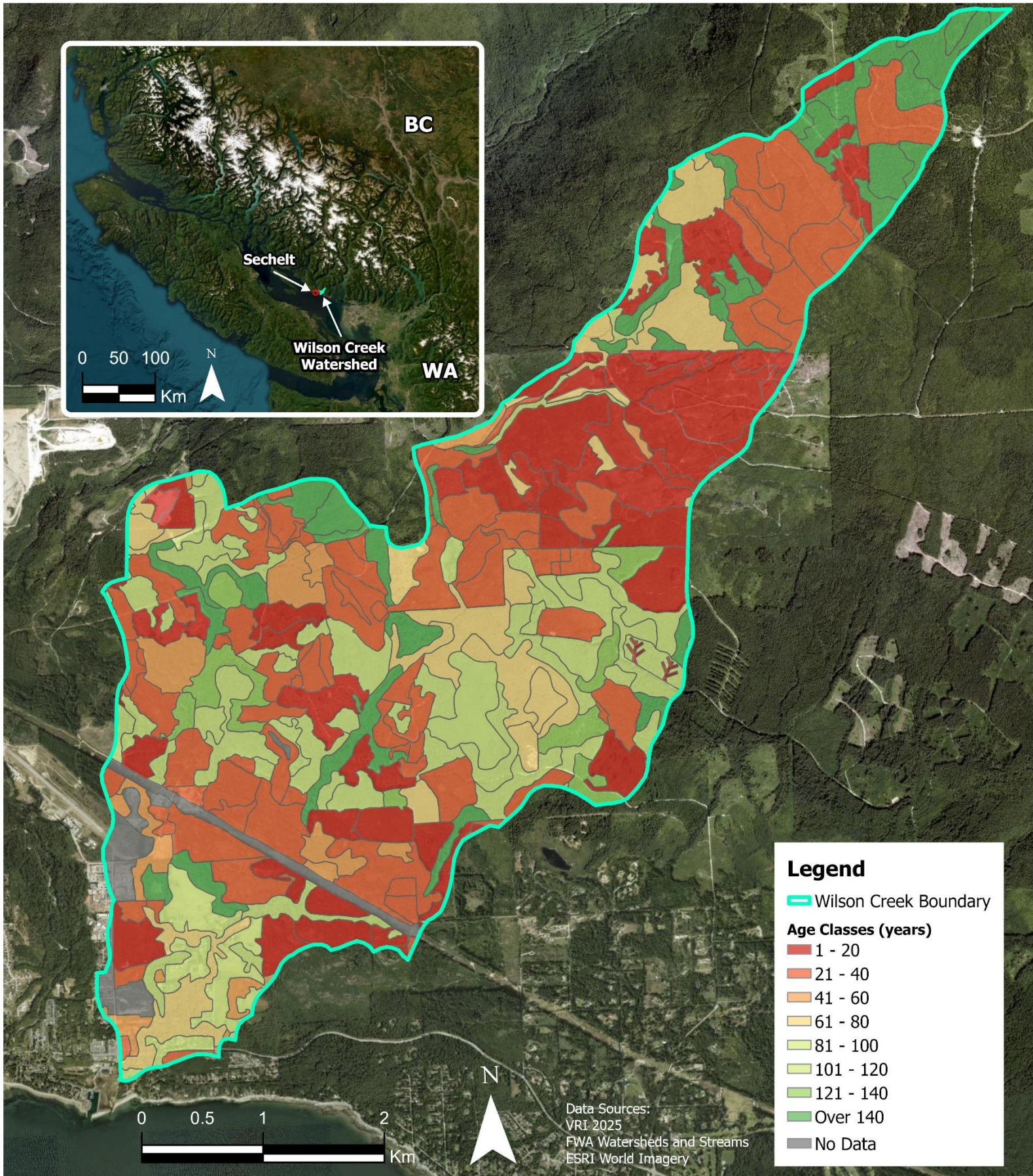


# Wilson Creek Watershed: Peer Review and Re-Assessment



DR. YOUNES ALILA, P.ENG  
JANUARY, 2026

## ***Land Acknowledgement***

I would like to acknowledge that ts'ukw'um (Wilson Creek) is situated on the traditional, ancestral, and unceded lands of the shíshálh Nation, who hold Aboriginal rights and title to their lands, water, and resources. I recognize and respect their self-governance, established through the Sechelt Indian Band Self-Governance Act, and their ongoing efforts towards self-determination and reconciliation. Nothing in this report is intended to abrogate or derogate from the Aboriginal rights or title of the shíshálh Nation.

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## ***Qualification***

I am a forest hydrologist, a registered professional engineer with EGBC (Engineers and Geoscientists British Columbia), and a full professor (Faculty of Forestry and Environmental Stewardship, University of British Columbia, Vancouver). I graduated from the University of Ottawa with a Bachelor degree in civil engineering in 1985, a Master degree in water resources in 1987, and a Doctorate in hydrology in 1994. My PhD thesis research work on *A Regional Approach for Estimating Design Storms in Canada* was nominated for the Annual Governor General's Award. From 1992 to 1996, I worked as a project engineer in Metro Vancouver. In 1996, I joined the Forest Resource Management Department of the Faculty of Forestry and Environmental Stewardship at the University of British Columbia, where I teach and conduct research on climate and land use change effects on water resources. I have published over fifty papers in a wide range of fundamental and applied science journals. My publications on the topic of forest harvesting effects on floods were the subject of two press releases by the American Geophysical Union in 2012. I was the recipient of the American Geophysical Union (AGU) "Editor's Citation for Excellence in Refereeing" Award<sup>1</sup> in 2003 and 2012 in recognition of my "outstanding service to the authors and readers of *Water Resources Research Journal* of AGU."

## **Particularly Relevant Expertise**

The particular expertise I bring to the peer review of the Wilson Creek Watershed Assessment is the following: (1) I have performed and published a large body of peer-reviewed research on the relationship between forestry and hydrology; (2) The developing focus of my research has been on the application of the science of cause and effect to forest hydrology; (3) Because of my research and field work I have acquired what I have good reason to regard as unparalleled knowledge of how to ascertain the hydrological effects of logging in British Columbian watersheds; and (4) I am bound to the extremely high standards of intellectual honesty demanded of academic researchers. I have served as an expert witness in three cases: Randy Saugstad vs. Tolko industries Ltd. (logging effects on hydrology, 2015), Waterway Houseboats Ltd. vs. British Columbia (flood hydrology unrelated to

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<sup>1</sup>According to the American Geophysical Union, "the purpose of this citation is to express publicly the gratitude of AGU to those whose reviews have been particularly commendable". My contributions to the peer review process of the research work of other scientists were referred to as "invaluable in maintaining a high-quality standard" on this award certificate. A public announcement listing the AGU awardees in 2003 and 2012 is found on EOS:

- <https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004EO490008>
- <https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2013EO390004>

logging, 2018), and Ray Chipeniuk and Sonia Sawchuk vs. BCTS & Triantha (logging effects on hydrology, 2022).

***Disclaimer***

This report was prepared by Dr. Younes Alila, P.Eng., for the account of That Bloomin Farm. The material in it reflects Dr. Alila's best judgement, in the light of the information available to them, 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. Dr. Alila accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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## ***List of Acronyms***

AR: Atmospheric River

ET: Evapotranspiration

CV: Coefficient of Variation

ECA: Equivalent Clearcut Area

FFC: Flood Frequency Curve or Flood Frequency Distribution

GS-SW: Groundwater – Surface Water Interactions

RCSF: Roberts Creek Study Forest

ROS: Rain-on-Snow

SCCF: Sunshine Coast Community Forest

SWE: Snow-water Equivalent

UHE: Unit Hydrologic Effect

WAR: Water Available for Runoff

WCW: Wilson Creek Watershed

WSC: Water Survey of Canada

## *Acknowledgements*

I would also like to acknowledge my graduate student, Kyle Bishop, who contributed to the overall completion of this peer review and re-assessment. Kyle assisted in writing, conceptualization, visualization, and editing.

I would like to recognize that all claims made in this peer review report are that of my own, and I take full responsibility for all of the arguments, statements, and opinions within this report.

## ***Executive Summary***

ts'ukw'um, also known as the Wilson Creek watershed (WCW), located on the Sunshine Coast of British Columbia, has experienced intensive historical forest harvesting. In 2012, Glynnis Horel conducted a watershed assessment of Wilson Creek at the request of the Sunshine Coast Community Forest (SCCF).

The outcomes of this peer review aim to provide insight into the portions of the Wilson Creek Watershed Assessment that lack rigour, while also demonstrating the true level of disturbance and hydrologic change seen in the watershed.

The current framework of watershed assessments in British Columbia is constrained by deterministic, non-causal means of analysis that does not adequately capture watershed-level hydrologic response. One's ability to understand the cohesive interactions of hydrology, geomorphology, forest disturbance, and hence, cumulative effect depends on whether the framework used is causal. In watersheds, the hydrologic response emerges from interactions among climate and physiography that operate across space and time. As a result, these cause-effect relationships can only be captured holistically when an analysis is conducted at the watershed scale. To fully capture the causal power that emerges from watershed scale interactions, it is most appropriate to use a probabilistic framework as a means of assessment and prediction. Such a framework invokes the dimension of frequency, which is fundamentally associated with extreme events, and has a non-linear, inverse relationship with magnitude. In other words, a probabilistic framework effectively communicates the size and probability of a given extreme event occurring, supported by watershed-scale interactions across climate and physiography. This framework reveals the sensitivity associated with coastal snow-transient environments, shedding light on the power of the forest in mitigating both hydrological and geomorphological extremes.

The Wilson Creek Watershed Assessment (Horel, 2012) relies on microscale methods, including stand-level Equivalent Clearcut Area (ECA), in an attempt to quantify watershed-scale forest disturbance. ECA is calculated and reported for both the watershed and the SCCF operating area in WCW. However, after presenting the results, the relevance of ECA to hydrologic function as a meaningful indicator is dismissed by Horel without substantial explanation or discussion. This is puzzling to us because typically, in watershed assessments, ECA is calculated and then used to determine the consequential hydrologic risk based on some thresholds (e.g., low (<20%), medium

(20-30%), and high (>30%) (Winkler et al., 2010)). The fact that WCW already had an ECA of 47%, would have disqualified it from any further harvest. Instead, the high ECA is downplayed, and other arguments are presented. This creates a disconnect between using ECA metrics to quantify disturbance and the actual interpretation that follows, limiting the ability of the 2012 assessment to characterize hydrologic risk in WCW. This inconsistency regarding the role of ECA in Horel (2012) raises a conundrum or dichotomy.

There are several other areas in Horel (2012) that we believe must be improved upon and could help inform future watershed assessments across the province. Key issues arise in: i) the approach of analyzing peakflow trends, ii) models used to predict climatic conditions in snow-transient watersheds, iii) canopy-driven snowmelt processes such as meltwater drip, iv) regenerating stands of trees and associated consequences on drought, v) the road density in WCW, vi) the geomorphic sensitivity of stream channels and associated infrastructure, vii) the riparian assessment, and viii) the presence of aquifers and linkage to groundwater.

- i) Using data from the neighbouring Roberts Creek watershed, Horel (2012) uses conventional statistics to gain insight into peakflows in WCW. The statistics of extremes must be used, which would have indicated the sensitivity to hydrologic change in coastal snow-transient watersheds like WCW. Due to the uniqueness of a watershed's physical characteristics and historical disturbance, using Roberts Creek as a proxy for WCW does not adequately capture its unique hydrologic conditions.
- ii) Predictive climate models like ClimateWNA should be used with skepticism as they reflect generalized conditions and make assumptions that disagree with the high variability seen in coastal snow-transient watersheds. Issues in the predictive accuracy of these models arise in variable mountainous conditions, as lapse rates are always changing, given storm characteristics over time. As such, these models should be used as an introduction to a watershed at best, and a wider variability of conditions must be adopted.
- iii) Although forest canopy processes are briefly mentioned, there is little follow-up on the forest's ability to control snowpack, especially processes such as meltwater drip that occurs in mid to high elevations in snow-transient watersheds in rain-on-snow (ROS) dominated months. We believe that the intercepted snow that melts from the forest

- canopy and drips to the soil or snowpack below helps encourage the slow infiltration of water, providing a mode of groundwater recharge in snow-transient watersheds, thus, lowering the variability of peakflows and low flows. In general, more could be done to acknowledge watershed-level forest canopy processes, or lack thereof, given the degree of historical forest harvesting in WCW.
- iv) Another key aspect related to groundwater and drought is that of regenerating stands of trees. WCW has numerous stands with young trees due to previous harvesting operations. Regenerating trees transpire at higher rates than mature forests, resulting in soil and groundwater moisture depletion. Consequently, this will negatively impact summer low flows and increase drought risk. In turn, lower low flows will decrease a watershed's buffering capacity, leading to a higher peakflow risk the following season. This concept is known as *Hydrologic Whiplash*.
  - v) The impacts of forest roads on hydrology and the high road density of WCW are mentioned. Although it was found that the watershed may have a lessened hydrological effect in comparison to catchments with similar road densities, it is still important to recognize the overall cumulative impacts that these roads demonstrate at the watershed level, and their associated implications on changes in flood frequency.
  - vi) Using a probabilistic framework, one can see a change in flood frequency across a range of all return periods given forest disturbance. Consequently, this means that both large and small floods will increase in frequency and magnitude. Geomorphic change is often experienced through smaller, more frequent channel-altering events. As such, under increased forest disturbance, small to medium-sized channel-altering events will increase in magnitude, occur more frequently, and have longer durations, leading to increased sedimentation and channel instability. Moreover, this is significant given that past extremes are becoming more frequent in this altered flow regime. This story holds for infrastructure designed for large return period floods. Higher sustained flows at lower return periods will result in increased geomorphic work on existing infrastructure, leading to a higher probability of failure. Additional forest harvesting will only increase this risk.
  - vii) The current riparian conditions of WCW represent a dynamic system. We completed a new riparian assessment in 2024, comparing stops from the 2012 Wilson Creek

Watershed Assessment, among several newly added field stops. Given cumulative effect over time and additional forest harvesting since 2012, WCW's channel morphology has seen significant change since the previous assessment (Horel, 2012). Notable differences in riparian conditions between the two assessments can be seen, with channel-altering processes being intensified. From the headwaters to the outlet of WCW, our assessment reveals a channel network that has been degraded since 2012. Downstream portions of WCW show destabilization as a result of cumulative upstream forest disturbance.

- viii) Lastly, at the time the Horel (2012) was written, the surrounding aquifers were not mapped. WCW has two aquifers, the East Porpoise Bay and East Sechelt Delta aquifers. Likely, WCW contributes significantly to recharging these aquifers, and a formal discussion must be completed to provide context into their implications on watershed-level hydrology.

WCW has experienced significant historical disturbance through forest practices. We believe that Horel (2012) overlooks the current state of cumulative effect in the catchment, and that WCW is currently at a high level of hydrological risk. Continued forest harvesting will only contribute to increased geomorphological and hydrological risk. Had an assessment that stems from a probabilistic framework been utilized, the inherent sensitivity associated with coastal snow-transient watersheds would have been realized.

Throughout Horel (2012) there are several issues that are systematically overlooked, which, in our opinion, have led to the current state of high risk to hydrology and geomorphology in WCW.

- Classifications of the watershed being rain-dominated or snow-transient
- The mention of meltwater drip with no elaboration
- Downplaying the effects of road density
- Not invoking the dimension of frequency
- Quantifying the level of disturbance using ECA

We urge the reader to keep in mind these issues surrounding hydrological risk when reviewing this peer review and reassessment. Therefore, given the watershed's high risk, forest harvesting operations in WCW should be suspended until the forest has recovered hydrologically.

## ***1. Introduction to Scope of Peer Review***

Forest hydrology is dominated by two overarching frameworks that intend to enable predictive capabilities, conceptual understanding, and experimental design. One framework has dominated the literature for over a century, and the other has, for the last two decades, challenged traditional knowledge. The foundational difference between these frameworks is whether they are causal in watershed systems. As a result, they tell opposing stories about the effect of forest removal on hydrology.

The first framework is reductionist and magnitude-focused. It is deterministic in nature and links specific hydrologic processes such as evapotranspiration (ET), canopy interception, and the shading of snow to changes in single peakflow event magnitudes. However, causal power at the watershed scale emerges from interactions among a watershed's shape, size, drainage density, elevation range, aspect distribution, and storages such as soils, lakes, aquifers and wetlands, and from how these features interact with vegetation and climate over time to either amplify or attenuate peakflows and low flows. When these watershed level features are not accounted for, interpretations of changes in hydrologic extremes become incomplete and potentially misleading. Due to its deterministic nature, this framework is non-causal with respect to a watershed-scale response, as it cannot establish whether forest removal alters the probability of extreme event occurrence. Consequently, it does not account for the effects of forest removal on the *frequency* of extreme events, such as flooding, droughts, and landslides.

The second framework is holistic and probabilistic in nature, hence frequency-focused. Rather than interpreting the influence of localized processes on the magnitude of single events, it considers how natural variability and/or anthropogenic changes in the landscape, climate, and vegetative cover over time influences the peakflow magnitude-frequency relation. This framework therefore operates at the macroscale. By linking these changes to probability, this framework is causal, displayed through changes in the flood frequency distribution (FFC).

In large systems, causal power often increases with larger scales (Eric Hoel, 2017). Thus, causal power is scale dependent. In hydrologic systems, this is a result of two reasons. First, the drivers of peakflows are demonstrated through the interactions of physiographic and climatic factors, which are multiple. This means that numerous factors interact simultaneously across a watershed to produce a peakflow. Second, the drivers of peakflows are chancy. This means that interactions

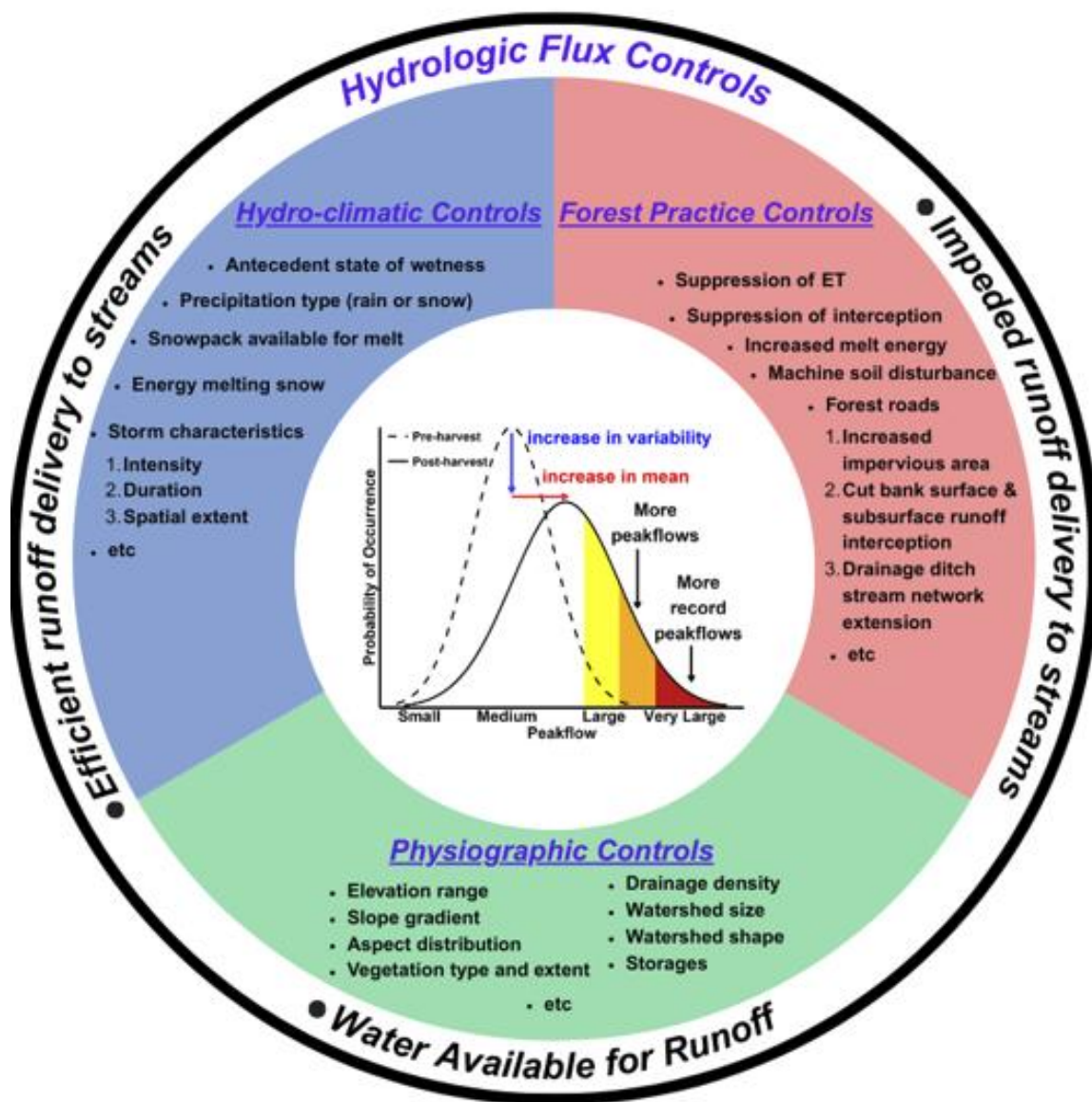
between physiography and climate occur randomly over time. Therefore, the multiple and chancy drivers of a peakflow interact to produce a peakflow of a given magnitude and frequency. The magnitude-frequency relationship of extreme events is fundamental for predicting and understanding the power of forests and the associated effects of forest disturbance.

Each watershed has its own individualized overarching climate and distribution of physiographic characteristics that demonstrate *uniqueness* (Beven, 2000). Watersheds show similar generalized characteristics based on hydro-climatic regime and size, but to a high degree, each catchment is unique unto itself with respect to the multiple and chancy drivers of peakflows. Integrating these distinctive features at the watershed level reveals a high level of causal power, opposing stand-level metrics and a deterministic framework at microscales. This is where the predictive abilities of a probabilistic framework and its associated understanding of environmental and climatic controls thrive, and arguments for deterministic frameworks collapse.

Horel (2012) relies on a microscale means of analyzing WCW and attempts to reconcile it with the watershed macroscale. Unfortunately, this creates challenges, as processes observed at the microscale cannot always be extrapolated to the macroscale. Watersheds are holistic systems that display emergent behaviour, whereby the whole is typically greater than, though at times comparable to or even less than, the sum of its parts. To understand a watershed at the macroscale, a probabilistic framework must be used that reveals cause and effect, and hence the true impacts of forest removal on the magnitude and frequency of all flow sizes and durations.

### ***1.1 Probabilistic Understanding***

The physical understanding used to interpret the predictions made by a probabilistic framework should stem from the same framework. Such means of understanding are rooted in a deep history of interpretation of environmental controls on the flood frequency distribution (Pham & Alila, 2024). One can see that through probabilistic understanding, watersheds are influenced by a variety of controls found in the form of physiography and overall climate over time (i.e., space and time). A peakflow's magnitude and frequency are a direct reflection of the interaction between these controls. Through a probabilistic understanding, one can determine the extent to which each control influences changes in the mean, variance, and skewness parameters of the FFC following forest harvesting. Combinations of these parameters arise when the amount of moisture is increased in a watershed, travels to a stream more efficiently, or is impeded on its path to a stream.



**Figure 1.** Conceptual diagram illustrating how forest practices interact with hydro-climatic and physiographic controls to alter the peakflow frequency distribution. Forest harvesting can increase both the mean and variability of peakflows (shown in the central probability density function display), leading to more frequent and more severe large peakflow events. Forest harvesting may also alter the shape (skewness) of the peakflow frequency distribution, though our figure depicts shifts in mean and variability for illustrative purposes only. The combined influence of these controls, which interact stochastically across space and time, governs emergent hydrologic flux responses and changes in the exceedance probability of large peakflows (Bishop & Alila, 2026). Similar logic should be applied to other extremes, such as droughts and landslides.

These terms are coined: water available for runoff (WAR), synchronization, and desynchronization. As a result, FFC parameters can increase, decrease, or remain similar to pre-harvest conditions. Using similar logic, probabilistic understanding can be applied to other extremes, such as droughts and landslides. This comes through an understanding of a watershed's inherent *uniqueness*.

When considering the effects of forest disturbance on the change in the magnitude and frequency of extreme events, one should derive a probabilistic understanding from the diagram above. The influence of forest practices, hydro-climatic factors, and physiography has varying effects on changing the flood frequency distribution. With respect to increased forest practices, factors that generally increase the mean, variability, and hence lead to synchronization of runoff, per se, find themselves in a dry climate, small elevation range, small aspect distribution, dense drainage network, and a rounded watershed shape. Conversely, an example of a situation of an increase in mean and decreased variability, as a result of desynchronization, is likely to stem from a dry climate, large elevation range, large aspect distribution, sparse drainage network, and elongated watershed shape. This conceptual diagram highlights the multivariate nature that arises at the watershed scale and the probabilistic understanding needed to interpret interactions. Furthermore, it is through the various combinations available in this conceptual diagram that one can truly comprehend and utilize the power of probabilistic understanding.

With respect to these principles and the provided conceptual diagram, one can exercise probabilistic understanding to determine the change of flood mean, variability, and, as a result, the existing FFC. By extension, changes in the FFC as a result of forest practices can be determined by a fluency in probabilistic understanding. This provides an effective tool to complete an assessment, given a strong understanding of the *uniqueness* that each watershed possesses.

### ***1.2 Current Conditions of Wilson Creek***

Map 1 (page 46) represents the current conditions of WCW, with consolidated cutblock data presented from 1981 onward. As seen, a significant amount of harvesting has taken place since 1981 within the watershed. Hand-drawn polygons with reference to ortho imagery were created to fill data gaps in the private land parcels at mid-elevation of the watershed. Since 2012, additional forest harvesting has occurred in WCW. Satellite imagery, in addition to consolidated cutblock

data from the BC Government, was compared from 2012 to 2025. This provided an ~8% increase in cutblock harvest, raising the ECA of WCW from 47% to ~55% (Map 2, page 47).

## ***2. Critique of Analysis***

The following section will evaluate areas of the 2012 Wilson Creek Watershed Assessment that lack rigour. Additionally, the current state of hydrology in WCW is discussed under a probabilistic lens.

### ***2.1 Conventional Statistics vs Statistics of Extremes***

Horel (2012) evaluates the peakflows at Roberts Creek using long-term averages and a time series to infer conditions in WCW. We have reservations about relying on this time series and long-term averages. Making recommendations based on this type of analysis can be misleading, and a probabilistic framework should be used that accounts for the dimension of frequency. This is the only way to truly appreciate the super-sensitivity of ROS regimes and the shallow slope revealed by the flood frequency curve (FFC).

To demonstrate the sensitivity of coastal ROS-dominated environments like WCW, we have created a dimensionless FFC adopted from Beckers et al. (2002). This study selected gauged basins with long-term streamflow data collected by the Water Survey of Canada (WSC). The data are characterized by hydro-climatic regime in BC and watershed size. It is then normalized, scaling by the mean annual flood ( $Q_t/Q_2$ ), providing a means to compare watersheds with similar hydro-climatic regimes and catchment size. From these curves, one can conclude that coastal FFCs become more sensitive (i.e. shallower in slope) with increasing spatial scales. Therefore, the coastal normalized FFC for the 22 km<sup>2</sup> was used as baseline conditions to demonstrate the relative position of WCW's post-harvest FFC (Figure 2).

Given the physical characteristics, climate, and level of disturbance in WCW, one can use probabilistic understanding to infer a range of post-harvest FFCs. To do so, harvest rates of snow-transient watersheds from the literature were used to determine a range of post-harvest flood frequency curves for WCW.

Understanding WCW before forest disturbance will provide context to how harvesting influences the peakflow regime. To do so, forest harvesting across the watershed, physiographic characteristics, and climate must be considered cumulatively. WCW has a circular nature from sea

level to around 425 m and then becomes narrow and elongated to its maximum elevation of 1,161 m. Naturally, the circular portion of the basin will have a swifter response time than the elongated portion of the basin. This causes runoff desynchronization and decreases the variability of the pre-harvest FFC. The large elevation distribution of 0 to 1,161 m will also contribute to runoff desynchronization in WCW. Lastly, the presence of the aquifer in the lower portions of WCW acts as a storage in the watershed, contributing a buffer to peakflows, and dampening variability. When considering the post-harvest FFC, one must reason with the same physical and climatic characteristics as the pre-harvest FFC, while factoring in the location of cutblocks and the percent of the watershed harvested.

Overall, WCW has experienced a large amount of historical disturbance through forest practices. Upper elevation privately owned portions of the watershed have been mostly clearcut and are slowly recovering. Lower elevations have experienced extensive historical harvesting as well. The lower-elevation circular shape and the higher-elevation elongated shape of WCW will exhibit altered hydrologic responses. As a result of increased harvest, greater energy available for snowmelt during ROS events is observed at higher elevations of the watershed and is now showing synchronization with lower elevations. Additionally, this is confounded by the predominantly southwest aspect of WCW. This leads to a more variable response and a steeper slope in the FFC. Loss of canopy-snow interactions, like meltwater drip, will increase peakflow variability and steepen the slope of the FFC through reduced baseflow (Blöschl & Sivapalan, 1997). Regenerating stands of trees will also reduce baseflow as they transpire moisture at a higher rate, in turn increasing peakflow variability (Perry & Jones, 2017; Segura et al., 2020). A similar story can be said about roads increasing runoff efficiency and intercepting subsurface water through cutbanks, and hence, increasing flow variability.

We have produced several scenarios shown in Figure 2, providing a range of what we believe sufficiently explains the current state of WCW. These scenarios were created with support from Table 1, a compilation of published studies on snow-transient watersheds that have similar characteristics, and a variety of cut rates and their corresponding changes in peakflows. The maximum scenario with the highest unit hydrologic effect (UHE) of 1.19 was chosen with reference to Big Elk Creek of Idaho (Tonina et al., 2008). This watershed has a large elevation range and size of 30 km<sup>2</sup>, which are both similar to WCW. WCW has experienced a much greater

cut rate than Big Elk Creek, but given the large unit hydrologic effect of this study, we decided it was appropriate that it is the *maximum scenario*. A heightened range is that of the Hard and Ware Creeks in western Washington (Storck et al., 1998). This study evaluated scenarios using the Distributed Hydrology Soil and Vegetation Model (DHSVM), which is considered the gold standard of hydrologic modelling at the watershed level among researchers. These creeks are smaller in size (5.2 km<sup>2</sup>), with a high road density similar to WCW. This study only isolated the effects of roads on peak streamflow, so it has been used as a reference point for a post-harvest curve considering the road density in WCW. H.J. Andrews watershed 1 is smaller in size and 100% clearcut, providing a 38.7% increase in peakflows (Rong, 2017). This watershed represents a low-to-moderate UHE. The North Fork Snoqualmie River also saw 100% clearcut, and produced a 31% increase in peakflows. Despite this watershed being much larger at 165 km<sup>2</sup>, the complete removal of forest cover places this watershed in a similar category as H.J. Andrews watershed 1, rather than a lower bound for the post-harvest minimum. Given the lowest UHE values in Table 1 (~0.3-0.4), which arise from H.J. Andrews watershed 1 and the North Fork Snoqualmie River, scaling these sensitivities to WCW supports a conservative minimum post-harvest FFC increase of 25%. At the upper end, a UHE value similar to Jamieson Creek (0.70) implies a larger peakflow increase when considering disturbance. Given that WCW is larger in size and has experienced a great amount of harvesting, we conservatively set the *maximum post-harvest* FFC to 50%. An average between the maximum and minimum range of the post-harvest FFC has been plotted on Figure 2, and changes in peakflow frequencies have been additionally shown in Table 2.

A holistic approach using a probabilistic framework is the only way to fully appreciate how these controls interact with each other to alter FFC parameters and increase peakflow variability in WCW. The fragility of coastal snow-transient watersheds is driven by the physics that rule ROS-governed snowmelt at the macroscale. Due to the nature of this FFC, even these small increases in magnitude from forest harvesting can result in large increases in frequency (Allen & Ingram, 2002; Johnson & Alila, 2023). This is seen in the 100-year event becoming a ~20-year event, the 50-year event becoming a ~10-year event, the 20-year event becoming a ~5-year event, and the 10-year event becoming a ~4-year event. These curves are divergent, showing an unchecked separation between the post-harvest and pre-harvest FFCs at high return periods. As mentioned previously, this is due to the increased synchronization effect expected in WCW. These concepts surrounding unchecked changes in FFCs are elaborated on and discussed in depth by Johnson & Alila (2023),

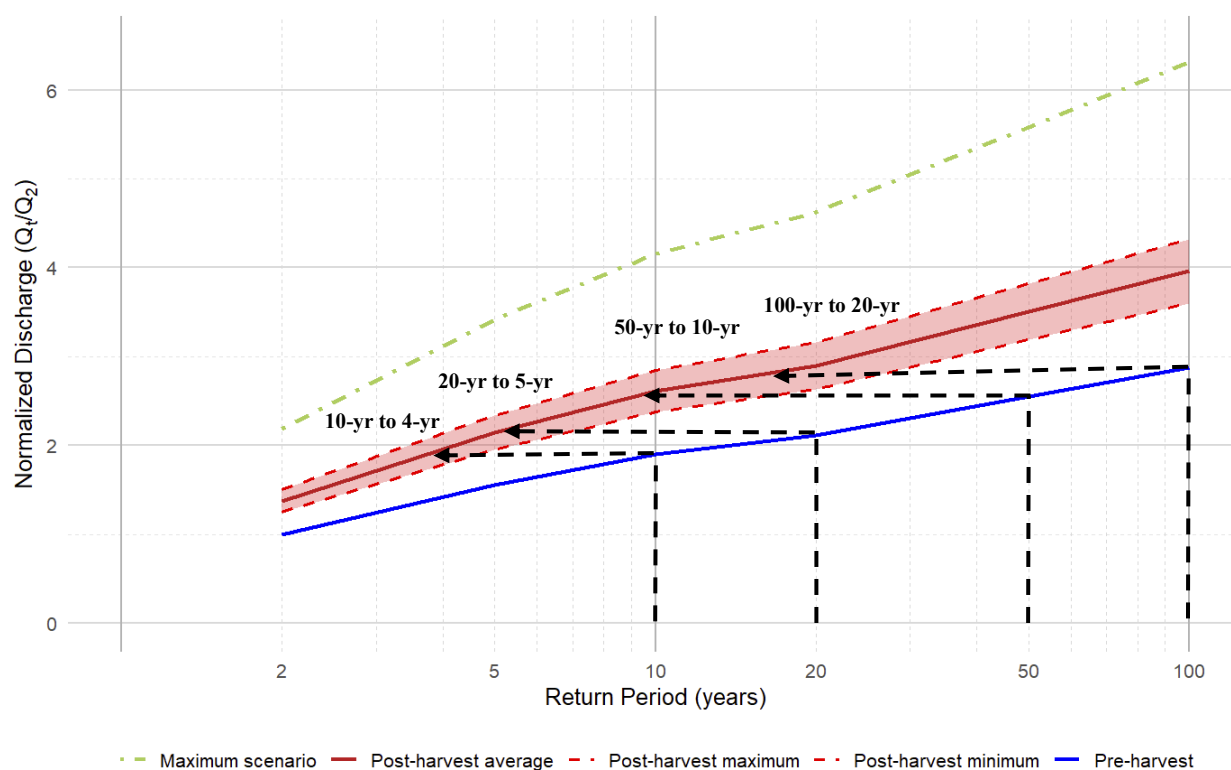
Kaluarachchi & Alila (2025), and Pham & Alila (2024). With additional forest harvesting in WCW, consequences could further strain the already fragile hydrology and geomorphology. By extension, negative outcomes associated with the increase in magnitude and frequency of these events will be experienced by fish populations, water quality, infrastructure, channel stability, and downstream communities.

**Table 1.** Summary of snow-transient literature related to forest harvesting effect on peakflows

<b>Study Sites</b>	<b>Climate</b>	<b>Elevation Range</b>	<b>Details</b>	<b>Reference</b>	<b>Unit Hydrologic Effect</b>
Big Elk Creek (Idaho)	Maritime snow-transient	946 - 1612 m	21% forest harvesting can increase ROS peakflows by 25% on average (Q9 to Q3.6)	Tonina et al. (2008)	1.19
North Fork Snoqualmie River (Washington)	Maritime snow-transient	350 - 1800 m	100% clearcut can increase ROS peakflows by 31% (1989)	Storck et al. (1998)	0.31
Hard & Ware Creeks (Washington)	Maritime snow-transient	460 - 1200 m	High road density increases peakflows by 16-27% (five largest storms of 1992)	Storck et al. (1998)	0.64 - 1.08
H.J. Andrews Watershed 1 (Oregon)	Maritime snow-transient	439 - 1027 m	100% clearcut increases peakflows by 38.7% on average	Rong (2017)	0.387
H.J. Andrews Watershed 3 (Oregon)	Maritime snow-transient	471 - 1080 m	25% patch cut increases peakflows by 12.2% on average	Rong (2017)	0.49
Jamieson Creek (Seymour Watershed, British Columbia)	Maritime snow-transient	305 – 1310 m	19.2% clearcut increases peakflows by 13.5%	Golding (1987)	0.70

**Table 2.** Forest Harvesting effects on peakflow frequencies at WCW.

Peakflow before harvesting	Peakflow after harvesting	Approximate effect
100-year	20-year	5 times
50-year	10-year	5 times
20-year	5-year	4 times
10-year	4-year	2.5 times



**Figure 2.** Normalized pre-harvesting, post-harvesting range and maximum scenario FFCs for WCW, demonstrating the effects of forest harvesting practices on peakflow magnitude and frequency.

## 2.2 Modelling Exercises and Transient Rain-on-Snow Characteristics of Wilson Creek

Horel (2012) uses ClimateWNA to differentiate the proportions of precipitation falling as snow and rain in WCW. Further, conclusions are drawn upon with the use of this model:

*“ClimateWNA mean annual variables for precipitation falling as snow (7-16% of total precipitation in the 300-900m elevation zone) in Wilson watershed suggest that under normal conditions, snowmelt is likely to be a small component of peak flows.” (p.7)*

*“Wilson Creek has a rain-dominated hydrology. Over 90% of the watershed is in the rainfall or transient snow zone, in about equal areas.” (p.18)*

We have concerns with the use of this model and the resulting conclusion that snowmelt will provide a small component to peakflows. We also interpret WCW’s hydrology as snow-transient rather than rain-dominated, based on observed characteristics and other studies in similar watersheds (e.g., Beaudry, 1984; Berris & Harr, 1987; Floyd, 2012; Hudson, 2001, 2002; Rong, 2017; Storck et al., 1998). ClimateWNA has a high degree of uncertainty when applied to mountainous snow-transient coastal terrain and was created to establish baseline climate conditions in BC’s interior. *Instead of making conclusions regarding snow and rainfall percentages with this model, one should use this tool with skepticism, and for a generalized introduction to a watershed.* We argue that WCW is snow-transient and that snowmelt plays a key role in peakflow generation. This is further confirmed by the fact that over half of WCW’s area is within the ROS and snow zones.

ClimateWNA was developed to interpret future climate scenarios, aiding in resource management activities. Importantly, the model was used in combination with seed providence trials in the Faculty of Forestry and Environmental Stewardship at the University of British Columbia (Wang et al., 2006, 2010). Applications and use of this tool were developed for subdued interior environments where conditions are easier to predict, contrasting complex coastal mountainous terrain. Variability in terrain plays a key role in the model’s ability to interpret and accurately depict outcomes. With changing lapse rates and temperatures that hover around 0 °C in the snow-transient zone, ClimateWNA will face challenges in interpolating conditions between meteorological stations. Lapse rates pose a significant issue when modelling in the Pacific Northwest as a result of large spatial and temporal variability in mountainous environments (Brunengo, 2012; Minder et al., 2010). Storm and weather processes will also influence the lapse rate (Kirchner et al., 2013). Due to these issues, ClimateWNA has limitations when applied to

coastal mountainous snow-transient environments such as WCW, and results should be interpreted cautiously. Further, it is not well-suited for interpreting the driving factors of peakflows in these environments.

Interestingly, Horel (2012) chose to rely on ClimateWNA to conclude that WCW is rain-dominated despite numerous studies in southwest BC that consider ROS-dominated watersheds and their inherent sensitivity. Even within a deterministic framework, ROS is the most sensitive hydro-climatic regime to forest harvesting. For instance, in the neighbouring Roberts Creek Study Forests, Hudson (2001) observed peakflow magnitudes that exceeded 289% and 247% over expected after harvesting. These peakflows were known to be ROS events. ROS conditions are also explained by Beaudry (1984) in the Jamieson Creek Experimental Watershed, located in the Seymour watershed in the North Shore Mountains. Temperature fluctuations are highlighted in the transient zone with the mention of snow accumulation and melt occurring throughout the winter. Hudson (2002) and Floyd (2012) stress the ROS nature of Russell Creek in the northeastern portion of Vancouver Island in their studies.

Given canopy removal through forest harvesting, ROS processes of snow accumulation and melt are intensified, with the highest probability of ROS events occurring in the snow-transient elevation zone. Brunengo (2012) shows that while using a stochastic framework, an elevation of around 800 m contributes most to peakflow generation, known as peak-ROS, with contributions beginning at 500 m. ROS regimes can produce highly variable peakflows through melt timing and synchronization at various elevations (Garvelmann, 2015). These findings align with Figure 1 and the discussion surrounding controls on synchronization. For example, creating openings at mid-elevation through forest harvesting enables greater amounts of energy to melt the snowpack, which in turn will synchronize snowmelt and peakflow generation with lower elevations. Conversely, higher elevations will contribute to peakflow generation at a later time period than mid or low elevations due to energy influences and a cold snowpack. This is an example of desynchronization. It is crucial to recognize the adverse effects of synchronization when considering system variability, particularly under the inherent sensitivity of ROS-dominated watersheds. Moreover, it is important to recognize that ROS processes will intensify under a changing climate (Musselman et al., 2018).

### ***2.3 Climate Change***

In light of climate change, it is also important to acknowledge the increasing frequency and magnitude of ROS events (Sezen et al., 2020). Moreover, variation in the spatial and temporal characteristics will be impacted (Hotovy et al., 2024). At high mountainous elevations, the frequency of ROS events are expected to increase, resulting in large increases in flood risk (Cohen et al., 2015; Musselman et al., 2018). This is particularly significant for WCW, especially with the increasing probability of atmospheric rivers (AR) as climate change persists (Corringham et al., 2022). Documented by Gillett et al. (2022), an AR and ROS event in southwestern BC saw catastrophic flooding. The AR raised the freezing level above 2000 m and contributed to a great amount of snowmelt.

With the current state of forest harvesting in WCW and the potential for increased disturbance, the threat of the compounding nature of floods and droughts presents itself. This concept is known as *hydrologic whiplash* and is expected when floods increase the risk of a same-season drought (Hammond et al., 2025). For example, if a large amount of snow accumulates in clearcut areas and is rapidly melted through a large ROS event, such as an AR, a flood is likely to occur. Under forested conditions, much of the snowmelt that influenced the flood would have slowly contributed to groundwater over the winter or gradually melted in the spring, recharging groundwater and reducing the risk of drought. Instead, the snowmelt, now part of the flood, no longer contributes to groundwater recharge, leaving less sustained summer baseflow and amplifying drought risk.

### ***2.4 The Presence of Meltwater Drip***

*“In the absence of sublimation, under melting conditions, snow held in the trees either melts directly out of the trees, or falls to the ground and then melts” (p.8)*

This brief description, written by Horel (2012), alludes to the existence of both mass release and meltwater drip in WCW, but does not elaborate on the significance or importance of these mechanisms to high and low flows. Meltwater drip is a hallmark of a snow-transient environment, and in our opinion, it has significant implications for the mitigation of peakflows and droughts in WCW. Further, we believe that the typically milder slope of coastal snow-transient FFCs is a staple signature of the presence of sustained meltwater drip. Additionally, this makes the peakflow regime supersensitive to forest harvesting, especially in the form of clearcutting.

In snow-transient environments where temperatures hover around 0 °C, snow that is intercepted by a forested canopy will melt and drip to either the snowpack or soil below, dissipating snowpack and recharging groundwater. Many stand-level studies have described meltwater drip and the conditions required for its existence. Storck et al. (2002) reported upwards of 60% of snow being intercepted by the canopy and 72% of intercepted snow contributing to meltwater drip in a snow-transient environment. In certain conditions, dripping water will penetrate through the snowpack and directly into the soil (Bründl et al., 1999). With canopy energy dynamics in mind, meltwater drip can provide large contributions to midwinter melt in snow-transient settings (Lundquist et al., 2013). In the context of midwinter melt, moisture will slowly release into the soil, increasing baseflow over the winter months. Increased baseflow will aid in the buffering of peakflow events while maintaining moisture to resist drought. This is seen in decreased variability of coastal snow-transient FFCs. Reduced variability and an FFC with a milder slope will contribute to peakflow magnitude and frequency that is supersensitive to forest disturbance.

In the neighbouring Roberts Creek Study Forest, Hudson (2001) shows that variable retention sites develop a snowpack, whereas sites with mature intact forest that contribute to meltwater drip fail to produce a snowpack. Similar findings were also observed by Hubbart et al. (2015) and Berris and Harr (1987) where discussions are highlighted about the canopy's ability to dissipate snowpack, stressing that forested sites can melt up to 70% of an existing snowpack before an ROS event. These studies are important to keep in mind when considering the mitigative abilities of meltwater drip. If snow accumulates in a clearcut area, it can quickly be washed away as a result of a ROS event. Consequently, the rapid loss of snowpack will increase surface runoff, potentially leading to peakflow events, while decreasing groundwater recharge and contributing to drought. In turn, this will also increase the variability of peakflows observed in WCW's FFC. Through increased FFC variability, larger flood events will see greater influences on their magnitude and frequency. This highlights the important role meltwater drip plays in both flood and drought mitigation.

Other settings in coastal southwestern BC mention and discuss meltwater drip and the conditions that influence its existence. In the Jamieson Creek Experimental Watershed, Beaudry (1984) discusses that a range of -0.5 to 1.5 °C produces wet snowfall, showing the sensitivity of snowfall to temperature and contributions to meltwater drip in snow-transient environments. Similarly,

Hudson (2002) notes that snowfall can start to form at a critical temperature of 2 °C, with a linear increase in the percentage of precipitation seen as snow as the temperature approaches 0 °C. This was documented in Russell Creek in northeastern Vancouver Island, which has seen several ROS-related studies and technical reports. Floyd (2012) also noted the need to consider meltwater drip in Russell Creek, underscoring its importance in maritime climates which possess transient snowpacks.

Rong (2017) demonstrated a process analogous to meltwater drip called fog drip, investigating treatment and control watersheds in the H.J. Andrews Research Forest, Oregon. Fog drip occurs where dense fog is captured by a forest canopy and drips to the soil or snowpack below. In the control watershed of Fox Creek, around 30% of the annual water balance is attributed to fog interception (Harr, 1982). Rong (2017) posited that fog drip contributed to the abnormally low coefficient of variation in Fox Creek, as increases in baseflow can result in decreases in peakflow variability (Blöschl & Sivapalan, 1997). With groundwater boundaries extending much further than surface water boundaries, it is important to recognize the implications that meltwater drip has on snowpack, leading to groundwater recharge (Lundberg et al., 2016). As such, the elongated shape of WCW, paired with contributions to meltwater drip from mature forest, could contribute to reducing peakflow variability, imposing extra watershed-level sensitivity (Rong, 2017).

By eliminating meltwater drip through forest harvesting in snow-transient environments, a vital mitigative mechanism against floods and droughts is lost. With the history of extensive forest harvesting and the expected slow recovery of meltwater drip, this presents a significant challenge for hydrologic resilience in WCW. WCW has experienced an increase in peakflow variability as a result of the suppression of meltwater drip, leading to a more variable flooding regime. This has resulted in significant implications for increases in the magnitude and frequency of WCW's post-harvest FFC (Figure 2). Considering existing disturbance, forest management practices should prioritize meltwater drip and its mitigative abilities, such that future contributions to floods and droughts can be averted.

### ***2.5 Regenerating Trees and Resulting Drought Risks***

Through silvicultural practices, trees are planted and regenerated after harvesting is completed. The intensity of planting is a product of desired stocking density and chosen silvicultural techniques. Given high-intensity planting after the default means of forest harvesting in BC,

clearcutting, one must consider the large-scale water consumption of regenerating trees and subsequent consequences for groundwater depletion. After 15 years of being established, regenerating trees are responsible for summer streamflow deficits (Perry & Jones, 2017). Relative to both mature and old-growth reference conditions, deficits were observed to be around 50%. Similarly, Segura et al. (2020) found summer stream flow deficits after forest harvesting and the introduction of regenerating trees in the Alsea Watershed in Oregon. Deficits were observed 40 to 53 years post-treatment after clearcuts of 17% in 1956 and 82% in 1966, with relative reductions of 50% less than the mature reference stands. Given the extent of clearcutting in the past in WCW, it is likely that regenerating trees have contributed to low flow deficits, and future forest harvesting will only add cumulatively to already existing deficits. With the introduction of regenerating trees contributing to groundwater deficits, confounded by the removal of inputs from meltwater drip, this could have significant implications for groundwater depletion.

## ***2.6 Forest Roads***

Forest roads influence and alter the surface of a watershed through the creation of cutbanks, drainage ditches, the implementation of culverts, and an increase in the overall impervious ground cover of a watershed. Cutbanks contribute to the interception of groundwater, rerouting it into surface water. This leads to potential deficits and contributes to drought. The creation of drainage ditches and culverts effectively increases the drainage density of a watershed, increasing the efficiency with which water is delivered to channels and the outlet (Harr et al., 1975; Jones & Grant, 1996). This, in turn, increases the variability of the FFC through efficient routing and increases the mean through the conversion of groundwater to surface water (Wemple et al., 1996). This is further echoed by the study of Rong (2017), which observed this phenomenon of roads synchronizing runoff at the watershed scale. Confounding adverse influences on the increase in magnitude and frequency of floods are found through the suppression of ET from forest harvesting and the necessary creation of forest access roads. When one views this through probabilistic understanding at the watershed macroscale, it will become apparent how the alteration of groundwater dynamics can lead to consequential effects on both floods and droughts.

Horel (2012) reports a high road density of 3.6 km/km<sup>2</sup> in WCW with alterations in the surface catchment. Also noted is the subdued topography, permeable surface deposits, small drainage density in the lower watershed, and the potential for less interception from cutbanks. It is

concluded that due to these reasons, WCW will experience less of an influence on flows compared to watersheds with similar road densities. The road density of WCW is already high, and even accounting for other moderating characteristics, it is likely to exert a significant influence on hydrology. Watersheds with high road density typically show substantial disturbance in catchment water rerouting that can have consequences in shifting the variability of flows, and hence the FFC. Moreover, many roads in WCW run parallel to slope or contour lines, enabling a greater opportunity to influence subsurface interception through cutbanks. This suggests to us that in areas where the stream is relatively uniform, more water travels downslope as groundwater, rather than travelling towards streams. In watersheds like WCW that possess a high road density, it is necessary to consider the cumulative effect of the described roads and what they may contribute to the alteration of the FFC at the watershed scale.

## ***2.7 Geomorphic Sensitivity***

Failure of infrastructure and stream integrity in a catchment can be both hydrologic and geomorphic in nature. Hydrologic failure is a result of a peakflow that exceeds the design capacity of a given piece of infrastructure or contributes to the immediate failure of stream integrity.

With respect to geomorphic failure, the increased frequency and duration of small, medium, and even large flow events under a specified design threshold will contribute cumulatively to destabilizing channels and undermining infrastructure by repeatedly mobilizing sediment, eroding banks and exerting sustained hydraulic stresses. This is especially important given that past extreme events are being seen more frequently and are becoming the norm as a result of forest disturbance and climate change. Moreover, due to historical logging and numerous sediment sources present in WCW, caution should be exercised when evaluating future logging activities. Future forest harvesting is likely to contribute to an increase in both the magnitude and frequency of existing flows, challenging the integrity of current infrastructure and streams. By avoiding a means of investigation that addresses hydrologic change through a probabilistic framework, higher levels of runoff will place more frequent stress on infrastructure, leading to large replacement costs that will occur more frequently (Hui et al., 2018).

This is confounded by the fact that the design process for infrastructure does not incorporate the cumulative consequences of all flows that will increase in intensity and frequency as a result of forest disturbance (Figure 2). While only addressing stationary assumptions, most design processes

may also not adequately acknowledge future disturbances and their potential consequences (Cheng & AghaKouchak, 2014). By developing a probabilistic understanding of these risks and invoking a framework that understands frequency-magnitude relations, consequences can effectively be managed and prevented.

With additional forest harvesting in WCW, the risk of geomorphic and hydrologic failure will increase. Horel (2012) outlines the sediment sources and risks in her report, but to fully appreciate the hazards and risks associated, one must use a probabilistic means of investigation. Through this type of investigation, hydrologic and geomorphic failure will be fully understood.

### ***2.8 Current Riparian Conditions***

To supplement the conducted riparian assessment of Horel (2012), we completed a new riparian assessment in December 2024. This new riparian assessment enables comparison over the 12 years since the assessment of Horel (2012) took place. All maps, terminology, and comments from the 2012 assessment were taken into account when completing this new assessment. Our new riparian assessment in 2024 contains new field stops in addition to all the pre-established stops present in Horel (2012). The only stop not visited was stop 25, as access proved challenging. Changes were documented in the riparian condition as a result of alterations that contributed to the stream network system due to increased disturbance and cumulative effects in WCW. An interactive [ArcGIS Online map](#) has been created with clickable field stops that show photos of the current riparian and channel conditions.

In addition to this interactive map with descriptions, four field stops have been selected to compare differences from 2012 to 2024. A field stop in each nested watershed (Husdon, Wilson, and East Wilson) in WCW has been selected alongside the field stop nearest to the outlet where Wilson Creek meets the Sunshine Coast Highway. These field stops are stops 1, 26, 20, and 16 respectively.



**Figure 3.** Field stop 1, photo 1 from Husdon Creek (Horel, 2012).



**Figure 4.** Field stop 1, photo 2 from Husdon Creek (Horel, 2012).



**Figure 5.** Field stop 1 from Husdon Creek looking upstream. December 2024 field visit.



**Figure 6.** Field stop 1 from Husdon Creek looking downstream. December 2024 field visit.

Figures 3-6 contrast the 2012 and 2024 riparian conditions of field stop 1. Bank erosion can be seen between upstream-facing Figures 3 and 5, with generally stable conditions. Figures 4 and 6 reveal a starker contrast with a large difference in riparian conditions. A windthrow event has led to many trees present in Husdon Creek. This can lead to sediment entrapment and sediment sources in this portion of the creek. A significant blockage of the channel like this can also reduce fish habitat.

Field stop #26. Wilson Creek at Bloom residence. May 11, 2012.

Photo 62. Escarpment on west gully sidewall. Gaciofluvial gravelly sand overlying marine sediments (silt, clayey



**Figure 7.** Field stop 26, photo 62 from Wilson Creek showcasing the landslide at the Bloom residence (Horel, 2012).

Photo 63. Looking downstream from location of Photo 62. Old wood debris jam with some more recent debris accumulation. Old wood mossy.



**Figure 8.** Field stop 26, photo 63 from Wilson Creek (Horel, 2012).



**Figure 9.** Field stop 26 from Wilson Creek, showing the landslide area. December 2024 field visit.



**Figure 10.** Field stop 26 from Wilson Creek looking downstream. December 2024 field visit.

Figures 7-10 contrast the 2012 and 2024 riparian conditions of field stop 26. The landslide area (Figures 7 and 9) has been overgrown since 2012, but alluvial deposits have begun to accumulate at the toe of the slope. Additionally, groundwater was being intercepted just above the clay layer. Figures 8 and 10 show downstream conditions at field stop 26. Since 2012, woody debris has continued to accumulate in the log jam area.



Photo 52. Looking upstream from bridge.

**Figure 11.** Field stop 20, photo 52 from East Wilson Creek (Horel, 2012).



Photo 53. Upstream from Photo 52, looking upstream.

**Figure 12.** Field stop 20, photo 53 from East Wilson Creek (Horel, 2012).



**Figure 13.** Field stop 20 from East Wilson Creek looking upstream. December 2024 field visit.



**Figure 14.** Field stop 20 from East Wilson Creek, further upstream. December 2024 field visit.

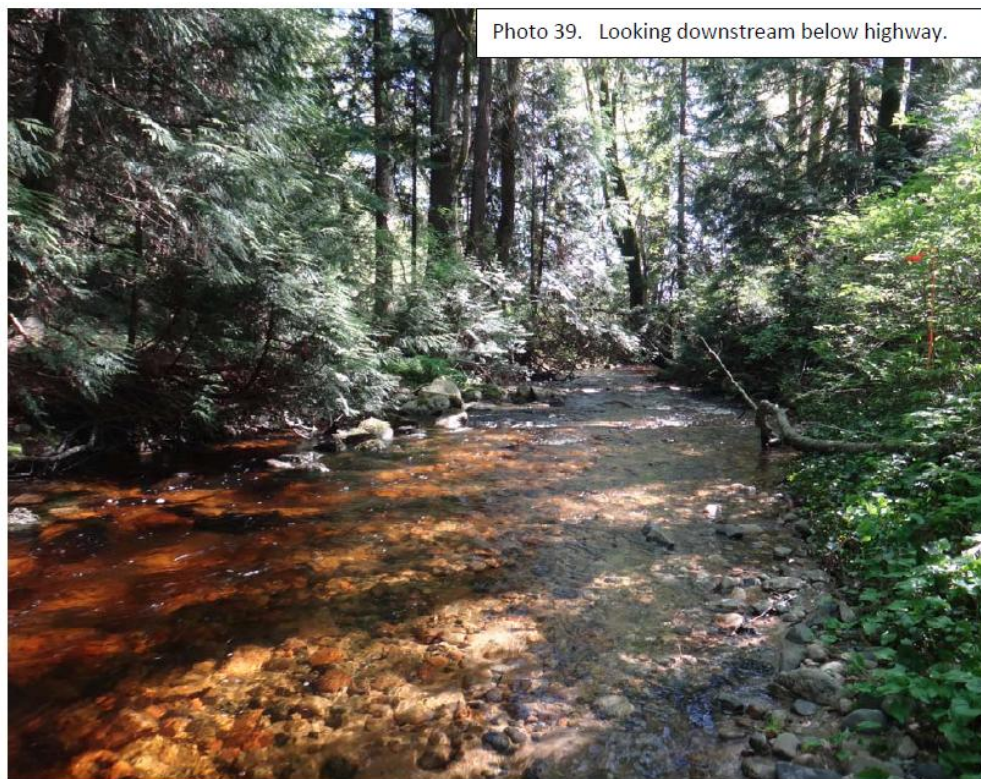


**Figure 15.** Field stop 20 from East Wilson Creek. Bank erosion has caused trees to fall in the channel. December 2024 field visit.

More apparent changes can be observed between the 2012 and 2024 riparian assessments at field stop 20. Recent windthrow can be seen in the channel in Figures 11 and 12. Mid-channel bars in Figure 12 appear to have mostly uniform grain sizes, whereas the comparative photo of 2024 (Figure 13) shows many larger, poorly sorted grain sizes. This is also evident in Figure 14. Additionally, there is evidence of bank erosion and disturbance since 2012, with trees falling into the channel and their roots contributing as sediment sources (Figure 15). Channels appear to be unstable at this field stop.



**Figure 16.** Field stop 16, photo 38 from East Wilson Creek at the Sunshine Coast Highway (Horel, 2012).



**Figure 17.** Field stop 16, photo 39 from Wilson Creek at the Sunshine Coast Highway (Horel, 2012).



**Figure 18.** Field stop 16 from Wilson Creek, looking downstream from the Sunshine Coast Highway crossing. December 2024 field visit.



**Figure 19.** Field stop 16 from Wilson Creek, looking further downstream from the Sunshine Coast Highway crossing. December 2024 field visit.



**Figure 20.** Field stop 16 from Wilson Creek, upstream from the Sunshine Coast Highway crossing. December 2024 field visit.

Figures 16-20 show the differences between 2012 and 2024 at field stop 16, which is closest to the outlet of WCW. Upstream of this location, all nested watersheds have joined. Below the culvert, bank erosion has occurred with clear overtopping. An additional photo of 2024 upstream conditions, not highlighted in the 2012 report, has been included (Figure 20). Large-scale bank collapse and erosion can be observed with an unstable channel.

Throughout WCW, it appeared that channel processes had been intensified, and the channels had been altered geomorphologically. Large quantities of windthrow, trees toppled from eroded and undercut banks, log jams, large bars, and movement of large grain sizes (i.e. boulders) were present when completing this assessment. With the additional harvesting that took place after the completion of the 2012 assessment, the increased magnitude and variability of peakflow events (Figure 2, Table 2) have altered channel morphology and influenced the sensitive nature of the stream network. Differences in the photos of the stream channel from 2012 can be compared with

the new photos taken in 2024. This was evident in the observed cumulative effect downstream of the large harvest operation spanning from 370 m to 790 m. We acknowledge that formerly glaciated mountainous streams are subject to change, and often lack a state of equilibrium (Hassan et al., 2014). However, forest harvesting contributes to the intensification of hydrologic processes that promote channel-altering behaviour.

## ***2.9 Aquifers and Groundwater Considerations***

Horel (2012) mentions deep soil and surficial deposits in the lower third of WCW and their potential contributions to sustaining baseflow, but neglects to consider the potential existence of any aquifers. When considering glacial deposits that make up a portion of the southwest coast of British Columbia, it is important to consider how such deposits may influence baseflow, groundwater – surface water (GW-SW) interactions and the potential implications of losing coastal streams.

WCW contains two aquifers that were mapped in 2018. The East Porpoise Bay (AQ 564) aquifer extends to around 180 m above sea level and is comprised of fractured crystalline granodiorite and dioritic bedrock (Map 3, page 48). Additionally, the East Sechelt Delta (AQ 566) aquifer extends 100 m above sea level and is characterized by unconfined glacial outwash made up of sand and gravel (Map 3). It is believed that there is connectivity between AQ 564 and AQ 566, with the potential of stream water being lost to these aquifers at certain times of the year. The spatial extent of recharge is unknown for these aquifers, but WCW likely plays a crucial role in recharge. This was observed in the 2024 field visit to WCW. The summation of the runoff in upstream tributaries did not add up to the observed discharge at the outlet of WCW.

Coastal environments provide a physiographic setting in which GW-SW interactions are highly connected (Foster & Allen, 2015). Such interactions are found in gaining and losing streams. A gaining stream sees inflow from groundwater where the water table is higher than that of the stream, and a losing stream sees connection to groundwater, which removes water from the streambed with a water table lower than that of the stream (Winter, 2000).

Given that AQ 566 is comprised of permeable sand and gravel, low elevation, subdued portions of WCW could be losing to this aquifer. This is further supported by Foster and Allen (2015), who conducted a study on Vancouver Island in the Cowichan River watershed. The Cowichan River as

it passes over AQ 186, which is made of the same sand and gravel material as AQ 566 present in WCW. It is described that the Cowichan River passes over AQ 186, where the topography is subdued, losing large volumes of water. These losses are greater in the winter months when river levels are high, and the groundwater table may still be low (Foster & Allen, 2015). In contrast, higher elevation upstream locations see gaining streams in the Cowichan Valley. Another similar documented scenario is that of the Mamquam River, which sees losses to AQ 398 (Kerr Wood Leidal Associates Ltd., 2001). Once again, this aquifer is composed of sand and gravel. Notably, the Mamquam River feeds into the much larger Squamish River system about 6 km from its outlet.

A portion of WCW's streamflow is likely lost to aquifers. If one invokes the high level of disturbance present in WCW and considers aquifer recharge, an interesting story can be told. Through the removal of forest cover, water will likely fail to contribute as much to groundwater and instead travel to streams as surface water. This will be seen in the form of rapid snowmelt in clearcut areas from ROS events, rather than slow melt mediated by the forest canopy through processes like meltwater drip. This effectively results in less aquifer recharge, lower amounts of baseflow, and an increased variability in the FFC. Consequently, streams near the aquifer may contribute more frequently (i.e., losing) rather than slow groundwater processes contributing to stable groundwater levels.

## ***2.10 Problems Associated with ECA***

### ***2.10.1 Shortcomings***

We would like to preface this section by acknowledging that Horel (2012) has reported ECA in WCW, but then dismisses its relevance in quantifying the level of disturbance and associated risk to hydrology with little justification. This section will highlight the shortcomings of ECA, reiterating its fundamental deficiencies.

ECA is a deterministic stand-level metric that attempts to quantify the level of disturbance in a given area. It is non-spatial and reductionist and does not capture the causal power that emerges at the watershed level. By assigning a percentage of disturbance to a selected area, one immediately underestimates the effect on hydrology. It requires very little understanding of how a catchment operates spatially. Watersheds are spatial systems that are holistic, multivariate, and complex in nature. Macroscale features reveal themselves through the climate, physiography, and disturbance. Intuitively, harvesting in hydrologically sensitive areas or differing locations and elevations would

have very different effects on catchment hydrology. Furthermore, harvesting in these areas may contribute to response synchronization across a watershed. This highlights the most critical flaw in ECA: the summation of stand-level processes does not address the interactions of macroscale processes in space and time at the watershed level. Watersheds are holistic systems that display emergent behaviour, whereby the whole is typically greater than, though at times comparable to or even less than, the sum of its parts. In addition, ECA does not provide information on how the frequency and magnitude of extreme events will change with respect to future forest disturbance.

An additional and equally important flaw of ECA is found in stand-level recovery curves and their inability to represent watershed-level recovery. These curves suggest that when a stand grows to an adequate height (which occurs quickly, ~30-40 years), snow and rainfall interactions with the forest canopy will be fully recovered. Stand-level hydrologic recovery aligns with a 40-year timeline (Harr et al., 1989; Harr & Coffin, 1992). Another story can be told for the hydrologic recovery of runoff in the channel, which is dependent on the watershed scale. These two metrics differ largely, with the latter taking longer time periods to recover. It also must be noted that the recovery of magnitude and frequency of peakflows may not recover at the same rate, with frequency recovery much slower.

When calculating disturbance using ECA, one does not recognize any subsurface hydrologic processes due to the limited focus on canopy interception and stand height. Conversely, with active groundwater contribution in coastal watersheds coming from processes like meltwater drip, and most hydrology in forested environments occurring underground, a significant portion of hydrology goes unnoticed while using ECA. This, in turn, has consequences for underestimating the correct level of disturbance and true hydrologic recovery (i.e., that of flows in the channel). For this reason, ECA fundamentally underestimates the effects of forest practices on floods and droughts.

ECA has significant limitations when used to quantify disturbance due to it is a deterministic, stand-level metric that does not establish cause and effect through a watershed scale response. It is magnitude-focused and does not accurately quantify the extent of disturbance, and as a result, the potential for hydrologic change. In other words, it is not designed to assess the effects of forest harvesting on the frequency of extreme floods and droughts.

As a result of its deterministic, non-causal design and its resulting reliance on the microscale rather than the macroscale, ECA, through its use of stand-level recovery curves, its inability to quantify below-ground processes, and its inability to address effects on frequency, does not reveal the true causal power of forests on hydrology. Through using a probabilistic framework, one reveals a much more sensitive hydrology to forest disturbance. Moreover, with a larger watershed and larger peakflow events, forests also have a stronger ability to mitigate extremes. In this way, a probabilistic framework is uniquely well-suited to uncovering the causal role and power of forests in shaping and mitigating the magnitude and frequency of peakflows.

### ***2.10.2 ECA in Relation to Wilson Creek***

The following passages provide context for the usage of ECA in Horel (2012):

*“ECA gives only an indication of potential streamflow changes based on the extent of forest modification. An ECA of 50% does not mean that stream flows may have changed, or recovered, by this amount. In particular, **ECA is not an indicator of watershed or stream conditions.**”*  
(p.8)

*“**ECA is not an indicator of hydrologic function at either the watershed or stream scale**”* (p.9)

*“ECAs [in Wilson Creek] indicate overall high potential for hydrologic change. Note that “a high potential for hydrologic change” **does not mean that significant flow increases, or impacts to stream channels, have necessarily occurred.**”*(p.12)

As prefaced at the beginning of this section, Horel (2012) presents ECA calculations but concurrently states that ECA should not be interpreted as an indicator of hydrologic function. This represents inconsistencies between the metric used to quantify forest disturbance and the interpretation that follows it. The ECA threshold decision-making process is described by Winkler & Boon (2017):

*“Equivalent clearcut area was then compared to either legislated or expert opinion–defined harvest thresholds that were considered acceptable for the area (Reid 1993; Berg et al. 1996). If watershed-scale*

*ECA exceeded the set threshold, downstream resources were assumed to be at risk either until adequate recovery occurred or until harvest plans were modified to result in a smaller ECA increase (Reid 2010). This approach assumed that by limiting streamflow increases in higher-order streams, lower-order stream channels would also be protected (King 1989).” (p.2)*

Horel (2012) does not report any ECA thresholds (e.g., Low: <20%, Medium: 20-30%, High: >30% (Winkler et al., 2010)) or conclude upon any appropriate level of future forest harvest when discussing ECAs. This is because WCW already sat at an ECA of 47% in Horel (2012), which would qualify as much higher than the “high” threshold of 30%. Returning to the quotes at the beginning of this subsection, ECA is downplayed, contrasting with its historical weight in determining the level of disturbance and its ability to guide future forest harvest. Further, considering the high ECA in WCW, it is important to recognize that quantification of disturbance using this method underestimates the magnitude of disturbance on hydrology. Stand-level ECA attempts to assess hydrology at the macro watershed scale but does so using deterministic methodologies. Using a probabilistic framework reveals the amount of disturbance in WCW coherently coupled with climate and landscape features, and hence, appropriately assesses the effect on hydrology and potential for hydrologic change.

Horel (2012) also reports ECAs for the SCCF’s Wilson Creek tenure (41%) and WCW (47%) separately. With analysis from Map 2, without adjusted recovery, which would be small, in 2025, WCW currently sits at an ECA of 55%. If one is to quantify any level of disturbance, it should be evaluated at the watershed scale. When reporting ECAs for a small area of WCW, such as the SCCF, one loses the causal power at the macroscale and does not accurately depict the extent of disturbance and subsequently, the effect on hydrology. This gives an incomplete picture when considering the cumulative effect across WCW and the high level of disturbance already present. If one is to consider forest operations in WCW, disturbance must be quantified holistically and cumulatively across space and time at the macroscale. Through this, a mild slope of the FFC is portrayed, characteristic of a super-sensitive coastal watershed. The current hazards and risks in WCW should be determined at the macroscale, aided by the use of FFCs.

Unfortunately, the use of ECA in the 2012 Wilson Creek Watershed Assessment does not suggest much about the true level of disturbance in the watershed. One should aim to use alternative means through probabilistic understanding to holistically determine the extent of forest disturbance across a watershed. Risk must be assessed under a probabilistic framework that enables the user to determine the changes in both magnitude and frequency of extreme events given future forest disturbance. A probabilistic framework is frequency-focused and provides a holistic, coherent interpretation of how the climate interacts with physiographic features in a watershed. The use of deterministic-reductionist methods dramatically underestimates the power of forests in mitigating hydrology and geomorphology. Consequently, it will lead to misleading outcomes.

### ***3. Conclusions***

In its current state, WCW is characterized by a high level of disturbance, with severely altered hydrology. Considering the extent of cumulative forest and stream network disturbance in WCW, a long recovery period must be considered, such that it has sufficient time to reacquire adequate hydrologic functionality. Given such a high level of hydrologic risk and potential impacts on fish, water quality, infrastructure, and downstream communities, any additional forest harvesting in the watershed is out of the question.

Peakflows in Wilson Creek are sensitive to forest harvesting. Table 2 shows that the 100-year event became a ~20-year event, the 50-year event became a ~10-year event, the 20-year event became a ~5-year event, and the 10-year event became a ~4-year event.

Stand-level hydrologic recovery studies show a 40-year timeline (Harr et al., 1989; Harr & Coffin, 1992). Recovery of runoff in the channel behaves differently from stand-level hydrologic recovery, taking longer and being watershed-scale dependent. The frequency of floods may also recover more slowly than the magnitude.

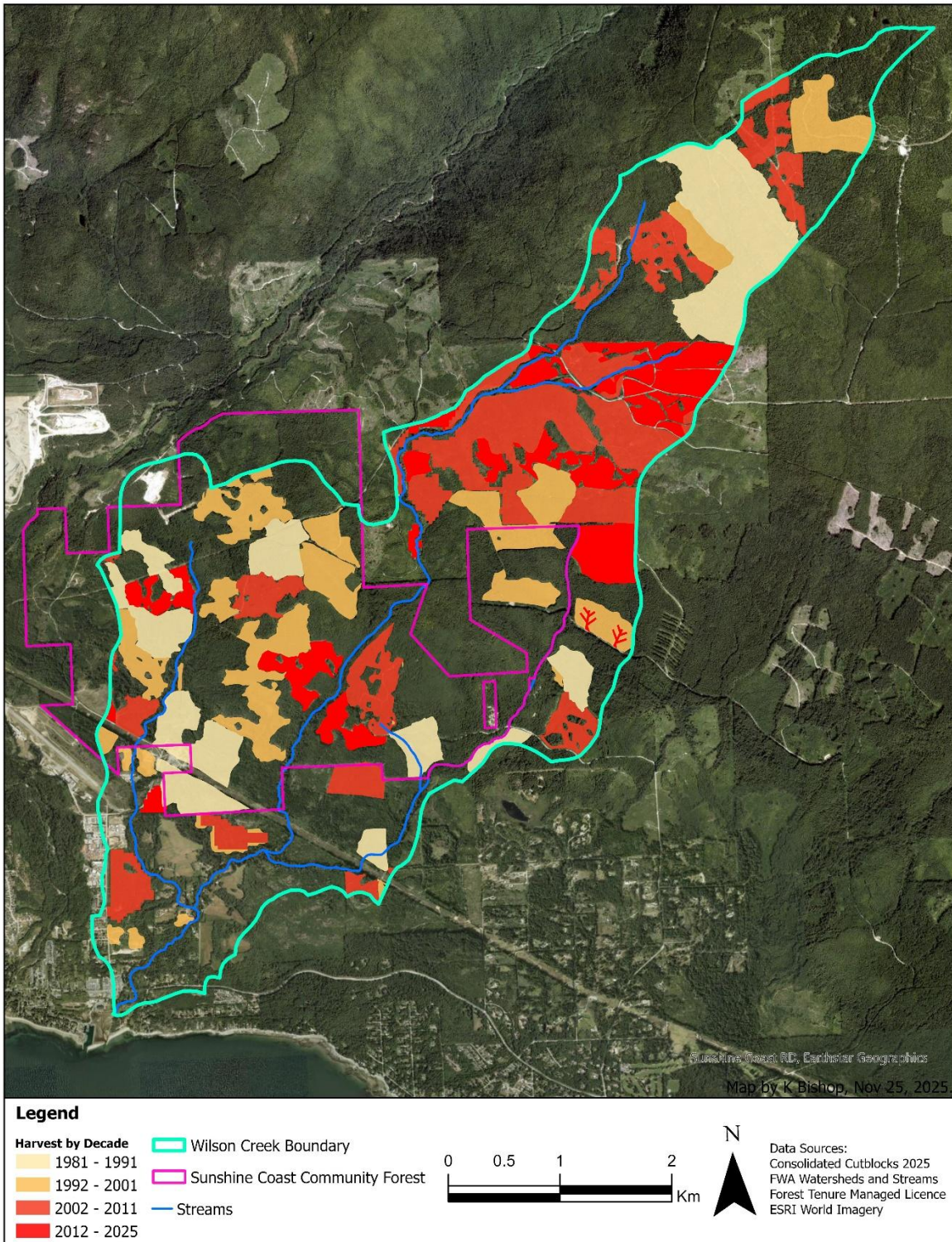
The risk of downstream consequences is too high to continue forest harvesting in WCW, given its current state. This is further corroborated by the geomorphic change through intensified channel-altering processes and overall channel sensitivity seen in the riparian assessment carried out in December 2024.

Peakflows and droughts have increased in magnitude and frequency in WCW. These are experienced by the removal of forest cover, construction of forest roads that intercept groundwater

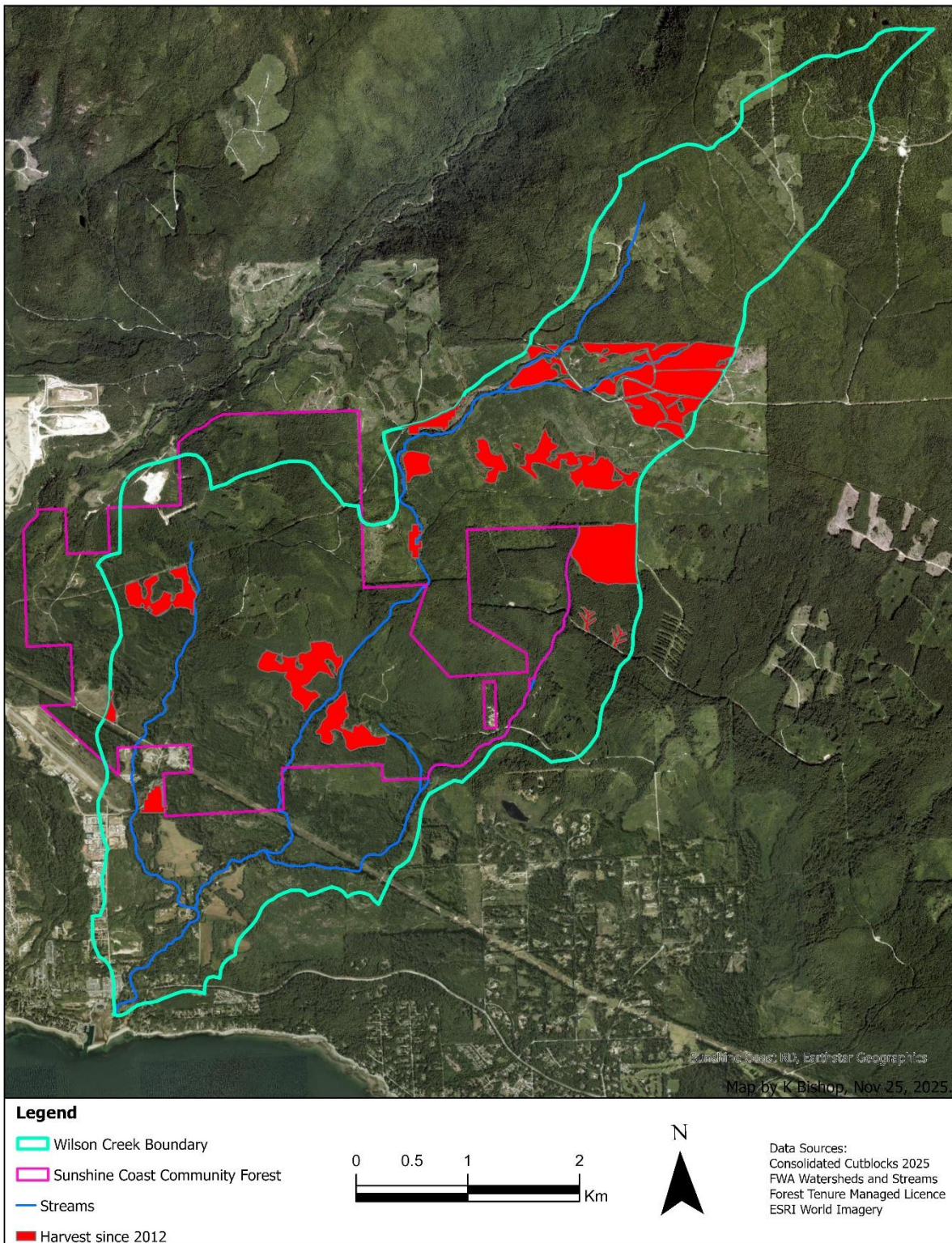
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and increase runoff efficiency, suppression of meltwater drip's groundwater inputs, increased frequency and magnitude of ARs which will rapidly melt snow from cutblocks, young regenerating stands consuming large amounts of water, the loss of runoff to aquifers, and the compounding mechanism of hydrologic whiplash. As such, we recommend that WCW be given time to regain its hydrologic integrity, and no further forest harvesting be conducted in the foreseeable future.

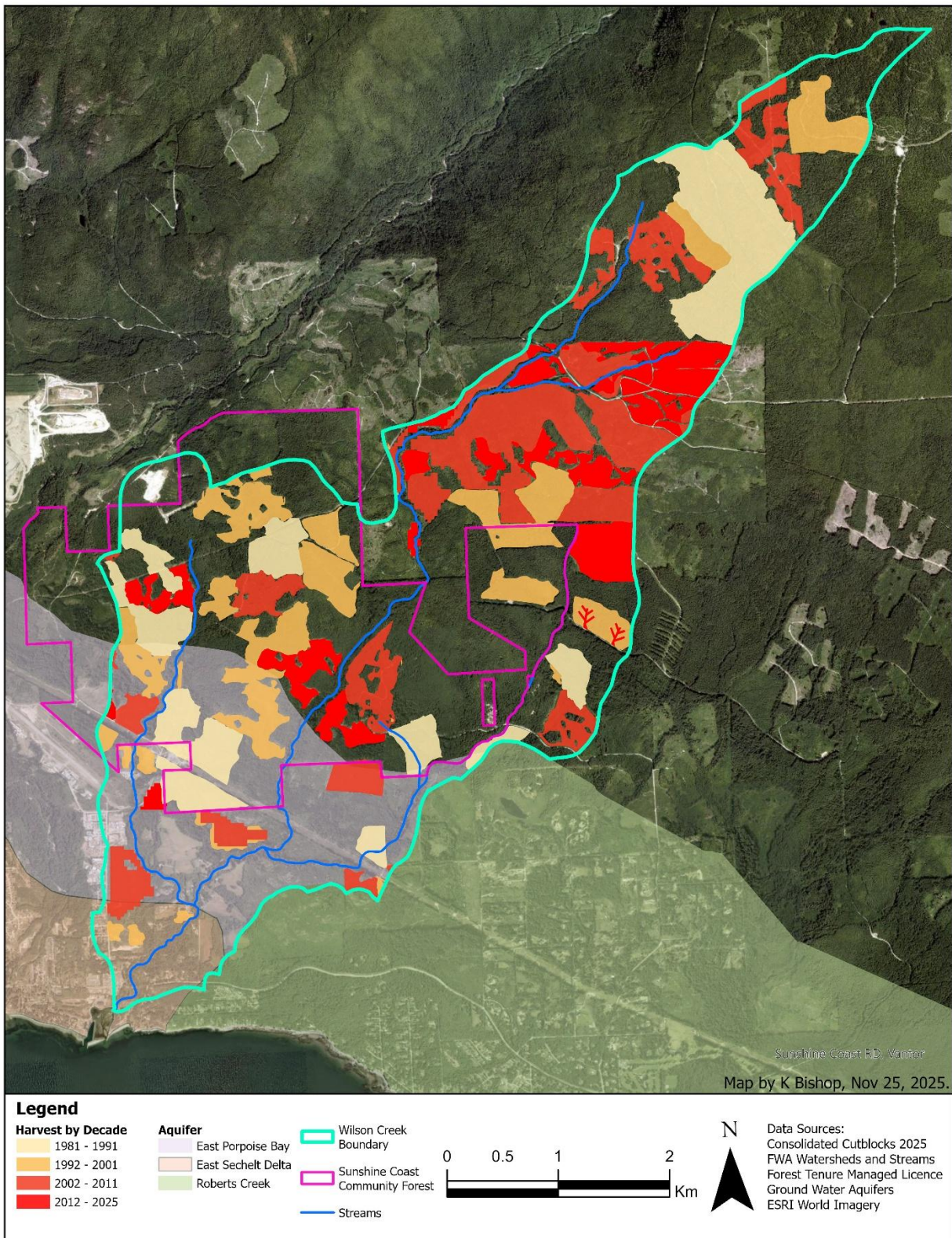
## Maps



**Map 1.** Consolidated cutblock data of Wilson Creek displaying the harvest record from 1981 to 2025. Undocumented cutblocks can be seen in the upper mid-elevation, privately owned, largely clearcut portions of Wilson Creek.



**Map 2.** Forest harvest from 2012 to 2025 in Wilson Creek. ECA has been raised to 55% without additional recovery



Map 3. Location of aquifers in Wilson Creek with reference to harvest record from 1981-2025.

## References

- Allen, M. R., & Ingram, W. J. (2002). Constraints on future changes in climate and the hydrologic cycle. *Nature*, 419(6903), 224–232. <https://doi.org/10.1038/nature01092>
- Beaudry, P. (1984). Effects of forest harvesting on snowmelt during rainfall in coastal British Columbia. *University of British Columbia*. <https://doi.org/10.14288/1.0096022>
- Beckers, J., Alila, Y., & Mtiraoui, A. (2002). On the validity of the British Columbia Forest Practices Code guidelines for stream culvert discharge design. *Canadian Journal of Forest Research*, 32(4), 684–692. <https://doi.org/10.1139/x02-010>
- Berris, S. N., & Harr, R. D. (1987). Comparative snow accumulation and melt during rainfall in forested and clear-cut plots in the Western Cascades of Oregon. *Water Resources Research*, 23(1), 135–142. <https://doi.org/10.1029/WR023i001p00135>
- Beven, K. J. (2000). Uniqueness of place and process representations in hydrological modelling. *Hydrology and Earth System Sciences*, 4(2), 203–213. <https://doi.org/10.5194/hess-4-203-2000>
- Bishop, K., & Alila, Y. (2026). Forests and Floods: A causal stochastic approach shows that macro can beat micro. *In Review*.
- Blöschl, G., & Sivapalan, M. (1997). Process controls on regional flood frequency: Coefficient of variation and basin scale. *Water Resources Research*, 33(12), 2967–2980. <https://doi.org/10.1029/97WR00568>
- Bründl, M., Schneebeli, M., & Flühler, H. (1999). Routing of canopy drip in the snowpack below a spruce crown. *Hydrological Processes*, 13(1), 49–58. [https://doi.org/10.1002/\(SICI\)1099-1085\(199901\)13:1<49::AID-HYP700>3.0.CO;2-L](https://doi.org/10.1002/(SICI)1099-1085(199901)13:1<49::AID-HYP700>3.0.CO;2-L)
- Brunengo, M. (2012). *Where Is the Rain-on-Snow Zone in the West-Central Washington Cascades?: Monte Carlo Simulation of Large Storms in the Northwest*. <https://doi.org/10.15760/etd.689>
- Cheng, L., & AghaKouchak, A. (2014). Nonstationary Precipitation Intensity-Duration-Frequency Curves for Infrastructure Design in a Changing Climate. *Scientific Reports*, 4(1), 7093. <https://doi.org/10.1038/srep07093>
- Cohen, J., Ye, H., & Jones, J. (2015). Trends and variability in rain-on-snow events. *Geophysical Research Letters*, 42(17), 7115–7122. <https://doi.org/10.1002/2015GL065320>
- Corringham, T. W., McCarthy, J., Shulgina, T., Gershunov, A., Cayan, D. R., & Ralph, F. M. (2022). Climate change contributions to future atmospheric river flood damages in the western United States. *Scientific Reports*, 12(1), 13747. <https://doi.org/10.1038/s41598-022-15474-2>
- Floyd, W. C. (2012). Snowmelt Energy Flux Recovery During Rain-on-Snow in Regenerating Forests. *University of British Columbia*. <https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0073024>

- Foster, S. B., & Allen, D. M. (2015). Groundwater—Surface Water Interactions in a Mountain-to-Coast Watershed: Effects of Climate Change and Human Stressors. *Advances in Meteorology*, 2015, 1–22. <https://doi.org/10.1155/2015/861805>
- Gillett, N. P., Cannon, A. J., Malinina, E., Schnorbus, M., Anslow, F., Sun, Q., Kirchmeier-Young, M., Zwiers, F., Seiler, C., Zhang, X., Flato, G., Wan, H., Li, G., & Castellan, A. (2022). Human influence on the 2021 British Columbia floods. *Weather and Climate Extremes*, 36, 100441. <https://doi.org/10.1016/j.wace.2022.100441>
- Golding, D. L. (1987). Changes in streamflow peaks following timber harvest of a coastal British Columbia watershed. *Forest Hydrology and Watershed Management*.
- Hammond, J., Anderson, B., Simeone, C., Brunner, M., Muñoz-Castro, E., Archfield, S., Magee, E., & Armitage, R. (2025). Hydrological Whiplash: Highlighting the Need for Better Understanding and Quantification of Sub-Seasonal Hydrological Extreme Transitions. *Hydrological Processes*, 39(3), e70113. <https://doi.org/10.1002/hyp.70113>
- Harr, R. D. (1982). Fog Drip in the Bull Run Municipal Watershed, Oregon. *JAWRA Journal of the American Water Resources Association*, 18(5), 785–789. <https://doi.org/10.1111/j.1752-1688.1982.tb00073.x>
- Harr, R. D., & Coffin, B. A. (1992). Influence of Timber Harvest on Rain-On-Snow Runoff: A Mechanism for Cumulative Watershed Effects. *Interdisciplinary Approaches in Hydrology and Hydrogeology*, 455–469.
- Harr, R. D., Coffin, B. A., & Cundy, T. W. (1989). Effects of timber harvest on rain-on-snow runoff in the transient snow zone of the Washington Cascades: Interim final report. *Timber-Fish-Wildlife Project*.  
<http://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub4647.pdf>
- Harr, R. D., Harper, W. C., Krygier, J. T., & Hsieh, F. S. (1975). Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. *Water Resources Research*, 11(3), 436–444. <https://doi.org/10.1029/wr011i003p00436>
- Hassan, M. A., Brayshaw, D., Alila, Y., & Andrews, E. (2014). Effective discharge in small formerly glaciated mountain streams of British Columbia: Limitations and implications. *Water Resources Research*, 50(5), 4440–4458. <https://doi.org/10.1002/2013WR014529>
- Hoel, E. (2017). When the Map Is Better Than the Territory. *Entropy*, 19(5), 188. <https://doi.org/10.3390/e19050188>
- Horel, G. (2012). *Wilson Creek Watershed Assessment*.  
[https://www.sccf.ca/\\_files/ugd/5b0e15\\_d526a41bd82e48928a33dc1d21969081.pdf](https://www.sccf.ca/_files/ugd/5b0e15_d526a41bd82e48928a33dc1d21969081.pdf)
- Hotovy, O., Nedelcev, O., Seibert, J., & Jenicek, M. (2024). *Rain-on-snow events in mountainous catchments under climate change*. <https://doi.org/10.5194/egusphere-2024-2274>

Hubbart, J. A., Link, T. E., & Gravelle, J. A. (2015). Forest Canopy Reduction and Snowpack Dynamics in a Northern Idaho Watershed of the Continental-Maritime Region, United States. *Forest Science*, 61(5), 882–894. <https://doi.org/10.5849/forsci.14-025>

Hudson, R. (2001). Roberts Creek Study Forest: Preliminary effects of partial harvesting on peak streamflow in two S6 creeks. *Vancouver Forest Region*.

Hudson, R. (2002). *Effects of Forest Harvesting and Regeneration on Peak Streamflow in a Coastal Watershed*.

Hui, R., Herman, J., Lund, J., & Madani, K. (2018). Adaptive water infrastructure planning for nonstationary hydrology. *Advances in Water Resources*, 118, 83–94. <https://doi.org/10.1016/j.advwatres.2018.05.009>

Johnson, R. S. H., & Alila, Y. (2023). Nonstationary stochastic paired watershed approach: Investigating forest harvesting effects on floods in two large, nested, and snow-dominated watersheds in British Columbia, Canada. *Journal of Hydrology*, 625, 129970. <https://doi.org/10.1016/j.jhydrol.2023.129970>

Jones, J. A., & Grant, G. E. (1996). Peak Flow Responses to Clear-Cutting and Roads in Small and Large Basins, Western Cascades, Oregon. *Water Resources Research*, 32(4), 959–974. <https://doi.org/10.1029/95wr03493>

Kaluarachchi, S., & Alila, Y. (2025). Why forests can mitigate floods of all sizes: Evaluating the scientific basis for forest-based flood mitigation. *In Review*.

Kerr Wood Leidal Associates Ltd. (2001). Community water supply systems in the Sea to Sky Land and Resource Management Plan area. *Prepared for the Ministry of Environment, Lands and Parks, BC Environment, Lower Mainland Region*.

Kirchner, M., Faus-Kessler, T., Jakobi, G., Leuchner, M., Ries, L., Scheel, H., & Suppan, P. (2013). Altitudinal temperature lapse rates in an Alpine valley: Trends and the influence of season and weather patterns. *International Journal of Climatology*, 33(3), 539–555. <https://doi.org/10.1002/joc.3444>

Lundberg, A., Gustafsson, D., Stumpp, C., Kløve, B., & Feiccabrino, J. (2016). Spatiotemporal Variations in Snow and Soil Frost—A Review of Measurement Techniques. *Hydrology*, 3(3), Article 3. <https://doi.org/10.3390/hydrology3030028>

Lundquist, J. D., Dickerson-Lange, S. E., Lutz, J. A., & Cristea, N. C. (2013). Lower forest density enhances snow retention in regions with warmer winters: A global framework developed from plot-scale observations and modeling. *Water Resources Research*, 49(10), 6356–6370. <https://doi.org/10.1002/wrcr.20504>

Minder, J. R., Mote, P. W., & Lundquist, J. D. (2010). Surface temperature lapse rates over complex terrain: Lessons from the Cascade Mountains. *Journal of Geophysical Research: Atmospheres*, 115(D14), 2009JD013493. <https://doi.org/10.1029/2009JD013493>

- Musselman, K. N., Lehner, F., Ikeda, K., Clark, M. P., Prein, A. F., Liu, C., Barlage, M., & Rasmussen, R. (2018). Projected increases and shifts in rain-on-snow flood risk over western North America. *Nature Climate Change*, 8(9), 808–812. <https://doi.org/10.1038/s41558-018-0236-4>
- Perry, T. D., & Jones, J. A. (2017). Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. *Ecohydrology*, 10(2), e1790. <https://doi.org/10.1002/eco.1790>
- Pham, H. C., & Alila, Y. (2024). Science of forests and floods: The quantum leap forward needed, literally and metaphorically. *Science of The Total Environment*, 912, 169646. <https://doi.org/10.1016/j.scitotenv.2023.169646>
- Rong, W. (2017). Revealing Forest Harvesting Effects on Large Peakflows in Rain-on-Snow Environment with New Stochastic Physics. *University of British Columbia*. <https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0354383>
- Rong, W., Bishop, K., & Alila, Y. (in review). Stochastic Hydrology Reveals the Controls of Forest Harvesting—Peakflow Causal Relations in Snow-Transient Environment. *Journal of Hydrology*.
- 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. <https://doi.org/10.1016/j.jhydrol.2020.124749>
- Sezen, C., Šraj, M., Medved, A., & Bezak, N. (2020). Investigation of Rain-On-Snow Floods under Climate Change. *Applied Sciences*, 10(4), 1242. <https://doi.org/10.3390/app10041242>
- Storck, P., Bowling, L., Wetherbee, P., & Lettenmaier, D. (1998). Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. *Hydrological Processes*, 12, 889–904.
- Storck, P., Lettenmaier, D. P., & Bolton, S. M. (2002). Measurement of snow interception and canopy effects on snow accumulation and melt in a mountainous maritime climate, Oregon, United States. *Water Resources Research*, 38(11). <https://doi.org/10.1029/2002WR001281>
- Tonina, D., Luce, C. H., Rieman, B., Buffington, J. M., Goodwin, P., Clayton, S. R., Ali, S. Md., Barry, J. J., & Berenbrock, C. (2008). Hydrological response to timber harvest in northern Idaho: Implications for channel scour and persistence of salmonids. *Hydrological Processes*, 22(17), 3223–3235. <https://doi.org/10.1002/hyp.6918>
- Wang, T., Hamann, A., Spittlehouse, D. L., & Aitken, S. N. (2006). Development of scale-free climate data for Western Canada for use in resource management. *International Journal of Climatology*, 26(3), 383–397. <https://doi.org/10.1002/joc.1247>
- Wang, T., O'Neill, G. A., & Aitken, S. N. (2010). Integrating environmental and genetic effects to predict responses of tree populations to climate. *Ecological Applications*, 20(1), 153–163. <https://doi.org/10.1890/08-2257.1>

## Wilson Creek Watershed: Peer Review and Re-Assessment

Wemple, B. C., Jones, J. A., & Grant, G. E. (1996). Channel network extension by logging roads in two basins, western Cascades, Oregon. *JAWRA Journal of the American Water Resources Association*, 32(6), 1195–1207. <https://doi.org/10.1111/j.1752-1688.1996.tb03490.x>

Winkler, R. D., & Boon, S. (2017). Equivalent Clearcut Area as an Indicator of Hydrologic Change in Snow-dominated Watersheds of Southern British Columbia. *Prov. B.C., Victoria, B.C, Exten. Note 118*. <https://doi.org/www.for.gov.bc.ca/hfd/pubs/Docs/En/En118.htm>

Winkler, R. D., Redding, T. E., Spittlehouse, D. L., Smerdon, B. D., & Carlyle-Moses, D. E. (2010). The Effects of Forest Disturbance on Hydrologic Processes and Watershed Response. *Compendium of Forest Hydrology and Geomorphology in British Columbia*, 179.

Winter, T. (2000). *Ground water and surface water: A single resource*. Diane Publishing.