Watershed Performance Targets for Rainwater Management – French Creek Water Region

Phase 1 – Hydrologic Modelling and Performance Targets

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DISCLAIMER

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EXECUTIVE SUMMARY

The Regional District of Nanaimo (RDN) is located on the eastern coast of Vancouver Island, British Columbia. The RDN is committed to developing a regional strategy on rainwater management, including the development of performance targets to mitigate the impacts of land development. The French Creek Water Region within the RDN has been selected as a pilot area to test the concept and approach of developing watershed performance targets. This study is Phase 1 of the pilot program and focuses on establishing performance targets based on the water balance methodology. In Phase 2, further work on implementation, monitoring, and adaptive management of the performance targets will be completed.

The water balance methodology aims to mitigate adverse impacts from development by mimicking the natural water balance of a watershed. The targets aim to “sink, slow, and spread” rainwater to help replicate natural processes (Partnership for Water Sustainability, 2014). Within this study four targets are specified: baseflow release rate, retention volume, infiltration system area, and flood detention volume.

The overall objectives of the performance targets are ensuring no increase in the magnitude of flood events, providing similar performance below the 2-year duration on a flow duration curve, and maintaining the groundwater component of the water balance.

To establish the performance targets, a hydrologic model of the French Creek water region was developed using U.S. EPA’s HSPF[1] modeling framework and run using a long-term simulation. The model uses hourly data over a 60-year period to simulate runoff under current, pre-development, and future land use conditions. A climate change scenario was also developed using seasonal precipitation multipliers to simulate a decrease in precipitation in the summer and an increase in precipitation in the fall through spring.

The water region was divided into upper, middle, and lower regions based on generalized land use and physiographic character. Performance targets were established for the middle and lower portions of the water region where development pressures are greatest. Targets were not established for the upper portion of the watershed, because it is primarily forested and current long-term plans show minimal change from pre-development to future scenarios. For minor development in the upper region, targets from the mid-region may be applied. If more extensive development were to occur, it is recommended that supplemental analyses take place.

A series of performance targets were established that considered mitigating future development, and future development with climate change, back to both pre-development and current development conditions. Overall, widespread application of the performance targets were able to mitigate adverse changes in flows resulting from the future development condition back to both pre-development and current conditions. The addition of climate change resulted in a need for significantly increased detention volume – particularly in the middle region – which may not be feasible to implement.

[1] HSPF stands for Hydrologic Simulation Program Fortran; Version 12.5 was used for the study.

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1 INTRODUCTION

1.1 Project Overview and Objectives

The Regional District of Nanaimo (RDN) is located on the eastern coast of Vancouver Island, British Columbia. The RDN is divided into seven water regions which are comprised of several watersheds and sub-watersheds spanning from the Nanaimo River north to Deep Bay. Under the Liquid Waste Management Plan (LWMP) approved in 2014, the RDN is committed to developing a regional strategy on rainwater management in coordination with member municipalities (RDN, 2014). As part of the regional rainwater strategy, watershed performance targets and standards to mitigate the impacts of land development will be established.

Prior to implementing regional rainfall performance targets, the French Creek Water Region within the RDN is being used as a pilot area to test the concept and approach. The French Creek Water Region is the smallest water region in the RDN with a total area of 121 km^2. It contains the communities of Qualicum Beach and Parksville along with a growing rural region. A number of creeks are located within the Water Region including French Creek, Grandon Creek, and Morningstar Creek. The region is considered at risk due to rapid development, multiple jurisdictions, as well as existing water quality and runoff concerns (RDN, 2010).

The development and implementation of performance targets for the French Creek Water Region have been split into two phases. Phase 1, covered within this study, focuses on the development of the rainfall performance targets based on a water balance methodology. Background of the water balance methodology is further described in Section 1.2.

Phase 2 of the project will focus on implementation, monitoring, and adaptive management of the performance targets, and is expected to take place in 2022.

1.2 Water Balance Methodology

1.2.1 Background

The development and alteration of natural areas by humans results in an overall change in the natural hydrology of a watershed. Urban development increases the imperviousness of an area, reducing the vegetation coverage and increasing the volume of surface runoff. This increase in surface runoff decreases the moisture captured by the surface soils and volume of water transmitted to deep groundwater. The amount of water available for evapotranspiration back to the atmosphere is also decreased.

These alterations in the overall water balance influence the health of a watershed:

- An increase in surface runoff can result in increased flooding and subsequent damage to properties and development.
- Water quality can be negatively influenced with increased imperviousness and can impact fish habitat (Horner and May, 1998; May et al., 1997).

- Greater peak discharge rates combined with increases in the amount of time (or duration) that flows occur can result in increased erosion and channelization of streams (Booth, 1990; Booth et al., 2002; Booth and Jackson, 1997; Ministry of Environment, 2002).

The goal of the water balance methodology is to mitigate the adverse impacts from development by mimicking the natural water balance of a watershed (Partnership for Water Sustainability, 2014). This can be achieved through watershed specific targets which take into consideration the local climate, soils, hydrology, and groundwater system. The watershed specific targets focus on three pathways which water enters a stream: surface flow, interflow, and groundwater flow. The targets aim to encourage design that "sinks, slows, and spreads" rainwater to help replicate natural processes. The performance targets used to achieve this are:

1. Baseflow Release Rate (L/s/ha of impervious area) – Replicates interflow, used to augment stream discharge
2. Retention Volume (m^3/ha of impervious area) – Replicates interflow storage, used to control interflow rate and allow time for water to infiltrate to the groundwater
3. Infiltration System Area (m^2/ha of impervious area) – Replicates groundwater recharge, area where water can infiltrate to groundwater

These performance targets can be implemented in a watershed through distributed source control design such as infiltration trenches, bioswales, and rain gardens. These facilities are generally well suited for the smaller, more frequent events that make up the majority of rainfall in a year (van der Gulik, T. & Finnie, J., 2008). Additional and separate detention storage is needed to mitigate peak runoff from more extreme storms (e.g., up to 50-year event). This additional flood detention is often more suited to centralized facilities, such as neighborhood-scale stormwater ponds. For the purposes of this study, a fourth performance target, flood detention volume (m^3/ha of development), has been set to control the peak flows.

1.2.2 Performance Target Analysis

In British Columbia, the water balance methodology aims to provide a science-based approach which considers the unique variability of a watershed instead of applying a prescriptive approach (e.g., capture 50% of the mean annual rainfall) (Ministry of Environment, 2002). For this study, the performance targets have been set based on the approach outlined by the Partnership for Water Sustainability (2014):

- Develop a continuous long-term hydrological model representative of current conditions. A continuous model, instead of an event-based model, is required to appropriately simulate the different processes used within the water balance methodology (groundwater, interflow, evapotranspiration).
- Calibrate and verify the hydrological model.
- Simulate pre-development and future conditions, considering land use change and climate change.
- Define performance targets through an iterative process which minimizes retention and infiltration sizes while achieving rainwater management objectives.

For the purposes of this project, the rainwater management objectives used to set the performance targets include:

- No increase in the magnitude of flood events (2-year to 50-year flows);
- No increase in the duration of the 2-year event, and similar performance below the 2-year duration on a flow duration curve;
- The groundwater component of the water balance is maintained. It is important that the groundwater component is not significantly decreased or increased. Loss to the groundwater system can cause issues with baseflow and water availability whereas excessive infiltration can cause local groundwater table and slope stability issues.

1.3 Reference Documents

The following documents were reviewed for regional context, and to inform the assumptions during the development of the hydrologic model, land use, and performance targets.

Regional District of Nanaimo

- Official Community Plans for Areas ‘F’ and ‘G’ (RDN, 2008, 2018a)
- Land Use and Subdivision Bylaw No. 500 (RDN, 2021)
- RDN Liquid Waste Management Plan (RDN, 2014)
- Drinking Water and Watershed Protection Plan (RDN, 2020)
- Floodplain Management Bylaw No. 1469 (RDN, 2018b)
- Lakes District and Schooner Cove ISMP (KWL, 2013)
- Water Budget Project, French Creek Water Region (Waterline Resources, 2013)
- Water Quality Assessment and Objectives for French Creek (Ministry of Environment, 2014)
- French Creek Impervious Surfaces Study (MWLAP, 2001)
- French Creek Watershed Study (MWLAP, 2002)
- Wetland Classification and Geologic Assessment (MABRRI, 2017)

City of Parksville

- Official Community Plan (City of Parksville, 2013)
- City of Parksville Storm Drainage Master Plan (Koers & Associates, 2016)
- City of Parksville Engineering Standards and Specifications (City of Parksville, 2018)
- City of Parksville Works and Services Bylaw No. 1235 (City of Parksville, 2011)
- City of Parksville Sanitary and Storm Sewerage Bylaw No. 1319 (City of Parksville, 1999)
- Shelly Creek Water Balance and Sediment Reduction Plan (Dumont, J., 2017)

Town of Qualicum Beach

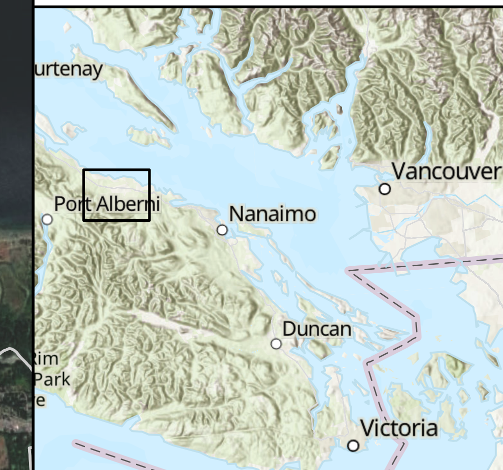
- Official Community Plan (Town of Qualicum Beach, 2018)
- Town of Qualicum Beach Engineering Standards and Specifications (Town of Qualicum Beach, 2016)
- Town of Qualicum Beach Community Climate Change Adaptation Plan (Town of Qualicum Beach, 2020)
- Town of Qualicum Beach Land Use and Subdivision Bylaw No. 580 (Town of Qualicum Beach, 2021)
- Town of Qualicum Beach Sewer Connection and Regulation Bylaw No. 732 (Town of Qualicum Beach, 2019)

General Assessment and Design Guidelines

- Ministry of Transportation and Infrastructure Design Guidelines for Land Development (BC MoTI, 2019)
- Stormwater Planning Guidebook for British Columbia (Ministry of Environment, 2002)
- ‘Beyond the Guidebook’ Series: Introduction to the Guidebook (van der Gulik, T. & Finnie, J., 2008)
- ‘Beyond the Guidebook’ Series: Watershed-Specific Performance Targets (Stephens, K. & Dumont, J., 2008)
- Primer on Integrated Rainwater Management on Vancouver Island (Living Rivers & Partnership for Water Sustainability in BC, 2012)
- Primer on Water Balance Methodology for Protecting Watershed Health (Partnership for Water Sustainability, 2014)
- MMCD Design Guidelines for Stormwater Management (Master Municipal Construction Documents Association, 2014)

2 WATER REGION OVERVIEW

The French Creek Water Region spans north from Parksville to Qualicum Beach on Vancouver Island, extending west up towards Mount Arrowsmith. The upper portion of the water region is characterized by steep, forested slopes with elevations ranging up to 1080 m. Further east, the elevation gradually changes to lowlands primarily used for agricultural and rural purposes with some commercial and industrial land use. The lowest portion of the water region is the most developed, containing the communities of Qualicum Beach and Parksville. An overview of the water region is shown in Figure 2.1.



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- WSC Gauge
- Model Climate Station
- Stream
- Administrative Boundary
- French Creek Water Region

DATA SOURCES: ESRI WORLD IMAGERY; INSET - WORLD TOPOGRAPHIC; WATERSHED AND STREAMS - BC FWA

SCALE - 1:70,000

0 1 2 3 km

N

Coordinate System: NAD 1983 CSRS UTM ZONE 9N
Units: METRES

Job: 3006259 | Date: 18-OCT-2021

FRENCH CREEK RAINFALL MANAGEMENT

OVERVIEW OF FRENCH CREEK WATER REGION

FIGURE 2.1

SWM, \\mainfile-nan\Projects\Active\3006259 French Creek Rainfall Management\95 GIS\3006259_SWM_Figures1to6.aprx

The climate within the region is generally characterized by cool, wet winters and mild, dry summers. Climate normals for Coombs, located in the middle of the water region, are shown in Figure 2.2. Precipitation within the region varies spatially due to topography and the rain shadow of Mount Arrowsmith. The upper portions of the water region can receive upwards of 1900 mm annually, whereas the mid and lower portions receive closer to 1200 mm and 1000 mm, respectively (Wang et al., 2012) .

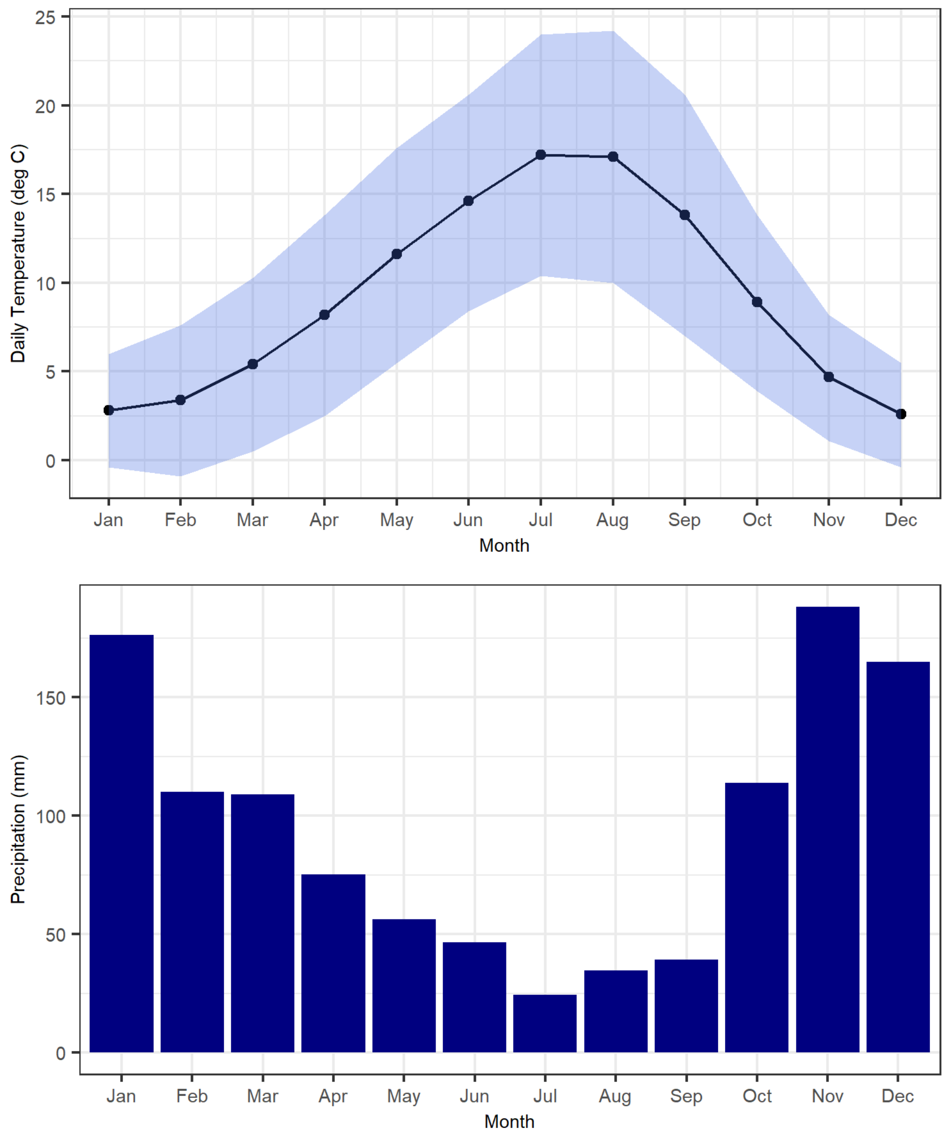


Figure 2.2 Coombs monthly climate normals (1980-2010) for temperature (top) showing mean monthly temperature (black line) and monthly minimum and maximums (blue band) and precipitation (bottom)

Projected impacts of climate change within the region include an increase in average annual temperature and hot days (defined as temperature exceeding 30°C) (Town of Qualicum Beach, 2020). Overall, average annual precipitation is expected to increase; however, a decrease in summer precipitation is expected. Extreme and heavy rain events are also expected to become more intense and more frequent. Changes in precipitation have already been observed within the Georgia Depression ecoprovince, of which the French Creek Water Region is part of, with an increase of average annual precipitation of 14% per century (British Columbia Ministry of Environment, 2016).

The French Creek Water region contains a number of small watersheds, as summarised in Table 2.1, with the largest watershed being French Creek. The region also contains a number of areas without a defined waterbody that discharge directly to the ocean.

Table 2.1 French Creek Water Region Watershed Areas

Watershed	Drainage Area (km^2)
French Creek	66.0
Grandon Creek	7.6
Morningstar Creek	15.9
Romney Creek	6.4
Beach Creek	7.7
Carey Creek	8.9

Peak flow within the region is predominately rainfall dominated, and typically occurs in October through March. Some precipitation in the upper regions of the water region may fall as snow so it is possible for rain on snow events to occur in the upper water region which would contribute to larger peak flows (MWLAP, 2002). Flow within the streams declines from April through September.

The upper, higher-elevation region of French Creek is generally characterized by morainal deposits (glacial till) while the gravelly fluvial, glaciomarine, and marine deposits are more common in the lower slopes and along the streams (BC Ministry of Environment and BC Ministry of Agriculture and Fisheries, 1989). The marine deposits typically consist of silt, sand, and minor gravel units and the glaciomarine units have interbedded units of clay and silt separated from sand and gravel units. The upper morainal deposits range from sand to clay with coarse sediment appearing as large terraces and ridges (MABRRI, 2017).

Two bedrock aquifers and four unconsolidated sand and gravel aquifers and one confined sand and gravel aquifer have been mapped within the French Creek Region (Barroso et al., 2020) Two of the sand and gravel aquifers and one of the bedrock aquifers are used heavily and classified as having moderate vulnerability (Waterline Resources, 2013). In the upper watershed, the bedrock aquifer (220) provides inflows to French Creek for half its length and likely plays an important role in maintaining baseflow in the summertime. In the lower watershed, two of the confined sand and gravel aquifers (216 and 217) feed groundwater or seepage to French Creek (Barroso et al., 2020). Significant recharge areas have been defined from Qualicum Beach all the way up to the upper water region at a coarse scale (Waterline Resources, 2013).

3 HYDROLOGIC MODEL

3.1 Model Selection

Three potential hydrologic modelling software were considered for this study: the Water Balance Model, Hydrological Simulation Program - FORTRAN (HSPF), and the U.S. Environmental Protection Agency Storm Water Management Model (EPA-SWMM). The Water Balance model is a model supported by the Partnership of Water Sustainability in BC and acts as an interface to QUALHYMO that facilitates the water balance methodology set out by the Partnership for Water Sustainability to establish performance targets (Partnership for Water Sustainability, 2014). HSPF is a hydrological model developed and maintained by the U.S. EPA and is used throughout North America for extended hydrological and water quality simulations. HSPF is ideally suited for continuous simulations at a watershed scale. EPA-SWMM (Version 5) is also maintained by the U.S. EPA and is used to simulate single event or continuous hydrological simulations, primarily in urban settings. The benefits and limitations of each model are briefly summarized in Table 3.1.

Table 3.1 Benefits and limitations of hydrological models considered for study

Model	Benefits	Limitations
Water Balance Model	Designed for water balance performance target development Creates required outputs (easier workflow) Long climate term data sets available Can simulate all required flow components (groundwater, interflow, and surface runoff) Can define a range of stormwater treatment practices (e.g. ponds and/or LID)	Watershed scale models are limited to two catchments
HSPF	Default parameter sets available for region Flexible discretization Can simulate all required flow components (groundwater, interflow, and surface runoff) Can define a range of stormwater treatment practices (e.g. ponds and/or LID) Long history and user base for performing continuous simulation applications in similar climates.	Post-processing of results required (frequency analysis, flow duration curves etc.) outside of software
EPA-SWMM	Can define a range of stormwater treatment practices (e.g. ponds and/or LID) through user friendly LID treatment GUI.	Groundwater simulation can be difficult, requires calibration

Based on the benefits and limitations, HSPF (Version 12.5) was selected for this study. It has a long history of use for watershed scale continuous simulation of runoff from mixed land uses in settings like French Creek where the antecedent moisture conditions prior to a storm can be more important than the volume of rainfall alone. HSPF has also become widely popular in the Puget Sound region of Washington State due to the establishment of several regional parameter calibration datasets by the United States Geological Survey-USGS (Berris, 1995; Dinicola, 1990; Mastin, 1996) that were based on calibrations to dozens of headwater subbasins in western Washington and have since been found to provide a reasonable initial calibration in similar environments within the region. Having a reliable initial parameter set is very helpful in basins like French Creek where there is limited monitoring data available for flow calibration. Due to the similarities in the soil and geology of Vancouver Island to that of the basins used by the USGS for its parameter sets, the USGS parameters were also suitable for use as the calibration starting point for this study. Additionally, HSPF can simulate any number of subbasins and streams. Although the Water Balance model is designed for performance target development, the study area for this project requires more than two catchments to adequately capture the numerous streams and differences in climate and topography. SWMM was deemed inappropriate for this study due to the limitations of the groundwater component within the model, and the lack of calibration data for groundwater.

3.2 Model Development and Calibration

The primary inputs to the HSPF model are forcing data (precipitation and evapotranspiration) and spatial data (subbasins, soils, slope, and land use). As noted previously, the USGS regional parameters for HSPF (Dinicola, 1990) were used as the initial parameters for calibrating the model. The parameters include unique parameter sets for different combinations of cover, soil, and slope. These include forest, pasture, and grass land covers along with till, outwash, and saturated soil types common in the region. The following section describes the data inputs used to develop the model and the subsequent model calibration.

3.2.1 Forcing Data

Analysis of local rainfall data sets within the French Creek region show significant variability in recorded rainfall due to the local topography and the rain shadow effect of Mount Arrowsmith. The upper water region receives more precipitation than the mid and lower portions of the water region. Table 3.2 summarises available annual precipitation data at Environment Canada's Qualicum Beach, Coombs, and Cameron Lake station representative of the water region at different elevations.

Table 3.2 Annual average precipitation at regional Environment Canada stations

Location	Station Elevation (m)	Average Annual Precipitation (mm)
Qualicum Beach Airport	58.2	705
Coombs	98.1	1137
Cameron Lake	193.0	1559

To account for the spatial variability, three continuous hourly rainfall datasets from 1962 to 2020 were developed for the lower, mid, and upper water region. The low and mid data sets were based on data at Qualicum Beach and Coombs. For the upper water region, an orographic correction was applied based on the relationship between the lower stations and Cameron Lake. The rainfall datasets are supplemented based on relationships between regional Environment Canada stations (Comox, Nanaimo) and the three local Environment Canada datasets (Qualicum Beach Airport, Coombs, Cameron Lake). Double mass curves between the regional EC stations and local stations were created, with the slope of the double mass curve used as a precipitation multiplier. Table 3.3 summarises the available data and precipitation multipliers. Data from Qualicum Beach Airport was favoured when available over data from Nanaimo and Comox.

Table 3.3 Regional precipitation infill stations

Regional EC Station	Available Daily Data	Available Hourly Data	Precipitation Multiplier		
			Lower	Mid	Upper
Comox	1942-2020	1962-2006	0.729	0.987	1.559
Nanaimo	1947-2020	1985-2016	0.718	1.002	1.583
Qualicum Beach Airport	2006-2020	2014-2020	1.000	1.361	2.150

Monthly evaporation data for the model is based on Environment Canada's monthly pan evaporation normal (1981 – 2010) for the Comox A station. An adjustment factor of 0.75 was used to translate the pan evaporation to potential evapotranspiration values.

3.2.2 Spatial Data

Subbasins

23 subbasins within the French Creek Water Region were delineated. Subbasin boundaries were delineated using the BC Freshwater Atlas (BC Freshwater Atlas, 2018), and were checked against a digital elevation model (DEM) provided by the RDN. The subbasins can generally be categorized into three regions (lower, mid, and upper) which were used to guide the analysis and development of performance targets. Figure 3.1 shows the subbasins and their associated region.

Soils

Surficial geology was classified into three primary categories (till, outwash, saturated soil), which match those used by the USGS parameter sets. Surficial geology data for the region was obtained from the BC MOE (BC Ministry of Environment and BC Ministry of Agriculture and Fisheries, 1989). Soils were classified based on the texture apart from saturated soils which were based on a drainage value of "Very Poor" (Table 3.4). Figure 3.2 shows the distribution of soils within the study area.

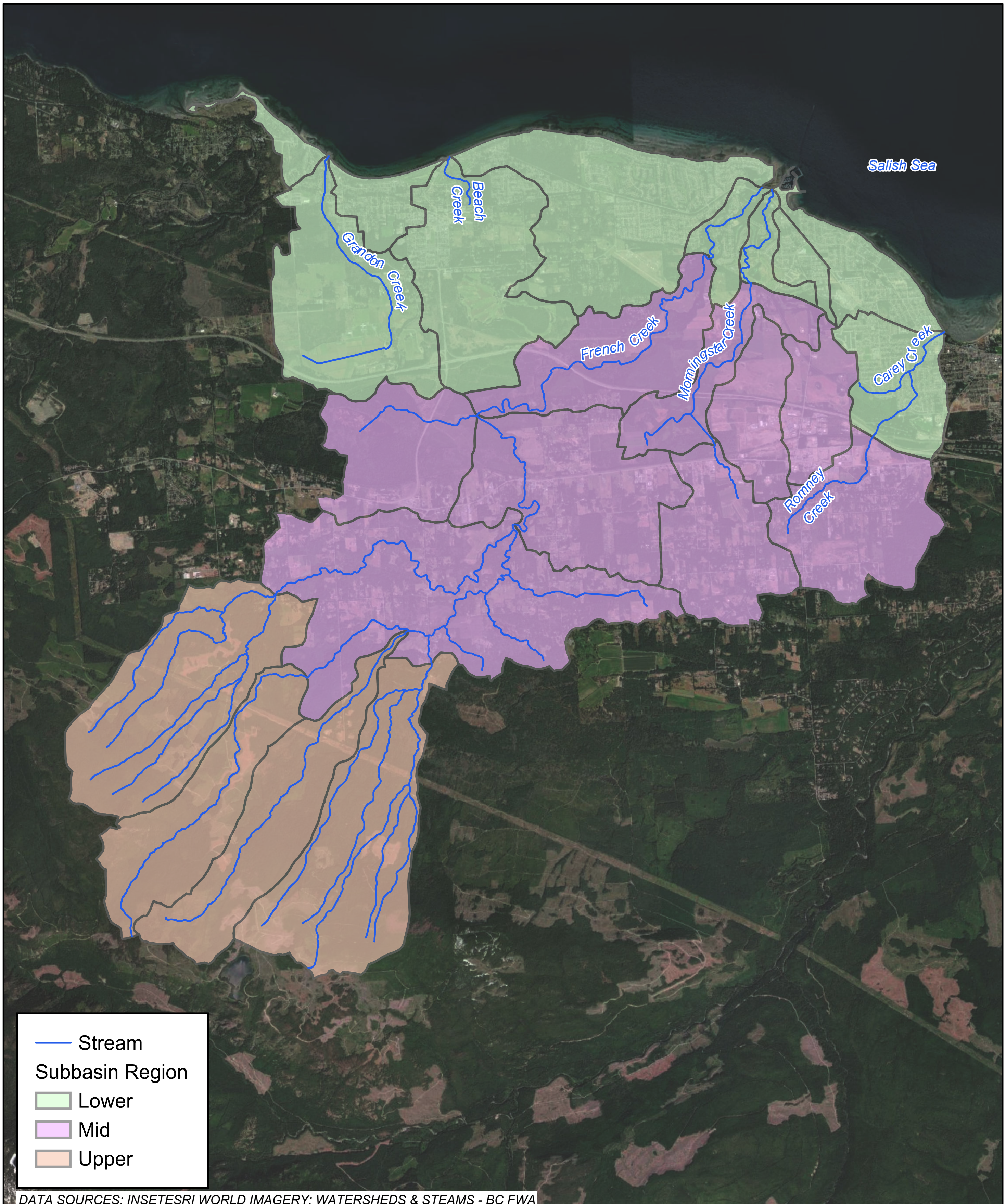
Table 3.4 Model soil classification

Soil Property	Soil Classification	HSPF Classification
Texture	Sandy Loam	Till
	Loam	Till
	Silty Loam	Till

Soil Property	Soil Classification	HSPF Classification
	Sand	Outwash
	Loamy Sand	Outwash
	Silty Clay Loam	Till
Drainage	Very Poor	Saturated

Slope

Within the USGS parameterization, slope is used to differentiate flat (0-6%), medium (6-15%) and steep areas (greater than 15%) that are underlain by till. The DEM provided by the RDN was used to develop slope classifications as shown in Figure 3.3.



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SCALE - 1:90,000

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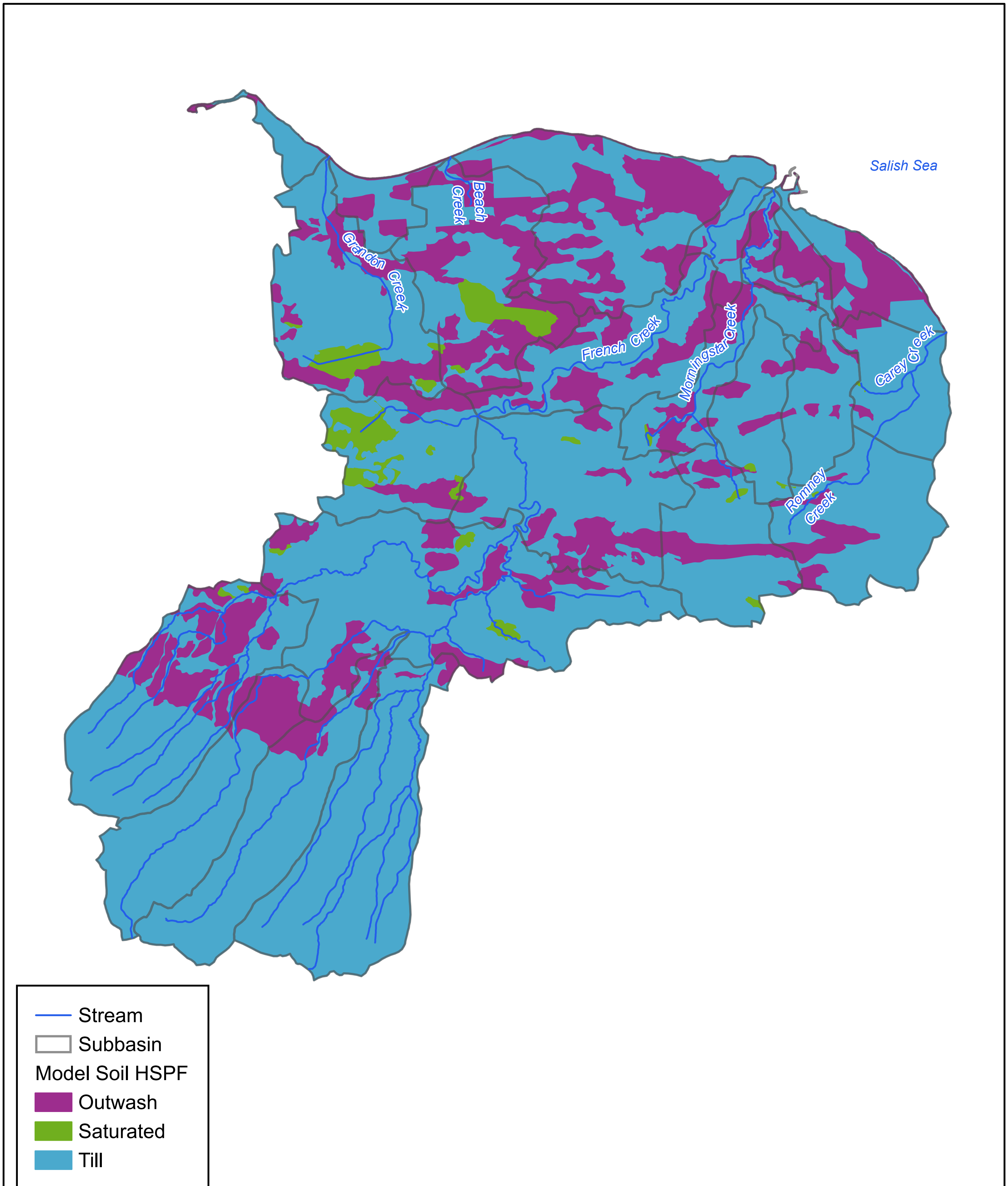
Date: 18-OCT-2021

FRENCH CREEK RAINFALL MANAGEMENT

FRENCH CREEK MODEL SUBBASINS AND REGIONS

FIGURE 3.1

SWM, \\mainfile-nan\Projects\Active\3006259 French Creek Rainfall Management\95 GIS\3006259_SWM_Figures1to6.aprx



DATA SOURCES: WATERSHEDS & STEAMS - BC FWA

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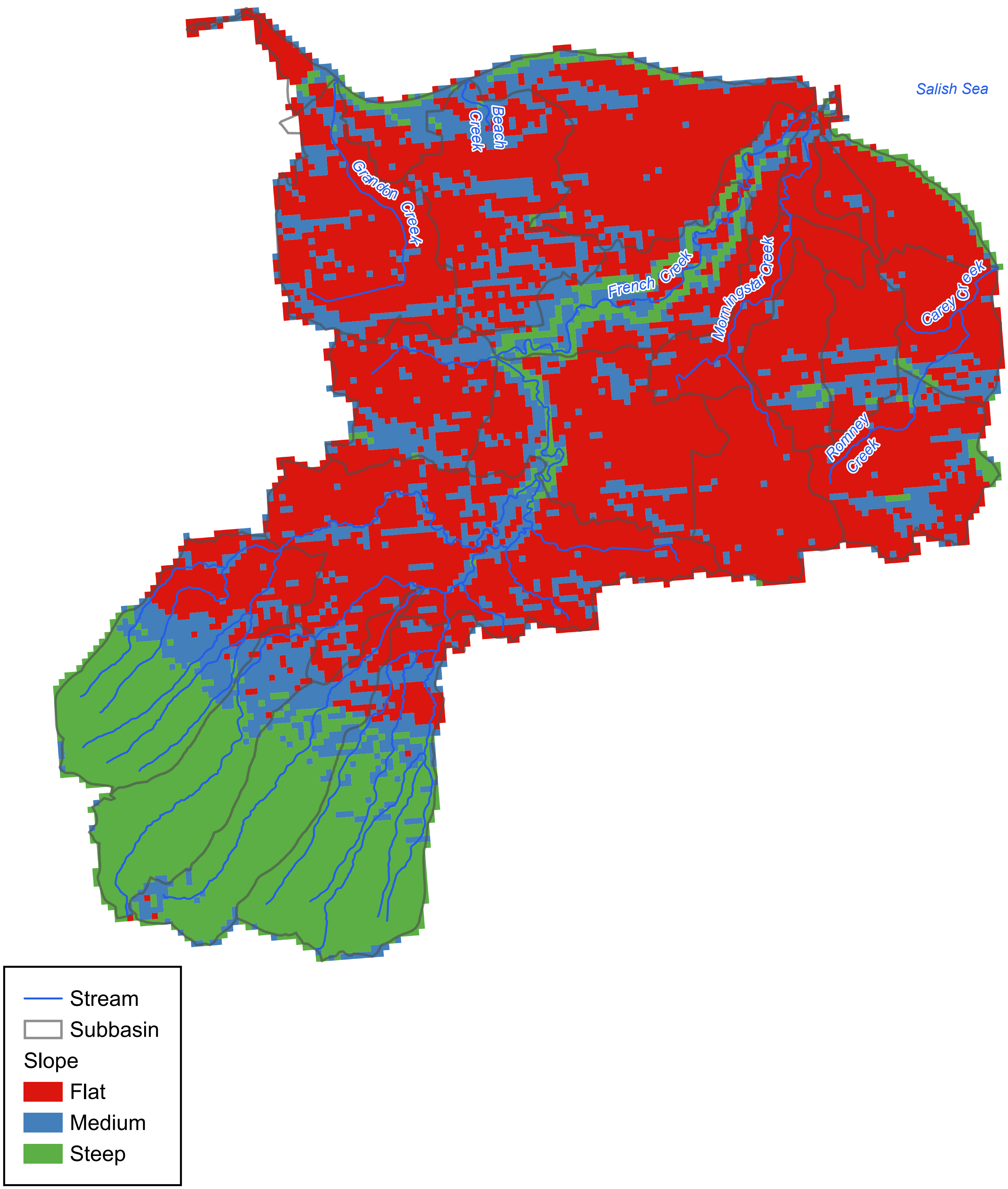
FRENCH CREEK RAINFALL MANAGEMENT

MODEL SOIL CLASSES

FIGURE 3.2



DATA SOURCES: WATERSHEDS & STEAMS - BC FWA

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FRENCH CREEK RAINFALL MANAGEMENT

MODEL SLOPE CLASSIFICATION

FIGURE 3.4

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Land Use and Impervious Areas

Within the study, three land cover scenarios are used: pre-development (forested), current development, and future development. Land cover data at a 30 m spatial resolution is available for 2015 from the Government of Canada (Natural Resources Canada, 2015). However, the resolution of the developed (impervious) areas is very coarse and simply classifies the region as urban. Instead of using the land cover data set, land use classifications (e.g. residential, commercial, industrial) within the region was used in conjunction with representative land cover percentages to create future and current land cover data sets.

For the current scenario, land use data is based on zoning data from the RDN, Qualicum Beach, and Parksville. The future land use scenario is based on official community plan (OCP) land use designations. Each jurisdiction uses slightly different zoning and OCP classification terminology; the land use categories used in the model and how these relate to each jurisdiction's terminology are summarised in Table 3.5 through Table 3.7. Current and future land use distribution is shown in Figure 3.4 and Figure 3.5.

Current zoning data is not representative of actual land use as all zoned areas are not necessarily built out fully. To help compensate for this difference, the land cover data from Natural Resources Canada (2015) was overlain with the zoning data. Where the land cover dataset showed a classification of "forest", a land cover of forest was applied instead of the zoning land cover. Additionally, where the zoning / OCP land use was forested the land cover data was overlain to attempt to get the resolution of open space (i.e. cleared forest, but still vegetated) versus forested land cover.

Table 3.5 Relationship between model land cover and RDN Zoning and OCP Land Use

Model Land Cover	RDN Zoning	RDN OCP Land Use
Agricultural Rural	• Agriculture 1 – 1.27 • Rural 1 – 3 • Rural Residential 2-2.9	• Rural • Rural Residential 1 -3 • Rural Resource
Commercial	• CD-18 Alberni Highway Mini Storage Commercial 1 -6 • Recreation 1 Resort Commercial Zone	• Commercial • Commercial/Industrial Mixed
Comprehensive	• Fairdowne Comprehensive Development • Wembley Comprehensive Development • Comprehensive Development 1 - 51	• Comprehensive Mixed Use • French Creek Mixed Use
Forest	• Conservation 1 Zone • Forest/Resource • Parks and Open Space • Resource Management 4 Zone	• Park Lands • Parkland/Greenspace/Natural Area • Resource • Resource Lands within FLR
Industrial	• Industrial 1 – Industrial 3 • Salvage and Wrecking	• French Creek Harbor • Industrial
Institutional	• Institutional/Community Facility 1 – 2 • Public 1 – 3	• Institutional • Wembley Neighborhood Centre

Model Land Cover	RDN Zoning	RDN OCP Land Use
Medium Density Residential	• Manufactured Home Park 1 – 2 • Residential Zone 1-6 • Village Residential 3 – 3.8	• Neighborhood Residential
Transportation	-	• Transportation Corridor

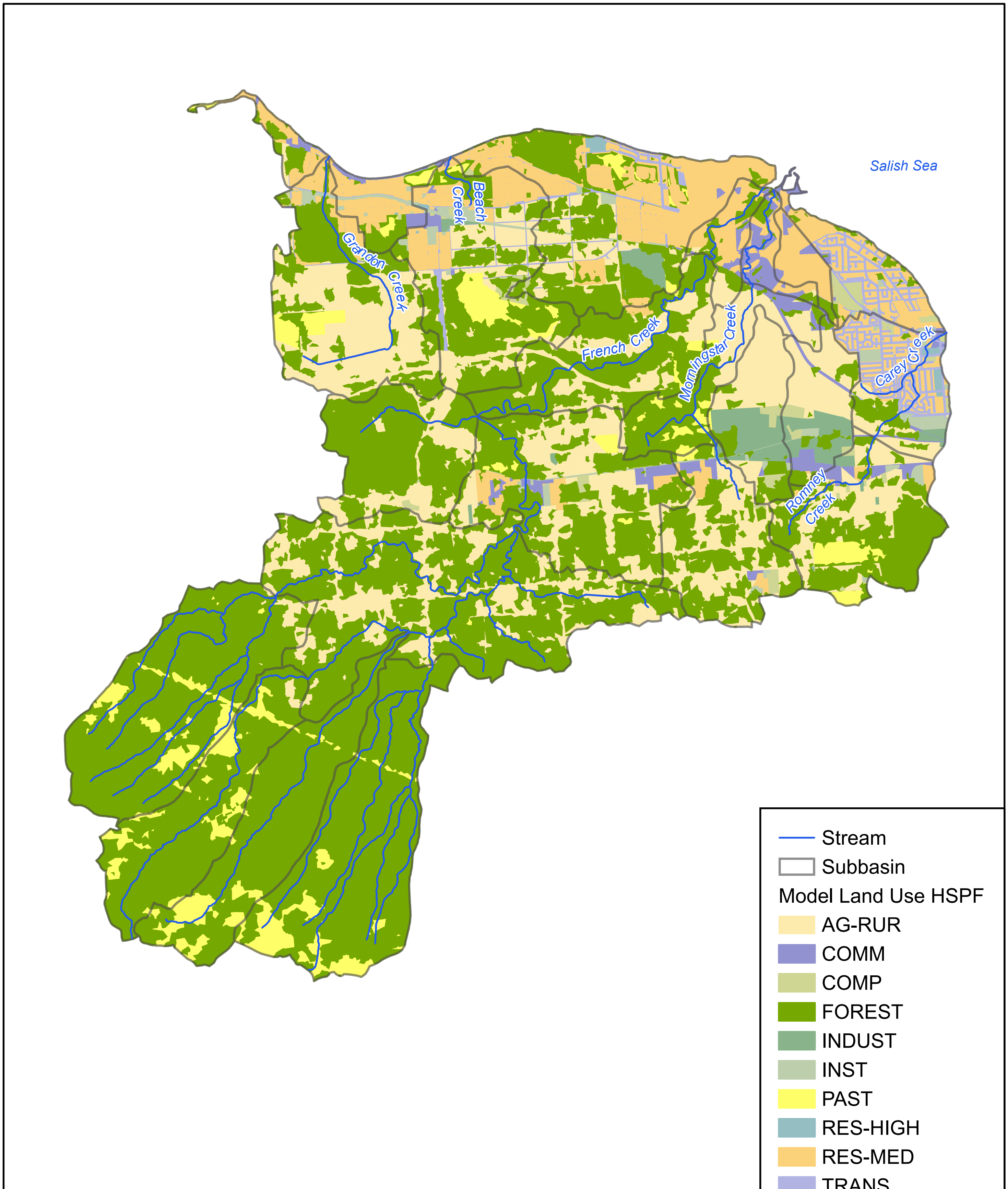
Table 3.6 Relationship between model land cover and Qualicum Beach Zoning and OCP Land Use

Model Land Cover	Qualicum Beach Zoning	Qualicum Beach OCP Land Use
Agricultural Rural	• Rural 1-3 Zone	• Rural
Commercial	• Commercial 1 Zone • Commercial Residential 1 Zone • Utility 1 Zone	• Commercial
Comprehensive	• Comprehensive Development 1 -16 Zone	-
Forest	• Conservation 1-3 Zone • Recreation 1-4 Zone • Water 1 Zone	• Estate Residential • Parks and Recreation • Possible Destination Resort • West Qualicum Beach Open Space
High Density Residential	• Residential 5, 17, 19, 20	-
Industrial	• Industrial 1-2	• Light Industrial
Institutional	• Institutional 1-9	• Institutional • School site
Medium Density Residential	• Residential 1-4, 6-16, 18 • Small Lot Residential 1	• Multi-family residential • Single-family residential • Village neighborhood
Transportation	• Roads	-

Table 3.7 Relationship between model land cover and Parksville Zoning and OCP land Use

Model Land Cover	Parksville Zoning	Parksville OCP Land Use
Agricultural Rural	• Agricultural	• Agricultural
Commercial	• Commercial Tuan • Downtown Commercial • Downtown Residential Commercial • Highway Commercial • Local Commercial • Neighborhood Commercial • Service Commercial • Service Station Commercial • Tourist Commercial	• Downtown core • Highway Commercial • Neighborhood Commercial • Local Grocery • Tourist Commercial • Downtown Waterfront • Mixed Use (Highway Commercial) • Shopping Centre Commercial
Comprehensive	• Comprehensive Development	• Mixed Use (Edge)
Forest	-	• Restricted Recreation
Grass	-	• Parks and Open Space
High Density Residential	• Civic Centre Residential Apartment Zone • High Density Residential	• Multi-unit Residential

Model Land Cover	Parksville Zoning	Parksville OCP Land Use
	• High Density Residential and Care • Mixed waterfront commercial-residential zone • Residential High Density	
Industrial	• Industrial	• Industrial • Industrial (Service)
Institutional	• Civic and technology Center • Health care • Private institutional • Public institutional • Recreation	• Community Use
Medium Density Residential	• Civic Centre Residential Townhouse • Manufactured Home Residential • Medium Density Residential • Resort Area Tourist Accommodation Zone • Single family residential • Small lot residential	• Resort Lands • Transitional Residential Lands • Single Unit Residential
Transportation	• Transportation and Recreation Corridor Zone	-



DATA SOURCES: WATERSHEDS & STEAMS - BC FWA

REGIONAL DISTRICT OF NANAIMO

nhc northwest hydraulic consultants

SCALE - 1:90,000

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Coordinate System: NAD 1983 CSRS UTM ZONE 9N
Units: METRES

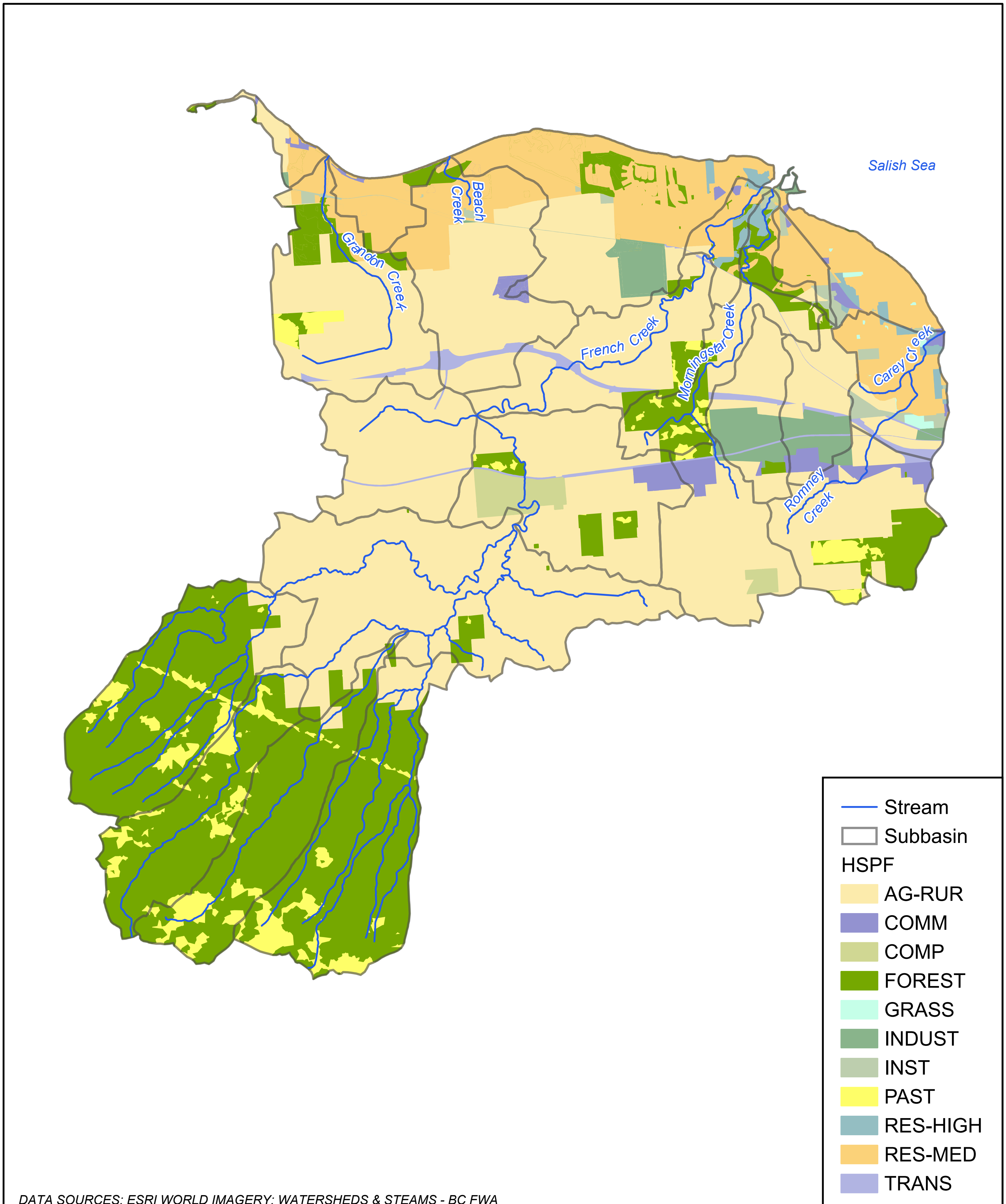
Job: 3006259

Date: 18-OCT-2021

FRENCH CREEK RAINFALL MANAGEMENT

CURRENT LAND USE BASED ON ZONING

FIGURE 3.4



DATA SOURCES: ESRI WORLD IMAGERY; WATERSHEDS & STEAMS - BC FWA

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Coordinate System: NAD 1983 CSRS UTM ZONE 9N
Units: METRES

Job: 3006259 | Date: 18-OCT-2021

FRENCH CREEK RAINFALL MANAGEMENT

FUTURE LAND USE BASED ON OCP

FIGURE 3.5

SWM, \\mainfile-nan\Projects\Active\3006259 French Creek Rainfall Management\95 GIS\3006259_SWM_Figures1to6.aprx

The land use data was translated to land cover based on weighted land cover percentages within each sub-basin. Most importantly, is the effective impervious area (EIA) which generates direct runoff. EIA differs from total impervious area (TIA) in that it is the area which is hydraulically connected to the receiving stream or stormwater system. TIA includes all impervious areas within a development site, including areas which run off to pervious areas, and may be infiltrated or attenuated and cause a very different hydrologic response in the receiving watercourse than runoff from impervious areas that is directed straight into the stream or stormwater system.

Remaining pervious area in the model is split up into forest, pasture (undeveloped land and deforested area), and grass (landscaped areas) which impacts evapotranspiration and runoff generation within the surface and soil layers. The representative land cover percentages are based off NHC's experience with typical development densities within the greater west coast region. EIA was increased between the current and future scenarios to represent additional impervious areas within existing parcels that may not be captured by using OCP land use alone (e.g. construction of patios, garages, sheds, that over time can have a cumulative impact on runoff). Table 3.8 and Table 3.9 summarize the land cover breakdown for each existing and future land use category.

Table 3.8 Current development land cover representation

Land Use	Effective Impervious Area (%)	Forest (%)	Pasture (%)	Grass (%)
Agricultural Rural	4	3	78	15
Commercial	85	0	0	15
Comprehensive	60	0	0	40
Forest	0	100	0	0
Grass	0	0	0	100
Industrial	60	0	0	40
Institutional	45	0	0	55
Pasture	0	0	100	0
High-Density Residential	45	0	0	55
Low-Density Residential	5	15	20	60
Medium Density Residential	20	0	0	80
Transportation	80	0	0	20

Table 3.9 Future development land cover representation

Land Use	Effective Impervious Area (%)	Forest (%)	Pasture (%)	Grass (%)
Agricultural Rural	7	3	68	22
Commercial	90	0	0	10
Comprehensive	70	0	0	30
Forest	0	100	0	0
Grass	0	0	0	100
Industrial	90	0	0	10
Institutional	60	0	0	40
Pasture	0	0	100	0
High-Density Residential	48	0	0	52
Low-Density Residential	10	15	11	64
Medium Density Residential	28	0	0	72
Transportation	90	0	0	10

3.2.3 Calibration

There is limited data within the French Creek region suitable for model calibration. Water Survey of Canada operated a gauge on French Creek from 1990-1996 (French Creek above Pumphouse, 08HB078). For most years only seasonal data exists; however, continuous data is available from October 1994 to March 1996. This period was used for model calibration as it captures both low and high flows.

As previously discussed, a standard regional parameter set from the USGS was used as an initial point for the model calibration. From there, the parameters of the hydrologic units in HSPF were adjusted to visually match the model output to the observed data. The overall simulated and observed hydrographs at a daily time step are shown in Figure 3.6.

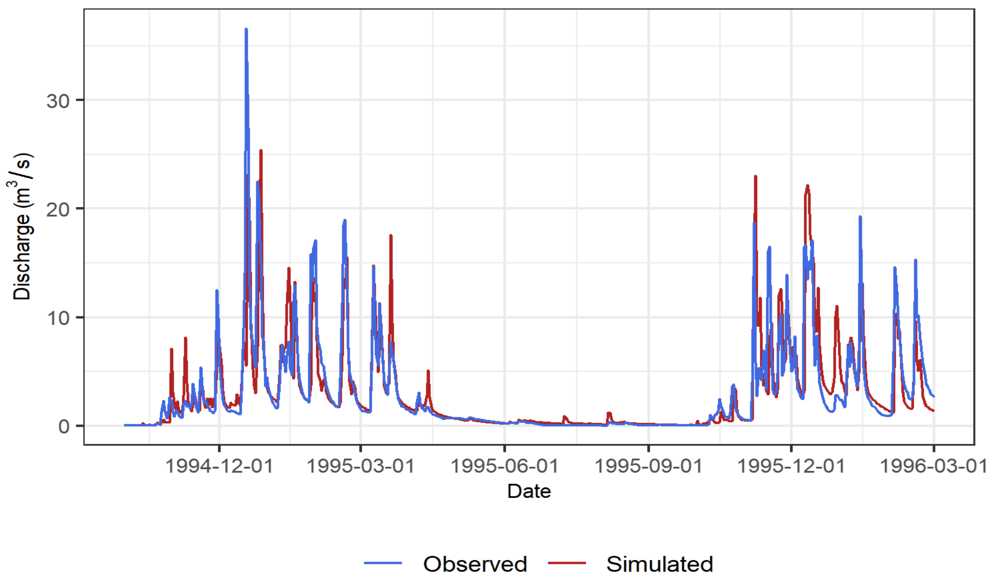

Figure 3.6 Simulated and observed hydrographs at French Creek above Pumphouse

In general, the model can simulate the overall volume well with a percent bias of 6%. The Nash Sutcliffe Efficiency (NSE) of the model during the calibration period was 0.6. NSE is a measure of goodness of fit for hydrologic models ranging from -∞ to 1 with 1 indicating that the observed and simulations are the same. There does not appear to be a consistent bias in over- or under-estimation of peaks.

Remaining unresolved errors in the model calibration are likely due to input data, in particular:

- Wide spatial variation in local precipitation amounts, intensities, and timing is expected across the water region. Attempts were made to capture this variation by using three separate timeseries in the model; however, there would likely be additional variation than is captured by these datasets. Regional precipitation correlations were used therefore the exact timing and magnitudes of precipitation events within the model time series may not be fully accurate.
- The land use dataset used in the model is based on current development conditions; however, the calibration period is 25-years older. The land use changes upstream of the gauge appear to be minor based on a comparison of land use data from 1990 to 2015 (Agriculture and Agri-Food Canada, 2015; Natural Resources Canada, 2015), but changes in development within the water region may impact the calibration.

Despite the limitations with model calibration, we expect the model to be suitable for the purpose of this project, especially since the performance targets will be set based on the relative change between the current condition and other scenarios. Improvement of the model may be achieved in the future if sufficient long-term input and calibration data is collected over a period of several years.

There have been several other gauges installed by Fisheries and Ocean Canada (DFO, Pacfish) near the outlet of French Creek in recent years. This data is understood to be the responsibility of Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) in partnership with Fisheries and Oceans Canada (DFO). This data was not used for calibration due to identified potential stage shifts in the data, short seasonal operation periods (flume data), a lack of discharge measurements at high flows, as well as known issues with the gauging locations. To make this data more useful in the future, we recommend that measurements be taken at higher flows to extend the rating curves. Frequent quality assurance and quality control procedures should also be undertaken to ensure that the data is reliable for hydrologic analyses.

3.3 Model Simulations

3.3.1 Model Scenarios

A number of alternate model simulations were developed based on the calibrated model to inform the development of performance targets. The primary simulations used for the development of performance targets include current condition , pre-development, future land use, and future land use including effects of climate change on precipitation. Two additional simulations looking at the effect of existing policy were also developed for the analysis. Each simulation is described below.

Current

Input data for the current condition model is described in Section 3.2. Land cover within the model is based on existing zoning with some modifications made to better reflect actual land use conditions. The model has been calibrated to observed data on French Creek which gives this model scenario the greatest certainty in simulated flow conditions.

Pre-Development

The pre-development[2] simulation uses the same parameter set as the current condition model. However, the land cover has been modified such that the entire French Creek Water Region is forested. The hydrologic function of wetlands and grasslands which may have existed prior to any development are not accounted for. The pre-development model is used as the baseline scenario for the natural water balance.

Future Development

The future development simulation also uses the same parameter set as the current condition model, with the land cover updated to represent full build-out per the OCP land use classification. The proportion of effective impervious area for the different land covers has been increased to represent infilling and densification from the current condition (see Section 3.2 for additional information on the EIA modification).

Future Development with Climate Change

The future development with climate change simulation uses the future development model as the basis for land use change. To account for potential impacts due to climate change the input precipitation series was modified to represent future conditions. Seasonal multipliers were developed based on mid-century projections for the high-emissions scenario (RCP 8.5) from the CanESM2 climate ensemble

[2] In this report, 'pre-development' refers to the natural, forested condition prior to any land development. 'Current' condition refers to the existing state of land development, and 'future development' refers to the anticipated future land development state based on land use plans.

(Pacific Climate Impacts Consortium, 2021). The multipliers are summarized in Table 3.10 and result in higher precipitation in the fall through spring and lower precipitation in the summer. The overall effect is an increase in average annual precipitation.

Table 3.10 Precipitation multipliers for climate change scenario

Season	Months	Precipitation Multiplier
Winter	December – February	1.12
Spring	March – May	1.12
Summer	June – August	0.73
Fall	September - November	1.04

The use of precipitation multipliers provides a reasonable estimation of potential changes to the water balance under climate change; however, it does not explicitly account for changes in temperature and evapotranspiration, nor potential shifts in the timing of rainfall. Further, the frequency and intensity of extreme rainfall events does not increase. A more detailed analysis which includes changes in temperature, evapotranspiration, and the timing, and frequency of rainfall would be required if the model were to be used to gain a more comprehensive understanding of climate change impacts to the watershed. The purpose of the climate change adjustment for this study is to assess the change in flow durations associated with seasonal precipitation trends, which can be addressed with the seasonal precipitation multipliers.

Existing Policy

There are a number of jurisdictions within the French Creek Water Region responsible for the review of stormwater and drainage plans, including the BC Ministry of Transportation and Infrastructure (MOTI), the Regional District of Nanaimo, The City of Parksville and Town of Qualicum Beach. NHC reviewed policies and design guidelines for each jurisdiction, and found that while strict design criteria are available for managing changes due to development for larger events (5-year or 10-year return periods), language around rainwater management tends to only be suggestive (e.g. developers 'should' or 'are encouraged' to implement rainwater management). While the jurisdictions within the French Creek water region are committed to rainwater management, and outline its importance in many of their policies, the lack of clear requirements means that it is often up to the engineers involved in development to provide their opinion on what rainwater management on new developments will look like. To better understand how much of an impact current policy may have on the overall water balance, NHC developed a model scenario to reflect it.

To represent existing policy within the model, a typical process of stormwater management plans within the region was followed; flood detention storage was provided on new developments to maintain the 10-year return period event to pre-development flow rates for each model sub-basin. The required storage volume was first based on a single event and then increased iteratively to account for additional volume from the continuous simulation. Runoff from the impervious areas of each subbasin was routed through the detention facility. Land use in this scenario was based on the future development land use condition. Applying detention storage to all impervious areas within the sub-basin likely overestimates the attenuation across the basin, since not all existing development areas would be routed through it.

Source controls were not applied to this scenario due to the lack of consistency in rainwater management design requirements across the water region.

Existing Policy and Climate Change

To understand the impact of both existing policy and climate change, the existing policy scenario described above was run with the climate change adjusted data from the future development and climate change scenario. The detention volume of the facilities was not increased to account for the increase in precipitation from climate change, because existing design guidelines do not include a requirement to consider climate change impact on storage when mitigating post-development flows to pre-development levels.

3.4 Model Results

The base scenarios described in Section 3.3.1 helps to develop an understanding of the current and natural water balance and the impact of future development and climate change on the water balance. The current water balance and influence of development and climate change is discussed in the following sections along with the impact of existing policy.

3.4.1 Influence of Development and Climate Change

The water balance for the French Creek water region is reported by the upper, mid, and lower region for the current scenario in Table 3.11 with a monthly summary by region shown in Figure 3.7.

Table 3.11 Current Annual Water Balance for the French Creek Water Region

Water Balance Component	Upper (mm)	Mid (mm)	Lower (mm)
Precipitation	1851	1019	741
Evaporation	454	370	298
Surface Runoff	30	64	121
Interflow	744	206	79
Groundwater	625	382	246

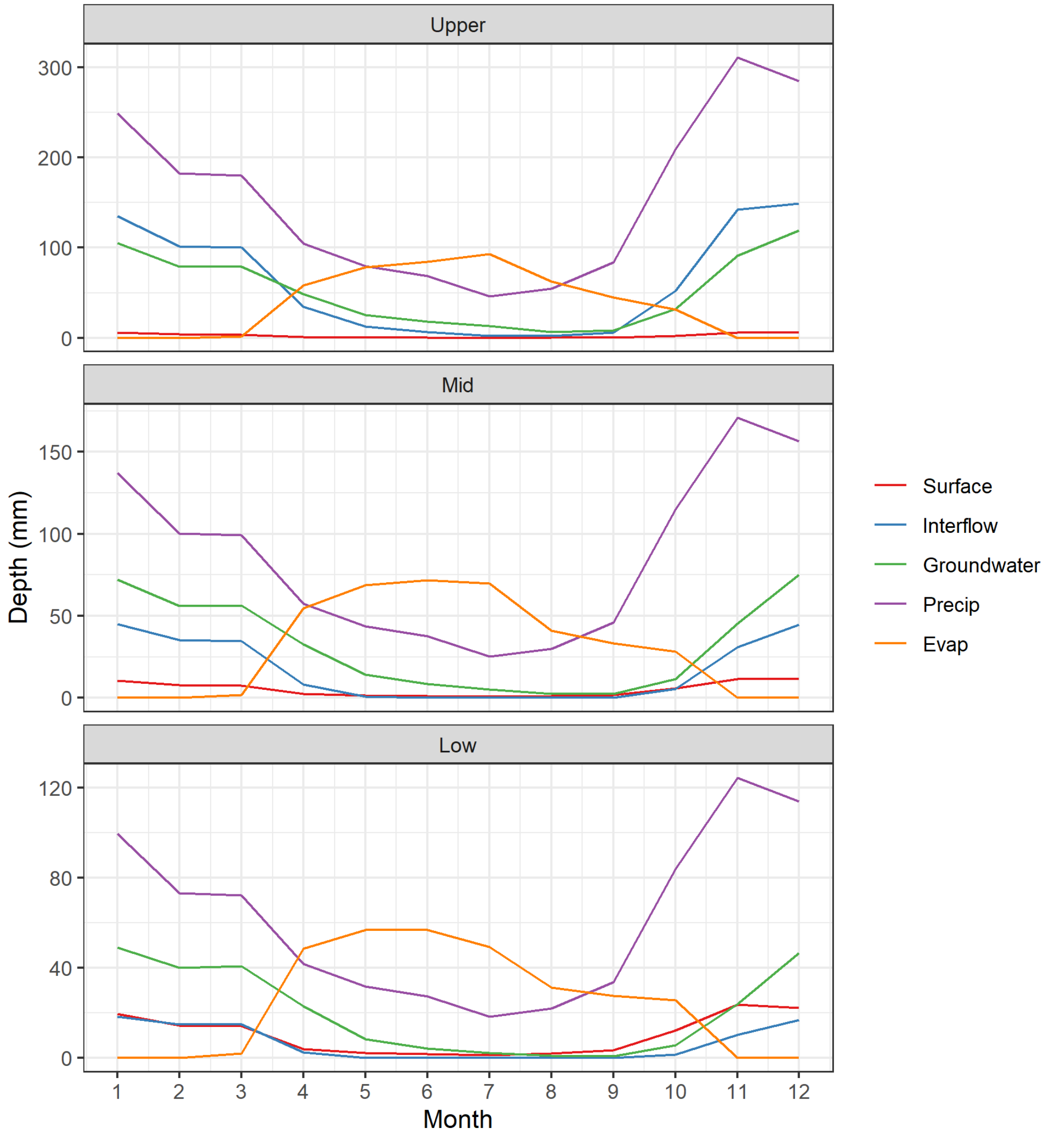

Figure 3.7 Seasonal water balance for the upper, mid, and lower water region under current conditions

Within the current scenario, precipitation is highest in the upper water region and decreases to the lower water region, showing the influence of topography within the region. The amount of evapotranspiration is also the highest in the upper water region because of larger forested areas and a greater amount of moisture available to be evaporated. Surface runoff is the highest in the lower water region where the current conditions are more developed (larger impervious areas) than the mid and upper water region. Conversely, the upper water region has a higher proportion of interflow and groundwater than the mid and lower portions of the water region. This is a result of the development in the mid and lower regions where hardened surfaces reduce infiltration of water to the groundwater system as well as shallow interflow.

A comparison of the water balance under the various development scenarios (pre-development, current, and future) is shown in Figure 3.8. Similar trends are seen in the upper, mid, and lower regions across the water region; however, the relative impact is much greater in the mid and lower regions where there is more extensive development. As development increases from the pre-development to future condition, there is an increase in the surface runoff. This increase in surface runoff decreases the volume of water transmitted back to groundwater as well as decreases the amount of water available for evapotranspiration and interflow.

The climate change scenario, at the scale of the annual water balance, shows the overall increase in precipitation across the basin, and consequent increases in each component of the water balance. The relative proportion of evaporation, surface runoff, interflow, and groundwater flow remain the same as the future scenario.

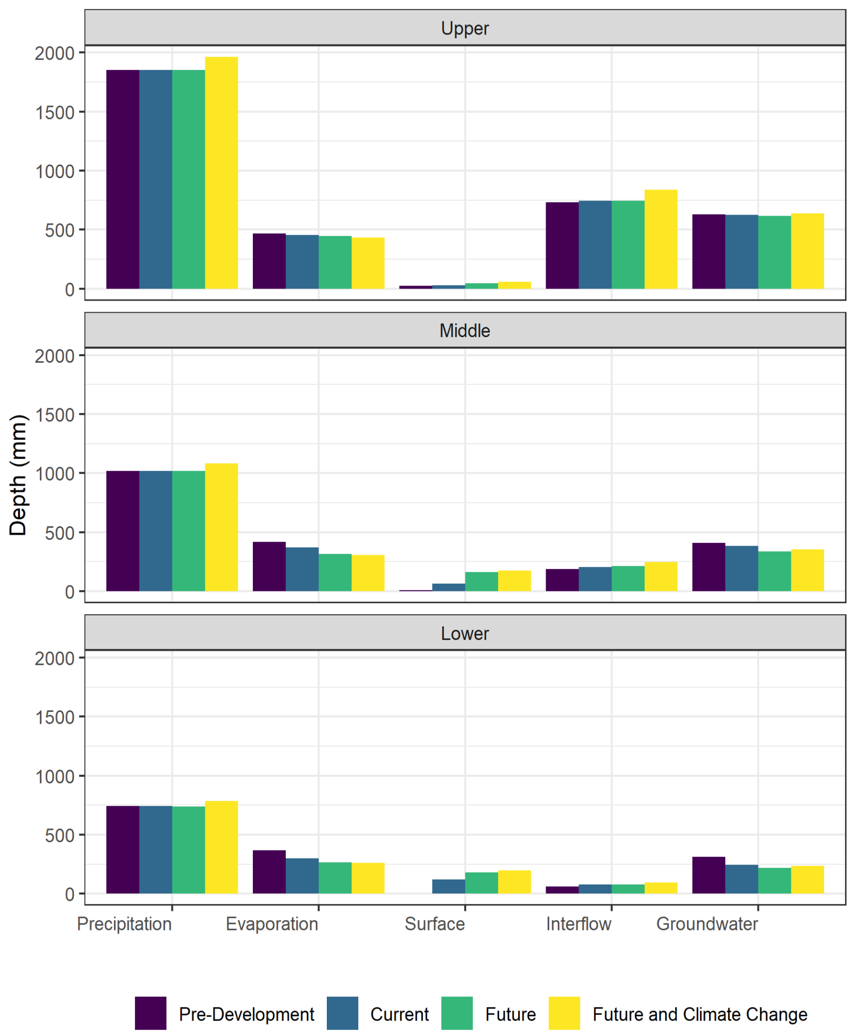

Figure 3.8 Overview of the water balance for the upper, mid, and lower region of the French Creek Water Region

Flow duration exceedance (FDE) curves were developed for each model scenario, as shown in Figure 3.9. FDE curves show the proportion of time specified discharges were exceeded over the model simulation period. The 2-year return period flows and mean annual discharge from the current condition model are shown on the figures for reference.

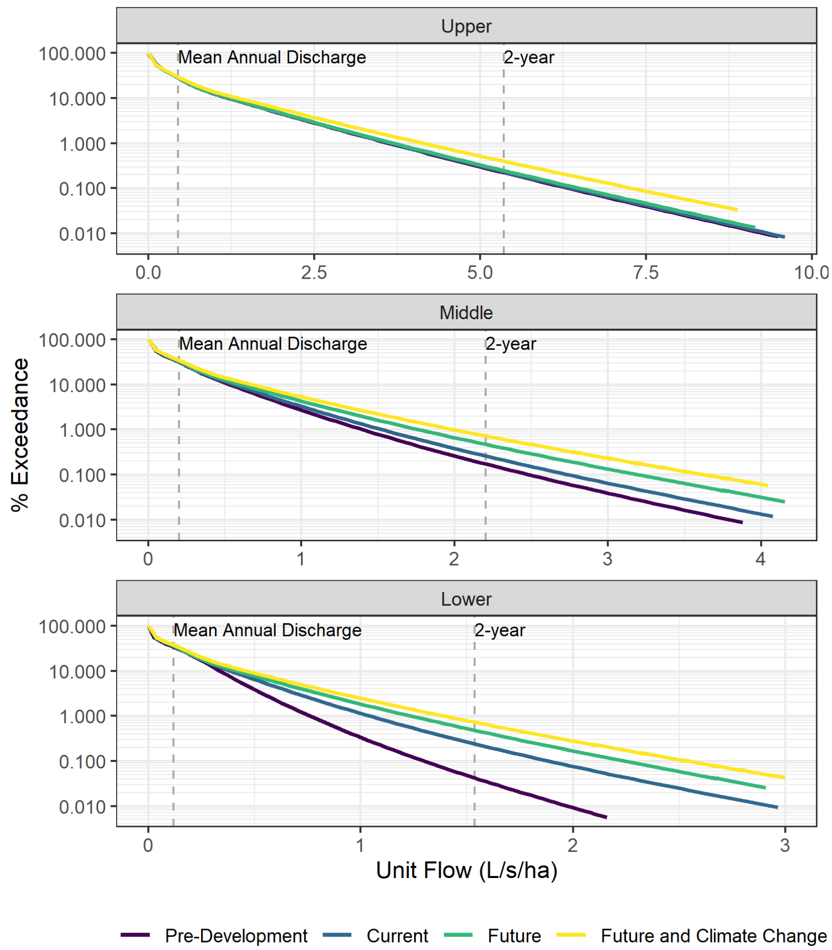

Figure 3.9 Flow duration curves for the upper, middle, and lower French Creek Water Region

The FDE curves show a negligible impact between the pre-development and future condition in the upper water region. This is a result of the upper water region being predominantly forested in all three development conditions (pre-development, current, and future). At the scale of the model, temporary hydrological impacts due to forestry (change in canopy age, disturbances to soil, etc.) are not modelled. It is likely that there are in fact temporary and local impacts within this region. At a site or stand scale typical hydrologic impacts related to forest disturbance (clear cuts and development of roads and infrastructure) include a decrease in interception and evaporation and a subsequent increase in soil moisture available for streamflow (Winkler et al., 2010). The increase in water availability can cause rapid and higher peaks and greater summer low flows after harvesting. The magnitude of increase in peak flow and low flows varies depending on the spatial distribution and area of disturbance, and watershed storage capacity relative to the water input. For the purposes of this project, it is assumed that best management practices within the forestry industry are followed and implemented in the upper water region and that performance targets will not be used to dictate forestry practices. This may include measures such as considering climate change precipitation patterns when designing equivalent clear-cut area (ECA) limits, retaining or restoring riparian vegetation next to streams, designing infrastructure to accommodate increased flows, and avoiding locating roads and cutblocks above unstable terrain (Ministry of Forests, Lands and Natural Resource Development, 2016). Increased flows in the upper region are seen in the climate change scenario, where overall precipitation and runoff is greater. Within the middle and lower water region, the flow duration curves show a shift towards a greater duration of flows with both development and climate change.

A flood frequency analysis was also performed for each scenario, as shown in Figure 3.10. The regional frequency analysis was performed by fitting a generalized extreme value (GEV) distribution to the modelled peak flows using the method of L-moments in the statistical language ‘R’ (Hornik, 2016). Similar to the flow duration curves, the upper portion of the water region shows no substantial change between pre-development and future conditions due to limited change in land cover. However, the increase in precipitation because of climate change results in increased peak flows in the upper region. The mid and lower regions show an increase in flows with increased development and climate change.

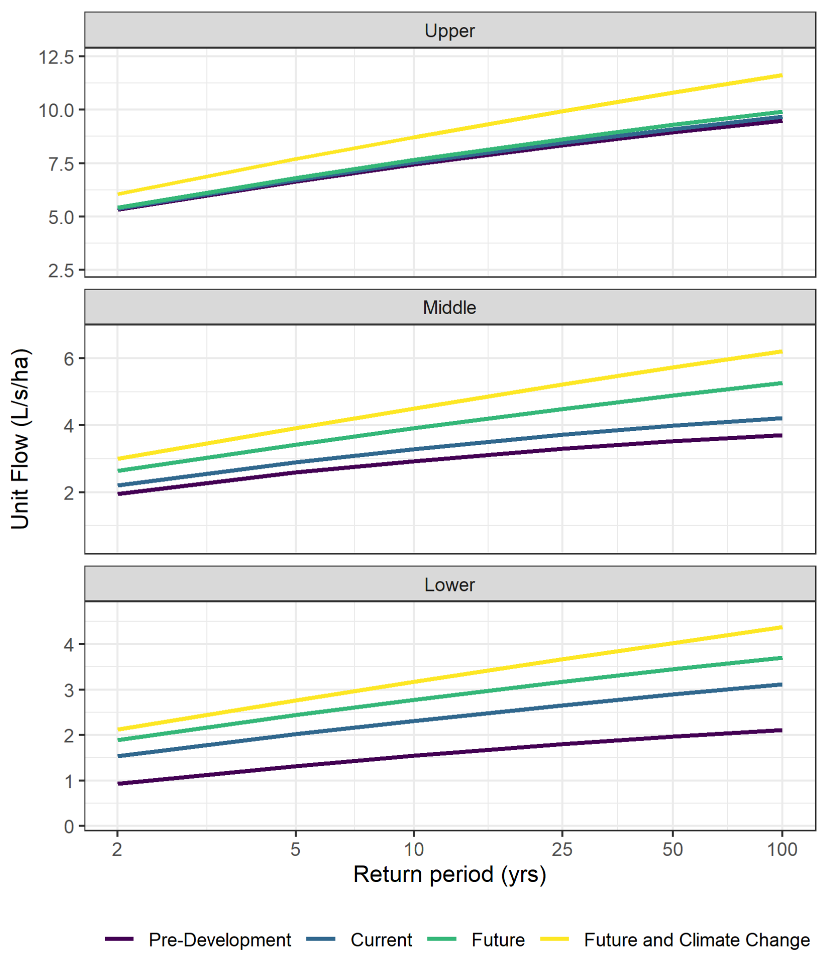

Figure 3.10 Frequency analysis for the upper, middle, and lower French Creek Water Region

Figure 3.11 shows the mean annual hydrograph for the four different scenarios. There is a distinct shift in the timing of the rise of the hydrograph from pre-development to developed conditions. As development occurs, less water is transmitted through the deep groundwater which has a longer time lag. Since less water is being transmitted via the deep groundwater and instead by interflow and surface flow there is a quicker increase in flow between October and January. Additionally, the forested units within the model have a greater capacity to hold moisture (soil and interception) than the impervious and developed area resulting in additional lag time to saturate the system enough to produce runoff relative to the developed area. During the low flow period (July through September) the developed conditions have a higher rate, likely due to the quick response when rainfall does occur versus the slower transmission during pre-development conditions.

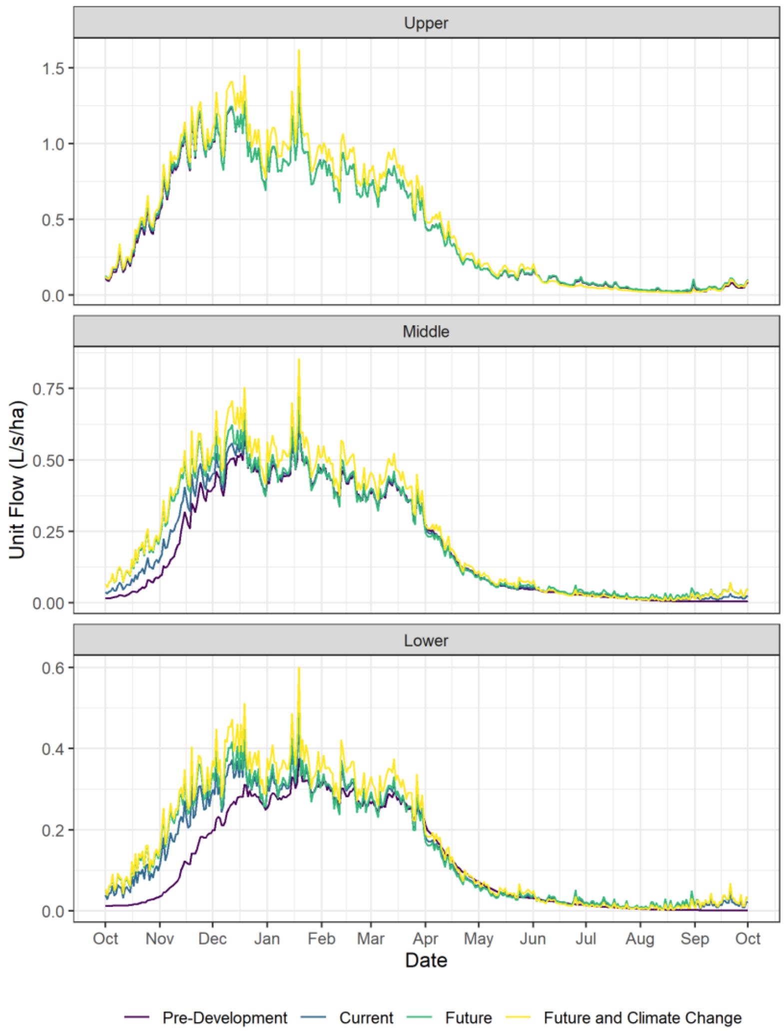

Figure 3.11 Daily average annual hydrograph for the upper, mid, and lower water region under different development scenarios

Other hydrologic indicators were examined to show the impact of development including the high pulse count, high pulse count range, and the average annual and seasonal 7-day low flows (Table 3.12). These indicators help show the impact of development but can also be used during performance target development and monitoring to show the influence of performance targets on stream health. High pulse count is the number of times daily flow increases above twice the mean annual discharge. High pulse range is the count of the number of days between the first high pulse and last high flow pulse during a water year. High pulse counts and range have been correlated with measures of development and degradation of biological health (DeGasperi, C.L. et al., 2009). An increase in high pulse count and high pulse range is expected in response to land development. The mean annual high pulse counts are shown in Table 3.12. As expected, an increase in pulse counts is seen in response to an increase in development. No significant difference is observed between the future and future and climate change scenario. The high pulse count range also increases with increased development but indicates that high pulses are not seasonal even in the pre-development condition.

The analysis of low flows provides an indication of the watershed's baseflow response to development and climate change. The 7-day low flows during the wet season (winter) baseflow decrease with increased development due to the redistribution of runoff from subsurface flow to overland flow (Konrad and Booth, 2002). In the dry-season (summer) low flows have increased with development. This can be caused by the replacement of forests with more shallow vegetation which consumes less water overall. Since the summer low flows do not decrease in a similar manner as during the wet season, this may indicate that urbanization impacts the shallow subsurface flow much more than deep subsurface flow which maintains summer baseflow (Konrad and Booth, 2005; Rosburg et al., 2017). Less precipitation during the summer months in the climate change scenario results in lower baseflows whereas greater precipitation during the winter months ends up increasing baseflow.

Table 3.12 Mean annual high pulse count, range and 7-day low flows for the upper, mid, and lower water region under different development scenarios.

Region	Scenario	High Pulse Count	High Pulse Count Range (days)	Annual 7-Day Low Flow (L/s/ha)	Summer 7-Day Low Flow (L/s/ha)	Winter 7-Day Low Flow (L/s/ha)
Upper	Pre-Development	14	342	0.0051	0.013	0.231
	Current	14	342	0.0071	0.015	0.229
	Future	15	342	0.0080	0.015	0.227
	Future and Climate Change	15	344	0.0057	0.010	0.239
Middle	Pre-Development	9	320	0.0012	0.004	0.152
	Current	12	327	0.0030	0.006	0.150
	Future	15	340	0.0040	0.007	0.138
	Future and Climate Change	15	341	0.0029	0.005	0.147
Lower	Pre-Development	6	279	0.0003	0.001	0.102
	Current	16	342	0.0010	0.002	0.102
	Future	20	345	0.0014	0.003	0.093
	Future and Climate Change	20	345	0.0011	0.002	0.101

3.4.2 Existing Policy

The impact of existing policy on the water balance and hydrologic function was also examined. Existing policy was only applied to the mid and lower portions of the water region where the impacts of development are most prominent.

In terms of the water balance, if the outflow from the detention is considered as surface runoff, the proportion of the overall water balance does not change between the existing policy scenarios and the future unmitigated development scenarios, as shown in Figure 3.12. There is a continued loss to the groundwater as existing policy does not address infiltration.

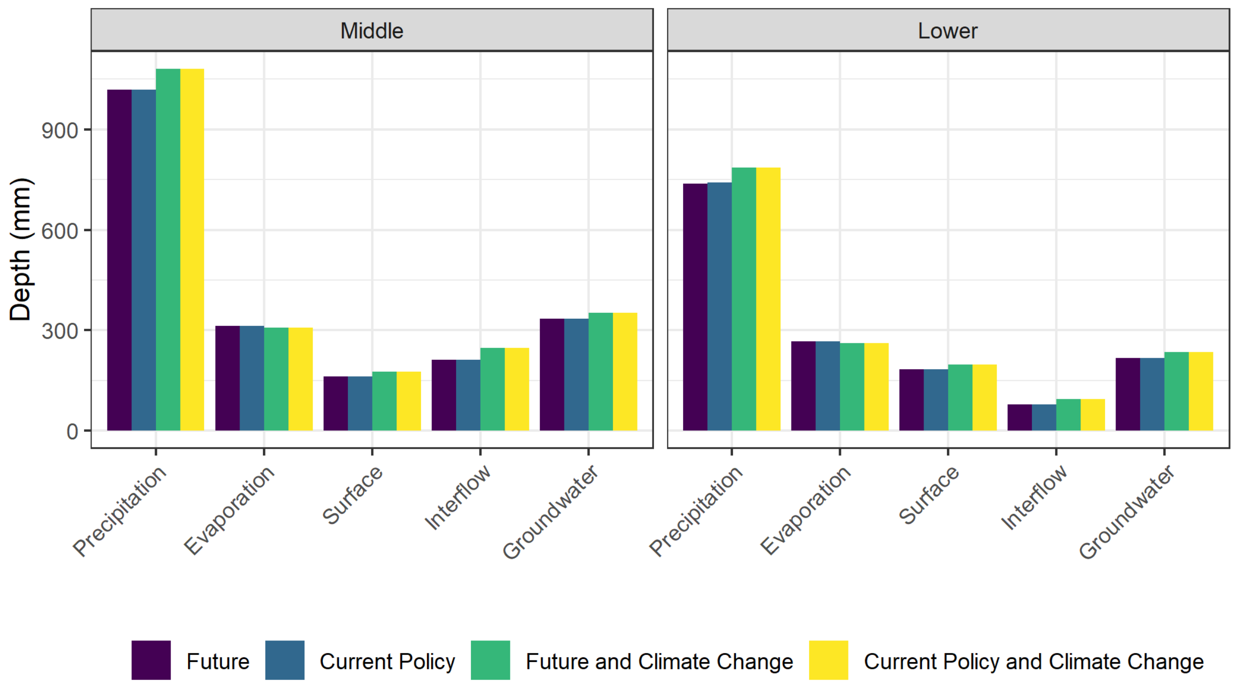

Figure 3.12 Influence of current policy on future water balance.

Although the overall water balance does not change compared with the future condition (i.e. unmitigated future land use), the existing policy does reduce peak flows within the water region. Figure 3.13 shows the mitigated peak flows from the existing policy scenario. Detention storage can reduce peaks to the pre-development levels. However, in the climate change scenario these flows are not completely reduced back to pre-development levels. Existing policy would have to be modified to ensure that climate change is accounted for during to design to reduce peak flows back to pre-development levels.

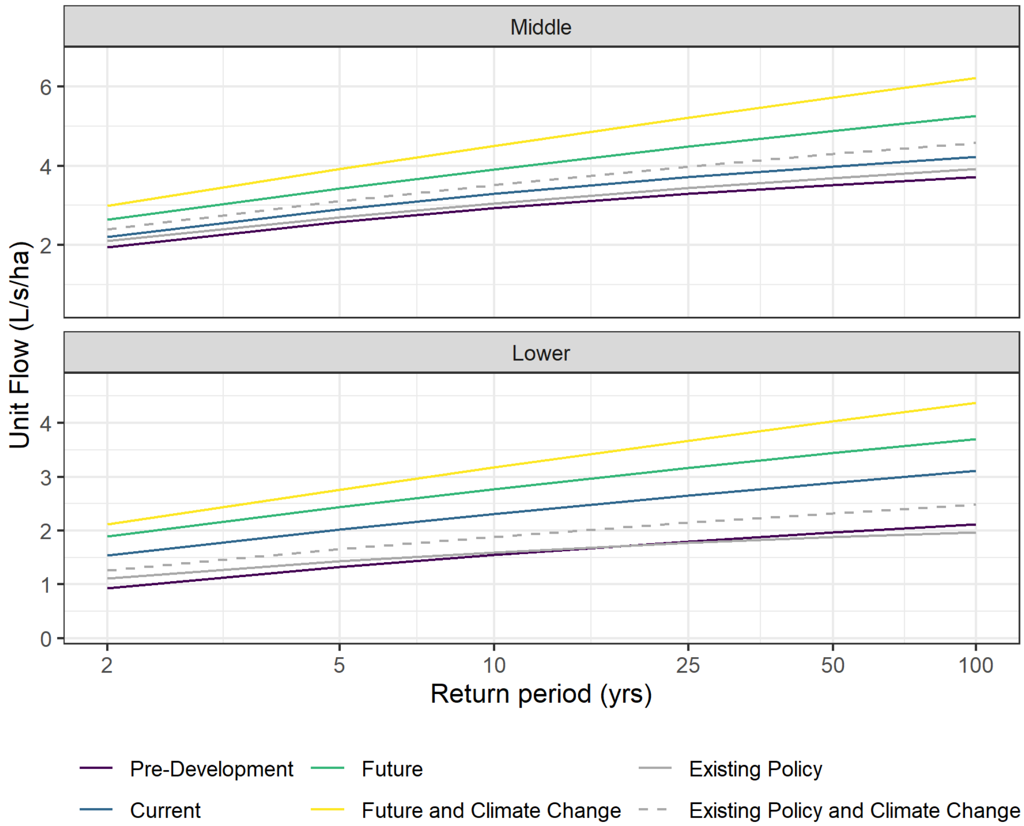

Figure 3.13 Comparison of existing policy peak flows to other model scenarios

Since existing policy only focuses on flood peaks, there is an increase in flow durations, especially for flows less the 2-year compared to the pre-development condition (Figure 3.14). These increases in duration can result in increased erosion and impacts to fish habitat, suggesting that detention storage needs to be used in conjunction with other means of attenuating moderate flows. Under climate change conditions the duration of flows increases further.

As noted in Section 3.3.1, the assumption made for both of the existing policy scenarios is that peak flow detention is provided to all flow from impervious areas. There are currently impervious areas which do not provide peak flow detention, so this scenario may be overly optimistic.

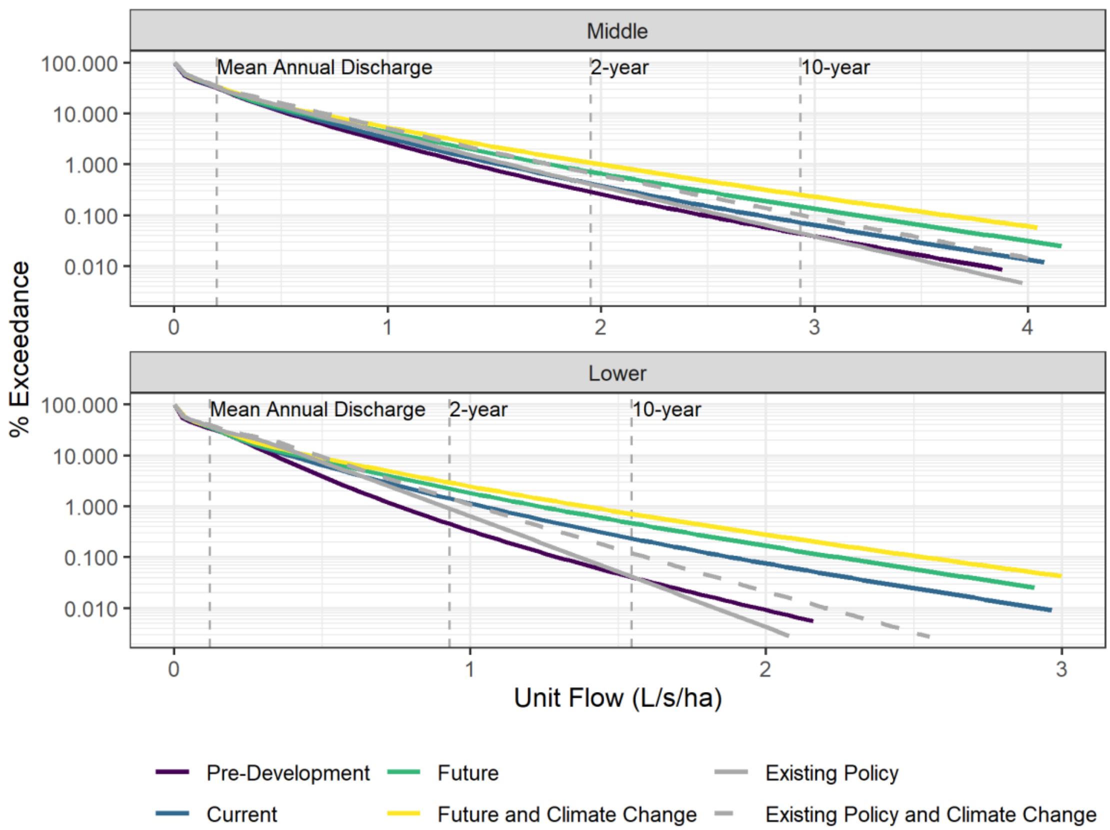

Figure 3.14 Comparison of existing policy flow duration curves to other model scenarios

4 PERFORMANCE TARGETS

4.1 Methodology

Unique sets of performance targets have been defined for the mid and lower regions of the French Creek Water Region. Since minimal urbanization to the upper water region is expected to occur, a unique set of performance targets has not been defined for this area. The performance targets are intended for urban development and not forest management. It is assumed that forest management companies within the upper region will continue to implement best practices in terms of hydrological impacts and no significant changes of the land cover will occur. For smaller developments within the upper region (such as new residential, commercial, or industrial developments), the performance targets established for the mid-region may be applied. If more widespread development were to occur, especially on the slopes within this region, supplemental analysis should be undertaken to confirm or amend the performance targets.

As described in Section 1.2, four performance targets are defined to help replicate the natural water balance and control flood peaks:

1. Baseflow Release Rate (L/s/ha of impervious area) – Replicates interflow, used to augment stream baseflow discharge
2. Retention Volume (m^3/ha of impervious area) – Replicates interflow storage, used to control interflow rate and allow time for water to infiltrate to the groundwater
3. Infiltration System Area (m^2/ha of impervious area) – Replicates groundwater recharge, area where water can infiltrate to groundwater
4. Flood Detention Volume (m^3/ha of developed area) – Reduces peak flows and peak flow durations of more extreme events (2- to 50-year) to avoid downstream flooding. Typically applied as neighbourhood-scale detention, rather than on a lot-level.

The target baseflow release rate has been set at the mean annual discharge (L/s/ha) from the natural (pre-development) condition. This allows for augmentation of baseflows, while controlling any stored volume in a manner that mimics the natural interflow. For the mid and lower regions, the target baseflow release ret is set at 0.20 L/s/ha and 0.14 L/s/ha, respectively. With the target baseflow release rate set, the retention volume, infiltration system area, and flood detention volume are set iteratively to achieve the performance target objectives. The performance target objectives have been defined as:

- No increase in the magnitude of flood events (2-year to 50-year flows).
- No increase in the duration of the 2-year event, and similar performance below the 2-year duration on a flow duration curve[3].
- Maintain the groundwater component of the water balance. Ensure that the groundwater component is not significantly increased, as excessive infiltration can cause issues with nearby utilities, slope stability etc.

To decrease future costs of the system, the retention volume, infiltration system area, and flood detention volume are minimized to the smallest area or volume that still achieves the objectives of the performance targets.

The infiltration rate from the infiltration area was set at 1 cm per hour. This is in line with typical infiltration for silty loam and loam (Metro Vancouver, 2012). Soils within the region range from silty clay loams (with a typical infiltration rate of 0.15 cm per hour) to sandy loam and loamy sand (2.5 to 6.1 cm per hour). Ideally when a source control facility is designed, testing would be performed to determine the actual infiltration rate at the base of the facility. If in implementation, a site deviates from the infiltration rate used within this study, the design should modify the infiltration area such that an equivalent volume is captured by the infiltration facilities. or the flood detention volume, the maximum release rates were set at the 2-year peak flow with an allowance for overflow.

Within this phase of the study, a series of performance targets were developed to understand the stress of land use development and land use development and climate change. Mitigation, or application of

[3] Standards for low impact development typically match pre-developed discharge rates from 8% to 50% of the 2-year peak flow (Department of Ecology, State of Washington, 2016).

the performance targets, is only applied to flow from impervious areas. Mitigation is not applied to runoff from pervious areas such as forest and grass. The performance targets are set assuming all existing development is eventually redeveloped or retrofitted instead of only mitigating impacts based on future impervious areas. The range of targets help to understand the size of storage and infiltration facilities that would be needed to achieve various objectives.

The various performance target scenarios developed for the analysis are:

1. Performance targets required to mitigate future land use to pre-development conditions;
2. Performance targets required to mitigate future land use and climate change to pre-development conditions;
3. Performance targets required to mitigate future land use to current conditions;
4. Performance targets required to mitigate future land use and climate change to current conditions.

Ideally, performance targets would be applied that would mitigate future land use and climate change impacts to pre-development conditions to negate changes to hydrology across the water region. However, this can result in onerous requirements for developers, which may not be implemented because they are too stringent. Ultimately, targets selected should balance improvements to watershed health with the practicality of implementing them widely within the context of development. The balance between practicality and watershed health will be explored during Phase 2 of this study. At that time, performance targets will be selected from the range of results developed in this study.

4.2 Performance Targets

The four sets of performance targets for the mid and lower region are summarized in Table 4.1 and Table 4.2, respectively.

Table 4.1 Performance targets for mid region scenarios

Target	Mitigate future land use to pre-development	Mitigate future land use and climate change to pre-development	Mitigate future land use to current	Mitigate future land use and climate change to current
Baseflow Release Rate (L/s/ha)	0.2	0.2	0.2	0.2
Retention Volume (m^3/ha)	450	900	150	850
Infiltration System Area (m^2/ha)	120	60	75	30
Flood Detention Volume (m^3/ha)	750	3000	450	1750

Table 4.2 Performance targets for lower region scenarios

Target	Mitigate future land use to pre-development	Mitigate future land use and climate change to pre-development	Mitigate future land use to current	Mitigate future land use and climate change to current
Baseflow Release Rate (L/s/ha)	0.12	0.12	0.12	0.12
Retention Volume (m^3/ha)	350	550	75	200
Infiltration System Area (m^2/ha)	100	60	30	10
Flood Detention Volume (m^3/ha)	650	1800	250	470

4.3 Verification of Performance Targets

The effectiveness of the performance targets in reducing peak flows for the scenarios for the 2-, 5-, 10- and 50-year event are summarized in Table 4.3. The flows within the table are the average unit area peak flows from each region. Actual peak flows on a different scale (i.e. watershed) may differ from those presented in the table. The table shows that peak flows from the future scenario can be mitigated back to pre-development and current levels. However, peak flows from the climate change scenario are not fully mitigated to pre-development levels, especially in the mid-watershed.

Table 4.3 Mitigated peak flows from performance target scenarios

Region	Return Period	Pre-Development (L/s/ha)	Mitigated to Pre-Development		Current (L/s/ha)	Mitigated to Current	
			Future (L/s/ha)	Future and Climate Change (L/s/ha)		Future (L/s/ha)	Future and Climate Change (L/s/ha)
Mid	2	1.9	1.9	2.1	2.2	2.2	2.2
	10	2.9	2.9	3.3	3.3	3.3	3.4
	50	3.5	3.6	4.1	3.9	4.1	4.2
Lower	2	0.9	0.9	1.1	1.5	1.5	1.6
	10	1.5	1.6	1.6	2.3	2.4	2.6
	50	1.9	2.0	2.0	2.9	2.8	3.1

The effectiveness of the mitigation scenarios on the flow duration curves are shown in Figure 4.1 and Figure 4.2.

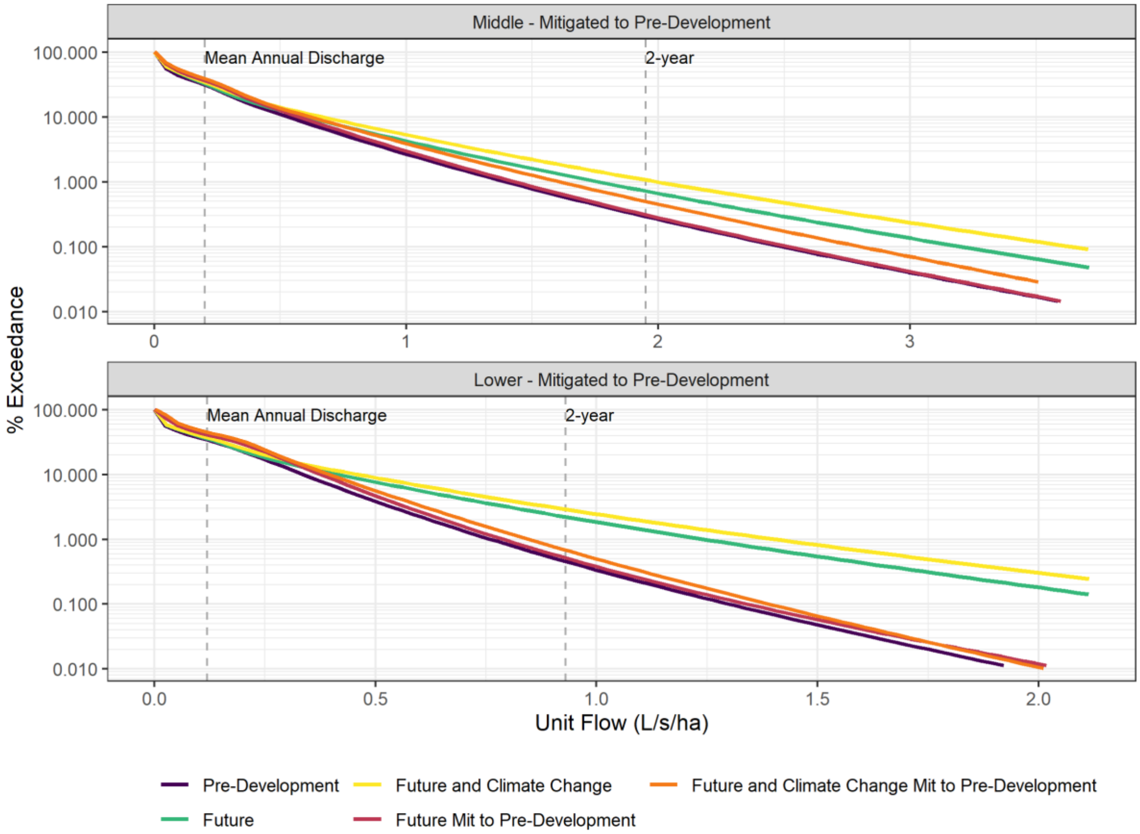

Figure 4.1 Flow duration curves for mid and lower water region showing mitigation to pre-development conditions

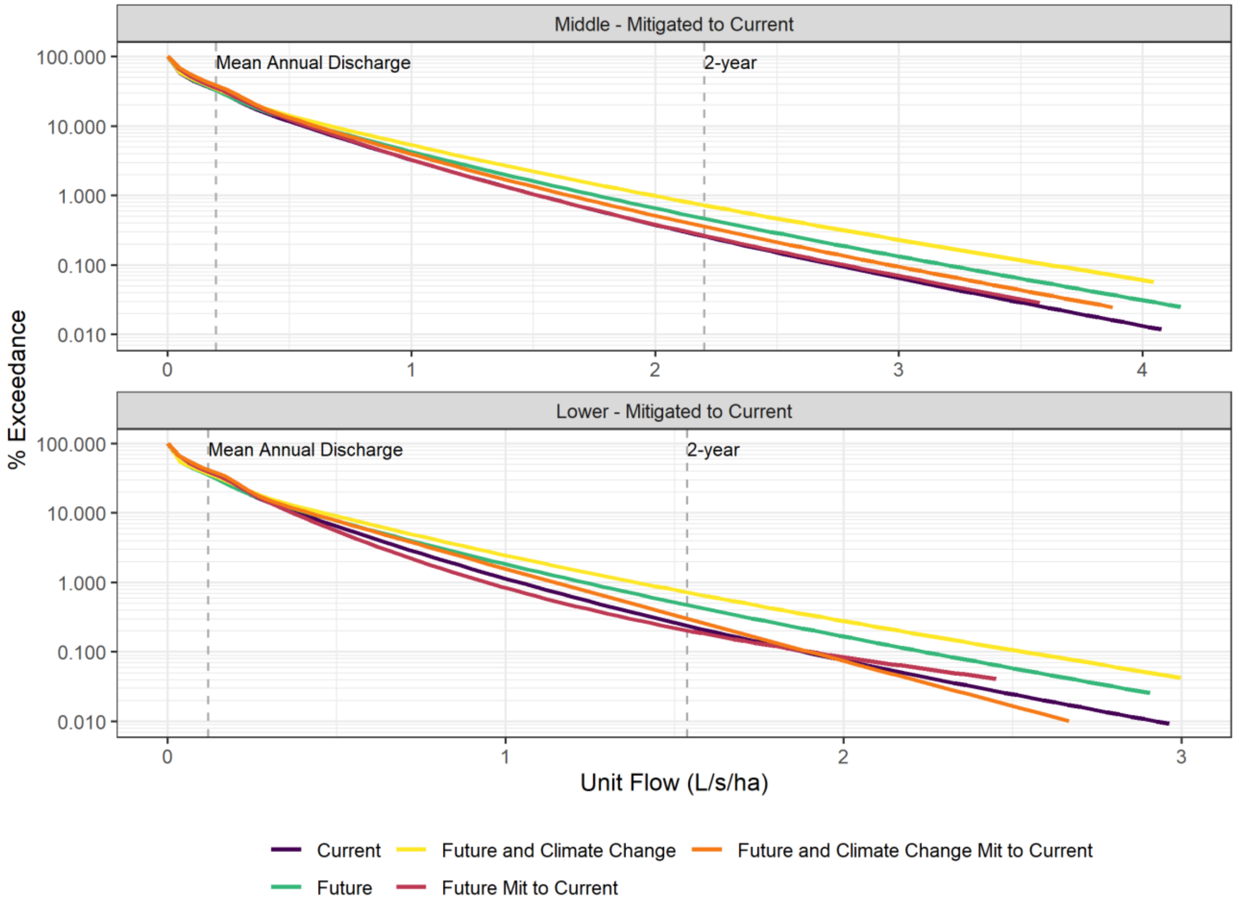

Figure 4.2 Flow duration curves for mid and lower water region showing mitigation to current conditions

In addition to flow duration and peak flows, the high pulse count and range and winter 7-day low flow hydrologic indicators were also compared between the different scenarios. The mitigation scenarios can reduce the number of high pulse counts to similar values seen in pre-development conditions, as summarized in Table 4.4.The winter 7-day low flows are supplemented by the baseflow provided from the source controls.

Table 4.4 Summary of mitigated average annual high pulse count and range

Region	Scenario	High Pulse Counts	High Pulse Range (days)	Winter 7-Day Low Flow (L/s/ha)
Middle	**Pre-Development**	**9**	**320**	**0.15**
	Future mitigated to pre-Development	11	323	0.18
	Future and climate change mitigated to pre-development	11	326	0.19

Region	Scenario	High Pulse Counts	High Pulse Range (days)	Winter 7-Day Low Flow (L/s/ha)
	Current	**12**	**327**	**0.15**
	Future mitigated to current	11	322	0.17
	Future and climate change mitigated to current	12	325	0.19
Lower	**Pre-Development**	**6**	**279**	**0.10**
	Future mitigated to pre-Development	8	319	0.15
	Future and climate change mitigated to pre-development	9	318	0.16
	Current	**16**	**345**	**0.10**
	Future mitigated to current	9	317	0.13
	Future and climate change mitigated to current	10	315	0.14

The application of performance targets to future development scenarios shows the pre-development and current conditions can be re-established. Mitigating the effects of both development and climate change is more difficult. Within the mid-region, peak flows and flow durations are reduced but do not fully mimic pre-development nor current development conditions. Within the lower region, peak flows and flow durations can mimic current development conditions but are not restored to pre-development conditions.

The incomplete mitigation of climate change impacts is not unexpected. Even with no future development, the water balance, peak flows and duration would all shift due to the change in rainfall. Within both regions, the increase in precipitation due to climate change results in an increase in duration of high flows and increase in peaks from the impervious and pervious surfaces. Mitigation, which is only applied to flow from impervious areas, was unable to fully compensate for the increase in flow from pervious areas. As a result, the mid region is unable to fully meet the rainfall management objectives as there is a larger portion of pervious area. Peak flows and flow durations from the future land use and climate change scenario are reduced; but are not fully mitigated. Performance targets are set at a rate such that further increase in the detention volumes does not result in substantial differences in the peak flows and flow durations. Within the lower region, there is a larger proportion of imperious area (more controlled flows) so flows can be mitigated to the current condition but are unable to fully meet the pre-development conditions. Mitigation measures would need to be applied to runoff from both pervious and impervious areas to meet pre-development conditions. Applying mitigation measures to runoff from pervious areas in the form of the performance targets presented in this study is likely not practical. Other adaptation and mitigation measures should be explored in conjunction with rainfall management targets to address climate change on a watershed scale. This could include actions such as maintaining natural assets (forests, wetlands), retaining and restoring riparian areas along streams, integrating flood management into land use planning, and modelling and reducing agricultural and irrigation water demand.

The climate change scenario used in the analysis was a high emissions (RCP 8.5) mid-century scenario and was implemented using seasonal precipitation multipliers. To further explore the impacts of climate change and potential mitigation and adaptation measures, it is recommended that a sensitivity analysis to different RCP scenarios be performed along with a more comprehensive climate change analysis.

4.4 Future Implementation Considerations

Implementation, monitoring, and adaptive management of the performance targets is to be explored further in Phase 2 of the project. Notably, the performance targets established in this study are based on average unit flows from the mid and lower regions and are set to provide an overall improvement in watershed health if widely applied. Deviation from these targets should be considered in certain cases, for example:

- Close proximity to wetlands, lakes and other sensitive receiving watercourses. Where stormwater is generated from a land use with pollutants of concern (nutrients, fuels, toxic chemicals etc.) which could have a negative impact on water quality within a wetland or lake deviation from the performance targets should be considered, such as reduction or elimination of the infiltration area. In these cases the targets should focus on flow detention instead.
- Groundwater drinking source areas. While source control practices are important for groundwater recharge, care should also be taken when pollutants of concern are present. In these cases, deviation from the performance targets should be considered, such as the reduction or elimination of the infiltration area. Source control practices should also avoid being located close to well heads and septic systems.
- Direct discharge to marine water. Where stormwater directly discharges to marine water and has limited contribution to the groundwater and surface water system, the performance targets may not be warranted. Alternate considerations focused on minimizing erosion may be more important.
- Site specific cases. Application of the performance targets should consider unique site-specific elements of concern, such as limited depth to groundwater, poor infiltration, bedrock, perched water tables, slope stability concerns, and nearby utility trenches that may be flooded. Application of performance targets to source control design should always be assessed on a case-by-case basis for applicability.
- Non-urban developments. The performance targets are focused on negating impacts from an increase in development (commercial, residential, industrial areas). The performance targets are not suited for other alterations to the landscape such as forestry practices. In these cases, industry best management practices should be applied to mitigate adverse impacts to hydrology.
- For flood detention volumes to effectively manage impacts of existing development, broader neighbourhood-scale facilities may need to be implemented, in addition to smaller lot-level facilities. Flood detention volumes presented within this study may need to be refined on a neighbourhood-scale basis to ensure adequate flood control.

5 CONCLUSIONS

The performance targets given in Section 4 provide a range of targets that can be referenced when reviewing development applications to ensure that proposed rainwater management approaches on development are sufficient to minimize changes to the water balance in the French Creek water region. Existing policies and design guidelines show strong support for rainwater management and restoration of the natural hydrologic function across the region, but the mechanisms for achieving this are not yet in place.

Additional work regarding implementation, monitoring, and adaptive management will be conducted as part of Phase 2, to provide further recommendations on how these results may be used effectively, and potentially applied elsewhere within the RDN.

The hydrologic model developed for this project was purpose-built to establish performance targets and review the overall changes to water balance from development. Additional modifications may be made in the future to improve the results and explore certain aspects in greater detail. Potential areas for further work include:

- More in-depth analysis of climate change impacts, including the sensitivity of performance targets to alternative emissions scenarios and time horizons; more detailed modification of the input data sets that reflects extreme events with greater magnitudes and frequency; prolonged drought periods and shift in seasonal precipitation timing; consideration of temperature changes on evapotranspiration.
- Collection of additional high-quality flow and rainfall data within the French Creek water region to improve model calibration. Measurements should be taken at higher flows, rating curves developed and maintained, and frequent quality assurance / quality control conducted on the data.
- Improved land cover data sets based on remote sensing imagery to obtain a more accurate depiction of current build-out.
- Development of specific performance targets broken out by other indicators. For example, performance targets could be set based on different soil permeability.
- Consideration of water quality. Presently, it is presumed that water quality will be considered and maintained during detailed design of source control facilities, by limiting the proportion of impervious tributary area that runs off into source control facilities. More detailed assessment of water quality may be warranted.

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