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August 25, 2023

BY EMAIL

Tom Johnson
Woodlands Manager
BC Timber Sales, Chinook Business Area
46360 Airport Rd
Chilliwack, BC V2P 1A5

RE: Peer review of Phases 1, 2, and 3 of the Mt Elphinstone South Watershed Assessment

Dear Mr Johnson,

I am writing as legal counsel to Elphinstone Logging Focus ("ELF") in response to BCTS' community engagement process for the 2023-2027 Sunshine Coast Operating Plan.

My client recently retained Dr Younes Alila,[1] a professor of forest hydrology in the UBC Faculty of Forestry, to undertake a peer review of Phases 1, 2, and 3 of the Mt Elphinstone South Watershed Assessment ("Watershed Assessment") conducted for BCTS by Polar Geoscience Ltd ("Polar Geoscience").[2]

In the enclosed peer review report, Dr Alila raises several important issues relating to the methodology employed by Polar Geoscience. While I implore BCTS to review Dr Alila's report in its entirety, several of his report's points are worth particular emphasis:

- The Watershed Assessment examines the hydrology of the study area using a microscale, stand-level metric. In doing so, it fails to account for the causal power that comes with an increase of scale to the watershed level. As a result, the Watershed Assessment does not effectively address cumulative effects, nor does it capture the true risk of forest harvesting in the study area.

[1] See: https://forestry.ubc.ca/faculty-profile/younes-alila/.
[2] For access to Phases 1, 2, and 3, see: https://www.for.gov.bc.ca/ftp/TCH/external/!publish/InformationSharing/Mt_Elphinstone_South_Watershed_Assessment/ (accessed on August 25, 2023).

- The Watershed Assessment's use of ECA thresholds results in an underestimation of the effects of forest harvesting, especially in relation to watershed-level recovery. Simply put, stand-level recovery is not a surrogate for watershed-level recovery.

- Several hydrologic mechanisms are missing from the Watershed Assessment. This includes the role of meltwater drip in mitigating peak flows and droughts in a coastal rain-on-snow environment. Further, the effects of roads and regenerating forests were not appropriately linked to both droughts and peak flows.

- The sensitivity associated with coastal rain-on-snow hydroclimatic regimes is much greater than identified in the Watershed Assessment.

- The Watershed Assessment overlooked the potential implications on geomorphic sensitivity that come alongside an increase in frequency of peak flows. This relates to both channel destabilization and the overall stability of infrastructure in the area.

In light of the above, ELF is concerned that the Watershed Assessment does not adequately capture the risks to people and property if the proposed Timber Sale Licence, TA0521, proceeds as planned. Further, it is unclear how proceeding with TA0521 as planned will meet the government's objectives for soil and water, among other objectives set out in BCTS' Forest Stewardship Plan for the Chinook Business Area.[3]

Accordingly, ELF requests the following:

1) BCTS undertake additional hydrologic study of Mt Elphinstone South, with the assistance of a qualified professional, utilizing the probabilistic framework recommended by Dr Alila in the enclosed peer review report;

2) the auctioning and logging of TA0521 be deferred until the above additional study is undertaken; and

3) the results of the above additional study be made publicly available and open to comment in the same manner as the Watershed Assessment.

[3] See: https://www2.gov.bc.ca/gov/content/industry/forestry/bc-timber-sales/fsp/sunshine-coast (accessed on August 25, 2023).

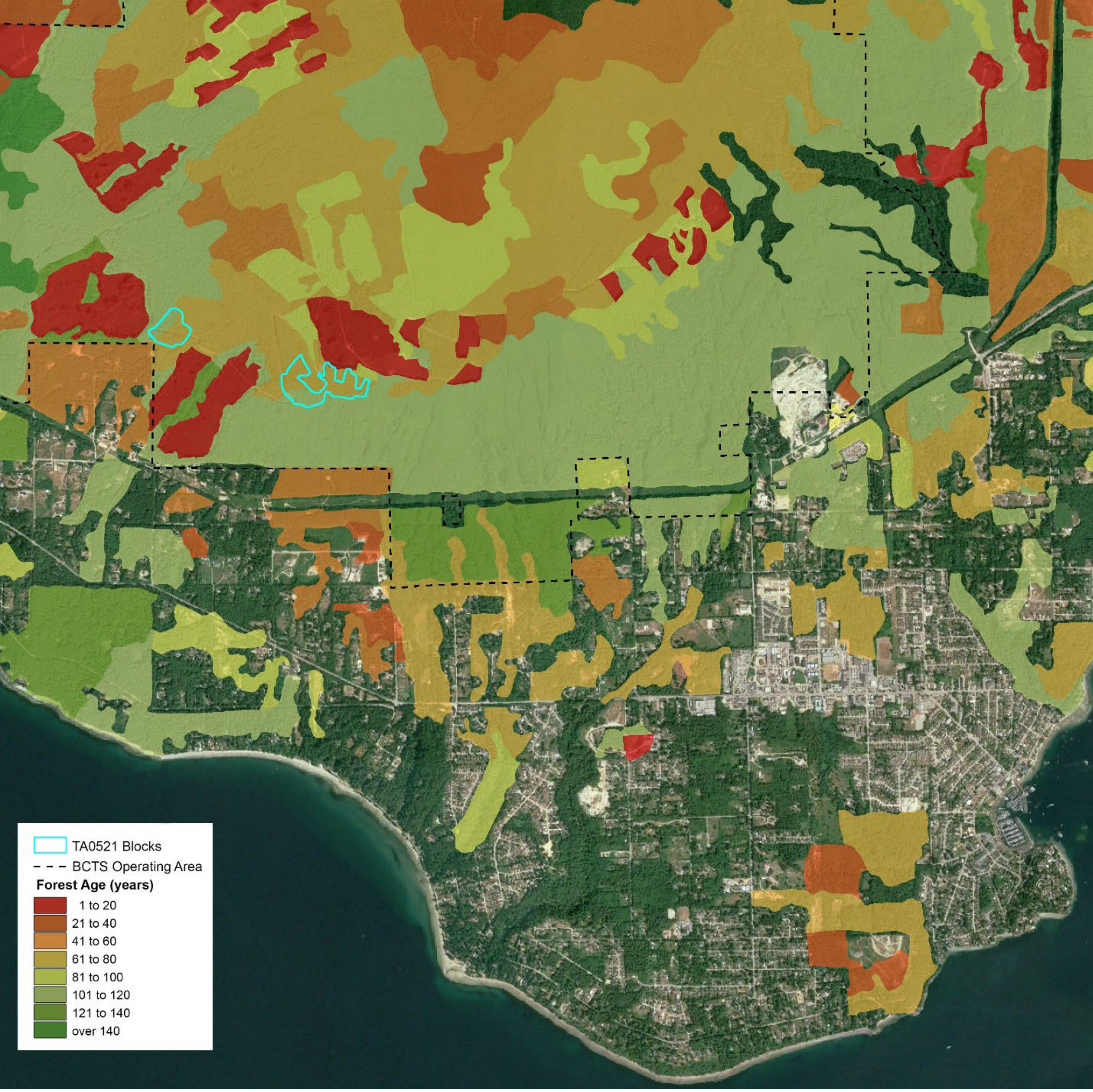
As is clearly apparent from the numerous climate change-fueled natural disasters happening as you read this letter, old methods of doing business need to be urgently rethought. As such, I look forward to BCTS' response to the above requests.

Regards,

Ian Moore, Barrister & Solicitor

cc: Elphinstone Logging Focus, Dr Younes Alila, Pierre Aubin (BCTS), Stacey Gould (BCTS)

Encl.: Peer Review of Mt Elphinstone South Watershed Assessment



Peer Review of Mt. Elphinstone South Watershed Assessment: Phases 1, 2 & 3 Reports

DR. YOUNES ALILA, P.ENG
August 21, 2023

This peer review report evaluated original and final Watershed Assessment reports published by Polar Geoscience. The draft release timeline of said reports is as follows:

- Mt. Elphinstone South Watershed Assessment: Phases 1, 2 Draft (March 7, 2023)
- Mt. Elphinstone South Watershed Assessment: Phases 1, 2 Final Report (July 13, 2023)
- Mt. Elphinstone South Watershed Assessment: Phase 3 Final Report (July 20, 2023)

Access to the report files can be found at the following link:
https://www.for.gov.bc.ca/ftp/TCH/external/!publish/InformationSharing/Mt_Elphinstone_South_Watershed_Assessment/

Qualification

I am a forest hydrologist, a registered professional engineer with EGBC (Engineers and Geoscientists British Columbia), and a full professor (Faculty of Forestry, 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 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[1] 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 Mt. Elphinstone South Watershed Assessment: Phases 1, 2 & 3 Reports by Polar Geoscience 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

[1]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

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 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 Elphinstone Logging Focus ("ELF"). 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

API: Antecedent Precipitation Index

BCTS: British Columbia Timber Sales

ECA: Equivalent Clearcut Area

FFC: Flood Frequency Curve or Flood Frequency Distribution.

ROS: Rain-on-Snow

SCRD: Sunshine Coast Regional District

WAR: Water Available for Runoff

Acknowledgements

I would like to extend my gratitude to my graduate student Kyle Bishop, whose invaluable contributions played a pivotal role in the completion of this peer review. His commitment and dedication were instrumental in the entire process. Kyle demonstrated exceptional skill in help with synthesizing relevant literature, and analyzing data, alongside writing, and editing drafts.

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

British Columbia Timber Sales (BCTS) has proposed forest development plans within the Sunshine Coast Regional District (SCRD) and has conducted a collaborative undertaking with Polar Geoscience in performing a watershed assessment of proposed harvest areas.

The purpose of this peer review report is to provide a comprehensive analysis of the generated watershed assessment and to provide feedback on techniques, framework, methods, and overall quality of content within the said report. The feedback generated from this peer review of Polar Geoscience's assessment will provide insight to various stakeholders about values at risk in the Elphinstone area that accompany forest harvesting in sensitive rain on snow (ROS) dominated coastal watersheds of British Columbia.

Within the current framework, watershed assessment in British Columbia examines the hydrology of the microscale at the stand level while failing to fully account for the emerging crucial hydrology of the macroscale at the watershed level. An increase in the causal power of the forest comes with an increase in scale, providing the ability to fully comprehend and appreciate the intricate interdependencies of cumulative hydrologic and geomorphic effects that emerge with the disturbance of forested watersheds. A probabilistic framework is the only means of understanding causal power as it invokes the dimension of frequency and its intricate highly non-linear and inverse relationship to magnitude. Such a framework reveals hyper-sensitive hydrology and geomorphology to forest disturbances in this kind of coastal environment. With this knowledge in mind, the role of the forest and its mitigative abilities against cumulative effects intensify with an increase in scale.

Current microscale, stand-level methods of equivalent clearcut area (ECA) used by Polar Geoscience do not reveal the real causal power of the forests and are responsible for underestimating the cumulative effects on sensitive coastal watersheds. The consequences of these methods and how they have influenced the creation of Polar's watershed assessment have raised concerns about potential shortcomings that pose risks to the watersheds in the Elphinstone area.

The most notable characteristic of watershed assessments in British Columbia today while using ECA methods is the ability to set risk thresholds. Such thresholds stem from an old non-probabilistic and, hence, non-causal mode of thinking leading them to be outdated. Polar has set points of interest in which they have limited the harvest of a watershed to certain thresholds in BCTS chart areas and over individual watersheds. These thresholds allow forest companies to exploit harvesting up to given threshold limits. Focusing on upstream points of interest in the operational area of BCTS is misleading because they suggest that the respective catchments will have a reasonable level of risk associated with downstream points of interest. Realistically, one must acknowledge the methods through which ECA assesses the level of disturbance and related risk is fundamentally flawed in its rationale. This allows the harvest of more timber with the aim to remain credible by abstaining from exceeding predetermined, non-causal, and outdated thresholds of risk. In reality, risk must be evaluated using a probabilistic framework that is transparent in its construction and leaves little question as to what thresholds are deemed acceptable and most importantly why.

Other issues of concern are rooted in various facets of the report in addition to the aforementioned underestimations in scalable causal power arising from the use of ECA and the ability to manipulate risk thresholds. Such issues stem from (i) the power associated with hydrological processes of melt drip, (ii) contrasts between stand vs watershed level hydrologic recovery after logging, (iii) the role of roads in a forested watershed, (iv) the ability to differentiate snow-transient (ROS) and pluvial dominated driven hydrology as a means of framework selection, and (v) geomorphic sensitivity of channels and related infrastructure failure. All of these themes are echoed by Polar's choice to cite studies that utilize a causal, probabilistic framework as a means of investigation, but it is rather interesting that they have chosen a more antiquated investigative approach in conducting their assessment.

Meltwater drip is a key component of ROS-dominated environments and is crucial for the renewal and recharge of groundwater during ROS months from October to mid-spring in mid to high-elevation coastal environments. Precipitation intercepted by a forested canopy melts and drips to the soil below, providing a constant source of melt and water infiltration into the soil. Polar overlooked this vital feature, integral to the maintenance of natural groundwater recharge processes as a mitigative means to both extremes of droughts and peak flows.

Recovery curves are a means to investigate how a watershed will regain its hydrological function as trees regenerate in a forested watershed. There is a body of literature with different opinions and findings on how coastal environments regain their abilities to re-establish their hydrological functionality after forest harvesting. Simply put, stand-level recovery is not a surrogate of watershed-level recovery due to the causal power imposed by the macroscale. The current recovery curves also ignore the power that comes along with utilizing the dimension of frequency and negates important below-ground processes. Additionally, current recovery curves do not account for the fact that the effects of magnitude and frequency recover at different rates with frequency recovering much slower.

Considerations of roads were widely missed out as a large body of literature was neglected, notably the work of Rong (2017) who provides exceptional explanations of the functions of roads in a coastal ROS environment. Such discussions invoke insight from a body of literature that considers the role of cumulative effect in a probabilistic manner, with insights into how a flood frequency curve (FFC) can be altered with the construction of roads.

Through the use of a probabilistic framework, one can identify the mechanisms that drive certain hydroclimatic regimes of rain and ROS. Unfortunately, Polar Geoscience didn't use such a framework and, as a consequence, missed out on the ability to assess both rain and ROS-dominated hydrology and attribute processes that contribute to their drivers. The sensitivity and severity that can potentially arise from ROS-dominated hydrology is a significant risk to consider.

The increase in the frequency of peak flows that comes with forest harvesting is telling, as peak flows across a wide range of severities are becoming more and more frequent. This will have major consequences for infrastructure as design processes consider peak flow magnitude and fail to account for the sustained geomorphic work of more frequent peak flows that are less than the design capacity. Infrastructure downstream of the proposed cutblocks will fail as a result of increasing peak flow frequency and potential impacts will follow. The same can be said for the stability of the current channel network. Historically, channel instabilities in the study area have occurred and infrastructures have been collapsing. Such already heightened geomorphic risk can only intensify with default logging practices.

When viewed in the probabilistic causal framework, it becomes increasingly evident that the watersheds of concern are already at considerably higher risk than portrayed in the assessment produced by Polar Geoscience, especially in the background of the new climate realities caused by global warming. The discrepancy in risk is a result of an outdated framework that relies on a deterministic, non-causal, and stand-level means of analysis.

All of these shortcomings and missed opportunities are reflected in this peer review report. Further, in-depth discussions are provided that shed light on the need for change in how watersheds are assessed and why the proposed forest development in the SCRD must be rethought to consider the cumulative effects of upstream forest disturbances and their overall risk on an extensive set of downstream values.

Introduction to Scope of Peer Review

I.J. Good once said *"We are controlled by nature, but by discovering causes we can recover some of the control"* (Good, 1988, p. 407). Scientists and, by association, professionals in the field of hydrology are constantly reminded that our "*ultimate goal is to understand hydrological causality*" (Blöschl et al., 2019, p. 424) because there is no defensible science outside causal inference (Pearl, 2009).

Currently, there are two predominant modes of experimental design when considering the scope of forest hydrology. The old framework is reductionist, i.e., operates at the tree and stand level microscales and, hence negates causal power provided by the watershed level macroscales. Furthermore, the old framework is deterministic, i.e., derives from the failure to recognize the science and professional practice significance of the effects of forest removal on the frequency of extremes (e.g., floods, droughts, and landslides). The second framework is holistic and probabilistic, i.e., operates at the watershed macroscale and, hence, designed to unravel the causal power provided at this scale.

Scale is an important concern when assessing watersheds as causal power more commonly increases at greater scales. To investigate a watershed solely using microscale stand-level metrics, one would miss out on the emerging causal power imposed by the holistic and coherent functioning of the watershed, in addition to climate-physiographic characteristics and their interactions at greater scales. It is through the macroscale that both watershed (space) and climate (time) characteristics work in harmony to culminate, for instance, a peak flow of a given magnitude and frequency. The relationship between magnitude and frequency is undeniable, being the basis for understanding and predicting the effects of forests and forest disturbance on extremes using a probabilistic framework. To use holistic-probabilistic watershed and an old outdated reductionist deterministic stand-level frameworks interchangeably, as conducted by Polar Geoscience, would be conflicting. These frameworks differ greatly in their means of evaluation and ability to accurately depict cause and effect relations between forest disturbances and hydrology and as a consequence, geomorphology.

To understand the role that disturbance has on the frequency of a class of events, one must rely on the linkages governed by space and time through probabilistic physics. Probabilistic physics recognizes that the physical world exhibits inherent stochastic behaviour. Unlike deterministic physics and prediction, probabilistic counterparts utilize methods to understand and quantify the likelihood of various outcomes, providing a comprehensive view of complex, multivariate, and stochastic watershed systems. Within this line of thinking one can see that relatively modest increases in magnitude can result in shocking increases in frequency (Allen & Ingram, 2002). This knowledge is well-known in the science of extremes and is a well-established phenomenon when it comes to investigating extreme events under a probabilistic framework. One can truly appreciate the sensitivity of watersheds and how disturbance impacts both the magnitude and frequency under this only mode of causal investigation.

The role that causality plays at the watershed scale is a product of the location of cutblocks, climate characteristics, and the physiographic features present in a watershed. These features are unique to every individual watershed and should be treated as such. This causal power is where we see the culmination of overarching governing principles, contrasting the likes of a stand-level investigation that only compares de-coherent small parts of a watershed, rather than the coherent-whole system. This is where microscale arguments of ECA fail and revealing arguments of probabilistic physics thrive in explanation.

Conceptual Model of Probabilistic Physics

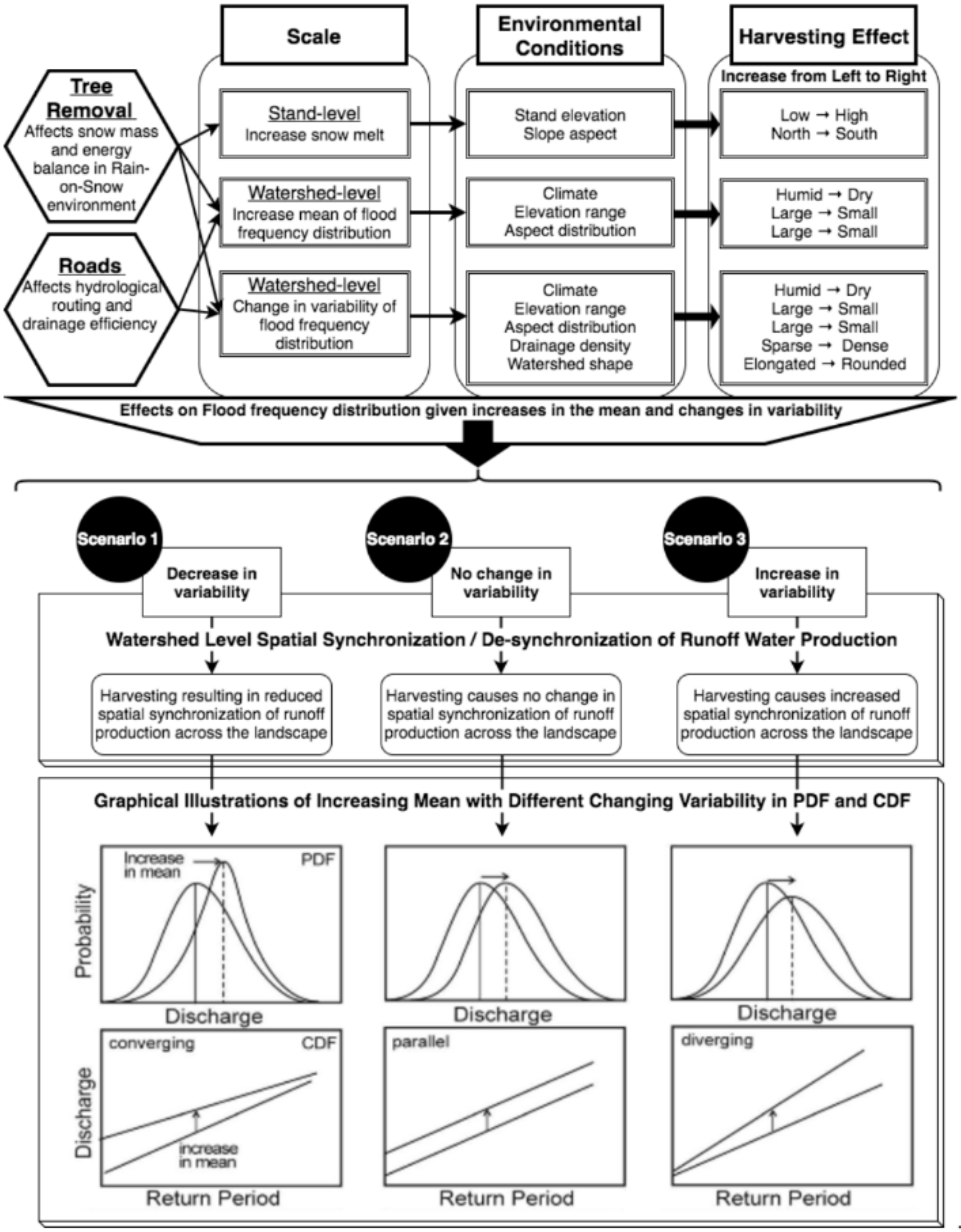

Figure 1. A conceptual model depicting the physical controls of forest harvesting effects on peak flows in a probabilistic framework. Skewness can be affected by harvesting practices, but only changes in the mean and variability are demonstrated in this diagram (adopted after Rong, 2017)

The conceptual diagram above (**Figure 1**) provides two in-depth explanations. The first explanation in the top half of the diagram shows how both the construction of roads and the removal of trees through forest harvesting relate to scale and physiographic features. For example, observing at the watershed scale after disturbance will show changes in the FFC which will be seen as alterations in the mean and variability of peak flows. If an increase in mean and variability was observed, one could attribute that to physiography causing a synchronization of runoff. Dry climate, small elevation range, small aspect distribution, dense drainage density and rounded watershed shape all contribute to an increase in mean and variability and hence, runoff synchronization. A scenario where the mean increases, but variability decreases is a consequence of runoff desynchronization. One could relate this to a potentially dry climate, large elevation range, large aspect distribution, sparse drainage density and an elongated watershed shape. Various outcomes and scenarios are produced by this conceptual diagram, highlighting the possibility of many interactions that either lead to runoff synchronization or desynchronization. The bottom half of the diagram contains an explanation that shows how changes in variability and mean relate to the FFC.

Under the new probabilistic framework if forest harvesting is to increase peak flows it will be via the effects on the peak flow frequency distribution and, hence, its parameters such as mean and variability. Given the causal power of physiographic watershed characteristics, the mean and variability can alter in differing proportions. Interactions between such characteristics and hydrology will change and the watershed will respond in a different manner. For instance, the suppression of evapotranspiration through tree removal introduces more moisture into a system and causes a change in the behaviour of a watershed.

To understand what may increase the mean of a FFC, one must ask the question "what disturbance-based mechanisms can increase the amount of moisture available to contribute to runoff?" Factors that influence the change in mean find themselves in the suppression of evapotranspiration, increased energy for snowmelt, disturbance of soil and runoff synchronization. In other words, any process that increases the water available for runoff (WAR) will subsequently increase the mean of the FFC.

To understand what may increase the variability of a FFC, one must ask "What increases the efficiency with which water is delivered to the outlet of a watershed?" It is important to note that these factors can also influence the skewness of the FFC, in which case the effects of logging on peak flows will be even bigger. Such processes that can result in an increase in variability include wetter soils, the above-mentioned runoff synchronization, soil disturbance, increased energy available for snowmelt, and forest roads. Subsequently, any process that decreases the efficiency with which runoff is delivered to the outlet will result in a decrease in system variability. Note that these same mechanisms can affect the mean, variability, and skewness but to different degrees.

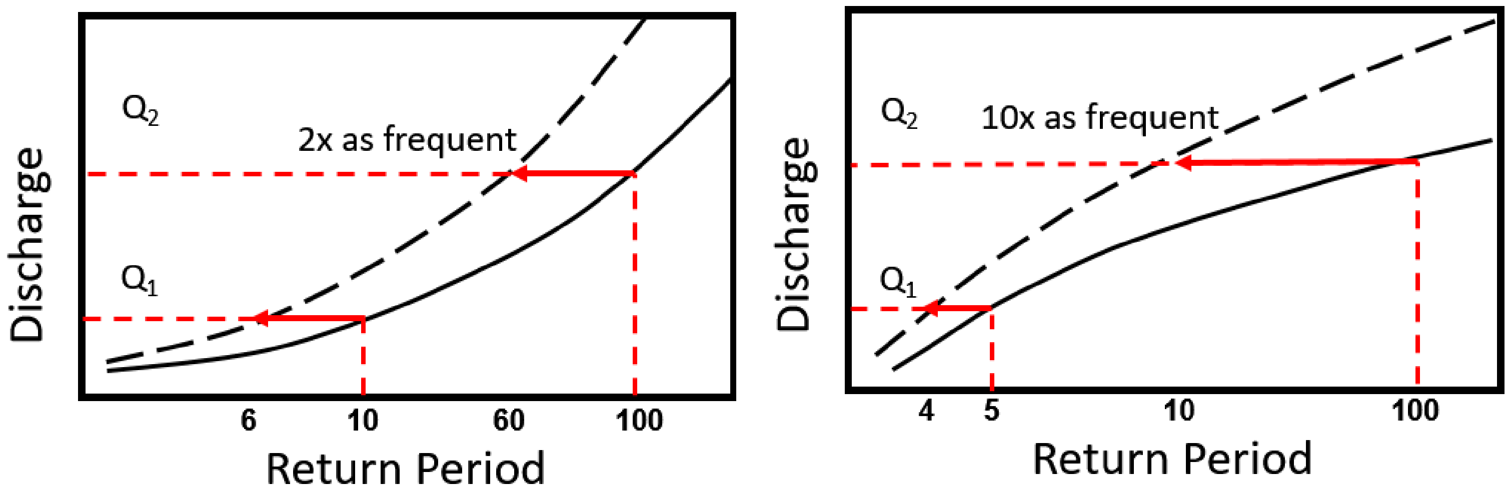

Figure 2. Examples of shallow and steep FFCs with relation to increases in return periods.

To comprehend and appreciate the super sensitivity of coastal watersheds to forest harvesting, we must invoke FFCs. Notably, the FFC on the right demonstrates properties of a shallow slope and the curve on the left demonstrates the properties of a steep slope. As the slope is a surrogate of variability, it can also provide physically meaningful insight into the changes in frequency given forest harvesting.

As a thought experiment, suppose forest harvesting increased the magnitude of all peak flows in this hypothetical watershed. Looking at our established FFCs we can see alternate changes in frequency and differing levels of sensitivity. The same increase in magnitude leads to much bigger increases in frequency when the FFC is milder in slope. In particular, this is where large peak flows become much more frequent, but it is also imperative to recognize the substantial increase in small to medium-sized peak flows. With the increased frequency of small to medium-sized peak flows, infrastructure will see a continuous beating of higher magnitudes of streamflow. With design specifications typically reserved for a given much higher return period peak flow, the engineering design does not account for the increase in frequency of peak flows across the much wider range of magnitudes below the design criterion. It will be the constant battering of infrastructure that will lead to failure. This can be seen as either purely hydrologic in nature or rather geomorphic from the increased channel destabilization and associated increases in sediment and debris production, transport, and deposition.

Assessment of Analysis

Influences on Peak Flow Variability

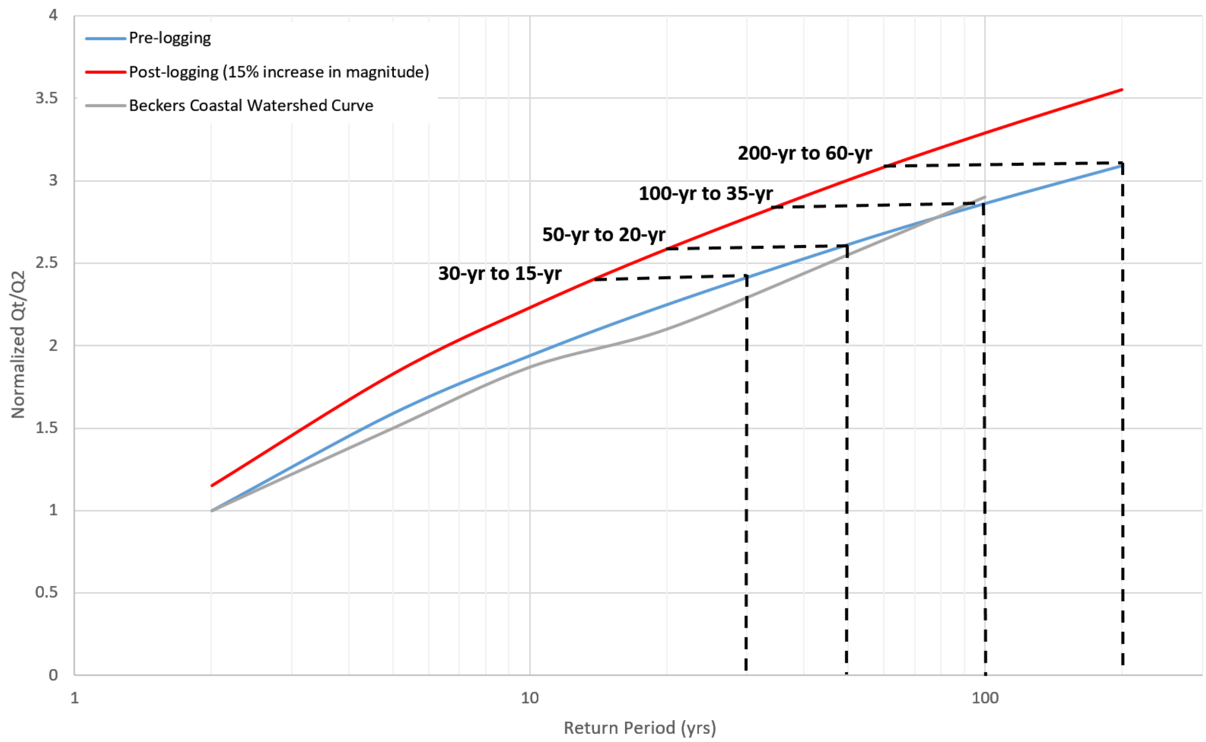

Figure 3. A GEV distribution fit to 71 years of peak flows at Roberts Creek illustrates how peak flow frequencies are super sensitive to a hypothetical modest increase (15%) in peak flow magnitude. Beckers et al. (2002) validates the fact that the mildness in slope of the FFC is typical of coastal watersheds

The dimensionless, normalized FFC using long-term observed data from Roberts Creek in the blue curve shows the sensitivity provided by ROS regimes and gives a baseline of what is to be expected in a coastal environment seen in the grey curve (Beckers et al., 2002). This method scales observed data to the mean annual flood such that effective and meaningful comparisons can be inferred (Beckers et al., 2002). Also provided in this explanation is a hypothetical logging-induced mere 15% increase in magnitude at Roberts Creek. One must appreciate the displayed sensitivity to such a modest increase in magnitude as small, medium, and large events become more frequent. Increases in frequency can be observed as the 30 to 200-yr events become approximately 2 to 3 times more frequent, indicating that the larger the flood event, the more frequent it will become. To reiterate, it is the inherent mildness and curvature of the dimensionless observed FFC, typical of coastal watersheds in the Pacific Northwest, which reveals the fragility of the hydrology and geomorphology to forest disturbance in the form of the default clearcut logging practices, especially in the background of global warming. The behaviour resulting from the physics of snowmelt-driven peak flows leads to mild increases in magnitude, but as a result of the nature of the upper tail of the frequency distribution, large changes in frequency can occur (Johnson & Alila, 2023; Allen & Ingram 2002; p.229).

Meltwater Drip and Groundwater

The snow transient or ROS environment of coastal BC is characterized by a mild-slope FFC as observed at Roberts Creek (**Figure 3**). The mechanisms of meltwater drip are what come together to create such a unique signature and provide crucially sustained groundwater recharge during winter months.

As explained by van Heeswijkan et al. (1996), transient ROS-dominated snowpacks of the Pacific Northwest are thin, possess high liquid water contents and receive increased energy from rainfall events. Meltwater drip demonstrates a localized, comparable and variable version of ROS phenomenon with meltwater penetrating to the soil surface (Brundl et al., 1999). Such a phenomenon is a result of the interception capacity of forests, with upwards of 60% of snow being intercepted by the canopy and 72% of intercepted snow contributing to meltwater drip falling on the snowpack (Storck et al., 2002). Additionally, as seen by Hubbart et al. (2015), meltwater drip moved through the snowpack and infiltrated into the soil. When considering the effects that meltwater drip has on a snowpack, the disruption and changes of snow cover is an important process for groundwater renewal (Lundberg et al., 2016). This highlights the importance that forest canopy and meltwater drip contribute to the recharge of groundwater in a basin, being a highly prevalent occurrence in coastal watersheds. It is also important to recognize the spatial variability of snowmelt input to groundwater renewal systems as they heavily rely on the causal power of macroscale controls within ground and bedrock watershed topographies (Lundberg et al., 2016). Groundwater contributing area can extend far beyond the study watershed, typically defined by the topography of the land, and is dependent on the geologic history and bedrock topography. As winter months persist, meltwater drip and ROS events will contribute to the drawn-out recharge of groundwater storages. As seen by Blöschl & Sivapalan (1997), an increase in base flow decreases overall watershed variability. In the case of meltwater drip adding to groundwater recharge, variability will decrease and the observed shallow, super-sensitive FFC is observed.

The study of Rong (2017) revealed an analogue process to meltwater drip known as fog drip. As implied in the name of fog drip, in coastal ROS environments coastal fog is intercepted by the foliage of trees and then subsequently trickled to the snowpack below. Within the study site of Fox Creek, 30% of the annual water balance is attributed to fog drip interception (Harr, 1982). Similar to meltwater drip, a localized long term, slow ROS mechanism will be experienced. This provides constant energy to the below snowpack and provides melt processes that like meltwater drip, contribute to groundwater recharge. Given forest harvesting through large clearcuts, fog interception is supressed and a much larger amount of snow will accumulate, providing more WAR. Like meltwater drip, fog drip has considerable, tangible outcomes on snowpack energy dynamics, groundwater mechanisms and renewal, and overall contributions to reducing variability in the FFC. Like the FFC of Roberts Creek, the study site of Fox Creek demonstrated extremely sensitive behaviour with a mild FFC as a result of the fog drip interception. Notably this creek was the most sensitive among the nine control-treatment watersheds within the study of Rong (2017).

Drought has been a common occurrence on the sunshine coast over recent years. An example of this within the SCRD is the water conservation restrictions beginning in May of 2022 lasting until and being lifted in February of 2023. The timeline is as follows:

Stage 1: May 1st – July 27th, 2022

Stage 2: July 27th – Aug 22nd, 2022

Stage 3: Late August 12th, 2022

Stage 4: Aug 31st – Dec 13th, 2022

Stage 1: Dec 13th 2022 – Feb 6th, 2023

Restrictions lifted: Feb 6th, 2023

The slow replenishing of water into Chapman Lake can be attributed to groundwater recharge through meltwater drip processes. In February of 2023, 138cm of snow was measured at the Chapman Lake snow pillow station. Through the months of October to February, precipitation in the mid to high elevation region could have only fallen as snow. The falling snow as be intercepted by the forest canopy and contributed to the recharge of Chapman Lake through meltwater drip. The dominance of longwave radiation in the canopy during winter months far outweighs the contributions of shortwave radiation above the canopy or in the open, and is known as the radiative paradox (Sicart et al., 2004). Through the radiative paradox, ample energy will be provided to melt intercepted snow in the canopy. Another investigation by Lundquist et al. (2013) provides a global study into how longwave radiation under the forest canopy with temperatures greater than -1ºC can contribute to midwinter melt, reducing snowpack more than in open areas. One can recognize how Chapman Lake was charged as groundwater slowly made its way back into the reservoir during winter months. This circumstantial evidence delivers great insight into how the hydrology of coastal environments is super sensitive with the constant buffer of meltwater drip that provides higher base flow in streams and as a consequence low variability of peak flows year around. If this melt drip mechanism is suppressed by clearcut logging the severity, duration, and frequency of both peak flows and droughts will be exacerbated, especially more so in the background of global warming.

Regenerating Forest and Drought

Regenerating forests through silvicultural practices is necessary in order to re-establish the hydrological functionality of a forested watershed. Discussions on the rate in which groundwater consumption of regen is observed are necessary in the context of groundwater removal surrounding drought. In the context of water consumption after planting, Perry and Jones (2017) discovered that at their study site in HJ Andrews Experimental Watershed in Oregon, regen was responsible for the deficits in summer streamflow within 15 years of being established. Additionally, summer stream flows of Douglas-fir produced summer deficits of 50% from ages 25 to 40 years relative to their reference. Regenerating stands are responsible for the consumption of more moisture and providing moisture deficits with regard to a mature forest. One must consider the implications that this will have on overall conditions of summer drought on the Sunshine Coast.

Forest Roads

Roads have a large impact in changing the physical characteristics of a watershed. Rerouting of water through ditches, intercepting subsurface runoff through cutbanks and increasing the overall impervious area in which water cannot infiltrate into the soil are all characteristics of roads. The removal of groundwater through cutbanks will lead to deficits and contribute to droughts. In short, roads will increase the drainage density of a watershed, contributing more avenues to transport water out of a catchment in a highly efficient manner (Harr et al., 1975). The introduction of forest harvesting and increase in WAR will provide greater amounts of moisture for existing roads to reroute to main channels. Polar chose to highlight the HJ Andrews study of Jones (2000) in which the variability in peak flows is increased a substantial deal through various treatments including a selection of silvicultural systems and roads. This study neglected to isolate the effects of roads on peak flows and was constructed using an outdated non-causal framework. In contrast, the study site of Rong (2017) at Fox Creek allowed the isolation of the effects of roads on peak flows in a probabilistic manner and large increases in both magnitude and variability of peak flows were observed. The density and location of roads are representative of synchronization potential within a catchment given macroscale physiographic conditions of watershed response (Rong, 2017). In other words, at a larger scale, roads will contribute to watershed level synchronization and increase in variability with respect to the rerouting of water flow (Rong, 2017). Additionally, this inhibits portions of moisture from contributing to groundwater recharge and will be present in cutblock G043B4P8, which will require the construction of cut banks as proposed in the Phase 3 report. Forest roads will contribute to a large disruption in peak flow variability as they increase the efficiency with which runoff is delivered to the main channel.

The above-mentioned processes of meltwater drip suppression, regen consumption contributions to groundwater deficits, and forest roads all contain the ability to have impacts on the forests mitigative abilities to withstand both peak flows and droughts. This highlights the interconnected nature of both peak flow and drought regimes within coastal watersheds. Furthermore, this stresses the need to recognize the super sensitivity of coastal watersheds. If one disturbs the peak flow regime, inadvertently they will also be influencing drought conditions. This intricate, inherent relationship goes both ways. To provide further context as an example, if one suppresses meltwater drip through forest harvesting, base flow will decrease. As a consequence, decreased base flow will contribute to higher variability of peak flows over and above the increase in variability induced by the increase in snow accumulation and melt energetics in the cutblocks. Not only are above-surface mechanisms of greater snow accumulation and melt energetic are experienced, but below-surface groundwater are altered too.

Hydroclimatic Regimes: Rain-on-snow in Comparison to Rain

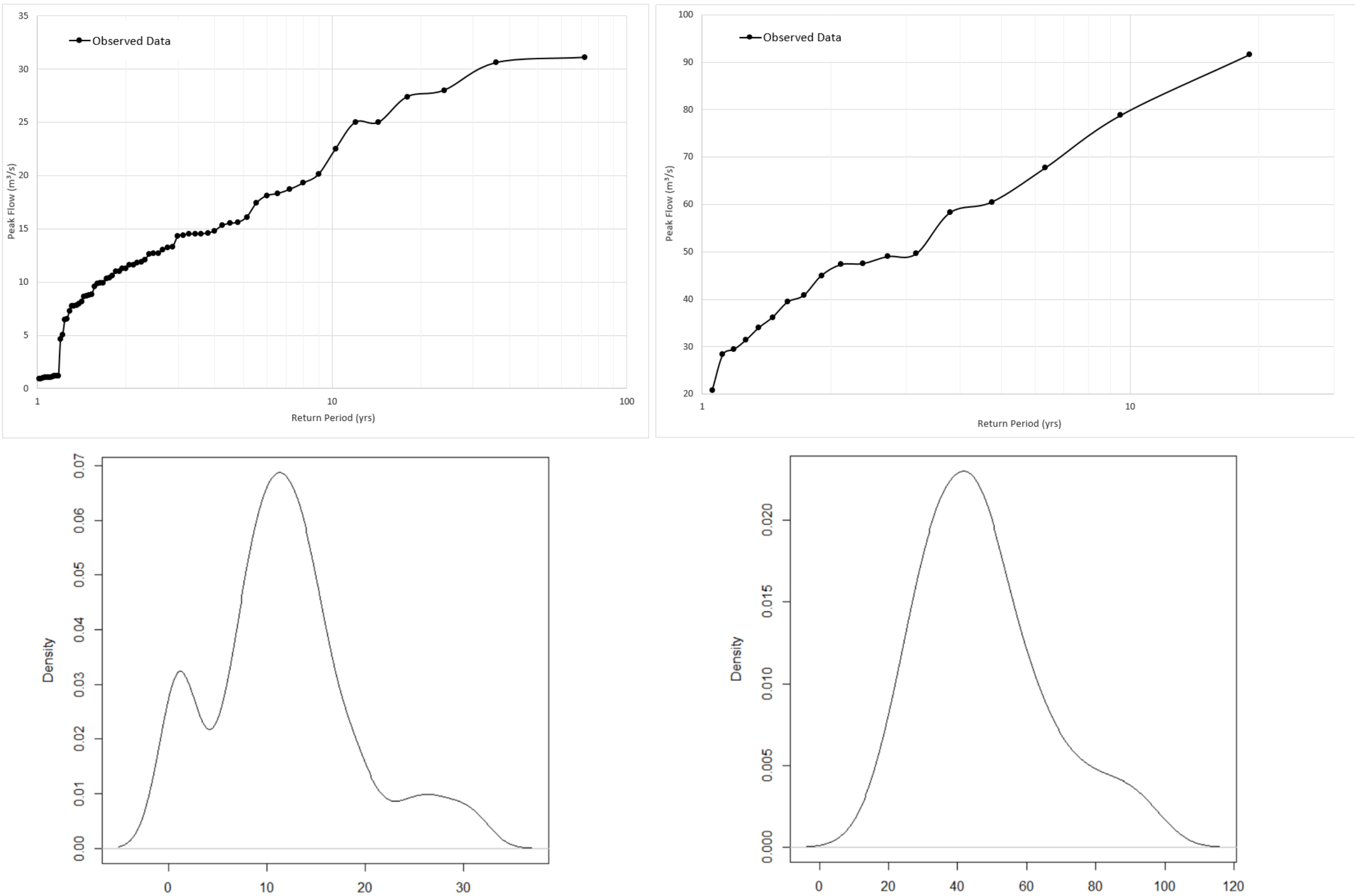

Figure 4. Observed data at Roberts Creek (left) and observed data at Chapman Creek (right). Both observed data sets contain a FFC and for comparison, a probability density function (PDF).

The above conditions present data plotted at Roberts and Chapman Creeks. Further investigation confirms that there are two evident step changes in the FFC, and three separate populations present in the PDF at Roberts Creek. Chapman Creek sees a similar scenario with one break in the FFC, revealing two populations in the PDF. These step changes can be attributed to different populations of runoff generation mechanisms. Namely, the upper two populations in Roberts Creek and the upper population in Chapman Creek being controlled by ROS processes. The curve reveals the super sensitivity displayed by coastal watersheds in ROS environments.

Looking at the physical characteristics of the Elphinstone area, one can attribute rain and snow pillow measurements to the likelihood of ROS event occurrence given the elevation range.

The coastal ROS study of Brunengo (2012) found that the elevation in which ROS has the most contribution to peak flow generation is 800m, with a sharp increase in contributions beginning at 500m. Trubilowicz and Moore (2017) show that in their coastal mountain sites, large ROS events (associated with more than 40mm of rain) can melt snowpack and increase WAR by 25% when compared to a rainfall event. Furthermore, it was decided by the authors that ROS events occurred in the months of November, December, and January. With this in mind, one could analyze the antecedent precipitation index (API) before peak flows at Roberts Creek, while also confirming snow pillow data records. Our API analysis revealed that 75% of peak flows were in ROS months and 73% of all peak flows were associated with more than 40mm of rain leading up to the event. Nearby snow pillow data were extracted from Chapman Creek, which had a similar elevation (1022m) as the headwaters of the Elphinstone assessed watersheds. Snow pillow measurements lead one to believe that there was snow on the ground for the vast majority of these events with over a meter of snow on the ground in all measured years (except 2004) since 1965 in the month of February.

ROS environments are characterized as follows. The energy provided by a storm that contributes to snowmelt results in significant magnitudes of moisture being contributed to runoff (Wayand et al., 2015). The characteristics of a storm which influences the melt of snow and contributes to WAR include turbulent heat exchanges and wind. Using the causal power that comes at the watershed level, it is known that based on hypsometry, mid-elevation bands in a watershed host the greatest WAR in ROS environments (Brunengo, 2012). Polar Geoscience appropriately chose to use an ROS band across the study area at the recommendation of Dr. Floyd, but fell short of appropriately describing the remaining hydrologic processes that come alongside pluvial and ROS regimes. It was claimed that peak flows are controlled by ROS interactions and all other hydrological processes are a result of pluvial relations as stated by Polar Geoscience (2023, p. 120):

"In summary, the hydrology of the assessment watersheds is driven predominantly by rainfall; however, rain-on-snow is considered the principal driver of peak flows"

As explained previously this is simply not the case. The produced FFCs clearly demonstrate the stochastic hydrology that produces peaks in the study area. Polar should further specify the importance of ROS and highlight the sensitivity of this hydroclimatic regime. This regime brings the greatest risk when forest harvesting is concerned due to its ability to produce highly variable, large-magnitude peak flow events. If one were to consider a system where rain drives functions then they are disingenuous to many other purposes that exist in a watershed such as groundwater recharge mechanisms and low-flow systems.

As described in Rong (2017), the construction of openings after forest harvest in ROS environments increases the amount of available snowpack and heightens snowmelt processes. Simply stated the intensification of ROS processes will be experienced when the canopy is removed. Additional facets of ROS environments that were missed by Polar are that of peak-ROS and ROS synchronization with respect to elevation (Brunengo, 2012; Garvelmann et al., 2015; Rong, 2017). Such studies bring to bear the causal power that comes with investigations at a much larger scale than that of stand level and highlight how investigations at the catchment scale are imperative to understand the physical relationships of ROS dynamics. Brunengo (2012) states in a stochastic framework, peak-ROS occurs at an elevation band with which WAR is greater than rainfall, leading to a great amount of sensitivity in potential ROS conditions. This is to say that lower elevations with less snow will have less contribution to ROS related peak flow, higher elevations will also contribute less to ROS-related peak flows due to the rain falling on cold snow, and mid-elevations will be more likely to see peak-ROS conditions. The blocks outlined in phase three fall within this peak-ROS area. Furthermore, Garvelmann et al. (2015) highlights that the timing of melt at all elevations with relation to ROS events contributes to peak flow synchronicity, suggesting that higher elevations contribute to a peak flow at a later period in time as cold snow is affected by the energy input of rainfall. In a clearcut scenario at the proposed mid-elevation cutblocks, more energy will reach the snowpack and flows will see synchronization with lower elevation melt processes, contributing to larger peak flows. On the contrary, lower and mid elevations will be desynchronized with higher elevations that possess a time lag in snow melt. These studies show great insight into the sensitivity of clearcutting highly volatile coastal ROS environments.

Geomorphic Sensitivity

Given an influx of moisture to a forested watershed, it is known that the failure of infrastructure can be both hydrologic and geomorphic. Hydrologic failure finds itself in a peak flow with a generated runoff greater than that of the design capacity of a given piece of infrastructure. On the other hand, geomorphic failure will be seen in smaller, longer-duration, more frequent peak flows that are responsible for destabilizing infrastructure. Such peak flows are below design capacity, but carry more sediments and woody debris that compromise the integrity of infrastructure over time. The increase in magnitude, frequency, and duration due to forest harvesting will challenge the resilience of current infrastructure. Higher levels of runoff will be encountered by infrastructure more frequently, and replacement costs will be incurred more frequently (Hui et al., 2018). The design process of culverts and bridges considers certain return periods and negates the inclusion of cumulative consequences of frequent high-intensity flows which can have increasingly adverse effects. Most current design processes also look at stationary assumptions and fail to address non-stationary conditions that come with changes in extremes over time (Cheng & AghaKouchak 2014). In the context of British Columbia forest harvesting is a significant driver to shifting extremes.

The probability of geomorphic failure in current infrastructure increases with forest harvesting activities in a watershed. The underestimation of risk through reductionist ways of thinking confirms such a possibility. Polar describes sediment yields and stream channel stability risks being low or moderate with insensitivity in stream channel stability (7.5) to changing inputs of both hydrologic and sediment inputs. Subsequently, it is stated that low-risk situations still coincide with the potential for large events of sediment production. This is of particular concern as cutblock G043B4P8 is subjected to conditions of steep slopes that may present erosion potential and other means of sediment production. An increase in moisture can also have negative implications for the sensitivity of slope stability, bringing even more concern to the 60% slopes present in cutblock G043B4P8 (Harr & Coffin 1992). Through the present proposed scenario this is the case as shown by Polar, but to fully appreciate the sensitivity of present channels, FFCs curves should be constructed and causal inference should be utilized.

Polar Geoscience (2023, p.74) cited the engineering consulting report of Delcan (2009) in relation to the effects of future climate change on the magnitude of peak flows to guide the Ministry of Transportation in the area of infrastructure. The reported increases in the magnitude of peak flows from Delcan (2009) appear to be significant underestimations of what would occur under a changing climate scenario. Polar Geoscience (2023, p. 74) states:

"Projected increases for the 2- year to 200-year return period peak flow events ranged from roughly 3% to 10% depending on the watershed."

These percent increases in the magnitude of peak flows are inconsistent with those described by the recent peer-review article of Gillet et al. (2022) who reported a 60% increase in the magnitude of the 100-year event for coastal watersheds. In addition, if recommendations are being made to the Ministry of Transportation, it is imperative that the increase in the frequency of small to medium peak flows be addressed to account for geomorphic mode of failure of infrastructure.

Polar Geoscience did not fully identify the true sensitivity and high level of risk that lies in these coastal watersheds, with or without the additional effects of clearcut harvesting. These underestimations of risk and lack of appreciation of the hydrologic and geomorphic sensitivities to disturbance are the consequences of watershed assessments in an old and outdated framework. This can lead to serious consequences if plans are to follow through as intended.

ECA and its Shortfalls

The ECA method is a means to estimate overall disturbance in a given area and is constructed to provide a non-spatial, de-coherent stand-level harvesting metric. When considering the macroscale holistic and coherent nature of a watershed, restricting oneself to stand level, microscale quantification methods can lead to harsh underestimations on hydrology. It must be understood that watershed processes are not simply the summation of stand-level events, but a result of the overall macroscale processes that work in harmony and discourse (Juarrero, 2023). In other words, the whole is often greater than the sum of all of its parts. These macroscale processes take the form of physiography, climate, and location of disturbance in the watershed. With this in mind, there are several concerns regarding Polar's usage of ECA and its working, restrictive definitions.

To begin with, the most foundational issue with ECA is that it estimates disturbance using a stand-level recovery curve, which is not a surrogate of watershed recovery response. This is to say that there is no existing recovery curve at the watershed-level, only the stand-level. The metrics provided of Hudson and Horel (2007) are classical ECA, stand-level metrics and see recovery occurring quite quickly. This knowledge is at the stand-level and fails to comprehend the causal power that arises at the watershed level. In the study of Rong (2017), little signal of recovery was detected until 20 years after harvesting. It is through the comparison of observed and expected peak flow data that they were able to detect recovery and liken it to past studies (Harr et al., 1989; Harr & Coffin, 1992). Through the lenses of a probabilistic framework, it can also be seen that changes in magnitude and frequency do not recover at the same rate with frequency recovering much slower than magnitude. Additional assumptions surrounding ECA come to bear through Polar's usage of tree growth modelling exercise. Though these models are standard in the forest industry, it would have been appreciable to have a greater level of transparency with the details of the assumptions made by these models.

Another notable shortcoming of the ECA method is that it focuses primarily on above-surface processes such as snow accumulation and melt processes. ECA fails to capture the broader scope of tree removal on below-surface processes such as groundwater recharge, subsurface recharge, and evapotranspiration. Deciding upon cut levels which fail to address important subsurface hydrologic processes could result in substantial problems around drought as seen in the Sunshine Coast region recently.

It is through these inadequacies that the design of ECA fails. Such a deterministic microscale measure was not designed to evaluate the increasing causal power that comes at the watershed scale, hence it is unable to reveal the effect of extreme peak flows and droughts. The removal of forest not only affects the magnitude but the frequency of extreme events. To this end, the way to make an experiment defensible is to use a framework that addresses both magnitude and frequency simultaneously. To evaluate magnitude and frequency simultaneously is to respect the inherent inverse and highly non-linear relationship of the FFC.

Polar utilizes ECA thresholds of 20, 30, and 40% when quantifying risk. These thresholds were created by Winkler et al. (2010) and were never directly referenced, though they too were created using an old, outdated, deterministic-reductionist, and non-causal framework. To begin with, these thresholds are highly likely to underestimate disturbance levels and the corresponding effects on both hydrology and geomorphology.

The means to maintain current peak flow level of hazard downstream and limit peak flow hazard in BCTS operational areas is misguided as a result of these deterministic ECA thresholds. One cannot simply relate small increases in ECA to an overall incremental risk threshold metric, as conducted by Polar. In other words, setting a predisposed level of risk through ECA and then harvesting incrementally to stay within this imposed level of risk is a self-fulfilling prophecy. This is common practice in the forest industry and is how licensees have enabled increases in ECA percentages in relation to predetermined thresholds. In other words, maintaining the current level of risk should negate harvesting completely, rather than staying below a certain percentage of disturbance. Every increase can heighten the risk of hazards depending on the role of macroscale and the only way to know is to use the proper framework. True risk metrics are found at greater scale of landscape and climate where greater causal power lies. Through these features, the FFC is produced and a mild, shallow slope can be observed which portrays the sensitive nature of coastal watersheds. This is also to say that the larger the spatial and temporal scale, the milder the FFC will become, therefore more sensitive to hydrologic and geomorphic risk. Moreover, the desire to maintain a low peak flow threshold of 20% in the BCTS operational area is misleading. Peak flow hazards must recognize the increasing causal power that is coupled with an increase in scale from the stand level to watershed scale. This is to say that if one is to look at the level of risk, it should be assessed at the watershed level. BCTS possessing the desire to maintain the low peak flow hazard level in their operational area is irrelevant as peak flow risk is determined at a higher level of causal power.

The above-outlined threshold discussion is complemented by the study of Rong (2017) where in a coastal ROS environment with a similar FFC and meltwater processes, a 25% patch cut of a watershed showed large increases in peak flow magnitude. The study areas in Fox Creek showed 10-30% increase in peak flow magnitude. This brought about a two to eleven-times increase in peak flow frequency. It is also important to recognize that in addition to the described fog drip mechanisms, some study sites in Fox Creek had constructed forest roads similar to the proposed blocks in Phase 3 of Polar's report.

Risk must be assessed under a causal, probabilistic framework that understands watershed-level interactions through present physiographic features. Unique features lead to the emergence of intrinsic levels of risk in a catchment. The causal power of the watershed scale is where we see the coherent and holistic-whole system nature or a watershed-level response come to fruition. De-coherent, non-holistic metrics through ECA fail to address the true problems at hand that arise from super-sensitive coastal watersheds in British Columbia.

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