Their review suggests that the effect of forest harvesting on groundwater is highly dependant on the hydrogeologic landscape, which is defined by the bedrock and surficial geology, soil type, and topography.

In general, and similar to low flows noted above, forest harvesting results in a reduction of site-level interception and transpiration. Even though this may be offset by increased evaporation post-harvest at the soil surface (due to increased solar radiation and wind in the forest opening), an increase in net soil moisture is expected following forest harvesting (Smerdon et al., 2009). Such an increase in soil moisture can in turn can lead to an increase in the water table. One study at Carnation Creek on the west coast of Vancouver Island, BC, reported increases in the water table of 30-50 cm after logging, which persisted for 10-years, despite recovery of vegetation (Heatherington, 1998). However, another study in the same watershed recorded increases between 9-28 cm and noted the response to be highly variable across the study site, particularly below new roads (Dhakal and Sidle, 2004). For example, peak pressure head (a proxy for the groundwater table) was recorded as being 50 cm lower below a newly constructed road as a result of shallow groundwater interception from the road cut above (Dhakal and Sidle, 2004). Groundwater tables can also be increased locally as a result of soil disturbance, whereby the disturbed soils cause water to infiltrate more slowly into the soil, leading to a build-up of the water table (Heatherington, 1982; 1998).

Increased site-level groundwater tables can translate to an increase in groundwater recharge downslope; however, whether such an increase occurs, or is measurable, is highly dependant on groundwater travel times (Smerdon, et al., 2009). Increases in groundwater recharge as a result of forest harvesting will only be realized if the persistence of forest disturbance effects is within the same order of magnitude as the time for groundwater flow to reach the area of recharge. Pike et al. (2010a) notes that potential increases in recharge as a result of forest harvesting may be detectable at local scales, where recharge occurs relatively quickly; however, may not be detectable in slower responding and larger-scale flow regimes. They further state that the effect of forest harvesting on recharge areas in the uplands could go undetected in adjacent valley-bottom aquifers for decades, and that these effects could be masked or magnified by climate variability and/or change.

3.1.4. Effects of Residential and Commercial Development on Streamflows

Residential and commercial development has long been known to result in increased runoff volume and peak flows as a result of the conversion of green spaces to impervious areas and the establishment of stormwater drainage systems intended to effectively convey water and reduce flooding (NRCC, 1989; Urbonas and Roesner, 1993). Impervious areas (e.g., paved roads, rooftops, etc.) increase the volume and rate of runoff transmitted to streams (BC MWLAP, 2002). For example, Blum et al. (2020) looked at 280 catchments in the United States and found that annual floods increased by 3.3% on average for each percentage point increase in impervious land cover. Similarly, Prosdocimi et al. (2015) found a "significant" effect of increasing urbanization levels on high flows in an urbanized catchment in the UK, although they did not quantify the increase. Villarini et al., (2009) also found using nonstationary flood frequency analysis that rapid urbanization caused an increase in frequency of the 100-year flood event. May et al. (1998 and references therein) state that stream ecosystem impairment begins when roughly 10% of a watershed is covered by impervious area. Additionally, conventional storm water management infrastructure, which are often composed of ditches and pipes, are designed to rapidly transport runoff to nearby streams (BC MWLAP, 2002). As such, the receiving waters are typically subject to increased flows which can alter channel morphology and negatively impact aquatic habitat.

3.2. SEDIMENT YIELD

As described by Jordan (2001), sediment can be divided into two broad categories: fine[33] and coarse[34]. Fine sediment is carried in suspension in water and is deposited only when streamflow velocity is low. Fine sediment in suspension within the water column increases stream turbidity[35], which is a measure of the sediment content in water, with increasing turbidity usually associated with increasing suspended sediment[36] concentrations. Stream turbidity is a concern since it can have physiological effects on fish (Newcombe, 2003). If utilized for potable water, turbid source water can also foul filters, interfere with disinfection of drinking water (i.e., shield pathogens from the effects of disinfection), is aesthetically unpleasing, and increases the total available surface area of solids in suspension upon which bacteria can grow (Cavanagh et al., 1998 and Pike et al., 2010c). Coarse sediment is transported along the stream bed and is of interest due to its effect on stream channel stability, water supply infrastructure, and fish habitat. These are further discussed in Section 3.4.

Sediment yield refers to the rate of sediment flux through a watershed. It is a function of the collective processes of *erosion*[37] and *sedimentation*[38] throughout a watershed and depends on the erodibility or rate of erosion from each area or source and the degree of hillslope-stream coupling

---

[33] Includes fine sand, silt and clay (i.e., particle sizes ≤0.25 mm)

[34] Includes medium sand and large particles (>0.25 mm)

[35] Turbidity is the amount to light scattered by a fluid (Stednick, 1991) and is measured in nephelometric turbidity units (NTUs).

[36] Suspended sediment normally consists of clay, silt and very fine sand particles less than 0.1 mm (100 micron) in diameter (MacDonald et al., 1991).

[37] Erosion refers to processes, by the action of water or wind, that displaces soil particles. Also known as sediment generation or sediment production.

[38] Sedimentation refers to the process of deposition of soil particles usually within a waterbody. Also known as sediment loading or sediment delivery.

(i.e., connectivity between the source of erosion and the stream network). Furthermore, for sediment to cause harm it must be transported to the location of a value of interest; this depends on the effectiveness of the stream to transport displaced sediment (i.e., stream power) from the point of entry to the location of interest.

Erosion is associated with several processes, including:

- Surface erosion of soils through the processes of raindrop/splash erosion[39], sheet erosion[40] and/or rill and gully erosion[41].
- Streambank erosion, whereby streamflows cause toe cutting and bank sloughing along streambanks, and
- Landslides (e.g., rockfall, debris slide, debris flows, rockslide, slump, etc.).

Soil erosion can often be mitigated by the presence of an effective and protective soil cover, usually in the form of vegetation and organic matter (e.g., grass, shrubs, trees, etc.); however, it can include coarse rock, mulch, wood debris or manufactured erosion control products. Thus, where vegetation and organic matter are lost by forest development or other natural disturbances (e.g., wildfire), the likelihood and rate of erosion tends to increase unless control measures are implemented.

In terms of assessing sediment yield, focus is on identifying the likelihood that watershed disturbance, such as forest development, increases the rate of sediment supply to the stream network, relative to natural or background rates. It considers both sediment production (i.e., erosion) and sediment delivery to the stream network (i.e., sedimentation), where it may affect elements-at-risk. The potential change in sediment yield is derived through consideration of *sediment generation potential*[42] and *sediment delivery potential*[43].

The following highlights where sediment is typically generated in a forestry context – along roads and from landslides. Although cutblocks can be subject to erosion, in the event that heavy equipment trafficking occurs under adverse soil moisture conditions, there is usually ample organic material (i.e., woody debris and slash) that serves as a protective soil cover such that

---

[39] Raindrop/splash erosion refers to soil particles that are dislodged by raindrop impacts.

[40] Sheet erosion refers to the process by which saturated soil particles are uniformly removed by surface runoff.

[41] Rill and gully erosion are described as long, narrow depressions formed in soils by concentrated surface runoff.

[42] Sediment generation potential is the likelihood that land use activity will increase the magnitude and/or frequency of sediment production (i.e., erosion) considering: terrain stability, soil erodibility, evidence of mass wasting, extent and location of resource roads, and other land-use related soil disturbance.

[43] Sediment delivery potential is the likelihood that sediment generated in upslope or instream sources will reach the stream network and be transported downstream to an element-at-risk. Factors considered include: hillslope-stream coupling, stream gradient, and location of lakes and wetlands.

erosion rates are low if not negligible (Jordan, 2001). Streambank erosion and general instability is another source of erosion and sedimentation (Section 6.4).

3.2.1. Roads

The effects of resource roads on sediment yields are well documented in the literature (Luce, 2002; and Wemple et al., 2001). Along roads, there are three main components to consider: 1) the cut slope and ditch, 2) the road surface, and 3) fill slope. Of these components, active road surfaces are often the primary producer of fine sediment to streams (Reid and Dunne, 1984), particularly in areas where landslides are infrequent (Bilby et al., 1989). For example, in a study in western Washington, Reid and Dunne (1984) found that a paved road (i.e., where sediment was only sourced from cut slopes and ditches) generated only 1% of the sediment yield of a heavily used[44] gravel road. Moreover, they estimated sediment production from road cuts to be roughly 5% of the combined production rate from roads for the study watershed (Reid and Dunne, 1984). However, in areas prone to landslides, sediment production from road-related landslides triggered during extreme storm events can often outweigh chronic sediment inputs from road surfaces (Wemple et al., 2003).

A study conducted on a medium-sized road-affected stream, located in Haida Gwaii, BC found that 18 ± 6% of the suspended sediment in the study reach was derived from nearby road surfaces (Reid et al., 2016). The same study found that road-derived sediment inputs were significantly greater during the wetter winter months, and during higher intensity rainstorms. During fall and winter rainstorms, 5% to 70% of sediment inputs to the streams were derived from roads compared to 0.5% to 15% during the spring and summer (Reid et al., 2016). A similar study using simulated rainfall on a road surface in the same watershed found that the intensity of rainfall and number of loaded logging trucks were the primary and secondary controls on road surface sediment production, respectively (van Meerveld et al., 2014). Similarly, Reid and Dunne (1984) found that roads contributed 7.5 times more sediment when heavily used, compared to when they are not in use. Van Meerveld et al., (2014) also found that increases in sediment concentrations persisted for up to 30 minutes following the passage of a loaded logging truck.

In addition to precipitation intensity and traffic, road surface material also plays an important role in determining sediment yield from road surfaces. Silt-sized particles are most prone to erosion, as they can be easily transported in suspension via overland flow, whereas coarser aggregate is less easily eroded and transported. Erosion rates are also lower for road surfaces with a high clay content as a result of particle aggregation (Luce and Black, 1999).

If cut slopes are required during road construction, near-surface groundwater flow becomes intercepted, increasing runoff and hence erosion potential along ditches. Sediment yield from cut

---

[44] Heavy use was considered to be more than four loaded trucks per day.

slope erosion and ditches is often the greatest immediately after road construction. Erosion rates tend to decrease as vegetation recovers along cut slopes and in ditch lines following construction. In western Oregon, one study found that cut slopes and ditches cleared of vegetation produced approximately seven times more sediment than those where vegetation was retained (Luce and Black, 1999).

Erosion of the fill slope is typically only significant at poorly designed culvert outlets (i.e., with no armour) or where uncontrolled drainage occurred across the road surface due to a fault in the drainage system (e.g., plugged culvert) (Jordan, 2000). In addition to drainage system failures, factors influencing observed erosion rates include climate (e.g., the wetter the location, the higher the rate of erosion) and the presence of groundwater (e.g., seeps). Secondary factors include soil coarse fragment content, soil depth and road gradient (Jordan, 2000).

Adverse effects can often be mitigated through proper road design, construction, and maintenance (Carson and Younie, 2003). Mitigation should be incorporated during all phases of operation (i.e., planning, construction, use and deactivation). Such options could include but are not limited to utilizing existing roads, minimizing road lengths/number of crossings, avoiding problematic soils, crossing at right angles to streams, and adhering to wet-weather shutdown guidelines.

As part of the Forest and Range Evaluation Program (FREP), a protocol has been developed for evaluating the potential impact of forestry and range use on water quality (Maloney et al., 2018). Known as the Water Quality Effectiveness Evaluation (WQEE), this protocol is intended for detailed site-level assessments to evaluate the effectiveness of the Forest Range and Practices Act (FRPA) and its regulations in achieving stewardship objectives. Specifically, the FREP WQEE is a tool used to estimate sediment contributions from forestry activities, with a particular emphasis on sediment contributions from roads. This protocol is intended to act as a monitoring tool and is considered beyond the scope of a watershed assessment. Although most roads were observed during the field reviews, a formal evaluation, such as the FREP WQEE, was not conducted and sediment yield was evaluated at an overview-level.

3.2.2. Landslides

Landslide is a generic term that refers to a suite of mass movement (or mass wasting) processes, such as rockfall, debris slides, debris flows, and debris floods. In mountainous areas of coastal BC, landslides are a natural process that occurs throughout the landscape when the gravitational forces and hydrologic conditions exceed the strength of the soil (or rock). Where hillslopes are coupled to streams, landslides can have significant impacts on instream values (e.g., fish habitat) and other values downstream (e.g., human health, property and infrastructure).

The frequency of landslide occurrence has long been recognized as potentially increasing following forest harvesting and road and trail construction (Pike et al., 2010b). This is especially the case where road construction does not adequately consider potentially unstable terrain and the influence of drainage diversions (e.g., road cuts, ditches and culverts) on natural surface and groundwater flow patterns. Following high-profile landslides in coastal BC in the late 1970s and early 1980s, including one in the assessment area (discussed below), forest management practices in landslide-prone terrain were critically reviewed by the provincial agencies. This was followed by implementation of the *Forest Practices Code of British Columbia Act (FPC)* in 1994[45], which required professional terrain assessment and improvements in road planning and construction. As a result, the added level of diligence substantially reduced the frequency of post-logging landslides (FPB, 2005).

3.2.3. Local Examples

Clough Creek Debris Flow

An example of a pre-FPC landslide occurred along Clough Creek in November 1983. In this case, a debris flow initiated near the 1,000 m elevation (stream km 6) at a location where logging occurred 15 years earlier (FPB, 2006). According to the Forest Practices Board (FPB) (2006) and Emergex (2005), the event was triggered by rainfall-saturated soils that slumped into the creek where it entrained old logging debris and flowed approximately 6 km downslope, where it forced evacuation of homes and caused considerable property damage. Based on an examination of historical air photos, drainage diversion along an old road upslope is suspected to have been a contributing factor. Historical air photos also suggest that although riparian vegetation has effectively recolonized disturbed riparian areas, and is dense, the channel has only modestly recovered and has a lack of large diameter functional wood in the channel. Although this is not critical for the bedrock- and colluvial-dominated channel morphology, it could mean that sediment transport is not well regulated along the creek.

Whittaker Creek Washout at Lower Road

A recent washout of Lower Road at Whittaker Creek, a relatively small drainage between Smales Creek and Higgs Brook, demonstrates the risks associated with poorly managed (urban) stormwater drainage above a steep ravine. According to Carson (2020), the washout that occurred on February 1, 2020 was one of several mass movement events associated with stormwater drainage upslope of the ravine since the 1960s. In addition to damage to the crossing, a debris flow was triggered for 400 m to the ocean, where it damaged several properties and caused considerable aggradation (APPENDIX E, FIGURES 117-119). The 2020 washout occurred in response to an extreme runoff generated by a two-day rainstorm, which appears to have been exacerbated by interception and conveyance of runoff along the highway and road ditches. Diversion of flows from Smales Creek to Whittaker Creek along the highway ditch is also suspected as a contributor to the flows observed at the Lower Road crossing of Whittaker Creek. Carson (2020) noted that Smales Creek has since been rerouted to flow east along the road ditch

---

[45] The *Forest Practices Code (FPC)* was subsequently replaced by the *Forest and Range Practices Act (FRPA) in 2004.*

towards End/Walker Creek (rather than west towards Whittaker Creek) and estimated this may reduce storm flows by up to 25% in Whittaker Creek. Carson (2020) considers the primary contributing factors to the washout to be the Smales Creek diversion and lack of maintenance of the extensive culvert system along the steep ravine floor below Lower Road.

3.3. RIPARIAN FUNCTION

Riparian function is the interaction of various hydrologic, geomorphic, and biotic processes across a range of spatial and temporal scales within the riparian environment. As a result, riparian function includes a wide variety of processes that determine the character of the riparian area[46] and exerts an influence on the adjacent aquatic and terrestrial environment. Riparian areas provide several functional roles which include providing critical habitat for insects, amphibians and other wildlife; providing food sources for aquatic insects and shelter for fish; filtering nutrients from water; dissipating energy during flood events; filtering sediment from entering a stream; and offers wind protection. In the context of watershed management, riparian function is often defined more narrowly, focussing on three specific processes:

1) the provision of bank stability mostly through root strength, particularly where alluvial materials are involved (e.g., along floodplains and fans)[47],
2) the recruitment of large woody debris (LWD) to aquatic systems, which helps to control the movement of coarse sediment in stream channels as well as providing fish habitat (e.g., cover), and
3) the provision of shade to aquatic systems that can help maintain stream temperatures.

Loss of riparian function can affect channel equilibrium and result in bank erosion, channel shifting, and sedimentation. This can have negative effects, such as fish and fish habitat degradation, water quality reduction, infrastructure (e.g., stream crossings) damage, and private land damage or loss. Moreover, blowdown in riparian areas can potentially contribute excessive amounts of wood, sediment and debris to the channel.

When assessing riparian function, focus is on identifying the degree to which natural riparian function (e.g., to provide shade, cover, stream habitat, stream bank stability, etc.) has or will be disturbed by watershed disturbance. Loss of riparian function can affect channel equilibrium (Section 3.4) and result in bank erosion, channel shifting, and sedimentation. The riparian function hazard incorporates both the level of past riparian forest cover disturbance and the degree to which it has recovered.

---

[46] Riparian area (or zone) is an area of land adjacent to a stream, river, lake or wetland that contains vegetation that, due to the presence of water, is distinctly different from the vegetation of adjacent upland areas.

[47] By promoting bank stability, riparian vegetation mitigates sediment generation (i.e., erosion).

Similar to the WQEE protocol described in Section 3.2.1, a FREP protocol has been developed for evaluating riparian condition (Trip et al., 2022). The purpose of the riparian FREP protocol is to assess the effectiveness of riparian management practices and evaluate the functioning condition of streams and riparian areas. These protocols are intended for detailed site-level assessments and were not applied as part of this review. For the purposes of this assessment, a high-level overview of riparian function was conducted to evaluate the current riparian condition and its effect on sediment yield and channel stability. This included reviews of historical air photos and other imagery, as well as ground-based reviews at selected locations along the streams (FIGURE 2.1).

3.4. CHANNEL STABILITY

Channel stability, better described as *dynamic channel equilibrium*, refers to a state of balance resulting from the interplay of four basic factors (streamflow, sediment yield, sediment particle size, and channel gradient) that maintains alluvial or semi-alluvial stream channels in their most efficient and least erosive form. The term "dynamic" is important, as the energy of a stream is always at work sustaining or re-establishing its equilibrium condition. Land-use impacts at site-specific or watershed scales have the potential to upset dynamic channel equilibrium thereby triggering a process of stream adjustments. If one of the four factors change, one or more of the other variables must increase or decrease proportionally if equilibrium is to be maintained. For example, if channel gradient is increased (e.g., by channel straightening) and streamflow remains the same, either the sediment load or the size of the particles must also increase. Likewise, if flow is increased and the channel gradient remains constant, sediment load or sediment particle size has to increase to maintain channel equilibrium. Under these conditions, a stream seeking a new equilibrium (i.e., in a state of disequilibrium) will tend to erode more of its banks and bed, transporting larger particle sizes and a greater sediment load. Such channel disequilibrium or destabilization may be undesirable as it can result in increases in fine and coarse sediment yield, which can affect downstream water quality, fish and fish habitat, and water supply and transportation infrastructure (e.g., bridges and culverts).

Salmon and trout egg-to-fry survival is dependent on the stability of redds and a well oxygenated flow of water. During the rising limb of a storm hydrograph, redds may be at risk of scour. Furthermore, during the receding limb of the storm hydrograph, finer sediments may deposit and plug the interstices of redds, thus compromising oxygen flow. Both effects can result in reduced fry survival (Schrivener and Tripp, 1998). While fine sediment may be transported during a range of flows, coarse sediment is generally stored for long periods in channel banks and bars, and typically moves episodically, usually when flows approach or exceed bankfull.

Analysis of channel stability requires an understanding of current or baseline stream channel conditions both in terms of channel equilibrium (i.e., does the channel display evidence of disequilibrium from past impacts either streamflow and/or sediment-related?) and channel sensitivity to future disturbance. The analysis also requires estimation of potential future streamflow and sediment yields, including the influence of climate change and/or forestry.

The sensitivity of a channel is also referred to as its *channel response potential* (Montgomery and Buffington, 1997 and 1998). *Channel response potential* is the inherent susceptibility of a stream channel to changes in discharge and sediment supply. It is a factor controlling whether and to what extent forest disturbance effects, if any, will be realized. Channels can be broadly described as *alluvial*[48], *semi-alluvial*[49] or *non-alluvial*[50], and relative channel response potential tends to decrease in that respective order. Reach-specific response potential is further affected by influences such as channel confinement, riparian vegetation[51], and presence of in-channel large woody debris. Differences in reach morphology and physical processes result in different potential responses to similar changes in discharge or sediment supply (Montgomery and Buffington, 1997 and 1998).

The assessment streams were observed in several locations (FIGURE 2.1); however, no formal or systematic stream channel stability procedure was applied in this assessment. Such an approach is considered beyond the scope of this review. Similar to the assessment of riparian function discussed above, channel stability was assessed at an overview level.

---

[48] Alluvial channels are those comprised of potentially mobile sediments deposited by the stream (e.g., sand and gravel). The nature of these channels makes them relatively more sensitive to disturbance than semi-alluvial or non-alluvial channels.

[49] Semi-alluvial channels are those comprised of a combination of potentially mobile alluvium and immobile material (e.g., bedrock, colluvium, glacial lag-deposits).

[50] Non-alluvial channels are those comprised largely of immobile material (e.g., bedrock, colluvium, glacial lag-deposits).

[51] Riparian vegetation serves many purposes (e.g., to provide shade, cover, stream habitat, stream bank stability, etc.) and can be a major factor contributing to the robustness of channels and observed channel response. Loss of riparian function can affect channel equilibrium and result in bank erosion, channel shifting, and sedimentation. The level of past riparian forest cover disturbance and the level of recovery of the riparian vegetation are both considered in characterizing channel response.

4. WATERSHED OVERVIEW

4.1. LOCATION & ACCESS

The assessment area is located approximately 4 to 6 km northwest of Gibsons Town Centre on the southwest slopes of Mt. Elphinstone. Access to the upper portions of assessment area is via Largo Road northbound from the Sunshine Coast Highway (101), then by the Sechelt-Roberts Creek Forest Service Road (FSR) (7575) and several branch roads. Lower portions of the assessment area are accessed via several local roads between Gibsons and Roberts Creek. A BC Hydro Transmission Line right of way (ROW), which has a gated access road and trail for much of its length also crosses the assessment area between elevations of 200 and 400 m (FIGURE 4.1).

FIGURE 4.1 *View eastward along the BC Hydro ROW, near a tributary to Chaster Creek at an elevation of 295 m. Photo DSC09916, August 27, 2020.*

4.2. PHYSIOGRAPHY

The assessment area is located in a transitional area between the Georgia Lowlands and Pacific Ranges of the Coast Mountains (Holland, 1976). The area is characterized by moderate relief and gently to moderately sloping terrain on the southwest side of Mt. Elphinstone. Although this area is drained by several streams, there are no major valleys. Below an elevation of about 160 m, these slopes are skirted by a broad gently rolling terrace (i.e., Upper Gibsons Bench) consisting of a sequence of glacial deposits (FIGURE 4.2) (Section 4.4). Steeper slopes are found along the outer edge of this terrace near the oceanfront, as well along several incised gullies (FIGURE 4.3).

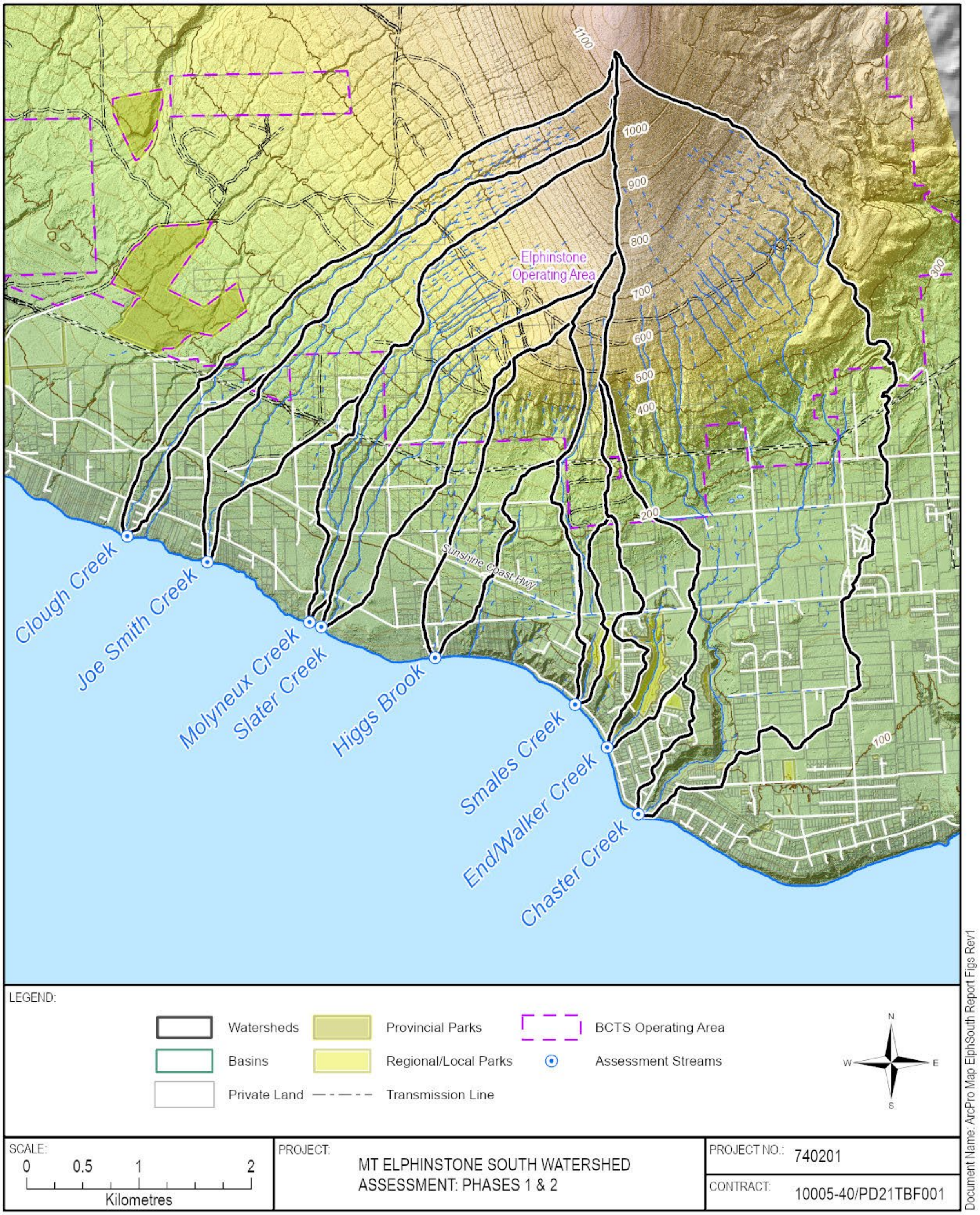


FIGURE 4.2 *Assessment area topography and elevations.*

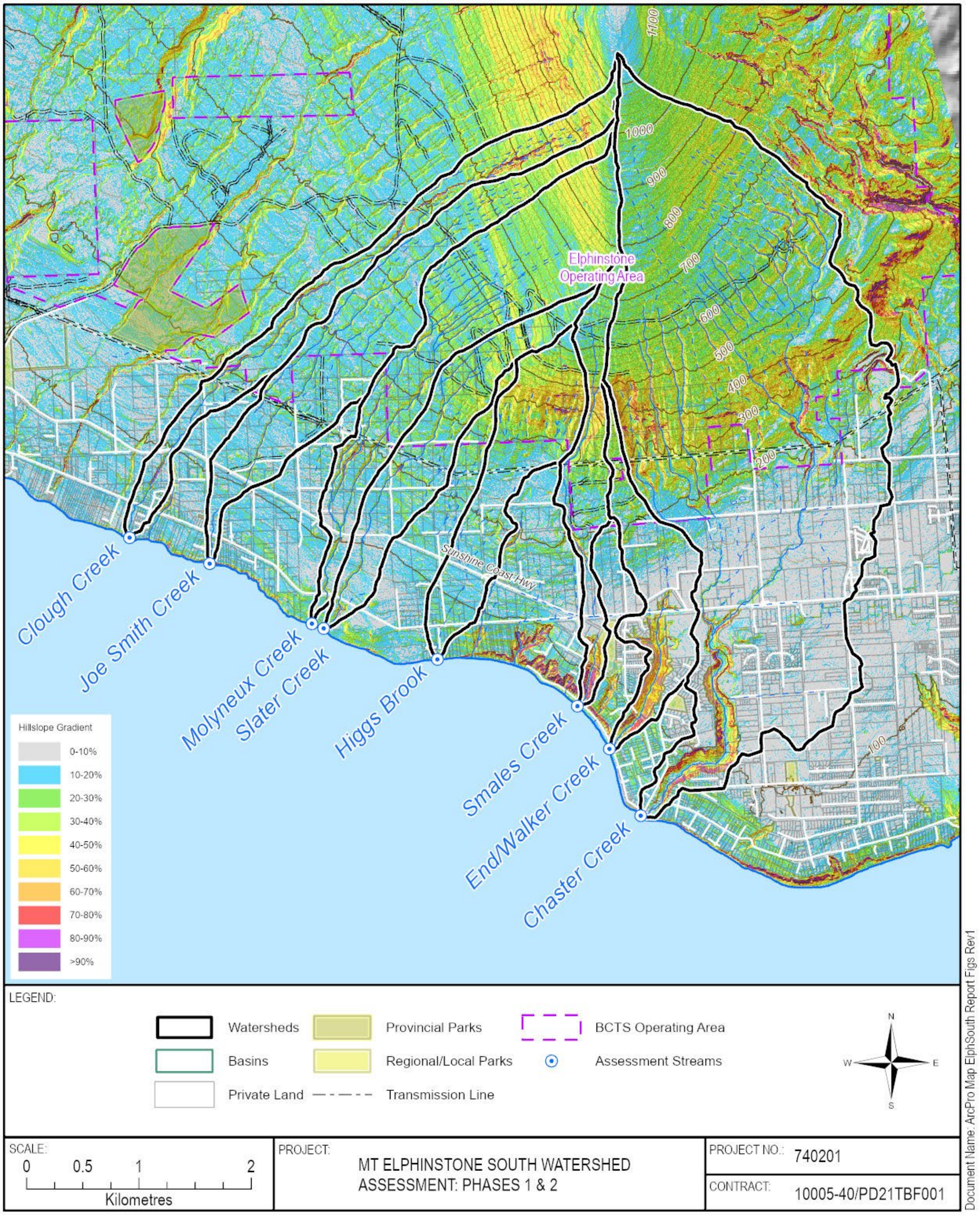


FIGURE 4.3 *Hillslope gradients in the assessment area.*

Eight stream catchments have been identified with some potential for BCTS forest development (henceforth referred to as "assessment streams" or "assessment watersheds", TABLE 4.1). Each of these streams has one or more tributaries and flows into the Strait of Georgia. The assessment area has a high density of subparallel gullies, which is especially evident on LiDAR bare-earth imagery (FIGURE 4.4, MAP 1). Many of these gullies however do not necessarily contain stream channels[52] with perennial or intermittent flow, however, they may be paths for near-surface groundwater flow. It is important to emphasize that the streams presented on the maps herein are identified using GIS techniques (i.e., flow accumulation modelling) with LiDAR data and have not necessarily been field verified.

Within the assessment area, drainage areas of the eight stream catchments range from 0.95 km² to 10.73 km² (95 ha to 1,073 ha). Total watershed relief in the assessment area ranges from approximately 540 m to 1,140 m. The median watershed elevations range from 130 m to 500 m. Hillslope gradients within the area reflect gently to moderately sloping terrain, with 67-87% of the drainage areas gentler than 30% slope and 81-96% of its drainage area gentler than 40% slope. As noted above, the remaining steeper areas are generally found near the oceanfront and along incised gullies. Slope aspects in the Chaster Creek watershed are biased to southeast slopes, whereas in the other watersheds aspects are biased towards southwest-facing slopes.

---

[52] According to Province of BC (2018), a "stream" means a watercourse, including a watercourse that is obscured by overhanging or bridging vegetation or soil mats, that contains water on a perennial or seasonal basis, is scoured by water or contains observable deposits of mineral alluvium, and that: (a) has a continuous channel bed that is 100 m or more in length, or (b) flows directly into (i) a fish stream or a fish-bearing lake or wetland, or(ii) a licensed waterworks.

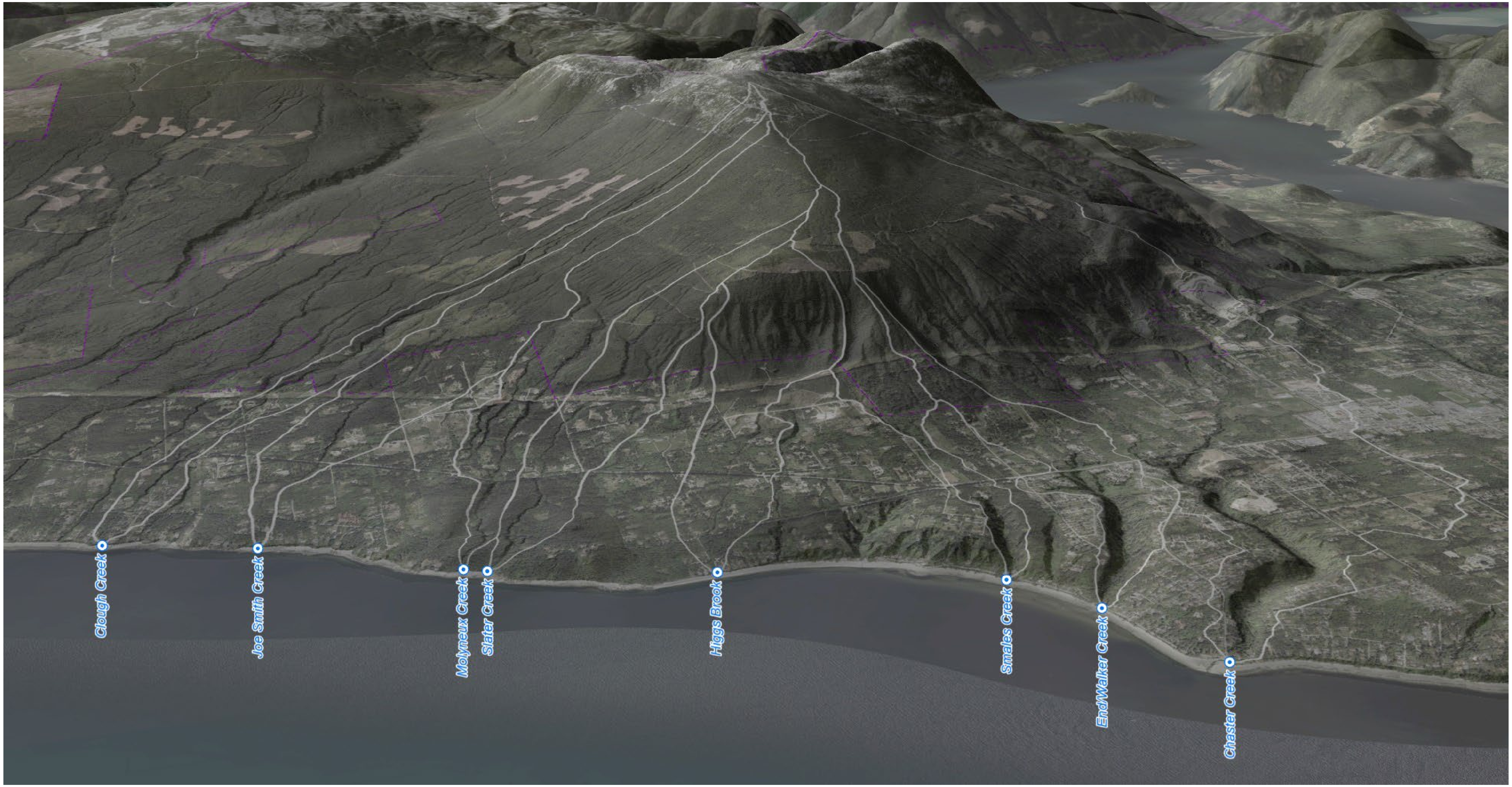


FIGURE 4.4 *3D perspective view of the southwestern slopes of Mt. Elphinstone and the eight stream catchments of the assessment area (outlined in white). Vertical exaggeration 1.25x. DEM source: Province of BC and SCRD; Imagery source: ESRI (2021).*

TABLE 4.1 *Characteristics of the eight principal stream catchments in the assessment area.*

Watershed Units																
Stream / Watershed	**Chaster Creek**		**End / Walker Cr**		**Smales Creek**[53]		**Higgs Brook**		**Slater Creek**		**Molyneux Creek**		**Joe Smith Creek**		**Clough Creek**[54]	
Drainage Area																
Total drainage area (ha)	1,072.90		114.84		94.61		145		142.42		264.79		228.64		154.15	
Total drainage area (sq km)	10.73		1.15		0.95		1.45		1.42		2.65		2.29		1.54	
Elevations (Hypsometric data)																
Minimum elevation (m)	0		0		0		0		0		0		0		0	
Maximum elevation (m)	1,140		540		800		640		720		1,080		1,040		1,140	
Total watershed relief (m)	1,140		540		800		640		720		1,080		1,040		1,140	
H40 elevation (H40) (m)	440		135		320		300		300		560		360		480	
H50 (median) elevation (m)	300		130		260		260		240		500		300		360	
H60 elevation (H60) (m)	200		125		240		220		200		440		260		280	
Slope Gradient	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**
0-10%	285.49	26.6%	43.55	37.9%	14.24	15.1%	14.68	10.1%	20.29	14.2%	17.88	6.8%	29.9	13.1%	18.96	12.3%
11-20%	212.5	19.8%	26.23	22.8%	24.81	26.2%	56.38	38.9%	58.58	41.1%	80.49	30.4%	117.17	51.2%	55.86	36.2%
21-30%	226.55	21.1%	14.96	13.0%	25.19	26.6%	28.48	19.6%	39.54	27.8%	96.32	36.4%	52.09	22.8%	27.98	18.2%
31-40%	174.01	16.2%	9.13	8.0%	13.42	14.2%	17.58	12.1%	17.6	12.4%	44.9	17.0%	21.3	9.3%	22.79	14.8%
41-50%	89.37	8.3%	4.43	3.9%	5.72	6.0%	14.54	10.0%	5.05	3.5%	19.83	7.5%	6.34	2.8%	15	9.7%
51-60%	42.98	4.0%	3.62	3.2%	4.44	4.7%	9.35	6.4%	0.9	0.6%	3.72	1.4%	1.4	0.6%	6.44	4.2%
61-70%	24.5	2.3%	4.88	4.2%	2.71	2.9%	3.17	2.2%	0.27	0.2%	1.15	0.4%	0.35	0.2%	3.61	2.3%
71-80%	9.87	0.9%	5.12	4.5%	1.71	1.8%	0.46	0.3%	0.13	0.1%	0.34	0.1%	0.06	0.0%	2.07	1.3%
81-90%	4.4	0.4%	2.26	2.0%	1.5	1.6%	0.18	0.1%	0.06	0.0%	0.08	0.0%	0.02	0.0%	1.05	0.7%
90% +	3.24	0.3%	0.62	0.5%	0.91	1.0%	0.17	0.1%	0.03	0.0%	0.03	0.0%	0.01	0.0%	0.41	0.3%
Slope Aspect	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
North	144.18	13.4%	24.48	21.3%	4.31	4.6%	1.48	1.0%	2.8	2.0%	3.32	1.3%	2.73	1.2%	4.39	2.8%
East	317.84	29.6%	22.16	19.3%	10.46	11.1%	4.71	3.2%	3.35	2.4%	8.01	3.0%	3.58	1.6%	3.5	2.3%
South	527.93	49.2%	49.64	43.2%	65.64	69.4%	121.4	83.7%	89.85	63.1%	118.28	44.7%	141.63	61.9%	84.48	54.8%
West	82.96	7.7%	18.51	16.1%	14.23	15.0%	17.41	12.0%	46.44	32.6%	135.12	51.0%	80.69	35.3%	61.78	40.1%
BEC Sub-zones/Variants	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
MH mm1	18.88	1.8%	-	-	-	-	-	-	-	-	0.23	0.1%	0.43	0.2%	5.61	3.6%
CWH vm2	195.09	18.2%	-	-	8.92	9.4%	-	-	0.76	0.5%	59.16	22.3%	14.13	6.2%	24.06	15.6%
CWH dm	575.66	53.7%	47.84	41.7%	66.79	70.6%	105.87	73.0%	107.22	75.3%	181.7	68.6%	176.96	77.4%	94.19	61.1%
CWH xm1	283.27	26.4%	67	58.3%	18.89	20.0%	39.13	27.0%	34.44	24.2%	23.7	9.0%	37.12	16.2%	30.3	19.7%
Land Base	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Crown Forest Land Base	584.87	54.5%	6.36	5.5%	43.59	46.1%	59.71	41.2%	70.04	49.2%	204.72	77.3%	124.64	54.5%	95.58	62.0%
Timber Harvest Land Base	454.31	42.3%	5.97	5.2%	39.22	41.5%	56.08	38.7%	65.78	46.2%	191.79	72.4%	113.35	49.6%	88.66	57.5%
Private Land	380.22	35.4%	70.12	61.1%	23.75	25.1%	75.45	52.0%	80.13	56.3%	54.79	20.7%	77.97	34.1%	36.94	24.0%
Parks or protected areas	3.89	0.4%	16.68	14.5%	4.08	4.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Area of lakes	0.22	0.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Area of wetlands	-	-	-	-	-	-	-	-	-	-	-	-		0.0%	-	-

---

[53] Also known locally as Elmer Creek.

[54] Also known as Clough Brook.

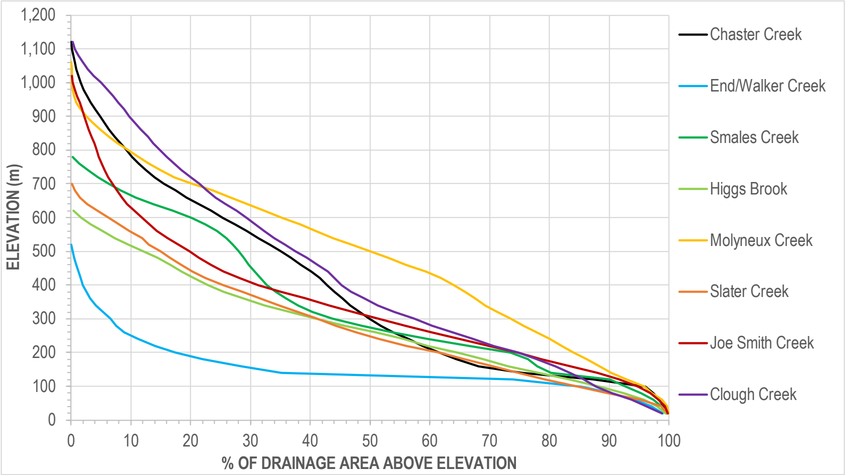


FIGURE 4.5 *Hypsometric (area-elevation) curves for the watersheds of interest in the assessment area.*

The assessment streams range considerably in size based on location and drainage area. The largest assessment stream by drainage area is Chaster Creek, while the smallest is Smales Creek. With the exception of the lower 4.5 km of Chaster Creek, which is alluvial[55] (Madrone, 2015), all of the streams are characterized as primarily non-alluvial or semi-alluvial[56]. As noted above, each stream is fed by one or more gullies that tend to be relatively deeper and incised in the Chaster Creek, Smales Creek and Higgs Brook watersheds (FIGURE 4.2). At higher elevation, several of these gullies have no surface flow, but presumably convey subsurface flow. With decreasing elevation, surface flow becomes evident, and depending on drainage area, streams may have perennial, seasonal or intermittent surface flow. The degree of channel incision varies throughout the area and depends on stream size and erodibility of surficial materials. Several of the streams become less incised as they emerge from the upper slopes onto the Gibsons bench. However, as they drop below 100 m elevation near the oceanfront, several streams (i.e., Chaster Creek, End/Walker Creek and Smales Creek) re-enter incised gullies before flowing into the ocean.

Stream gradients are presented in FIGURE 4.6. Chaster Creek is unique amongst the stream reviewed, as its lower 4.5 km has relatively low gradients, averaging 4.1%. Above that, stream gradient rises rapidly to in excess of 20%. The other streams are similar as their lower reaches have gradients of about 10%+/-, whereas their upper reaches are about 20% or steeper. Selected photos of the assessment streams are provided in APPENDIX E. Stream channel conditions as observed during our field reviews are summarized in Section 6.4.

---

[55] Alluvial channels are those comprised of potentially mobile sediments deposited by the stream (e.g., sand and gravel). The nature of these channels makes them relatively more sensitive to disturbance than semi-alluvial or non-alluvial channels.

[56] Semi-alluvial channels are those comprised of a combination of potentially mobile alluvium and immobile material (e.g., bedrock, colluvium, glacial lag-deposits).

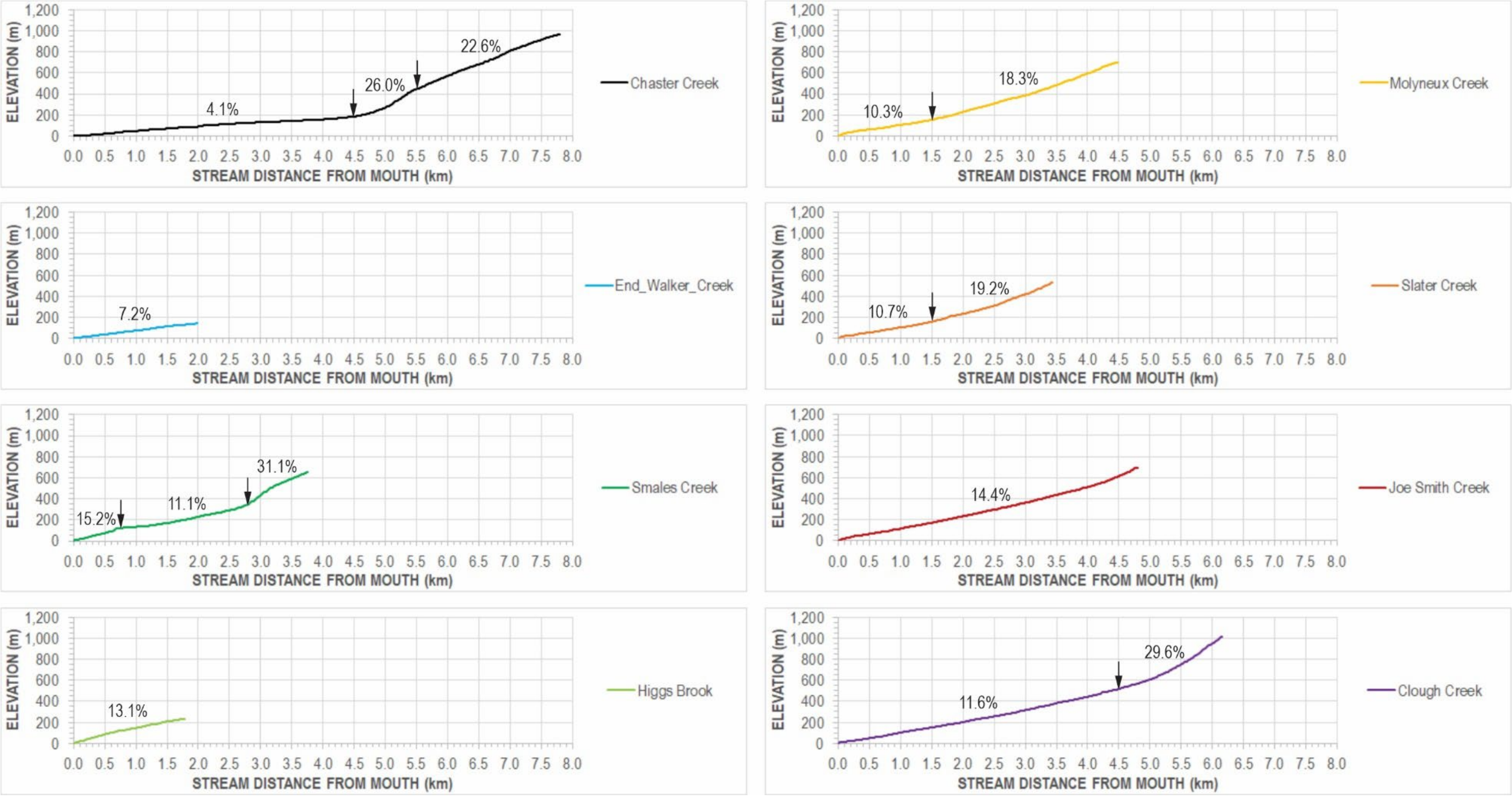


FIGURE 4.6 *Representative longitudinal profiles of the streams in the watersheds of interest in the assessment area. There are several tributaries in each watershed, many of which are not shown. Stream gradients for main reaches are shown.*

4.3. BEDROCK GEOLOGY

The description of bedrock geology provided below is based on Cui et al. (2019) and Journeay and Monger (1994).

Three bedrock geology units are located within the assessment area (FIGURE 4.7). According to Cui et al. (2019), the southwest side is underlain by variably foliated granodiorite of early Cretaceous-aged rocks of the Quatam, Sakinaw Lake, Malaspina and Quarry Bay plutons. The centre of the assessment area is underlain by Late Jurassic-aged, variably foliated granodiorite and quartz diorite of the Paradise River Pluton. The northeast portion of the area is underlain by Jurassic-aged sedimentary and metamorphic rocks of the Bowen Island Group, including, sandstone, siltstone, argillite and greenschist (Journeay and Monger, 1994).

Characteristics of the bedrock, including mineral composition and structure, determine the shape and texture of its weathered material. These characteristics influence the shape and size of clasts (i.e., rock fragments) and the matrix texture of soils that are created. Sandstone weathers to sand and siltstone breaks down into silt. Sedimentary rocks, where bedded, tend to fracture along bedding planes to produce slab-shaped clasts. Foliated or schistose metamorphic rocks, such as greenschist, break down into silt and consequently result in silty matrix soil. Such rocks fracture along foliation planes to produce slab-shaped clasts. Where well jointed, igneous rocks, break into blocks and boulders and can produce bouldery tills. On weathering, the rock breaks down into silt and sand and consequently, areas of granitic bedrock tend to produce till with a silty sand matrix.

Waterline (2013) noted that joints and fractures in the local rock types were roughly parallel and perpendicular to the boundaries of the three bedrock formations in the area. Fractures in bedrock can contribute to mountain block recharge to downslope aquifers. Waterline (2013) note that little is known about the contact between the Bowen Island Group and the Paradise River Formation and the role it might play in groundwater movement and specifically recharge of the Gibsons Aquifer (discussed in Section 4.12.2).

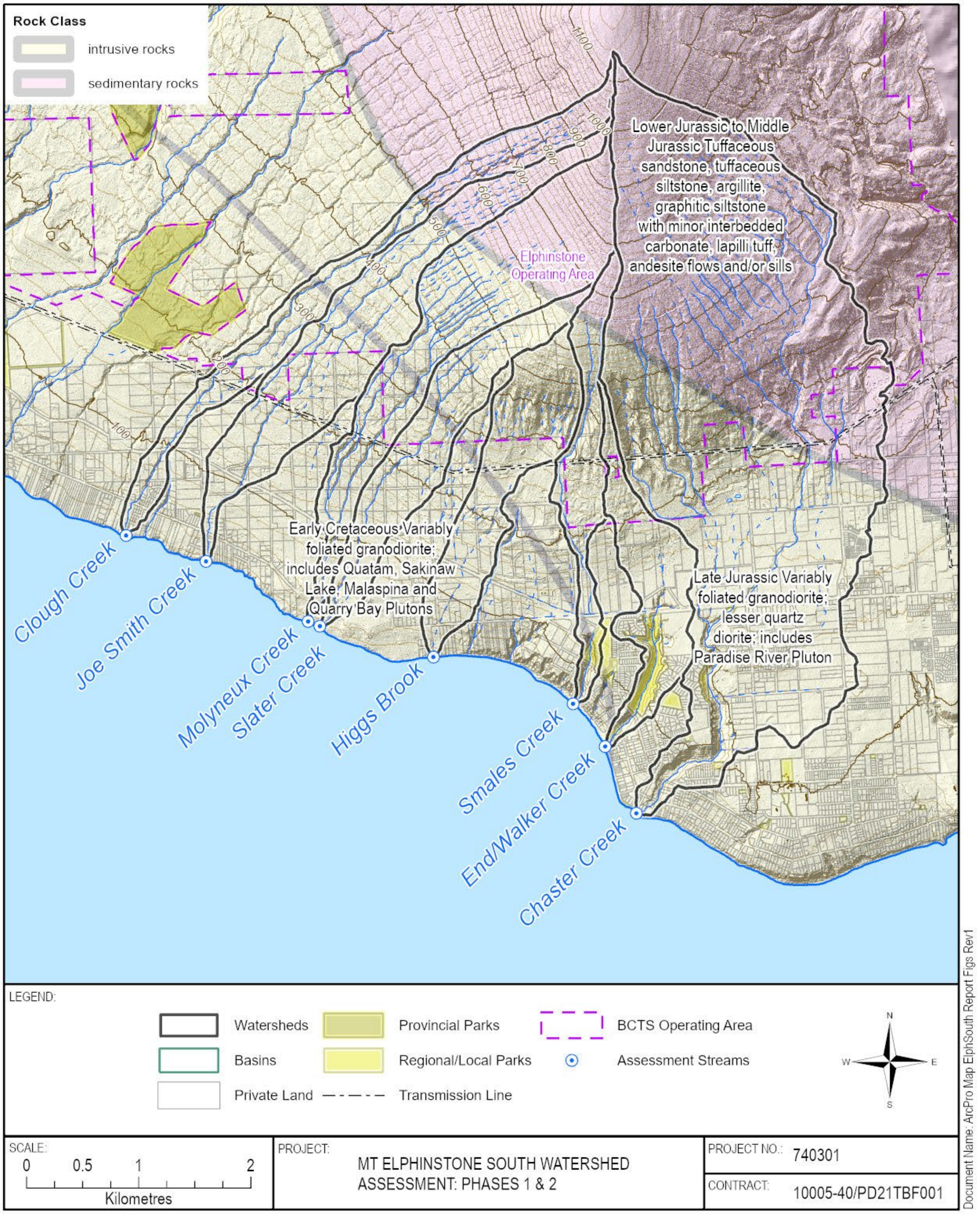


FIGURE 4.7 *Bedrock geology underlying the assessment area.*

4.4. SURFICIAL GEOLOGY

The description of surficial geology provided below is based on Advisian (2019), Madrone (2015), McCammon (1977), Ryder et al., (1980), Statlu (2018), Waterline (2013), and our field observations.

The assessment area was subject to several Quaternary glaciations (i.e., over the past 2.6 million years); however, the unconsolidated sediments present within the area were primarily deposited during Fraser Glaciation, which occurred between 29,000 and 11,000 years ago[57]. Some of these sediments were subsequently subject to post-glacial erosional and depositional processes that occurred over the Holocene period (i.e., over the last 10,000 years); these are referred to as Salish sediments. Surficial materials in the assessment area differ by location and elevation, and can be characterized as follows: 1) areas above 180 m elevation, 2) southwest-facing slopes below 180 m elevation, and 3) southeast facing slopes below 180 m (TABLE 4.2). Above an elevation of approximately 180 m, hillslopes are characterized by a blanket of till (known as Vashon till) over bedrock (FIGURE 4.8). Fluvial downcutting into the till has formed a relatively high density of subparallel gullies in the area. Generally, till thickness decreases with elevation with scattered bedrock outcrops noted on the upper slopes (FIGURE 4.9). Colluvium may also be present where hillslope gradient is greater than about 70%. Similar materials as those above 180 m elevation are also found below 180 m elevation on southwest-facing hillslopes between Clough Creek and Slater Creek. However, these materials also are covered by a discontinuous blanket of glaciofluvial sands and gravel (Upper Capilano Sediments) over glaciomarine clays (Lower Capilano Sediments) (McCammon, 1977).

FIGURE 4.8 *View of till exposed in a roadcut near one of the western tributary gullies to Chaster Creek near an elevation of 650 m. Photo DSC00256, August 27, 2020.*

---

[57] In some areas, remnants of pre-Fraser Glaciation sediments may be found beneath the Fraser Glaciation sediments.

FIGURE 4.9 *Example of thin soil over bedrock at this aggregate pit near the watershed divide between Higgs Brook and Slater Creek at an elevation of 560 m. Photo DSC00134, August 27, 2020.*

The surficial geology on the south-east facing slopes below 180 m elevation (i.e., Upper Gibsons Bench) is relatively complex. This is largely due to its low elevation and location where sediments have accumulated, as well as a history of sea level change during the Quaternary period[58]. A simplified cross-section of the hillslope along the center of the Chaster Creek watershed and through the Gibsons Aquifer is provided in FIGURE 4.10. Above bedrock and Pre-Vashon marine deposits are Pre-Vashon glaciofluvial sediments (also referred to as Quadra Sands), which are typically 10s of metres thick. These sediments form the confined Gibsons Aquifer. Above that is Vashon Till and Lower Capilano Sediments consisting of glaciomarine clays – both the till and glaciomarine sediments act as an aquitard above the Gibsons Aquifer. Above that is a discontinuous layer of Upper Capilano glaciofluvial sediments that were formed from outwash sediments and raised deltas deposited during isostatic rebound. The unconfined Capilano Aquifer is located within the Upper Capilano sediments. Post-glacial Salish sediments may also be present at the surface.

---

[58] Near the end of the Fraser Glaciation, the relative sea level was at an elevation of 180 m on the Sunshine Coast due to the weight of the Cordilleran ice sheet depressing the land surface.

TABLE 4.2 *Summary of the surficial geology in the assessment area.*

Area	Material Name	Age	Material Type	Material Description	Thickness	Notes
All areas above 180 m elevation	Salish Sediments	Post-glacial (Holocene)	Alluvium and colluvium	Sands and gravels	Variable, 1 m to several metres.	Floodplain deposits in creeks and fans on lower slopes
	Upper Capilano Sediments	Late-stage Fraser Glaciation (deposition during iso-static rebound of land)	Glaciofluvial sediments	Sands and gravels	Typical thickness 6 – 10 m. Based on LiDAR bare-earth data, may extend to about 300 m above Town of Gibsons in some locations and as high as 440 m on slopes above Roberts Creek.	Discontinuous on lower slopes. Late Fraser glaciation glaciofluvial outwash deltaic deposits into elevated 180 m asl sea level. Overlies Vashon Till. Local gravel pits are located in these deposits.
	Vashon till/drift	Fraser Glaciation	Basal till (pockets of glaciofluvial and glaciolacustrine sediments)	Consolidated, primarily sandy till with coarse fragments (with minor silt and clay). Statlu (2018) noted cemented (placic) layers at 1.0 m to 1.2 m depth.	Generally found as a blanket (a few metres thick) overlying bedrock, thinning to a veneer with elevation. Found primarily below 1,000 m. Overlies bedrock.	Overlies bedrock.
Southwest-facing slopes below 180 m elevation	Salish Sediments	Post-glacial (Holocene) Sediments (younger than about 11,000 years)	Alluvial sediments and colluvium	Sands and gravels	Variable, 1 m to several metres	Floodplain deposits in creeks and fans on lower slopes. May overlie Capilano and Vashon sediments.
	Upper Capilano	Late-stage Fraser Glaciation (iso-static rebound of land)	Glaciofluvial sediments	Sands and gravels	Variable, 0 to 10 m thick.	Late Fraser glaciofluvial outwash and deltaic sediments deposited during late glacial sea level lowering from 180 m asl to present day levels. Discontinuous cover over Capilano glaciomarine sediments. Local gravel pits are located in these deposits.
	Lower Capilano	Late-stage Fraser Glaciation (weight of glaciers compressed the land up to 180 m on the Sunshine Coast)	Glaciomarine and marine sediments	Stony, till-like clay. Roberts Creek aquitard	Variable (a few centimetres up to several metres thick). Overlies Vashon till.	Up to 180 m elevation.
	Vashon till	Fraser Glaciation	Basal till (pockets of glaciofluvial and glaciolacustrine sediments)	Highly consolidated, primarily sandy till with coarse fragments (with minor silt and clay). Low permeability, forms cap (aquitard) over Roberts Creek aquifer	Variable, commonly 1 m to 4 m but may be locally thicker. Likely overlies bedrock. It is possible there are pockets of pre-Vashon materials underlying this till unit.	This layer exists throughout most of the region although it is possible there are gaps.
Southeast-facing slopes below 180 m (i.e., Upper Gibsons Bench)	Salish Sediments	Post-glacial (Holocene) Sediments (younger than about 11,000 years)	Alluvial sediments and colluvium	Sands and gravels	Variable, 1 m to several metres	Floodplain deposits in creeks and fans on lower slopes. May overlie Capilano and Vashon sediments (possibly Quadra sands where creeks are deeply incised.
	Upper Capilano Sediments (perched water table in these sediments in Upper Gibsons area, Capilano Aquifer	Late-stage Fraser Glaciation (iso-static rebound of land)	Glaciofluvial sediments	Sands and gravels	Variable, generally 6 to 10 m thick.	Late Fraser glaciofluvial outwash and deltaic sediments deposited during late glacial sea level lowering from 180 m to present day levels. Discontinuous cover over Capilano glaciomarine sediments. Local gravel pits are located in these deposits.
	Lower (Basal) Capilano Sediments	Late-stage Fraser Glaciation (weight of glaciers compressed the land up to 180 m asl on the sunshine coast)	Glaciomarine and marine sediments	Stony, till-like clay. Part of the Gibson’s Aquitard).	Variable (a few centimetres to up to 9 m thick). Overlies Vashon till	Up to 180 m elevation.
	Vashon till / drift (Gibson Aquitard)	Fraser Glaciation	Basal till (pockets of glaciofluvial and glaciolacustrine sediments)	Highly consolidated, primarily sandy till with coarse fragments (with minor silt and clay). Low permeability, forms cap (aquitard) of variable thickness over the pre-Vashon sands and gravels.	Variable, commonly 1 m to 4 m but can be up to 30 m. (may overlie bedrock where glaciers eroded away pre-Vashon sediments). Vashon till cap is absent in some locations.	This layer exists throughout most of the region although it is possible there are gaps.
	Pre Vashon (Quadra Sands)– upper unit, Gibsons (confined) Aquifer	Transition of pre to early Fraser Glaciation	Fluvial deposits	Sands and gravels, likely deposited in a series of coalescing river deltas	Commonly 40 m thick in Gibsons Aquifer, 12 to 18 m thick in Chaster Creek	Visible in Langdale and Chaster Creeks otherwise only recorded in well logs. Around the Strait of Georgia, occurs generally at elevations less than 100 m elevation.
	Pre-Vashon - lower unit	Pre-Fraser glaciation (Olympia nonglacial interval – older than 29,000 years ago)	Marine deposits	Laminated, stony clays deposited during a period of marine submergence, overlies bedrock		

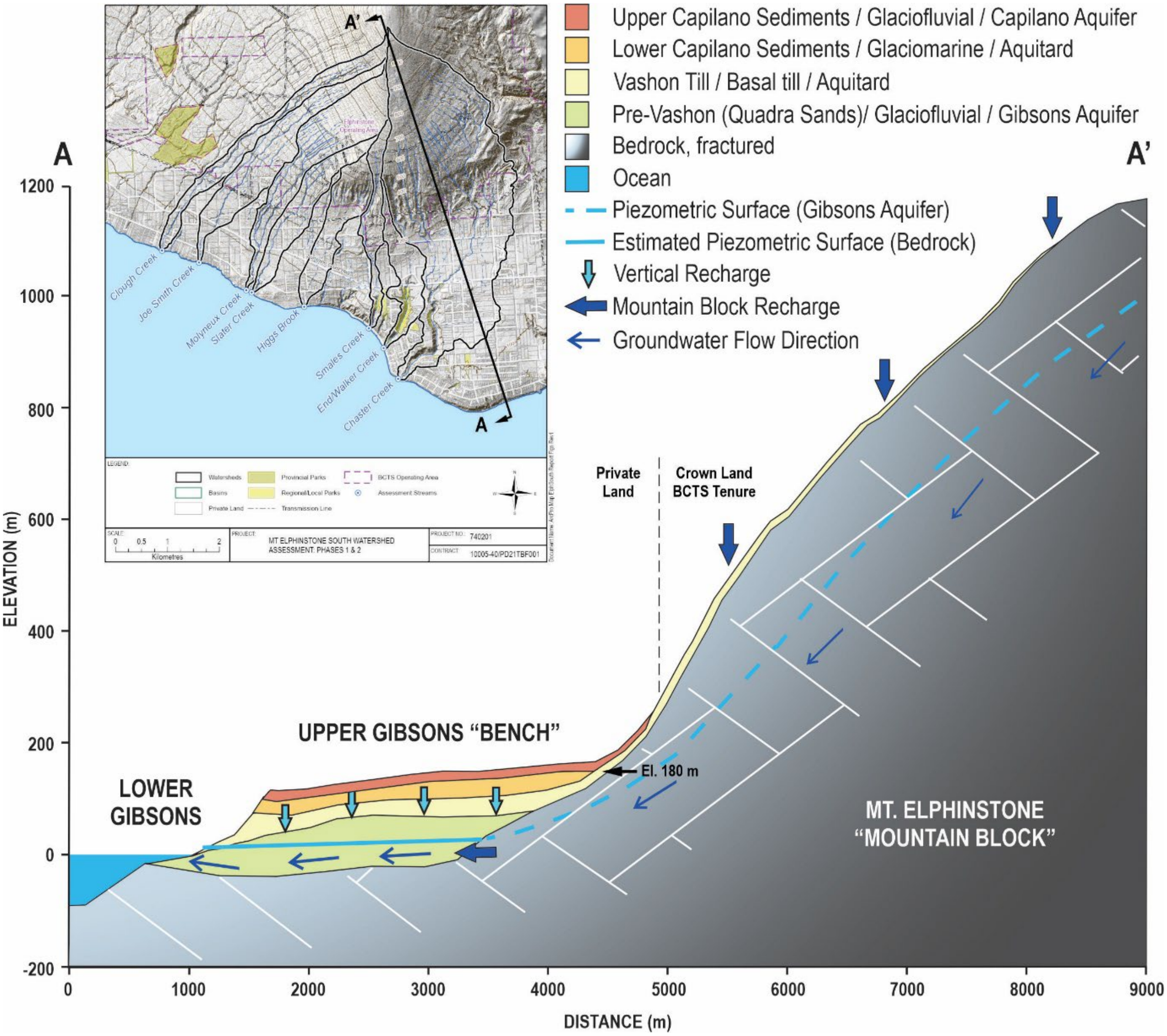


FIGURE 4.10 *Simplified cross-section down the approximate center-line of the Chaster Creek watershed (not to scale). Adapted from Doyle (2013). Post-glacial Salish sediments (uppermost strata) and pre-Vashon marine sediments (lowermost strata above bedrock) are not shown.*

4.5. BIOGEOCLIMATIC ZONES

Forests within the assessment area primarily lie within the Coastal Western Hemlock biogeoclimatic zones, with only a small portion at highest elevations in the Mountain Hemlock zone (TABLE 4.1, FIGURE 4.11). The following summary is from Green and Klinka (1994).

The Mountain Hemlock Windward Moist Maritime (MH mm1) subzone is located at high elevations in maritime areas of the mainland coast. The lower elevational limit is between 800 m and 1,000 m and the upper limit is between 1,100 m and 1,350 m. It is characterized by long, wet cold winters and short, cool moist summers. Annual precipitation is typically on the order of 2,600-2,900 mm[59], with snowfall accounting for about 30%. The substantial snowpack can persist into July. Forests are dominated by amabilis fir (Ba) and mountain hemlock (Hm) and to a lesser extent yellow cedar (Yc). In the assessment area MH mm1 occupies 24 ha or 1% of the assessment area.

The Coastal Western Hemlock Montane Very Wet Maritime Variant (CWH vm2) is generally located between 650 m and 1,000 m and grades into the Mountain Hemlock zone above. It is characterized by wet, humid climate with cool short summers and cool winters. Annual precipitation in the CWH vm2 is typically slightly lower than in the MH mm1 subzone, with a smaller proportion falling as snow. Forests tend to be dominated by Western Hemlock (Hw), amabilis fir (Ba) and to a lesser extent western red cedar (Cw), yellow cedar (Yc), and mountain hemlock (Hm).

The Coastal Western Hemlock Dry Maritime Subzone (CWH dm) tends to occur below 650 m elevation and has warm, relatively dry summers and moist, mild winters with little snowfall. Annual precipitation is on the order of 1,860 mm, with snowfall accounting for only 5%. Forests are dominated by Douglas-fir (Fd), western red cedar (Cw) and Western Hemlock (Hw).

The Coastal Western Hemlock Very Dry Eastern Variant (CWH xm1) is generally located from sea level to approximately 150 m elevation in the assessment area and has warm, dry summers and moist, mild winters with relatively little snowfall. Snowfall often accounts for less than 5% of annual precipitation. Forests are dominated by Douglas-fir (Fd), accompanied by Western Hemlock (Hw) and minor amounts of western red cedar (Cw).

---

[59] These precipitation estimates are broad generalizations for the BEC subzone. Recorded precipitation presented in Section 4.6 is considered a more accurate representation of precipitation in the assessment area. Additionally, the BEC zone climate estimates are based on climate normal from the past, which may differ somewhat from current conditions.

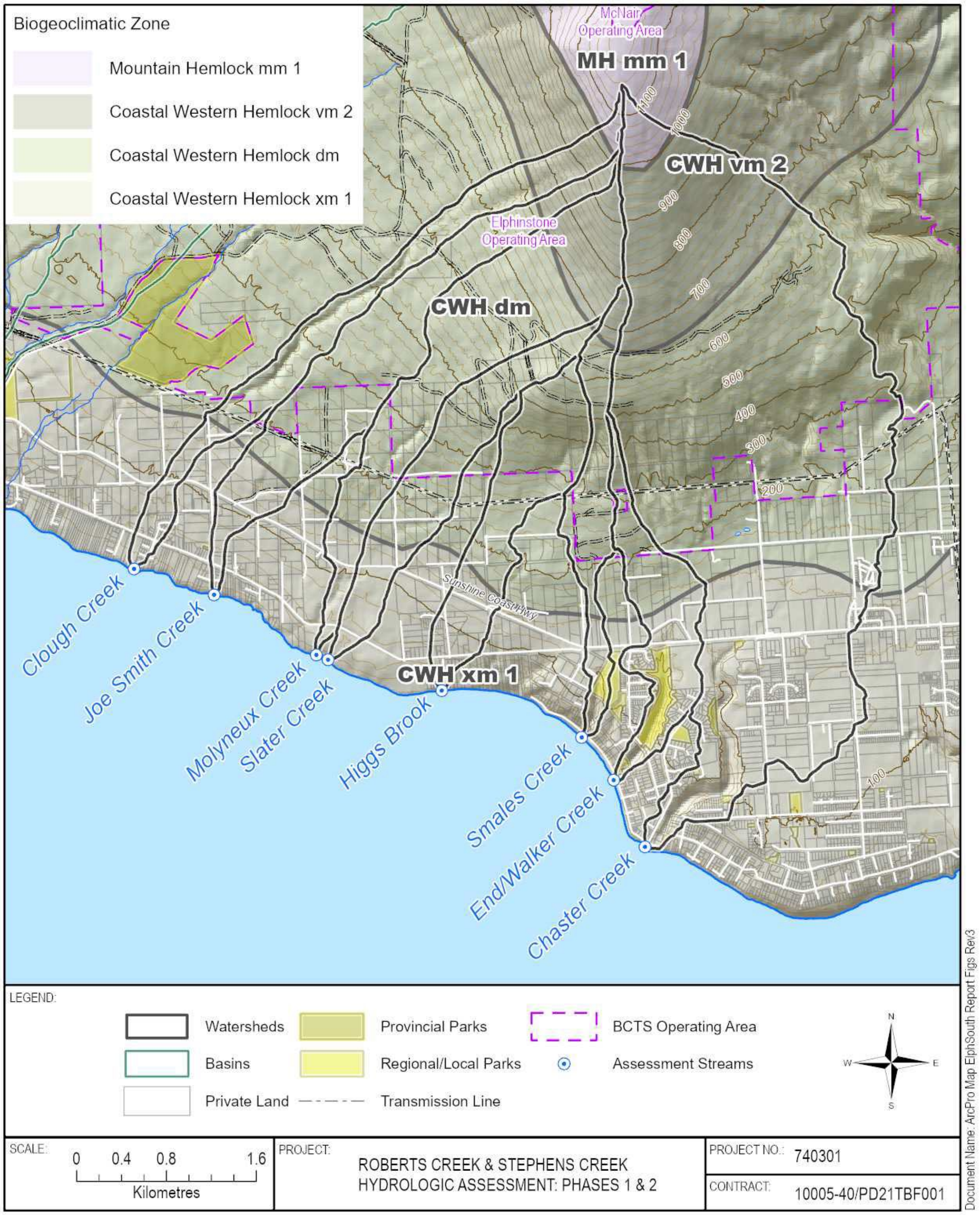


FIGURE 4.11 *Biogeoclimatic zones in the assessment area.*

The BEC subzone variants are a good proxy for identifying areas where the removal of forest cover may have a disproportional effect on flow. In general, the wetter and colder the variant, the greater the potential for forest harvesting to increase streamflow. As such, the MH mm1 and CWH vm2 subzones are considered more sensitive to forest cover removal than the drier subzones in the lower portion of the assessment area.

4.6. CLIMATE

The assessment area lies within a coastal maritime climate that experiences relatively warm dry summers and mild wet winters. Snowfall occurs occasionally throughout the winter with transient snowpacks developing at middle- and upper-elevations. Seasonal snowpacks can develop at high elevations; however, this varies considerably from year to year. Similarly, snow on the ground at sea-level is not common, although does occur occasionally. To illustrate the inter-annual variability in snow cover across the assessment area, remotely sensed snow cover data from the National Operational Hydrologic Remote Sensing Center[60] is presented for two years in FIGURE 4.12.

According to the Pacific Climate Impacts Consortium (PCIC) data portal[61], 13 weather stations have operated along the Sunshine Coast between Langdale and Sechelt (TABLE 4.3). Of these stations, only two are currently operating: Gibsons Gower Point (Environment Canada Station 1043152, El. 34 m, 1961-present) and TS Elphinstone (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Wildfire Management Branch Station 1002, El. 593 m, 2008-present) (MAP 1). The former is generally representative of lower elevations whereas the latter is representative of mid elevations in the assessment area.

The available weather data at Gibsons Gower Point and TS Elphinstone demonstrate that temperature patterns are relatively consistent in the area although elevation differences result in daily temperature difference with elevation by a few degrees on average (FIGURE 4.13). The available data also show that precipitation patterns are similar, both reflecting wet winters and dry summers (FIGURE 4.14). The higher elevation TS Elphinstone station, however, tends to receive about 40% greater precipitation annually than the Gower Point station. It is important to note that these stations aren't equipped to measure snow, and therefore provide no indication of total snowfall or how often snow is on the ground.

Rainstorms can occur throughout the year; however, they are more prevalent in fall and winter as a result of frontal systems off the Pacific Ocean (FIGURE 4.15). At Gibsons Gower Point, the likelihood of a 24-hour storm in excess of 25 mm varies from 0.5% in June to 5.9% in November.

---

[60] https://www.nohrsc.noaa.gov/interactive/html/map.html

[61] https://www.pacificclimate.org/data/bc-station-data

At the higher elevation TS Elphinstone station, the same likelihood ranges from 1.1% in May to 9.7% in December. 24-hour storms in excess of 50 mm are rare at Gibsons Gower Point and have a 1-2% likelihood of occurrence at TS Elphinstone between August and April. 24-hour storms in excess of 50 mm have not been observed at either weather station between May and July.

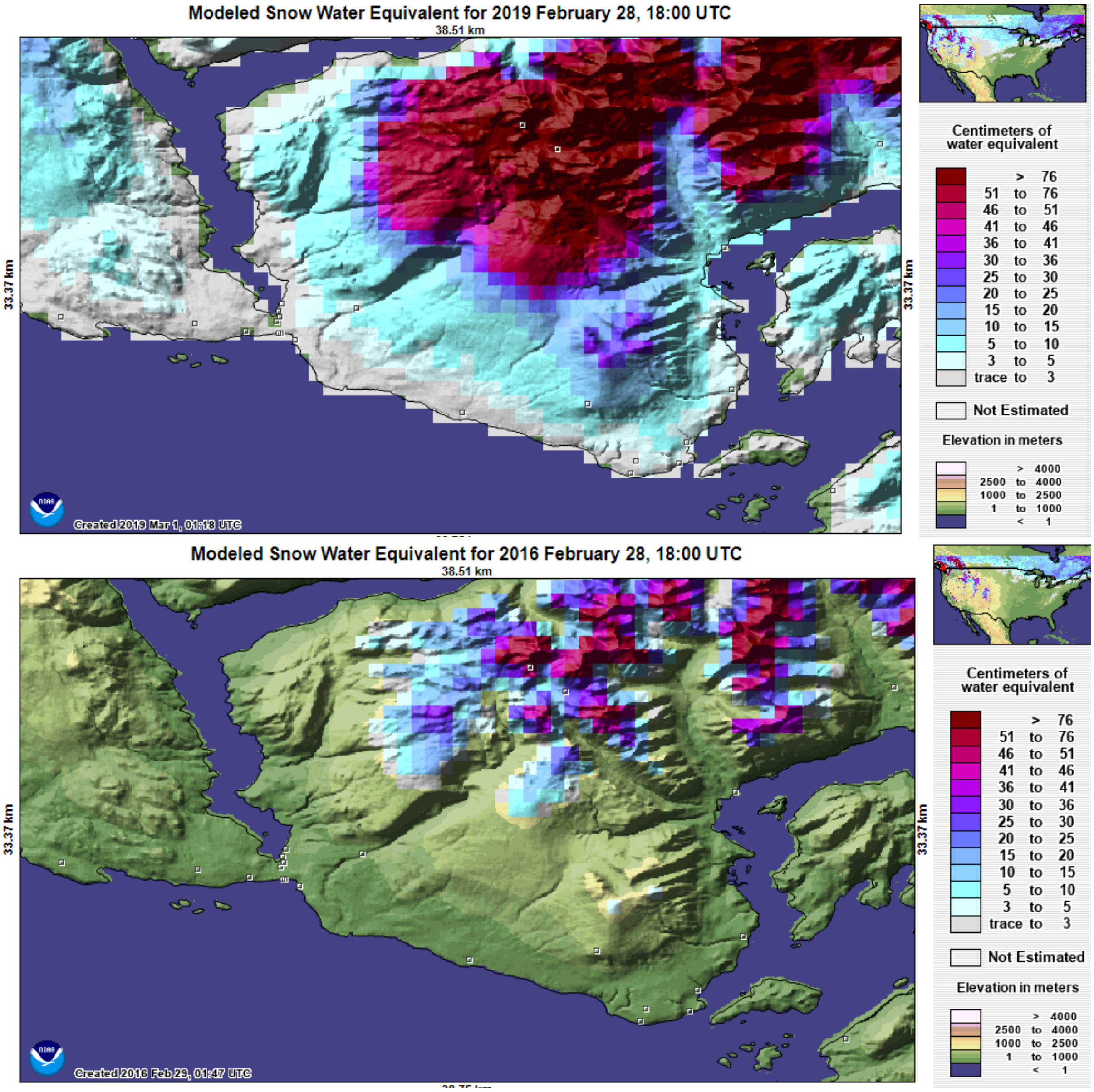


FIGURE 4.12 *Remotely sensed snow cover data for the assessment area. The upper plot shows snow cover for the end of February 2019. The lower plot shows snow cover for the same day in 2016. Maps sourced from National Operational Hydrologic Remote Sensing Center.*

TABLE 4.3 *Weather stations along the Sunshine Coast between Langdale and Sechelt (PCIC station data portal, 2021).*

Network Name	Native ID	Station Name	Lat.	Long.	Elev. (m)	Record Start	Record End
ARDA	104408	EXASPERATED	49.463	-123.714	110	1973-06-06	1975-11-20
ARDA	104327	HOOKED	49.438	-123.664	82	1973-09-28	1975-12-16
ARDA	104417	JOE SMITH CK	49.418	-123.570	290	1974-10-30	1975-12-16
ARDA	104307	ROBERTS PARK	49.433	-123.623	125	1973-05-30	1975-12-16
EC	1043150	GIBSONS	49.400	-123.517	62	1949-02-08	2006-07-31
EC	1043152	GIBSONS GOWER POINT	49.386	-123.541	34	1961-10-01	present
EC	1046791	ROBERTS CREEK	49.400	-123.683	4	1924-01-01	1942-11-30
EC	1046795	ROBERTS CREEK EAST	49.433	-123.617	143	1956-02-01	1960-12-31
EC	1047172	SECHELT	49.450	-123.700	86	2007-08-02	2017-12-31
ENV-AQN	M104273	LANGDALE FERRY TERMINAL	49.434	-123.472	15	1987-09-11	2016-08-09
FLNRORD-WMB	46	SECHELT ORCHARD	49.450	-123.719	75	1999-09-27	2009-11-04
FLNRORD-WMB	1002	TS ELPHINSTONE	49.428	-123.565	593	2008-03-08	present
MOTIm	12001	GIBSONS	49.407	-123.532	140	1988-10-31	1995-03-31

ARDA: Agricultural and Rural Development Act Network; EC: Environment Canada; ENV-AQN: BC Ministry of Environment; Air Quality Network; FLNRORD-WMB: BC Ministry of Forests, Lands, and Natural Resource Operations - Wildfire Management Branch; MOTIm: Ministry of Transportation and Infrastructure (manual).

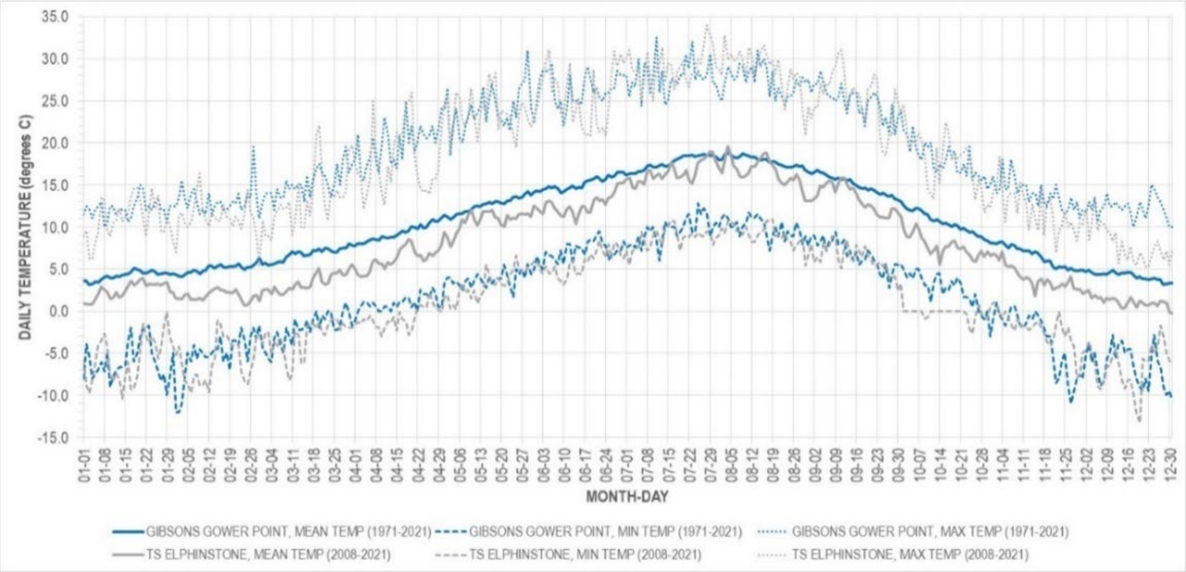


FIGURE 4.13 *Daily minimum, maximum and mean temperatures for Gibsons Gower Point (EC 1043152, El. 34 m, 1971-2021) and TS Elphinstone (FLNORD-WMB 1002, El. 593 m, 2008-2021).*

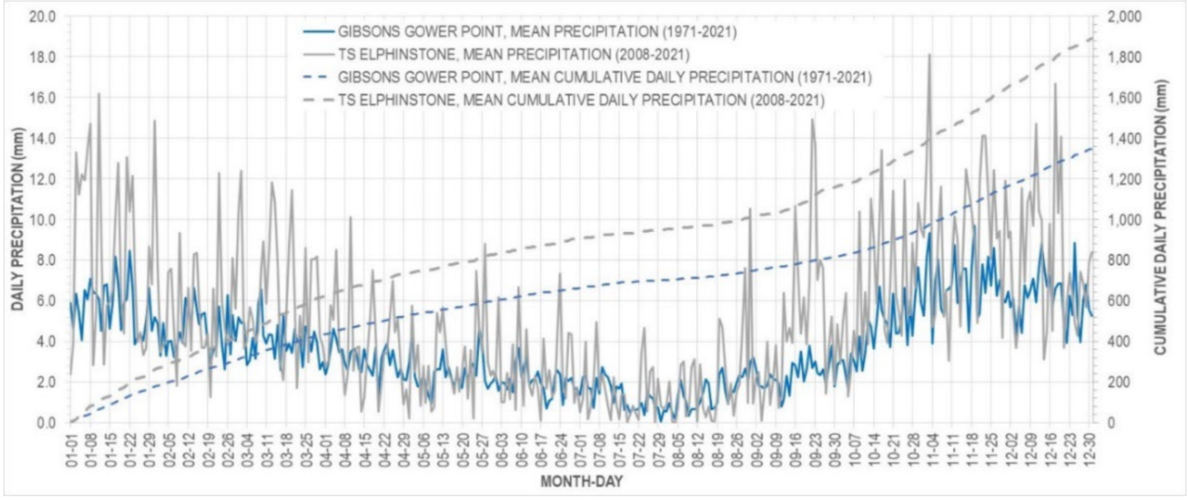


FIGURE 4.14 *Mean daily precipitation and cumulative daily precipitation for Gibsons Gower Point (EC 1043152, El. 34 m, 1971-2021) and TS Elphinstone (FLNORD-WMB 1002, El. 593 m, 2008-2021).*

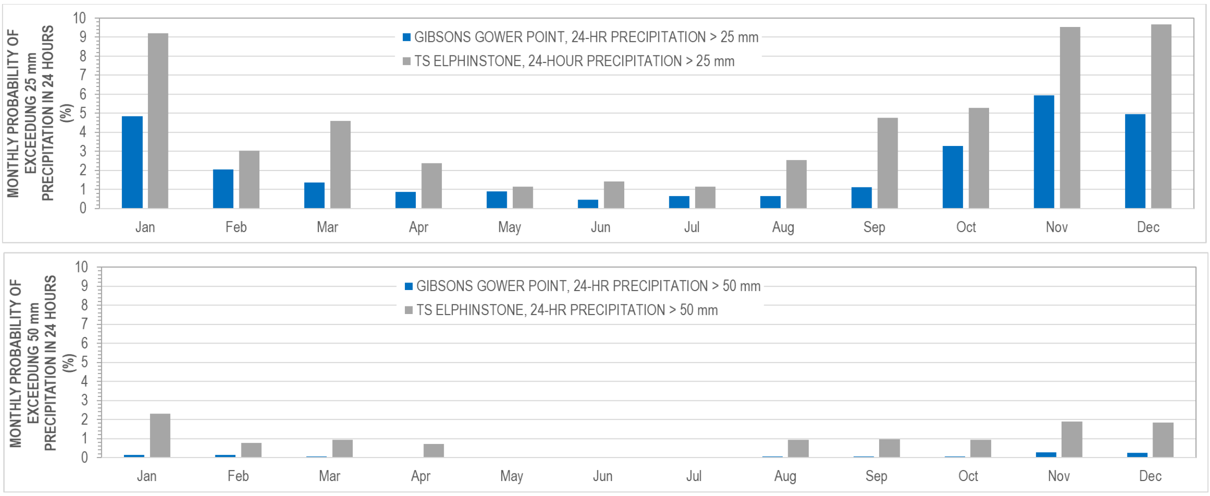


FIGURE 4.15 *Monthly probability of daily precipitation exceeding 25 mm (upper plot) and 50 mm (lower plot) on a monthly basis for Gibsons Gower Point (EC 1043152, El. 34 m, 1971-2021) and TS Elphinstone (FLNORD-WMB 1002, El. 593 m, 2008-2021).*

In order to characterize the climate throughout the assessment area, climate normals (for 1991-2020) were estimated using ClimateBC (version 7.30), an application that uses available weather station data and adjusts these to account for location, elevation and other factors (Wang et al., 2022). Historical climate normals were extracted at representative locations and elevations. This includes the following locations (TABLE 4.4, FIGURE 4.16, MAP 1):

- 150 m West: 49.415806°, -123.585478°, El. 150 m;
- 150 m East: 49.411449°, -123.536288°, El. 150 m;

- 550 m West: 49.429574°, -123.569038°, El. 550 m;
- 550 m East: 49.428034°, -123.543003°, El. 550 m; and
- 1,000 m: 49.444345°, -123.554066°, El. 1,000 m.

At lower elevations, as represented by “150 m West” and “150 m East”, monthly mean temperatures are estimated to range from 4.0 °C in December to 17.8 °C in August. Annual precipitation ranges from 1,359 to 1,493 mm, of which about 3% falls as snow. At mid elevations, represented by “550 m West” and “550 m East”, monthly mean temperatures range from 0.4 °C in December to 16.3 °C in August. Annual precipitation is estimated at 1,944 mm, with 6% of that falling as snow. At higher elevations, as represented by “1,000 m”, mean monthly temperatures range from -0.5 °C in December to 14.8 °C in August. Annual precipitation is estimated to be 2,442 mm with 13% of that as snow. These data indicate that rainfall and to a lesser extent rain-on-snow are the dominant drivers of runoff in the assessment watersheds. However, it is important to recognize that the amount of precipitation as snow is represented as an average. As illustrated in FIGURE 4.12, there is tremendous variability in snow cover from year to year. Even though only a relatively small percentage of annual precipitation falls as snow, the snowfall typically occurs over a short period and has the potential to melt quickly, particularly during a warm rain-on-snow event (William Floyd pers. comms., 2023).

Under normal conditions, the assessment area is expected to have a climate moisture deficit (i.e., evapotranspiration exceeds precipitation) during summer. On average, lower elevations are expected to have a moisture deficit typically between May and August, whereas mid and upper elevations are typically in deficit in July and August (Wang et al., 2022). However, exceptions can occur (e.g., fall of 2022), where deficits persist well into the fall. This can have a direct influence on streamflows in late summer and fall.

When considering the effects of storms on peak flows and other hydrogeomorphic hazards, it is also important to consider shorter storm durations that occur over hours and days. Modelled precipitation for storms of different durations and intensities are summarized in TABLE 4.6. These data, which represent current conditions and future projections (discussed below) are derived from climate modelling by Western University (2021).

TABLE 4.4 *1991-2020 climate normals for representative elevation bands in the assessment area. Source: Wang et al. (2022).*

Month	**ID**	**150 m West**			**150 m East**			**550 m West**			**550 m East**			**1,000 m**		
	lat.	49.415806°			49.411449°			49.429574°			49.428034°			49.444345°		
	long.	-123.585478°			-123.536288°			-123.569038°			-123.543003°			-123.554066°		
	elev.	150 m			150 m			550 m			550 m			1,000 m		
		Mean Temp (°C)	**Min Temp (°C)**	**Max. Temp (°C)**	**Mean Temp (°C)**	**Min Temp (°C)**	**Max. Temp (°C)**	**Mean Temp (°C)**	**Min Temp (°C)**	**Max. Temp (°C)**	**Mean Temp (°C)**	**Min Temp (°C)**	**Max. Temp (°C)**	**Mean Temp (°C)**	**Min Temp (°C)**	**Max. Temp (°C)**
Jan		4.2	1.8	6.6	4.1	1.7	6.5	2.6	0.6	4.6	2.4	0.3	4.5	0.8	-0.8	2.5
Feb		4.9	1.8	8.0	4.9	1.8	8.1	3.5	0.4	6.5	3.2	0.2	6.2	1.7	-1.1	4.5
Mar		6.3	2.8	9.8	6.4	2.8	10	4.5	1.5	7.5	4.4	1.3	7.5	2.4	0.0	4.8
Apr		9.0	4.9	13	9.0	4.9	13.2	7.1	3.6	10.6	7	3.3	10.7	5	2.0	7.9
May		12.6	8.2	17.1	12.7	8.2	17.2	10.9	6.9	14.8	10.7	6.5	14.9	8.8	5.3	12.2
Jun		14.9	10.7	19.2	15.0	10.6	19.4	13.2	9.3	17.0	13.0	9.0	17.0	11.1	7.7	14.4
Jul		17.5	13	22	17.6	13	22.1	16.1	11.9	20.2	16.0	11.6	20.3	14.4	10.5	18.2
Aug		17.7	13.2	22.2	17.8	13.2	22.4	16.3	12.2	20.5	16.3	11.9	20.6	14.8	11	18.6
Sep		14.7	10.6	18.8	14.8	10.6	19.0	13.5	9.7	17.3	13.4	9.5	17.4	12.1	8.6	15.5
Oct		10.1	7.0	13.2	10.1	7.0	13.3	8.6	5.9	11.4	8.5	5.7	11.4	7.0	4.7	9.2
Nov		6.3	3.6	9.1	6.3	3.6	9.1	4.6	2.4	6.9	4.5	2.1	6.9	2.7	0.9	4.5
Dec		4.1	1.7	6.5	4.0	1.6	6.4	2.4	0.4	4.4	2.2	0.1	4.3	0.5	-1.1	2.1
Annual		**10.2**	**-**	**-**	**10.2**	**-**	**-**	**8.6**	**-**	**-**	**8.5**	**-**	**-**	**6.8**	**-**	**-**
		Mean Precip. (mm)	**Precip. as snow (mm water equiv.)**	**Climatic moisture deficit (mm)**	**Mean Precip. (mm)**	**Precip. as snow (mm water equiv.)**	**Climatic moisture deficit (mm)**	**Mean Precip. (mm)**	**Precip. as snow (mm water equiv.)**	**Climatic moisture deficit (mm)**	**Mean Precip. (mm)**	**Precip. as snow (mm water equiv.)**	**Climatic moisture deficit (mm)**	**Mean Precip. (mm)**	**Precip. as snow (mm water equiv.)**	**Climatic moisture deficit (mm)**
Jan		200	11	0	207	12	0	284	27	0	274	28	0	356	64	0
Feb		131	5	0	141	6	0	187	15	0	184	17	0	232	41	0
Mar		135	3	0	147	3	0	202	15	0	198	16	0	258	61	0
Apr		93	1	0	97	1	0	152	7	0	146	7	0	206	31	0
May		67	0	21	72	0	17	104	2	0	103	2	0	137	7	0
Jun		57	0	39	59	0	39	87	0	0	84	0	4	113	2	0
Jul		34	0	72	36	0	71	55	0	44	56	0	44	75	1	15
Aug		38	0	53	43	0	50	48	0	37	50	0	36	55	1	22
Sep		71	1	0	75	1	0	114	2	0	110	2	0	153	4	0
Oct		139	1	0	165	1	0	188	2	0	198	2	0	227	5	0
Nov		209	8	0	238	10	0	285	22	0	289	24	0	344	53	0
Dec		183	9	0	213	10	0	240	23	0	250	26	0	285	56	0
Annual		**1,359**	**40**	**-**	**1,493**	**44**	**-**	**1,944**	**115**	**-**	**1,943**	**124**	**-**	**2,442**	**325**	**-**

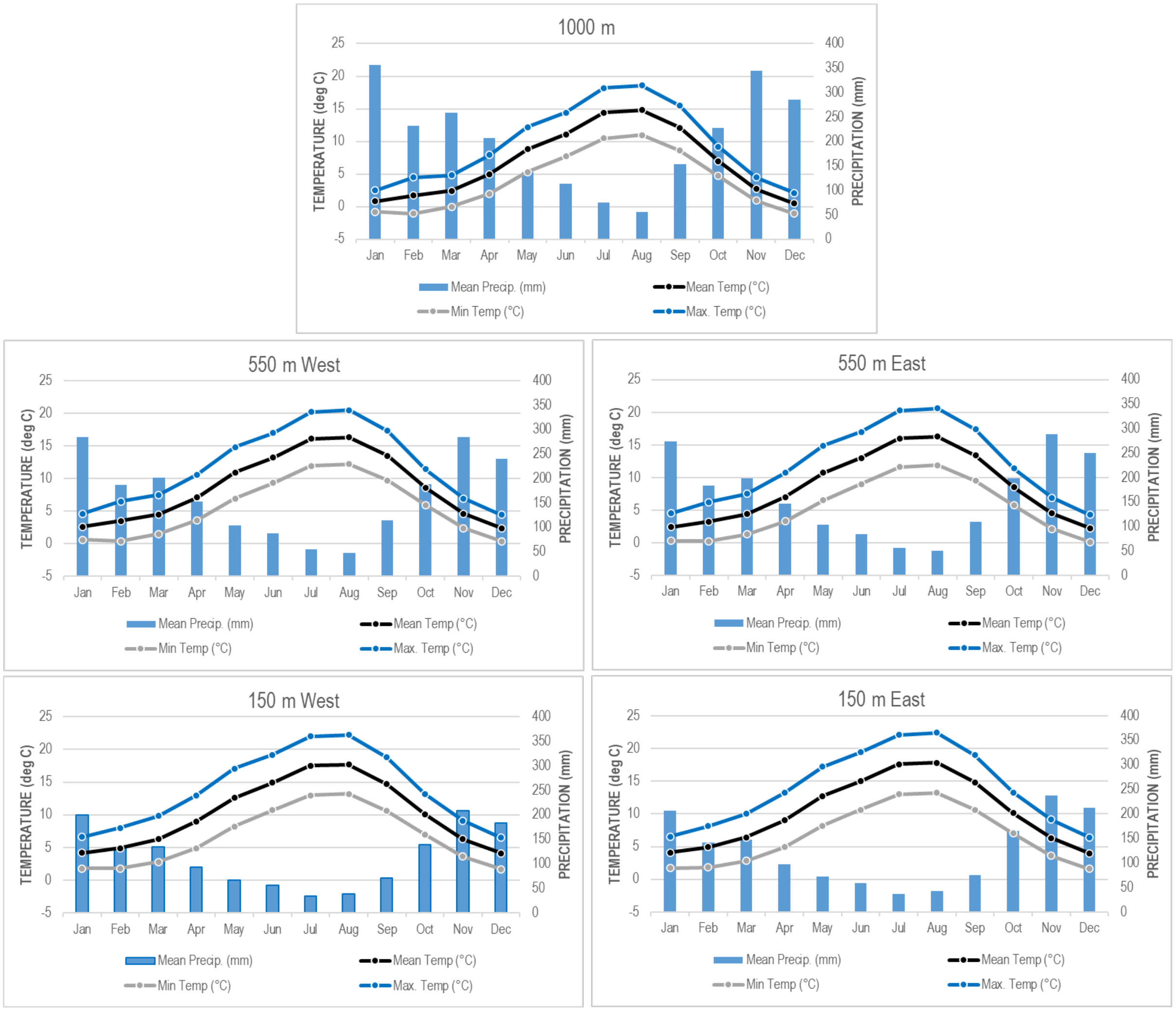


FIGURE 4.16 *1991-2020 climate normals for representative locations in the assessment area.*

4.7. CLIMATE VARIABILITY & CHANGE

4.7.1. El Niño/Southern Oscillation & Pacific Decadal Oscillation

In addition to climate variations associated with elevation (i.e., location) and seasons, the climate on the Sunshine Coast is influenced by large-scale atmospheric circulation patterns that occur over inter-annual time scales. The two most important are the Pacific Decadal Oscillation (PDO) and the El Niño/Southern Oscillation (ENSO) (BC MWLAP, 2002). The PDO pattern is known to fluctuate between warm and cold phases roughly every 20-30 years. The ENSO relates to changing ocean currents and atmospheric pattern in the Indian and Pacific Oceans and predominantly impacts winter conditions every few years (Nelson et al., 2012). The cold, wet phase of the ENSO is known as a *La Niña* and the warm, dry phase of the ENSO is known as the *El Niño.*

There are six combinations of the PDO (cool and warm) and ENSO (cool, neutral, warm) phases that have been historically observed that affects regional climate. The potential for precipitation and temperature extremes tends to be greater when PDO and ENSO are in-phase. For example, when both PDO and ENSO are experiencing a cool phase more snow tends to accumulate, and conversely, when both PDO and ENSO are in the warm phase there tends to be a thinner snowpack. There is relatively poor predictive ability when PDO and ENSO are in opposite phases (e.g., cool-warm or warm-cool) (Wang et al., 2014). Patterns of ENSO and PDO between 1979 and 2020 are shown in FIGURE 4.17.

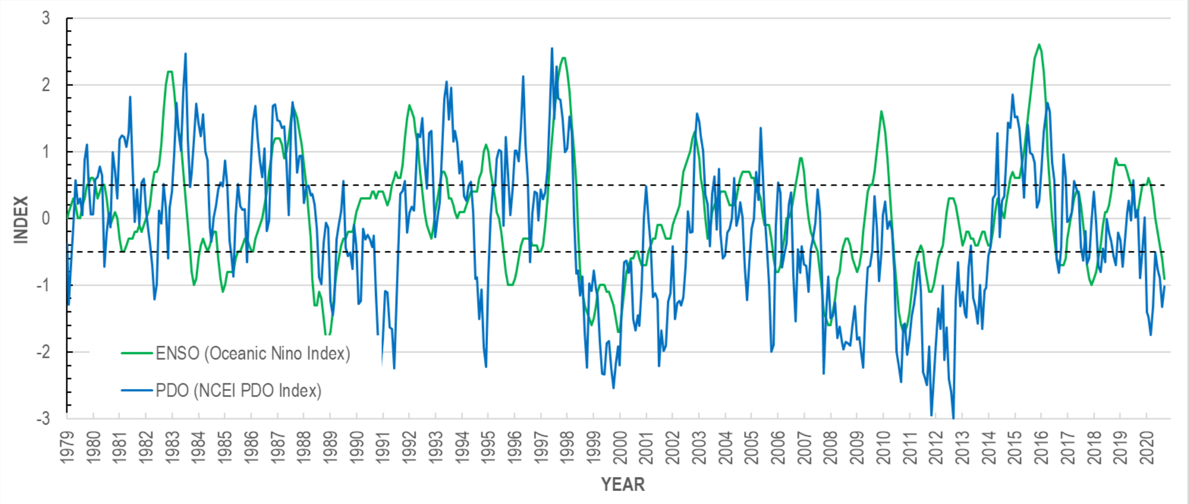


FIGURE 4.17 *ENSO and PDO Index patterns from 1979 – 2020. Horizontal lines roughly indicate boundaries between warm (> 0.5), neutral (0.5 to – 0.5), and cool (< -0.5) phases. ENSO data from NOAA (2020a) and PDO data from NOAA (2020b).*

4.7.2. Climate Change

There is scientific consensus that the Earth's climate is changing, primarily due to greenhouse gas emissions. This change has and will continue to affect the climate of the South Coast. According to the Pacific Climate Impacts Consortium (PCIC, 2013), warming has already occurred over the last century in all seasons in the region. A report by the British Columbia Ministry of Environment (BC MOE, 2016) indicates that the assessment area has experienced an increase average precipitation by 14% per century from 1900 to 2013. However, climate trend analyses in the Pacific Northwest suggest that summertime precipitation has been decreasing over the last several decades, resulting in increased drought (Abatzoglou et al., 2014; Kormos et al., 2016). Such effects have been realised locally as the Sunshine Coast has experienced Stage 4 "Severe" drought in five of the past eight years. The worst of which occurred in the fall of 2022, forcing the Sunshine Coast

Regional District to declare a state of local emergency that banned non-essential commercial water-use (MacDonald, 2022). Enso conditions over the past eight years have been largely neutral suggesting the drought conditions may be driven by climate change.

Understanding future climate scenarios is generally conducted by analyzing the output of a number of global climate models. The Plan2Adapt tool[62] uses an ensemble of 12 different global climate models (GCMs)[63], each using one run of the RCP 8.5 (high emissions) greenhouse gas emissions scenario[64]; this set of projections is referred to as the "ensemble" (PCIC, 2021). These projections are statistically downscaled using empirical climate data to produce predictions at a 4 km resolution. Projections for the Sunshine Coast are summarized in TABLE 4.5. The mean value derived from the ensemble of climate model projections suggests the mean annual temperature is currently (i.e., 2020’s) 1.6 °C higher than the 1961-1990 mean annual temperature and will be 3.0 °C higher by the 2050s and 4.7 °C higher by the 2080s.

TABLE 4.5 *Summary of climate change projections for the Sunshine Coast. Refer to PCIC (2021) for details on climate modelling and down-scaling method.*

Climate Variable	Season	Projected change from 1961-1990 period			
		by 2050s[65]		by 2080s[66]	
		Median	Range	Median	Range
Mean Temperature (°C)	Annual	+3.0°C	+2.0°C to +4.1°C	+4.7°C	+3.5°C to +6.4°C
Precipitation (%)	Annual	-1.0%	-5.0% to +3.4%	+4.8%	-4.5% to +10%
	Summer	-13%	-40% to +1.4%	-22.0%	-55% to -5.7%
	Winter	+0.97%	-4.0% to +5.4%	+9.7%	-3.5% to +17%
Snowfall (%)[67]	Annual	-54%	-61% to -45%	-75%	-83% to -57%
	Winter	-56%	-59% to -45%	-69%	-81% to -54%
	Spring	-58%	-68% to -38%	-83%	-91% to -55%

---

[62] Accessible at: Plan2Adapt.ca. All projections are referenced to the 1961-1990 period.

[63] Each GCM comes from a different modelling centre (e.g., the Hadley Centre (UK), National Centre for Atmospheric Research (USA), Geophysical Fluid Dynamics Laboratory (USA), and Commonwealth Scientific and Industrial Research Organisation (Australia).

[64] By the end of the 21st century, the RCP 8.5 scenario from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) includes an atmospheric concentration of greenhouse gases, expressed as carbon dioxide (CO2) equivalent, of approximately 950 ppm.

[65] Refers to period 2040-2069.

[66] Refers to period 2070-2099.

[67] This variable may have a low baseline value. 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. In other words, given the low proportion of precipitation as snow on ***average***, a small change in magnitude can translate into a large relative change (i.e., change in %).

Projected precipitation changes have relatively higher uncertainty than temperature changes, partly due to the challenges of modelling complex terrain in BC. Nevertheless, general trends from these modelling results indicate that on an annual basis precipitation may increase slightly by the 2080s. However, the models suggest a shift towards drier summers and wetter winters, with a greater proportion of rain falling instead of snow at higher elevations. These projections are based on relatively coarse spatial data and present one average response for the Sunshine Coast. One study projected similar precipitation trends for Campbell River on Vancouver Island, BC, with increased precipitation in the winter and a decrease in the summer (Zwiers et al., 2011). However, the authors noted greater uncertainty in the projected magnitude of change for winter versus summer precipitation. Due to differences in elevations throughout the Sunshine Coast, there will likely be considerable variation in terms of how a specific watershed responds to climate change. The highest elevations in the assessment watersheds, which already receive limited annual snowfall, are projected to receive even less in the future as precipitation falls increasingly in the form of rain as opposed to snow. As a result, the hydrologic regime of the assessment streams will be increasingly dominated by rainfall (Islam et al., 2017; 2019; Jeong and Sushama, 2017). However, there is still a possibility for more frequent anomalous snowfall with the shift in weather patterns, resulting in snow still occurring to sea level on occasion (William Floyd pers. comms., 2023).

Given the relatively limited storage available in the assessment watersheds (i.e., in soils and as groundwater), streamflow changes are expected to reflect precipitation changes with increases expected during winter (up to 9.7% more by the 2080s, largely in the form of rain) and reductions during summer (as much as 22.0% less by the 2080s). The recent drought conditions and state of local emergency experienced on the Sunshine Coast in late summer and fall 2022 provide some indication of the possible adverse effects of such reductions in precipitation[68].

Climate warming is also projected to increase high-intensity precipitation (Burn et al., 2011), which has potential to result in a greater frequency and magnitude of flooding (Sobie, 2020). For example, in their evaluation of the human influence on the November 14, 2021 British Columbia floods, Gillett et al. (2022) concluded that human-induced climate change has increased the probability of such extreme streamflow events by roughly 120-330%. Sharma and Déry (2019) found a statistically significant increase in the frequency of landfalling atmospheric rivers between 1979 and 2016. Moreover, they found a higher likelihood of occurrence of such events during neutral ENSO phases and positive phases of the PDO (Sharma and Déry, 2019). Moreover, Murdock et al. (2016) found that for Metro Vancouver, three-hour extreme precipitation events that would normally be exceeded every ten years (i.e., ten-year return period), are projected to occur almost every three years by the 2050s.

---

[68] https://vancouversun.com/news/local-news/sunshine-coast-drinking-water-supply-issues-culminate-in-state-of-emergency

The intensity of precipitation events is commonly evaluated using intensity-duration-frequency (IDF) curves, that show the relationship between storm intensity and magnitude of precipitation that is expected for a given return period. The IDF_CC tool (Western University, 2021) provides estimates for how IDF curves will change into the future, given a number of different greenhouse gas emissions scenarios. It bases these estimates on gauge data (i.e., Gibsons, Environment Canada Station 1043150) along with downscaled global climate models (Schardong et al., 2020).

TABLE 4.6 presents the estimated total precipitation for a range of storm durations and return periods (i.e., magnitude) under "current" conditions at Gibsons. In addition, the table presents projected storm-related precipitation totals for the 2050s and 2080s based on an ensemble of 23 global climate models (GCMs) and RCP 8.5[69]. By the 2050s, storms with 2-year, 10-year, and 50-year return periods, are expected to deliver increased rainfall by 6-11%, 11-14%, and 12-24%, respectively. By the 2080s, storms with 2-year, 10-year, and 50-year return periods, are expected to deliver increased rainfall by 14-20%, 22-24%, and 30-38%, respectively. These results indicate that the intensity of rainstorms is projected to increase into the future, and that the greatest increases are projected to be associated with high intensity, low frequency storms. This is an important consideration when designing new bridges, culverts or drainage infrastructure, or when assessing the capacity of existing infrastructure to future floods. It is also an important consideration in designing and planning erosion and sediment control measures during construction activities.

TABLE 4.6 *Modeled total precipitation (mm) for storms of different intensities and durations at Gibsons (Environment Canada Station 1043150)*[70] *(Western University, 2021).*

Storm Duration (hours)	Total Precipitation (mm)								
	Return Period								
	2-Year			10-Year			50-Year		
	Current	2050s	2080s	Current	2050s	2080s	Current	2050s	2080s
1	10.7	11.2	12.0	15.0	17.0	18.5	19.1	23.7	25.7
2	15.0	15.9	17.1	22.0	24.5	26.8	28.1	35.9	38.8
6	26.2	29.1	31.3	33.4	37.6	40.9	39.8	44.5	49.1
12	37.4	40.9	44.1	47.6	54.4	58.7	56.7	68.6	73.7
24	54.9	59.9	64.6	70.4	79.7	87.0	84.0	100.8	110.4

4.8. HYDROLOGY

The assessment area is located within the Western South Coast Mountains hydrologic zone (Ahmed, 2017). As noted above, lower relief coastal watersheds, such as the assessment

---

[69] RCP 8.5 is the representative concentration pathway resulting in radiative forcing of 8.5 W/m^2 by 2100 and where radiative forcing continues to rise beyond 2100. This RCP represents a scenario that leads to the greatest climate change impacts when compared to other RCPs.

[70] Latitude: 49.40° N, Longitude: -123.51° E

watersheds have a pluvial (rain-dominated) hydrologic regime[71] in which streamflows are normally generated by fall and winter rainstorms. According to Eaton and Moore (2010), the temporal pattern of streamflow closely follows that of rainfall. Highest monthly stream discharge typically occurs in November and December when the most intense frontal systems move over the coast of BC. The lowest monthly flows occur in July and August, when high-pressure systems typically direct precipitation-generating weather systems away from southern BC. Since the assessment watersheds receive snowfall, albeit infrequent and in a relatively low proportion compared to rain, under certain conditions snowmelt can be a major contributor to stream flows, especially during warm rain-on-snow events associated with atmospheric rivers. Such rain-on-snow events are generally recognized as having the potential to produce relatively high magnitude peak flow events (Pomeroy et al., 2016; Trubilowicz and Moore, 2017; van Heeswijk et al., 1996). Moreover, rain-on-snow can occur across all elevations.

There are relatively few Water Survey of Canada (WSC) hydrometric stations on the Sunshine Coast (TABLE 4.7), and none are located within the assessment watersheds, with the exception of Chaster Creek above Highway No. 101, which was briefly gauged in 1965 and therefore of little utility. Only the WSC station Roberts Creek at Roberts Creek is currently active and has a lengthy record. The record, however, is potentially affected by water use upstream (i.e., it has a regulated flow regime). The only station with a lengthy record of natural flows is Chapman Creek above Sechelt Diversion; however, it was discontinued in 1988. Chapman Creek also drains considerably higher relief terrain with a significant snowpack. As a result, Chapman Creek has a hybrid flow regime in which snowmelt is major contributor to runoff along with rainfall, unlike the rainfall-dominated runoff in the assessment area.

In spite of the streamflow record for Roberts Creek at Roberts Creek potentially reflecting some human influence, it provides an approximation of the magnitude and pattern of streamflows in the assessment area. This record also demonstrates the relatively rapid runoff generation in response to storms, which is a function of several watershed characteristics common in the assessment area, including shallow soils, gullied terrain and limited lake and wetland storage. FIGURE 4.18 presents the annual hydrograph of daily unit discharge for Roberts Creek at Roberts Creek in units L/s/km^2. Unit discharge allows the comparison of streamflows between streams with differing drainage areas[72] [73].

---

[71] Occasionally, a melting snowpack within a limited area at the highest elevations of the assessment watersheds may augment storm-related runoff.

[72] To calculate discharge in m^3/s, multiply the unit discharge in L/s/km^2 by [0.001 x drainage area in km^2].

[73] Runoff can also be presented in unit-based terms of mm. However, the period over which the runoff occurs should be specified (e.g., annual, monthly, daily).

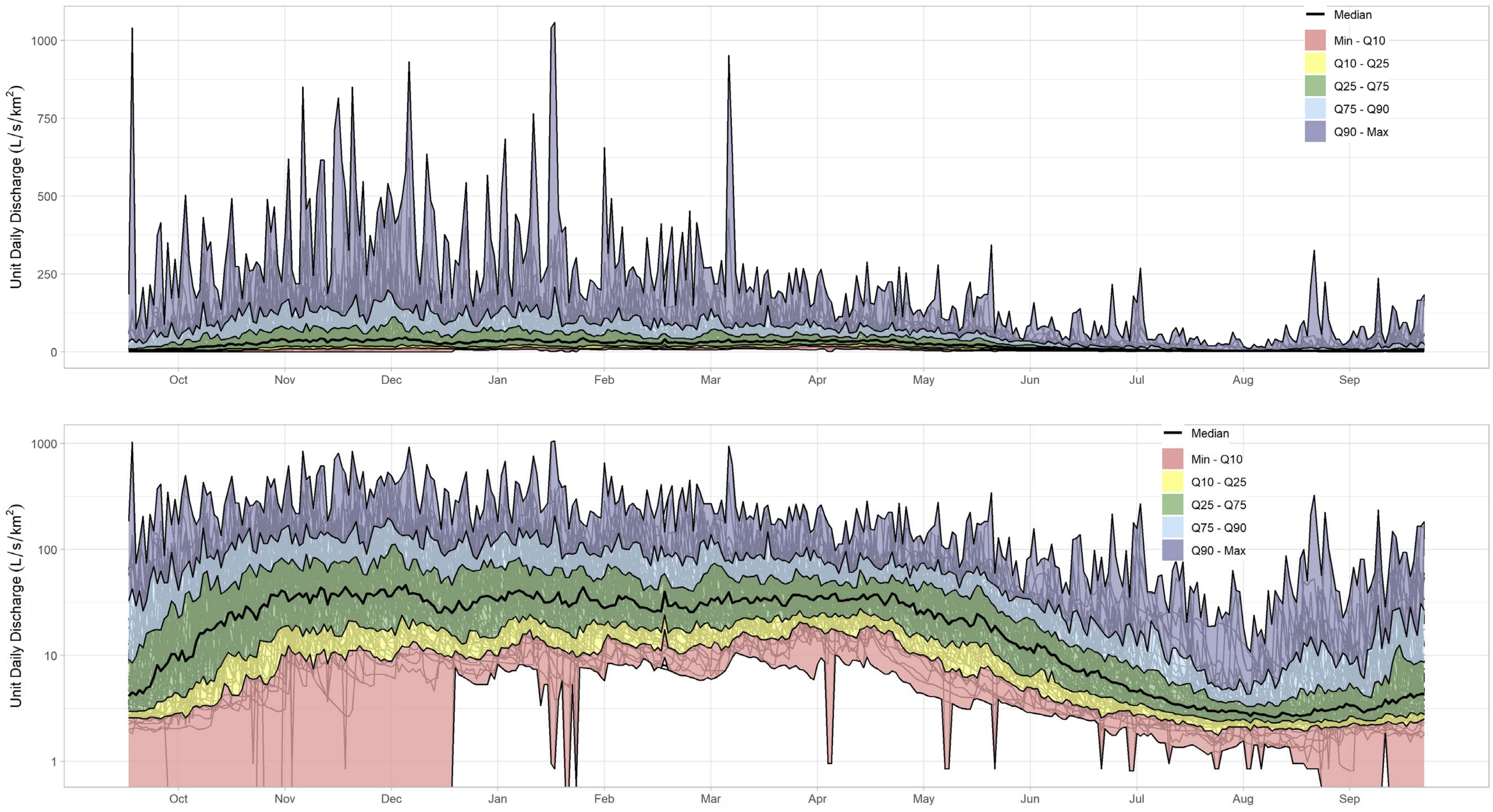


FIGURE 4.18 *Daily streamflow from the Water Survey of Canada (WSC) hydrometric station Roberts Creek at Roberts Creek (WSC No. 08GA047 from 1959-present. The lower plot has a logarithmic vertical scale to better visualise low flows. The black line represents the median daily discharge over the period of record. Selected percentile flows (10th, 25th, 75th and 90th), whereby the Q10, for example, represents the 10% lowest flows, are also shown to demonstrate the range in historical flows. Note the different vertical scales on the upper and lower plots. The Min-Q10 records show zero or near zero values from September to December (note the y-axis does not go to zero).*

TABLE 4.7 *Water Survey of Canada hydrometric stations along the Sunshine Coast between Langdale and Sechelt (Province of BC, 2021f).*

Station No.	Station Name	Natural / Regulated	Record Start	Record End
08GA051	Langdale Creek at Highway No. 101 near Gibsons	Natural	1965-05-11	1968-09-30
08GA050	Chaster Creek above Highway No. 101	Natural	1965-05-11	1965-09-30
08GA047	Roberts Creek at Roberts Creek	Regulated	1959-04-28	present
08GA046	Chapman Creek near Wilson Creek	Regulated	1959-04-27	1970-12-14
08GA060	Chapman Creek above Sechelt Diversion	Natural	1970-07-02	1988-10-25
08GA078	Chapman Creek below Sechelt Diversion	Regulated	1993-01-01	2003-12-31

TABLE 4.8 summarizes the recorded streamflow statistics for the Chapman Creek and Roberts Creek hydrometric stations as well as estimated streamflow statistics for the eight assessment streams. These estimates are based on data presented by Ahmed (2017). Based on this data, normal annual unit runoff in the eight streams is estimated to be lower than Roberts Creek, ranging from 440 mm in End/Walker Creek to 900 mm for Molyneux Creek. Unit peak flows and summer low flows are also less in the eight streams of interest than Roberts Creek. With the exception of Chaster Creek, all streams of interest likely have zero or near-zero flows under summer low flow conditions.

TABLE 4.8 *Estimated streamflows for the eight streams of interest based on the regional hydrometric data and relations presented by Ahmed (2017).*

Stream / Location	Drainage area	Median elevation	Normal annual runoff			10-year Peak Flow		10-year 7-day June-September Low Flow	
	(km^2)	(m)	(mm)	(L/s/km^2)	(m^3/s)	(L/s/km^2)	(m^3/s)	(L/s/km^2)	(m^3/s)
Chapman Creek above Sechelt Diversion (WSC 08GA060)	63.06	978	2,094	6.64	4.19	1,882	118.7	2.69	0.170
Roberts Creek at Roberts Creek (WSC 08GA047)	29.40	606	1,089	3.45	1.01	1,530	45.0	1.60	0.047
Assessment streams[74]:									
Chaster Creek	10.73	300	610	1.93	0.207	1,100	11.8	0.800	0.009
End/Walker Creek	1.15	130	440	1.39	0.016	1,050	1.21	0.200	0.000
Smales Creek[75]	0.95	260	580	1.84	0.017	1,080	1.03	0.180	0.000
Higgs Brook	1.45	260	580	1.84	0.027	1,080	1.57	0.210	0.000
Molyneux Creek	2.65	500	900	2.85	0.076	1,250	3.31	0.310	0.001
Slater Creek	1.42	240	550	1.74	0.025	1,070	1.52	0.210	0.000
Joe Smith Creek	2.29	300	610	1.93	0.044	1,100	2.52	0.300	0.001
Clough Creek	1.54	360	700	2.22	0.034	1,150	1.77	0.220	0.000

---

[74] Estimates are presented for the mouth of each stream.

[75] Assumes natural conditions without human diversions. Field evidence, however, suggests Smales Creek is currently diverted towards End/Walker Creek and potentially Whittaker Creek along the Sunshine Coast Highway.

4.9. HYDROLOGIC EFFECTS OF CLIMATE CHANGE

As described in Section 4.7.2, climate change will affect both temperature and precipitation in British Columbia and the Sunshine Coast for years to come. According to the Pacific Climate Impacts Consortium (PCIC, 2013), warming has already occurred over the last century in all seasons in the South Coast region. The South Coast is likely to see continued warming for several decades to come (PCIC, 2013, 2021). Despite an increase in average annual precipitation over the last century (BC MOE, 2016), summer precipitation has been decreasing (Abatzoglou et al., 2014; Kormos et al., 2016). Although projected precipitation changes are less certain, annual precipitation is projected to decrease by 1.0% by the 2050s and increase by 4.8% by the 2080s. More importantly, decreased precipitation is projected in summer by 13% and 22% by the 2050s and the 2080s, respectively. In winter, precipitation projections vary, with the median projection increasing by 0.97% by the 2050s and 9.7% by the 2080s (TABLE 4.5).

Changes to air temperature and precipitation are projected to decrease snow accumulation, increase winter rainfall, and promote earlier snowmelt (Winkler et al., 2010b; Hatcher and Jones, 2013; Islam et al., 2017, 2019). A recent study evaluated 46 long-term streamflow gauges in the United States and Canada to determine changes to the flow regime and found an increased influence of rainfall on flood regimes (Burn and Whitfield, 2023). In the assessment watersheds, this is expected to result in thinning of an already limited and/or transient snowpack. As a result, snow is expected in the long-term to play a decreasing role in the annual hydrograph. Nonetheless, snowfall is still expected to occur in the future, and across all elevations (William Floyd, pers. comms., 2023), as demonstrated several times in recent years. Snow is therefore expected to continue to contribute to flooding during fall and winter rain-on-snow events.

Additionally, the severity of individual rainstorms is expected to increase in the region, particularly for high intensity, low frequency winter storms and atmospheric rivers (Section 4.7.2). Given rainfall is the dominant driver of runoff in the assessment streams, there is an increased potential for high winter streamflows in the future (Musselman et al., 2017).

Climate change will also affect the timing, duration, and magnitude of low flows in the assessment streams. In addition to the reduction of an already limited or transient snowpack, projected reductions in summertime precipitation will directly reduce late summer and early fall streamflows and may increase the duration of zero or near-zero flow conditions already noted along some of the assessment streams, especially those that have been subject to sedimentation or aggradation from past fluvial activity.

4.10. LAND USE & FOREST COVER DISTURBANCE

An understanding of historical context within the assessment area is important to understand the current condition and natural processes as well as for projecting risks associated with future forest development. The primary disturbance agents identified in the assessment area includes historic wildfire, land clearing and residential and commercial development on the lower slopes (i.e., on Upper Gibsons Bench and along the coast), and forestry on Crown land along the mid and upper slopes. In addition, major linear infrastructure, including the Sunshine Coast Highway (Highway 101) and BC Hydro transmission line rights-of-way (ROWs), as well as many public roads are present in the area. The highway and transmission line ROWs runs roughly parallel to the coast at elevations of about 100 m, and 200 m to 300 m, respectively. Recreational use on Crown land is widespread, with several hiking, mountain biking, equestrian and ATV trails located throughout the assessment area.

4.10.1. Forestry

The assessment area has a long history of development-related forest cover disturbance with virtually all of the area logged or affected by wildfire at some time since the late 19th century. Forests currently consist of maturing second growth (FIGURE 4.19) or regenerating stands following second-pass harvesting; this is clearly evident by the mosaic of forest ages and canopy heights in the area (FIGURE 4.20 - FIGURE 4.22).

A review of historical air photos indicates that as urban and rural development progressed along the lower slopes between Gibsons and Roberts Creek, logging occurred within the second growth stands on the upper slopes. By 1947, logging by clearcutting was noted between 400 m to 700 m elevation along most of the assessment area. Access was primarily from the Roberts FSR. Between 1967 and 1976, logging expanded further upslope of the original opening towards the height of land. Meanwhile the original opening was regenerating, albeit deciduous species tended to colonize moist area along gullies and minor streams. This may have affected the water balance along riparian areas, with increased vegetative demands during the growing season. Logging after the late 1976 appears to have occurred at a slower rate, with several relatively small openings established through the 1980s and 1990s. During this period some private land logging was noted as was some research trials in the Roberts Creek Research Watershed.

According to the Sunshine Coast Museum & Archives[76], coastal logging outposts were established in the area before any towns were developed. In the Gibsons area in the late 19th century, timber harvesting provided an opportunity for agricultural development. Between 1900 and 1930 logging in the area supported several mills. Early on, logs were transported by horses, oxen and manual labour; however, after 1914 logging began to mechanize, and by the 1930s the use of chainsaws,

---

[76] https://www.sunshinecoastmuseum.ca/early-logging.html

steam donkeys which winched logs from the bush, flumes, and later, truck logging for transport became commonplace. In 1906, a major wildfire near Leek Road (in the vicinity of lower Higgs Brook) spread over 5 km towards Gibsons, burning a mill, log flume and considerable timber throughout the area. Although the fire paused logging activity for a time, it became a catalyst for expanded settlement on the Sunshine Coast.

The distribution of forest ages within BCTS Chart (FIGURE 4.20) provides some indication on levels of past forest disturbance. There are a mix of seral stages (early seral, mid-seral and mature-seral) with few forest stands older than about 160 years (i.e., no old-seral). Mature stands are often located within ravines or as small patches across the slope. Forest age distributions for each assessment watershed are provided in Section 6.1.2. The decade that experienced the peak level of forest disturbance (either by harvesting or forest fire) is presented for each watershed unit in TABLE 4.9 and suggests that the level of disturbance typically peaked around 100-110 years ago (i.e., between 1911-1920). Exceptions include End/Walker Creek and Molyneux Creek, which experienced peak levels of forest disturbance between 1891-1900 and 1941-1950, respectively.

The age of a stand is also indicative of relative water consumption. This is a result of differences in site-level evapotranspiration rates for different seral stages (discussed further in Section 6.1.2). As such, the pie charts presented in FIGURE 4.20 and FIGURE 6.5 are broken into four classes, meant to represent relative water consumption. The potential implications of stand age distributions on low flows is discussed further in Section 6.1.2.

FIGURE 4.19 *Example of mature second growth stands near Reed Road. The location is approximately 50 m north of the west end of Reed Road. Photo DSC09810, August 26, 2020.*

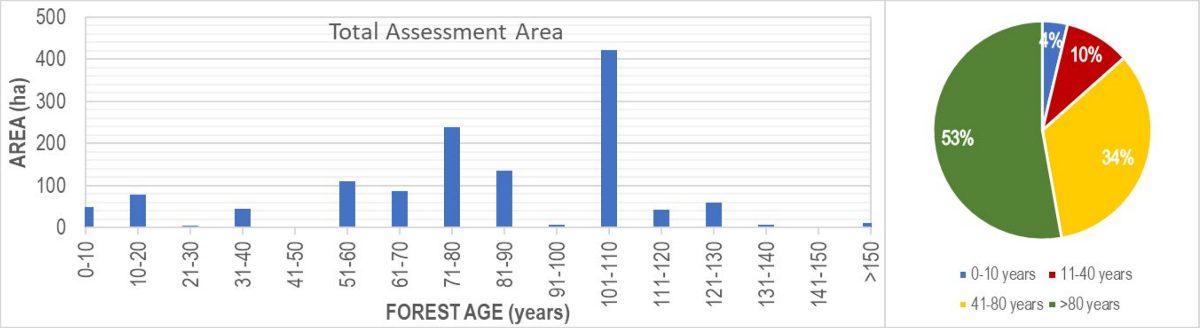


FIGURE 4.20 *Distribution of forest ages in the assessment area. The histogram presents age classes by decade. The pie chart shows stand age distribution for four age classes.*

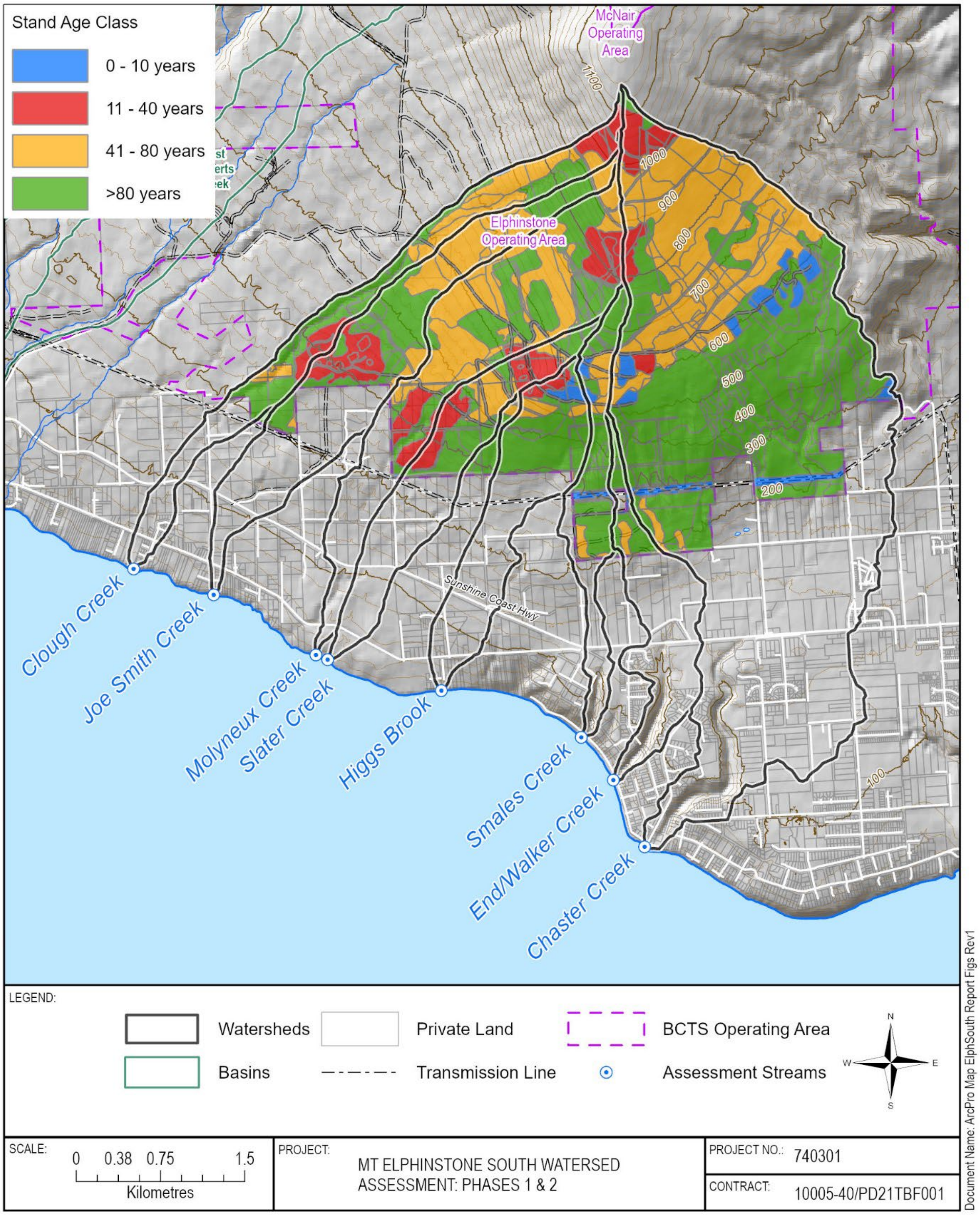


FIGURE 4.21 *Spatial distribution of forest stand ages within BCTS Chart.*

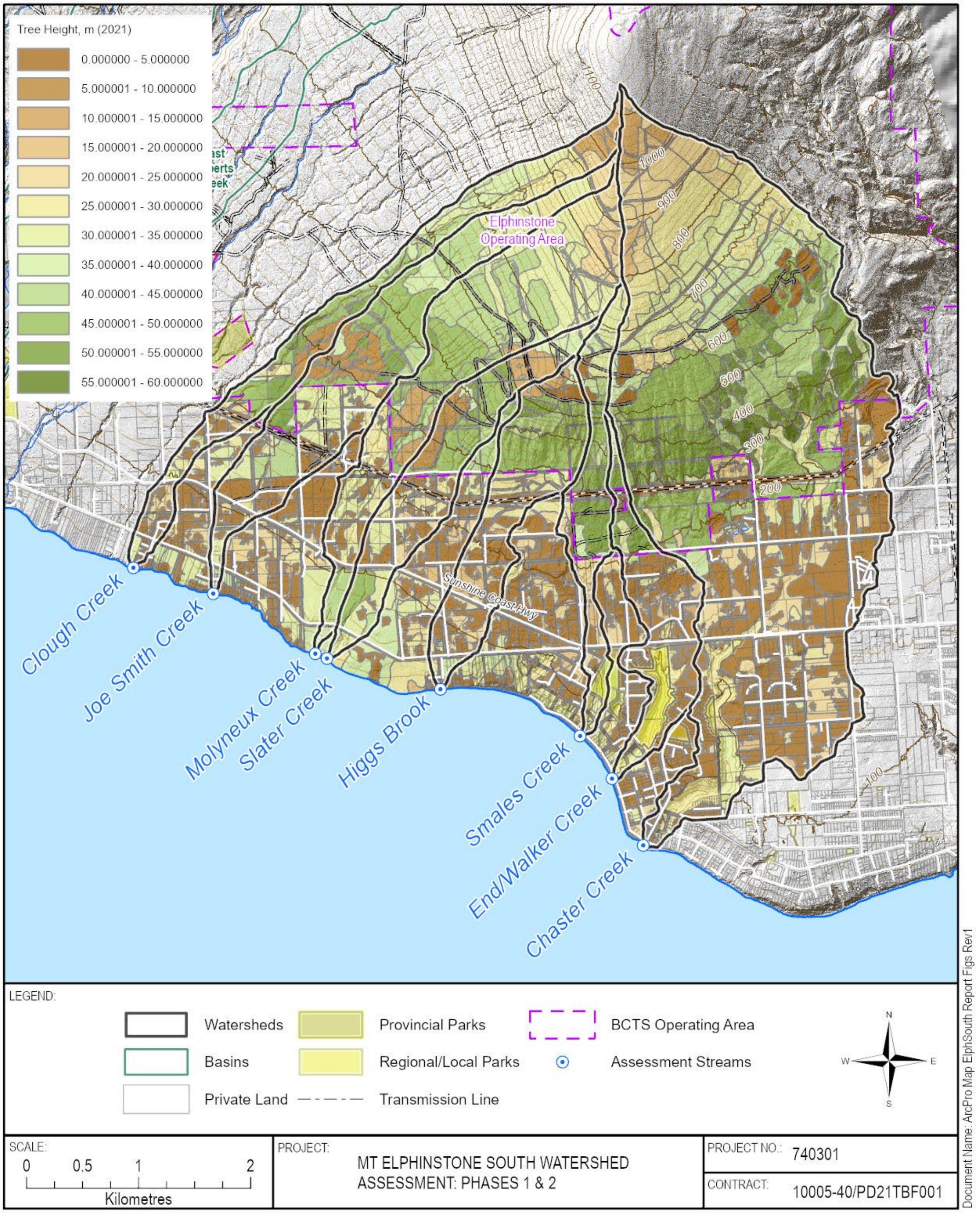


FIGURE 4.22 *Spatial distribution of projected (2021) forest canopy heights in the assessment area.*

TABLE 4.9 *Peak decade and level of forest disturbance within BCTS Chart.*

Stream / Watershed	Chaster Creek	End / Walker Cr	Smales Creek	Higgs Brook	Slater Creek	Molyneux Creek	Joe Smith Creek	Clough Creek
Peak disturbance years	1911-1920	1891-1900	1911-1920	1911-1920	1911-1920	1941-1950	1911-1920	1911-1920
Peak disturbance (%)[1]	38%	46%	26%	68%	26%	23%	36%	30%

Notes: 1) Peak level of disturbance is represented as the proportion of the watershed area within BCTS Chart and corresponds to the decade listed above.

4.10.2. Residential and Commercial Areas

Private property within the Sunshine Coast Regional District (SCRD) and Town of Gibsons is located along the lower slopes of the assessment area. These properties support varied land uses, including residential, commercial, agricultural, and recreational use. Within the identified urban-interface watersheds, private land accounts for 20.7% to 56.3% of the drainage area (TABLE 4.1). The area subject to residential and commercial development in the assessment area is presented in FIGURE 4.23. For the purposes of hydrologic recovery modelling (Section 6.1.1), we have assumed that cleared areas on private land will be without mature forest canopy indefinitely.

The hydrology of the lower portion of the assessment area has been heavily influenced by various levels of urban development. Permanent land clearing, paving, and implementation of storm management infrastructure has adversely changed the runoff response in the lower portion of most of the assessment watersheds, although to varying degrees. Observations such as these may be cause for concern, depending on downstream values and their sensitivities, and are a major reason that has driven efforts over the last couple decades to improve stormwater planning by local governments (Stephens et al., 2002). We are aware the SCRD in cooperation with the Ministry of Transportation and Infrastructure has had urban stormwater assessments done, intended to help guide infrastructure planning and design (Delcan, 2009). With the anticipated increase in higher density residential communities as population increases, and a transition from open crop farming to greenhouse farming, Delcan (2009) provided estimates on projected changes to streamflow in the assessment area. Projected increases for the 2- year to 200-year return period peak flow events ranged from roughly 3% to 10% depending on the watershed. Delcan (2009) recommended that one mitigation strategy would be to require on-site vegetation and tree canopy retention with new development. They further recommended that the SCRD evaluate the results from the Tree Canopy Research Project[77] at the University of British Columbia and potentially update their existing Tree Cutting Bylaw (No. 350, 1991)[78].

---

[77] https://ece-treecanopy.sites.olt.ubc.ca/

[78] It is unknown whether these recommendations have since been applied by the SCRD.

Given the level of residential and commercial development in the assessment area, the assessment streams have likely been conditioned to some extent to an increase in streamflow over the last century. However, the level of urban development varies for each watershed and is often concentrated in high density clusters, while other "urbanized areas" may be more rural in nature and highly vegetated. The relative level of urban development[79] and location of densely urbanized areas within each watershed are as follows:

- Roughly 27% of the Chaster Creek watershed is considered urbanized, with densely urbanized areas concentrated in the southeast and south-central portion of the watershed;
- Roughly 48% of the End/Walker Creek watershed is considered anthropogenically disturbed, although a majority of the disturbance appears rural Dense urban areas are concentrated along the eastern and western margins of the center of the watershed;
- Roughly 11.5% of the Smales Creek watershed has been anthropogenically disturbed and is predominantly rural;
- Roughly 27% of the Higgs Brook watershed has been anthropogenically disturbed and is largely rural in nature;
- Roughly 17% of the Slater Creek watershed has been anthropogenically disturbed and is largely rural in nature;
- Roughly 6% of the Molyneux Creek watershed has been anthropogenically disturbed and is largely rural in nature;
- Roughly 15% of the Joe Smith Creek watershed has been anthropogenically disturbed and is largely rural in nature; and
- Roughly 13% of the Clough Creek watershed has been anthropogenically disturbed and is largely rural in nature.

There is also an abundance of public and private roads distributed across the lower portions of the assessment area. These roads alter the drainage network as runoff is conveyed off of road surfaces and into adjacent ditch lines. Water is then transported along ditches until the ditch intersects a stream. Of note is the Sunshine Coast Highway which runs perpendicular to most of the assessment streams (MAP 1).

---

[79] The areas of residential and commercial development were determined using the LiDAR canopy height model and PlanetLabs satellite imagery and do not include naturally disturbed (i.e., by wildfire) areas or areas subject to forest harvesting.

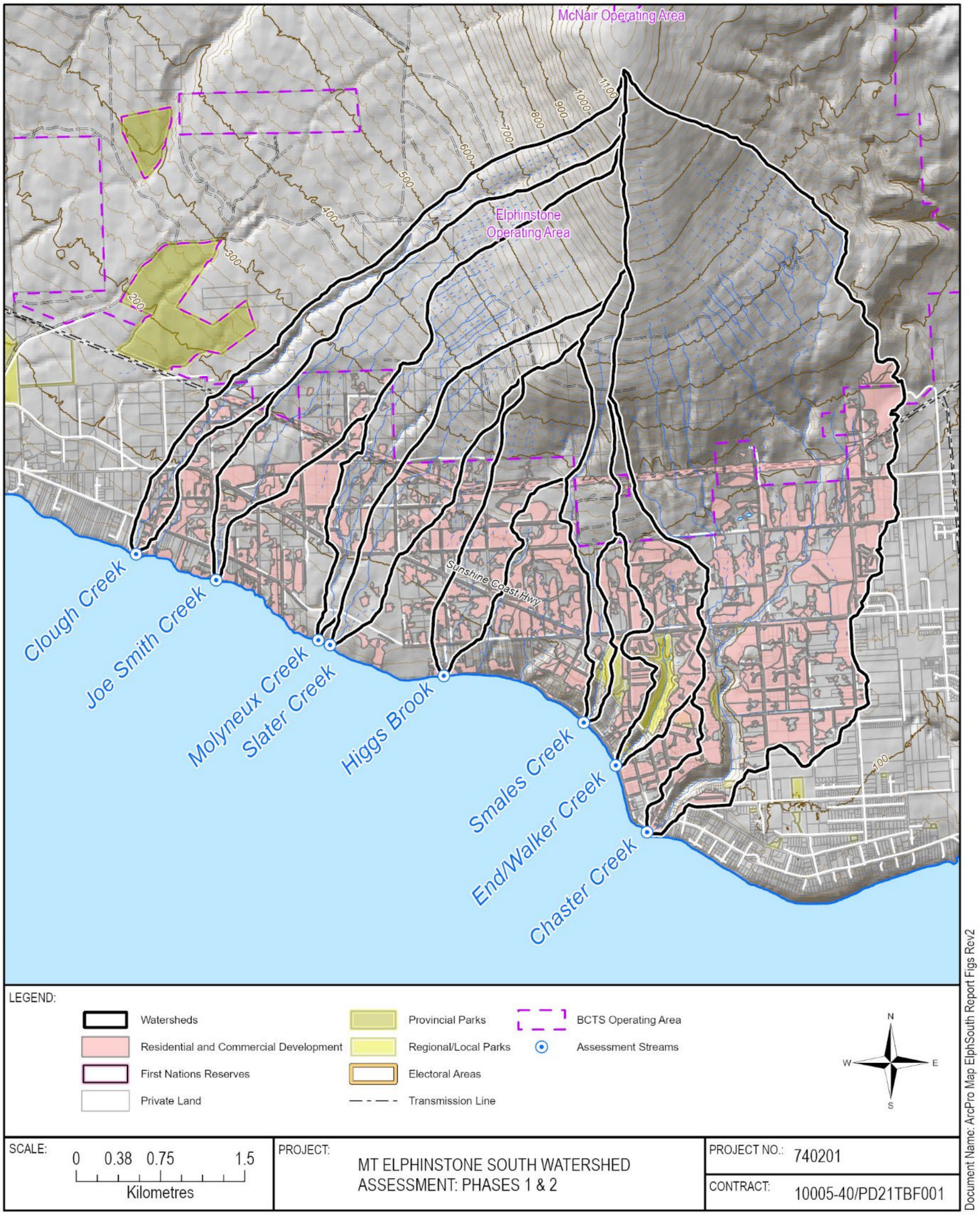


FIGURE 4.23 *Residential and commercial development within the assessment area.*

4.10.3. Biotic Disturbances

According to provincial surveys, natural disturbance agents have had limited effects within the assessment area (Province of British Columbia, 2021e). This includes the following:

- 0.8 ha of severe Douglas-fir beetle identified in 1996 within the upper Chaster Creek watershed;
- 26.8 ha of light Douglas-fir beetle and light laminated root rot in 2019 in the Clough Creek and Joe Smith Creek watersheds;
- 3.3 ha of light root disease identified in 2008 and 8.8 ha of light Laminated Root Rot identified in 2019 in the in the upper Higgs Brook watershed; and
- 28.7 ha of trace White pine Blister Rust at mid-elevations in the Molyneux Creek and Slater Creek watersheds.

Although a Western Hemlock Looper outbreak has been noted on the southern coast in the last few years[80], no records of its presence in the assessment area were identified.

4.10.4. Wildfire

According to the provincial wildfire database (Province of British Columbia, 2021d), a 40.9 ha wildfire occurred in 1941 just beyond the northeast boundary of the Chaster Creek watershed near the 800 m elevation; however, less than 2 ha of the Chaster Creek watershed was affected. No data is available regarding the major 1906 wildfire noted in Section 4.10.1.

While thinning stands (i.e., selective harvest), in conjunction with prescribed burning, can be an effective management option for mitigating wildfire risk in some wildfire regimes (Prichard et al., 2021), it may not be a suitable option for the assessment area. Halofsky et al., 2020 states that in wet forests of the Pacific Northwest, lowering stand density, reduces competition between trees, which can increase water availability. However, given that wetter, coastal forests of the Pacific Northwest generally experience infrequent, stand-replacing wildfire during periods of extreme drought, thinning of these forests may not significantly alter wildfire risk (Halofsky et al., 2018), although the fire regime may change with climate change.

---

[80] https://globalnews.ca/news/8152889/western-hemlock-looper-moth-outbreak/

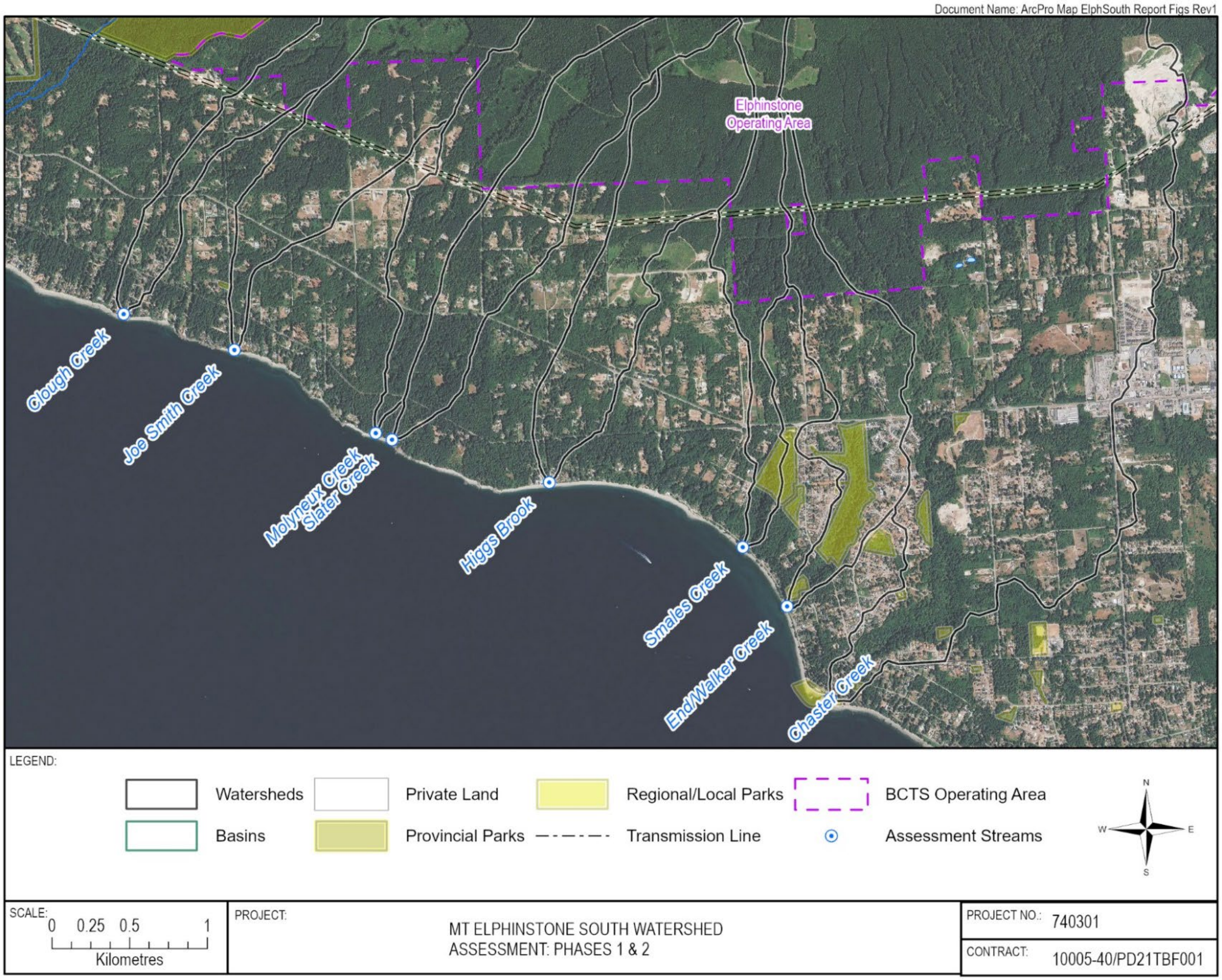


FIGURE 4.24 *Satellite image (2019) of the lower elevations of the assessment area showing the extent of land clearing and urban development.*

4.11. ROBERTS CREEK STUDY FOREST

The Roberts Creek Study Forest is located roughly 6 km west of the assessment area and was initiated to evaluate alternatives to clearcutting for harvesting and managing forests. One of the studies key objectives was to evaluate the influence of alternative silviculture systems on peak flows relative to conventional clearcut logging. Two alternative silviculture systems were implemented in the study forest in 1998 and 1999, which include variable retention, either by dispersed retention or grouped retention, and a strip shelterwood cut (i.e., strip cut). For the variable retention treatments, roughly 18% of the canopy was retained in patches and dispersed trees, and applied to 44% of the catchment area. Roughly 45 - 50% of the canopy was retained in the strip shelterwood cut, and applied to 32% of the catchment area. The treatments were applied in two phases to two small S6[81] stream catchments ranging in size from 39 ha to 61 ha.

Hudson (2001) applied the paired watershed approach[82], which involves comparing peak flows generated from a control catchment to those generated from the treatment catchments. The differences in peak flow response from each silviculture system can then be evaluated. Hudson (2001) found higher variability in the peak flow response from the dispersed and grouped variable retention treatments relative to the catchment subject to strip shelterwood cut. In the variable retention treatments, peak flows were sometimes lower, unaffected, or much higher than in the control. In the catchment subject to strip shelterwood cut, peak flows were more consistently affected by harvesting, although the effect was relatively small. The higher variability in the variable retention treatments was thought to be due to their greater response to rain-on-snow events. Deeper and more continuous snowpacks developed in the openings of the variable retention treatments relative to the strip shelterwood cut. As a result, more water was available for runoff during rain-on-snow events in the variable retention treatments, resulting in a greater peak flow response. Given the narrow openings in the strip shelterwood cut treatment, snowpack development was heavily influenced by the forest edges, and only able to develop in the center of openings. As such, snowpacks were thin and discontinuous relative to the larger openings in the variable retention treatments.

In addition to evaluating peak flow effects, the study forest was also used to evaluate the effect of variable retention and strip shelterwood treatments on water quality (Hudson and Tolland, 2002) and sediment production from blowdown (Hudson and D'Anjou, 2001). Given that nitrate is

---

[81] S6 streams are identified as non-fish bearing streams not within a community watershed that are less than 3 m wide. https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture/silvicultural-systems/silviculture-guidebooks/riparian-management-area-guidebook

[82] It is important to note that the chronological pairing approach was applied in this study, which has since been deemed an "uncontrolled" experiment (Alila et al., 2009; Yu and Alila, 2019). As such, the results should be interpreted cautiously.

considered one of the most sensitive indicators of watershed disturbance, Hudson and Tolland, (2002) compared nitrate concentrations in groundwater and surface flow from both treatment catchments. The researchers found increases in nitrate levels following treatments; however, the increases were not proportional to the area harvested. They speculated that the differing responses were largely due to differences in watershed characteristics rather than from the treatment effect and concluded that further research was required to obtain conclusive results.

Although the Forest Practices Code did not require buffer strips along S6 streams, first-order[83] S6 streams tended to be used as falling boundaries and were buffered. Initial attempts at buffering first-order streams often resulted in blowdown which could lead to sedimentation in the streams. As such, buffers were widened to reduce blowdown potential; however, questions remained on the best management approaches for zero-order[84] S6 streams that flow through cutblocks. Given the high density of zero order streams along Mount Elphinstone, establishing buffer strips around all of them is not practical. As such, Hudson and D'Anjou (2001) evaluated blowdown potential on a zero-order stream subject to a shelterwood cut silviculture system. The treatment was termed a Uniform Two-pass Shelterwood with Reserves, which involved the dispersed retention of Douglas fir and western red-cedar at a density of 90 stems per hectare and included eight yarding corridors located 30 – 60 m apart. Following the treatment, blowdown of susceptible leave trees occurred, which included three trees rooted in the stream channel. As a result, two large pulses of suspended sediment were recorded during the storm, increasing peak sediment concentrations by roughly ten-times relative to pre-treatment levels. The authors concluded that the proper streamside management for zero-order streams subject to partial harvesting systems is to remove trees adjacent to the channel with a high windthrow potential, while retaining understory vegetation to maintain stream channel stability. They also found that a buffer strip width of 20 m with edge feathering and/or canopy pruning was effective at mitigating blowdown potential along first-order S6 streams. It is important to note, however, that the authors highlight that this was a pilot study and was not a completely controlled experiment. The results should therefore be interpreted cautiously.

4.12. WATER USE

4.12.1. Surface Water Use

Although there are no registered community watersheds in the assessment area, according to the BC Water Rights Database (Province of British Columbia, 2022a), downstream or downslope of BCTS' Chart there are 59 currently registered water licences across the eight assessment

---

[83] In this study, a first-order stream is considered an S6 stream that conveys flow year-round (i.e., perennial).

[84] In this study, a zero-order stream is considered an S6 stream that does not convey flow year-round (i.e., ephemeral).

watersheds (FIGURE 4.25, TABLE 4.10, MAP 1)[85]. This includes licences to support domestic use, commercial enterprise, waterworks (local provider), and land improvement (general). In July 2021, BCTS contacted the registered holders of these water licensees to request information on their water system and permission to enter their property during field reviews. For those water licensees who granted permission to enter their property, a field meeting and review was conducted by Polar on July 12-16, 2021 to document stream conditions and existing water supply infrastructure (e.g., intakes, distribution lines). A summary of the field review is provided in APPENDIX C.

In the Chaster Creek watershed, there are 11 current water licences[86]. This includes three waterworks licences held by the Town of Gibsons[87] and eight privately held domestic licences. One land improvement licence (to supply water for a pond) is also associated with one of the domestic licences. Point-of-diversions (PODs) (i.e., water intakes) associated with seven of the 11 licences in the Chaster Creek watershed were field reviewed. Although some derelict water supply infrastructure (e.g., water pipes, barrels, etc.) was identified (APPENDIX C), no active functional domestic water intakes were identified[88]. Some water intakes and distribution pipes may have been damaged or rendered ineffective in past floods, and it is likely that several of the water licensees now rely on municipal water or groundwater for their domestic water requirements.

Within the End/Walker Creek watershed, there are four domestic and two land improvement licences. During the field review PODs for two of the four domestic and one of the two land improvement licences were reviewed. Of the two domestic licences reviewed, a water intake was observed at only one; however, it is unclear whether it is currently utilized. The one land improvement licence on McComb Brook was associated with a “fish pond”; however, the pond was heavily grown in and does not appear currently maintained given the debris at the pond outlet and sedimentation observed.

One domestic licence is located on Smales Creek, locally known as Elmer Creek. During the field review, water supply infrastructure was noted in the creek. This included a rudimentary intake, located in a pool with sufficient depth (sedimentation appears to be an issue), and PVC pipe along the creek.

---

[85] Based on our field review, some of the registered water licences are not being utilized at present (Appendix C).

[86] According to Madrone (2015), there may also be some unlicensed water use.

[87] We understand that these licenses are not actively been utilized. Water for the Town of Gibsons is sourced principally from groundwater or from the Sunshine Coast Regional District (SCRD) system, which is sourced from Chapman Creek and seasonally from the Chaster Well (Waterline, 2013).

[88] Only the pond associated with the land improvement licence was noted as functional.

In the Higgs Brook watershed, there are three current domestic licences, one of which also permits commercial enterprise use (i.e., for a children's farm). All but one of the domestic licences was field reviewed. Based on conversations and field review, most licences are not actively used. In at least one case, groundwater is used instead.

Three domestic licences are registered in the Slater Creek watershed. The POD location of one of the three was field reviewed; the other two were assessed from public roads above or below the property associated with the licence. In all cases, no evidence of actively used water intakes was identified.

A total of 15 domestic water licences are located in the Molyneux Creek watershed. Nine of these were field reviewed and in only two cases could we confirm that the water system was functional and/or actively used. In each case, however, groundwater is the primary water source, and surface water is used as a supplementary source (e.g., for irrigation). Evidence of former water systems were identified in three of the nine licences reviewed; however, the systems associated with these licences were in disrepair and are non-functional.

Within the Joe Smith Creek watershed, there are 11 domestic water licences, seven of which were field reviewed. Of these seven, only the uppermost one appeared to be in active use; all others reviewed were in disrepair, damaged or seemingly abandoned.

Nine domestic water licences are located in the Clough Creek watershed. Eight of these were field reviewed. Of these eight licences, active use was confirmed at only two locations. Some intakes may have been abandoned following the debris flow in 1983 and/or may have been replaced by groundwater supplies or municipal water.

In addition to the assessment watersheds, there are several current licences in "residual areas"[89] between Smales Creek and Higgs Brook as well as between Higgs Brook and Slater Creek (FIGURE 4.25, TABLE 4.10). This includes licences on Corwallis Creek, Pelican Brook, Leek Creek and East Leek Creek. None were field reviewed as these sources have little to no surface connectivity to BCTS' Elphinstone operating area.

---

[89] Residual areas (or face units) are areas between defined drainage areas of interest. Streams, if present, are typically smaller and convey less streamflow than those within the identified assessment streams.

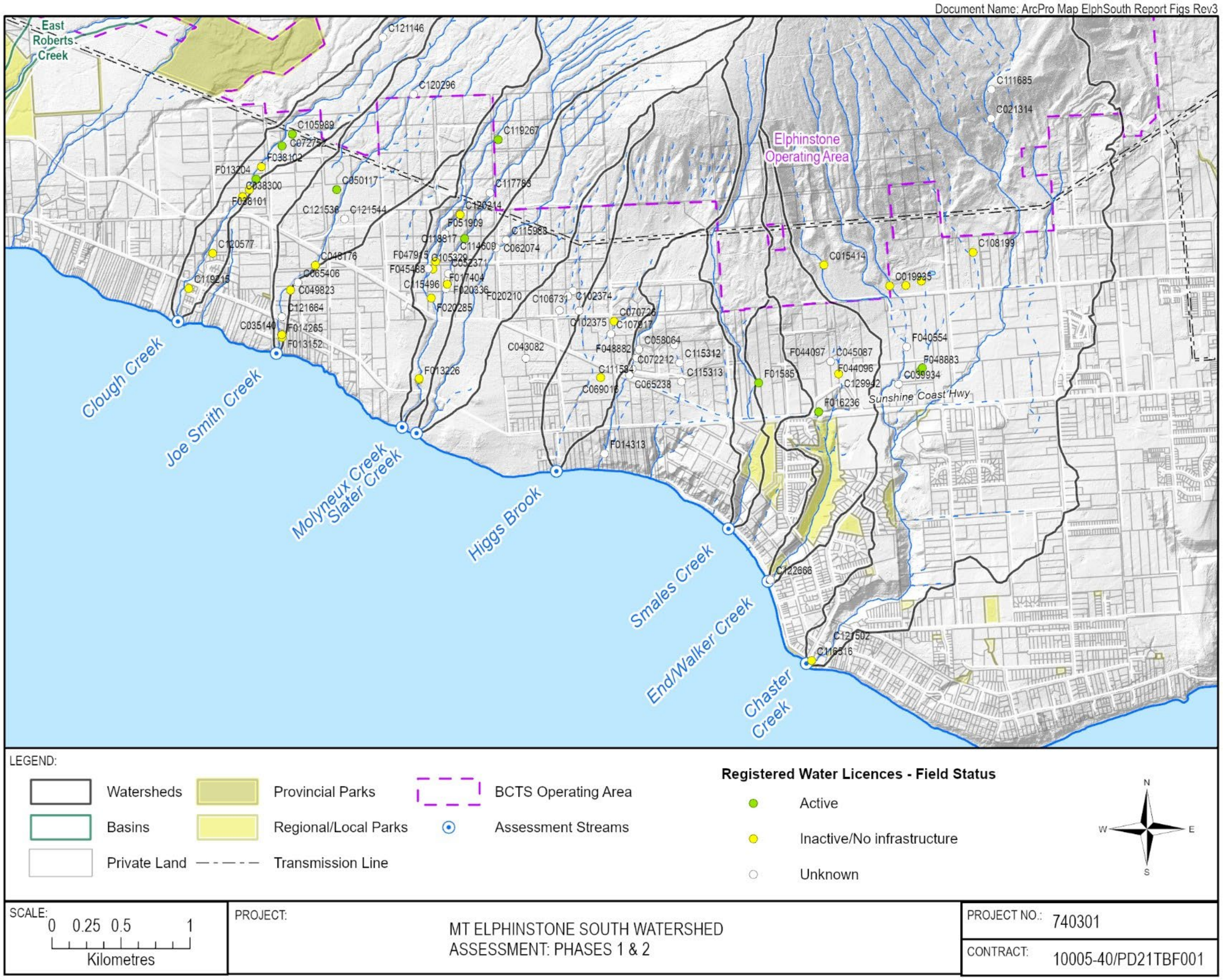


FIGURE 4.25 *Current water licences in the assessment area.*

TABLE 4.10 *List of current surface water licences within the eight assessment watersheds. Licences are organized by watershed in order of approximate stream distance from mouth (km). Refer to MAP 1 for location.*

Watershed	Source	Stream distance (km)	Licence	POD[90]	Priority Date (YYYYMMDD)	Purpose	Qty	Units
CHASTER CREEK	**Chaster Creek**	0.02	**F020212**	PD44711	19600714	01A - Domestic	2.27305	m³/day
	Chaster Creek	0.05	**C116516**	PD44713	19540607	01A - Domestic	2.27305	m³/day
	Chaster Creek	0.24	**C121502**	PD44715	19540513	01A - Domestic	2.27305	m³/day
	Shirley Creek (Chaster Trib 4.1)	2.70	**C039934**	PD45975	19710608	01A - Domestic	2.27305	m³/day
	Webb Brook (Chaster Trib 4.1.2)	3.10	**F048883**	PD45973	19731113	01A - Domestic	2.27305	m³/day
	Webb Brook (Chaster Trib 4.1.2)	3.10	**F048883**	PD45973	19731113	04A - Land Improve: General	-	-
	Webb Brook (Chaster Trib 4.1.2)	3.10	**F048883**	PD45972	19731113	01A - Domestic	2.27305	m³/day
	Webb Brook (Chaster Trib 4.1.2)	3.10	**F048883**	PD45972	19731113	04A - Land Improve: General	-	-
	Shirley Creek (Chaster Trib 4.1.1)	3.15	**F040554**	PD45979	19571002	01A - Domestic	2.27305	m³/day
	Co-op Springs (Chaster Trib 4.1.4.2)	3.60	**C019935**	PD45949	19410915	00A - Waterworks: Local Provider	199118.74	m³/yr
	Co-op Springs (Chaster Trib 4.1.4.2)	3.60	**C019935**	PD45950	19410915	00A - Waterworks: Local Provider	-	-
	Co-op Springs (Chaster Trib 4.1.4.2)	3.60	**C019935**	PD45951	19410915	00A - Waterworks: Local Provider	-	-
	Inge Creek (Chaster Trib 4.1.1.1.1)	4.30	**C015414**	PD45077	19410915	00A - Waterworks: Local Provider	82966.143	m³/yr
	Trethewey Spring (Chaster Trib 4.1.2.2)	4.10	**C108199**	PD63202	19540329	01A - Domestic	2.27305	m³/day
	Chaster Creek	5.30	**C021314**	PD45983	19520916	00A - Waterworks: Local Provider	331864.57	m³/yr
	Chaster Creek	5.5	**C11685**	PD45984	19740124	01A - Domestic	2.27305	m³/day
END/ WALKER CREEK	**End Creek**	0.02	**C122666**	PD44717	19671017	01A - Domestic	2.27305	m³/day
	McComb Brook	1.40	**F016236**	PD45931	19520927	04A - Land Improve: General	616.74	m³/yr
	End Creek	1.72	**C129942**	PD45073	19350404	01A - Domestic	4.54609	m³/day
	End Creek	1.84	**C045087**	PD45075	19750121	04A - Land Improve: General	4.54609	m³/day
	End Creek	1.84	**F044096**	PD45075	19610425	01A - Domestic	2.27305	m³/day
	End Creek	1.84	**F044097**	PD45075	19711207	01A - Domestic	2.27305	m³/day
SMALES CREEK	**Elmer Creek**	1.14	**F015851**	PD45080	19510215	01A - Domestic	4.54609	m³/day

---

[90] POD: point of diversion (i.e., water intake)

Watershed	Source	Stream distance (km)	Licence	POD[90]	Priority Date (YYYYMMDD)	Purpose	Qty	Units
HIGGS BROOK	**Higgs Brook**	0.76	**C069016**	PD45103	19781107	01A - Domestic;	2.27305	m³/day
	Higgs Brook	0.76	**C069016**	PD45103	19781107	02D - Comm. Enterprise	4.54609	m³/day
	Higgs Brook	1.1	**C107917**	PD69089	19940323	01A - Domestic	2.27305	m³/day
	Higgs Brook	1.23	**C070726**	PD45105	19620720	01A - Domestic	2.27305	m³/day
SLATER CREEK	**Valentine Spring**	1.24	**F020210**	PD45121	19670401	01A - Domestic	2.27305	m³/day
	Slater Creek	1.57	**C062074**	PD45125	19820824	01A - Domestic	4.54609	m³/day
	Slater Creek	1.66	**C115988**	PD75827	20010216	01A - Domestic	2.27305	m³/day
MOLYNEUX CREEK	**Molyneux Creek**	0.43	**F013226**	PD45128	19430824	01A - Domestic	2.27305	m³/day
	West Molyneux Creek (Molyneux Trib 1)	1.10	**F020285**	PD45913	19580806	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.16	**F017404**	PD45136	19550829	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.19	**C115496**	PD75493	20000713	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.22	**F020336**	PD45138	19670919	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.27	**C052371**	PD45181	19781016	01A - Domestic	2.27305	m³/day
	Dora Brook (near Molyneux Trib 1.1)	1.30	**C105329**	PD66484	19920630	01A - Domestic	2.27305	m³/day
	West Molyneux Creek (Molyneux Trib 1.2)	1.30	**F045488**	PD45914	19671121	01A - Domestic	2.27305	m³/day
	West Molyneux Creek	1.35	**F047915**	PD45916	19680708	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.41	**C114609**	PD74933	19990806	01A - Domestic	2.27305	m³/day
	Molyneux Creek (Trib 2)	1.56	**C118817**	PD77998	20030908	01A - Domestic	2.27305	m³/day
	West Molyneux Creek (Molyneux Trib 1.2)	1.60	**F051909**	PD45917	19721211	01A - Domestic	2.27305	m³/day
	West Molyneux Creek (Molyneux Trib 1.2)	1.80	**C120214**	PD78822	20041203	01A - Domestic	2.27305	m³/day
	Carol Brook (near Molyneux Trib 2)	1.94	**C117783**	PD77416	19980929	01A - Domestic	4.54609	m³/day
	West Molyneux Creek (Molyneux Trib 1.2)	2.40	**C119267**	PD78322	20040216	01A - Domestic	2.27305	m³/day
JOE SMITH CREEK	**Joe Smith Creek**	0.12	**F014265**	PD60230	19480827	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.14	**C035140**	PD60229	19690827	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.14	**F013152**	PD60229	19450406	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.28	**C121664**	PD60226	19490904	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.52	**C049823**	PD60223	19600718	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.58	**C065406**	PD60222	19871126	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	0.78	**C048176**	PD60220	19760426	01A - Domestic	4.54609	m³/day
	Joe Smith Creek	1.16	**C121536**	PD45927	19520124	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	1.16	**C121544**	PD45927	19600408	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	1.36	**C050117**	PD45928	19770815	01A - Domestic	2.27305	m³/day
	Joe Smith Creek	2.28	**C120296**	PD78884	20041220	01A - Domestic	4.54609	m³/day
CLOUGH CREEK	**Clough Brook**	0.26	**C119215**	PD60240	19271111	01A - Domestic	4.54609	m³/day
	Clough Brook	0.62	**C120577**	PD79007	20050404	01A - Domestic	2.27305	m³/day
	Clough Brook	1.1	**C038300**	PD60238	19700730	01A - Domestic	2.27305	m³/day
	Clough Brook	1.16	**F038101**	PD60235	19550628	01A - Domestic	2.27305	m³/day
	Clough Brook	1.25	**F013204**	PD60234	19451020	01A - Domestic	2.27305	m³/day
	Clough Brook	1.35	**F038102**	PD60233	19520917	01A - Domestic	2.27305	m³/day
	Clough Brook	1.59	**C072752**	PD64132	19900723	01A - Domestic	2.27305	m³/day
	Clough Brook	1.66	**C105989**	PD67221	19890119	01A - Domestic	2.27305	m³/day
	Clough Brook	2.76	**C121146**	PD79317	20050823	01A - Domestic	4.54609	m³/day

Watershed	Source	Stream distance (km)	Licence	POD[90]	Priority Date (YYYYMMDD)	Purpose	Qty	Units
RESIDUAL AREA BETWEEN SMALES CREEK & HIGGS BROOK	**Cornwallis Creek**	-	C058064	PD45095	19820218	01A - Domestic	2.27305	m^3/day
	Cornwallis Creek	-	C065238	PD45089	19860717	01A - Domestic	2.27305	m^3/day
	Cornwallis Creek	-	C072212	PD45091	19781117	02D - Comm. Enterprise: Enterprise	9.09218	m^3/day
	Cornwallis Creek	-	C111584	PD45093	19550818	01A - Domestic	2.27305	m^3/day
	Cornwallis Creek	-	F014313	PD45084	19450403	01A - Domestic	2.27305	m^3/day
	Cornwallis Creek	-	F048882	PD45093	19750221	01A - Domestic	2.27305	m^3/day
	Pelican Brook		C115312	PD65312	19911031	01A - Domestic	2.27305	m^3/day
	Pelican Brook		C115312	PD65312	19911031	03B - Irrigation: Private	1233.48	m^3/day
	Pelican Brook		C115312	PD65312	19911031	02E - Pond & Aquaculture	-	m^3/day
	Pelican Brook		C115312	PD75314	19911031	01A - Domestic	-	m^3/day
	Pelican Brook		C115312	PD75314	19911031	03B - Irrigation: Private	-	m^3/year
	Pelican Brook		C115312	PD75314	19911031	02E - Pond & Aquaculture	7.46468	m^3/day
	Pelican Brook		C115313	PD75309	19911031	03B - Irrigation: Private	2207.929	m^3/day
RESIDUAL AREA BETWEEN HIGGS BROOK & SLATER CREEK	**East Leek Creek**	-	C102375	PD63608	19910411	02I32 - Swimming Pool	0	Total Flow
	Leek Creek	-	C043082	PD45107	19731105	01A - Domestic	2.27305	m^3/day
	Leek Creek	-	C043082	PD45107	19731105	03B - Irrigation: Private	12334.8	m^3/year
	Leek Creek	-	C102374	PD63610	19910411	03B - Irrigation: Private	2466.96	m^3/year
	Leek Creek	-	C102374	PD63610	19910411	01A - Domestic	2.27305	m^3/day
	Leek Creek	-	C102374	PD63611	19910411	03B - Irrigation: Private	-	m^3/year
	Leek Creek	-	C102374	PD63611	19910411	01A - Domestic	-	m^3/day
	Leek Creek	-	C106731	PD45113	19570401	01A - Domestic	2.27305	m^3/day

Note that some water licences may be associated with multiple PODs.

4.12.2. Aquifers & Groundwater Use

Aquifers

The description of aquifers in the assessment area, provided below, is based on Advisian (2019), Waterline (2013), and McCammon (1977).

There are two principal aquifers located on the lower southern slopes of Mt. Elphinstone: Roberts Creek bedrock aquifer No. 555 and Gibsons/SCRD Grahams Landing/Elphinstone (Gibsons) confined alluvial aquifer No. 560 (FIGURE 4.26)[91]. A third shallower aquifer (Capilano Aquifer) is located above both principal aquifers; however, it is generally less productive and less utilized.

The Roberts Creek Aquifer is located in bedrock and spans the length of lower south and southwest-facing slopes. Bedrock is covered by about 20 m +/- of surficial materials. Recharge of this bedrock aquifer likely occurs by the following processes:

- mountain block recharge where precipitation infiltrates the upland bedrock joints and fractures or moves as groundwater along the contact between surficial materials and underlying bedrock; or as
- direct precipitation over the aquifer, which infiltrates through the surficial materials and into joints and fractures in the bedrock.

The Gibsons Aquifer is located in and around the Town of Gibsons within glaciofluvial sands and gravels (Pre-Vashon, Quadra Sands) overtop a bedrock basin. The aquifer is capped by Vashon basal till and Lower Capilano clay-rich glaciomarine sediments, both of which serve as an aquitard due to their low permeability. The aquitard lies beneath nearly 200 m of surficial material on the Gibsons Bench. The aquitard varies in thickness between 1 m and 10s of metres. Previous studies suggest there may be areas where the aquitard is absent in the centre of the aquifer. Recharge of the aquifer likely occurs by the following processes:

- mountain block recharge where precipitation infiltrates the upland bedrock joints and fractures or moves as groundwater flows along the contact between surficial materials and bedrock. About 55% of recharge to the aquifer is estimated to occur by mountain block recharge (Waterline, 2013);
- direct precipitation over the aquifer, which infiltrates through the confining surficial materials and into the aquifer. This process is expected to be significant only where confining materials are thin or absent; and
- infiltration along influent (i.e., losing) streams that have their incised streambed below confining (i.e., aquitard) materials.

---

[91] Aquifer 1220 (Eastern slope of Mt Elphinstone) is to the east and effectively outside of the assessment watersheds.

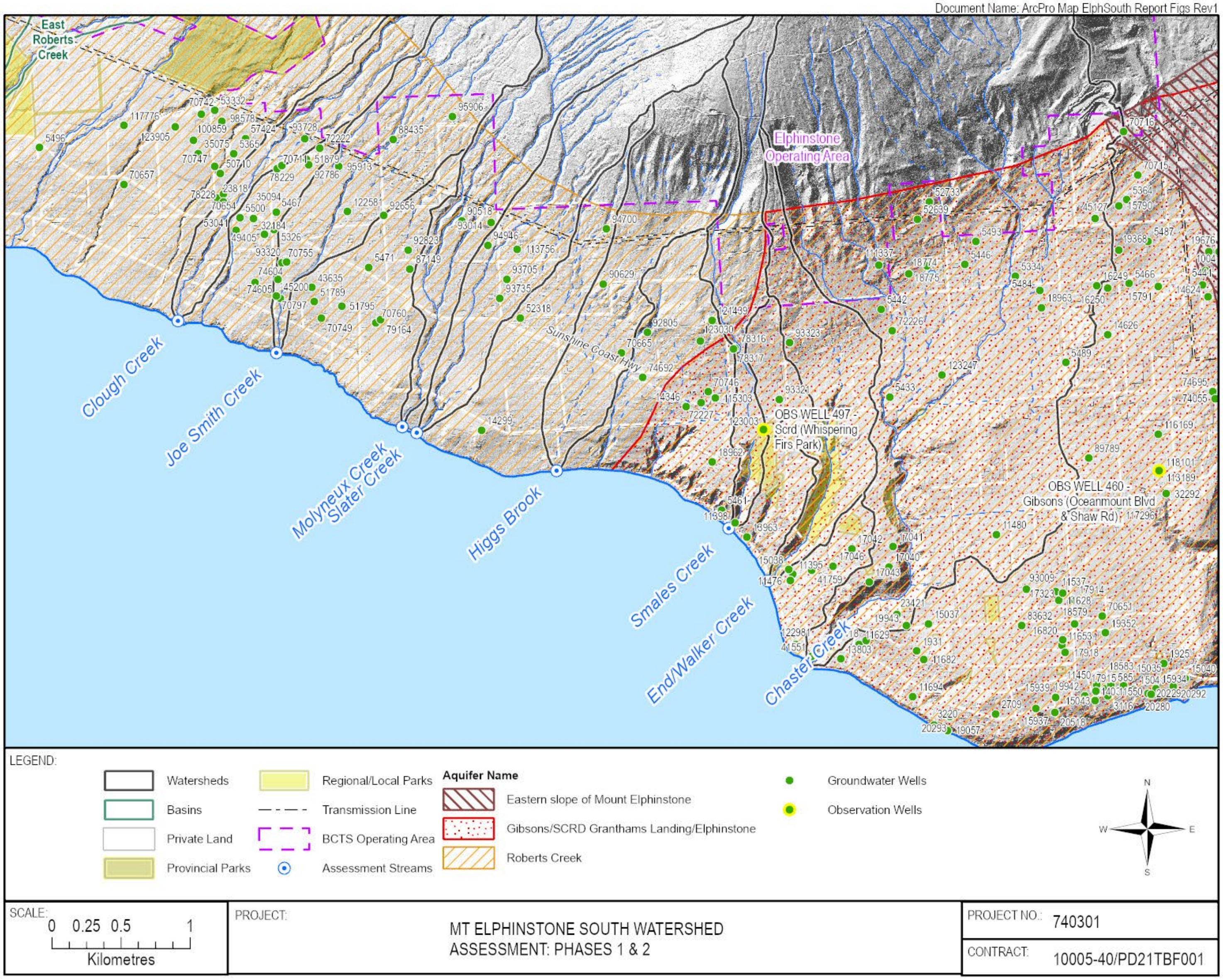


FIGURE 4.26 *Provincially recorded aquifers and groundwater wells in the assessment area. Well tag numbers are indicated.*

A seasonal perched water table has been noted in some areas of glaciofluvial sands and gravels of the Upper Capilano sediments. This water may contribute to springs in the area and supports limited seasonal usage from relatively shallow wells.

Groundwater Wells

According to the BC Groundwater Wells and Aquifers database (Province of British Columbia, 2021b), 94 wells are registered within or between[92] the eight assessment watersheds (FIGURE 4.26, APPENDIX D, MAP 1). A total of 42 wells are associated with the Roberts Creek Aquifer, whereas 30 are associated with the Gibsons Aquifer. The remaining 22 wells are unassigned to an aquifer within the provincial database. The majority of the wells on the southwest-facing slopes source water from the Roberts Creek bedrock aquifer, while those on the Upper Gibsons Bench source water from the confined Gibsons Aquifer (Madrone, 2015). An undetermined number of wells source water from the relatively shallow unconfined Capilano Aquifer. However, as noted above, this aquifer tends to have limited seasonal use.

4.13. FISHERIES RESOURCES

Although none of the assessment streams are provincially recognized as Fisheries Sensitive Watersheds (FSWs), some support known fisheries values (FIGURE 4.27). According to provincial fish inventories (Province of British Columbia, 2021c) and SCRD and DFO (2021), fish have been recorded or suspected in Chaster, End/Walker, Molyneux, and Clough Creeks.

Of the assessment streams with known fish values, Chaster Creek supports the greatest number of fish species. In its lower reaches, below 3 m high falls, located 0.5 km downstream of the Sunshine Coast Highway (near stream km 2), the following species have been identified:

- Anadromous Cutthroat Trout,
- Sculpin,
- Chinook Salmon,
- Chum Salmon,
- Coho Salmon,
- Cutthroat Trout,
- Pink Salmon,
- Rainbow Trout, and
- Steelhead.

---

[92] Area between assessment watersheds are identified as residual areas.

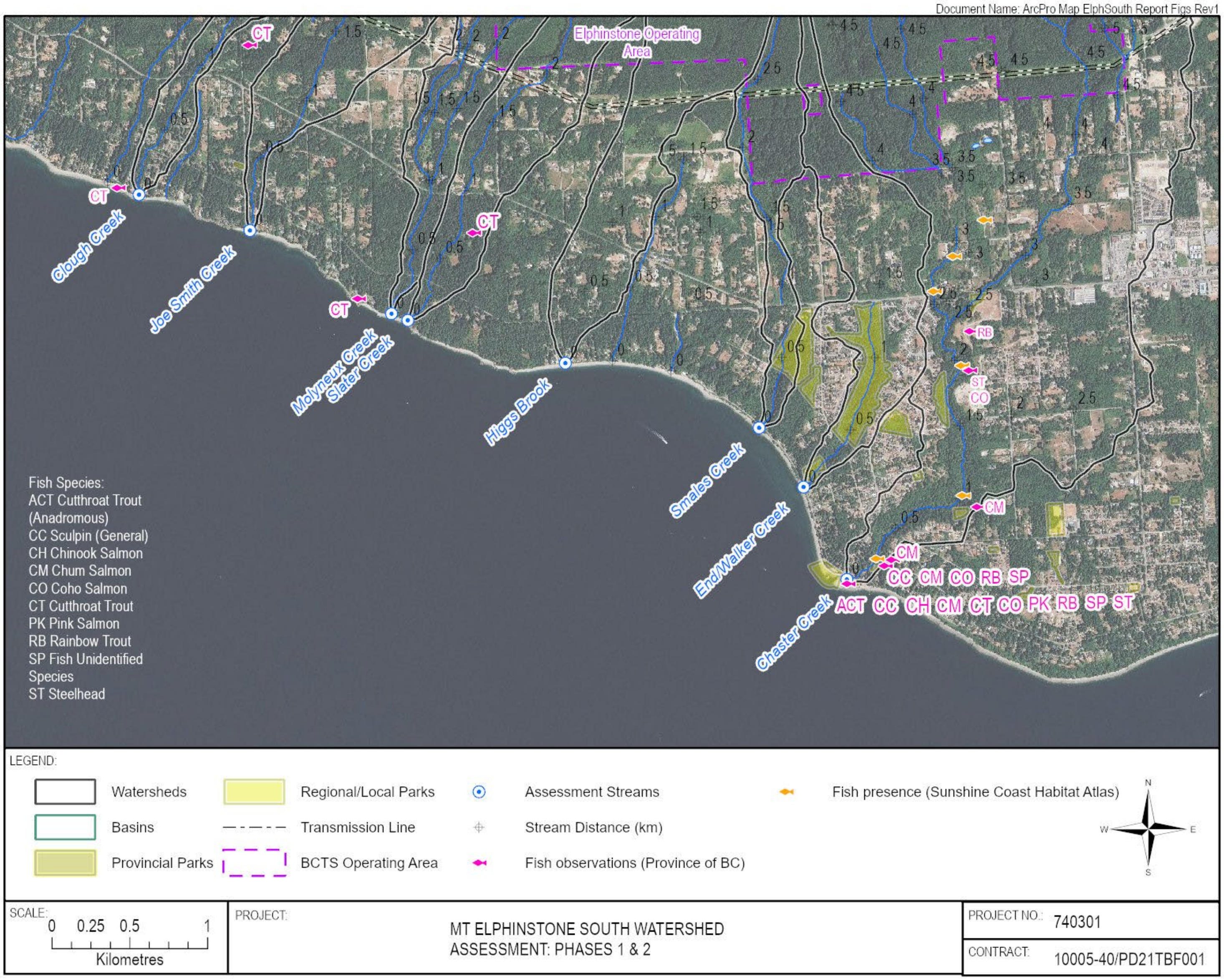


FIGURE 4.27 *Recorded fish presence in the assessment area. Note that some points may be offset due to inaccurate legacy base maps upon which the data is based.*

Above the falls on Chaster Creek near stream km 2.5, Rainbow Trout have been recorded. Although fish have not been recorded further upstream, SCRD and DFO (2021) suggest fish presence in the mainstem and several of the major tributaries of Chaster Creek. Similarly, fish presence is suspected in lower End/Walker Creek (i.e., below the Sunshine Coast Highway). Cutthroat trout are recorded in Molyneux Creek[93] near stream km 0.6 and Clough Creek near stream km 1.2. In addition, SCRD and DFO (2021) suggest that fish may be present in Clough Creek to approximately an elevation of 560 m.

We are unaware of any studies on these streams that have identified what specific factors are limiting fish distributions; however, we suspect that culverts on most streams near the mouth are one restriction as are falls, such as on Chaster. Steep gradients and coarse bed materials are also common.

---

[93] The fisheries database refers to legacy base mapping, which names the stream where Molyneux Creek is located as Joe Smith Creek (i.e., not the same Joe Smith Creek referred to in this report). In addition, the legacy mapping shows the alignment of the creek incorrectly crossing over Slater Creek.

5. WATERSHED VALUES

As noted in Section 2.1, risk identification is the first step in a risk analysis. It involves identifying the watershed values present in the watershed that could potentially be affected by one or more hydrogeomorphic hazards or processes[94]. TABLE 5.1 identifies the primary values identified during the course of this assessment. This list is not intended to be exhaustive[95], but rather guide the assessment in considering what hydrogeomorphic processes should be evaluated. Based on our review of available background information from the assessment area, and with reference to BCTS Watershed Risk Management Framework checklists, TABLE 5.1 identifies the following principal values for consideration: human safety, private property, transportation, utilities, water rights & use, and fish and fish habitat. Furthermore, TABLE 5.2 identifies the potential hazard types specific to the eight assessment streams.

TABLE 5.1 *Summary of identified values within the assessment area.*

Value	Notes on potential type of risk
Human Safety	Residents, workers and the travelling public may be present at various locations downstream of BCTS' Chart. Recreational users and workers may also be present within BCTS Chart. Some may also be vulnerable to hydrogeomorphic hazards (e.g., floods, debris flows, debris floods, etc.) if they are present near streams subject to such hazards at the time they occur. Flood conditions may develop in response to noticeable storm events, usually over an extended period (hours to days). In such cases, there is typically some warning (e.g., rising stream levels) so that risks to human safety can be effectively mitigated (e.g., by evacuating flood-prone areas). Although less common, relatively destructive debris floods or debris flows can potentially be initiated along some of the incised gullies in the assessment area. Such events may occur as a result of natural or development-related sediment and debris delivery from landslides or sediment mobilization along stream channels (e.g., if log jams breach).
Private Property	Several private residences, properties, roads, including stream crossings, water intakes and wells are identified in the assessment area. Some of these values may potentially be vulnerable to flooding-related damage along the eight streams of interest and/or their tributaries.
Transportation Infrastructure	Several public roads (e.g., Sunshine Coast Highway #101, Gibsons Way, Lower Road, Ocean Beach Esplanade, Reed Road) are located downstream of BCTS' Chart and cross streams in the assessment area that may be subject to damage from flooding or other hydrogeomorphic events. In addition, there are several resource roads and trails that cross streams that are subject to flooding in the assessment area.
Utilities	Electrical and telecommunication lines run principally along public highways and public roads or along transmission line rights-of-way. Although these may be subject to service interruption as a result of windstorms and blowdown, they are generally not

---

[94] These values are referred to as potential elements-at-risk.

[95] First Nation cultural or archeological sites, aesthetic, or effects on corporate social licence are not considered.

Value	Notes on potential type of risk
	subject to the hydrogeomorphic hazards considered in the assessment (Section 2.3). Underground natural gas pipelines may, however, be susceptible to flood-related scour where they cross streams (e.g., along Lower Road).
Water Rights & Use	As noted in Section 4.9, domestic water is sourced from several locations within or downslope of BCTS' Chart. This includes Chaster Creek and some of its tributaries, as well as End/Walker Creek, Smales Creek, Higgs Brook, Slater Creek, Molyneux Creek, Joe Smith Creek and Clough Creek. In addition, there are licences on small streams in residual areas between Higgs Brook and Slater Creek as well as between Smales Creek and Higgs Brook. It should be recognized, however, that of the total number of surface water licences registered in the assessment area, a relatively small percentage are currently in use (Section 4.12.1). Many licences are associated with private water systems that have been damaged by natural fluvial activity (e.g., aggradation), abandoned or otherwise not utilized for a number of reasons (e.g., alternative source available from municipality or from groundwater). Domestic water supply can potentially be affected if there is a reduction of supply (i.e., drought), specifically in late summer and early fall. In addition, water quality (e.g., turbidity) can potentially be affected by land use activities upslope, especially where soils are disturbed. Lastly, water intakes, particularly those that are poorly engineered or constructed, may be susceptible to floods. While water quality requirements are not as stringent, irrigation and land improvement water use can similarly be impaired if supplies decrease or if water intakes are subject to damage. Such use is noted in Webb Brook (Chaster Creek watershed) and Leek Creek (residual area between Higgs Brook and Slater Creek). As noted in Section 4.12.2, a total of 94 groundwater wells are recorded downstream of BCTS' Chart. These wells source water from two main sources: the largely confined alluvial Gibsons Aquifer and the bedrock Roberts Creek Aquifer. Some wells may also source water from the unconfined alluvial Capilano Aquifer (Section 4.12.2).
Fish and fish habitat	Several fish species are present downstream of BCTS' Chart, principally within Chaster Creek and its tributaries as well as lower End/Walker Creek, Molyneux Creek and Clough Creek. Potential changes to peak and low flows (magnitude, frequency and/or duration) may affect habitat values (e.g., via channel degradation/aggradation, loss of functioning wood, stream cover, food sources). Instream flows for fish survival may also be adversely affected during drought usually in late summer and early fall. Sedimentation associated with land uses can also be detrimental to fish habitat, impacting both water quality and stream channel conditions.

TABLE 5.2 *Summary of type of hazard by stream catchment.*

Hazard	Elements-at-risk	Chaster Creek	End/Walker Creek	Smales Creek	Higgs Brook	Slater Creek	Molyneux Creek	Joe Smith Creek	Clough Creek
1) **Peak flows** (flooding, debris flood, and/or debris flow) - increased magnitude, frequency and/or duration	a) Human safety	✓	✓	✓	✓	✓	✓	✓	✓
	b) Private property (e.g., flooding of property, damage or loss of land, damage to stream crossings, damage to water intakes and wells)	✓	✓	✓	✓	✓	✓	✓	✓
	c) Transportation & Utilities	✓	✓	✓	✓	✓	✓	✓	✓
2) **Low flows & aquifer recharge** – reduced baseflows and/or groundwater recharge	a) Water rights & use	✓	✓	✓	✓	✓	✓	✓	✓
	b) Instream flow requirements for fish	✓	✓	X	X	X	✓	X	✓
3) **Sediment yield** - increased erosion and subsequent deposition of sediment in streams	a) Water quality, for domestic use and fish	✓	✓	✓	✓	✓	✓	✓	✓
4) **Channel instability** (i.e., channel disequilibrium) associated with increased flooding, sediment yield and/or loss of riparian function.	a) Private property (e.g., loss of land, damage to stream crossings and water intakes)	✓	✓	✓	✓	✓	✓	✓	✓
	b) Fish habitat	✓	✓	X	X	X	✓	X	✓
5) **Water contamination by pollutants**	a) Water quality, for domestic use and fish	✓	✓	✓	✓	✓	✓	✓	✓

"**X**" denotes not applicable (value not identified)

6. SUMMARY OF HAZARDS IN THE ASSESSMENT AREA

This section reviews the types of hydrogeomorphic processes or hazards that have potential to affect identified values in the assessment watersheds (Section 5). This includes an overview of the hazard, a description of current watershed conditions and processes that influence that hazard, and the potential effects of forest development in the context of projected climate change. As indicated in Section 1.2, this assessment does not review specific forest development plans but rather forest development in general.

6.1. STREAMFLOW REGIME

Two primary goals of this assessment were to: 1) identify the likelihood and/or degree to which past disturbance in the assessment area influences the hydrologic regime; and 2) identify the likelihood and/or degree to which the hydrologic regime will change in response to potential future forest development. The potential for a change in the streamflow regime is assessed by considering the history of disturbance in the watershed as well as physical characteristics that influence runoff generation potential [e.g., climate, forest characteristics, elevation, slope, aspect, gradient, soils and method and extent of harvesting (i.e., ECA)], and the potential for runoff synchronization. Discussion of potential changes to the streamflow regime are discussed below for peak flows, low flows and aquifer recharge as effects on each may have the potential to adversely affect identified watershed values.

6.1.1. Peak Flows

As noted in Section 3.1, evaluation of peak flow hazard considers runoff generation potential and runoff synchronization. The former consideration is potentially influenced by ECA, a factor that differs from most other intrinsic characteristics of a stream catchment in that can be influenced by forest management. In coastal watersheds, an evaluation of ECA typically includes identifying overall ECAs and ECAs within the elevation bands where rain, rain-on-snow zone or snow runoff generation typically occur (Hudson and Horel, 2007). Runoff generation during rain-on-snow events is often responsible for generating the most severe floods. Moreover, rain-on-snow tends to be more sensitive to forest disturbance than rain-only events. As such, and following recommendations from Dr. William Floyd, the evaluation of ECA was conducted assuming that rain-on-snow occurs at all elevations and a single rain-on-snow recovery curve was applied across all elevations of the assessment area.

We are aware of only one previous ECA recommendation in the assessment area by Madrone (2015). Based on their assessment of Chaster Creek they recommended that ECA within BCTS' Chart be capped at 25%. This threshold was identified as a measure to reduce the likelihood of adversely increasing peak flow, particularly along the lower, more sensitive alluvial reach of Chaster Creek where intakes were identified. In other creeks, such as Molyneux Creek (which was mistakenly identified as Joe Smith Creek due to the inaccurate legacy base maps), Madrone did not provide an ECA recommendation, believing the non-alluvial or semi-alluvial stream is sufficiently robust not to be adversely affected by any potential harvesting-related peak flow increases.

Based on the characteristics of the assessment watersheds, the runoff generation potential (RGP) is considered high in all watersheds with exception of End/Walker Creek above Highway 101, Smales Creek below Highway 101[96], and Higgs Brook. RGP is considered low for these three stream reaches given they have considerable surface flow discontinuity and a propensity for water losses through infiltration.

With consideration of RGP and the research literature (Section 3.1.1), a majority of the assessment watersheds are expected to have a low peak flow hazard if ECA is below 20%. Between 20 and 30%, peak flow hazard is moderate, and above 30% such hazard is high. Exceptions to these hazard ratings include Smales Creek and Higgs Brook. In these creeks, the RGP is lower due to the discontinuous channels, therefore, peak flow hazard thresholds are higher . Current ECAs and how they relate to peak flow hazards for each assessment watershed is described below.

Current ECAs are spatially presented in FIGURE 6.1. To evaluate how the level of disturbance varies throughout the assessment area, additional points-of-interest (POIs) were identified along the assessment streams. ECAs were evaluated for overall watershed area and for the area above each POI. In total, 31 POIs were identified (FIGURE 6.2, FIGURE 6.3), and were generally placed in the following locations:

- At the confluence of major tributaries, to evaluate ECAs for basins and sub-basins;
- At elements-at-risk, to evaluate the level of disturbance upstream of these points; and
- At the boundary of BCTS' Chart to approximate the level of disturbance within the forest cover land base (i.e., the area not influenced by residential and commercial development).

Current ECAs above each POI and for the portion of BCTS Chart above each POI are identified in TABLE 6.2. Projected future ECAs that account for hydrologic recovery (assuming no additional forest development) are identified in APPENDIX E. The intent of the long-term projections is not to predict what actual conditions will be like in future (as specific forest development plans or

---

[96] The RGP for Smales Creek above Highway 101 is considered high.

other natural disturbances are unknown), but rather to demonstrate the pattern and rate of hydrologic recovery that is expected under current conditions in each of the assessment watersheds.

Peak flow hazard for each POI is presented in TABLE 6.2 and FIGURE 6.3 and described below. The ECA recommendations put forth assume a clearcut silviculture system. If a selective harvest silviculture system (i.e., thinning) is used, ECAs are scaled based on the values in TABLE 6.1.

TABLE 6.1 *Assumptions for ECA calculations for a selective harvest silviculture system [from BC MOF (1999)].*

Basal Area Removed	ECA Assumption
<20%	100% recovery (i.e., 0% ECA)
20% to 40%	0.2 of area harvested[97]
40% to 60%	0.4 of area harvested
60% to 80%	0.6 of area harvested
>80%	0% recovery (i.e., (100% ECA)

ECA recommendations for each POI in TABLE 6.2 are based on the objective to limit the increase in peak flow hazard at POIs downstream of BCTS Chart, while maintaining ECAs below 20% for the portion of the watershed within BCTS Chart. It is important to recognize that in a nested system, the ECA recommendations for all watershed units must be met simultaneously. For example, if the ECA recommendation for a nested basin is greater than for the larger watershed in which it is nested, ECAs within the nested basin can increase as long as the larger watershed ECA recommendations are not exceeded. Given that Chaster Creek and Molyneux Creek have nested drainages, the maximum additional ECA to maintain current peak flow hazard levels are presented in FIGURE 6.4.

ECAs in the assessment area demonstrate that the extent of forest cover disturbance is greatest in the lower portion of the watersheds, which have been subject to varying degrees of residential and commercial development (FIGURE 4.23). This skews the overall watershed ECAs (i.e., above the mouth of each stream) and is likely to have resulted in streamflows along lower reaches of each creek that are effectively permanently urban-influenced[98].

---

[97] For example, 1 ha subject to 35% removal would have an ECA of 0.2 ha.

[98] There is considerable variability in the level of residential and commercial development between watersheds (Section 3.1.4).

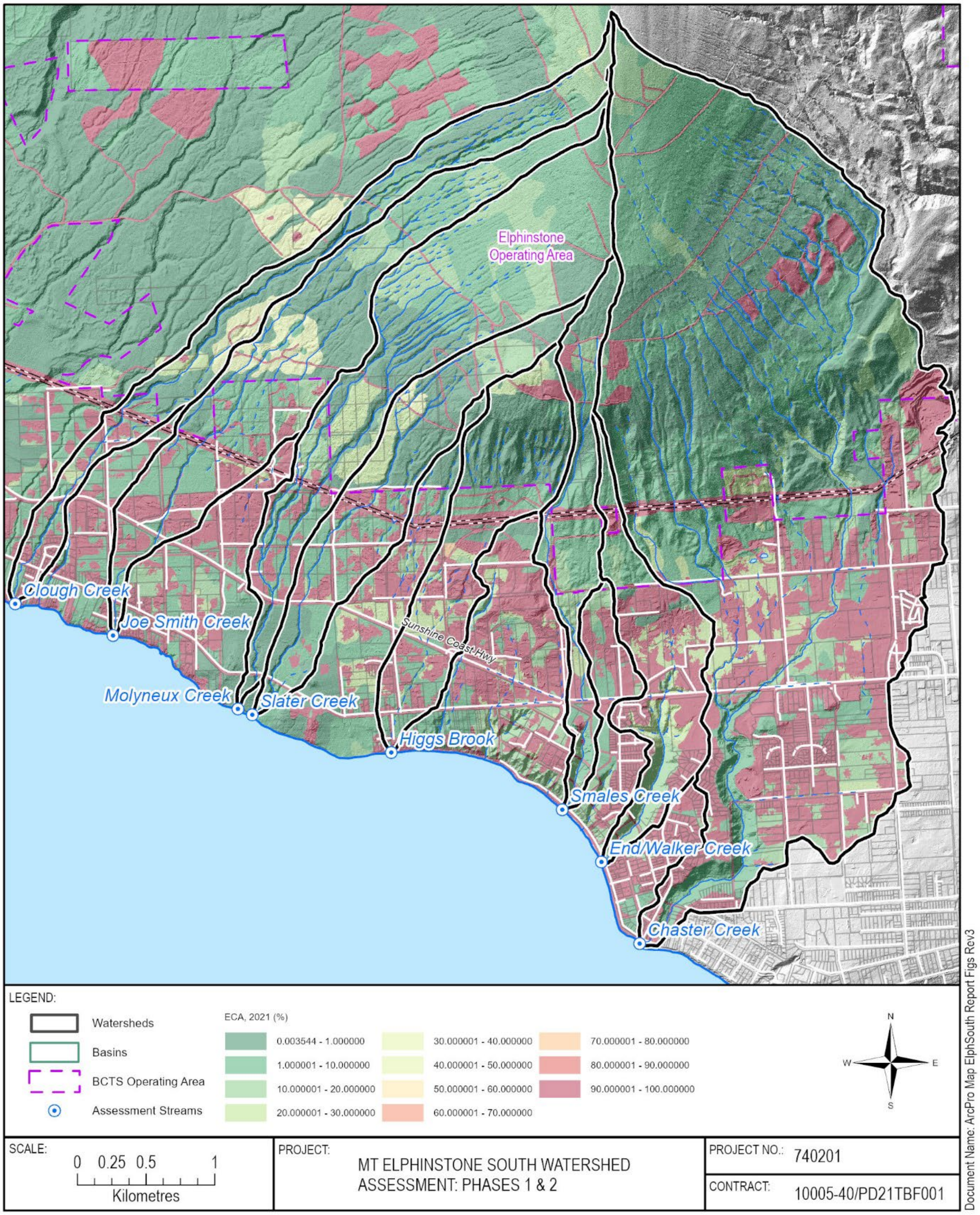


FIGURE 6.1 *Equivalent clearcut areas (ECAs) for the assessment area.*

POI #	Point of Interest (POI)
1	Chaster Creek at the mouth
2	Chaster Creek below Shirley Creek
3	Chaster Creek above Shirley Creek
4	Shirley Creek
5	Chaster Creek at BCTS Chart boundary
6	Inge Creek at BCTS Chart boundary
7	Tretheway Spring at BCTS Chart boundary
8	Co-op Spring at BCTS Chart boundary
9	End/Walker Creek at the mouth
10	End/Walker Creek at Highway 101
11	Smales Creek at the mouth
12	Smales Creek at Highway 101
13	Higgs Brook at the mouth
14	Higgs Brook above Highway 101
15	Slater Creek at the mouth

POI #	Point of Interest (POI)
16	Slater Creek above Highway 101
17	Slater Creek at BCTS Chart boundary
18	Molyneux Creek at the mouth
19	Molyneux below Tributary 1 and 2
20	Molyneux Tributary 1
21	Molyneux Tributary 1 at BCTS Chart boundary
22	Molyneux Tributary 2
23	Molyneux Tributary 2 at BCTS Chart boundary
24	Joe Smith Creek at the mouth
25	Joe Smith Creek above Highway 101
26	Joe Smith Creek at BCTS Chart boundary
27	Clough Creek at the mouth
28	Clough Creek above Highway 101
29	Clough Creek at BCTS Chart boundary
30	Clough Creek at Licence C121146

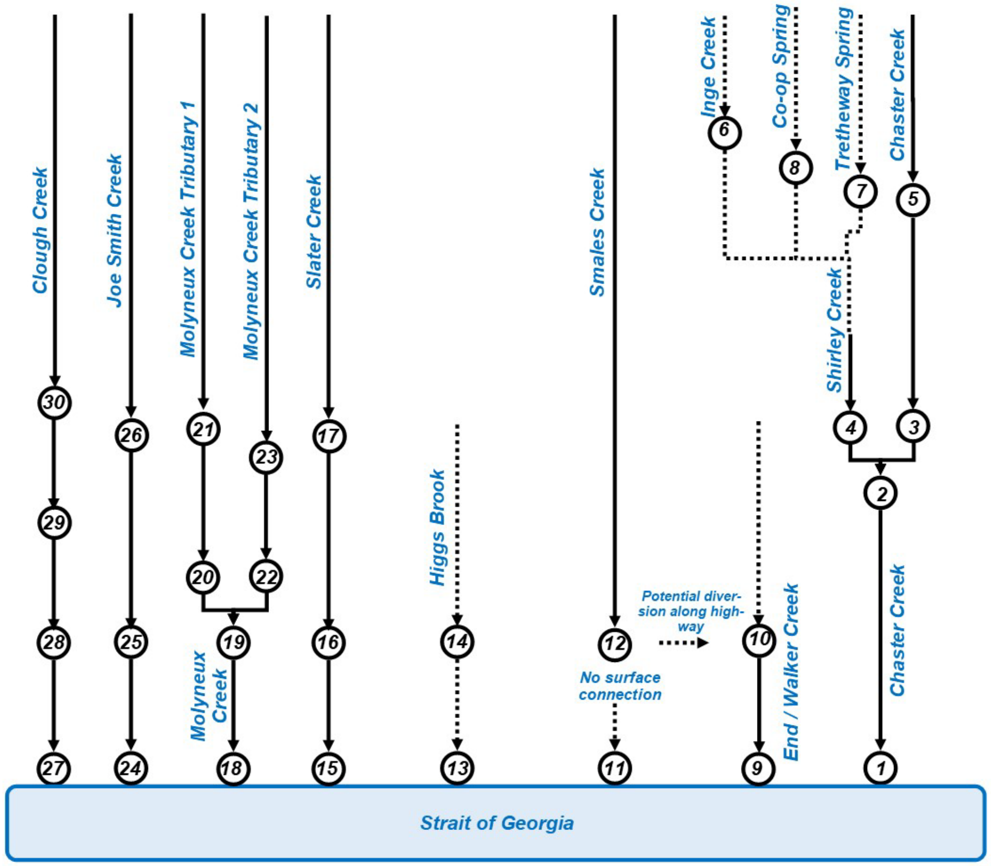
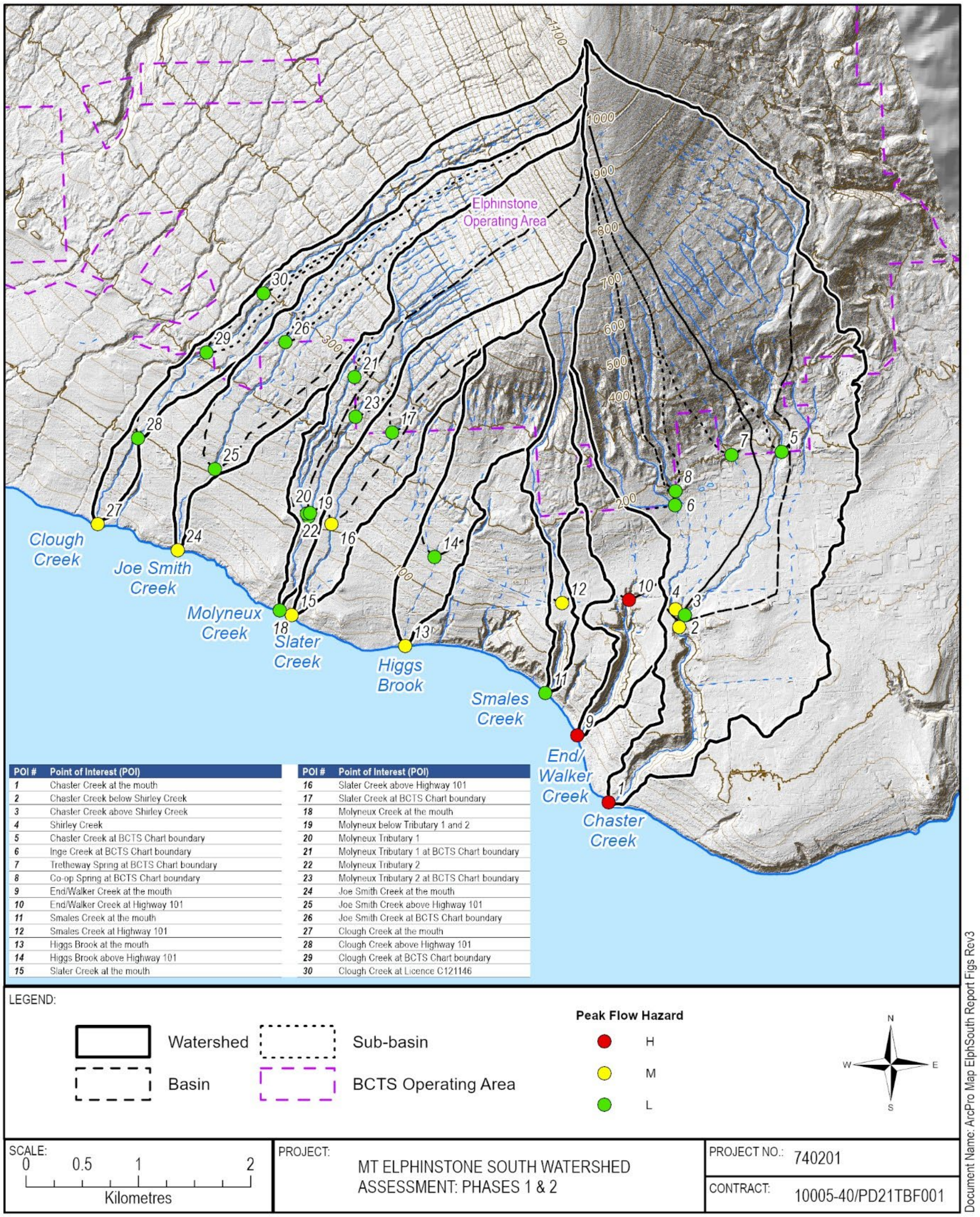


FIGURE 6.2 *Schematic of the assessment watersheds including points-of-interest (POIs)*



POI #	Point of Interest (POI)
1	Chaster Creek at the mouth
2	Chaster Creek below Shirley Creek
3	Chaster Creek above Shirley Creek
4	Shirley Creek
5	Chaster Creek at BCTS Chart boundary
6	Inge Creek at BCTS Chart boundary
7	Tretheway Spring at BCTS Chart boundary
8	Co-op Spring at BCTS Chart boundary
9	End/Walker Creek at the mouth
10	End/Walker Creek at Highway 101
11	Smales Creek at the mouth
12	Smales Creek at Highway 101
13	Higgs Brook at the mouth
14	Higgs Brook above Highway 101
15	Slater Creek at the mouth

POI #	Point of Interest (POI)
16	Slater Creek above Highway 101
17	Slater Creek at BCTS Chart boundary
18	Molyneux Creek at the mouth
19	Molyneux below Tributary 1 and 2
20	Molyneux Tributary 1
21	Molyneux Tributary 1 at BCTS Chart boundary
22	Molyneux Tributary 2
23	Molyneux Tributary 2 at BCTS Chart boundary
24	Joe Smith Creek at the mouth
25	Joe Smith Creek above Highway 101
26	Joe Smith Creek at BCTS Chart boundary
27	Clough Creek at the mouth
28	Clough Creek above Highway 101
29	Clough Creek at BCTS Chart boundary
30	Clough Creek at Licence C121146

FIGURE 6.3 *Points-of-interest (POIs) used to evaluate ECAs. Peak flow hazard at each POI is also presented.*

TABLE 6.2 *Current ECAs and peak flow hazard (PFH) levels above points-of-interest (POIs) in the assessment area. ECAs are presented in both hectares and % of overall drainage area. Due to nested stream catchments in several assessment watersheds, recommended ECA constraints are based on the most limiting constraint amongst the nested catchments.*

Assessment Watershed	POI #	POI	Area above Points-of-Interest						Area within BCTS Chart					Maximum Additional ECA to Maintain Current PFH (ha) [4]	ECA Assuming Maximum Harvest Occurs (ha)	ECA Assuming Maximum Harvest Occurs (%)	Summary of Maximum Additional ECA to Maintain Current PFH
			Drainage Area (ha)	Current ECA Above POI (ha)	Current ECA Above POI (%)	Current Peak Flow Hazard (PFH)	Maximum ECA to Maintain Current Peak Flow Hazard		Chart (ha)	Current Chart ECA (ha)	Current Chart ECA (%)	Default Maximum					
							ECA Above POI (ha)	ECA Above POI (%)				Chart ECA (ha)	Chart ECA (%)				
Chaster Creek	**1**	Chaster Creek at the mouth	1,072.9	363.9	33.9%	**High**	429.2	40%	626.2	65.3	10.4%	125.2	20%	~~59.9~~	~~391.5~~	~~36.5%~~	No more than 27.6 ha may be harvested within BCTS Chart within the Chaster Creek watershed, while at the same time < 11.4 ha is harvested above POI 3, <16.2 ha above POI 4, and <6.3 ha, <8.6 ha, and <6.6 ha above POIs 6-8, respectively.
	2	Chaster Creek below Shirley Creek	733.4	152.5	20.8%	**Moderate**	220.0	30%	577.8	56.0	9.7%	115.6	20%	~~59.6~~	~~180.1~~	~~24.6%~~	
	3	Chaster Creek above Shirley Creek	399.1	68.5	17.2%	**Low**	79.8	20%	343.8	33.8	9.8%	68.8	20%	**11.4**	79.9	20.0%	
	4	Shirley Creek	334.6	84.1	25.1%	**Moderate**	100.4	30%	234.3	22.3	9.5%	46.9	20%	**16.2**	100.3	30.0%	
	5	Chaster Creek at BCTS Chart Bdry	336.6	32.6	9.7%	**Low**	67.3	20%	336.6	32.6	9.7%	67.3	20%	~~34.8~~	~~44.0~~	~~13.1%~~	
	6	Inge Creek at BCTS Chart Bdry	102.7	14.3	13.9%	**Low**	20.5	20%	102.4	14.0	13.7%	20.5	20%	6.3	20.5	20.0%	
	7	Tretheway Spring at BCTS Chart Bdry	72.9	6.0	8.2%	**Low**	14.6	20%	69.4	4.2	6.1%	13.9	20%	8.6	14.6	20.0%	
	8	Co-op Spring at BCTS Chart Bdry	49.7	3.3	6.7%	**Low**	9.9	20%	48.9	2.7	5.6%	9.8	20%	6.6	9.9	20.0%	
End/Walker Creek	**9**	End/Walker Creek at the mouth	114.8	65.7	57.2%	**High**	-	-	19.3	2.6	13.3%	3.9	20%[1]	**1.3**	67.0	58.3%	No more than 1.3 ha may be harvested within BCTS Chart.
	10	End/Walker Creek above Hwy 101	64	35.7	55.7%	**High**	-	-	19.3	2.6	13.3%	3.9	20%[1]	**1.3**	37.0	57.7%	
Smales Creek	**11**	Smales Creek at the mouth	94.6	23.3	24.7%	**Low**[2]	-	-	62.1	10.2	16.5%	12.4	20%	**2.2**	25.5	27.0%	No more than 2.2 ha may be harvested within BCTS Chart.
	12	Smales Creek above Highway 101	79.6	17.8	22.3%	**Moderate**	23.9	30%	62.1	10.2	16.5%	12.4	20%	**2.2**	19.9	25.1%	
Higgs Brook	**13**	Higgs Brook at the mouth	145	53.7	37.0%	**Moderate**[3]	-	-	60.6	5.7	9.3%	12.1	20%	**6.5**	60.1	41.5%	No more than 6.5 ha may be harvested within BCTS Chart.
	14	Higgs Brook above Hwy 101	111.2	33.9	30.5%	**Low**[3]	-	-	60.6	5.7	9.3%	12.1	20%	**6.5**	40.4	36.3%	
Slater Creek	**15**	Slater Creek at the mouth	142.4	37.2	26.1%	**Moderate**	42.7	30%	72.0	10.7	14.8%	14.4	20%	**3.7**	41.0	28.8%	No more than 3.7 ha may be harvested within BCTS Chart, while no more than 1.8 ha harvested above POI 16.
	16	Slater Creek above Hwy 101	80.6	19.9	24.7%	**Moderate**	24.2	30%	58.2	9.8	16.8%	11.6	20%	1.8	21.7	27.0%	
	17	Slater Creek at BCTS Chart Bdry	54.1	8.6	15.9%	**Low**	10.8	20%	54.1	8.6	15.9%	10.8	20%	~~2.2~~	~~10.4~~	~~19.2%~~	
Molyneux Creek	**18**	Molyneux Creek at the mouth	264.8	38.2	14.4%	**Low**	53.0	20%	207.2	18.7	9.0%	41.4	20%	**14.7**	53.0	20.0%	No more than 14.7 ha may be harvested within BCTS Chart, while at the same time no more than 8.8 ha is harvested above POI 20, and 6.4 ha is harvested above POI 22.
	19	Molyneux below Tributary 1 and 2	249.1	34.6	13.9%	**Low**	49.8	20%	206.9	18.6	9.0%	41.4	20%	~~15.2~~	49.3	19.8%	
	20	Molyneux Tributary 1	137.2	18.6	13.6%	**Low**	27.4	20%	111.5	9.0	8.1%	22.3	20%	8.8	27.4	20.0%	
	21	Molyneux Tributary 1 at BCTS Chart Bdry	107.5	8.6	8.0%	**Low**	21.5	20%	107.4	8.6	8.0%	21.5	20%	~~12.9~~	~~17.4~~	~~16.1%~~	
	22	Molyneux Tributary 2	111.9	16.0	14.3%	**Low**	22.4	20%	95.4	9.6	10.0%	19.1	20%	6.4	22.4	20.0%	
	23	Molyneux Tributary 2 at BCTS Chart Bdry	90.5	8.5	9.4%	**Low**	18.1	20%	90.5	8.5	9.4%	18.1	20%	~~9.6~~	~~14.9~~	~~16.5%~~	
Joe Smith Creek	**24**	Joe Smith Creek at the mouth	228.6	57.6	25.2%	**Moderate**	68.6	30%	132.0	13.4	10.2%	26.4	20%	~~11.0~~	~~61.5~~	~~26.9%~~	No more than 3.9 ha may be harvested within BCTS Chart.
	25	Joe Smith Creek above Hwy 101	190.8	34.2	17.9%	**Low**	38.2	20%	131.9	13.4	10.2%	26.4	20%	**3.9**	38.2	20.0%	
	26	Joe Smith Creek at BCTS Chart Bdry	64.6	6.1	9.5%	**Low**	12.9	20%	64.6	6.1	9.5%	12.9	20%	~~6.8~~	~~10.0~~	~~15.5%~~	
Clough Creek	**27**	Clough Creek at the mouth	154.1	31.8	20.6%	**Moderate**	46.2	30%	114.9	10.3	9.0%	23.0	20%	12.7	38.1	24.7%	No more than 6.3 ha may be harvested within BCTS Chart.
	28	Clough Creek above Hwy 101	134.9	20.7	15.3%	**Low**	27.0	20%	114.9	10.3	9.0%	23.0	20%	**6.3**	27.0	20.0%	
	29	Clough Creek at BCTS Chart Bdry	93.2	6.2	6.7%	**Low**	18.6	20%	93.2	6.2	6.7%	18.6	20%	~~12.4~~	~~12.5~~	~~13.4%~~	
	30	Clough Creek at Licence C121146	79.3	4.8	6.0%	**Low**	15.9	20%	79.3	4.8	6.0%	15.9	20%	~~11.1~~	~~11.1~~	~~14.0%~~	

Note:

1) Given the discontinuous channel in the upper portion of the watershed, peak flow hazard downstream is not expected to measurably change if ECAs within BCTS Chart are maintained below 20%.
2) Despite ECAs in excess of 20%, a low peak flow hazard is considered given the absence of a defined channel below Highway 101 (i.e., the channel is discontinuous).
3) Despite elevated ECAs, a reduced peak flow hazard is assigned based on the discontinuous channel. Higgs Brook disappears into the subsurface along Gibsons Bench.
4) When identifying the maximum additional ECA to maintain current PFH, consideration is given to the overall watershed constraint as well as the constraints for catchments nested within. Values in red and orange indicate the limiting constraints for that watershed unit. Values struck out would maintain current PFH for the respective POI/catchment; however, PFH would increase for another POI/catchment in the same watershed – thus values stuck out are not recommended.
5) Yellow highlighted cells show limiting factor for maximum ECA identified for each POI.

POI #	Point of Interest (POI)
1	Chaster Creek at the mouth
2	Chaster Creek below Shirley Creek
3	Chaster Creek above Shirley Creek
4	Shirley Creek
5	Chaster Creek at BCTS Chart boundary
6	Inge Creek at BCTS Chart boundary
7	Tretheway Spring at BCTS Chart boundary
8	Co-op Spring at BCTS Chart boundary
9	End/Walker Creek at the mouth
10	End/Walker Creek at Highway 101
11	Smales Creek at the mouth
12	Smales Creek at Highway 101
13	Higgs Brook at the mouth
14	Higgs Brook above Highway 101
15	Slater Creek at the mouth
16	Slater Creek above Highway 101
17	Slater Creek at BCTS Chart boundary
18	Molyneux Creek at the mouth
19	Molyneux below Tributary 1 and 2
20	Molyneux Tributary 1
21	Molyneux Tributary 1 at BCTS Chart boundary
22	Molyneux Tributary 2
23	Molyneux Tributary 2 at BCTS Chart boundary
24	Joe Smith Creek at the mouth
25	Joe Smith Creek above Highway 101
26	Joe Smith Creek at BCTS Chart boundary
27	Clough Creek at the mouth
28	Clough Creek above Highway 101
29	Clough Creek at BCTS Chart boundary
30	Clough Creek at Licence C121146

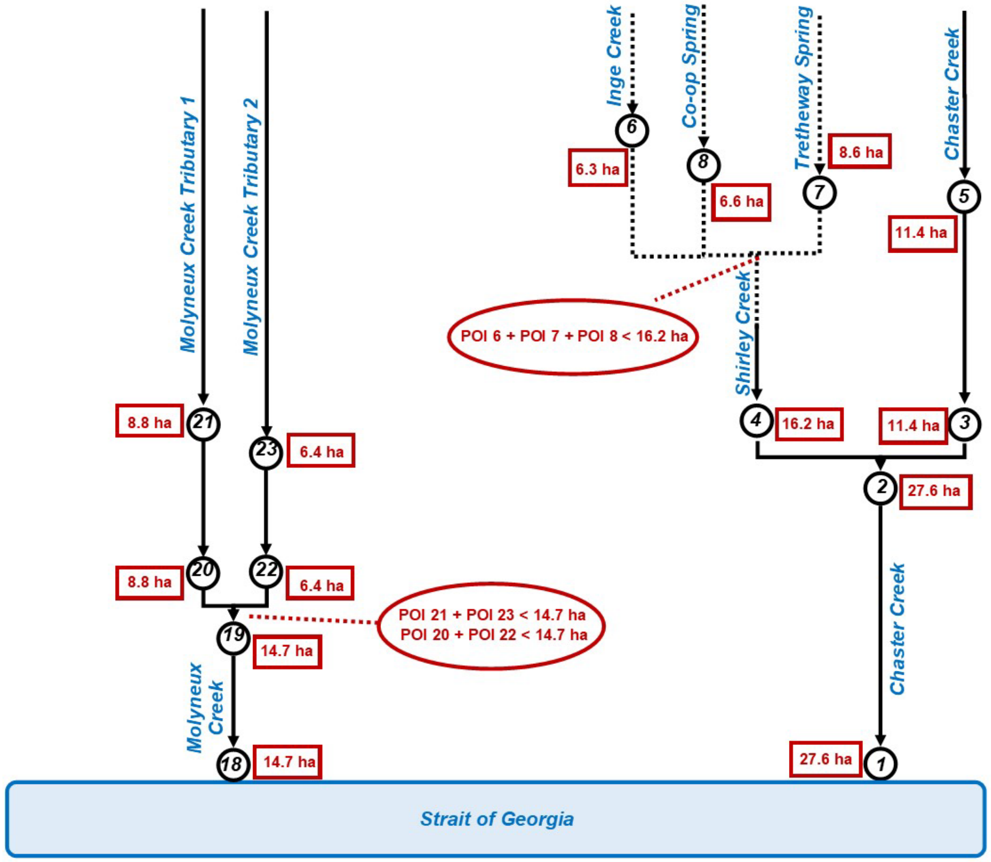


FIGURE 6.4 *Schematic of the maximum additional ECA (values in red) to maintain current peak flow hazard in the Chaster Creek and Molyneux Creek watersheds.*

The following descriptions by assessment stream identify the expected forest development effects on the current hydrologic condition. Even though BCTS maintains a low peak flow hazard within BCTS Chart, moderate and/or high peak flow hazards downslope of the chart are controlled by residential and commercial development. As such, meaningful reductions for some downstream POIs may never be realized because there is little to no hydrologic recovery associated with downstream residential and commercial development areas.

Chaster Creek

In the Chaster Creek watershed, eight POIs have been identified above which ECAs have been calculated (TABLE 6.2). Current ECA for the overall watershed (i.e., Chaster Creek at the mouth) is 33.9% (363.9 ha). Current ECA for the POIs within the watershed range from 6.7% for Co-op Spring at BCTS Chart Boundary to 25.1% for the Shirley Creek basin. The relatively high overall ECA is heavily weighted by residential and commercial land clearing in the lower portion of the watershed. Both the elevated ECA within this zone and the conversion of green spaces to impermeable surfaces and alteration of drainage patterns with stormwater infrastructure has likely had an influence on the rate at which urban runoff is conveyed to Chaster Creek. Similarly, relatively high ECAs in the Shirley Creek basin are in large part due to residential land clearing in the lower portion of the basin (between POI 4 and POIs 6-8). Current ECA for the portion the watershed within BCTS Chart is 10.4%; however, this does not represent an actual drainage unit and is only a proxy for the area disturbed.

As such, the current peak flow hazard (PFH) is considered high for the Chaster Creek stream reach between POI 1 and POI 2 (TABLE 6.2). A moderate peak flow hazard is identified for Chaster Creek below Shirley Creek (POI 2) and for the Shirley Creek basin (i.e., the streams between POI 4 and POIs 6-8). All stream reaches within BCTS Chart (POIs 5-8) currently have a low peak flow hazard. If BCTS is seeking development opportunities and wishes to maintain current peak flow hazard levels, ECAs within BCTS Chart should be limited to an increase of no more than 27.6 ha overall, while no more than 11.4 ha is harvested above POI 3, and no more than 16.2 ha is harvested above POI 4. An additional constraint is that ECAs within POIs 6-8 should be limited to an increase of no more than 6.3 ha, 8.6 ha, and 6.6 ha, respectively, while recognizing they can not exceed 16.2 ha collectively.

These recommendations reflect current (2021) conditions. More availability for harvest is expected in the future as stands recover. Recovery of 4.7 ha is projected by 2026 and 13.4 ha of recovery is projected by 2031 for the watershed overall (TABLE E.1, APPENDIX E).

End/Walker Creek

Current ECA in End/Walker Creek is 57.2% (65.7 ha) at the mouth, and 55.7% above Highway 101 (POI 10). Elevated ECAs are predominantly a result of residential and commercial land clearing in the lower three quarters of the watershed and high proportion of deciduous species[99] in the ravine below BCTS Chart. Moreover, altered drainage patterns due to stormwater infrastructure are noted throughout the urbanized area of the watershed. The crown land portion of the watershed has relatively low drainage density and few, if any, classified streams. ECA within BCTS Chart is currently 13.3%.

As such, the current peak flow hazard is considered high for End/Walker Creek at the mouth and End/Walker Creek above Highway 101. Given the discontinuous channel in the upper portion of the watershed, peak flow hazard downstream is not expected to measurably change if ECAs within BCTS Chart are maintained below 20%. In other words, future development of up to 1.3 ha within BCTS Chart would serve to incrementally increase ECA, although peak flow hazard is expected to remain high at the two POIs.

Given the prevalence of residential and commercial development, and high proportion of deciduous in the lower portion of the watershed, projected hydrologic recovery is relatively slow. By 2026 and 2031, ECAs are projected to increase by 0.1 ha and 0.4 ha, respectively.

Smales Creek

Current ECA above Smales Creek at the mouth is 24.7% (23.3 ha). ECA above Highway 101 (POI 12) is 22.3%. Elevated ECAs are in large part due to residential and commercial land clearing in the lower portion of the watershed, a relatively high proportion of deciduous species in the center of the watershed, and forest development in the upper portion.

Altered drainage patterns due to stormwater infrastructure are noted in lower parts of the watershed. Field observations indicate that surface water generated upslope of Highway 101 is most likely diverted eastward along the north side of the highway towards End/Walker Creek, with some potentially diverted westward towards Whittaker Creek, depending on streamflows. Flow diversion towards Whittaker Creek was a factor responsible in part for the washout that occurred at the Lower Road crossing of Whittaker Creek on February 1, 2020 (Carson, 2020). Furthermore, no evidence of a defined channel immediately below Highway 101 was noted during the field review. Despite an ECA greater than 20% at the mouth, a low peak flow hazard is identified for POI 11 given the discontinuity of the channel from the upper and lower portion of the watershed. Peak flow hazard at Highway 101 (POI 12) is considered moderate. These peak flow hazard ratings are not expected to change if ECA is maintained below 20% within BCTS' Chart. In other words, harvesting an additional 2.2 ha within BCTS Chart would serve to maintain a low peak flow hazard at the mouth and a moderate peak flow hazard at Highway 101. By 2026, ECAs are projected to recover by 0.8 ha, and by 2031, 1.8 ha of recovery is projected.

---

[99] Deciduous stands intercept less rain and snow relative to coniferous stands. As such, ECA for the portion of a stand occupied by deciduous species were scaled by 25%.

Higgs Brook

Current ECA in Higgs Brook is 37.0% (53.7 ha) at the mouth and 30.5% above Highway 101 (POI 14). Elevated ECAs are predominantly a result of residential and commercial development in the lower two-thirds of the watershed. ECA within BCTS Chart is 9.3%. Streams in the upper portion of the watershed disappear subsurface as hillslopes transition from steep to shallow on the Gibsons Bench, roughly in the center of the watershed. Streams daylight (i.e., emerge from the subsurface) as slopes steepen in the lower portion of the watershed. Given the discontinuity of the channels in the upper and lower portion of the watershed, a moderate peak flow hazard is considered at the mouth (POI 13) and a low peak flow hazard is considered at Highway 101 (POI 14), despite elevated ECAs.

In the future, peak flow hazard is not expected to change if ECAs within BCTS Chart are not increased by more than 6.5 ha (i.e., ECA does not surpass 20% within BCTS Chart). Given some relatively newer openings in the upper portion of the watershed, ECAs are projected to improve with tree regeneration, potentially allowing more availability for harvest in the short- and medium-term. ECAs are projected to recover by 1.3 ha and 3.0 ha by 2026 and 2031, respectively.

Slater Creek

Current ECA in Slater Creek is 26.1% (37.2 ha) at the mouth (POI 15), 24.7% above Highway 101 (POI 16), and 15.9% at BCTS Chart Boundary (POI 17). Elevated ECAs are primarily a result of residential development in the lower portion of the watershed, and forest development in the upper portion. As such, current peak flow hazard is moderate for Slater Creek at the mouth and Slater Creek above Highway 101, and low for Slater Creek at BCTS Chart Boundary.

Peak flow hazard is not expected to change for the POIs within the watershed if ECA within BCTS Chart is maintained below 20%. As such, current peak flow hazard is not expected to change with future development of 3.7 ha within BCTS Chart, while no more than 1.8 ha be harvested above POI 16. Given a high proportion of young, fast-growing stands in the upper portion of the watershed, hydrologic recovery is expected to occur relatively quickly. As such, ECAs are projected to recover by 2.8 ha by 2026 and by 4.2 ha by 2031.

Molyneux Creek

Current ECA at Molyneux Creek at the mouth is 14.4% (38.2 ha). Current ECA in the remaining POIs range from 8.0% at Molyneux Tributary 1 at BCTS Chart Boundary (POI 21) to 14.3% at Molyneux Tributary 2 (POI 22). ECAs are predominantly a result of residential land clearing in the lower portion of the watershed, forest development in the middle portion, and stands composed of 15 to 50% deciduous species in the upper portion of the watershed.

Current peak flow hazard is low throughout the entire watershed. In the future, peak flow hazards are expected to remain low in all POIs if no more than 14.7 ha is harvested within BCTS Chart, with no more than 8.8 ha harvested above POI 20, and 6.4 ha harvested above POI 22, recognizing that the collective sum above POI 20 and POI 22 can not exceed 14.7 ha. We recognize that this threshold is lower than the 25% threshold reported by Madrone (2015); however, we believe the conservatism is justified given the presence of some sensitive semi-alluvial stream reaches and at least two actively used water intakes (FIGURE 4.25). With hydrologic recovery, an additional 2.3 ha is projected to be available by 2026 and an additional 3.4 ha is projected to be available by 2031.

Joe Smith Creek

Current ECA in Joe Smith Creek is 25.2% (57.6 ha) at the mouth, 17.9% above Highway 101 (POI 25), and 9.5% at BCTS Chart Boundary (POI 26). Elevated ECA is predominantly due to residential development in the lower portion of the watershed, and forest development in the middle and upper portion. Moreover, stands composed of 15 to 50% deciduous species are noted in the upper portion of the watershed.

Current peak flow hazard is considered moderate at the mouth (POI 24), and low above Highway 101 (POI 25) and at BCTS Chart Boundary (POI 26). Current peak flow hazard is not expected to change as long as ECAs increase by no more than 3.9 ha within BCTS Chart. In the future, an additional 2.9 ha is projected to become available by 2026 and an additional 4.5 ha is projected to be available by 2031.

Clough Creek

Current ECA in Clough Creek is 20.6% (31.8 ha) at the mouth, 15.3% above Highway 101 (POI 28), 6.7% at BCTS Chart Boundary (POI 29), and 6.0% at surface water licence C121146 (POI 30). Elevated ECAs are a result of rural development in the lower portion of the watershed and forest development in the middle and upper portion.

Current peak flow hazard is moderate at Clough Creek at the mouth, and low in the remainder of the watershed (POI 28-30). In the future, peak flow hazard is expected to remain unchanged if no more than 6.3 ha is developed within BCTS Chart. With hydrologic recovery, an additional 2.2 ha and 3.3 ha is projected to become available by 2026 and 2031, respectively.

Effects of roads on peak flows

Although the removal of forest cover along road rights-of way are accounted for in ECA calculations, roads can also affect natural drainage patterns and increase runoff generation potential, thereby increasing the rate at which runoff water is delivered to streams. This is particularly important where roads intercept near-surface groundwater (Wemple and Jones, 2003).

Current (2021) road densities and lengths were calculated for the watershed units and are presented in TABLE 6.3. The road layer was compiled using the FTA, Digital Road Atlas, DEM bare earth hillshade, and streaming imagery. It is important to note, however, that these road densities were calculated solely from a GIS-based exercise and were not field verified. Moreover, no information was available to differentiate between existing and deactivated roads.

Unsurprisingly, total road lengths and road densities are high given the level of urban development in the lower portion of the assessment area. Urbanization is generally concentrated below approximately 300 m, and the area above 300 m is largely Crown Land. As such, road lengths and densities above 300 m can be considered to generally represent the influence of forestry.

Recommended road density management thresholds are not provided as they can be somewhat misleading. For example, a high density of well built (i.e., well-spaced and working drainages, robust road surface, etc.) may have a lesser effect on hydrology than a low density of poorly built roads. As such, only qualitative ratings are provided. Road densities above 300 m are generally low with exception of Smales Creek with a density of 6.29 km/km^2. Despite the high densities in Smales Creek, road conditions within the watershed were observed to be in good condition. The current road alignments in the assessment area are generally on relatively low gradient terrain (FIGURE 4.2). As a result, road cuts are likely to be relatively shallow. Furthermore, due to relatively rapid preferential flow and high drainage density, shallow groundwater and surface water flow rates are similar, such that road-related effects (e.g., interception of shallow groundwater flow and conveyance as ditch flow) on drainage patterns and flow rates are expected to be small. Based on this, the net effect of forest resource roads on near-surface groundwater interception and ultimately peak flow hazard is low.

TABLE 6.3 *Road lengths and road densities for the assessment watersheds. An elevation of 300 m serves as a rough approximation for the boundary between urban roads (below) and forest resource roads (above).*

Watershed Units								
Stream / Watershed	**Chaster Creek**	**End / Walker Cr**	**Smales Creek**	**Higgs Brook**	**Slater Creek**	**Molyneux Creek**	**Joe Smith Creek**	**Clough Creek**
Roads								
Total length (km)	33.33	4.27	9.47	6.53	3.81	7.47	13.78	4.89
Total density (km/km^2)	3.11	3.71	9.97	4.50	2.68	2.82	6.02	3.18
Total road area (ha)	50.49	8.89	6.33	10.92	9.63	9.83	11.50	6.33
Length below 300 m (km)	28.62	4.27	3.50	6.53	3.51	4.46	-	4.89
Density below 300 m (km/km^2)	2.67	3.71	3.68	4.50	2.47	1.68	-	3.18
Road area below 300 m (ha)	37.70	8.19	4.65	9.94	5.46	3.23	9.59	4.69
Length above 300 m (km)	4.71	-	5.98	-	0.30	3.01	5.05	-
Density above 300 m (km/km^2)	0.44	-	6.29	-	0.21	1.14	2.21	-
Road area above 300 m (ha)	12.79	0.70	1.68	0.99	4.18	6.60	1.90	1.65

6.1.2. Low Flows

The current distribution of seral stages across the assessment area indicates that nearly the entire forested land base has been either naturally disturbed (e.g., by wildfire) or harvested within the last 150 years. In other words, forests in the assessment area are predominantly, if not entirely, second growth stands. As such, the history of disturbance has potentially influenced low flows of the assessment streams. The distribution of forest age classes within BCTS Chart offers some indication of relative water consumption overall (FIGURE 4.20) and for each of the assessment watersheds (FIGURE 6.5). This type of analysis as part of a watershed assessment is novel and based on limited data, so, the analysis is restricted to a qualitative exercise. Four age classes were identified based on structural stages outlined in the Standard for Terrestrial Ecosystem Mapping in British Columbia (Ecosystems Working Group, 1998) and research literature on forest structure (Spies and Franklin, 1991) and on the effects of forest cover removal on low flows in the Pacific Northwest (e.g., Perry and Jones, 2017; Segura et al., 2020).

As discussed in Section 3.1.2, increases in late summer (i.e., July to September) flow volumes can occur in the first several years following forest cover removal[100]. The increase in late summer flow is associated with the elimination of interception and transpiration losses and a net increase in soil moisture, which may contribute to groundwater recharge. However, such increases typically persist from a few years (Segura et al., 2020) to upwards of fifteen years (Perry and Jones, 2017). Once sufficiently dense regenerating forest becomes established, the potential for water demands from the forest increases, often resulting in less water available for infiltration and runoff than prior to harvesting. This is a phenomenon referred to as *over-recovery*, whereby the density and forest cover provided by vigorously growing tree plantations exceeds the original stand. Perry and Jones (2017) found that persistent low flow deficits (i.e., over-recovery) were less likely to occur when openings were less than 8 ha and were unlikely to occur when catchments were subject to a 50% thinning (i.e., shelterwood) silviculture system. As forest stands age, evapotranspiration rates decrease and low flows will trend towards baseline conditions; however, a return to baseline can be a lengthy process. Segura (2020) found that summer streamflow generated from 40- to 53-year-old Douglas fir stands was still 50% less than runoff generated from the mature/old (90- to 170-year-old) Douglas fir stands.

---

[100] It is important to recognize that the majority of studies evaluating the effect of forest cover removal on low flows are based on 100% basal area removal.

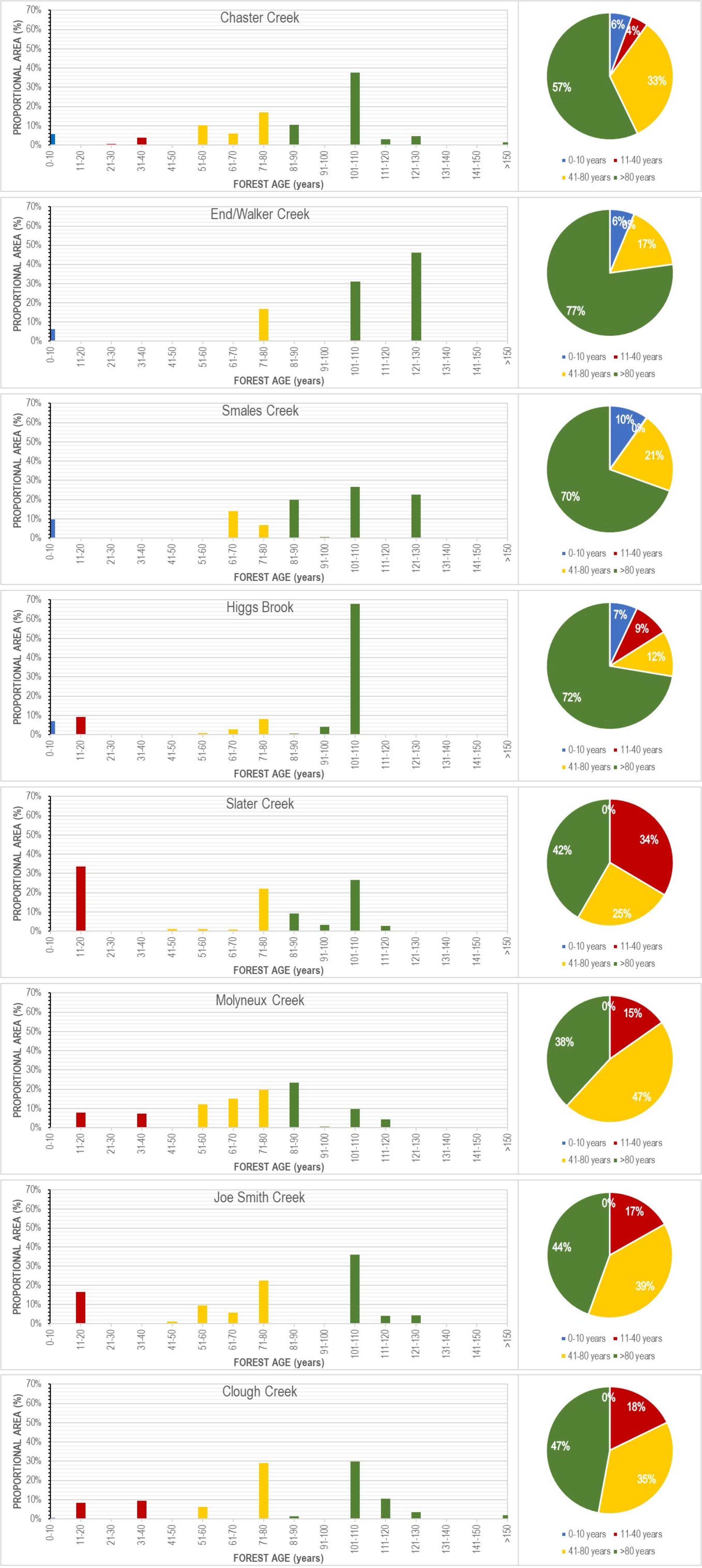


FIGURE 6.5 *Distribution of forest ages within BCTS Chart by watershed. The histogram presents age classes by decade. The pie chart shows stand age distribution for four age classes based on water consumption (i.e., evapotranspiration rates) relative to mature (i.e., >80-year-old) stands. Stands 0-10 years old are expected to have relatively low water consumption, stands 11-40 years are expected to have relatively high water consumption, stands 41-80 years are expected to have relatively moderate water consumption and stands >80-years are expected to have normal water consumption (i.e., baseline).*

As indicated above, forest stand ages throughout BCTS' Chart have been classified into four age classes to illustrate summer water use relative to baseline conditions. In this case, baseline conditions are represented by mature (>80-year-old) stands. Forest stands aged 0-10 years are considered to have relatively low water consumption, potentially resulting in water surpluses; young forest stands aged 11-40 years are considered to have relatively high water consumption; young/mature forest stands aged 41-80 years are considered to have relatively moderate water consumption; and mature forest stands greater than 80-years old are considered to have normal (baseline) water consumption. The likelihood that low flow conditions are currently being adversely affected in each of the assessment streams is assessed based on the distribution of forest ages in FIGURE 6.5. It is important to recognize, however, that as the age distributions change over time, so will the potential effect on low flows.

Upland Forest Cover

The likelihood that low flow conditions are adversely affected by the current distribution of seral stages is presented in TABLE 6.4.

Forest stands in Chaster Creek are predominantly old/mature stands (> 80-years old) followed by young/mature (41- to 80-year-old stands). Some over-consumption relative to baseline conditions can be expected from the young/mature stands. The proportion of young stands (11- to 40-year-old), however, is relatively small. Moreover, any over-consumption from these younger stands is expected to be somewhat counteracted by potential surpluses from the newer openings (0- to 10-year-old stands). As such, there is a moderate likelihood that flows during the late summer period (i.e., July to September) are currently reduced by the distribution of forest stand ages. Assuming no further development, the influence of maturing forest stands on late summer flows is expected to be slightly negative (i.e., increased potential for flow reduction) in the short-term as the new forest openings become established with young regenerating stands. Once the younger stands mature and evapotranspiration rates decrease, we would expect flows during the late summer period to be increased[101].

A vast majority of forest stands in End/Walker Creek are greater than 80-years old and the young/mature stands are predominantly 71- to 80-years old (histogram in FIGURE 6.5). As such, there is a low likelihood that low flows are currently affected by the distribution of forest stand ages. Assuming no further development, a reduction in late summer flows can be expected in the short-term as new forest openings become established with young regenerating stands. Late summer flow volumes are expected to increase in the long-term as young stands mature.

Forest stands in Smales Creek are predominantly greater than 80-years old, with the remaining 21% and 10% as young/mature and new openings, respectively. Some over consumption can be

---

[101] The increase in late summer flow conditions only accounts for the influence of forest cover and does not include potential reductions in flows associated with climate change.

expected by the young/mature stands; however, this is expected to be counteracted by potential surpluses from the newer openings. As such, there is a low likelihood that low flows are currently affected by the distribution of forest stand ages. There is potential for late summer flow to be reduced in the short-term, assuming no further development. This is a result of 10% of the watershed transitioning from new openings to young regenerating stands. As the young stands mature, late summer flows are expected to increase.

Forest stands in the Higgs Brook watershed are predominantly mature, followed by young/mature stands, young stands, and new openings. Higher water consumption relative to baseline conditions can be expected from the young and young/mature stands, although potential affects on low flows at the watershed scale are expected to be minor. Therefore, there is a low likelihood that low flows are currently affected by the distribution of forest stand ages. As forest stands mature, there is some potential for a reduction in late summer flows assuming no further development, although changes to the low flow regime are expected to be relatively minor compared to current conditions. The 7% of the watershed potentially contributing to increased late summer flows is expected to transition towards low flow deficits in the next ten years.

Forest stands within the Slater Creek watershed are 42% mature, 34% young, and 25% young/mature. Despite a dominance of mature stands, the over consumption of water from the young and young/mature stands are expected to influence the low flow regime in the watershed. As such, there is a high likelihood that the current distribution of forest ages is affecting low flows. Given the absence of new openings within the watershed, late summer flows are expected to increase in the future, assuming no further development. However, given the predominance of 11- to 20-year-old stands, late summer flows are expected to be reduced by regenerating stands for at least the next 20 to 30 years.

Forest stands in Molyneux Creek are predominantly young/mature, followed by mature, with a lesser proportion of young stands. Within the young/mature stands, forest ages are dominantly 60- to 80-years old and are expected to consume less water than younger stands within that age class. As such, there is a moderate likelihood that low flows are currently affected by the distribution of forest stand ages. Assuming no further development, late summer flows are expected to increase as younger stands mature, although flows are still expected to be reduced by regenerating stands for several decades.

In Joe Smith Creek, forests are composed of 44% mature, 39% young/mature, and 17% young stands. Despite a dominance of mature stands, higher water use from the young and young/mature stands is expected to influence the low flow regime. As such, there is a moderate likelihood that low flows are currently affected by the distribution of forest stand ages. Assuming no further development, late summer flows are expected to increase as younger stands mature, although late summer flows are still expected to be reduced by regenerating stands for several decades.

The distribution of stand ages within Clough Creek are similar to Joe Smith Creek. Therefore, there is a moderate likelihood that low flows in Joe Smith Creek are currently affected by the distribution of forest stand ages. Assuming no further development, late summer flows are expected to increase as younger stands mature, although late summer flows are still expected to be reduced by regenerating stands for several decades.

TABLE 6.4 *Effects of current stand age distributions on low flows in the assessment watersheds.*

Assessment Watershed	Likelihood that current forest structure is adversely affecting low flows
Chaster Creek	Moderate
End / Walker Creek	Low
Smales Creek	Low
Higgs Brook	Low
Slater Creek	High
Molyneux Creek	Moderate
Joe Smith Creek	Moderate
Clough Creek	Moderate

Riparian Areas

The research of Hicks et al. (1991) looked at the colonization of riparian areas by deciduous species following stream-side harvesting and suggested that evapotranspiration rates by such colonizing species could exceed those of the pre-harvest (mature) stand and result in reduced runoff during the low flow period. Moreover, Moore (2004) found evapotranspiration rates within the riparian areas of young Douglas fir forests exceeded those of mature forests by nearly 3.3 times. Historical logging practices in the assessment area often included harvesting of riparian areas, which led in some cases to colonization of deciduous species. The earliest available air photos from 1947 indicate that most riparian corridors were occupied by deciduous species by that time. Of note are the deeply gullied slopes in the Chaster Creek catchment below roughly 500 m elevation. These slopes have a very high density of sub-parallel incised gullies that are lined primarily with deciduous species. Roughly 20 to 25% of the forest cover is estimated to be deciduous in this area. In addition to the influence of the upland forest cover (i.e., everywhere excluding the riparian area) described above, the colonization of deciduous species within riparian corridors has likely resulted in increased water demands and consequently a reduction in low flows in most assessment streams. Fortunately, a majority of the deciduous vegetation is mature and therefore expected to utilize less water than it would have when it originally established (Moore et al., 2004). Harvesting deciduous riparian corridors as a means of potentially improving low flow conditions is not recommended. Any short-term amelioration of low flows would likely be superseded relatively quickly by rapidly regenerating and more vigorous young deciduous species.

The likelihood that low flows have been adversely affected by the current distribution of seral stages is low for End/Walker Creek, Smales Creek, and Higgs Brook; moderate for Chaster Creek, Molyneux Creek, Joe Smith Creek, Clough Creek; and high for Slater Creek. With regards to future development, recommendations to mitigate potential adverse effects on low flows are provided in Section 9.

6.1.3. Groundwater/Aquifer recharge

Although relatively little research has been conducted on potential interactions between forest management activities and groundwater systems (Smerdon et al., 2009), several factors suggest that if BCTS maintains a low peak flow hazard and low likelihood of adversely affecting low flows (as described above), the risks associated with BCTS development in the assessment area on the groundwater supply are low. Similar to low flows, forest harvesting results in a reduction of site-level interception and transpiration. As such, an increase in net soil moisture can be expected following forest harvesting (Smerdon et al., 2009). As noted above, such an increase may be observed for up to 10-15 years (Perry and Jones, 2017). Beyond that time, there is a potential for decrease, but only if opening size exceeds 8 ha or if >50% of the overstory canopy is removed.

Furthermore, most wells appear to be established sufficiently deep within regional-scale bedrock or confined alluvial groundwater systems at distances several 100s of metres if not kilometres from BCTS' Chart. As a result, travel times for groundwater flow from BCTS' Chart to the principal aquifers and wells are on the order of decades to centuries (Doyle, 2013). Waterline (2013) found that groundwater ages within the Gibsons aquifer ranged from 10 to 80 years. They noted that the older water is likely sourced from mountain block recharge, and that the younger water is entering the aquifer where gaps in the overlying aquitard exist along the Upper Gibsons Bench (FIGURE 4.10). Waterline (2013) also evaluated aquifer response to precipitation events and found that the shallow unconfined Capilano Aquifer responded rapidly to precipitation inputs, while the deeper confined Gibsons Aquifer responded to precipitation two to 15 days later. They concluded that the Gibsons Aquifer was not directly connected to the overlying Capilano Aquifer nor to Gibsons Creek, Charman Creek or Chaster Creek. However, an indirect connection from the surface to the aquifer does exist, which is presumed to be in the form of "recharge windows" from unmapped portions of the aquifer.

In the assessment area, an increase in the site-level water balance and hence increase in the site-level groundwater table is possible following harvest, although with a high level of variability. Depending on the proximity of the harvested area to the zone of groundwater recharge, an increase in recharge may be realized; however, it is likely to occur over timescales too large for the increase to be measurable. This is particularly the case for the deeper confined Gibsons Aquifer. Moreover, a majority of aquifer recharge occurs during the wetter fall and winter months. During these times, evapotranspiration rates are low and therefore the likelihood that the removal of forest cover would measurably influence groundwater recharge is low. Combined with the measures noted above to maintain low peak flow and low flow hazard, such long time-scales for groundwater movement relative to future forest harvest and silvicultural activities are likely to make harvest-related effects undetectable (Madrone, 2015).

6.1.4. Summary

In summary, the hydrology of the assessment watersheds is driven predominantly by rainfall; however, rain-on-snow is considered the principal driver of peak flows. Both relatively high ECAs due to the conversion of green spaces to impervious surfaces from residential and commercial land clearing, and stormwater infrastructure in urban areas is expected to have changed runoff generation potential along the lower reaches of the assessment streams. Moreover, most, if not all, forest stands in the upper portion of the assessment area have been subject to historical disturbance, either by wildfire or logging. As such, regenerating forest stands within BCTS Chart are at various levels of recovery and contain various proportions of deciduous species, which are considered less hydrologically recovered relative to coniferous stands.

Peak Flows

Based on the characteristics of the eight assessment streams, RGP is considered high for all watersheds with exception of End/Walker Creek above Highway 101, Smales Creek below Highway 101, and Higgs Brook, where RGP is considered low due to stream discontinuity. To identify peak flow hazard at various locations throughout the assessment area, 30 points-of-interest have been identified (FIGURE 6.2, FIGURE 6.3). With consideration of RGP and the research literature, recommended ECA maxima are provided on the basis of limiting increases in peak flow hazard at POIs downstream of BCTS Chart, while maintaining ECAs below 20% for the portion of the watershed within BCTS Chart.

Currently, ECAs within the assessment area range from 6.0% in forested BCTS Chart area to 57.2% including the urban / commercial areas. This means current peak flow hazards vary by point of interest (POI). A high peak flow hazard was identified for the following POIs:

- Chaster Creek at the mouth,
- End/Walker Creek at the mouth, and
- End/Walker Creek above Highway 101.

A moderate peak flow hazard was identified for the following POIs:

- Chaster Creek below Shirley Creek,
- Shirley Creek,
- Smales Creek above Highway 101,
- Higgs Brook at the mouth,
- Slater Creek at the mouth,
- Slater Creek above Highway 101,
- Joe Smith Creek at the mouth, and
- Clough Creek at the mouth.

A low peak flow hazard is identified for the remaining POIs.

If BCTS wishes to pursue development opportunities in the assessment watersheds, the maximum additional ECA available to maintain current peak flow hazard levels are identified (TABLE 6.2). These values range from 1.3 ha for End/Walker Creek (POIs 9 & 10) up to 16.2 ha for Shirley Creek (POI 4). Moreover, projected hydrologic recovery in terms of expected increases in ECA are provided in APPENDIX E.

Low Flows

With regards to summer low flows, the distribution of seral stages (i.e., forest ages) suggest that low flows have been influenced to varying degrees by historical disturbance. The likelihood that low flows have been adversely affected by the current distribution of seral stages is high for Slater Creek; moderate for Chaster Creek, Molyneux Creek, Joe Smith Creek, and Clough Creek; and low for End/Walker Creek, Smales Creek, and Higgs Brook. With respect to future development and based on the literature, alternative silviculture approaches in upland and riparian areas are recommended to minimize the likelihood of causing an incremental adverse effect on summer low flows. Furthermore, we also encourage the planting of a mix of conifer species similar to the pre-harvest (mature) stands to achieve similar long-term evapotranspiration rates.

Groundwater/Aquifer Recharge

If BCTS maintains current peak flow hazards and a low likelihood of adversely affecting low flows as described above, the risks associated with BCTS development in the assessment area on the groundwater supply are low. Site-level increases in the water balance can be expected following the removal of forest cover. This may result in localised increases in the groundwater table; however, such increases are only expected to persist for up to 10-15 years. Beyond that time, there is a potential for decrease, but only if opening size exceeds 8 ha or if >50% of the overstory canopy is removed. Given the long time periods associated with groundwater movement and recharge, to the confined Gibsons Aquifer, harvest-related effects are expected to be undetectable if the above constraints are met.

6.2. SEDIMENT YIELD

6.2.1. Roads

Based on our office and field review, few development-related sediment risks were identified in the assessment area[102]. Sechelt Roberts FSR (7575) and its branch roads have stable road surfaces

---

[102] As discussed in Section 3.2.1, no formal site-level assessment of sediment yield (i.e., FREP WQEE protocol) was conducted at stream crossings.

and functional drainage infrastructures were noted along all reviewed active roads (FIGURE 6.8). Consequently, the erosion potential from active roads is low. Erosion potential does marginally increase in the vicinity of crossings of incised gullies, due to the increased height of road cuts that are typically required; however, these site-level risks appear to have been effectively mitigated where necessary (FIGURE 6.9), and sediment risks are low.

Road Crossings

Given the relatively small size of the streams in the assessment area, downstream dilution of sediment inputs is minimal. As such, sediment contributions from roads, particularly at stream crossings, can result in increased sediment concentrations downstream. A total of 89 active stream crossings in the assessment area were identified during the field reviews (TABLE 6.5, FIGURE 6.7). Although this does not necessarily represent an exhaustive inventory, it does represent a large sample of the stream crossings in active use. The spatial distribution of crossings is summarized in TABLE 6.6. Overall, 35% of the crossings are located in Chaster Creek, with 18% in Molyneux Creek, 12% in Slater Creek, 11% in Clough Creek, and 10% in Joe Smith Creek. The remaining three watersheds have 5% or less of the crossings identified. The distribution of crossings within BCTS Chart (i.e., on resource roads) or outside of BCTS Chart (i.e., public roads and highways) varies by watershed (TABLE 6.6). They are roughly evenly distributed in Chaster Creek, Slater Creek, Molyneux Creek; however, they are heavily weighted to the non-Chart in End/Walker Creek, Higgs Brook, Joe Smith Creek, and Clough Creek. Only Smales Creek had a greater number of crossings in the BCTS Chart. A total of 80% of the active stream crossings identified are various types of culverts, whereas 16% are bridges and 4% are fords[103]. The specific type of crossing and size (if known) are presented in TABLE 6.5.

Although the number of stream crossings, or density of stream crossings per km^2 (reported in TABLE 6.6), may be useful as a high-level screening tool of the potential for sediment-related hazards (particularly on resource roads), we have placed little emphasis on this indicator for this assessment, instead relying on field-specific observations to evaluate the overall hazard in each watershed. Our field observations within BCTS Chart generally indicate that sediment hazards associated with stream crossings is low[104], largely as a result of gentle road grades, deactivation of unused roads, and effective control measures such as coarse gravel road surfacing and/or rock armour at culvert inlets and outlets or along bridge abutments. There are very few examples where sediment hazards are elevated in the assessment area within BCTS Chart. One includes bridge crossing No. 8 (FIGURE 6.7, FIGURE 6.9), where the road alignment passes through deep surficial sediments. Although control measures such as a rock retaining wall and coarse road

---

[103] Fords were identified principally along the BC Hydro right-of-way (ROW).

[104] The sediment hazard refers to the likelihood of measurable erosion and sedimentation to occur in the vicinity of stream crossings. It does not consider the potential for crossing damage or washout in the event of an extreme flood. Evaluation of design flows and flood conveyance at crossings is beyond the scope of the assessment.

surfacing reduce sediment hazards, the sediments in the vicinity still pose a moderate hazard. Such examples, however, are uncommon in the assessment area.

Potential Effects of BCTS Planned Development

BCTS' Chart within the assessment watersheds is largely characterized as gentle to moderate terrain (MAP 1, FIGURE 6.6). Sediment risks associated with forest development are primarily associated with the construction (including reactivation), maintenance, and use of new and existing roads and trails. Fine-textured soils may be susceptible to rutting, compaction and erosion if subject to mechanical disturbance or excessive traffic during wet weather or wet ground conditions. Sediment risks can, however, be mitigated with a number of control measures, depending on site-conditions. Several of these measures are outlined in Section 9. Assuming that these (or equivalent) control measures are documented in site-specific erosion control plans and are incorporated into road and harvest planning and construction, sediment yields and the risks associated with future forest development can be maintained at low levels.

FIGURE 6.6 *View of gentle terrain near 600 m elevation in the Molyneux Creek watershed. Photo DSC00206, August 27, 2020.*

TABLE 6.5 *List of active stream crossings identified during the course of the assessment.*

No.	Type	Road	Diameter (mm)
1	Bridge	Sechelt Roberts FSR 7575 Br16	-
2	Bridge	Sechelt Roberts FSR 7575 Br16	-
3	Bridge	Private	-
4	Bridge	Ocean Beach Esplanade	-
5	Bridge	Private	-
6	Bridge	Private	-
7	Bridge	Private (foot bridge)	-
8	Bridge	Sechelt Roberts FSR 7575 Br23	-
9	Bridge	Sechelt Roberts FSR 7575 Br23	-
10	Bridge	Sechelt Roberts FSR 7575	-
11	Bridge	Sechelt Roberts FSR 7575 Br23	-
12	Bridge	Sechelt Roberts FSR 7575 Br16	-
13	Bridge (suspected)	Private	-
14	Bridge (suspected)	Sechelt Roberts FSR 7575 Br16	-
15	Culvert	Pixton Road	400
16	Culvert	Russell Road	1100
17	Culvert	Lower Road	1000
18	Culvert	Leek Road	1000
19	Culvert	Highway 101	-
20	Culvert	Lower Road	1400
21	Culvert	Pixton Road	900
22	Culvert	Orange Road	1200
23	Culvert	Private	-
24	Culvert	Highway 101	900
25	Culvert	Lower Road	2000 + 600
26	Culvert	Sechelt Roberts FSR 7575 Br03	900
27	Culvert	Sechelt Roberts FSR 7575 Br03	600
28	Culvert	Sechelt Roberts FSR 7575 Br03	600
29	Culvert	Reed Road	1500
30	Culvert	Reed Road	1000
31	Culvert	Reed Road	1000
32	Culvert	Ocean Beach Esplanade	600
33	Culvert	Burton Road	900
34	Culvert	Highway 101	1200
35	Culvert	Ocean Beach Esplanade	1000
36	Culvert	Russell Road	900 (x2)
37	Culvert	Conrad Road	600
38	Culvert	Porter Road	600
39	Culvert	Highway 101	900
40	Culvert	Private	-
41	Culvert	Sechelt Roberts FSR 7575 Br23	-
42	Culvert	Sechelt Roberts FSR 7575 Br23	-
43	Culvert	Sechelt Roberts FSR 7575 Br23	-
44	Culvert	Sechelt Roberts FSR 7575 Br23	-
45	Culvert	Sechelt Roberts FSR 7575 Br23	-
46	Culvert	Sechelt Roberts FSR 7575 Br23	1000
47	Culvert	Sechelt Roberts FSR 7575 Br23	-
48	Culvert	Sechelt Roberts FSR 7575 Br23	-
49	Culvert	Sechelt Roberts FSR 7575 Br23	-
50	Culvert	Sechelt Roberts FSR 7575 Br23	-
51	Culvert	Highway 1010	600
52	Culvert	Private	1200
53	Culvert	Highway 101	1000
54	Culvert	Sechelt Roberts FSR 7575 Br21	-
55	Culvert	Ranch Road	-
56	Culvert	Harmen Road	800
57	Culvert	Sechelt Roberts FSR 7575 Br16	1200
58	Culvert	Sechelt Roberts FSR 7575 Br03	900
59	Culvert	Sechelt Roberts FSR 7575 Br03	900
60	Culvert	Sechelt Roberts FSR 7575 Br03	900
61	Culvert	Sechelt Roberts FSR 7575 Br03	900
62	Culvert	Sechelt Roberts FSR 7575 Br03	2100
63	Culvert	Sechelt Roberts FSR 7575 Br03	2100
64	Culvert	Private	-
65	Culvert (concrete)	Highway 101	-
66	Culvert (concrete)	Lower Road	1200
67	Culvert (concrete)	Highway 101	1000
68	Culvert (concrete)	Henry Road	1600
69	Culvert (concrete)	Highway 101	1600
70	Culvert (concrete)	Highway 101	900
71	Culvert (concrete)	Lower Road	1200
72	Culvert (log)	Private	-
73	Culvert (multiplate)	Reed Road	1700
74	Culvert (pipe arch)	Milliner Road	2400
75	Culvert (suspected)	Private	-
76	Culvert (suspected)	Private	-
77	Culvert (suspected)	Private	-
78	Culvert (suspected)	Private	-
79	Culvert (suspected)	Private	-
80	Culvert (suspected)	Private	-
81	Culvert (suspected)	Orange Road	-
82	Culvert (suspected)	Pixton Road	-
83	Culvert (suspected)	Porter Road	-
84	Culvert (suspected)	Sechelt Roberts FSR 7575 Br21	-
85	Culvert (suspected)	Sechelt Roberts FSR 7575 Br16	-
86	Ford	BC Hydro ROW	-
87	Ford	BC Hydro ROW	-
88	Ford	BC Hydro ROW	-
89	Ford	BC Hydro ROW	-

Notes:

1) The list of active stream crossings is based on field observations made during the course of the assessment and should not be considered an exhaustive list (i.e., this is not a detailed stream crossing inventory).
2) Locations of stream crossings are presented on FIGURE 6.7.
3) Diameter of stream crossing is identified where known.

TABLE 6.6 *Number of active stream crossings in the assessment area.*

Watershed	**Drainage Area (km^2)**	**Number of active stream crossings**				**Density of active stream crossings (#/km^2)**			
		Bridges	**Culverts**	**Fords**	**All**	**Bridges**	**Culverts**	**Fords**	**All**
Chaster Creek (BCTS Chart)	6.26	4	10	3	**17**	0.64	1.60	0.48	**2.71**
Chaster Creek (Non BCTS Chart)	4.47	1	13	-	**14**	0.22	2.91	-	**3.13**
Chaster Creek (Overall)	10.73	5	23	3	**31**	0.47	2.14	0.28	**2.89**
End/Walker Creek (BCTS Chart)	0.19	-	-	-	**-**	-	-	-	**-**
End/Walker Creek (Non BCTS Chart)	0.96	-	4	-	**4**	-	4.19	-	**4.19**
End/Walker Creek (Overall)	1.15	-	4	-	**4**	-	3.48	-	**3.48**
Smales Creek (BCTS Chart)	0.62	-	3	-	**3**	-	4.83	-	**4.83**
Smales Creek (Non BCTS Chart)	0.32	-	1	-	**1**	-	3.08	-	**3.08**
Smales Creek (Overall)	0.95	-	3	-	**3**	-	3.16	-	**3.16**
Higgs Brook (BCTS Chart)	0.61	-	-	-	**-**	-	-	-	**-**
Higgs Brook (Non BCTS Chart)	0.84	-	5	-	**5**	-	5.92	-	**5.92**
Higgs Brook (Overall)	1.45	-	5	-	**5**	-	3.45	-	**3.45**
Slater Creek (BCTS Chart)	0.72	1	5	-	**6**	1.39	6.95	-	**8.34**
Slater Creek (Non BCTS Chart)	0.70	1	4	-	**5**	1.42	5.68	-	**7.10**
Slater Creek (Overall)	1.42	2	9	-	**11**	1.41	6.34	-	**7.75**
Molyneux Creek (BCTS Chart)	2.07	3	5	-	**8**	1.45	2.41	-	**3.86**
Molyneux Creek (Non BCTS Chart)	0.58	1	7	-	**8**	1.74	12.15	-	**13.89**
Molyneux Creek (Overall)	2.65	4	12	-	**16**	1.51	4.53	-	**6.04**
Joe Smith Creek (BCTS Chart)	1.32	-	2	-	**2**	-	1.52	-	**1.52**
Joe Smith Creek (Non BCTS Chart)	0.97	2	4	-	**6**	2.07	4.14	-	**6.21**
Joe Smith Creek (Overall)	2.29	2	6	1	**9**	0.87	2.62	0.44	**3.93**
Clough Creek (BCTS Chart)	1.15	-	2	-	**2**	-	1.74	-	**1.74**
Clough Creek (Non BCTS Chart)	0.39	1	7	-	**8**	2.55	17.83	-	**20.38**
Clough Creek (Overall)	1.54	1	9	-	**10**	0.65	5.84	-	**6.49**
Total Assessment Area (BCTS Chart)	12.94	8	27	3	**38**	0.62	2.09	0.23	**2.94**
Total Assessment Area (Non BCTS Chart)	9.23	6	45	-	**51**	0.65	4.88	-	**5.53**
Total Assessment Area (Overall)	22.18	14	71	4	**89**	0.63	3.20	0.18	**4.01**

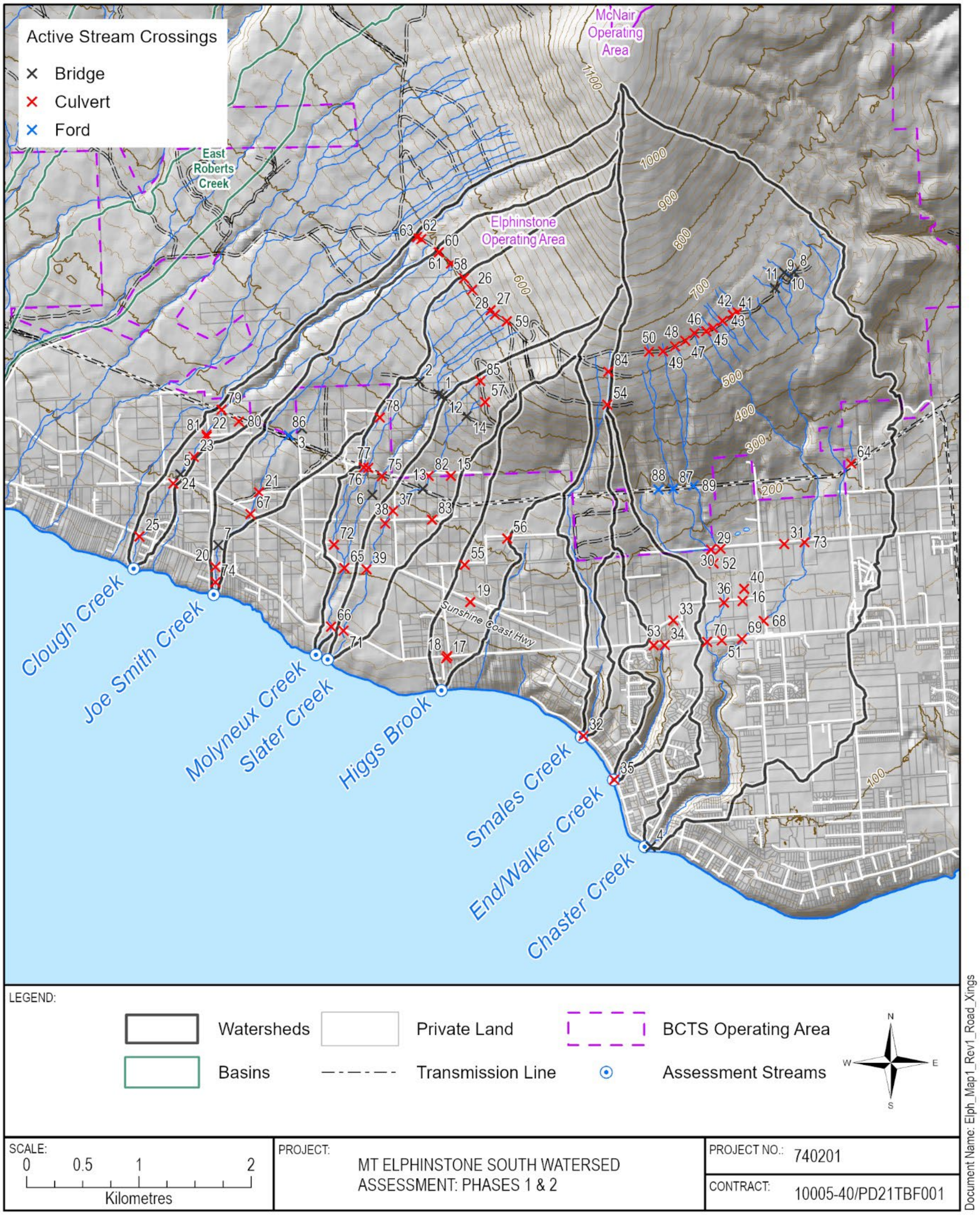


FIGURE 6.7 *Locations of active stream crossings in the assessment area.*

6.2.2. Landslides

In addition to the debris flow documented along Clough Creek in 1983 [prior to the *Forest Practices Code (FPC)* and *Forest and Range Practices Act (FPRA)*], a historical air photo review revealed several smaller development related landslides in the area. Air photos from 1947 to 1982 indicate little to no slope instability in the assessment area; however, air photos from 1990 indicate a series of four smaller debris slides initiated roughly 75 m to 250 m southeast of the 1983 Clough Creek debris flow headscarp. These smaller slides are suspected to have been initiated during the same 1983 storm. By 2003, the smaller slide paths had greened up; however, the headscarp of the 1983 Clough Creek debris flow was still unvegetated and may have been a source of sediment. No other development or natural landslides were noted in the assessment area based on historical air photo and field reviews.

Limited relief and gentle to moderate hillslope gradients generally reduce the likelihood of landslides in the area (Madrone, 2015) and thus current sediment yields from landslides are low. However, as evidenced by the Clough Creek and Whittaker Creek washout, debris flows and debris floods along incised gullies, while rare, can be triggered by land use activities, especially where natural drainage patterns are modified on or above potentially unstable slopes. Initiation of such events can occur by landslides along unstable gully sidewalls (usually triggered by excess soil moisture or disturbance by windthrow) or by entrainment of accumulated in-channel debris and sediment during high flows (usually after log jams decay, lose integrity and release stored sediment and debris). In order to avoid or mitigate the potential for landslides, BCTS regularly engages with qualified terrain professionals during the development planning process and has an active road inspection and maintenance program.

Potential Effects of BCTS Planned Development

Given the gullied terrain, steeper potentially sensitive terrain is found adjacent to streams both classified and non-classified. In order to maintain low sediment-related hazard, planning of road alignments and cutblocks should consider and take precautions to avoid alteration of natural drainage patterns upslope of sensitive gullied terrain, minimize windthrow in riparian zones (e.g., by having windthrow assessments performed) and avoid wherever possible physical soil disturbance in riparian zones by heavy equipment (e.g., by establishing machine-free zones along riparian corridors). Such control measures should be tailored to the risk posed by increased sediment yield on downstream values. For example, on Molyneux Creek, there are several water licences near or within BCTS' Chart, including one that was field-confirmed to be actively supplying potable water to a private residence. In such a case, effective cutblock and road layout upslope, combined with control measures are of paramount importance given the close proximity of the elements-at-risk.

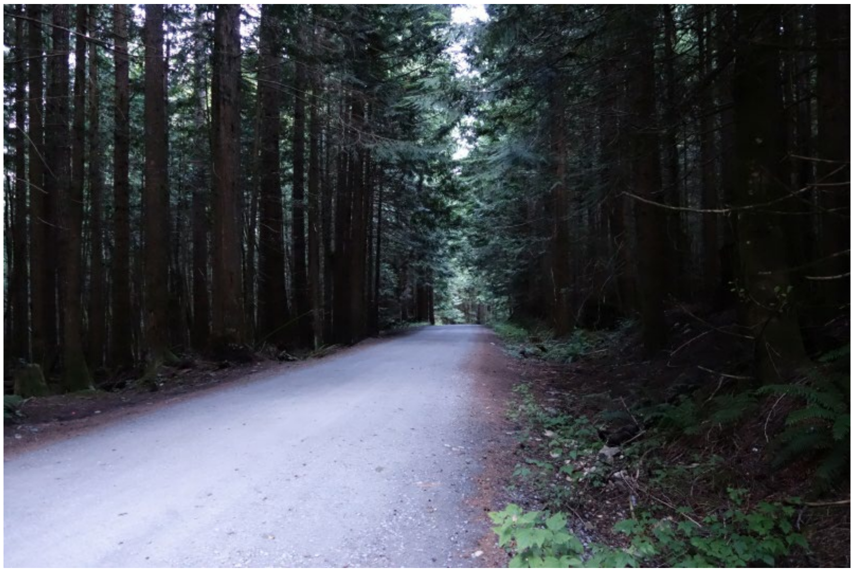


FIGURE 6.8 *View of the Sechelt Roberts FSR (7575 Br 3) within the Molyneux Creek watershed at an elevation of 545 m. This example shows a stable road surface with low erosion potential. Photo DSC00079, August 27, 2020.*

FIGURE 6.9 *View of the Sechelt Roberts FSR (7575 Br 23) crossing of a tributary to Chaster Creek at an elevation of 620 m. This example shows a retaining wall that was constructed to stabilize the cutslope and minimize sediment delivery to the stream below. Photo IMG_3093 (Placemark 36), August 24, 2020.*

6.3. RIPARIAN FUNCTION

When assessing riparian function, the focus is on identifying the degree to which natural riparian function (e.g., to provide shade, cover, stream habitat, stream bank stability, etc.) has or will be influenced by watershed disturbance. For the purposes of this assessment, a high-level overview of riparian function was conducted to evaluate the current riparian condition and its effect on sediment yield and channel stability. This included reviews of historical air photos and other imagery, as well as ground-based reviews at selected locations along the streams (FIGURE 2.1). As discussed in Section 3.3, applying the riparian FREP Protocol is considered beyond the scope of this assessment.

Historical conditions

A review of historical air photos dating from as early as 1947 serve to illustrate how historical logging practices and natural disturbances (e.g., wildfire) may have influenced riparian areas along the assessment streams. Most riparian corridors that had not been recently logged were dominated by deciduous species by 1947, which is suggestive that riparian areas were either subject to historic logging and/or naturally disturbed. In areas where logging had occurred close to 1947, the air photos reveal that riparian areas are logged along the upper reaches of all small streams with exception of Clough Creek. By 1957, the timber along the incised portion of Clough Creek between 400-700 m elevation had been logged, with little riparian vegetation remaining. By 1964, riparian areas/gullies along the mid-slopes, particularly in Chaster Creek, have a considerable deciduous component. The Chaster Creek ravine between stream km 1.0 and km 2.0 appears logged along its slopes by 1964. By 1967, the riparian areas logged in 1947 were densely colonized by deciduous species. By 1976, three sizeable clearcuts were noted with little to no riparian protection, which spanned across Joe Smith Creek, Molyneux Creek, Slater Creek and Higgs Brook at mid-elevations. By 1990, riparian areas along Clough Creek had been affected by the 1983 debris flow (Section 3.2.3).

Current Conditions

With the exception of road crossings and the BC Hydro right-of-way, riparian conditions within BCTS' Chart on Crown land within the eight assessment watersheds are characterized by mixed deciduous and second growth conifers with varying amounts of understory vegetation. Along classified streams, riparian vegetation is largely functional in providing bank stability and shade but is occasionally lacking in future recruitment of large woody debris. While most streams have ample volumes of instream wood, many of the stable larger-diameter pieces are disintegrating and are likely being replaced by smaller-diameter less stable wood recruited from the riparian zone. A reduction in stable in-stream wood could increase sediment transport rates over time (Montgomery et al., 2003), which could adversely affect stream crossings, water supply infrastructure and fish habitat. Although development in urbanized areas has resulted in localized riparian impacts due to the increased number of stream crossings and private properties with various land uses, riparian conditions were reasonably healthy and functional. This is partly due to the incised nature of many of the lower stream reaches (i.e., streams flow along deep ravines) that tend to prevent land use impacts. Credit, however, should also be given to the municipal government and residents for their stream and riparian stewardship. Where riparian disturbance was noted on private land, it tended to be localized and posed relatively low risk, since channels along the lower slopes with some exceptions are non-alluvial or semi-alluvial. In a few instances, watering locations for animals on agricultural properties could pose some downstream water quality risks. In other cases, localized reduction in riparian vegetation posed risks to property (i.e., buildings) adjacent to streams as a result of bank erosion (APPENDIX E, Figure 182). In turn, this has necessitated bank protection or retaining walls to be installed at some locations.

Potential effects of BCTS Planned Development

Conservation of water quality, fish habitat, wildlife habitat and biodiversity in riparian areas is an objective under Section 4.2.4 of BCTS' Forest Stewardship Plan #672 (BCTS Chinook Business Area, 2022). In order to achieve this objective, BCTS is tasked with identifying stream, lake and wetland riparian classes according to Sections 47, 48, and 49 of the *Forest Planning and Practices Regulation (FPPR);* adhering to restrictions in Riparian Management Areas, Riparian Reserve Zones and Riparian Management Zones as per Sections 50, 51, and 52(2) of *FPPR*; and where forest activities are planned for a Riparian Management Zone, meeting retention levels determined by a qualified professional through riparian assessment.

Normally, BCTS forest professionals plan harvesting opportunities to minimize disturbance of riparian zones along classified streams by establishing riparian reserves, wildlife tree retention areas (WTRAs), and/or machine-free zones. Road alignments are also planned, where possible, to minimize the number of stream crossings and localized riparian impacts. These general precautions are intended to minimize adverse effects on riparian function. Since a review of specific blocks was beyond the scope of this assessment, the riparian-related hazards associated with specific harvest plans cannot be determined at this time. However, such assessments are expected for the subsequent assessment phase.

6.4. STREAM CHANNEL STABILITY

Each of the eight assessment streams were field reviewed during Phase 1 and 2. Streams were observed above and below accessible locations, often near road crossings, and on or near private land with permission from property owners. Several stream reaches were fully reviewed if accessible. A selection of photos documenting current conditions observed along each stream is provided in APPENDIX F[105].

Overall, the assessment streams include a mix of channel morphologies and are generally non-alluvial on BCTS' Chart, and semi-alluvial or alluvial along the lower slopes. As noted above, despite historical disturbance to riparian areas, current riparian conditions are generally functional and wood debris is common. Furthermore, evidence of active bedload transport was common in most streams. A summary of channel response potential for each stream is presented in TABLE 6.7, and additional characteristics of each stream, which influences channel response potential, are provided below.

---

[105] For referencing purposes, photo locations are identified by stream name and distance upstream from the mouth (MAP 1). Tributaries that feed directly to the assessment streams are assigned numbers, e.g., Tributary 1, 2, 3. Streams that feed those tributaries would be identified by adding a decimal point, e.g., Tributary 1.1, 1.2, 1.3. And, streams feeding those (e.g., 1.1) would be assigned another decimal point, e.g., Tributary 1.1.1, 1.1.2, 1.1.3. If known, local stream names are also identified.

TABLE 6.7 *Channel response potential for the assessment streams.*

Assessment Streams	Channel Response Potential
Chaster Creek	**Low** above the Gibsons Bench and **Moderate** on and below the Gibsons Bench.
End/Walker Creek	**Low** on the Gibsons Bench and **Moderate** below.
Smales Creek	**Low** along the lower and upper reaches, **Moderate** in the middle reach.
Higgs Brook	**Low** to **Moderate**
Slater Creek	**Low**
Molyneux Creek	**Moderate**
Joe Smith Creek	**Moderate**
Clough Creek	**Low**

Chaster Creek

Photos of Chaster Creek are shown on Figure 1 through Figure 31 (APPENDIX E). Tributaries of Chaster Creek below the hydro right-of-way are shown on Figure 32 through Figure 62 and tributaries of Chaster Creek above the hydro right-of-way are shown on Figure 63 through 73 (APPENDIX E).

Chaster Creek is the largest of the assessment streams and is fed by several tributaries on the south side of Mt. Elphinstone. Many of these tributaries originate as non-classified drainages or minor intermittently flowing streams on the upper gullied slopes of the watershed (MAP 1). As these streams converge, flows and the degree of channel incision increases. Near the hydro right-of-way, most of the tributaries follow well-incised gullies. As the tributaries flow onto the Gibsons Bench, between roughly the hydro-right-of-way and Reed Road, stream gradients decrease markedly from 26% to 4% (FIGURE 4.6); however, the creeks remain incised. Near the Sunshine Coast Highway (101), most tributaries converge into either the mainstem Chaster Creek or Shirley Creek (Tributary 4.1 on MAP 1). Below the highway the mainstem enters a well-vegetated deeply incised ravine, which it follows for nearly 2 km to its mouth at Ocean Beach Esplanade. Along the ravine a series of falls near stream km 2 is noteworthy as it poses a barrier to upstream migrating fish.

Channel morphology varies along Chaster Creek from steep colluvial and bedrock channels on the upper slopes to boulder-dominated step-pool channels on the mid slopes. Lower slopes include a mix of boulder and cobble dominated plane-bed and riffle-pool morphologies with abundant functional instream wood that has formed several jams and regulates to some extent sediment transport along the creek. In spite of the abundance of wood, sediment transport rates appear high along Chaster Creek and are responsible for abundant deposits of boulder and cobble gravel noted throughout the lower stream reaches. Much of this sediment is supplied naturally from the abundance of glacially-derived sediments present along the length of the creek. Wood present along the channels tends to be mature and is deteriorating. As this occurs, debris jams should become increasingly unstable and with each storm, the likelihood of log jam collapse and sediment transport increases. Some of the observed characteristics and fluvial activity observed along Chaster Creek may possibly be associated with a stream channel still seeking equilibrium following a history of forest cover disturbance, including widespread wildfire in the early 1900s, and logging, which covered ~38% between 1911-1920 (Section 4.10). We speculate a similar situation may also exist in the other assessment streams; however, given their robust channel non-alluvial or semi-alluvial morphologies, such effects are much less evident.

Channel response potential (i.e., channel sensitivity) varies along Chaster Creek and is generally low along the slopes above the Gibsons Bench and moderate on and below the bench. As the channel is incised, contains abundant wood and coarse bed material, changes in channel morphology are unlikely. However, floods are capable of locally eroding banks, entraining in-channel sediment (i.e., stored behind debris jams) and transporting such sediment downstream. As a result, local channel conditions in terms of streambed texture and gradients have potential to change with changes to the flood regime, especially upstream of stream crossings where aggradation is often promoted. Even if the baseline hydrology remains unchanged, aggraded reaches often have low or no streamflow conditions in summer due to flows moving subsurface through accumulations of coarse sediment.

End/Walker Creek

Selected photos of End/Walker Creek below Reed Road are shown on Figure 74 through Figure 87, and those of End/Walker Creek above Reed Road are shown on Figure 88 through Figure 90 (APPENDIX E).

End/Walker Creek drains a considerably smaller and lower drainage area than Chaster Creek and thus has channel dimensions (i.e., widths and depths) several times smaller. MAP 1 shows that much of the End/Walker Creek drainage area falls on the Gibsons Bench with a relatively small area upslope. However, due to human alteration of drainage patterns along the highway, it appears that Smales Creek and possibly the residual area between Smales and End/Walker Creeks above the Sunshine Coast Highway drains towards McComb Brook, a tributary of End/Walker Creek. As a result, streamflows below the highway in End/Walker Creek may be higher than prior to human development in the area.

The upper portion of the End/Walker Creek watershed, while gullied, contains few if any perennial streams. Downslope movement of water is generally via subsurface flow to a point between Mountain and Burton Roads where small wetlands were observed. Water from these lower gradient areas then converges downstream near the Sunshine Coast Highway, where the mainstem of End/Walker Creek effectively begins its relatively steep (7% gradient) drop via a deeply incised ravine to the ocean. Along the well-vegetated ravine, woody debris is abundant as is coarse-textured sediment, sourced from the ample supply along the ravine walls. The lower ravine appears subject to stormflow, likely supplemented by the highway ditch diversion from Smales Creek noted above.

Overall, channel response potential or resilience to peak flows is low on the Gibsons Bench and moderate below, along the ravine. Functional riparian vegetation, abundant instream wood and relatively coarse-textured sediments tend to be resistant to morphologic change. However, similar to Chaster Creek, evidence of storm-related sediment transport is common. This may increase in future as instream wood, which regulates sediment transport, deteriorates.

Smales Creek

Photos of Smales Creek below Reed Road are shown on Figure 91 through Figure 111, whereas Smales Creek above Reed Road are shown on Figure 112 through Figure 116 (APPENDIX E).

The volume of runoff and size of Smales Creek at the mouth would suggest the creek drains a minor catchment area or has considerable infiltration losses. However, as noted above, diversion along the highway near the Sunday Cider entrance appears to convey Smales Creek towards McComb Brook, a tributary of End/Walker Creek (a portion of Smales Creek streamflow may also be diverted towards Whittaker Creek). Below the highway, Smales Creek is fed principally by groundwater that daylights along a deeply incised ravine. The channel along this section of creek has a cobble and boulder bed, dense riparian vegetation and abundant instream wood. Channel response potential is moderate.

Above the highway, Smales Creek follows a relatively well-incised gully for much of its length; the exception being the 500 m directly above the highway that flows along the Sunday Cider property. This lower gradient reach has a gravel-bed with riffle-pool morphology with some evidence of bank erosion due in part from local land use and riparian disturbance (e.g., trails, foot bridges). This lower gradient reach also promotes the deposition of sediments derived from upper reaches. Channel response potential is moderate. Smales Creek along the upper slopes is confined within a relatively deep gully, has abundant woody debris and coarse-textured sediment. As a result, channel response potential is low.

While Smales Creek follows the western boundary of its catchment, a considerable portion of the catchment to the east, much of which is within BCTS' Chart, contains no classified stream channels. It is expected that most of the precipitation on these areas generally moves subsurface as groundwater, where it may resurface downslope above the Sunday Cider property along an intermittently flowing tributary to Smales Creek, in an area of hydrophytic vegetation located in the residual area between Smales and End/Walker Creek, or in the Smales Creek ravine below the highway.

Higgs Brook

Photos of Higgs Brook are shown on Figure 120 through Figure 132 (APPENDIX E). Higgs Brook is a relatively steep (13%) cobble and boulder step-pool semi-alluvial channel. Streamflows vary considerably by location. Along the upper gullied slopes, streamflows are seasonal and discontinuous. Along mid and lower slopes, the mainstem is well-incised and has ample evidence of bank erosion and sediment transport. Although woody debris is present, it appears less functional than other assessment streams, which may be related to the effects of past floods. High levels of aggradation were noted in many areas; however, due to the confinement of the channel, widespread morphologic changes are unlikely. Channel response potential for Higgs Brook varies from low to moderate.

Slater Creek

Slater Creek is shown on Figure 133 through Figure 142 (APPENDIX E). In many ways, Slater Creek is similar to Higgs Brook with gradients of about 19% on the upper slopes to 11% on the lower slopes. The creek is similarly incised for most of its length and the channel is semi-alluvial with boulder and cobble step-pool channel. Wood debris is abundant and functional in regulating sediment transport. Overall disturbance from past flooding appears considerably less than in Higgs Brook. Channel response potential is low.

Molyneux Creek

Photos of Molyneux Creek below the hydro right-of-way are shown on Figure 143 through Figure 167, whereas photos of Molyneux Creek above the hydro right-of-way are shown on Figure 168 through 178 (APPENDIX E). Molyneux Creek differs from the other streams along the southwest side of Mt. Elphinstone that have relatively narrow watersheds. Similar to Chaster Creek, Molyneux Creek has many small sub-parallel gullies in the upper portion of the watershed where streams originate as non-classified drainages or minor intermittently flowing streams. These converge into two main channels near an elevation of 340 m[106]. Stream gradients along this semi-alluvial channel range from about 18% on the upper slopes to 10% on the lower slopes. As with most streams in the area, channels are deeply incised, have a boulder and cobble dominated bed and step-pool morphology heavily influenced by woody debris. Even though the creek has ample evidence of past flood-related sediment transport, the channel morphology appears relatively stable. Natural sediment transport, however, has apparently affected water supply infrastructure along the creek, burying and damaging several systems. As noted in Section 4.12.1, only 2 of 15 water licences were confirmed to be actively utilized. Overall, channel response potential is moderate.

Joe Smith Creek

Photos of Joe Smith Creek are shown on Figure 179 through Figure 206 (APPENDIX E). Joe Smith Creek has a relatively steep (14% gradient), semi-alluvial, boulder and cobble step-pool channel with varying volumes of woody debris and ample evidence of sediment transport. The creek is well-incised and is morphologically stable; however, localized bank erosion was evident in several locations, largely along private land where removal of riparian vegetation occurred. Although

---

[106] West Molyneux Creek (shown on MAP 1 as Molyneux Tributary 1.2) and Molyneux Creek mainstem (shown on MAP 1 as Molyneux Tributary 2)

bank protection or retaining walls have been used to mitigate such erosion, it appears to be a chronic issue along this stream subject to storm-related runoff. Channel response potential is moderate.

Clough Creek

Photos of Clough Creek are shown on Figure 207 through Figure 235 (APPENDIX E). Clough Creek drains a relatively long and narrow watershed that is fed by tributaries originating at the height of land on the south side of Mt. Elphinstone. Roughly five gullies with gradients approaching 30% converge to one relatively large gully at an elevation of 440 m. Downstream, gradients decline to about 11%. All but a 500 m reach between the hydro right-of-way and the highway are well incised and confined. The 500 m reach is partly confined, and was the location where in 1983 a debris flow, originating 5 km upslope, deposited much of its sediment and debris (Section 3.2.3). Similar to the other assessment streams, Clough Creek is semi-alluvial (i.e., bedrock or colluvium and alluvial sediments) with a coarse-textured streambed (boulders and cobbles). Also, given these characteristics, the channel is largely insensitive to change, in spite of naturally active sediment transport. While such sediment transport is not resulting in morphologic change, it does pose a risk to water supply infrastructure. Of the nine water licences on Clough Creek, only two were confirmed as actively being utilized. This is in part due to the natural fluvial activity present along this creek. Overall, channel response potential is low.

Potential Effects of BCTS Planned Development

As noted above, the likelihood of channel disequilibrium (i.e., instability) following forest development is based on channel response potential and whether there are measurable increases in flood magnitude/frequency and coarse sediment yield, as well as measurable reductions in riparian function and future woody debris recruitment.

Based on the most sensitive portions of each stream, channel response potential is moderate for all assessment streams except Slater Creek and Clough Creek, where it is low. Provided that peak flow hazard is not incrementally increased, sediment yields are not measurably increased, and riparian function is not impaired, there is a low likelihood of channel instability following forest development[107].

6.5. POLLUTANTS

Accidental oil and fuel spills and leaks associated with heavy equipment operation are of concern at any location, and especially in riparian areas along fish streams or streams that are relied upon for water supply. Pollutants have the potential to cause significant contamination of streams

---

[107] This is contingent upon effective control measures being implemented as outlined in Section 9.

and/or aquifers upon which the public rely for their water supply. BCTS Environmental Management System (EMS) environmental field procedure (EFP) 06 Fuel Handling outlines appropriate fuel storage & securing, dispensing, transportation, spill prevention and response measures, with restrictions specifically identified for riparian management areas. With strict adherence to and monitoring of these control measures during all forest development activities, risks of contamination should be minimized. As noted above in Section 6.2, we recommend that a Qualified Professional (QP) act as environmental monitor during forest development activities at a frequency and intensity commensurate with the level of activity on-site. The QP should ensure that all control measures are in place and functioning and that all EFPs are adhered to.

7. RISK SUMMARY

A main goal of this watershed assessment is to identify the potential hydrogeomorphic risks associated with future BCTS forest development in the assessment watersheds, although no specific plans have been confirmed. Key elements-at-risk, identified in Section 5, include: human safety, private property[108], transportation infrastructure, utilities, water rights & use, and fish and fish habitat. Peak flows (including floods, debris floods and debris flows), low flows & aquifer recharge, sediment yield, channel destabilization, and water contamination by pollutants are the principal hazards under review. If the likelihood or severity of one or more of these hazards is increased, there are elements at risk downstream that could be affected. Partial risk for each of the principal hazards are described in the following sections.

7.1. PEAK FLOWS

TABLE 7.1 provides a summary of the qualitative partial risk analysis for stream segments with a peak flow hazard above a low rating. Based on elements-at-risk identified along all assessment streams, peak flow risk in the assessment area is equivalent to peak flow hazard (Section 2.2). The following is a description of current peak flow risk for stream reaches between the 30 identified points-of-interest.

Chaster Creek

At Chaster Creek, peak flow risk ranges from high at the mouth to moderate below the confluence with Shirley Creek. Upstream of Shirley Creek, peak flow risk along Chaster Creek is low. Peak flow risk along Shirley Creek ranges from moderate at the mouth (POI 4) to low at the confluence with Inge Creek (POI 6), Tretheway Spring (POI 7), and Co-op Spring (POI 8). Peak flow risk for the Shirley Creek tributaries (POIs 6-8) are currently low.

End/Walker Creek

Peak flow risk is high along the entirety of End/Walker Creek; however, the stream is discontinuous in the upper portion of the watershed.

Smales Creek

Peak flow risk along Smales Creek ranges from low at the mouth to moderate at Highway 101 (POI 12). The low risk rating at the mouth is a result of a discontinuous channel with no defined channel noted below the highway. Above Highway 101 the peak flow risk is considered moderate.

---

[108] Includes, but is not limited to, residences, structures, water intakes, wells, stream crossings.

Higgs Brook

Peak flow risk along Higgs Brook ranges from moderate to low from the mouth to Highway 101 (POI 13 to POI 14). Despite relatively high ECAs, a low and moderate risk is considered due to the lack of surface connectivity from the upper and lower portion of the watershed, where surface flow disappears into the subsurface along the Gibson Bench.

Slater Creek

Peak flow risk along Slater Creek is moderate from the mouth to Highway 101 (POI 16), and ranges from moderate to low from the highway to the BCTS Chart boundary (POI 17).

Molyneux Creek

All streams within the Molyneux Creek watershed are considered to have a low peak flow risk.

Joe Smith Creek

Peak flow risk along Joe Ross Creek varies from moderate at the mouth to low at Highway 101 (POI 25). A low peak flow risk is identified for Joe Ross Creek upstream of Highway 101. Preventing an increase in peak flow hazard is desirable given the presence of some sensitive semi-alluvial stream reaches.

Clough Creek

Peak flow risk along Clough Creek varies from moderate at the mouth to low at Highway 101. Upstream of the highway the peak flow risk is considered low for all stream reaches.

Peak flow risk is not expected to incrementally increase if future BCTS development remains consistent with the recommendations outlined in Section 6.1.1. It should be recognized that incremental flood risks due to forest development are within a context of assessment watersheds currently with a low to high peak flow hazard, which are naturally subject to frequent rainstorm-driven and less frequent rain-on-snow-driven floods. Gradually increasing rainfall and storm intensity is projected with climate change. As a result, there is potential that peak flow risk may be amplified with the projected effects of climate change (Section 7.7).

TABLE 7.1 *Summary of stream segments with peak flow hazard above a low rating. Organized roughly in upstream order along each stream segment.*

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
Chaster Creek	Chaster Creek	0.00-2.30	Moderate to High	Fish & fish habitat	Several fish species have been recorded between the mouth and falls located near km 2.0 (refer to Section 4.13). The channel is fluvially active with considerable bedload transport. Log jams and aggradation noted throughout. Habitat conditions are highly variable.	000-030
				Chaster House and access bridge near stream km 0.02	Chaster House is located within a few metres of the left (east) bank of Chaster Creek and may be vulnerable to flooding and erosion given its proximity and elevation. A relatively low concrete retaining wall currently provides some erosion protection to the property.	002-003
				Domestic water licence F020212 (stream km 0.02)	No water supply infrastructure noted. Suspect the property is supplied by municipal water.	-
				Ocean Beach Esplanade bridge near stream km 0.04	This concrete bridge deck with relatively low freeboard (~1.5 m maximum above streambed) may be vulnerable to flooding and erosion during high flows. This may be exacerbated by aggradation.	004
				Domestic water licence C116516 (stream km 0.05)	No water supply infrastructure noted. Suspect the property is supplied by municipal water.	-
				Private bridge at stream km 0.10	This log and timber bridge has evidence of rot and has relatively low freeboard (~1.5 m maximum above streambed). Evidence of aggradation. This bridge could trap debris and/or collapse causing downstream effects.	005
				Domestic water licence C121502 (stream km 0.24)	Could not identify water supply infrastructure. Suspect the property is supplied by municipal water.	-
	Shirley Creek	2.30-3.50	Low to Moderate	Fish & fish habitat (suspected)	Fish (rainbow trout) have been recorded above the falls (near stream km 2.0) in Chaster Creek and tributaries.	-
				Highway 101 crossing (#70) near stream km 2.50	900 mm diameter concrete culvert. Large woody debris noted near inlet. Recommend clearing of culvert to prevent culvert plugging.	037

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				Domestic water licence C039934 (stream km 2.70)	Could not identify water supply infrastructure. Suspect the property is supplied by municipal water.	038
				Russell Road crossing (#36) near stream km 3.00	Russell Road culvert was reportedly washed out 8 years ago. Current crossing consists of a pair of 900 mm diameter culverts.	039
				Domestic water licence F040554 (stream km 3.15)	Could not identify water supply infrastructure. Suspect the property is supplied by municipal water.	-
				Private properties between Highway 101 and Russell Road	This section of channel through private land was not accessed during the review. Likely affected by past flooding and erosion as such effects are noted upstream and downstream.	-
				Private properties between Russell Road and Reed Road (including private road crossing)	Property owners have reported flood and erosion concerns associated with tributaries to Shirley Creek. A November 2021 atmospheric river event recently resulted in bank erosion and downcutting along Inge Creek, a stream that was reportedly diverted from the End/Walker Creek watershed to the Chaster Creek watershed by a property owner following a 1994 flood. The 2021 flood also damaged a private road crossing, which has since been repaired.	-
End/Walker Creek	End/Walker Creek	0.00-1.40	Moderate to High	Fish & fish habitat (suspected)	Little information is available on the fisheries values of this stream. Culvert at mouth may impede upstream fish movement. The channel is fluvially active with considerable bedload transport. Log jams and aggradation noted throughout. Habitat conditions are highly variable.	-
				Ocean Beach Esplanade crossing at stream km 0.00	1000 mm diameter culvert.	075
				Private property near Ocean Beach Esplanade near stream km 0.05	Private property is protected by a low concrete retaining wall along the right (north) bank of End/Walker Creek.	076

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				Land improvement water licence C122666 (stream km 0.05)	Cylindrical concrete sump noted in middle of creek. Unknown conditions and whether it is in operation as an intake. This intake is exposed to potential fluvial activity.	076
				Highway 101 crossing (#34) of End/Walker Creek at stream km 1.20	1200 mm diameter concrete culvert. Outlet is 4 m above streambed on south side of highway. Plunge pool scour noted.	080
				Highway 101 crossing (#53) of McComb Brook at stream km 1.20	1000 mm diameter culvert. Outlet is 4 m above streambed	-
				Water licence F016236 (stream km 1.40)	Above highway is a 15 m x 15 m "fish" pond with 6-inch diameter pipe that controls outflow on a 2 m tall concrete weir. Outlet was plugged with debris. The pond is heavily grown-in and appears unmaintained.	081
Smales Creek	Smales Creek	0.80-1.70	Low to Moderate	Private property (e.g., Sunday Cider) near stream km 0.80	Property with Sunday Cider business. Owner has owned property for 6 years. 2020 had the highest winter storm peak flow they have observed. For 4 years in a row this stream has been close to overflowing the banks. Stream is dry most of the year, but owner concerned about peak flows. Stream is fluvially active with aggradation causing reduced channel capacity through the property. Bank heights are variable and property is at risk of flooding.	094-101
				Domestic water licence F015851 near stream km 1.10	Rudimentary water supply system noted in stream. Intake(s) in pools with exposed water line along stream bed.	098
Higgs Brook	Higgs Brook	0.00-0.80	Moderate	Trail near mouth	Higgs Brook parallels a public trail near the mouth. Evidence of erosion is noted where riparian vegetation is scant.	121
				Private property (stream km 0.10)	Private property has evidence of erosion on the left (east) bank of Higgs Brook. A utility building is at risk of being undermined with continued erosion. Bank protection is recommended to prevent loss damage to building and potential stream impacts.	123
				Crossings at Lower Road & Leek Road (#17	1000 mm diameter culverts. Scour noted below culverts and along channel in the vicinity of the crossings.	127

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				& 18 near stream km 0.25)		
				Private property (stream km 0.25-0.80)	Higgs Brook has a relatively steep (10-20%) channel and passes through several private properties. The channel is fluvially active with bank erosion, downcutting and sediment transport noted throughout. Below the highway, a children's farm is adjacent to the stream, and has evidence of bank disturbance by farm activities.	-
				Highway 101 crossing (#19) at stream km 0.80	Stream crossings was not observed in the field.	-
Slater Creek	Slater Creek	0.00-1.00	Moderate	Lower Road crossing (#71) at stream km 0.25	1200 mm diameter concrete culvert. Woody debris noted near inlet. Recommend clearing to prevent culvert plugging.	134
				Highway 101 crossing (#39) at stream km 1.00	900 mm diameter culvert.	-
		1.00-2.00	Low to Moderate	Private property between Highway 101 and Pixton Road	This segment of Slater Creek flows through multiple properties. It is an incised channel with coarse streambed. Bank erosion is common as is evidence of aggradation. Most residences are located well above the stream and are at low risk of flooding. A possible exception includes the properties near the BC Hydro right-of-way, where the creek passes through a series of ponds.	-
				Domestic water licences F020210 (Valentine Spring) near stream km 1.24	No information available as private land could not be accessed.	-
				Domestic water licence C062074 near stream km 1.57	No information available as private land could not be accessed.	-
				Crossing at Porter Road (#38) near stream km 1.40	600 mm diameter culvert below approximately 2.5 m of road fill. Road could be at risk of washout in the event of debris and sediment plugging. Recommend culvert capacity review.	138

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				Crossing at Conrad Road (#37) near stream km 1.55	600 mm diameter culvert. Road could be at risk of washout in the event of debris and sediment plugging. Recommend culvert capacity review.	-
				Domestic water licence C115988 near stream km 1.66	No information available as private land could not be accessed.	-
				Crossings at Pixton Road (#82) near stream km 2.00	Culvert suspected at Pixton Road with private bridge on driveway nearby.	-
Joe Smith Creek	Joe Smith Creek	0.00-0.80	Low to Moderate	Private property between mouth and Highway 101	Joe Smith Creek flows through multiple properties. It is a relatively steep incised channel often flowing over bedrock or coarse sediments. Bank erosion is common as is evidence of aggradation. Erosion is particularly noteworthy near the mouth where riparian function is limited.	179-198
				Domestic water licence F014265 at stream km 0.12	Property owner does not currently use water licence. Potable water supplied by municipality.	-
				Domestic water licence C035140 at stream km 0.14	Stream channel reviewed in vicinity of mapped intake. No water infrastructure noted. Suspect propertied supplied by municipal water system.	-
				Domestic water licence F013152 at stream km 0.14	Stream channel reviewed in vicinity of mapped intake. No water infrastructure noted. Suspect property supplied by municipal water system.	-
				Milliner Road crossing (#74) at stream km 0.15	Pipe arch culvert, approximately 2.4 m wide 1.2 m high.	184
				Domestic water licence C121664 at stream km 0.28	PVC pipe presumably associated with the water licence was noted in the culvert crossing of Lower Road and down a portion of the channel below Lower Road. Above Lower Road the channel is aggraded and the water distribution line is obscured. The intake could not be identified; it is likely buried under debris and/or sediment. It is unknown whether it remains functional.	189-190
				Lower Road crossing (#20) at stream km 0.30	1400 mm diameter culvert	189

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				Private foot bridge (#7) at stream km 0.45	Foot bridge spans creek. Abutments may be at some risk but coarse rock and bedrock mitigate erosion risk.	194
				Domestic water licence 049823 at stream km 0.52	Property owner has not used water licence or well for last 10 years. Property is serviced by municipal water. PVC pipe is exposed at several locations along the channel. Intake location appears buried by sediment.	195
				Domestic water licence C065406 at stream km 0.58	Did not access property. Suspect that property is serviced by municipal water similar to neighbours.	-
				Domestic water licence C048176 at stream km 0.58	Reviewed channel in the vicinity of the mapped POD. No functional intake or water supply infrastructure noted. Some equipment in disrepair noted. Channel aggraded and may have buried intake. Suspect the property is serviced by municipal water.	-
				Private driveway culvert crossing near stream km 0.70 (not listed in stream crossing inventory)	Five 600 mm diameter culverts on private driveway. Evidence of debris plugging and aggradation. Potential washout of this crossing could cause a cascading effect downstream at Lower Road.	198
				Highway 101 crossing (#67) at stream km 0.8	1000 mm diameter concrete culvert.	199
Clough Creek	Clough Creek	0.00-0.90	Low to Moderate	Fish & fish habitat (suspected)	Little information is available on the fisheries values of this stream. Cutthroat trout have been recorded near the mouth. The channel is fluvially active with considerable bedload transport. Aggradation noted throughout. Habitat conditions are highly variable.	-
				Private properties between the mouth and Highway 101	Clough Creek is a fluvially active stream with active bedload. The channel is generally incised or confined and poses low risk to properties. Bank erosion and aggradation are common and may pose local issues some properties however.	207-218
				Domestic water licence C119215 at stream km 0.26	Concrete weir noted at stream km 0.3 (below Lower Road). Appears full of sediment and non-functional. No evidence of serviceable water supply system. Suspect this licence dating back from 1927 is no longer in use.	210

Watershed	Stream segment	Stream distance (km)	Peak flow hazard P(H)	Potential elements-at-risk	Notes	Refer to figures in Appendix E (Volume 2)
				Lower Road crossing (#25) at stream km 0.30	2000 mm diameter culvert with additional 600 mm diameter secondary culvert. Inlet protected by a concrete block retaining wall that has evidence of deterioration. Above lower road is a private foot bridge. Recommend review of structural stability of retaining wall at culvert inlet.	211, 213
				Domestic water licence C120577 at stream km 0.62	Reviewed stream in the vicinity of the licence. Did not identify any water supply infrastructure.	216
				Highway 101 crossing (#24) at stream km 0.90	900 mm diameter culvert that may be undersized. Road embankment, however on south side of highway is slumping and potentially poses a sediment hazard. Recommend stabilization of road fill and review of culvert capacity.	219

7.2. LOW STREAMFLOWS

Water supply during late summer and fall is of great concern on the Sunshine Coast, especially following drought conditions experienced in 2022[109]. Inadequate water supplies directly affect water users as well as fish and aquatic organisms. It should be noted that low streamflows at a specific location can be affected not only by the volumetric rate of water conveyed along a stream, but also stream conditions, specifically where a stream is aggraded and some or all of the available streamflow moves sub-surface. In this section, reference is made to the volumetric rate of flow and not the effect of aggradation on surface flow.

With consideration of the physical watershed characteristics, meteorological drivers, and current distribution of seral stages (i.e., stand ages) across the assessment area, the research literature suggests that the likelihood that low flows have been adversely affected by forest cover disturbance to date varies from low to high across the assessment area. Increased low flow risk[110] is primarily a result of higher water use associated with younger regenerating stands relative to older mature stands.

Based on the identified elements-at-risk, low flow risk in the assessment area is currently high in Slater Creek; moderate in Chaster Creek, Molyneux Creek, Joe Smith Creek, and Clough Creek; and Low in End/Walker Creek, Smales Creek, and Higgs Brook.

It should be recognized that these risk ratings are within a context of assessment watersheds that are subject to decreasing summer precipitation and increasing temperatures, which not only reduce natural water supply but also result in increasing water demand. As a result, there is potential that low flow risk may be amplified with the projected effects of climate change (Section 6.6) even though the incremental risk from forest harvesting remains low.

7.3. GROUNDWATER/AQUIFER RECHARGE

Assuming BCTS maintains current peak flow and low flow risks, the risks associated with BCTS development in the assessment area on the groundwater supply and aquifer recharge are low. Site-level increases in the water balance can be expected following the removal of forest cover, which may result in localised increases in the groundwater table. However, such increases are only expected to persist for up to 10-15 years. Beyond that time, there is a potential for decrease,

---

[109] https://www.scrd.ca/files/File/Community/EmergencyOps/2022-Nov-15%20Drought%20Order%202%20amended%20non-critical%20use%20SCRD%20signed%20copy.pdf

[110] A higher low flow risk is considered as an increased likelihood that forest disturbances have negatively influenced the magnitude, timing, and frequency of low flows.

but only if opening size exceeds 8 ha or if >50% of the overstory canopy is removed. Given the long time periods associated with groundwater movement and recharge to the confined Gibsons Aquifer, harvest-related effects are expected to be undetectable if the above constraints are met.

7.4. SEDIMENT YIELD

Sediment yields from BCTS' Chart, associated both with sediment generation on roads and by landslides, are currently low. In part this is due to well planned, constructed and maintained resource roads, consideration of riparian management zones, and referral to qualified professionals to identify terrain-related risks or blowdown risks and provide options for risk mitigation. Reliance on such professionals has been standard practice since the implementation of the Forest Practice Code[111], which was implemented to reduce the likelihood of events such as debris flow that occurred in Clough Creek in 1983.

Potential sediment risks associated with future forest development are primarily associated with the construction (including reactivation), maintenance, and use of new and existing roads and trails, and with potentially sensitive (gullied) terrain adjacent to streams. Assuming that best management practices around streams and riparian zones as identified in BCTS' Environmental Management System (EMS) and environmental field procedures (EFPs) are followed and control measures identified in Section 9 are considered, sediment yields and the hazards associated with planned forest development can be maintained at low levels.

7.5. STREAM CHANNEL STABILITY

Based on our office and field analyses, channel response potential (i.e., channel sensitivity) is moderate in all assessment streams but Slater Creek and Clough Creek, where it is low. This means that while some localized reaches have potential to adjust morphologically, they are generally insensitive to changing hydrologic or sediment inputs. This robustness is driven by the incised or confined nature of most channels, the coarse-textured (cobble and boulder) gravel streambed, lateral and vertical control provided by bedrock or erosion-resistant glacial deposits (e.g., till), the functional riparian conditions, and/or the ample supply of functional wood debris. Given these factors, channel stability risks associated with forest development on BCTS' Chart are presently low and are expected to remain so assuming that the peak flow hazard and sediment hazard are not incrementally increased.

It is important to recognize that low risks do not imply that the assessment streams are or will be static or fluvially inactive. The assessment streams are fluvially active and do naturally respond to rainstorm- and rain-on-snow-driven events with episodes of sediment transport. Evidence of

---

[111] Subsequently replaced with the *Forest and Range Practice Act (FRPA)* in 2004.

such activity is widespread. In most cases, this is regulated by functional wood debris. However, this debris is mature and deteriorating at various rates. As debris jams collapse over a number of years to decades, there will be natural increases in sediment pulses, even without any measurable change to the flood regime.

7.6. POLLUTANTS

As noted in Section 7.6, pollutants such as fuel, can pose a risk to water quality in the event of spills and leaks. Such risk is omnipresent across the assessment watersheds, particularly along highways, roads and more densely populated urban areas. On BCTS' Chart on Crown land, such hazards are low and can be mitigated with planned future forest development by strict adherence to BCTS EMS and EFPs. As a result, the risks posed by planned forest development is expected to be low.

7.7. CLIMATE CHANGE CONTEXT

Each of the hydrogeomorphic risks described above should be understood within the context of on-going and future climate variability and change. As discussed in Section 4.7, the hydrology of the assessment watersheds is driven principally by fall and winter rain, with snow and subsequently rain-on-snow occasionally influencing the watersheds. With limited surface storage (e.g., lakes, reservoirs, wetlands), streamflows in the assessment watersheds generally have a high runoff generation potential[112] that closely reflect the magnitude, frequency and duration of rainstorms in the region.

The climate of the assessment area is influenced not only by large-scale atmospheric circulation patterns that occur over inter-annual time scales (PDO and ENSO), but also long-term climate change associated with anthropogenic greenhouse gas emissions (PCIC, 2013, 2021). Temperatures have steadily increased over many decades, and are projected to further increase in future under a number of assumed CO_2 emission scenarios; RCP 8.5 is utilized here for discussion. On the Sunshine Coast, annual temperature is projected to increase by 4.7 °C by the 2080s (PCIC, 2021). This poses several risks, including, but not limited to, elevated stream temperatures and reductions in water quality for fish, increased water demands for irrigation, increased potential for drought, and increased severity and extent of wildfires.

In addition, evaporation could intensify as temperatures rise as will the transfer of heat from oceans to the air. This could mean stronger winds and increased risk of blowdown of susceptible trees. It also could mean more frequent and intense rainstorms. By the 2080s, storm-related rainfall

---

[112] Exceptions include End/Walker Creek above Highway 101, Smales Creek below Highway 101[112], and Higgs Brook.

is projected to increase by up to 20% for relatively frequent 2-year return period events and up to 40% for relatively rarer 50-year return period events (Western University, 2021). High intensity precipitation, often associated with land-falling atmospheric rivers, are expected to be of higher magnitude and occur more frequently as a result of climate change (Murdock et al., 2016; Gillett et al., 2022).

On an annual basis, precipitation is expected to modestly increase (+4.8%) by 2080. However, seasonal changes pose more direct risks in the assessment watersheds. By the 2080s, winter precipitation is projected to increase by 9.7%. This may increase the potential for flooding, but it may also be beneficial for water supply if some of this water recharges local aquifers. Summer precipitation, however, is projected to decrease by 22% by the 2080s, which could mean an increased severity and frequency of drought conditions, which could reduce late summer and fall low flows.

Given these ongoing and increasing pressures, minimizing incremental increases to current hazard levels within BCTS' Chart with regards to peak flows, low flows, sediment yield and channel instability is paramount to the conservation of water resources and protection of watershed values. As such, risk management options should be implemented as part of future forest development planning. These recommendations are summarized in Section 9.

Although outside the scope of this assessment, overall watershed management, particularly in light of the projected changes from climate change (e.g., increased frequency and magnitude of storm) will also require effective coordination by local and provincial government, First Nations, and other stakeholders in order to identify and implement active control measures outside of BCTS Chart to reduce near- and long-term hazards. This could include reforestation along lower reaches and engineering approaches to mitigate the effects of projected higher flows and lower flows in urban areas.

8. CONCLUSIONS

This report summarizes the results of a watershed assessment of eight urban interface streams (i.e., assessment streams/watersheds) on the southern slopes of Mt. Elphinstone between Gibsons and Roberts Creek, BC (MAP 1). These streams include (from east to west): Chaster Creek, End/Walker Creek, Smales Creek, Higgs Brook, Slater Creek, Molyneux Creek, Joe Smith Creek, and Clough Creek. The principal objectives of the assessment are to review the current conditions within each of the assessment watersheds, identify the potential hydrogeomorphic hazards and risks from potential future forest development within BCTS' Chart on downslope watershed values, and provide risk management options to reduce, mitigate or avoid such risks. It is important to recognize that the scope of the assessment is intended to provide BCTS with direction on how to proceed with forest development planning in order to minimize hydrogeomorphic risks; it does not review specific forest development plans.

The assessment is guided by BCTS' *Watershed Risk Management Framework* (Polar, 2022) and is consistent with *Joint Professional Practices Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector* (Engineers and Geoscientists British Columbia and Association of British Columbia Forest Professionals, 2020). The approach includes office-based analyses and field-based reviews performed in two phases. The first phase examined watershed and underlying aquifer characteristics, levels of past land use disturbance, identification of potential watershed values downslope of BCTS' Chart, and identification of potential hazards and risks. The second phase refined the risk analysis by obtaining stakeholder knowledge of the area and conducting further field review of streams and potential elements-at-risk. A third phase of assessment work separate from this report will be focussed on site-level review of specific forest development plans.

Within the assessment watersheds, the following downslope/downstream potential elements-at-risk were identified: human safety, private property, transportation infrastructure, utilities, water rights & use, and fish and fish habitat. Peak flows, low flows, sediment yields, channel destabilization, and water contamination by pollutants are the principal hazards under review.

Based on an understanding of history of the area, current conditions, and the context of ongoing and future climate change, an analysis of current and projected future hazards and risks from forest development within BCTS' Chart in the assessment watersheds was conducted. Based on this assessment, the following conclusions were drawn:

Streamflows (Peak and Low Flows) and Aquifer Recharge

1. The assessment streams have a rain-dominated flow regime, with highest flows generally driven by frontal systems in November and December. Rain-on-snow is considered to be

the dominant process responsible for major, potentially damaging floods at all elevations. Assuming the presence of a snowpack, rain-on-snow runoff is often most severe when warm temperatures, strong winds, and intense rainfall, potentially associated with an atmospheric river (AR), coincide. Given the limited relief of the assessment watersheds, snow is transient in many years, and often plays a minor role in the annual hydrograph of the assessment streams. It can, however, be a significant component in cooler years when seasonal snowpacks can form at lower elevations.

2. Based on the physical watershed characteristics that affect runoff generation, meteorological conditions typical of the area, and land uses, the runoff generation potential (RGP) for the assessment watersheds is high in all watersheds with exception of End/Walker Creek above Highway 101, Smales Creek below Highway 101[113], and Higgs Brook. RGP is considered low for these three stream reaches given they have considerable surface flow discontinuity and a propensity for water losses through infiltration. This means that streamflows generally respond somewhat rapidly to precipitation inputs in most of the assessment watersheds. As such, the flood regime closely reflects the magnitude, frequency and duration of rainstorms in the assessment area.

3. Low (base) flows in the assessment streams, which are controlled by rainfall inputs and groundwater contributions, are generally at their lowest in July and August, under the influence of high-pressure weather systems but can extend well into the fall (e.g., fall 2022).

4. The climate of the assessment area is influenced not only by large-scale atmospheric circulation patterns that occur over inter-annual time scales (PDO and ENSO), but also long-term climate change associated with anthropogenic greenhouse gas emissions. PCIC (2021) project that average annual temperatures and precipitation will increase by 4.7 °C and 4.8% by the 2080s, respectively (assuming RCP 8.5).

5. Increased temperatures with climate change are projected to pose a number of risks, including, but not limited to elevated stream temperatures and reductions in water quality for fish, increased potential for drought, increased water demands for irrigation, and increased severity and extent of wildfires. In addition, evaporation will intensify as temperatures rise as will the transfer of heat from the ocean to the air. This could mean more intense windstorms and rainstorms along the Sunshine Coast.

6. Although the range of uncertainty in future precipitation projections is considerable, on an annual basis precipitation is projected to decrease by 1.0% by the 2050s and increase by 4.8% by the 2080s (PCIC, 2021). Summer precipitation, which is relevant to the

---

[113] The RGP for Smales Creek above Highway 101 is considered high.

maintenance of water supplies and instream flows for fish, is projected to decrease by 13% by the 2050s, and 22% by the 2080s. This suggests an increasing potential for drought conditions on the Sunshine Coast. Conversely, seasonal precipitation in winter is projected to only slightly increase by 0.9% by the 2050s; however, by the 2080s, the increase rises to 9.7% (PCIC, 2021). These increases could be beneficial in replenishing aquifers; however, they also could increase antecedent soil moisture conditions leading up to potential storm-driven flood events. According to Western University (2021), storm-related rainfall intensity is also projected to increase. Relatively frequent rainstorms with a 2-year return period are projected to increase in magnitude by 6-11% by the 2050s and 14-20% by the 2080s. Rarer 50-year return period storms are projected to increase by 12-24% by the 2050s and 30-38% by the 2080s (Western University, 2021). These changes would suggest an increased likelihood of floods over time. Moreover, occasional snowfall can still be expected to occur in the future across all elevations (William Floyd, pers. comms., 2023). Rain-on-snow generated peak flows are therefore expected to persist in the future.

7. Peak flow hazard is a function of runoff generation potential and runoff synchronization (Section 2.3.1). The former is potentially influenced by Equivalent Clearcut Area (ECA), an index of forest disturbance and regrowth in a watershed, which can be influenced by forest management. Following recommendations from Dr. William Floyd[114], the evaluation of ECA was conducted assuming that rain-on-snow is the primary peak flow generating mechanism and can occur at all elevations. Therefore, ECA was evaluated using a single rain-on-snow recovery curve from Hudson and Horel (2007) and was applied across all elevations.

8. ECAs in the assessment area demonstrate that the extent of forest cover disturbance is greatest in the lower portion of the watersheds, which have been subject to varying degrees of residential and commercial development. This skews the overall watershed ECAs (i.e., above the mouth of each stream) and is likely to have resulted in streamflows along lower reaches of each creek that are urban-influenced, although to varying degrees. Moreover, most, if not all, forest stands in the upper portion of the assessment area have been subject to historical disturbance, either by wildfire or logging. As such, regenerating forest stands within BCTS Chart are at various levels of recovery and contain various proportions of deciduous species, which are considered less hydrologically recovered relative to coniferous stands.

9. ECAs were evaluated for drainage areas upstream of 30 points-of-interest (POIs) in the assessment area. Currently, ECA ranges from 6.0% in forested BCTS Chart area to 57.2% above a POI which includes extensive rural/residential and commercial development.

---

[114] Research Hydrologist for the Coast area Research Section, BC Ministry of Forestry.

This means current peak flow hazards vary by POI. A high peak flow hazard was identified for the following POIs:

- Chaster Creek at the mouth,
- End/Walker Creek at the mouth, and
- End/Walker Creek above Highway 101.

A moderate peak flow hazard was identified for the following POIs:

- Chaster Creek below Shirley Creek,
- Shirley Creek,
- Smales Creek above Highway 101,
- Higgs Brook at the mouth,
- Slater Creek at the mouth,
- Slater Creek above Highway 101,
- Joe Smith Creek at the mouth, and
- Clough Creek at the mouth.

A low peak flow hazard is identified for the remaining POIs.

10. Although the removal of forest cover along road rights-of way are accounted for in ECA calculations, roads can affect natural drainage patterns and effectively increase runoff generation potential through the interception of shallow groundwater flow and conveyance as ditch flow to the stream network. In the assessment watersheds, the likelihood of such effects, both associated with current and future roads is low. This stems from a combination of relatively rapid preferential shallow subsurface flow along effectively impermeable surficial materials or bedrock and relatively high drainage density. As a result, shallow groundwater and surface water flow rates are similarly rapid, such that road-related effects on drainage patterns and rates are expected to be small.

11. With regards to summer low flows, the distribution of seral stages (i.e., forest ages) suggest that low flows have been influenced to varying degrees by historical disturbance. The likelihood that low flows have been adversely affected by the current distribution of seral stages is low for End/Walker Creek, Smales Creek, and Higgs Brook; moderate for Chaster Creek, Molyneux Creek, Joe Smith Creek, Clough Creek; and high for Slater Creek. With respect to future development, recommendations are provided in Section 9 to minimize the likelihood of causing an incremental adverse effect on summer low flows.

12. If BCTS maintains current peak flow hazards and a low likelihood of adversely affecting low flows (as described in Section 9), the risks associated with BCTS development in the assessment area on the groundwater supply are low. Site-level increases in the water balance can be expected following the removal of forest cover. This may result in localised

increases in the groundwater table; however, such increases are only expected to persist for up to 10-15 years. Beyond that time, there is a potential for decrease, but only if opening size exceeds 8 ha or where thinning occurs, if >50% of the overstory canopy is removed. Furthermore, most wells downslope of BCTS' Chart appear to be established sufficiently deep within regional-scale bedrock or confined alluvial groundwater systems at distances several 100s of metres if not kilometres from BCTS' Chart. Given the long time periods associated with groundwater movement and recharge, to the confined Gibsons Aquifer, harvest-related effects are expected to be undetectable if the above constraints are met.

Sediment Yield

13. Few forest development-related sediment risks were identified in the assessment area. Overall, the current erosion potential from active roads is low. Erosion potential does marginally increase in the vicinity of crossings of incised gullies, due to the increased height of road cuts that are typically required; however, these site-level risks appear to have been effectively mitigated where necessary, and sediment risks remain low.

    A total of 89 active stream crossings in the assessment area were identified during the field reviews. Although this does not necessarily represent an exhaustive inventory, it does represent a large sample of the stream crossings in active use. Our field observations within BCTS Chart generally indicate that sediment hazards associated with stream crossings is low[115], largely as a result of gentle road grades, deactivation of unused roads, and effective control measures such as coarse gravel road surfacing and/or rock armour at culvert inlets and outlets or along bridge abutments. There are very few examples where sediment hazards are elevated in the assessment area within BCTS Chart.

14. In addition to the debris flow documented along Clough Creek in 1983 [prior to the *Forest Practices Code (FPC)* and *Forest and Range Practices Act (FPRA*)], a historical air photo review revealed several smaller development-related landslides initiated roughly 75 m to 250 m from the Clough Creek debris flow headscarp. These smaller slides are suspected to have been initiated during the same 1983 storm. No other development or natural landslides were noted in the assessment area. Limited relief and gentle to moderate hillslope gradients combined with BCTS' operating procedures that require engagement with qualified terrain professionals where necessary during the development planning process, reduces the likelihood of landslides in the assessment area, such that current sediment yields from landslides are low.

---

[115] The sediment hazard refers to the likelihood of measurable erosion and sedimentation to occur in the vicinity of stream crossings. It does not consider the potential for crossing damage or washout in the event of an extreme flood. Evaluation of design flows and flood conveyance at crossings is beyond the scope of the assessment.

15. Potential sediment risks with future forest development are likely to be associated with the construction (including reactivation), maintenance, and use of new and existing roads and trails. Fine-textured soils, where present, may be susceptible to rutting, compaction and erosion if subject to mechanical disturbance or excessive traffic during wet weather or wet ground conditions. These risks can, however, be effectively mitigated with a number of control measures, depending on site-conditions. Several of these measures are outlined in Section 9. Assuming that these (or equivalent) control measures are effectively implemented, sediment yields and the risks associated with future forest development can be maintained at low levels.

Riparian Function

16. With the exception of road crossings and the BC Hydro right-of-way (ROW), riparian conditions within BCTS' Chart on Crown land within the eight assessment watersheds are characterized by mixed deciduous and second growth conifers with varying amounts of understory vegetation. Along classified streams, riparian vegetation is largely functional in providing bank stability and shade but is occasionally lacking in future recruitment of large woody debris. While most streams have ample volumes of instream wood, many of the stable larger-diameter pieces are disintegrating and are likely being replaced by smaller-diameter less stable wood recruited from the riparian zone. A reduction in stable in-stream wood could increase sediment transport rates over time, which could adversely affect stream crossings, water supply infrastructure and fish habitat. Urbanization in the lower portion of the assessment area increases the potential for localized reductions in riparian function (e.g., near stream crossings and private properties); however, given the incised nature of most stream reaches, riparian areas remain largely intact and functional.

17. BCTS forest professionals plan harvesting opportunities to minimize disturbance of riparian zones along classified streams by establishing riparian reserves, wildlife tree retention areas (WTRAs), and/or machine-free zones. Road alignments are also planned, where possible, to minimize stream crossings and localized riparian impacts. These general precautions are intended to minimize adverse effects on riparian function. Since a review of specific blocks will be completed during Phase 3, the riparian related hazards associated with specific harvest plans cannot be determined at this time.

Stream Channel Stability

18. A selection of photos documenting current conditions observed during the field review along each stream is provided in Appendix E. Overall, the assessment streams include a mix of channel morphologies and are generally non-alluvial on BCTS' Chart, and semi-alluvial or alluvial along the lower slopes. Additional description of each of the assessment streams is provided in Section 6.4.

19. The likelihood of channel disequilibrium (i.e., instability) following forest development is a function of channel response potential and whether there are measurable increases in flood magnitude/frequency and coarse sediment yield, as well as measurable reductions in riparian function and future woody debris recruitment. Based on the most sensitive portions of each assessment stream, channel response potential is moderate for all assessment streams except Slater Creek and Clough Creek, where it is low. The robustness of the assessment streams is a function of their incised or confined nature, the coarse-textured (cobble and boulder) gravel streambed, lateral and vertical control provided by bedrock or erosion-resistant glacial deposits (e.g., till), the riparian conditions, and/or the ample supply of functional wood debris. Given these factors, the hazard associated with channel instability is presently low in all assessment streams. Provided that peak flow hazard remains low, sediment yields are not measurably increased, and riparian function is not impaired, there is a low likelihood of channel instability associated with future forest development in the assessment watersheds.

Pollutants

20. BCTS Environmental Management System (EMS), environmental field procedure (EFP) 06 Fuel Handling outlines appropriate fuel storage & securing, dispensing, transportation, spill prevention and response measures, with restrictions specifically identified for riparian management areas. With strict adherence to these control measures during all future forest development activities, risks of contamination can be minimized.

Risk Analysis

21. A main goal of this watershed assessment is to determine the potential hydrogeomorphic risks associated with future BCTS forest development in the assessment watersheds and provide risk management options to avoid or mitigate such risks. Key elements-at-risk include: human safety, private property, transportation infrastructure, utilities, water rights & use, and fish and fish habitat. Peak flows (including floods, debris floods and debris flows), low flows & aquifer recharge, sediment yield, channel destabilization, and water contamination by pollutants are the principal hazards under review herein.

22. TABLE 7.1 provides a summary of the qualitative partial risk analysis for stream segments with a peak flow hazard above a low rating. These results indicate the current likelihood of the hazards reviewed are predominantly low, although some are moderate or high along specific stream reaches. Management recommendations to maintain current hazard ratings are provided in Section 9. Subsequent development plans will be subject to Phase 3 analysis of site-level risks and conditions.

Each of the hydrogeomorphic risks described above should be understood within the context of on-going and future climate variability and change (Sections 4.7 and 7.7). Given these ongoing and increasing pressures, minimizing incremental increases in hazard ratings within BCTS' Chart with regards to peak flows, low flows, sediment yield and channel instability is paramount to the conservation of water resources and protection of watershed values. As such, risk management options should be implemented as part of future forest development planning. These are summarized in Section 9.

9. RISK MANAGEMENT OPTIONS

This section outlines management recommendations available to avoid or mitigate the hydrogeomorphic risks identified above.

Streamflow Regime (Peak and Low Flows) & Aquifer Recharge

1. Based on the characteristics of the assessment watersheds and the research literature, ECA recommendations for each POI were formed on the basis of limiting incremental increases in peak flow hazard at POIs downstream of BCTS Chart. Moreover, it is recommended that the ECA be below 20% for the portion of the watershed within BCTS Chart. The ECA recommendations made include a level of conservatism beyond what previous assessments (i.e., Madrone, 2015) have identified in the assessment area, and furthermore these recommendations are considered prudent within the context of climate change (Section 7.7), the inherent uncertainty in ECA estimates (APPENDIX B), and the values identified along each stream (APPENDIX C). The maximum additional ECA to avoid increasing current peak flow hazards while also maintaining ECAs below 20% within BCTS Chart are listed in TABLE 9.1. These values represent current (2021) conditions and are expected to change with hydrologic recovery.

TABLE 9.1 *Maximum additional ECA to avoid incremental increase in peak flow hazard.*

Assessment Watershed	Recommended additional ECA within BCTS Chart to avoid incremental increase in peak flow hazard
Chaster Creek	**≤ 27.6 ha overall AND** ≤ 11.4 ha above POI 3 ≤ 16.2 ha above POI 4 ≤ 6.3 ha above POI 6[116] ≤ 8.6 ha above POI 7[116] ≤ 6.6 ha above POIs 8[116]
End/Walker Creek	**≤ 1.3 ha overall**
Smales Creek	**≤ 2.2 ha overall**
Higgs Brook	**≤ 6.5 ha overall**
Slater Creek	**≤ 3.7 ha overall AND** ≤ 1.8 ha above POI 16
Molyneux Creek	**≤ 14.7 ha overall AND** ≤ 8.8 ha above POI 20 ≤ 6.4 ha above POI 22.
Joe Smith Creek	**≤ 3.9 ha overall**
Clough Creek	**≤ 6.3 ha overall**

---

[116] The collective ECA of POIs 6-8 must not exceed 16.2 ha to meet the constraint imposed on POI 4.

2. Alternative silvicultural[117] approaches should be considered to minimize the incremental increases to current peak flow hazards. This includes small openings[118], strip cuts or individual tree selection. Such approaches would aim to preserve natural levels of wind exposure and shade and have been reported to reduce hydrologic risks (Hudson, 2001).

3. In order to manage runoff generation at the site-level, it is important to maintain natural drainage patterns throughout all watersheds. This includes continued alignment of new roads to avoid or minimize interception of surface or near-surface groundwater. If groundwater interception cannot be avoided, minimize the heights of road cuts and/or use alternative road construction methods (e.g., overlanding and using coarse, porous rock ballast) with limited disturbance to natural drainage. Restore natural drainage patterns by deactivating unnecessary roads and trails, and lastly, avoid excessive soil compaction to prevent creation of preferential pathways for runoff during and following forest harvesting.

4. Where feasible, the promotion of urban forest is recommended to promote hydrologic recovery in areas subject to residential and commercial development.

5. With respect to future development, the literature suggests that to minimize incremental adverse effects on summer low flows, alternative silviculture approaches should be considered. These approaches include small openings or individual tree selection (i.e., thinning). The principal objective of applying such silvicultural approaches is to limit changes to site-level energy balance by promoting shade to reduce the potential for increased solar radiation, and limiting the potential for increased energy from wind (i.e., turbulent heat fluxes) following harvest.

   In the late summer low flow period, riparian zones serve as primary conduits for water movement. Riparian area retention should be a management objective to limit the potential for increased water demands from recolonizing deciduous and coniferous species, which tend to be higher than mature conifer species. For S4 and larger streams, current riparian management and free-growing standards should serve to minimize not only disturbance of sensitive riparian areas, but also the likelihood of deciduous colonization in such areas. For the smaller S5 and S6 streams, a management zone is recommended within defined gullies or draws[119]. Unless riparian reserves are sufficiently windfirm, thinning or retention of nonmerchantable species may be preferred for S5 and

---

[117] The ECA recommendations assume a clearcut silviculture system. If a selective harvest silviculture system is used, ECAs are scaled based on the values in TABLE 6.1.

[118] If more than one opening is associated with a single cutblock, the space between openings should be large enough such that the adjacent opening us sufficiently buffered from wind and solar radiation.

[119] These areas should be determined through site-level field review.

S6 streams to limit the risk of blowdown associated with reserves (Hudson and D'Anjou, 2001). Moreover, thinning with relatively high retention levels would serve to maintain some level of shade and reduce the potential for deciduous colonization. Based on the above, the following management options should be considered[120]:

In riparian areas:

- For S4, S5, and S6 streams, a management zone is recommended within gullies or draws, and these areas should be prioritized for relatively high retention levels in order to minimize changes in riparian water demands via evapotranspiration.

In upland areas:

- Maintaining net opening size to less than 8 ha[121],
- Implementing partial harvest silviculture systems (i.e., thinning), or
- A combination thereof.

6. Climate change is projected to increase stress on water supply and water quality in the assessment area. In light of such projections, forest management could play a role in mitigating climate change and supporting long-term sustainable water supply through establishment of a broad range of seral stages across each watershed. This has the potential to reduce overall water demands from the forest land base, to promote biodiversity, and could reduce the potential for interface wildfires, which are expected to become increasingly common and severe with climate change. While difficult to quantify, we also encourage the planting of a mix of species[122] similar to the pre-harvest (mature) stands to achieve similar evapotranspiration rates in the long-term. A total resource planning approach with water sustainability as one of its key objectives is one option to consider. Such an approach could complement and directly inform the Source to Sea Project[123] and Elphinstone-Gibson Watershed/Aquifer dialogue recently hosted by the Town of Gibsons.

7. Many crossings in the urban areas and on MOTI roads were installed several decades ago and may be undersized in light of climate change projections. They may also become more prone to debris plugging as mature instream wood deteriorates and is transported downstream. We recommend that BCTS share this information with MOTI, the Sunshine Coast Regional District, and Town of Gibsons. We recommend the appropriate party

---

[120] These management objectives should be met while maintaining the ECA thresholds identified previously.

[121] If more than one opening is associated with a single cutblock, the space between openings should be large enough such that the adjacent opening is sufficiently buffered from wind and solar radiation.

[122] Stocking standards require a mix of species, particularly along riparian areas (Tom Johnson, pers. comms., 2023).

[123] https://gibsons.ca/sustainability/natural-assets/source-to-sea-project/

consider a stream crossing review to pre-emptively identify and replace undersized or potentially non-functional crossings, especially those which pose higher downstream environmental risks with failure.

Sediment Yield

8. In order to minimize the risk of increasing sediment yields associated with landslides, BCTS should continue to retain qualified professionals to identify terrain-related and blowdown risks and provide options for risk mitigation. Madrone (2015) recommended that within the Chaster Creek watershed all potential development areas between 200 m and 600 m elevation be assessed for terrain stability, and they further cautioned against road construction or harvesting in two areas with a high density of steep, deeply-incised gullies. We concur with these recommendations; however, with the benefit of high-resolution LiDAR-based bare-earth imagery, we further recommend that terrain stability assessments guide forest development planning in all eight assessment watersheds where harvesting or road construction is planned on slope gradients exceeding 50%. This largely occurs along deeply-incised gullies identified in FIGURE 9.1.

9. While the potential for generation and delivery of sediment to the stream network from current roads is low, BCTS should continue to employ best management practices around streams and riparian zones as identified in BCTS' Environmental Management System (EMS) and environmental field procedures (EFPs). This includes adherence to wet weather shutdown procedures (Statlu, 2018b) during all forestry activities involving heavy equipment not only for safety reasons (for which they were developed) but also to minimize soil erosion and sediment delivery to the stream network.

   Moreover, to help minimize sediment risks during future forest development, we recommend that works involving potential soil disturbance or large cuts and fills within 50 m of a stream channel and installation of bridges or major culverts be monitored by a Qualified Professional (QP) at a frequency and intensity commensurate with amount of soil disturbance and stream values at risk.

   The QP should be experienced in erosion and sediment control and should be in direct communication with BCTS should a stop work order be necessary in the event that weather or other factors that pose unacceptable risks (e.g., damaged or ineffective control measures) are identified. Furthermore, we recommend that prior to harvesting, a monitoring program be established, preferably by the same QP, to gauge the specific sediment contributions from those specific roads and road crossings that will be utilized. Monitoring and record keeping should adhere to FREP WQEE protocols and sample locations before, during and after road construction and harvest.

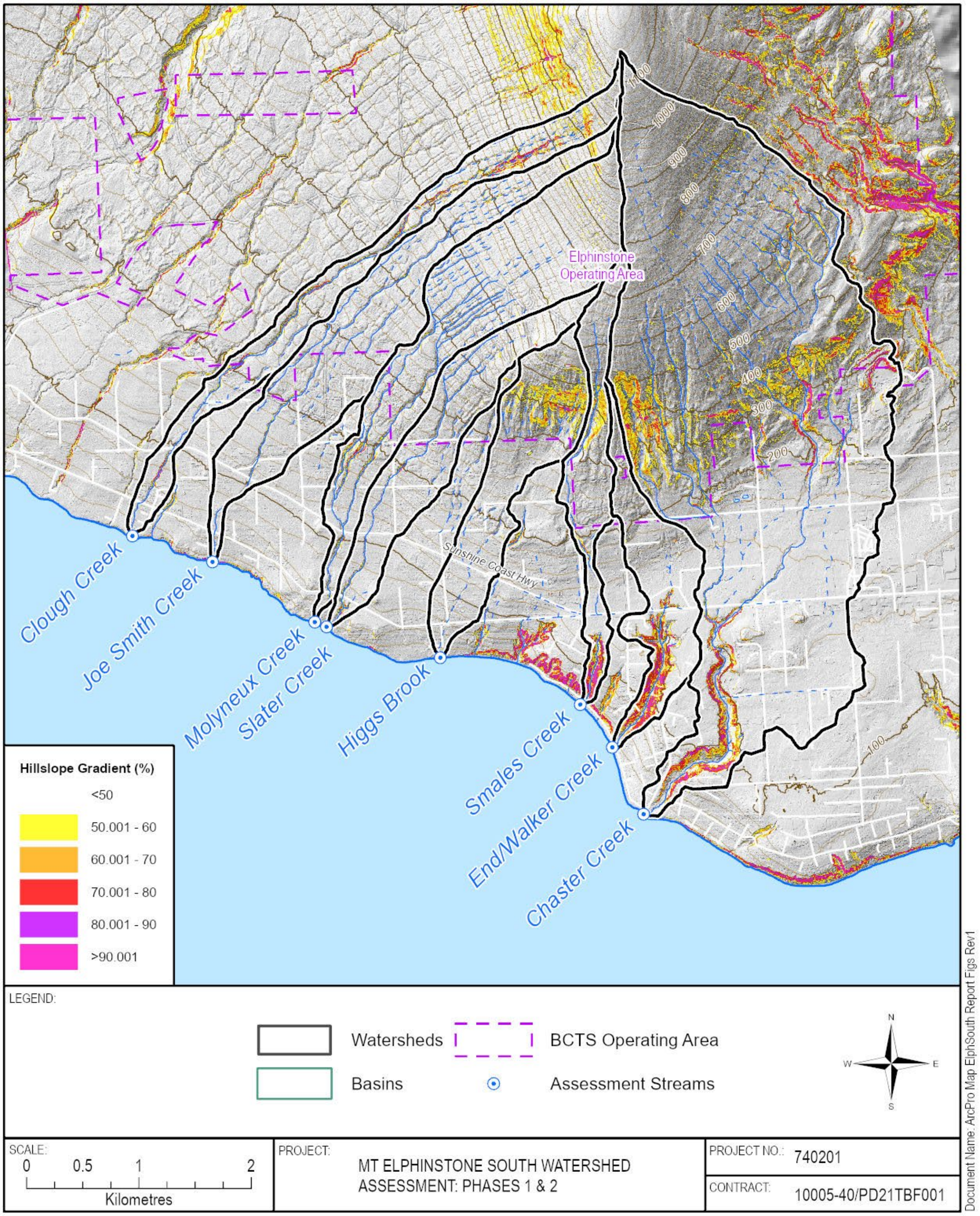


FIGURE 9.1 *Hillslope gradients in excess of 50% in the assessment area*

10. It is recommended that road building and surface materials be sourced from the lower portion of the assessment area (or other area offsite) where the geology is primarily intrusive rocks (FIGURE 4.7). The sedimentary rocks in the upper portion of the assessment area are expected to be more erosive, with a greater potential to increase suspended sediment if transported to streams.

11. In order to maintain low sediment-related hazard, planning of road alignments and cutblocks should consider and take precautions to avoid alteration of natural drainage patterns upslope of sensitive gullied terrain, minimize windthrow in riparian zones (e.g., by having windthrow assessments performed) and avoid wherever possible physical soil disturbance in riparian zones by heavy equipment (e.g., by establishing machine-free zones along riparian corridors). Such control measures should be tailored to the risk posed by increased sediment yield on downstream values. For example, on Molyneux Creek, there are several water licences near or within BCTS' Chart, including one that was field-confirmed to be actively supplying potable water to a private residence. In such a case, effective cutblock and road layout upslope combined with control measures are of paramount importance given the close proximity of an element-at-risk.

12. Future sediment risks can further be mitigated using control measures, currently employed by BCTS. These include the following:
    - Avoiding, where possible, road alignments near riparian areas and areas with high hillslope-stream connectivity;
    - Reducing surface erosion on cut and fill slopes by planning road alignments that: i) minimize the height of road cuts; ii) avoid fine-textured soils, especially in groundwater seepage areas; and iii) utilize appropriate erosion control measures[124], with the guidance of a qualified erosion control professional;
    - Reducing the erosion of ditches by: i) minimizing ditch flow with establishment of water-bars and cross-ditches spaced according to field conditions; and ii) applying appropriate erosion control measures along ditches with the guidance of a qualified erosion control professional[125];
    - Reducing erosion of the road surface and improving drainage off the road surface by: i) establishing an appropriate density of water bars and/or cross ditches, ii) crowning, out-sloping or in-sloping road surfaces, and iii) regular grading to minimize rutting while being careful not to leave grader berms that may prevent drainage of the road surface; iv) limiting the lengths of climbing grade where possible; v) elevating the road surface with coarse road ballast if areas of high groundwater/soil moisture are encountered; and vi) where necessary, adding a

---

[124] For example, hydro- or pneumatically-applied mulch/seed, or installation of erosion control blankets.

[125] For example, riprap, turf-reinforcement mat, seeding.

cap of aggregate over the native soil, underlain by geotextile (to avoid downward migration of the aggregate);

- Reducing erosion at stream crossings by: i) ensuring the crossing is appropriately sized to permit the design flow, and the design flow accounts for the projected increases in storm intensity in the future (Section 4.7.2); and ii) armoring culvert inlets and outlets, typically with riprap; and
- Reducing surface runoff to streams by: i) minimizing the length of ditches that directly flow into streams; and ii) directing ditch flow via cross-ditches into stable forested areas where there is no classified stream within a short distance downslope.
- Reducing sediment risks at bridge crossings by regularly cleaning bridge decks.

13. The alignment of new road crossings should be perpendicular to the orientation of the channel and only in areas with lateral stability to minimize interference with natural hydrogeomorphic processes (e.g., alluvial fans, debris flow gullies). Climbing roads on fans should be avoided and fail-safe designs should be considered where roads are aligned across active gullies or alluvial fans.

14. Risk ratings and detailed mitigation options should be included in all phases of access from construction to deactivation. This includes culvert sizing or location, stabilization of road cuts, fills and road surface, erosion and sediment controls, and any special site- and weather-specific shut-down guidelines [over and above those outlined by Statlu (2018b)] to avoid heavy equipment trafficking and sediment production.

Riparian function

15. In accordance with the Riparian Management Area Guidebook[126], riparian reserves should be established on S1-S3 streams to avoid reduction of riparian function and to mitigate erosion and sediment delivery. For S4, S5, and S6 streams, retention of mature overstory and nonmerchantable timber is recommended within their respective riparian management zones.

16. Based on recommendations from Hudson and D'Anjou (2001), in areas subject to a partial harvest silviculture system, trees adjacent to S6 streams with a high windthrow potential should be removed to mitigate the potential for increased sedimentation as a result of blowdown. Moreover, windthrow assessments will be increasingly important if projections for more intense windstorms materialize.

---

[126] https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture/silvicultural-systems/silviculture-guidebooks/riparian-management-area-guidebook

Pollutants

17. To avoid water contamination, we recommend that all forest development activities follow strict adherence to BCTS EMS and EFPs for the appropriate fuel storage & securing, dispensing, transportation, spill prevention and response measures, including specific restrictions within riparian management (or reserve) zones.

Site Level Recommendations

18. Inge Creek currently flows along Reed Road in a ditch that has evidence of downcutting and scour. The creek originally did not flow along this stream alignment, but was established in the 1990s post-flooding by a property owner. To mitigate for erosion along Reed Road and reduce the potential for sedimentation downstream, control measures should be considered for the ditch.

19. The following site level recommendations are identified from TABLE 7.1. Should these recommendations not fall within BCTS Chart area or are beyond BCTS' authority, we recommend that BCTS inform the appropriate party of the issues identified below.

    Chaster Creek:

    - Recommend clearing the large woody debris noted at the inlet of 900 mm diameter culvert at the Highway 101 crossing (#70) along Shirley Creek near stream km 2.50.

    Higgs Brook

    - Bank protection is recommended near stream km 0.10 to prevent loss or damage to the undermined utility building and potential stream impacts.

    Slater Creek

    - Recommend clearing the large woody debris noted at the inlet of 1,200 mm diameter culvert at the Lower Road crossing (#71) along Slater Creek near stream km 0.25.
    - Recommend a review of culvert capacity at the Porter Road crossing (#38) along Slater Creek near stream km 1.40.
    - Recommend a review of culvert capacity at the Conrad Road crossing (#37) along Slater Creek near stream km 1.55.

    Clough Creek

    - Recommend a review of structural stability of the retaining wall at the culvert inlet at Lower Road crossing (#25) along Clough Creek near stream km 0.30.
    - Recommend stabilization of road fill and review of culvert capacity for the 900 mm diameter culvert located at the Highway 101 crossing (#24) along Clough Creek near stream km 0.90.

10. REFERENCES

Abatzoglou, J. T., Rupp, D. E., & Mote, P. W. (2014). Seasonal climate variability and change in the Pacific Northwest of the United States. Journal of Climate, 27(5), 2125-2142.

Advisian (Worely Parsons Canada). 2019. Stage 1 Foundational Mapping, Hope, Morseby Island, Sunshine Coast, and Ucluelet, BC. Unpublished report completed for the Ministry of Environment and Climate Change Strategy.

Ahmed, A. 2017. Inventory of Streamflow in the South Coast and West Coast Regions. BC Ministry of Environment and Climate Change Strategy, Knowledge Management Branch, Victoria, BC.

Alila, Y., P.K. Kuras, M. Schnorbus and R. Hudson. 2009. Forests and floods: A new paradigm sheds light on age-old controversies. Water Resources Research, 45, W08416.

Alila, Y., & Green, K. C. (2014). Reply to comment by Bathurst on "A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments". Water Resources Research, 50(3), 2759-2764.

Austin, S.A. 1999. MSc Thesis: Streamflow response to forest management: a meta-analysis using published data and flow duration curves. Colorado State University.

Beaudry, P.G. 2013. Assessment and assignment of sensitivity ratings to sub-basins of the Anzac Watershed in the Parsnip Drainage – Omineca Region. Prepared for BC Ministry of Forests, Lands and Natural Resource Operations.

Bilby, R. E., Sullivan, K., & Duncan, S. H. (1989). The generation and fate of road-surface sediment in forested watersheds in southwestern Washington. Forest Science, 35(2), 453-468.

Birkinshaw, S. J. 2014. Comment on ''A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments'' by Kim C. Green and Younes Alila, Water Resources Research, 50.

Bradford, M.J. and Heinonen, J.S. 2008. Low flows, instream flow needs and fish ecology in small streams. Canadian Water Resources Journal, 33 (2): 165 – 180.

British Columbia Ministry of Environment (BC MOE). 2016. Indicators of Climate Change for British Columbia, 2016 Update. Ministry of Environment, British Columbia, Canada.

British Columbia Ministry of Forests (BC MOF). 1999. Coastal watershed assessment procedure guidebook (CWAP). Interior watershed assessment procedure guidebook (IWAP). 2nd Ed, Ver. 2.1, Victoria, Forest Practices Code of B.C. Guidebook.

British Columbia Ministry of Water, Land and Air Protection (BC MWLAP). 2002. A Guidebook for British Columbia Stormwater Planning.

BC Ministry of Water, Land and Air Protection (BC MWLAP). 2002. Indicators of Climate Change for British Columbia.

Blum, A. G., Ferraro, P. J., Archfield, S. A., & Ryberg, K. R. (2020). Causal effect of impervious cover on annual flood magnitude for the United States. Geophysical Research Letters, 47(5). e2019GL086480. https://doi.org/10.1029/2019GL086480

Burn, D.H., R. Mansour, K. Zhang and P.H. Whitfield. 2011. Trends and variability in extreme rainfall events in British Columbia. Canadian Water Resources Journal, Vol 36(1): 67-82. https://www.tandfonline.com/doi/pdf/10.4296/cwrj3601067

Burn, D. H., & Whitfield, P. H. (2023). Climate Related Changes to Flood Regimes Show an Increasing Rainfall Influence. Journal of Hydrology, 129075.

Carson, B. 2020. A review of Whitaker Creek ravine failure that occurred on February 1, 2020 in Roberts Creek. Unpublished manuscript.

Carson, B. and M. Younie. 2003. Managing coastal forest roads to mitigate surface erosion and sedimentation: An operational perspective. Streamline Watershed Management Bulletin.

Cavanagh, N., R.N. Nordin, L.W. Pommen, and L.G. Swain. 1998. Guidelines for interpreting water quality data. B.C. Ministry of Environment, Lands and Parks, Water Management Branch, Victoria, BC.

Chapman Geoscience Ltd. (Chapman). 2003. Long-term effects of Forest Harvest on Peak Streamflow Rates in Coastal BC Rivers. Prepared for Forestry Innovation Investment, Vancouver, BC. March 31, 2003

Copeland, R.R., D.S. Biedenharn and J.C. Fischenich. 2000. Channel-forming discharge. US Army Corps of Engineers, ERDC/CHL CHETN-WII-5, December 2000. https://apps.dtic.mil/dtic/tr/fulltext/u2/a604706.pdf

Cui, Y., Miller, D., Schiarizza, P., and Diakow, L.J. 2019. British Columbia digital geology. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2017-8, 9p. https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology

Delcan. 2009. Integrated Stormwater Management Planning, Phase 2. Prepared for BC Ministry of Transportation and the Sunshine Coast Regional District. February 13, 2009.

Dhakal, A. S., & Sidle, R. C. (2004). Pore water pressure assessment in a forest watershed: simulations and distributed field measurements related to forest practices. Water Resources Research, 40(2).

Doyle, J. 2013. Integrating environmental tracers and groundwater flow modeling to investigate groundwater sustainability, Gibsons, BC. M.Sc. thesis, The University of British Columbia.

Eaton, B. and Moore, R.D. 2010. Chapter 4: Regional Hydrology. In: Pike, R.G. et al. (eds.) Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range Research Branch, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66, 85-110.

Ecosystems Working Group. (1998). Standards for terrestrial ecosystem mapping in British Columbia. Resources Inventory Committee, Government of British Columbia. Victoria, BC. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/tem_man.pdf

Emergex Planning Inc. (Emergex). 2005. Hazard risk and vulnerability analysis for the Sunshine Coast Regional District. https://www.scrd.ca/files/File/Community/EmergencyOps/HRVA%20SCRD_FINAL.pdf

Engineers and Geoscientists British Columbia and Association of British Columbia Forest Professionals (EGBC and ABCFP). 2020. Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector. Version 1.0, January 14, 2020. https://www.egbc.ca/getmedia/8742bd3b-14d0-47e2-b64d-9ee81c53a81f/EGBC-ABCFP-Watershed-Assessment-V1-0.pdf.aspx

Floyd, W.C. 2012. Snowmelt energy flux recovery during rain-on-snow in regenerating forests. PhD thesis, The University of British Columbia.

Forest Practices Board (FPB). 2006. BCTS Logging at Roberts Creek, Complaint Investigation 050653, FPB/IRC/117, May 2006.

Gillett, N. P., Cannon, A. J., Malinina, E., Schnorbus, M., Anslow, F., Sun, Q., ... & Castellan, A. (2022). Human influence on the 2021 British Columbia floods. Weather and Climate Extremes, 36, 100441.

Grant, G.E., S.L. Lewis, F.J. Swanson, J.H. Cissel, and J.J. McDonnell. 2008. Effects of Forest Practices on Peak Flows and Consequent Channel Response: A State-of-Science report for Western Oregon and Washington. USDA, Forest Service, Pacific Northwest Research Station, General Technical report PNW-GTR-760. May 2008.

Gray, A. N., Spies, T. A., & Easter, M. J. (2002). Microclimatic and soil moisture responses to gap formation in coastal Douglas-fir forests. Canadian Journal of Forest Research, 32, 332–343.

Green, K. 2015. Impacts of forest harvesting on stream channel stability in snowmelt regions. Forests and Water Workshop, Kelowna, BC, November 17, 2015.

Green, K. 2005. A Qualitative Hydro-Geomorphic Risk Analysis for British Columbia's Interior Watersheds: A Discussion Paper. Streamline Watershed Management Bulletin, Vol. 8, No. 2, Spring 2005. http://forrex.org/sites/default/files/publications/articles/streamline_vol8_no2_art4.pdf

Green, K.C. and Alila, Y. 2012. A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments. Water Resources Research, 48: W10503.

Green, R.N. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. Land Management Handbook Number 28. Ministry of Forests, Research Program. https://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh28.htm

Halofsky, J. S., Donato, D. C., Franklin, J. F., Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2018). The nature of the beast: examining climate adaptation options in forests with stand-replacing fire regimes. Ecosphere, 9(3), e02140.

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. Fire Ecology, 16(1), 1-26.

Hatcher, K.L., and Jones, J.A. 2013. Climate and streamflow trends in the Columbia River Basin: Evidence for ecological and engineering resilience to climate change. Atmosphere-Ocean, 1 – 20.

Hetherington, E.D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek Experimental Watershed. In Proc. Carnation Creek Workshop, a 10-year Review. G. Hartman (editor). Pac. Biolog. Sta., Nanaimo, B.C., pp. 45–62.

Heatherington, E. D. 1998. Watershed hydrology. In Carnation Creek and Queen Charlotte Islands fish/forestry workshop: Applying 20 years of coastal research to management solutions. D.L. Hogan, P.J. Tschaplinski, and S. Chatwin (editors). BC Ministry of Forests, Victoria, BC. pp. 33–40.

Hicks, B.J., R.L. Beschta and R.D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin, 27(2), 217-226.

Holland, S.S. 1976. Landforms of British Columbia, A Physiographic Outline. Bulletin 48.

Horel, G. 2006. Defining Active Fluvial Units. Ostapowich Engineering Services Ltd., April 1, 2006.

Horel, G. 2012. Wilson Creek Watershed Assessment. G. M. Horel Engineering. Prepared for Sechelt Community Projects Inc. August, 2012.

Hudson, R. 2000a. Snowpack recovery in regenerating coastal British Columbia clear-cuts. Canadian Journal of Forest Research, 30(4): 548-556.

Hudson, R. 2000b. Assessing snowpack recovery of watersheds in the Vancouver Forest Region. Forest Research Technical Report, TR-004, Hydrology. Vancouver Forest Region, Nanaimo, BC, November 2000.

Hudson, R. 2001. Roberts Creek Study Forest: Preliminary effects of partial harvesting on peak streamflow in two S6 creeks. Forest Research Extension Note EN-007. 1-9.

Hudson, R. 2002. Effects of forest harvesting and regeneration of peak streamflow in a coastal watershed. Forest Research Technical Report TR-022, Vancouver Forest Region, Nanaimo, BC. March 2002.

Hudson, R. 2003. Using combined snowpack and rainfall interception components to assess hydrologic recovery of a timber-harvested site: Working towards an operational method. Research Section, Vancouver Forest Region, BC Ministry of Forests. Nanaimo, BC. Technical Report TR-027. 38 pp.

Hudson, R., & Anderson, A. 2006. Russell Creek: Summary of research and implications for professional practice. Research Section, Coast Forest Region, BCMOF, Nanaimo, BC. Extension Note EN-022.

Hudson, R., & Tolland, L. (2002). Roberts Creek Study Forest: effects of partial retention harvesting on nitrate concentrations in two S6 creeks three years after harvesting. Nanaimo, BC: Vancouver Forest Region, Research Section.

Hudson, R. O., & D'Anjou, B. (2001). Roberts Creek Study Forest: the effects of shelterwood harvesting and blowdown on sediment production in a small zero-order creek. Vancouver Forest Region.

Hudson, R. and G. Horel. 2007. An operational method of assessing hydrologic recovery for Vancouver Island and south coastal BC. BC Forest Service, Nanaimo, BC, Forest Research Technical Report No. TR-032.

International Organization for Standardization (ISO). 2010, reaffirmed 2015. Risk management – Principles and guidelines. CAN/CSA-ISO 31000-10. Canadian Standards Association. National Standard of Canada.

Islam, S.U., Curry, C.L., Déry, S.J., and Zweirs, F.W. 2019. Quantifying projected changes in runoff variability and flow regimes of the Fraser River Basin, British Columbia. Hydrology and Earth System Sciences, 23: 811-828.

Islam, S.U., Déry, S.J., and Werner, A.T. 2017. Future climate change impacts on snow and water resources of the Fraser River Basin, British Columbia. Journal of Hydrometeorology, 18: 473 – 495.

Jeong, D. I. and Sushama, L. 2018. Rain-on-snow events over North America based on two Canadian regional climate models. Climate Dynamics 50: 303-316.

Jones, J. A. (2000). Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. Water Resources Research, 36(9), 2621-2642.

Jordan, P. 2001. Sediment budgets in the Nelson Forest Region. In Towes, D.A.A. and S. Chatwin (editors). Watershed Assessment in the Southern Interior of British Columbia: Workshop

Proceedings, March 9-10, 2000, Penticton, BC, BC Ministry of Forests, Research Branch, Victoria, BC. Working paper 57, pp. 174-188.

Jordan. P. 2000. Soil erosion hazard criteria for watershed assessments in the Southern Interior. Final report, FRBC Research Award No. KB97225-0RE, February 29, 2000.

Journeay, J.M. and J.W.H Monger. 1994. Geology and crustal structure of the southern Coast and Intermontane Belts, southern Canadian Cordillera, British Columbia; Geological Survey of Canada, scale 1:500,000.

Keppler, E.T. and R.R. Ziemer. 1990. Logging effects on streamflow: Water yield and summer low flows at Caspar Creek in Northwestern California. Water Resources Research, 26 (7), pp. 1669-1679.

Kim, J., Johnson, L., Cifelli, R., Thorstensen, A., & Chandrasekar, V. (2019). Assessment of antecedent moisture condition on flood frequency: An experimental study in Napa River Basin, CA. Journal of Hydrology: Regional Studies, 26(December 2018), 100629. https://doi.org/10.1016/j.ejrh.2019.100629

Kormos, P. R., Luce, C. H., Wenger, S. J., & Berghuijs, W. R. (2016). Trends and sensitivities of low streamflow extremes to discharge timing and magnitude in Pacific Northwest mountain streams. Water Resources Research, 52(7), 4990-5007.

Leopold, L. B. 1994. A view of the river. Harvard University Press, Cambridge.

Luce, C.H. 2002. Hydrological processes and pathways affected by forest roads: what do we still need to learn? Hydrological Processes, 16: 2901-2904.

Luce, Charles H.; Black, Thomas A. 1999. Sediment production from forest roads in western Oregon. Water Resources Research. 35(8): 2561-2570.

May, C. W., Horner, R. R., Karr, J. R., Mar, B. W., & Welch, E. B. (1998). The cumulative effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. In Proceedings of the Puget Sound Research.

MacDonald, N. 2022. Months-long drought on BC's Sunshine Coast prompts water ban, climate anxiety. The Globe and Mail. Published October 18, 2022. https://www.theglobeandmail.com/canada/british-columbia/article-drought-water-restrictions-sunshine-coast/

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. U.S. Environmental Protection Agency, Seattle, Washington. Tech. Rep. EPA910-9-91-001.

Madrone Environmental Services Ltd. 2015. Hydrologic assessment: Six watersheds, southwest face of Mt. Elphinstone. Prepared for BCTS Strait of Georgia Business Area. March 31, 2015.

Maloney, D., B. Carson, S Chatwin, M. Carver, P. Beaudry and S. Bleakley. 2018. Protocol for Evaluating the Potential Impact of Forestry and Range Use on Water Quality (Water Quality Effectiveness Evaluation). Forest and Range Evaluation Program, B.C. Min. Forest Range and Natural Resource Operations and B.C. Min. Env., Victoria, BC.

Marks, D., Kimball, J., Tingey, D., & Link, T. (1998). The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: A case study of the 1996 Pacific Northwest flood. Hydrological Processes, 12(10-11), 1569– 1587.

Marks, D., Link, T., Winstral, A., & Garen, D. (2001). Simulating snowmelt processes during rain-on-snow over a semi-arid mountain basin. Annals of Glaciology, k32, 195-202. doi:10.3189/172756401781819751

McCammon, J.W., 1977. Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River, and Campbell River Areas, Bulletin 65. Ministry of Mines and Petroleum Resources, Victoria, BC.

Montgomery, D.R. and Buffington, J.M. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin. vol. 109(5): 596-611.

Montgomery, D.R. and J.M. Buffington. 1998. Channel processes, classification, and response. In: River Ecology and Management, Naiman R. and R. Bilby (editors). Springer-Verlag New York Inc.

Montgomery, D.R., B.D. Collins, J.M. Buffington and T.B. Abbe. 2003. Geomorphic Effects of Wood in Rivers. American Fisheries Society Symposium.

Moore, G. W. (2004). Drivers of variability in transpiration and implications for stream flow in forests of Western Oregon. Oregon State University.

Moore, R.D., and Wondzell, S.M. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: A Review. Journal of the American Water Resources Association, 41 (4): 763 – 784.

Murdock, T.Q., S.R. Sobie, H.D. Eckstrand, and E. Jackson, 2012, revised April 2016: Georgia Basin: Projected Climate Change, Extremes, and Historical Analysis, Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 63 pp.

Musselman, K.N., Clark, M.P., Liu, C., Ikeda, K., and Rasmussen, R. 2017. Slower snowmelt in a warmer world. Nature Climate Change, 7: 214 – 220.

Nelson, H., K. Day, S. Cohen, D. Moore, and N. Hotte. 2012. Adapting to Climate Change in the San Jose Watershed. Department of Forest Resource Management, UBC, July 2012.

National Oceanic and Atmospheric Administration (NOAA). 2020a. Historical El Nino / La Nina episodes (1950-present), National Weather Service, National Centers for Environmental Prediction, Climate Prediction Center. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

National Oceanic and Atmospheric Administration (NOAA). 2020b. Pacific Decadal Oscillation (PDO). National Centers for Environmental Information. https://www.ncdc.noaa.gov/teleconnections/pdo/

National Research Council of Canada (NRCC). 1989. Hydrology of Floods in Canada, A Guide to Planning and Design. Ottawa, Ontario.

Newcombe, C.P. 2003. Impact assessment model for clear water fishes exposed to excessively cloudy water. Journal of the American Water Resources Association, 39 (3), 529-544.

Pacific Climate Impacts Consortium (PCIC). 2013. Climate Summary for: South Coast Region. November 2013. University of Victoria. https://pacificclimate.org/sites/default/files/publications/Climate_Summary-South_Coast.pdf

Pacific Climate Impacts Consortium (PCIC). 2017. PCIC Science Brief: The evolution of snowmelt and drought. University of Victoria.

Pacific Climate Impacts Consortium (PCIC). 2021. Plan2Adapt. https://services.pacificclimate.org/plan2adapt/app/

Perry, T.D. and Jones, J.A. 2017. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. Ecohydrology, 10 (2): 1 – 13.

Pike, R. et al. 2010a. Chapter 7: The Effect of Forest Disturbance on Hydrologic Processes and Watershed Response. In: Pike, R.G. et al. (eds.) Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range Research Branch, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66, 179-212.

Pike, R. et al. 2010b. Chapter 9: Forest Management Effects on Hillslope Processes. In: Pike, R.G. et al. (eds.) Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range Research Branch, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66, 275-329.

Pike, R. et al. 2010c. Chapter 12: Water Quality and Forest Management. In: Pike, R.G. et al. (eds.) Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range Research Branch, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66, 179-212.'

Pike, R., & Scherer, R. (2003). Overview of the potential effects of forest management on low flows in snowmelt-dominated hydrologic regimes. Journal of Ecosystems and Management.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E. and Stromberg J.C. 1997. The natural flow regime. BioScience, 47 (11): 769–784

Polar Geoscience Ltd. (Polar). 2022. Watershed Risk Management Framework, Guidance Document, Revision 1.0. Prepared for BC Timber Sales, Chinook and Strait of Georgia Business Areas. Polar File No. 741001/741002. March 2022.

Pomeroy, J. W., Fang, X., and Marks, D.G. 2016. The cold rain-on-snow event of June 2013 in the Canadian Rockies – characteristics and diagnosis. Hydrological Processes, doi: 10.1002/hyp.10905.

Prichard, S. J., Hessburg, P. F., Hagmann, R. K., Povak, N. A., Dobrowski, S. Z., Hurteau, M. D., ... & Khatri-Chhetri, P. (2021). Adapting western North American forests to climate change and wildfires: 10 common questions. Ecological applications, 31(8), e02433.

Prosdocimi, I., T. R. Kjeldsen, andJ. D. Miller (2015), Detection and attribution of urbanization effect on flood extremes using nonstationary flood-frequency models, Water Resources Research, 51, 4244–4262, doi:10.1002/2015WR017065.

Province of British Columbia. 2022a. Water Rights Licences – Public. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/water-rights-licences-public

Province of British Columbia. 2022b. Groundwater Wells. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/groundwater-wells

Province of British Columbia. 2022c. Known BC Fish Observations and BC Fish Distributions. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/known-bc-fish-observations-and-bc-fish-distributions

Province of British Columbia. 2022d. Fire Perimeters – Historical. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical#edc-pow

Province of British Columbia. 2022e. Pest Infestation Polygons. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/pest-infestation-polygons

Province of British Columbia. 2022f. Hydrometric Stations - Active and Discontinued. Spatial data downloaded from DataBC. https://catalogue.data.gov.bc.ca/dataset/hydrometric-stations-active-and-discontinued#edc-pow

Province of British Columbia. 2018. Forest Planning and Practices Regulation, B.C. Reg. 14/2004 (including amendments up to B.C. Reg. 41/2016, February 29, 2016). http://www.bclaws.ca/Recon/document/ID/freeside/14_2004#section1

Reid, L. M., & Dunne, T. (1984). Sediment production from forest road surfaces. Water Resources Research, 20(11), 1753-1761.

Reid, D. A., Hassan, M. A., & Floyd, W. (2016). Reach-scale contributions of road-surface sediment to the Honna River, Haida Gwaii, BC. Hydrological Processes, 30(19), 3450-3465.

Rong, W. (2017). Revealing forest harvesting effects on large peakflows in rain-on-snow environment with new stochastic physics (Master of Science Thesis, University of British Columbia). August, 2017.

Ryder, J., B. Thomson and I. Cotic. 1980. Terrain Inventory Mapping, Sechelt. BC Ministry of Environment. 1:50,000 scale.

Segura, C., Bladon, K. D., Hatten, J. A., Jones, J. A., Hale, V. C., & Ice, G. G. (2020). Long-term effects of forest harvesting on summer low flow deficits in the Coast Range of Oregon. Journal of Hydrology, 585, 124749.

Sharma, A. R., & Déry, S. J. (2020). Variability and trends of landfalling atmospheric rivers along the Pacific Coast of northwestern North America. International Journal of Climatology, 40(1), 544-558.

Schardong, A., S. P. Simonovic, A. Gaur, and D. Sandink. 2020. Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate at Gauged and Ungauged Locations, Water, Special Issue Extreme Value Analysis of Short-Duration Rainfall and Intensity–Duration–Frequency Models, 12, 1243; doi:10.3390/w12051243, open access, https://www.mdpi.com/2073-4441/12/5/1243/pdf

Schnorbus, M. and Alila, A. 2004. Forest harvesting impacts on the peak flow regime in the Columbia Mountains of southeastern British Columbia: An investigation using long-term numerical modeling. Water Resources Research, 40: W05205.

Smerdon, B.D., T. Redding and J. Beckers. 2009. An overview of the effects of management on groundwater hydrology. BC Journal of Ecosystems and Management, 10(1): 22-44. https://jem-online.org/index.php/jem/article/view/409

Smakhtin, V.U. 2001. Low flow hydrology: a review. Journal of Hydrology (240): 147 – 186.

Sobie, S.R. 2020. Future changes in precipitation-caused landslide frequency in British Columbia. Climate Change, 162: 465-484. https://doi.org/10.1007/s10584-020-02788-1.

Spies, T. A., & Franklin, J. F. (1991). The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. Wildlife and vegetation of unmanaged Douglas-fir forests, 91-109.

Statlu Environmental Consulting (Statlu). 2018a. Terrain stability, sedimentation, and hydrologic hazard assessment, Block G043C3ZD, Mt. Elphnstone/Gibsons. Prepared for BC Timber Sales, Chinook Business Area, Sunshine Coast Natural Resource District.

Statlu Environmental Consulting (Statlu). 2018b. Wet Weather Shutdown Criteria Harmonization. Prepared for BC Timber Sales, Chinook and Strait of Georgia Business Area. March 15, 2018.

Stednick, J.D. 1991. Wildland water quality sampling and analysis. Academic Press, San Diego, California.

Stednick. J.D. and Troendle, C.A. 2016. Chapter 12: Hydrological effects of forest management. In: Amatya, D.M., Williams, T.M., Bren, L. and de Jong, C. (Eds.) Forest Hydrology: Processes, Management, and Assessment. CAB International. Boston, M.A.

Stephens, K.A., P. Graham, and D, Reid. 2002. Stormwater Planning, A Guidebook for British Columbia. https://www2.gov.bc.ca/assets/gov/environment/waste-management/sewage/stormwater_planning_guidebook_for_bc.pdf.

Storck, P., D. P. Lettenmaier, and S. M. Bolton. 2002. Measurement of snow interception and canopy effects on snow accumulation and melt in a mountainous maritime climate, Oregon, United States, Water Resour. Res., 38(11), 1223, doi:10.1029/2002WR001281.

Surfleet, C.G. and A.A. Skaugset. 2013. The effect of timber harvest on summer low flows, Hinkle Creek, Oregon. Western Journal of Applied Forestry, 28(1), pp. 13-21.

Sunshine Coast Regional District (SCRD) and Fisheries and Oceans Canada (DFO). 2021. Sunshine Coast Habitat Atlas. https://cmnmaps.ca/SCRD/

Tripp, D.B., P.J. Tschaplinski, S.A. Bird and D.L. Hogan. 2022. Protocol for Evaluating the Condition of Streams and Riparian Management Areas (Riparian Management Routine Effectiveness Evaluation). Version 6.1. Revised by D. McGeough and L.J. Nordin. Forest and Range Evaluation Program, B.C. Ministry of Forests, Range, Natural Resource Operations and Rural Development.

Trubilowicz, J.W. and Moore, R.D. 2017. Quantifying the role of the snowpack in generating water available for run-off during rain-on-snow events from snow pillow records. Hydrological Processes, 31: 4136-4150.

Urbonas, B.R. and Roesner, L.A. 1993. Chapter 28 – Hydrologic design for urban drainage and flood control. In Handbook of Hydrology, D.R. Maidment (ed.), McGraw-Hill, Inc. pp. 28.1-28.52.

van Heeswijk, M., Kimball, J.S., and Marks, D. 1996. Simulation of water available for runoff in clearcut forest openings during rain-on-snow events in the western Cascade Range of Oregon and Washington. U.S. Geological Survey. Water-Resources Investigations Report 95-4219.

Van Meerveld, H. J., Baird, E. J., & Floyd, W. C. (2014). Controls on sediment production from an unpaved resource road in a Pacific maritime watershed. Water Resources Research, 50(6), 4803-4820.

Villarini, G., Smith, J. A., Serinaldi, F., Bales, J., Bates, P. D., & Krajewski, W. F. (2009). Flood frequency analysis for nonstationary annual peak records in an urban drainage basin. Advances in water resources, 32(8), 1255-1266.

Wang, Shanshan, Jianping Huang, Yongli He and Yuping Guan. 2014. Combined effects of the Pacific Decadal Oscillation and El Nino-Southern Oscillation on Global Land Dry-Wet Changes. Scientific Reports, 4: 6651, DOI: 10.1038/srep06651.

Wang, T., A. Hamann, and D. Spittlehouse. 2022. ClimateBC_v7.30. A program to generate climate normal, annual, seasonal and monthly data for genecology and climate change studies in Western North America (WNA) region. Department of Forest Sciences, University of British Columbia.

Waterline Resources Inc. (Waterline). 2013. Aquifer Mapping Study, Town of Gibsons, British Columbia. Submitted to Town of Gibsons, May 13, 2013, WL09-1578.

Western University. 2021. IDF_CC Tool 3.5: Computerized tool for the development of intensity-duration-frequency curves under climate change. Version 3.5. Available from: https://www.idf-cc-uwo.ca/home

Whitaker, A., Alila, Y. and Beckers, J. 2002. Evaluating peak flow sensitivity to clear-cutting in different elevation bands of a snowmelt-dominated mountainous catchment. Water Resources Research, 38(9): 1172.

Winkler, R. and Boon, S. 2017. Equivalent clearcut area as an indicator of hydrologic change in snow-dominated watersheds of southern British Columbia. Exten Note 118. https://www.for.gov.bc.ca/hfd/pubs/docs/en/EN118.pdf

Winkler, R. and S. Boon. 2015. Revised snow recovery estimates for pine-dominated forests in Interior British Columbia. Province of BC, Victoria, BC, Extension Note 116. https://www.for.gov.bc.ca/hfd/pubs/docs/en/EN116.pdf

Winkler, R.D., Moore, R.D., Redding, T.E., Spittlehouse, D.L., Smerdon, B.D., and Carlyle-Moses, D.E. 2010b. Chapter 7: The Effects of Forest Disturbance on Hydrologic Processes and Watershed Response. In: Pike, R.G. et al. (eds.) Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range Research Branch. 179 – 212.

Wise, M.P., G.D. Moore, and D.F. VanDine (editors). 2004. Landslide risk case studies in forest development planning and operations. B.C. Ministry of Forests, Research Branch, B.C. Land Management Handbook No. 56. https://www.for.gov.bc.ca/hfd/pubs/docs/lmh/lmh56.htm

Wemple, B.C. and J.A. Jones. 2003. Runoff production on forest roads in a steep mountain catchment. Water Resources Research, 39 (8), pp. 1-17.

Wemple, B., Swanson, F.J., and Jones, J.A. 2001. Forest roads and geomorphic process interactions, Cascade Range, Oregon. Earth Surface Processes and Landforms, 26: 191-204.

Wondzell, S.M. and J.G. King. 2003. Postfire erosional processes in the Pacific Northwest and Rocky Mountain Regions. Forest Ecology and Management, 178, 75-87.

Yu, X.J. and Y. Alila. 2019. Nonstationary frequency pairing reveals a highly sensitive peak flow regime to harvesting across a wide range of return periods. Forest Ecology and Management, 444 (15), pp. 187-206.

Zwiers, F. W., Schnorbus, M. A., & Maruszeczka, G. D. (2011). Hydrologic impacts of climate change on BC water resources. Summary Report for the Campbell, Columbia and Peace River Watersheds, Pacific Climate Impacts Consortium, University of Victoria, Victoria BC.

APPENDIX A: DEFINITIONS

ABCFP	Association of British Columbia Forest Professionals
Active Fluvial Units (AFUs)	The portion of a floodplain which water can be expected to flow during a runoff event of magnitude 1 in 100 years or more and that portion of an alluvial fan on which there is evidence of active hydrogeomorphic processes such as naturally occurring fluvial erosion or evidence of mass wasting. AFUs should be expected to occur on portions of all streams > 1.0 m stream channel width.
Adaptive Management Plan (AMP)	A monitoring or research initiative that is developed and implemented during operational planning, timber harvesting, silvicultural treatment, or road construction, including maintenance and deactivation phases, to examine the outcomes of management strategies and practices that vary from default legislative requirements, the results of which will inform the development of future management strategies and practices.
Agreement Holder	The holder of an agreement under British Columbia's Forest Act or Range Act.
Alluvial fan	A conical deposit of stream-derived sediment that is formed where stream gradient decreases and stream channels become laterally unconfined. These can exist either mid-slope or near the mouth of a stream.
Assurance Statement	A declaration by a Specialist assuring that the Specialist's work meets the intent and direction as provided by Joint Professional Practices Guidelines and a forest licensee's Watershed Risk Management Framework.
Bare Ground	All land surface not covered by vegetation, rock, or litter.
BC Timber Sales Program	An independent organization within the BC Ministry of Forests, Lands and Natural Resource Operations, created to develop Crown timber for auction. BCTS was founded in 2003 with a mandate to provide the cost and price benchmarks for timber harvested from public land in British Columbia. Through 12 Business Areas and an operational presence in 33 locations, BCTS manages some 20 percent of the provincial Crown allowable annual cut.
Bedload	Bedload is a term used to describe particles in a stream that are being carried or transported along the streambed.
Biogeoclimatic Classification System	A hierarchical classification system of ecosystems that integrates regional, local and chronological factors and combines climatic, vegetation and site factors.
Biogeoclimatic Unit	Part of the biogeoclimatic ecosystem classification system. Recognized biogeoclimatic units are a synthesis of climate, vegetation and soil data and are defined as "classes of geographically related ecosystems that are distributed within a vegetationally inferred climatic space."
Biogeoclimatic (BEC) Zone (and Subzone)	A BEC zone is a geographic area having similar patterns of energy flow, vegetation and soils, as a result of a broadly homogenous macroclimate. A BEC subzone is a unit with less climatic variability and a narrower geographic distribution than the zone. Subzones are distinguished by a unique composition of plant species. They are climatically based and represent precipitation and temperature regimes.
Blowdown (Windthrow)	Uprooting by the wind. Also refers to a tree or trees so uprooted.
Blue List Species	Species of special concern (formerly called "vulnerable") in British Columbia. These species are not immediately threatened, but are of concern because of characteristics that make them particularly sensitive to human activities or natural events.
Bog	A class of wetland characterized by a thick layer of sphagnum-based peat. It receives its water primarily from direct precipitation. Bog waters tend to be acidic and nutrient-poor.
Canopy Cover	The percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings within the canopy are included, and coverage may exceed 100 percent.
Channel	The stream banks and stream bed formed by fluvial processes.
Channel Bed	The bottom of the stream below the usual water surface. Beds contain sediments deposited by moving water, such as rocks, sand, gravel and sediment.

Channel Sensitivity (Channel Response Potential)	The inherent susceptibility of a stream channel to changes in discharge and sediment supply. The response of a channel may include changes in bed texture (e.g., grain size), geometry (i.e., width, depth, slope), planform (e.g., sinuosity), and/or bedforms (e.g., pools). Such potential responses have potential direct impacts on water quality, water supply infrastructure, and fish and fish habitat.
Clearcut	An area of forestland from which all merchantable trees have recently been harvested.
Climate	The average weather conditions of a place over many years.
Climate Change	An alteration within the climate system that departs significantly from previous average conditions and is seen to endure, bringing about corresponding changes in ecosystems and socio-economic activity.
Consequence	The effect on human well-being, property, the environment, or other things of Value, or a combination of these. Consequence can be certain or uncertain and have positive or negative effects. Most commonly, consequence is considered to be the change, loss, or damage to risk elements caused by a harmful event such as a flood or landslide.
Colluvium	Unconsolidated sediments deposited at the base of hillslopes. Colluvium is transported by hillslope processes and may range in size from silt to boulders.
Community Watershed	The drainage area above the most downstream point of diversion on a stream for which the water is for human consumption, and which is licensed under the *Water Act* for (i) a waterworks purpose, or (ii) a domestic purpose if the licence is held by, or is subject to, the control of a water users' community as incorporated under the *Water Act*. Community watersheds are designated under the Government Actions Regulation. To protect the water that is diverted for human consumption, such areas require special management to: conserve the quality, quantity and timing of water flow and prevent cumulative hydrological effects having a material adverse effect on water. There are currently 466 designated community watersheds in B.C. with most established in the 1980s and 1990s.
Control Measure	Actions and/or activities that are taken to prevent, eliminate or reduce the occurrence of an identified hazard.
Coupled Hillslope (Hillslope-stream coupling)	A channel is considered coupled to a hillslope when sediment mobilized on the hillslope by landslide activity directly enters the stream channel. Sediment delivery to coupled reaches is dominated by landslides, while sediment movement through the reach is by debris flow and fluvial processes. Channel gradient is typically >5 per cent. Coupled reaches are identified by the following indicators: • There is no valley flat; sediment or debris mobilized by landslides directly enters the stream channel; • The surrounding slopes are steep and likely to initiate landslides that can transfer sediment directly to the stream channel; • The channel is small relative to the volume of sediment and debris that may be transferred from the surrounding hillslopes; and • Debris flows may be initiated from within the reach.
Cross Ditch	A ditch excavated across the road at an angle and at a sufficient depth, with armouring as appropriate, to divert both road surface water and ditch water off or across the road.
Crown forested land base (CFLB)	The CFLB is the area of productive forested Crown land in a defined area. It does not include private land, non-forested areas like alpine, lakes, roads, or non-productive forest like brush. A proportion of old-growth targets can be located within the forested portion of parks, ecological reserves and other areas managed by the Crown. Within the CFLB, the area or amount of old-growth can be identified or located in constrained or inaccessible areas within the unit area to which the order applies, up to the target stated for each biogeoclimatic variant.
Crown Land	Land that is owned by the government of Canada or the province of British Columbia.
Crown Range	Crown land included within the boundaries of a range district, but does not include Crown land that is subject to a lease issued under the *Land Act*.

Culvert	A culvert is one or more pipes, pipe arches, or structures below the road surface, used to let water flow from one side of the road to the other.
Cumulative Effects	Cumulative effects are changes to environmental, social and economic values caused by the combined effect of past, present and potential future human activities and natural processes.
Cutblock	A specific area of land with defined boundaries, authorized for harvest.
Cutslope	The face of an excavated bank required to lower the natural ground line to the desired road profile.
Deactivation	Measures taken to stabilize roads and logging trails during periods of inactivity, which include control of drainage, removal of sidecast where necessary, and re-establishment of vegetation in preparation for permanent deactivation.
Debris	Wood and other organic materials typically mixed with mineral soils resulting from mass-wasting events which can be delivered to stream channels and the aquatic environment
Deleterious substance (as defined by Fisheries Act)	"A substance or water containing substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it degrades or alters water quality to the detriment of fish, fish habitat or use by man of fish found in the receiving water"
Domestic Water Intake	A domestic water intake is the point at which water is diverted from a stream for domestic purposes (e.g., human consumption, food preparation or sanitation and household purposes).
Dynamic Channel Equilibrium	A state of balance resulting from the interplay of four basic factors (sediment discharge, sediment particle size, streamflow, and channel gradient) that maintains alluvial stream channels in their most efficient and least erosive form. The term "dynamic" is important, as the energy of a stream is always at work sustaining or re-establishing its equilibrium condition. Land-use effects at site-specific or watershed scales can upset the dynamic equilibrium thereby triggering a process of stream adjustments. If one of the four factors change, one or more of the other variables must increase or decrease proportionally if equilibrium is to be maintained. For example, if channel gradient is increased (e.g., by channel straightening) and streamflow remains the same, either the sediment load or the size of the particles must also increase. Likewise, if flow is increased (e.g., by upslope forest cover removal) and the channel gradient stays the same, sediment load or sediment particle size has to increase to maintain channel equilibrium. Under these examples' conditions, a stream seeking a new equilibrium will tend to erode more of its banks and bed, transporting larger particle sizes and a greater sediment load. Such stream adjustments may be undesirable, particularly where they affect downstream elements-at-risk.
EGBC	The Association of Professional Engineers and Geoscientists of the Province of British Columbia, also operating as Engineers and Geoscientists BC.
Engineering/Geoscience Professional	Professional engineers, professional geoscientists, and licensees[127], who are registered or licensed by Engineers and Geoscientists BC and entitled under the Engineers and Geoscientist Act to engage in the practice of professional engineering or professional geoscience in British Columbia.
Element at Risk (Risk Element)	Values that are put at Risk by an identified source of harm or potential harm.
Ephemeral Drainage	An area of land where water drains away for brief, transient periods following an influx of moisture such as from localized snowmelt or heavy precipitation.
Equivalent Clearcut Area (ECA)	Equivalent clearcut area (ECA) is a commonly used index of the extent of forest disturbance and regrowth in a watershed (Winkler et al., 2010b). The ECA of a clearcut is derived by reducing the total area cut by recovery, which is estimated

---

[127] The use of the term "licensees" here means as defined in the Act.

	from relationships between snow accumulation and melt or interception of precipitation and crown closure (Winkler and Roach, 2005) or tree height (Hudson and Horel, 2007). The cumulative ECAs for all openings are summed to provide an ECA for the entire catchment (Winkler et al., 2010b).
Even-aged	A forest stand or forest type in which relatively small (10-20 years) age differences exist between individual trees. Even-aged stands are often the result of fire or a harvesting method, such as clearcutting or the shelterwood method.
Fish (as defined by Fisheries Act)	"Parts of fish; shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals; and the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals"
Fish-bearing	Lakes, streams, and ponds that have resident fish populations.
Fish Habitat (as defined by Fisheries Act)	"Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes"
Forest Management Activities	Activities carried out by Forest Professionals and others affecting forest ecosystems including, but not limited to, forest harvesting and roads; silviculture; forest wildfire prevention, suppression, and post-wildfire Risk Management; forest pathogen suppression and post-attack rehabilitation; and right-of-way clearing.
Forest Professional	Registered professional foresters, registered forest technologists, or special permit holders who are registered with or licensed by the Association of British Columbia Forest Professionals (ABCFP) and entitled under the Professional Governance Act to engage in the practice of professional forestry in British Columbia.
Framework	A written document that provides the context, scope, and standards for managing risks from forest management activities in a licensee's Chart. A framework is intended to optimize the use of organizational resources by focusing the greatest efforts on the areas of greatest concern. In managing risks to watershed values, the following principle should apply: as the severity of consequence increases, the degree of caution applied to risk management also increases.
Floodplain	An area of low-lying ground adjacent to streams that are primarily formed by stream-derived sediments and are subject to being flooded.
Fluvial	Pertaining to, or produced by, the action of a stream or river.
Forest and Ranges Practices Act (FRPA)	The Forest and Range Practices Act and its regulations govern the activities of forest and range licensees in BC. Replaced the Forest Practices Code of British Columbia Act.
Forest Licence (Forest Licensee)	A forest licence allows orderly timber harvest over a portion of a sustained yield management unit, and the timely reforestation of harvested areas according to a strategic resource management plan for each timber supply area. The licence has a term of 15 to 20 years, generally replaceable every five years (some are non-replaceable) and Charts that shift over time. A forest licence specifies an annual allowable cut, requires a management and working plan, and specified management activities.
Forest Resources	Resources and values associated with forests and range including, without limitation, soil, visual quality, timber, water, wildlife, fisheries, recreation, botanical forest products, forage, and biological diversity.
Forest Stewardship Plan (FSP)	A key planning element in the *Forest and Range Practices Act* framework and the only plan subject to public review and comment and government approval. In FSPs licensees are required to identify results and/or strategies consistent with government objectives for values such as water, wildlife and soils. These results and strategies must be measurable and once approved are subject to government enforcement. FSPs identify areas within which road construction and harvesting will occur but are not required to show the specific locations of future roads and cutblocks. FSPs can have a term of up to five years.
Free Growing	An established seedling of an acceptable commercial species that is free from growth-inhibiting brush, weed, and excessive tree competition; or young trees that are as high as or higher than competing brush, with one metre of free-growing space around their tops.

Geomorphology	The science of landforms with emphasis on their origin, evolution, form, and distribution across the physical landscape.
Geotextile Filter Fabric	A synthetic material placed on the flat, under road fill, with the primary functions of layer separation, aggregate confinement, and distribution of load.
GIS	Geographic Information System
Gully	A channel or small valley cut by concentrated, non-continuous runoff such as during snowmelt or following heavy rains.
Habitat	The place where an organism lives including the characteristics of that environment that make it especially well suited to meet the life cycle needs of that species.
Harvesting	The practice of felling and removing trees or the removal of dead or damaged trees from an area.
Hazard	A source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment, and other things of value; or some combination of these (Wise et al., 2004). Hydrologic and geomorphic processes in themselves are not hazards until they are identified as having the potential to harm a specific Value. When a hydrologic or geomorphic process has the potential to harm a Value, the process is a hazard in relation to that Value, and the Value becomes an element at risk in relation to that hazard. Note: The term hazard is sometimes used synonymously with the terms probability and likelihood of occurrence. Hazard, however, describes a harmful or potentially harmful event or situation, while probability and likelihood of occurrence describe the potential for the event or situation to occur. The interchangeable use of these terms is confusing and is discouraged.
Higher Level Plan	A resource management plan that establishes the broader, strategic context for operational plans. The objectives determine the mix of forest resources to be managed in a given area.
Hydraulicking (Hydraulic Mining)	Hydraulic mining, or hydraulicking, is a form of mining that uses high-pressure jets of water to dislodge rock material or move sediment. In the placer mining of gold, the resulting water-sediment slurry is directed through sluice boxes to remove the gold.
Hydrogeomorphic Hazards	A collective term use to describe hazards associated with hydrologic and geomorphic processes that often interact and affect the nature and characteristics of stream channels and watersheds. Examples include landslides, debris flows, debris floods, and floods.
Hydrologic Assessment	An investigation of a particular area, site, process, or event within a Watershed Unit. This type of assessment can involve a study of both hydrologic and geomorphic processes but may not include either the full scope of a Watershed Assessment or the entire area of a Watershed Unit. The objectives and scope of these assessments can vary widely, depending on the reason for the assessment.
Hydrologic Recovery	Refers to stand-scale interactions between forests and hydrologic processes, and means the extent to which a regenerating forest stand compares to a reference stand (typically a pre- disturbance stand) with respect to characteristics affecting streamflow response (rainfall interception, snowpack development, and ablation behaviour).
Hydrology	The science that deals with the waters above and below the land surfaces of the Earth; their occurrence, circulation and distribution, both in time and space; their biological, chemical, and physical properties; and their interaction with their environment.
Hydrometric	Pertaining to the measurement of components of the hydrological cycle including rainfall, flow characteristics of surface water, groundwater, and water quality.
Insolation	The amount of solar radiation that reaches the ground surface.
Interface Watershed	Watersheds that support land uses other than forestry and other resource-based industries (e.g., mining). Interface watershed may include one of more of the

	following: communities, settlements, private land, residences, commercial development, industrial operations, agriculture, public infrastructure, recreational areas.
Key watershed reporting unit	Defined as basins, sub-basins and residual areas within the Key Watersheds.
Landform	A distinct topographic feature, is three-dimensional in form, and is generally defined by ridges, valleys, shorelines, and skylines. Landform examples include hills and mountains.
Landslide	A movement of rock, debris or earth down a slope. Landslides can be a result of a natural events and/or human activities.
Licensee	An individual, company, or Provincial Crown agency that has the legal right to carry out Forest Management Activities on public or private land.
Likelihood	The chance of something happening. Likelihood is often expressed as the chance of occurrence over a given time period (ISO, 2015) using relative terms such as very low to very high or very unlikely to almost certain. Probability is a mathematical expression of likelihood. Note: If Specialists choose to use terms such as “hazard”, they should define the term as it is used in their reports. The use of the term “hazard” to mean “Likelihood” is discouraged.
Local Resource Use Plan (LRUP)	A plan approved by the district manager for a portion of the provincial forest that provides area-specific resource management objectives for integrating resource use in the area.
Major culvert	As per the *Forest and Range Practices Act (FPRA), Forest Planning and Practices Regulation (FPPR), a* "major culvert" means a stream culvert that (a) is one of the following: (i) a pipe having a diameter of 2 000 mm or greater; (ii) a pipe arch having a span greater than 2 130 mm; (iii) an open bottom arch having a span greater than 2 130 mm, or (b) has a maximum design discharge of 6 m3 per second or greater.
Managing Professional	An individual, typically a Member of ABCFP or EGBC, responsible for establishing and implementing the steps outlined in the Watershed Risk Management Framework, that addresses management of Hydrologic and Geomorphic Risks in relationship with Forest Development.
Mitigate	To take measures in advance to offset or reduce the Likelihood of negative effects; for example, distributing harvest areas with regard to aspect, elevation zone, or other factors to reduce the Likelihood that peak flow increases will occur, or to reduce the possible magnitude of peak flow increases, or to establish standard operating procedures for road construction to reduce the potential for instability or drainage problems.
Natural Resource District	A natural resource district is an administrative area established by the BC Ministry of Forest, Lands, Resource Operations and Rural development (FLNRORD) with resources and values associated with forest and range including, and without limitation to, soil, visual quality, timber, water, wildlife, fisheries, recreation, botanical forest products, forage, and biological diversity.
Objective	A concise, time-specific statement of measurable planned results that correspond to pre-established goals in achieving the desired outcome. Commonly includes information on resources to be used, forms the basis for further planning to define the precise steps to be taken, and the resources to be used and assigned responsibility in achieving the identified goals.”
Old Growth	A forest that contains live and dead trees of various sizes, species, composition, and age class structure. Old-growth forests, as part of a slowly changing but dynamic ecosystem, include climax forests but not sub-climax or mid-seral forests. The age and structure of old growth varies significantly by forest type and from one biogeoclimatic zone to another.
Old Growth Management Ara (OGMA)	Defined areas that contain, or are managed to attain, specific structural old-growth attributes and that are delineated and mapped as fixed areas.

Outslope	To shape the road surface to direct water away from the cut slope side of the road.
Overlanding	Placing road construction fill over organic soil, stumps and other plant materials, corduroy or geotextiles, any of which is required to support the fill.
Overstorey	That portion of the trees in a forest of more than one storey forming the upper or uppermost canopy layer.
Partial Cutting	A general term referring to silvicultural systems other than clearcutting, in which only selected trees are harvested. Partial cutting systems include seed tree, shelterwood, selection, and clearcutting with reserves.
Partial Risk	The likelihood of occurrence of a hazardous event and the likelihood of it affecting the site occupied by a specific element. Partial risk analysis is often used when it is sufficient to know whether or not a hazardous event or change to watershed process will reach or affect a watershed value. The extent of harm to the value of interest (i.e., vulnerability) is not investigated. A partial risk analysis is often the first level of investigation by a Specialist since the vulnerability of specific values (e.g., water supply infrastructure, fish and fish habitat, etc.) often requires assessments by other Specialists (e.g., engineers, biologists, foresters, etc.) who have greater knowledge of the elements-at-risk.
Point(s) of Interest	A point identified to establish the lower limit of a drainage area that is the subject of a Watershed Assessment or Hydrologic Assessment. Typically, it is at the location of a Value of interest (e.g., a water intake); or at a stream confluence or shoreline; or at the downstream limit of a fish-bearing reach of interest.
Peak flow	The maximum rate of discharge during a period of runoff. Peak flow may be associated with melting of a snowpack, rain storm, or combination of the two.
Peak flow hazard	Peak flow hazard refers to the likelihood and/or degree to which the baseline or pre-disturbance peak flow magnitude and frequency has or could change in response to watershed disturbance, specifically forest development (e.g., timber harvesting and road building); however, other land uses or natural disturbances that affect the forest land base are also considered. In simple terms, the peak flow hazard refers to the likelihood that flooding along a particular stream or stream reach will become measurably more severe or frequent under 1) current conditions, and then 2) following forest development or other disturbance, relative to baseline conditions.
Primary Forestry Activity	One or more of: timber harvesting, silviculture treatments, wildlife habitat enhancement, and road construction, maintenance, and deactivation.
Probability	A mathematical expression of Likelihood over a given time frame, using a number between 0 (an event will not occur) and 1 (an event will certainly occur).
Professional Biologist (RPBio)	A person admitted to and registered with the College of Applied Biology as a Professional Biologist.
Professional Engineer (PEng)	An Engineer who is a registered or licensed member in good standing with EGBC and typically is registered in the disciplines of geological engineering, mining engineering or civil engineering, which are designated disciplines of professional engineering.
Professional Geoscientist (PGeo)	A Geoscientist who is a registered or licensed member in good standing with EGBC and typically is registered in the disciplines of geology or environmental geoscience, which are designated disciplines of professional geoscience. Until 2000, EGBC referred to the discipline of environmental geoscience as 'geotechnics.'
Quantitative vs Qualitative	Quantitative estimates use numerical values or ranges of values, while qualitative estimates use relative terms such as high, moderate and low. Both quantitative and qualitative estimates can be based on either objective (statistical or mathematical) estimates or subjective (professional judgmental or assumptive) estimates, or some combination of both. No standard definitions exist for relative qualitative terms. Therefore, to avoid ambiguity, such terms must be defined with reference to quantitative values or ranges of values. Quantitative estimates may be no more accurate than qualitative estimates. The accuracy of an estimate does not depend

	on the use of numbers. Rather, it depends on whether the components of risk analyses have been appropriately considered; and on the availability, quality and reliability of required data.
Range	Any land supporting vegetation that is suitable for grazing.
Range Land	Crown range and land subject to an agreement under section 18 of the *Range Act*.
Reach	A relatively homogeneous portion of a stream that has a sequence of repeating structural characteristics.
Red Listed Species	Indigenous species that are extirpated, endangered or threatened in British Columbia.
Referral	The process by which applications for permits, licences, etc., made to one government agency by an individual or industry, are given to another agency for review and comment.
Reforestation	The re-establishment of trees on denuded forest land by natural or artificial means, such as planting and seeding.
Relief	The difference between highest and lowest elevations in a watershed unit.
Remediate	To take measures to fix effects after they have occurred; for example, deactivating old unstable roads or implementing sediment control measures on active roads.
Reserve	An area of forestland that, by law or policy, is not available for harvesting. Areas of land and water set aside for ecosystem protection, outdoor and tourism values, preservation of rare species, gene pool, wildlife protection, etc.
Reserve Zone	An area in which no timber harvesting is allowed to occur.
Residual Area (Face Unit)	An area located outside of defined stream catchments. A residual area is typically found between stream catchments and may have small streams (i.e., smaller than the scale of the stream catchments on either side) or no identified streams present. Nevertheless, the residual area may contribute dispersed surface runoff or groundwater to a stream below.
Rill	A small channel created on steep slopes by water erosion.
Riparian Area	The banks and adjacent areas of a stream, river, lake or wetland. It contains vegetation that, due to the presence of water, is distinctly different from the vegetation of adjacent upland areas.
Riparian Feature	River, stream, lake or wetland.
Riparian Function	Riparian vegetation serves many purposes (e.g., to provide shade, cover, stream habitat, stream bank stability, etc.) and can be a major factor contributing to the robustness of channels and observed channel response. Loss of riparian function can affect channel equilibrium and result in bank erosion, channel shifting, and sedimentation. The level of past riparian forest cover disturbance and the level of recovery of the riparian vegetation are both considered in characterizing channel response.
Riparian Leave Strip	An unharvested border of forest around a riparian feature.
Riparian Management Area (RMA)	An area that consists of a riparian management zone and a riparian reserve zone.
Riparian Management Zone (RMZ)	A portion of the riparian management area established to conserve the fish, wildlife habitat, biodiversity and the water values of the riparian management zone, and to protect the riparian reserve zone, if any, within the riparian management area.
Risk	The chance of injury or loss, expressed as a combination of the Consequence of an event and the associated likelihood of occurrence. Note: If Specialists choose to use terms such as “hazard”, they should define the term as it is used in their reports. The use of the term “hazard” to mean “Likelihood” is discouraged.
Risk Analysis	The systematic use of information to comprehend the nature of Risk and to estimate the level of Risk (ISO, 2015; Wise et al., 2004).
Risk Assessment	The overall process of Risk Identification, Risk Analysis, and Risk Evaluation (ISO, 2015.

Risk Evaluation	The process of comparing the results of Risk Analysis with Risk Tolerance Criteria to determine if the Risk is acceptable, tolerable, or unacceptable; weighs the estimated level of Risk against the expected benefits (ISO, 2015; Wise et al., 2004)
Risk Identification	The process of finding, recognizing, and describing Risks; involves identifying the Values, the sources of Risk (sources of potential harm), their causes, and the potential Consequences.
Risk Management	Coordinated activities to control risks.
Risk Tolerance Criteria	References against which the significance of a risk is evaluated. Generally, these are associated with defined qualitative or quantitative risk levels.
Road Deactivation	Consists of measures to stabilize roads and logging trails during periods of commercial harvesting inactivity. It includes controlling drainage, removing side-cast where necessary and re-establishing vegetation for permanent deactivation.
Road Prism	A road prism is the area consisting of the road surface, any cut slopes, ditches or road fill.
Road Rehabilitation	A rehabilitated road has all structures removed (including water bars and cross ditches), the road surface is loosened, surface re-contoured, and natural drainage patterns restored and trees planted (on forest land) to get roads back into forest production.
RPBio	Registered Professional Biologist
Runoff Generation Potential	Runoff generation potential or flood response potential (Green, 2015) describes the propensity at which precipitation and/or snowmelt are converted to surface runoff and ultimately streamflow. Watersheds with high runoff generation potential tend to have relatively rapid runoff generation, whereas those with low runoff generation potential tend to have slower runoff generation. Physical watershed characteristics that affect runoff generation include vegetation (e.g., forest type), soil type, geology, elevation, hillslope aspect, and hillslope gradient. Meteorological factors affecting runoff generation include the type of precipitation; rainfall intensity, amount and duration; distribution of rainfall over the drainage basin, antecedent precipitation, and other conditions that affect evapotranspiration such as temperature, wind, relative humidity and season. Land use, including forestry, may affect runoff generation potential by affecting site-level water balance following deforestation or reforestation and by affecting soil permeability along roads or areas trafficked by heavy equipment. Forestry effects are a function of several factors, including area harvested (i.e., ECA); size, shape and orientation of individual forest openings, and method of harvesting (e.g., ground, cable-based, or air).
Salvage Harvesting	Logging operations specifically designed to remove damaged timber (dead or in poor condition) and yield a wood product. Often carried out following fire, insect attack or windthrow.
Sediment Delivery Potential	The likelihood that sediment generated in upslope or instream sources will reach the stream network and be transported downstream to an element-at-risk (i.e., sedimentation). Factors considered include: hillslope-stream coupling, stream gradient, and location of lakes and wetlands.
Sediment Generation Potential	The likelihood that land use activity will increase the magnitude and/or frequency of sediment production (i.e., erosion) considering: terrain stability, soil erodibility, evidence of mass wasting, extent and location of resource roads, and other land-use related soil disturbance.
Sediment Yield	The rate of sediment flux through a stream system.
Seep	Wet areas, normally not flowing, arising from an underground water source.
Soil Disturbance	Disturbance to the soil in the net area to be reforested resulting from the construction of temporary access structures or gouges, ruts, scalps or compacted areas resulting from forestry activities. Without rehabilitation, disturbed sites often have reduced soil productivity and may not provide optimum growing conditions for new trees. For that reason, maximum allowable amounts of soil disturbance are set in regulation.

Specialist	An individual with specialized training, certification, and experience in a particular occupation, practice, or branch of learning. Such individuals include but are not limited to registered professionals with specialized expertise such as fisheries, Hydrology, Geomorphology or fluvial Geomorphology, slope stability, terrain mapping, erosion control and sediment management, aquatic or riparian terrestrial habitats, water quality, windthrow, forest health, or human health; and non-professionals who may be individuals with certification in specific occupational skills. Typically, the lead Specialist for a Watershed Assessment or Hydrologic Assessment would be a Specialist in Hydrology and/or Geomorphology.
Specific Risk	The risk of loss or damage to a specific element, resulting from a specific hazardous event or sustained change to watershed process occurring and of it affecting the location occupied by a specific element of value. Consideration of the vulnerability of the element-at-risk is required to estimate specific risk. For example, a common question may be: what is the extent of flood damage that could occur? How vulnerable is a water system to flooding (i.e., is there a backup source)?
Specific Value of Risk	The worth of loss or damage to a specific element, excluding human life, resulting from a specific hazardous event or sustained change to watershed process occurring and of it affecting the location occupied by a specific element of value.
Stakeholder	Any individual, group, or organization able to affect, be affected by, or believe they might be affected by, a decision or activity. Note that a decision-maker can be a Stakeholder.
Stream Bed	The bottom of the stream below the usual water surface.
Stream Channel	The stream bed and banks formed by fluvial processes, including deposited organic debris.
Streamflow Regime	The streamflow regime is described by the magnitude, frequency, and timing of streamflow.
Subordinate	Any person directly supervised by an Engineering/Geoscience Professional or Forest Professional who assists in the practice of the relevant profession; for example, a member-in-training, another person not registered or licensed to practice the profession(s), or another Engineering/Geoscience Professional or Forest Professional.
Sustainability	A state or process that can be maintained indefinitely. The principles of sustainability integrate three closely interlined elements-the environment, the economy and the social system-into a system that can be maintained in a healthy state indefinitely.
Sustainable Development	Preservation and protection of diverse ecosystems—the soil, plants, animals, insects and fungi—while maintaining the forest’s productivity.
Sustainable Forest Management	Management regimes applied to forest land which maintain the productive and renewal capacities as well as the genetic, species and ecological diversity of forest ecosystems.
Swamp	A tree or tall-shrub dominated wetland with mineral or occasionally peat soils that experiences periodic flooding and nearly permanent subsurface water flow. The waters are nutrient rich.
Synchronization	Refers to the how forest cover removal alters the rate and timing of snowmelt at different locations within a watershed so that there is an increase in the amount of water that is released from the snowpack over a given period (often the period of interest is around the peak streamflow in spring). The synchronization of hydrological processes is commonly attributed to increases in the magnitude of peaks flows (Moore and Wondzell, 2005).
Tenure Holder	An individual, group or company that holds a licence agreement under the Forest Act or Range Act.
Timber Harvesting Land Base	Crown forest land within the timber supply area where timber harvesting is considered both acceptable and economically feasible, given objectives for all

	relevant forest values, existing timber quality, market values, and applicable technology.
Tree Farm Licence (TFL)	An area-based tenure agreement that issues the rights to harvest an allowable annual cut in a specified area. These licences commit the licensee to manage the entire area under the general supervision of the Forest Service. Cutting from all lands requires Forest Service approval through the issuance of cutting permits. A TFL has a term of 25 years.
Understorey	Any plants growing under the canopy formed by other plants, particularly herbaceous and shrub vegetation under a tree canopy.
Upland	Land elevated above a riparian area.
Value	The specific or collective set of natural resources and human developments in a watershed that have measurable or intrinsic worth. Values can include human life and bodily harm, public and private property (including buildings, structures, lands, resources, recreational sites, and cultural heritage features), transportation systems and corridors, utilities and utility corridors, water supplies (for domestic, commercial, industrial, or agricultural use), aquatic and terrestrial habitats, visual resources, and timber.
Vegetative Cover	The plants or plant parts, living or dead, which protect the ground surface. Cover may also refer to the area of ground cover by plants of one or more species.
Vulnerability	A measure of the robustness (or alternatively the fragility) of a thing of Value, and its exposure to a source of Risk.
Watershed	An area of land drained by a stream or river, above a given point on a waterway that contributes runoff water to the flow at that point.
Watershed Assessment	Identification and analysis of hydrologic and geomorphic processes in a Watershed Unit that is consistent with Section 3.0 of EGBC and ABCFP (2020).
Watershed Routing Efficiency	The relative rate of water transmission through the drainage unit, considering the area and location of lakes and wetlands (i.e., storage), surficial geology and soils, drainage density, road density, and slope gradient.
Watershed Unit or Watershed Reporting Unit	The surface drainage area upstream of a defined Point of Interest. A Watershed Assessment may be for a single Watershed Unit, or may subdivide a large drainage area into smaller Watershed Units for the purpose of the assessment. The hierarchy of watershed units from large to small include: large watershed, watershed, basin, and sub-basin. Units smaller than sub-basins may be referred to as local drainages.
Wet Meadow	A class of wetland having mineral soils which are periodically saturated. Dominant vegetation consists of water-tolerant grasses, sedges, rushes and forbs.
Wetlands	Areas characterized by soils that are usually saturated and support mostly water-loving plants.
Windfirm	A single or stand of trees that retains the ability to withstand strong winds and thus resist overturning (i.e., to resist windthrow, windrocking, and major breakage).

APPENDIX B: EQUIVALENT CLEARCUT AREA MODELLING

Background

Equivalent Clearcut Area (ECA) is a commonly used metric to characterize hydrologic recovery following forest cover disturbance (e.g., harvesting) in forest hydrology. ECA reflects the extent of forest disturbance and regrowth (or recovery toward pre-disturbance conditions) in a watershed (Winkler et al., 2010b)[128]. The ECA of a clearcut is derived by reducing the total area cut by recovery, which is estimated from relationships between rainfall interception or snow accumulation/melt and crown closure or tree height (Hudson and Horel, 2007). The cumulative ECAs for all openings are summed to provide an ECA for entire watershed or portion thereof (Winkler et al., 2010b)[129].

ECA was originally used in provincial watershed assessment procedures as one of many indicators of peak flow hazard due to forest harvesting (BC MOF, 1999). It is important to recognize, however, the complexities and uncertainties in applying stand-scale recovery estimates (i.e., ECA indices) to the evaluation of hydrologic change at the watershed scale (Winkler et al., 2010b). Fortunately, the studies from which these stand-scale recovery estimates are based, are often conducted in small watersheds, similar in size and characteristics as the assessment watersheds. As such, there is greater confidence that outcomes from these studies are more directly relatable to the assessment area.

There are potential limitations and challenges in calculating and interpreting ECA. This includes the following:

- ECAs are calculated on the basis of defined drainage areas. Such areas must be defined for selected points-of-interest – usually the mouths of major streams (watersheds), tributaries (basins), or above elements-at-risk. If there are numerous points-of-interest within a watershed, ECAs can vary considerably depending on the location and distribution of disturbed areas (e.g., a concentration of cutblocks in the lower portion of a watershed);
- ECA modelling was developed for forested watersheds, and is not necessarily representative of urbanized areas. While the loss of forest cover can be accounted for (as done herein), ECAs do not account for the hydrologic effects of extensive impervious areas (e.g., buildings, roads), nor the widespread modification of natural drainage patterns vis a vis ditches, drains, and stormwater systems; and
- It should be noted that ECAs were developed based on changes to interception and snowmelt as a result of forest cover loss, and hence focused on peak flows. No formal

---

[128] The higher the ECA the lower the level of hydrologic recovery in a watershed. E.g., an ECA of 30%, implies 70% recovery, whereas 10% ECA implied 90% recovery.

[129] Some workers refer to the cumulative watershed-level ECA as equivalent clearcut index (ECI) (Madone, 2015) or hydrologically equivalent disturbed area (HEDA) (Beaudry, 2013). In order to reduce technical jargon, we refer to ECA as representing the hydrologic recovery of a defined area, e.g., watershed (unless otherwise specified).

work has been done in British Columbia to assess how forest cover loss affects transpiration rates and consequently low flows.

In spite of some caveats, ECA remains a useful approximation of the state of forest cover disturbance and hydrologic recovery (relative to pre-disturbance levels) in a watershed. It should be recognized, that although ECAs may be reported with some precision, in our opinion, there is always some uncertainty with the ECA assumptions and recovery estimates.

Methodology & Assumptions

Current ECAs were calculated for the assessment watersheds following a methodology adapted from Hudson and Horel (2007), which is based on research data on stand-level hydrologic recovery collected on Vancouver Island and Gray Creek near Sechelt (Hudson, 2000a, 2000b, 2001, 2002 and 2003). Stand-level hydrologic recovery is an index of the degree to which a regenerating forest stand is similar to old growth in its rainfall interception characteristics and its influence over snowmelt. The hydroclimatic conditions, tree growth and hydrological recovery at the research sites reported in Hudson and Horel (2007) are considered comparable to those in the watershed units of interest. Hudson and Horel (2007) propose evaluating mean recovery for three elevation bands as well as for the watershed overall. The elevation bands include 0-300 m, where rainfall is considered dominant; 300-1,200[130] m where rain and rain-on-snow is common; and >1,200 m where peak flows are considered to be primarily generated from snowmelt. Given that rain-on-snow can occur across all elevations, and that these events are often responsible for producing some of the largest peak flows, Dr. William Floyd (Research Hydrologist for the Coast Area Research Section, BC Ministry of Forestry) suggested applying a single rain-on-snow curve across all elevations. Furthermore, he suggested the Hudson and Horel (2007) cold rain-on-snow recovery curve was most applicable to the assessment area. As such, hydrologic recovery, and hence ECA, was evaluated using the cold rain-on-snow curve across all elevations.

Provincial sources were initially used to identify disturbed areas (e.g., harvested areas). The analysis referenced the Vegetation Resource Inventory (VRI) (with a harvest flag), RESULTS and Forest Tenure Authority (FTA), as well harvesting data supplied by BCTS. Issued blocks from the FTA layer and sold blocks from BCTS were treated as current depletions. Disturbed areas not captured by the provincial block sources, were manually flagged and/or digitized based on a detailed imagery review using available 2019 and 2020 satellite imagery[131] and LiDAR-derived canopy height model.

---

[130] This elevation band is further subdivided into two zones, the warm and cold rain-on-snow zone, each with their own recovery curve.

[131] PlanetLabs (Blackbridge) 2019 and Sentinel-2 (ArcGIS online) 2020.

Current road alignments were compiled from FTA, Digital Road Atlas, DEM bare earth hillshade, and streaming imagery. A single merged layer was created and reviewed against the 2019 satellite imagery. All roads were given a total clearing width of 15m.

Anthropogenic non-productive (NP) areas (e.g., gravel pits) on public and private land were flagged using BC Land Survey Codes in VRI and included in the tally of disturbed areas[132]. A manual satellite imagery review was necessary for many areas due to data gaps. As a result, additional NP area was added. Natural NP land (e.g., alpine, low SI stands, wetlands, etc.) were identified using BC Land Survey Codes from VRI, although these areas do not contribute to ECA as they are not disturbed. In other words, only areas presumed to be previously forested contribute to ECA.

Stand heights were estimated using 2019 LiDAR-derived 1 m x 1 m canopy height model (CHM) provided by BCTS. The LiDAR CHM was resampled to 5 m x 5 m and stands were assigned a median (50th percentile) CHM height. To model hydrologic recovery (i.e., ECA) over time, it was required that heights in 2019 be updated to the current year and then projected 50 years into the future. Based on site index, species composition, and stand age, a provincial tree growth modelling tool (i.e., SiteTools) was used to grow tree heights into the future (assuming no additional forest cover disturbance). For natural stands, the natural site index from VRI was utilized, whereas for managed stands a managed site index was generated using the BC Site Productivity data and the leading species. Roads and non-productive areas were not modelled for recovery. For stands containing deciduous species, ECAs for the deciduous portion were scaled by 25% to account for reduced interception of rain and snow by deciduous species relative to conifers. In other words, if a 20 ha stand was 20% deciduous, maximum hydrologic recovery for that stand could only be 19 ha (95% hydrologically recovered).

ECAs were compiled on a watershed-basis, using LiDAR-derived stream catchments. Streams derived from the LiDAR data were cross-referenced and refined with stream data from the Freshwater Atlas and Sunshine Coast Regional District. The drainage areas for the eight assessment streams were generated using GIS tools and were visually reviewed and edited to eliminate errors that often occur near roads and stream crossings. The streams and drainage areas were selectively field verified. In addition, checks were made against available stream survey information collected previously for BCTS.

---

[132] These areas are considered to be disturbed indefinitely with no assumed forest recovery.

APPENDIX C: SURFACE WATER LICENCE FIELD REVIEW NOTES

TABLE C.1 *List of current surface water licences in the assessment watersheds downstream of BCTS' Chart. Licences are organized by watershed in order of stream distance from the mouth (km). Refer to MAP 1 for location. Notes from the July 12-16, 2021 field review are provided. Some entries are for properties without water licences.*

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
CHASTER CREEK	**Chaster Creek**	0.02	**F020212**	PD44711	19600714	01A - Domestic	2.27305	m^3/day	Yes	Mapped point-of-diversion (POD) is located on Crown land. No water supply infrastructure identified in field. Suspect that property is supplied by municipal water system.
	Chaster Creek	0.05	**C116516**	PD44713	19540607	01A - Domestic	2.27305	m^3/day	Yes	No water supply infrastructure noted. Suspect that property is supplied by municipal water system.
	Chaster Creek	0.24	**C121502**	PD44715	19540513	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to visit property. Observed channel above and below property.
	Shirley Creek (Chaster Trib 4.1)	2.7	**C039934**	PD45975	19710608	01A - Domestic	2.27305	m^3/day	Yes	BCTS spoke with crew on-site. Polar accessed Shirley Creek behind new house under construction.
	Webb Brook (Chaster Trib 4.1.2)	3.1	**F048883**	PD45973	19731113	01A - Domestic	2.27305	m^3/day	Yes	BCTS visited property followed by Polar. Residence with pond roughly 5 m from structure. Homeowner concerned with logging; notices creek 'rises quickly' during heavy rain but pond stays fairly consistent level. Creek is 1 m wide with a bank of roughly 2-3 m. Flood risk generally low due to incised creek and ample bank height.
	Webb Brook (Chaster Trib 4.1.2)	3.1	**F048883**	PD45973	19731113	04A - Land Improve: General	-	-	Yes	See above.
	Webb Brook (Chaster Trib 4.1.2)	3.1	**F048883**	PD45972	19731113	01A - Domestic	2.27305	m^3/day	Yes	See above.
	Webb Brook (Chaster Trib 4.1.2)	3.1	**F048883**	PD45972	19731113	04A - Land Improve: General	-	-	Yes	See above.
	Shirley Creek (Chaster Trib 4.1.1)	3.15	**F040554**	PD45979	19571002	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to visit property. Observed channel below property at Russell Road (APPENDIX E, Figure 39).
	Co-op Springs (Chaster Trib 4.1.4.2)	3.6	**C019935**	PD45949	19410915	00A - Waterworks: Local Provider	199118.74	m^3/yr	Yes	Mapped POD is located on crown land. Reviewed Chaster Trib 4.1.1.2 (Co-op Spring) in vicinity of mapped POD. No water supply infrastructure noted.
	Co-op Springs (Chaster Trib 4.1.4.2)	3.6	**C019935**	PD45950	19410915	00A - Waterworks: Local Provider	-	-	No	Reviewed small stream downslope near Reed Road.
	Co-op Springs (Chaster Trib 4.1.4.2)	3.6	**C019935**	PD45951	19410915	00A - Waterworks: Local Provider	-	-	No	Reviewed small stream downslope near Reed Road.
	Inge Creek (Chaster Trib 4.1.1.1.1)	4.3	**C015414**	PD45077	19410915	00A - Waterworks: Local Provider	82966.143	m^3/yr	Yes	Mapped POD located on Crown land. Chaster Trib 4.1.1.1.1 (Inge Creek) reviewed near mapped POD. Old berm/weir across channel noted with vertical culvert riser. The former pond is all but filled with sediment (APPENDIX E, Figure 54), and the system appears abandoned and non-functional.
	Trethewey Spring (Chaster Trib 4.1.2.2)	4.1	**C108199**	PD63202	19540329	01A - Domestic	2.27305	m^3/day	Yes	BCTS met with father of Johan and Lehe. Father said that stream was part of Webb Brook. Pond is located on property, but not connected to brook. Groundwater relatively shallow. Polar reviewed stream in vicinity of mapped POD. Several private foot bridges across the stream. PVC pipe noted along stream, however did not see intake. Unclear whether water is being used from creek at this location.
END / WALKER CREEK	**End Creek**	0.02	**C122666**	PD44717	19671017	01A - Domestic	2.27305	m^3/day	Yes	Reviewed stream above mouth. About 50 m upstream along section protected by retaining wall is a cylindrical concrete sump in middle of creek. Unknown conditions and whether it is in operation (APPENDIX E, Figure 76). Intake is exposed to potential fluvial activity.
	McComb Brook	1.4	**F016236**	PD45931	19520927	04A - Land Improve: General	616.74	m^3/yr	Yes	Approximately 40 m above highway is a 15 m x 15 m "fish" pond with 6-inch diameter pipe that controls outflow on a 2 m tall concrete weir. Outlet not maintained and plugged with debris but after minor clearing flows increased and pond level dropped towards outlet level. The pond is heavily grown-in and appears unmaintained.

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
	End Creek	1.72	**C129942**	PD45073	19350404	01A - Domestic	4.54609	m^3/day	Yes	Mapped POD is located behind the tire shop. Channel has low energy and largely sand bed and brushy. Tires strewn in riparian zone. Could not find infrastructure associated with mapped POD.
	End Creek	1.72	**-**	-	-	-	-	-	Yes	BCTS visited property followed by Polar. Reviewed End/Walker Creek along property from Burton Road to Mountain Road. Evidence of seepage areas and low energy streams. Short palm trees growing at north end of property.
	End Creek	1.84	**C045087**	PD45075	19750121	04A - Land Improve: General	4.54609	m^3/day	No	Did not obtain permission to visit property. Observed channel below property.
	End Creek	1.84	**F044096**	PD45075	19610425	01A - Domestic	2.27305	m^3/day	No	See above.
	End Creek	1.84	**F044097**	PD45075	19711207	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to visit property. Observed channel below property.
SMALES CREEK	**Elmer Creek**	1.14	**F015851**	PD45080	19510215	01A - Domestic	4.54609	m^3/day	Yes	Property with Sunday Cider business. Mr. McDougall, owner, plans to develop apple orchard midway up property. Mr. McDougall has owned property for 6 years. Smales Creek referred to locally as Elmer Creek. 2020 had the highest winter storm peak flow they have observed. For 4 years in a row this stream has been close to overflowing the banks. Stream is dry most of the year, but is concerned harvesting will increase these storm / spring peak flows. Mr. McDougall is advocating the protection of forest within District Lot 1313 for conservation and recreation use by community.
HIGGS BROOK	**Higgs Brook**	0.76	**C069016**	PD45103	19781107	01A - Domestic;	2.27305	m^3/day	Yes	BCTS contacted property owner. Water licence is not used on Higgs Brook. Polar reviewed stream on west side of Farm Ventures. Channel incised and aggraded with lots of wood. Horse pen abuts creek with some localized riparian disturbance at watering location. PVC pipe noted along stream, however it does not appear to be currently functional (consistent with BCTS discussion with owner).
	Higgs Brook	0.76	**C069016**	PD45103	19781107	02D - Comm. Enterprise: Enterprise	4.54609	m^3/day	No	See above.
	Higgs Brook	1.1	**C107917**	PD69089	19940323	01A - Domestic	2.27305	m^3/day	No	Mapped POD located on Crown land. Did not obtain permission to visit property. Observed channel above and below property.
	Higgs Brook	1.23	**C070726**	PD45105	19620720	01A - Domestic	2.27305	m^3/day	Yes	Polar visited property. Owners used to have an intake when they first moved here 20 years ago but they don't currently use it. Higgs Brook typically dry in summer but there are wet areas due to springs in area. Currently there is a well near the stream adjacent to the property. Owner noted that recently there is less water in well partially due to larger development above which he says has altered natural drainage patterns. Skid trails and roads may have altered drainage. Noted a submersible pump in milk crate in infilled pond above old concrete weir. Low energy stream conditions.
	Higgs Brook		**-**	-	-	-	-	-	No	BCTS contacted property owner. No water licence located on property at 1913 Ranch Road. Ditch nearby that may feed Higgs Brook. Apparently, Higgs Brook doesn't flow much. Polar dd not visit property, however did review upstream on Scott property.
	Higgs Brook		**-**	-	-	-	-	-	No	BCTS obtained permission from property owners immediately west of 1913 Ranch Road. No water licence on property. Polar did not visit property, however did review small unnamed tributary to Higgs Brook at crossing of Ranch Road. Channel flows through 400 mm culvert at road, low energy channel with skunk cabbage noted.
SLATER CREEK	**Valentine Spring**	1.24	**F020210**	PD45121	19670401	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to access property. Reviewed Slater Creek near Sunshine Coast Highway (APPENDIX E, Figure 146), and at Porter Road (APPENDIX E, Figure 137).
	Slater Creek	1.57	**C062074**	PD45125	19820824	01A - Domestic	4.54609	m^3/day	Yes	Did not obtain permission to access property. Reviewed Slater Creek near Conrad Road (APPENDIX E, Figure 139). Did not see intake from near Conrad Road.

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
	Slater Creek	1.66	**C115988**	PD75827	20010216	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to access property. Reviewed Slater Creek near Conrad Road (APPENDIX E, Figure 139) and near Pixton Road (APPENDIX E, Figure 140). Did not see intake.
MOLYNEUX CREEK	**Molyneux Creek**	0.43	**F013226**	PD45128	19430824	01A - Domestic	2.27305	m^3/day	Yes	Reviewed stream in vicinity of POD. No intake or water supply infrastructure noted. Channel highly aggraded, abundant wood and functional riparian conditions.
	West Molyneux Creek (Molyneux Trib 1)	1.1	**F020285**	PD45913	19580806	01A - Domestic	2.27305	m^3/day	Yes	Reviewed stream in vicinity of POD. Did not see intake but noted stream crossing and outbuildings adjacent to stream. Channel is aggraded.
	Molyneux Creek (Trib 2)	1.16	**F017404**	PD45136	19550829	01A - Domestic	2.27305	m^3/day	No	Did not gain permission to access property.
	Molyneux Creek (Trib 2)	1.19	**C115496**	PD75493	20000713	01A - Domestic	2.27305	m^3/day	No	BCTS visited property. Owner doesn't use water licence, but uses well water. Polar did not visit property. Water licence not actively used. Observed channel above and below property.
	Molyneux Creek (Trib 2)	1.22	**F020336**	PD45138	19670919	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to visit property. Observed channel above and below property.
	Molyneux Creek (Trib 2)	1.27	**C052371**	PD45181	19781016	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to visit property. Observed channel above and below property.
	Dora Brook (near Molyneux Trib 1.1)	1.3	**C105329**	PD66484	19920630	01A - Domestic	2.27305	m^3/day	Yes	Channel reviewed in vicinity of mapped POD, however POD not seen.
	West Molyneux Creek (Molyneux Trib 1.2)	1.3	**F045488**	PD45914	19671121	01A - Domestic	2.27305	m^3/day	Yes	Channel reviewed in vicinity of mapped POD, however POD not seen.
	West Molyneux Creek	1.35	**F047915**	PD45916	19680708	01A - Domestic	2.27305	m^3/day	Yes	BCTS visited property followed by Polar. Stream reviewed in vicinity of mapped POD. Channel generally aggraded, some portions with exposed bedrock. Water supply intake is in disrepair and PVC pipes located along channel, which do not appear to be in use. Debris and gravel may have affected system in past.
	Molyneux Creek (Trib 2)	1.41	**C114609**	PD74933	19990806	01A - Domestic	2.27305	m^3/day	Yes	Polar reviewed stream near mapped POD. PVC pipes noted along relatively active creek. Intake not seen, however, may have been obscured by wood debris and gravel.
	Molyneux Creek (Trib 2)	1.56	**C118817**	PD77998	20030908	01A - Domestic	2.27305	m^3/day	Yes	BCTS visited property. Owner has a well, but uses water licence for extra garden water. East Molyneux is at top end of property. There is a trail beside stream at the bottom end that leads to a pump house. Polar subsequently visited property. Property owner has good well (110 ft deep). He waters garden with creek water but uses water from the well for the house. Well has 40 ft of overburden above bedrock. Access to creek down wooden stairs and small foot bridge across creek. Surface water system consists of screened intake in small pool that required periodic excavation of gravel by hand. PVC pipe runs down or parallel to creek and feeds a 1 m^3 tank with overflow pipe before continuing to gardens on property. Channel appears active and pipes are generally exposed to fluvial activity.
	West Molyneux Creek (Molyneux Trib 1.2)	1.6	**F051909**	PD45917	19721211	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to access property. Reviewed channel immediately upstream.
	West Molyneux Creek (Molyneux Trib 1.2)	1.8	**C120214**	PD78822	20041203	01A - Domestic	2.27305	m^3/day	Yes	Suspected location of former intake is approximately 50 m upstream of mapped POD (APPENDIX E, Figure 155 and Figure 156). Intake is currently under 1.5 m of gravel behind log jam. Barrel disconnected and system appears non functional and abandoned. PVC pipes noted in several locations, buried by gravel behind logjams.
	Carol Brook (near Molyneux Trib 2)	1.94	**C117783**	PD77416	19980929	01A - Domestic	4.54609	m^3/day	No	Did not gain permission to access property. POD is apparently above hydro right-of-way within a ravine.
	West Molyneux Creek (Molyneux Trib 1.2)	2.4	**C119267**	PD78322	20040216	01A - Domestic	2.27305	m^3/day	Yes	Mapped POD is located on Crown land. BCTS visited property, where owner noted issues since 2010, including washout of Firbirn Road, believed to be associated with

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
										forest clearing nearby. Polar subsequently visited property and met with Lorne and Rachel. They noted that Weyerhauser used to own all the properties nearby and logged 60 years ago +/-. Weyerhauser actions or inactions are blamed for changing drainage patterns causing roads to wash out around 2006. Neighbours had to rebuild road and install culverts. Road is now apparently built to MOTI standards due to subdivisions in area. Cutblock to east of block was windthrow treated by BCTS, however, blowdown has been observed onto their property. Water from the creek supplies the shop and house as needed. They have two wells also on property. Some irrigation on property. Fire protection system exists on property (10,000 L tank and hydrant). Water intake above house consists of metal screen secured in concrete on bedrock section of creek. The intake is robustly constructed but owner has challenges keeping it clear during heavy rains. Channel has approximately 20% gradient and has evidence of gravel transport and some scour along banks. Creek was relatively low on survey date, but owner said it has never gone dry in last 15 years. Distribution pipe (PVC) runs down a portion of the creek and may be exposed to fluvial activity. Owners also concerned about wildfire due to logging slash being left, blowdown and possible BCTS development upslope.
JOE SMITH CREEK	**Joe Smith Creek**	0.12	**F014265**	PD60230	19480827	01A - Domestic	2.27305	m^3/day	Yes	BCTS contacted property owners, permission granted by father. Polar visited this oceanfront property, some bank erosion along creek. Property owner does not currently use water licence. Potable water supplied by municipality. Property above has house under construction.
	Joe Smith Creek	0.14	**C035140**	PD60229	19690827	01A - Domestic	2.27305	m^3/day	Yes	Stream channel reviewed in vicinity of mapped POD. No water infrastructure noted. Suspect propertied supplied by municipal water system.
	Joe Smith Creek	0.14	**F013152**	PD60229	19450406	01A - Domestic	2.27305	m^3/day	Yes	Stream channel reviewed in vicinity of mapped POD. No water infrastructure noted. Suspect propertied supplied by municipal water system.
	Joe Smith Creek	0.28	**C121664**	PD60226	19490904	01A - Domestic	2.27305	m^3/day	Yes	PVC pipe presumably associated with the water licence was noted in the culvert crossing of Lower Road and down a portion of the channel below Lower Road (APPENDIX E, Figure 189 and Figure 190. Above Lower Road the channel is aggraded and the water distribution line is obscured. The intake could not be identified; it is likely buried under debris and/or sediment. It is unknown whether it remains functional.
	Joe Smith Creek	0.52	**C049823**	PD60223	19600718	01A - Domestic	2.27305	m^3/day	Yes	Polar met property owner, who has not used water licence or well for last 10 years. Property is serviced by municipal water. PVC pipe is exposed at several locations along the channel (APPENDIX E, Figure 195). Intake location appears buried by sediment.
	Joe Smith Creek	0.58	**C065406**	PD60222	19871126	01A - Domestic	2.27305	m^3/day	No	BCTS obtained permission to enter property. Polar did not access property. Suspect that property is serviced by municipal water like neighbours.
	Joe Smith Creek	0.78	**C048176**	PD60220	19760426	01A - Domestic	4.54609	m^3/day	Yes	BCTS obtained permission to enter property. Polar reviewed channel in the vicinity of the mapped POD. No functional intake or water supply infrastructure noted. Some equipment in disrepair noted. Channel aggraded and may have buried intake. Suspect the property is serviced by municipal water.
	Joe Smith Creek	1.16	**C121536**	PD45927	19520124	01A - Domestic	2.27305	m^3/day	No	Did not gain permission to access property. Reviewed stream conditions above Pixton Road near mapped POD (APPENDIX E, Figure 201).
	Joe Smith Creek	1.16	**C121544**	PD45927	19600408	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to access property. Reviewed stream conditions above Pixton Road near mapped POD (APPENDIX E, Figure 201).
	Joe Smith Creek	1.36	**C050117**	PD45928	19770815	01A - Domestic	2.27305	m^3/day	Yes	Mapped POD on Crown land. Polar reviewed stream near stream km 1.5. PVC distribution line runs along channel and is exposed to flows. Pipe appears to go up to intake above hydro right-of-way, presumably where summer flows are reliable. Mapped POD appears 350 m below actual intake location.

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
	Joe Smith Creek	1.54	**-**	-	-	-	-	-	Yes	BCTS visited property and got permission from father. No water licence used. Polar reviewed the property and noted an unnamed tributary to Joe Smith Creek approximately 1-2 m wide flows through property and supplies pond. Stream is channelized between rock retaining walls near residence. Stream is unmapped but likely follows a visible channel on the LiDAR bare earth at least to Sunshine Coast Highway. Drainage pattern beyond that is unknown.
	Joe Smith Creek	2.28	**C120296**	PD78884	20041220	01A - Domestic	4.54609	m^3/day	No	Did not gain permission to access property. Stream conditions reviewed below property at north end of Byng Road (APPENDIX E, Figure 204 and Figure 205).
CLOUGH CREEK	**Clough Brook**	0.26	**C119215**	PD60240	19271111	01A - Domestic	4.54609	m^3/day	Yes	Concrete weir noted at stream km 0.3 (below Lower Road) (APPENDIX E, Figure 210). Appears full of sediment and non-functional. No evidence of distribution line in service. Suspect this licence from 1927 is no longer in use.
	Clough Brook	0.62	**C120577**	PD79007	20050404	01A - Domestic	2.27305	m^3/day	Yes	Polar reviewed stream conditions in the vicinity of the POD, which is mapped east of the creek. Conditions of stream shown in APPENDIX E Figure 216. Did not find a water intake.
	Clough Brook	1.1	**C038300**	PD60238	19700730	01A - Domestic	2.27305	m^3/day	Yes	Reviewed stream conditions in the vicinity of the POD, which is mapped east of the creek. Did not find an intake. Possibly abandoned.
	Clough Brook	1.16	**F038101**	PD60235	19550628	01A - Domestic	2.27305	m^3/day	Yes	Reviewed stream conditions in the vicinity of the POD, which is mapped east of the creek. Did not find an intake. Possibly abandoned.
	Clough Brook	1.25	**F013204**	PD60234	19451020	01A - Domestic	2.27305	m^3/day	Yes	BCTS met with Doug, owner, who noted that stream was not accurately mapped, and that a washout occurred in the 1980s. Polar subsequently met with Doug who described the 1983 debris flow that caused extensive damaged to the property. During the event, the drainage pattern was changed temporarily. Water started to spill out near the hydro right of way, trees took out powerlines and starting piling up on his property west of the stream. Debris deposited on Orange Road, throughout the property and hit a barn. It also washed out the highway and Lower Road below. Water licence is a gravity system used sometimes (PVC pipe with screen). PVC pipe runs along creek and is vulnerable to flood damage. Artesian well on property.
	Clough Brook	1.35	**F038102**	PD60233	19520917	01A - Domestic	2.27305	m^3/day	No	Did not obtain permission to access property, however observed stream conditions above and below. Did not see intake.
	Clough Brook	1.59	**C072752**	PD64132	19900723	01A - Domestic	2.27305	m^3/day	Yes	Polar met with Bruce McNevin. POD incorrectly mapped east of the stream. It is located near stream km 1.5. Channel bed is mix of cobbles and boulders over bedrock. Water pump used next to creek in case of fire (APPENDIX E, Figure 226). A 90 ft deep well on property is primary source of potable water; it has never been dry.
	Clough Brook	1.66	**C105989**	PD67221	19890119	01A - Domestic	2.27305	m^3/day	Yes	Polar met with Murray Lawson and reviewed the stream channel and water supply infrastructure. Murray has lived on property for only 4 years; however, he observed evidence of the 1983 debris flow. The channel is a mix of bedrock and boulder and cobble alluvial channel sections. Murray noted hearing movement of gravel and cobbles during high flows. His water intake is located at hydro right of way at a reliable location to capture water. Intake consists of concrete stilling well connected to a PVC pipe that runs along the creek and eventually along the riparian zone to the residence. Some erosion potential identified along cleared riparian zone until area revegetates.
	Clough Brook	2.76	**C121146**	PD79317	20050823	01A - Domestic	4.54609	m^3/day	Yes	Met with friend of Jeff's. Reviewed stream channel conditions on the property. Channel is bedrock with boulders and cobbles and heavy blowdown. Gravel accumulations behind debris. Riparian largely intact and natural. Railway car bridge across creek (APPENDIX E, Figure 231 and Figure 232). POD is mapped several hundred metres above residence. Could not find intake or see any evidence of water supply infrastructure.

Watershed	Source	Stream distance (km)	Licence	POD	Priority Date (YYYYMMDD)	Purpose	Qty	Units	Field review and/or meeting with owner(s)	Notes
	Clough Creek Trib 1	1.9	-	-	-	-	-	-	Yes	Concrete weir and intake with 5 m by 5 m headpond noted above hydro right-of-way. No apparent license associated with this potential water diversion.

APPENDIX D: REGISTERED GROUNDWATER WELLS

TABLE D.1 *List of registered groundwater wells in the assessment area. Online information may be available at: https://apps.nrs.gov.bc.ca/gwells/well/<insert Well Tag No.>.*

Watershed Unit	Well Tag No.	Plate No.	Well Status	Well Classification	Intended Water Use	Licence Status	Artesian Well	Artesian Well Flow Rate (USgpm)	Finished Well Depth (ft below ground surface)	Bedrock Depth (ft below ground surface)	Yield (USgpm)	Static Water Level (ft below ground surface)	Well Diameter (inches)	Aquifer ID (see footnote)[133]	Aquifer Material
Chaster Creek	5334		New	Water Supply	Private Domestic	Unlicensed	N	-	16	-	-	14	-	560	Unconsolidated
Chaster Creek	5433		New	Unknown	Unknown Well Use	Unlicensed	N	-	32	-	-	-	-	1143	Unconsolidated
Chaster Creek	5442		New	Water Supply	Private Domestic	Unlicensed	N	-	-	-	-	-	-	1143	Unconsolidated
Chaster Creek	5446		New	Water Supply	Private Domestic	Unlicensed	N	-	10	-	-	1	-	560	Unconsolidated
Chaster Creek	5484		New	Water Supply	Private Domestic	Unlicensed	N	-	8	-	-	7	-	560	Unconsolidated
Chaster Creek	5489		New	Unknown	Unknown Well Use	Unlicensed	N	-	27	-	-	25	-	560	Unconsolidated
Chaster Creek	5493		New	Water Supply	Private Domestic	Unlicensed	N	-	-	-	-	-	-	1143	Unconsolidated
Chaster Creek	11480		New	Unknown	Unknown Well Use	Unlicensed	N	-	25	-	-	-	-	560	Unconsolidated
Chaster Creek	16249		New	Water Supply	Private Domestic	Unlicensed	N	-	10	-	-	-	-	560	Unconsolidated
Chaster Creek	17040		New	Unknown	Unknown Well Use	Unlicensed	N	-	141	-	-	-	-	560	Unconsolidated
Chaster Creek	17041		New	Unknown	Unknown Well Use	Unlicensed	N	-	60	-	-	-	-	560	Unconsolidated
Chaster Creek	17043		New	Unknown	Unknown Well Use	Unlicensed	N	-	68	-	-	-	-	560	Unconsolidated
Chaster Creek	18774		New	Unknown	Unknown Well Use	Unlicensed	N	-	120	118	-	5	-	560	Unconsolidated
Chaster Creek	18775		New	Unknown	Unknown Well Use	Unlicensed	N	-	40	-	-	-	-	1143	Unconsolidated
Chaster Creek	18963		New	Water Supply	Private Domestic	Unlicensed	N	-	24	-	-	-	-	560	Unconsolidated
Chaster Creek	19943		New	Unknown	Unknown Well Use	Unlicensed	N	-	260	-	25	228	-	560	Unconsolidated
Chaster Creek	23421	53866	New	Water Supply	Water Supply System	Unlicensed	N	-	364	-	240	232	-	560	Unconsolidated
Chaster Creek	41551		New	Unknown	Unknown Well Use	Unlicensed	N	-	105	-	50	28	-	560	Unconsolidated
Chaster Creek	45127		New	Unknown	Unknown Well Use	Unlicensed	N	-	160	-	-	-	-	560	Unconsolidated
Chaster Creek	52639	53546	Alteration	Water Supply	Private Domestic	Unlicensed	N	-	117	-	10	98	6	560	Unconsolidated
Chaster Creek	52733		New	Unknown	Unknown Well Use	Unlicensed	N	-	124	-	-	92	-	560	Unconsolidated
Chaster Creek	72226		New	Unknown	Not Applicable	Unlicensed	N	-	138	-	6	-	-	560	Unconsolidated
Chaster Creek	111337		New	Water Supply	Private Domestic	Unlicensed	N	-	335	-	25	245	6	560	Unconsolidated
Chaster Creek	123247	68011	New	Water Supply	Irrigation	Unlicensed	N	-	25	-	-	0	-		
Clough Creek	70654		New	Unknown	Unknown Well Use	Unlicensed	Y	2	60	19	2	-	-	555	Bedrock
Clough Creek	78228		New	Water Supply	Unknown Well Use	Unlicensed	N	-	145	-	50	-	-	555	Unknown
Clough Creek	93728	27211	New	Water Supply	Unknown Well Use	Unlicensed	N	-	105	20	10	20	6	555	Unknown
End/Walker Creek	93323		New	Water Supply	Private Domestic	Unlicensed	N	-	82	-	6	63	6	560	Unknown
Higgs Brook	70665		New	Unknown	Not Applicable	Unlicensed	N	-	320	-	5	-	-	555	Unknown
Higgs Brook	90629		New	Water Supply	Private Domestic	Unlicensed	Y	0.25	81	-	6.5	-	6.62		Unconsolidated
Joe Smith Creek	45200		New	Unknown	Unknown Well Use	Unlicensed	N	-	190	-	10	25	-	1143	Unconsolidated
Joe Smith Creek	70755		New	Unknown	Unknown Well Use	Unlicensed	N	-	105	14	5	-	-	555	Bedrock
Joe Smith Creek	70797		New	Water Supply	Private Domestic	Unlicensed	N	-	200	24	2	100	-	555	Bedrock
Joe Smith Creek	74605		New	Water Supply	Private Domestic	Unlicensed	N	-	250	-	6	-	-	555	Bedrock
Joe Smith Creek	88435	1E+05	New	Water Supply	Private Domestic	Unlicensed	N	-	275	-	6	-	6	555	Unknown
Joe Smith Creek	93320		New	Water Supply	Private Domestic	Unlicensed	N	-	140	-	3.5	-	6	555	Unknown
Joe Smith Creek	95906	27290	New	Water Supply	Unknown Well Use	Unlicensed	N	-	140	16	20	12	6	555	Bedrock

---

[133] Aquifer 1143 in the provincial aquifer database is described as "Not correlated at the time of interpretation / Insufficient info or does not correspond". https://apps.nrs.gov.bc.ca/gwells/aquifers

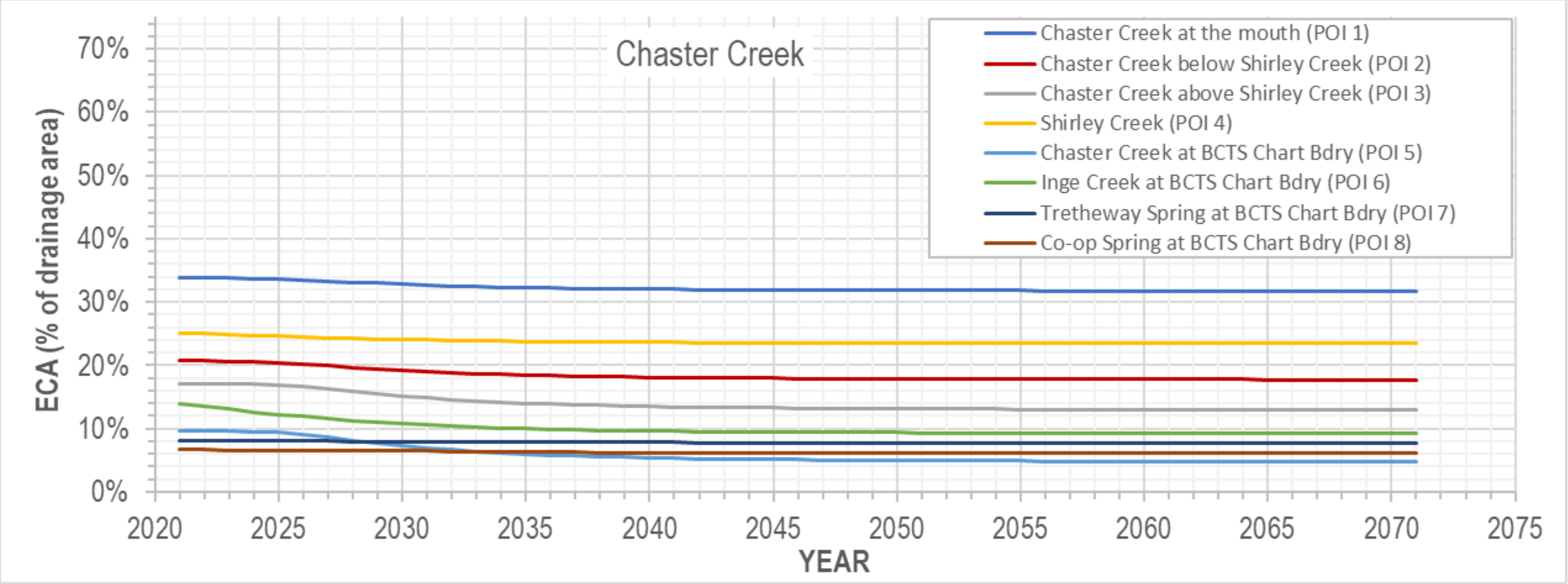
Watershed Unit	Well Tag No.	Plate No.	Well Status	Well Classification	Intended Water Use	Licence Status	Artesian Well	Artesian Well Flow Rate (USgpm)	Finished Well Depth (ft below ground surface)	Bedrock Depth (ft below ground surface)	Yield (USgpm)	Static Water Level (ft below ground surface)	Well Diameter (inches)	Aquifer ID (see footnote)[133]	Aquifer Material
Joe Smith Creek	95913	31004	New	Water Supply	Private Domestic	Unlicensed	N	-	300	38	2	90	6	555	Bedrock
Joe Smith Creek	122581	44143	New	Water Supply	Commercial and Industrial	Unlicensed	N	-	395	29	25	24	6		
Molyneux Creek	90518	16178	New	Water Supply	Private Domestic	Unlicensed	N	-	120	38	5	30	5.75	555	Bedrock
Molyneux Creek	93014		New	Water Supply	Private Domestic	Unlicensed	N	-	165	-	2.5	19	6	555	Bedrock
Slater Creek	93705	27201	New	Water Supply	Private Domestic	Unlicensed	N	-	285	18	5	20	6	555	Unknown
Slater Creek	93735	27202	New	Water Supply	Unknown Well Use	Unlicensed	N	-	220	18	20	25	6	555	Unknown
Slater Creek	94946	27280	New	Water Supply	Unknown Well Use	Unlicensed	N	-	140	38	4	31	6	555	Bedrock
Slater Creek	113756	36614	New	Water Supply	Commercial and Industrial	Licensed	N	-	240	83	5	-	6	555	Unknown
Smales Creek	11398		New	Water Supply	Private Domestic	Unlicensed	N	-	-	-	-	-	-	1143	Unconsolidated
Smales Creek	78316		New	Unknown	Not Applicable	Unlicensed	N	-	530	-	0.8	250	-	555	Unknown
Residual (Btw End/Walker & Chaster)	122981	0	New	Water Supply	Private Domestic	Unlicensed	N	-	30	-	-	-	-		
Residual (Btw End/Walker & Chaster)	11476	0	New	Water Supply	Private Domestic	Unlicensed	N	-	17	-	-	7	-	560	Unconsolidated
Residual (Btw End/Walker & Chaster)	11395	0	New	Water Supply	Private Domestic	Unlicensed	N	-	15	-	-	-	-	560	Unconsolidated
Residual (Btw End/Walker & Chaster)	41759	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	282	-	20	210	-	560	Unconsolidated
Residual (Btw End/Walker & Chaster)	15038	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	8	-	-	-	-	560	Unconsolidated
Residual (Btw End/Walker & Chaster)	17046	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	30	-	-	-	-	1143	Unconsolidated
Residual (Btw End/Walker & Chaster)	17042	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	191	-	-	-	-	560	Unconsolidated
Residual (Btw Smales & End/Walker)	13963	0	New	Water Supply	Private Domestic	Unlicensed	N	-	5	-	-	-	-	560	Unconsolidated
Residual (Btw Smales & End/Walker)	123003	62854	New	Monitoring (OW 497)	Not Applicable	Unlicensed	N	-	354	-	8	317	6	560	Unconsolidated
Residual (Btw Smales & End/Walker)	93321	0	New	Water Supply	Private Domestic	Unlicensed	N	-	130	-	2	117	6	560	Unknown
Residual (Btw Higgs & Smales)	5461	0	New	Water Supply	Private Domestic	Unlicensed	N	-	4	-	-	-	-	1143	Unconsolidated
Residual (Btw Higgs & Smales)	18962	0	New	Water Supply	Private Domestic	Unlicensed	N	-	12	-	-	-	-	560	Unconsolidated
Residual (Btw Higgs & Smales)	14346	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	18	-	-	-	-	1143	Unconsolidated
Residual (Btw Higgs & Smales)	72227	0	New	Unknown	Not Applicable	Unlicensed	N	-	425	242	1	250	-	555	Bedrock
Residual (Btw Higgs & Smales)	115303	52520	New	Water Supply	Private Domestic	Unlicensed	N	-	535	308	40	322	6		Unknown
Residual (Btw Higgs & Smales)	70746	0	New	Water Supply	Private Domestic	Unlicensed	N	-	400	227	1.5	196	-	555	Bedrock
Residual (Btw Higgs & Smales)	74692	0	New	Water Supply	Private Domestic	Unlicensed	Y	2	300	96	2	-	6	555	Bedrock
Residual (Btw Higgs & Smales)	78317	0	New	Water Supply	Unknown Well Use	Unlicensed	N	-	662	-	20	200	-	555	Unknown
Residual (Btw Higgs & Smales)	123030	0	New	Water Supply	Private Domestic	Unlicensed	N	-	18	-	-	-	-		
Residual (Btw Higgs & Smales)	92805	16257	New	Water Supply	Private Domestic	Unlicensed	N	-	500	190	3	181	6	555	Bedrock
Residual (Btw Higgs & Smales)	121439	61104	New	Water Supply	Private Domestic	Unlicensed	N	-	815	236	6.5	372	6		
Residual (Btw Slater & Higgs)	14299	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	185	35	4	24	-	555	Bedrock
Residual (Btw Slater & Higgs)	52318	0	New	Water Supply	Private Domestic	Unlicensed	N	-	465	19	3	-	-	555	Unconsolidated
Residual (Btw Slater & Higgs)	94700	27238	New	Water Supply	Unknown Well Use	Unlicensed	N	-	103	-	7	76	6	560	Unconsolidated
Residual (Btw Joe Smith & Molyneux)	70760	0	New	Water Supply	Private Domestic	Unlicensed	N	-	180	54	6	-	-	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	79164	0	New	Water Supply	Private Domestic	Unlicensed	N	-	170	-	3	41	-	555	Unknown
Residual (Btw Joe Smith & Molyneux)	70749	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	325	33	3	-	-	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	51795	0	New	Water Supply	Private Domestic	Unlicensed	N	-	360	16	1.5	-	-	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	51789	0	New	Water Supply	Private Domestic	Unlicensed	N	-	145	24	10	-	-	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	43635	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	240	17	10	80	-	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	87149	19725	New	Water Supply	Private Domestic	Unlicensed	N	-	202	-	-	-	6	555	Unknown

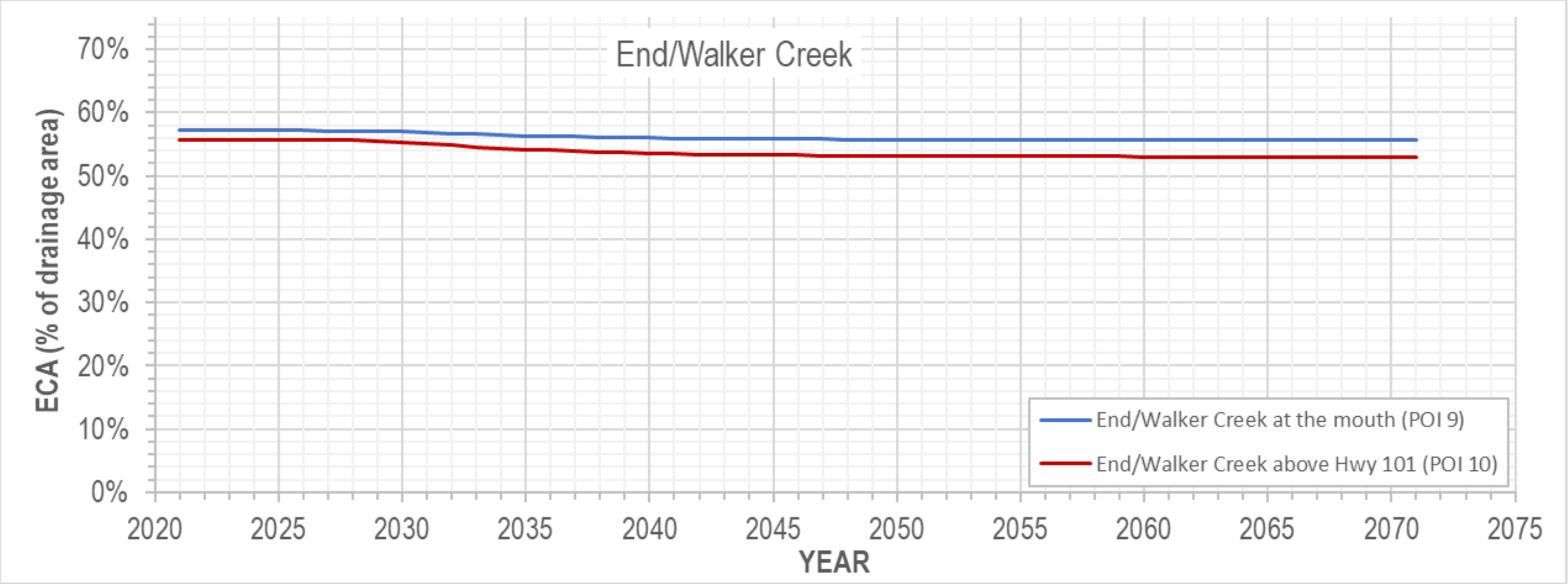
Watershed Unit	Well Tag No.	Plate No.	Well Status	Well Classification	Intended Water Use	Licence Status	Artesian Well	Artesian Well Flow Rate (USgpm)	Finished Well Depth (ft below ground surface)	Bedrock Depth (ft below ground surface)	Yield (USgpm)	Static Water Level (ft below ground surface)	Well Diameter (inches)	Aquifer ID (see footnote)[133]	Aquifer Material
Residual (Btw Joe Smith & Molyneux)	5471	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	10	-	-	1	-	1143	Unconsolidated
Residual (Btw Joe Smith & Molyneux)	92823	16256	New	Water Supply	Private Domestic	Unlicensed	N	-	375	55	3	58	6	555	Bedrock
Residual (Btw Joe Smith & Molyneux)	92656	0	New	Water Supply	Private Domestic	Unlicensed	N	-	320	-	4	8	6	555	Bedrock
Residual (Btw Clough & Joe Smith)	74604	0	New	Water Supply	Private Domestic	Unlicensed	N	-	275	17	2	-	-	555	Bedrock
Residual (Btw Clough & Joe Smith)	49405	0	New	Water Supply	Private Domestic	Unlicensed	N	-	75	-	10	-	-	1143	Bedrock
Residual (Btw Clough & Joe Smith)	53041	0	New	Water Supply	Private Domestic	Unlicensed	N	-	100	20	1	-	-	555	Bedrock
Residual (Btw Clough & Joe Smith)	5326	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	4	-	-	-	-	1143	Unconsolidated
Residual (Btw Clough & Joe Smith)	32184	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	38	-	-	-	-	1143	Unconsolidated
Residual (Btw Clough & Joe Smith)	5500	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	4	-	-	-	-	1143	Unconsolidated
Residual (Btw Clough & Joe Smith)	5467	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	7	-	-	1	-	1143	Unconsolidated
Residual (Btw Clough & Joe Smith)	35094	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	250	57	1	46	-	555	Bedrock
Residual (Btw Clough & Joe Smith)	70711	0	New	Unknown	Unknown Well Use	Unlicensed	N	-	105	26	3	56	-	555	Bedrock
Residual (Btw Clough & Joe Smith)	78229	0	New	Unknown	Not Applicable	Unlicensed	N	-	108	-	5	-	-	555	Unknown
Residual (Btw Clough & Joe Smith)	92786	16292	New	Water Supply	Private Domestic	Unlicensed	N	-	120	-	4	6	6	555	Bedrock
Residual (Btw Clough & Joe Smith)	51879	0	New	Water Supply	Private Domestic	Unlicensed	N	-	50	14	2	12	-	555	Bedrock
Residual (Btw Clough & Joe Smith)	72222	0	New	Water Supply	Private Domestic	Unlicensed	N	-	120	13	6	100	-	555	Bedrock

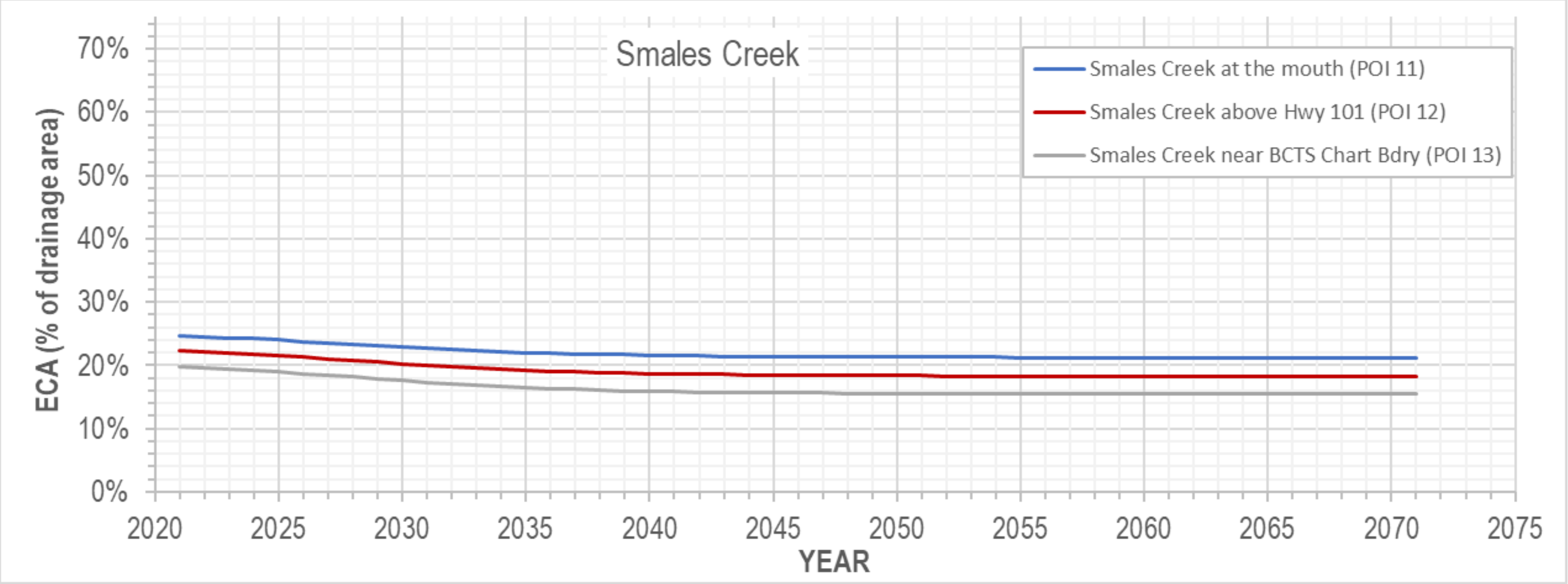
APPENDIX D: ECA PROJECTIONS

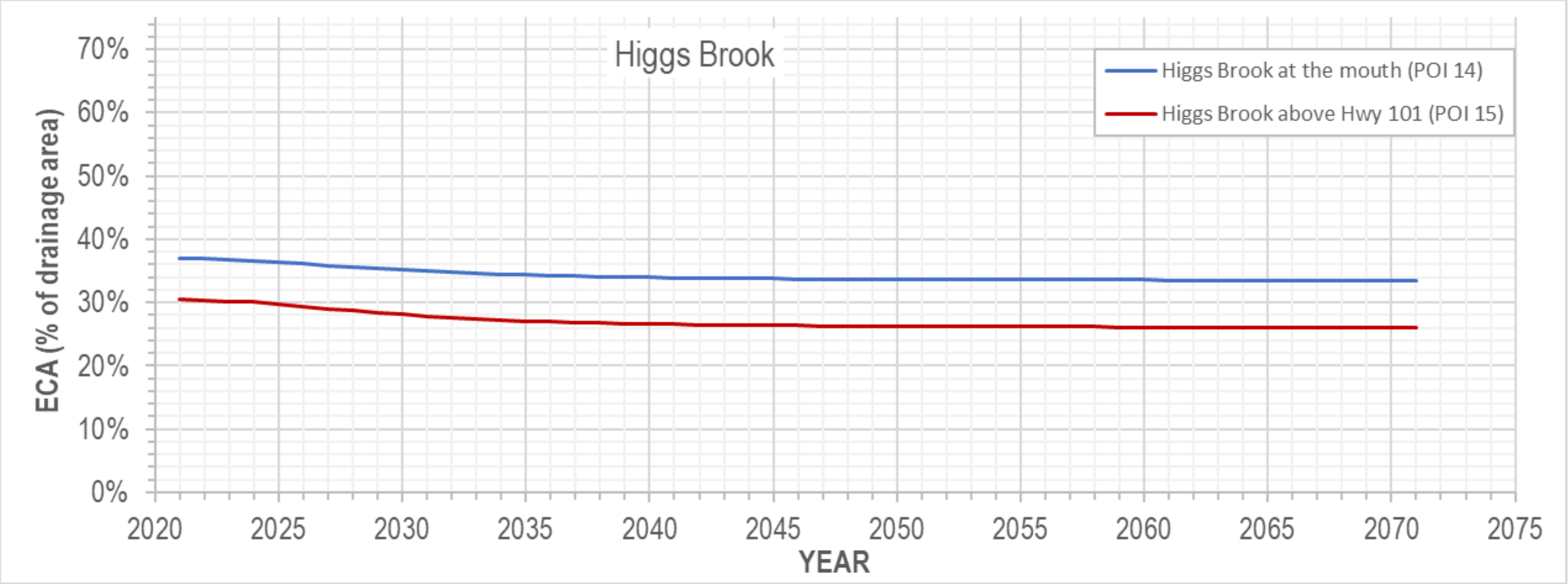
TABLE E.1 *ECA projections over the next 50-years for points-of-interest in the assessment area. ECAs are expressed as a % of drainage area and in hectares.*

Watershed	POI #	POI	Drainage Area (ha)	ECA (ha)							ECA (%)						
				Projection Year							Projection Year						
				0 (2021)	5 (2026)	10 (2031)	20 (2041)	30 (2051)	40 (2061)	50 (2071)	0 (2021)	5 (2026)	10 (2031)	20 (2041)	30 (2051)	40 (2061)	50 (2071)
Chaster Creek	1	Chaster Creek at the mouth	**1,072.9**	363.9	359.2	350.6	343.3	341.5	340.8	340.4	33.9%	33.5%	32.7%	32.0%	31.8%	31.8%	31.7%
	2	Chaster Creek below Shirley Creek	**733.4**	152.5	148.0	139.6	132.6	130.9	130.3	130.0	20.8%	20.2%	19.0%	18.1%	17.9%	17.8%	17.7%
	3	Chaster Creek above Shirley Creek	**399.1**	68.5	66.2	59.3	53.7	52.3	51.9	51.6	17.2%	16.6%	14.9%	13.4%	13.1%	13.0%	12.9%
	4	Shirley Creek	**334.6**	84.1	81.9	80.3	79.0	78.6	78.5	78.4	25.1%	24.5%	24.0%	23.6%	23.5%	23.5%	23.4%
	5	Chaster Creek at BCTS Chart Bdry	**336.6**	32.6	30.4	23.5	17.9	16.6	16.2	16.0	9.7%	9.0%	7.0%	5.3%	4.9%	4.8%	4.7%
	6	Inge Creek at BCTS Chart Bdry	**102.7**	14.3	12.2	10.9	9.8	9.6	9.6	9.5	13.9%	11.9%	10.6%	9.6%	9.4%	9.3%	9.3%
	7	Tretheway Spring at BCTS Chart Bdry	**72.9**	6.0	5.9	5.8	5.7	5.6	5.6	5.6	8.2%	8.0%	7.9%	7.8%	7.7%	7.7%	7.7%
	8	Co-op Spring at BCTS Chart Bdry	**49.7**	3.3	3.3	3.2	3.1	3.0	3.0	3.0	6.7%	6.6%	6.4%	6.2%	6.1%	6.1%	6.1%
End/Walker Creek	9	End/Walker Creek at the mouth	**114.8**	65.7	65.6	65.3	64.3	64.0	64.0	63.9	57.2%	57.2%	56.8%	56.0%	55.8%	55.7%	55.7%
	10	End/Walker Creek above Hwy 101	**64.0**	35.7	35.6	35.3	34.3	34.0	34.0	33.9	55.7%	55.6%	55.1%	53.5%	53.1%	53.0%	53.0%
Smales Creek	11	Smales Creek at the mouth	**94.6**	23.3	22.5	21.5	20.4	20.1	20.1	20.1	24.7%	23.8%	22.7%	21.5%	21.3%	21.2%	21.2%
	12	Smales Creek above Hwy 101	**79.6**	17.8	16.9	15.9	14.8	14.6	14.6	14.5	22.3%	21.3%	20.0%	18.6%	18.3%	18.3%	18.2%
	13	Smales Creek near BCTS Chart Bdry	**72.8**	14.4	13.6	12.6	11.5	11.3	11.3	11.2	19.8%	18.7%	17.3%	15.8%	15.5%	15.5%	15.4%
Higgs Brook	14	Higgs Brook at the mouth	**145.0**	53.7	52.4	50.6	49.1	48.8	48.6	48.6	37.0%	36.1%	34.9%	33.9%	33.6%	33.5%	33.5%
	15	Higgs Brook above Hwy 101	**111.2**	33.9	32.7	31.0	29.5	29.1	29.0	29.0	30.5%	29.4%	27.8%	26.5%	26.2%	26.1%	26.1%
Slater Creek	16	Slater Creek at the mouth	**142.4**	37.2	34.4	33.1	32.1	31.8	31.7	31.6	26.1%	24.2%	23.2%	22.6%	22.3%	22.3%	22.2%
	17	Slater Creek above Hwy 101	**80.6**	19.9	17.1	15.8	14.9	14.7	14.6	14.5	24.7%	21.2%	19.6%	18.5%	18.2%	18.1%	18.0%
	18	Slater Creek at BCTS Chart Bdry	**54.1**	8.6	6.1	5.0	4.2	4.0	3.9	3.8	15.9%	11.3%	9.2%	7.7%	7.3%	7.2%	7.1%
Molyneux Creek	19	Molyneux Creek at the mouth	**264.8**	38.2	36.0	34.9	34.0	33.7	33.6	33.5	14.4%	13.6%	13.2%	12.8%	12.7%	12.7%	12.6%
	20	Molyneux below Tributary 1 and 2	**249.1**	34.6	32.3	31.3	30.4	30.1	30.0	29.9	13.9%	13.0%	12.5%	12.2%	12.1%	12.0%	12.0%
	21	Molyneux Tributary 1	**137.2**	18.6	17.8	17.5	17.2	17.0	17.0	16.9	13.6%	13.0%	12.7%	12.5%	12.4%	12.4%	12.4%
	22	Molyneux Tributary 1 at BCTS Chart Bdry	**107.5**	8.6	8.1	7.8	7.6	7.5	7.4	7.4	8.0%	7.5%	7.3%	7.1%	7.0%	6.9%	6.9%
	23	Molyneux Tributary 2	**111.9**	16.0	14.5	13.8	13.2	13.1	13.0	13.0	14.3%	13.0%	12.3%	11.8%	11.7%	11.6%	11.6%
	24	Molyneux Tributary 2 at BCTS Chart Bdry	**90.5**	8.5	7.5	7.0	6.7	6.6	6.5	6.5	9.4%	8.3%	7.8%	7.4%	7.2%	7.2%	7.2%
Joe Smith Creek	25	Joe Smith Creek at the mouth	**228.6**	57.6	54.7	53.2	51.7	51.3	51.2	51.1	25.2%	23.9%	23.2%	22.6%	22.4%	22.4%	22.3%
	26	Joe Smith Creek above Hwy 101	**190.8**	34.2	31.4	29.9	28.6	28.3	28.2	28.1	17.9%	16.4%	15.7%	15.0%	14.8%	14.8%	14.7%
	27	Joe Smith Creek at BCTS Chart Bdry	**64.6**	6.1	5.2	4.8	4.5	4.5	4.4	4.4	9.5%	8.1%	7.5%	7.0%	6.9%	6.8%	6.8%
Clough Creek	28	Clough Creek at the mouth	**154.1**	31.8	29.6	28.4	27.3	26.8	26.6	26.5	20.6%	19.2%	18.4%	17.7%	17.4%	17.3%	17.2%
	29	Clough Creek above Hwy 101	**134.9**	20.7	18.5	17.3	16.2	15.8	15.6	15.5	15.3%	13.7%	12.9%	12.0%	11.7%	11.5%	11.5%
	30	Clough Creek at BCTS Chart Bdry	**93.2**	6.2	5.5	5.0	4.2	3.9	3.7	3.6	6.7%	5.9%	5.3%	4.5%	4.2%	4.0%	3.9%
	31	Clough Creek at Licence C121146	**79.3**	4.8	4.3	3.9	3.2	2.9	2.7	2.6	6.0%	5.4%	4.9%	4.0%	3.6%	3.4%	3.3%


Chaster Creek
Chaster Creek at the mouth (POI 1)
Chaster Creek below Shirley Creek (POI 2)
Chaster Creek above Shirley Creek (POI 3)
Shirley Creek (POI 4)
Chaster Creek at BCTS Chart Bdry (POI 5)
Inge Creek at BCTS Chart Bdry (POI 6)
Tretheway Spring at BCTS Chart Bdry (POI 7)
Co-op Spring at BCTS Chart Bdry (POI 8)
ECA (% of drainage area)
70%
60%
50%
40%
30%
20%
10%
0%
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
YEAR


End/Walker Creek
End/Walker Creek at the mouth (POI 9)
End/Walker Creek above Hwy 101 (POI 10)
ECA (% of drainage area)
70%
60%
50%
40%
30%
20%
10%
0%
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
YEAR


Smales Creek
Smales Creek at the mouth (POI 11)
Smales Creek above Hwy 101 (POI 12)
Smales Creek near BCTS Chart Bdry (POI 13)
ECA (% of drainage area)
70%
60%
50%
40%
30%
20%
10%
0%
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
YEAR


Higgs Brook
Higgs Brook at the mouth (POI 14)
Higgs Brook above Hwy 101 (POI 15)
ECA (% of drainage area)
70%
60%
50%
40%
30%
20%
10%
0%
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
YEAR

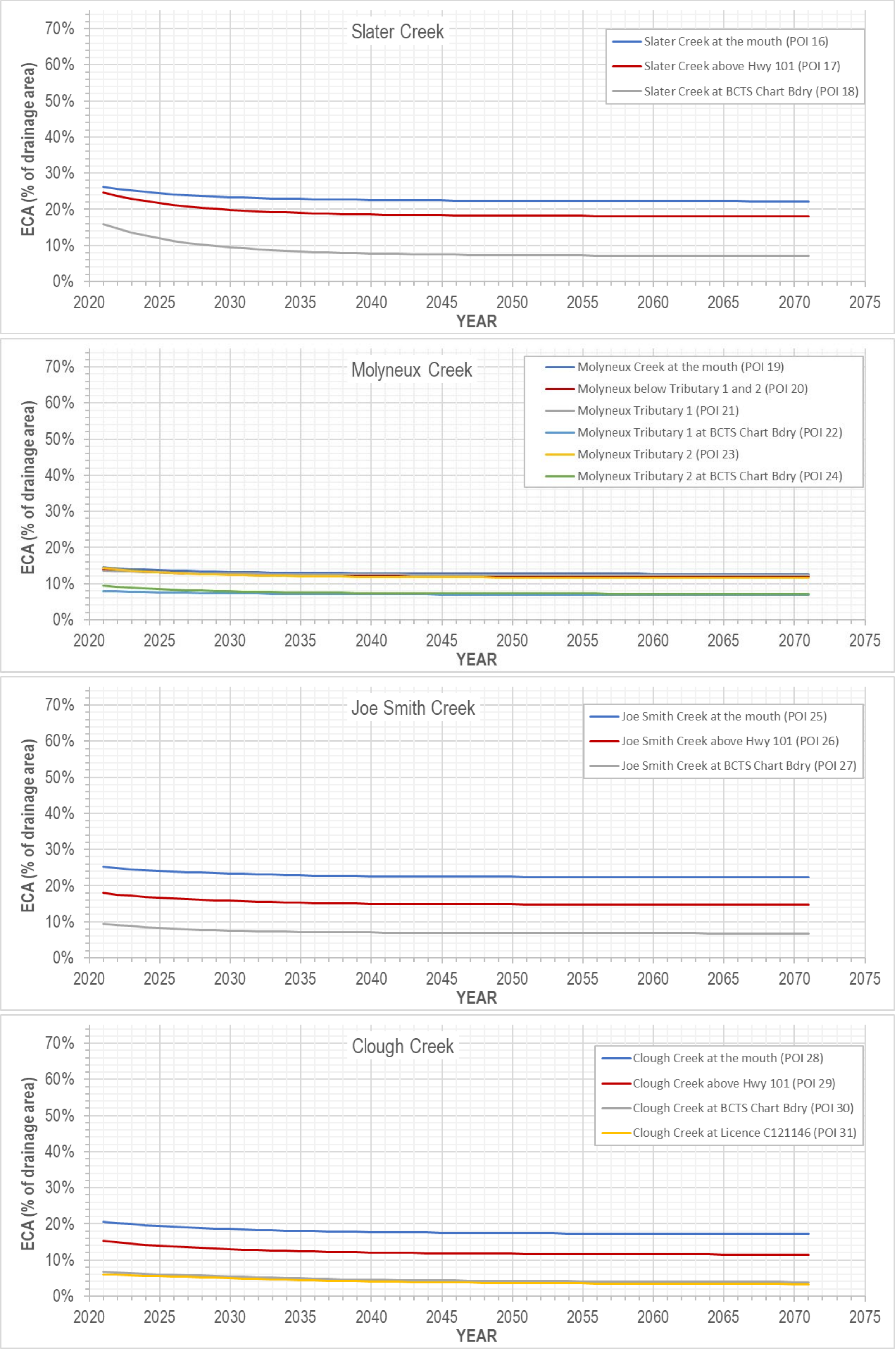


FIGURE E.1 *ECA projections over the next 50-years for points-of-interest in the assessment area. Relatively slow hydrologic recovery is noted for most of the assessment watersheds given the portion of residential and commercial area, where recovery does not occur.*