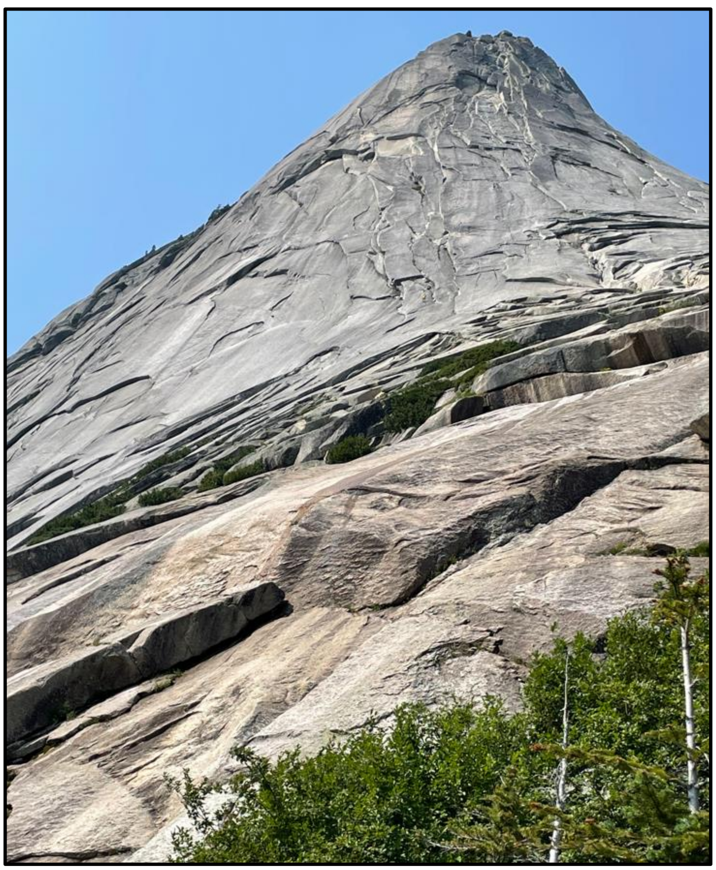
Western Geography

Southwest of Pincher Creek, AB, August 2024



Yak Peak south, NE of Hope, BC, August 2024

Volume 26 | 2024

Western Geography is the official open access academic refereed journal of the Western Division of the Canadian Association of Geographers. The objective of the journal is to publish original scholarly work including research notes on geographical themes or topics that emphasize western Canada and adjacent areas, or that are written by geographers from this region.
The editor and editorial board invite manuscripts of a methodological, empirical, theoretical, or philosophical nature that fall within this objective.

Western Geography's predecessors were the *Occasional Papers in Geography* published by the British Columbia (BC) Division of the Canadian Association of Geographers (CAG) and *BC Geographical Series*.

As with the first volume of *Western Geography* under the editorship of Michael Edgell, and continued by Jim Windsor, Neil Hanlon and Craig Coburn, submissions from students are encouraged.
Papers and posters presented at the annual WDCAG conferences are also encouraged.

(Volume 26 cover photos by Editor)

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To (formally) index *Western Geography* or not? This is the (discussion) question.

The *Western Geography* 25, 2023 Editorial wrote of the illustrious pedigree and importance of *Western Geography* and while this Editor stands by this statement, the reality of the 21st century publishing world is challenging for *Western Geography*. As stated in the Editorial in 2023, there are approximately 51 academic / scholarly journals in human and physical geography in Canada and more than 1000 worldwide. (data from *Ulrich's Periodicals Directory*, 2024). Researchers and writers have many more choices of where to publish in the 2020s than in 1990 when *Western Geography* began. Some Researchers and authors commented to yours truly that they would like to publish in *Western Geography* because of its focus but alas, *Western Geography* is not indexed, that is, its volumes and contents are not in any commercial publisher literature database (or indexing database).

While some web crawlers have crawled and indexed some articles from *Western Geography*, none of the articles listed in *Google Scholar* are from the *Western Geography* site hosted at UVic Department of Geography. Most of *Western Geography* articles via *Google Scholar* are from *CiteSeer* from Penn State College of Information Sciences and Technology, ResearchGate.net and Academia.edu and very few that were published after 2018. Although not exactly certain why this is the case, this volume of *Western Geography* will follow *Google Scholar's* suggestions https://scholar.google.com/intl/en/scholar/inclusion.html and specifically following below https://scholar.google.com/intl/en/scholar/inclusion.html#indexing
with:

- **Title**(s) with minimum 24 point font,
- **Author**(s) in minimum 16 point font with explicit format Author(s):
- and with an **Abstract** clearly labeled as such

so as more likely to be crawled by *Google Scholar* and the above-mentioned services.

Meanwhile, WDCAG Executive, *Western Geography* Editorial Board and WDCAG members need to think about whether *Western Geography* should be indexed by a journal literature indexing database service such as the *Directory of Open Access Journals* https://doaj.org/ or commercial services such as *Gale Canadian Periodical Index-CPI* or *ProQuest Canadian Business Current Affairs-CBCA*. Each of the above have specific criteria summarized below:
Directory of Open Access Journals-DOAJ specifies:

- publish minimum five research articles per year
- primary target audience of researchers or practitioners
- Editorial board and Referees

While *Western Geography* meets the latter two, we are struggling to meet the first criteria.
Other requirements are that the journal have an official International Standard Serial Number-ISSN and this could be obtained via Library and Archives Canada.
DOAJ also requires a specific Creative Commons license and since there are several https://chooser-beta.creativecommons.org/ this would also have to be discussed.

This Editor also reached out to
Gale Canadian Periodical Index-CPI and *ProQuest Canadian Business Current Affairs-CBCA*
as to their criteria and/or requirements to be indexed but as of Dec20, 2024 did not yet hear back.

At the upcoming WDCAG conference to be held at Thompson Rivers University-TRU in Kamloops, BC Thurs March 6- Sat March 8, 2025 these *Western Geography* issues will be discussed.

As for this volume of *Western Geography*, thank you to all of those who submitted and thanks to the Referees, including the guest Referees, for all their work.

daniel Brendle-Moczuk, MLIS
Managing Editor
Western Geography
University of Victoria, Canada

Mapping Hazardous Terrain for Search and Rescue Pre-Planning: A RPAS Study of Evans Valley in Golden Ears Provincial Park, BC

Author: **Scott Shupe**
Department of Geoscience, University of the Fraser Valley; email: scott.shupe@ufv.ca

Keywords:
RPAS, drones, SfM, mapping, 3D model, Kanaka Creek, mountainous terrain, Evans Creek, search and rescue

Abstract:
The rugged, mountainous terrain of British Columbia's Lower Mainland attracts a growing population seeking outdoor experiences, but it also poses significant challenges and dangers, often leading to injuries requiring search and rescue (SAR) assistance. This research aimed to enhance SAR operations by providing detailed terrain characterizations through Remotely Piloted Aircraft System (RPAS) imagery. The study focused on Evans Valley in Golden Ears Provincial Park, an area identified by Ridge Meadows SAR (RMSAR) as particularly hazardous for hikers, especially those venturing off-trail. The acquired imagery was used to create 2D and 3D data products, with a particular focus on the area around Evans Valley Trail. These procedures were based on a proof of concept conducted in the lower elevation Kanaka Creek Watershed south of the park. The resulting orthophotos, elevation models, and 3D models offer various perspectives of the terrain and map potential access routes between Evans Trail and Evans Creek to aid SAR teams in navigating the valley.

Introduction

Remote sensing technologies are essential tools for generating Geographic Information System (GIS) data used in environmental mapping and analysis. Among these technologies Remotely Piloted Aircraft Systems (RPAS), conventionally known as drones, have emerged as versatile platforms for capturing high-resolution spatial data. RPAS are utilized by a diverse group of users, including environmental researchers, land managers, urban planners, and increasingly, emergency response teams such as search and rescue (SAR) organizations. For SAR teams operating in rugged and mountainous regions, RPAS offer a means to enhance situational awareness and plan rescue missions more effectively. Despite the advancements in RPAS technology, the high cost of sophisticated mapping systems equipped with advanced sensors remains a barrier, especially for volunteer-based SAR teams and research programs with limited budgets with limited budgets. To bridge this gap this study conducted a proof-of-concept analysis to develop a workflow for acquiring and processing high-resolution aerial data using an affordable, consumer-level RPAS. The aim was to generate spatial data products capable of characterizing environmental features pertinent to SAR operations.

A secondary goal of this study was to assess mission planning software enhancements, which enables automatic altitude adjustments in response to elevation changes and offline mission saving. This feature is intended to address challenges posed by rugged terrain, where tall trees and steep elevation changes complicate RPAS mapping efforts (Trajkovski et al. 2020).

Imagery was collected over four study sites within the Kanaka Creek Watershed in Maple Ridge, British Columbia. Using structure-from-motion (SfM) analyses, orthophotos and 3D elevation datasets were created to evaluate contrasting land cover and environmental features. Building on these insights, the study then focused on mapping and modeling Evans Valley in Golden Ears Provincial Park (Figure 1), with the goal of identifying potential off-trail routes between Evans Trail and the downslope of Evans Creek—a hazardous area frequented by hikers.

This research highlights the usefulness of RPAS-based mapping for characterizing Evans Valley, including mapping potential off-trail routes between Evans Trail and Evans Creek. It also reveals limitations in data collection and mapping products in such rugged terrain. The resulting orthophotos, digital elevation models, 3D data models, and mapped routes have the potential to serve as pre-planning tools for the SAR community.

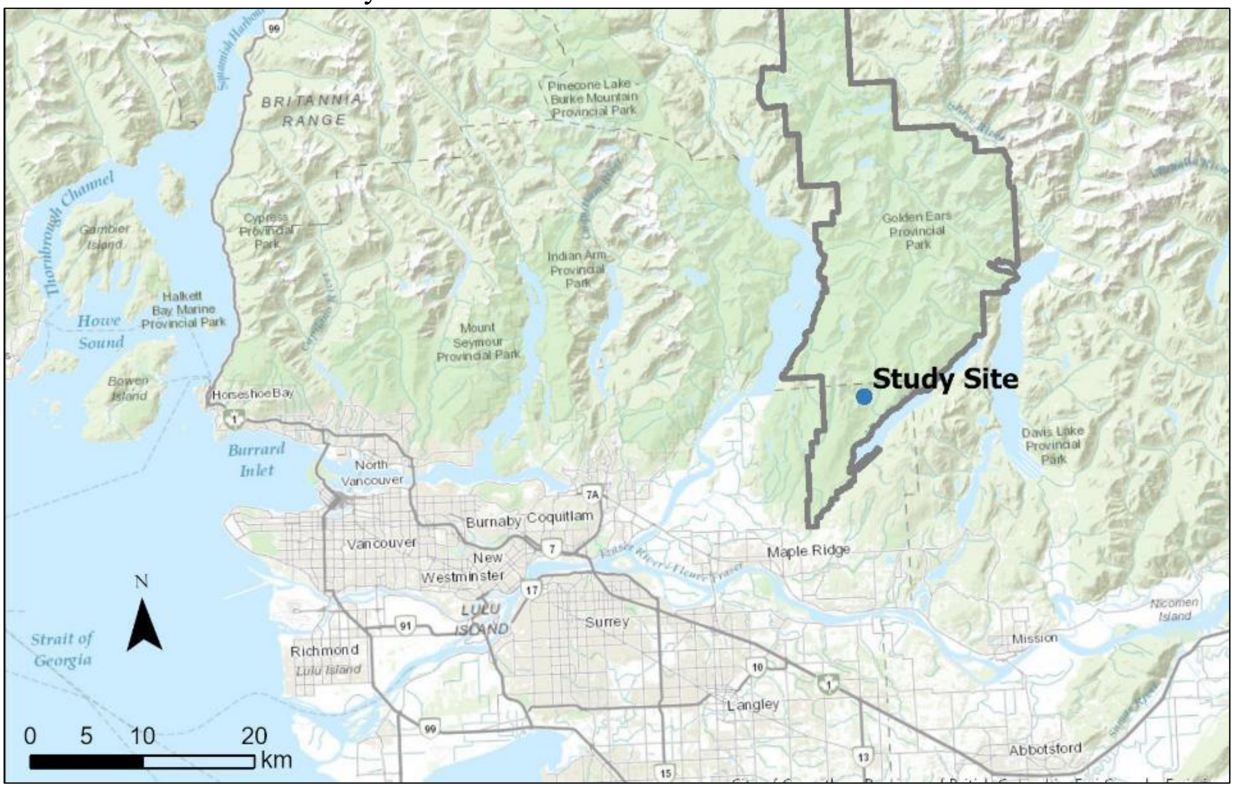

Figure 1: Location Map of Golden Ears Provincial Park in British Columbia.
The Evans Valley study site is in the southern portion of the park.

Background

The use of RPAS in search and rescue (SAR) operations, particularly in mountainous areas, has gained attention due to their ability to cover large areas quickly and provide high-resolution imagery (Lyu et al., 2023). Advances in technology and decreasing equipment costs have made all-weather aircraft with high-resolution thermal sensors and powerful zoom cameras more accessible to volunteer teams. However, the high cost of these advanced sensors remains a barrier to widespread adoption (Royal Institution of Chartered Surveyors, 2022).

A growing body of literature highlights the use of RPAS in SAR operations (Goodrich et al., 2008; Mishra et al., 2020; Queralta et al., 2020; Shakhatreh et al., 2019), primarily focusing on active monitoring and searching. While there is an increasing emphasis on pre-planning applications, such as optimizing RPAS coverage and connectivity (Hayat et al., 2020) and enhancing decision support (Nasar et al., 2023; Abi-Zeid et al., 2019), there remains a notable gap in the literature regarding the provision of customized, high-resolution terrain data to SAR personnel prior to operations. As the focus on pre-planning applications grows, the integration of advanced terrain mapping technologies becomes increasingly vital for optimizing SAR operations.

Visible spectrum Red-Green-Blue (RGB) cameras used for terrain mapping, are relatively low-cost compared to thermal imaging or 3D Lidar systems (Esteves Henriques et al., 2024). However, the emergence of SfM has revolutionized three-dimensional topographic surveys in physical geography by democratizing data collection and processing (Smith et al., 2016). Thus, 3D models can be generated at minimal cost as compared to the past. This is valuable for SAR teams that may not have a large budget, as understanding terrain is crucial for safety and effectiveness, especially in the rugged terrain of British Columbia (Richard Laing, personal communication). For example, knowledge of drainage systems too technical or time-consuming for rope teams can be critical. Furthermore, high-resolution imagery enables SAR teams to identify potential hazards, such as unstable ground or obstacles, before personnel deployment, thereby enhancing both safety and efficiency in operations.

While RPAS-based photogrammetry has been used in mountainous environments (Ćwiąkała et al., 2018; Giordan et al., 2020, Zarate et al., 2023. Šašak et al., 2019), it has not been done in SAR context per se. Lyu et al. (2023), in their survey on the use of RPAS in search in rescue, report on the use of photogrammetric methods in SAR, but these methods are confined to urban environments (Verykokou at al., 2016; Skondras et al. 2022) or in coastal disaster management (Rezaldi et al., 2021; Marfai et al., 2019).

While inexpensive RPAS may have limited utility in directly locating missing hikers, updated elevation datasets and 3D models from RPAS mapping can be valuable planning tools for SAR teams (Richard Laing, personal communication). RPAS offer less expensive and rapid topographic mapping advantages in contrast to traditional photogrammetric surveys and can provide data in areas challenging to access in the field. However, UAV-based photogrammetry in mountainous areas can be affected by extreme elevation differences during flight, which can cause gaps in data and variations in the resolution of individual images, thus impacting map scale in the final extracted map. To mitigate these issues, an optimal flight network should be designed before UAV deployment (Gargari et al., 2023). This involves understanding the terrain through field reconnaissance and coarse-level remote sensing, such as Google Earth. Identifying suitable RPAS takeoff points and mapping areas is also critical.

New consumer-level functionality in mission planning and flight software allows RPAS flight with automatic altitude adjustments in response to elevation changes and enabling offline mission saving (Dronedeploy, n.d.-a). However, this Terrain Awareness functionality is reliant on an underlying Digital Elevation Model (DEM), the resolution and quality of which vary by location. Consumer-level RPAS flight software often uses coarse global-resolution DEMs, such as NASA's Shuttle Radar Topography Mission (SRTM) data. While SRTM data typically represents the Earth's surface devoid of vegetation and buildings as a digital terrain model (DTM), in areas of dense vegetation, it may behave more like a digital surface model (DSM), incorporating some or all the vegetation into the elevation values (Farr et al., 2007). These limitations can affect the accuracy of Terrain Awareness, particularly in complex environments. The effectiveness of terrain awareness for RPAS flight planning and execution thus requires evaluation across diverse landscapes.

Methods

Study site selection and descriptions

Rick Laing of Ridge Meadows SAR (RMSAR) was consulted in winter 2021 to identify potential search and rescue areas. Based on these discussions, Evans Creek trail was chosen due to its rugged terrain and history of hiker incidents. Preliminary fieldwork locations within the drainage were identified using GIS analysis, primarily using Google Earth with an Evans trail vector overlay.

Golden Ears Provincial Park (Figure 1), where these areas are located, falls within unrestricted airspace, so no special permission from Transport Canada was needed for RPAS flights. However, permission to conduct RPAS missions within the park itself was needed and was obtained from BC Parks.

Field reconnaissance in early March 2021 involved hiking the Evans Creek trail to explore the terrain and establish viable launch sites. Evans Creek trail is challenging, with rugged terrain and steep slopes leading to the creek. The trail is fraught with obstacles like roots, boulders, and loose rock, posing significant risks, especially in wet conditions. The trail follows Evans Creek through a steep-sided valley with rapid elevation changes and dense vegetation, including trees over 100 meters in height (Figures 2, 3, and 4). In the uppermost section, the trail merges into the creek bed, making traversal difficult, particularly with snow cover that hides smaller rocks. Several missions were flown to map the area effectively, utilizing experience from a previous pilot project in the Kanaka Creek Watershed (Shupe, 2021).

Figure 2: Steep terrain in Evans Valley (photo: Shupe, 2021)

Figure 3: A portion of Evans Valley Trail as it ascends (photo: Shupe, 2021)

Figure 4: A portion of Evans Valley Trail close to a steep slope (photo: Shupe, 2021)

RPAS mission planning and flights

Mission planning was conducted using the free version of the DroneDeploy application on both iOS (iPad) and Android (smartphone) platforms. The RPAS was a Da-Jiang Innovations (DJI) Mavic 2 Pro weighing 907 grams and equipped with a 20-megapixel (MP) 2.54 cm Complementary Metal-Oxide-Semiconductor (CMOS) sensor (DJI, n.d.). The Mavic 2 Pro has a 28-millimeter equivalent focal length lens with an adjustable aperture from f/2.8 to f/11. The maximum flight time is 31 minutes with a maximum flight distance of 18 kilometers. The RPAS utilizes Global Navigation Satellite System (GNSS) specifically, the GPS (Global Positioning System) operated by the United States and GLONASS (Global Navigation Satellite System) operated by Russia. It is equipped with forward, backward, and side obstacle sensors. The likelihood of retrieving a crashed RPAS in the high tree canopy on steep slopes was very low. Therefore, conservative flight plans were implemented, with relatively high flight altitudes and narrow rectangular grid patterns oriented parallel to the valley to minimize the risk of contact with trees (Figures 5 and 6). Flight altitude for each mission was set at 80 m with a nominal pixel resolution of 2.3 cm. Front overlap was set at 75% and side overlap at 70%. Since the study sites were in mountainous areas out of cellular service range, planning required internet access and was done in the office. Rectangular gridded flight plans for each mission ranged in area from 3 hectares, over the lower portion of the trail, to 1 hectare upstream where the valley narrowed.

Field excursions for RPAS flights took place on March 17, March 26, and March 31, 2021, with one to three flights on each date. Figures 2, 5 and 6 indicate typical terrain in which the missions were flown.

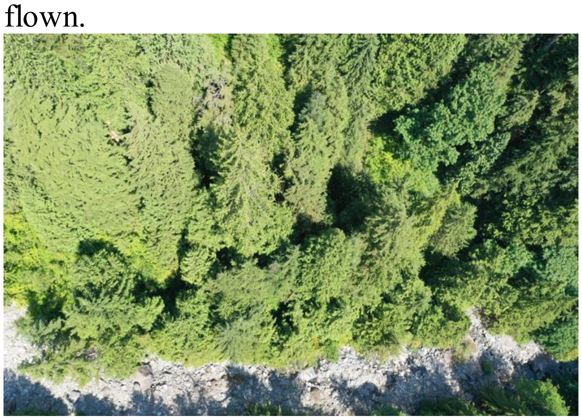

Figure 5: With rapidly climbing elevation in narrow valleys, a RPAS can get very close to the tree canopies, as seen here as the RPAS crosses Evans Creek (photo: Shupe, 2021)

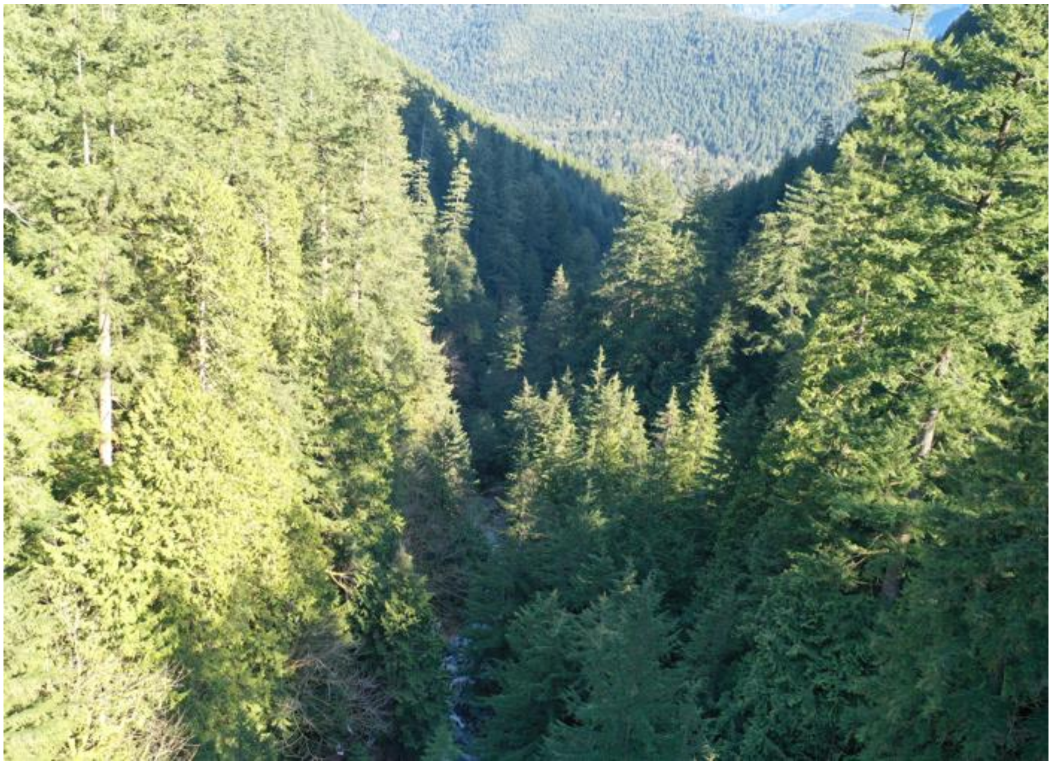

Figure 6: Portions of the valley narrowed making it a challenge to have a consistent flying height that captures detail (lower flying heights without impacting the canopy) (photo: Shupe, 2021)

Figure 7 shows one of the March launch sites within the creek itself. Additional launch sites were identified in the field on June 24, 2021; however, poor GPS satellite availability and issues with flight software prevented any flights on this date. However, successful flights did take place from these additional sites on July 26, 2021.

Figure 7: Launch site in the uppermost (western) portion of Evans Valley In March 17, 2021. The author is standing at the actual launch site in the center of the photoe (photo: Shupe, 2021)

Additional missions were planned for July 10 and July 24, 2023. Lower Evans Creek with its relatively open canopy, was identified as the safest launch site for testing the mid-2023 available terrain-adjusted flying feature of DroneDeploy's software (DroneDeploy, n.d.-b), as this site presented fewer risks of RPAS loss compared to upstream areas. Figure 8 shows the planned mission area. However, a sensor calibration issue, which caused severe image overexposure, was discovered as the first flight began. The mission was aborted as any acquired imagery would be unusable. This was resolved for the second mission through a vision sensor calibration protocol in the office. Unfortunately, the mission failed under the study site's condition of steep terrain and tall trees where the RPAS obstacle avoidance sensor engaged unexpectedly, halting the RPAS mid-flight. Despite efforts to reset missions at higher altitudes, further attempts were halted by the regulatory height limit of 122 meters set by Transport Canada (n.d.). Testing terrain-adjusted mapping missions from previous launch sites at higher elevations upstream was considered (Figure 6), but steeper terrain and the narrowing of the valley was expected to place the same constraints on flying, and thus no further missions were conducted. More details on these challenges will be discussed in the Discussion section.

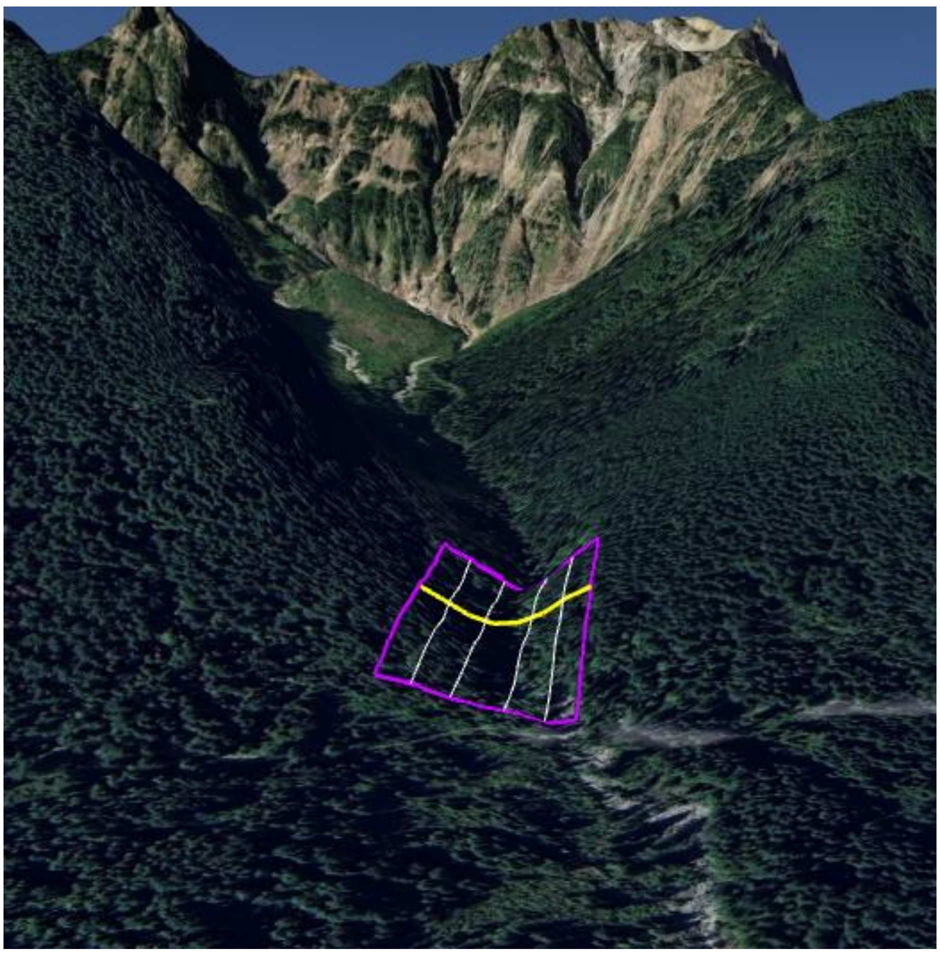

Figure 8: View Looking Upstream in Lower Evans Creek. The areas upstream of this location have less favorable conditions for RPAS launching sites and surrounding terrain compared to Lower Evans Creek. White and magenta lines here represent the approximate midpoint of the flight path.
The yellow line is a cross-section (see Figure 10).

Figure 9 shows the application's planned automatically adjusted flying height in response to terrain changes for the July 24 flight.

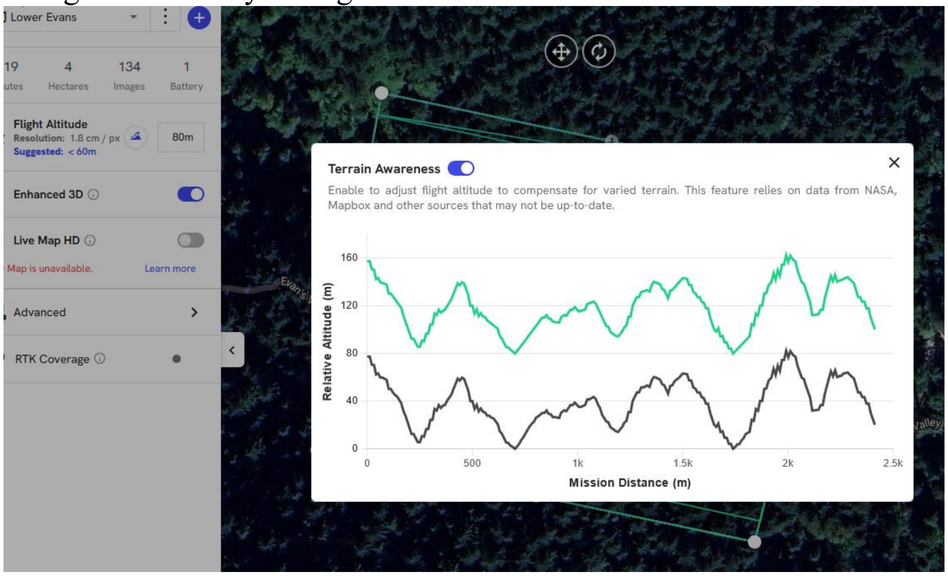

Figure 9: Terrain Awareness Settings. The black line represents the terrain height, automatically sourced from online elevation datasets by DroneDeploy. The green line indicates the terrain-adjusted flight paths.

Figure 10 shows the intended flight plan along with the changes in elevation.

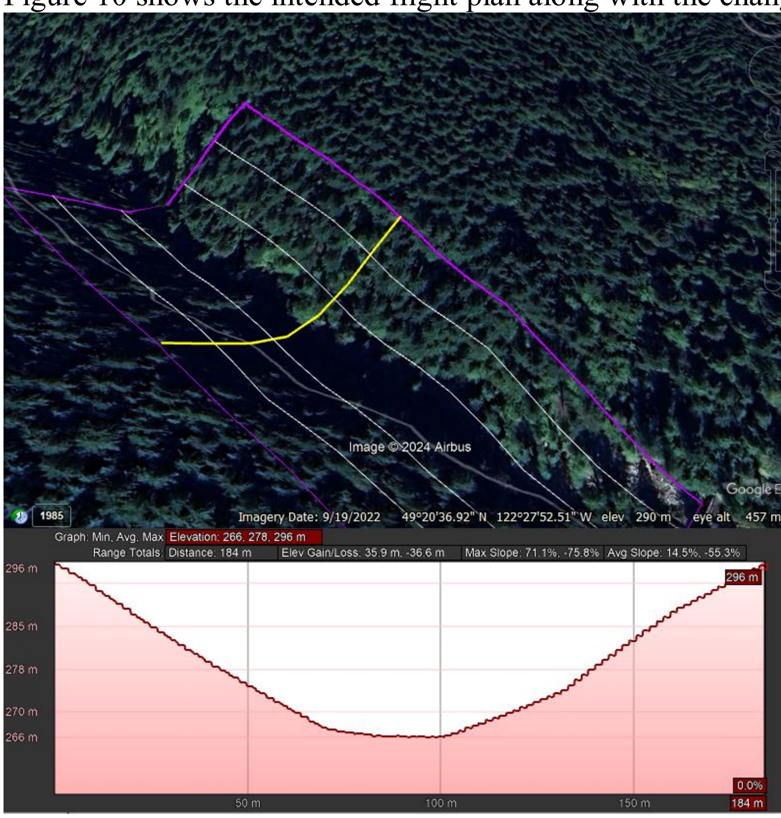

Figure 10: Cross-Section View of the Planned Lower Evans Creek Mission Area Using Google Earth (yellow line). Field observations suggest that the elevations shown on Google Earth for the study area are approximate and are likely not inclusive of tree heights. White and magenta lines show planned flight paths. The lines in the figure appear to follow the contours of the terrain, but the actual flight paths are maintained at a constant height above the ground and are flown as straight lines unless terrain adjusted.

Figure 11 indicates the total RPAS mapped area.

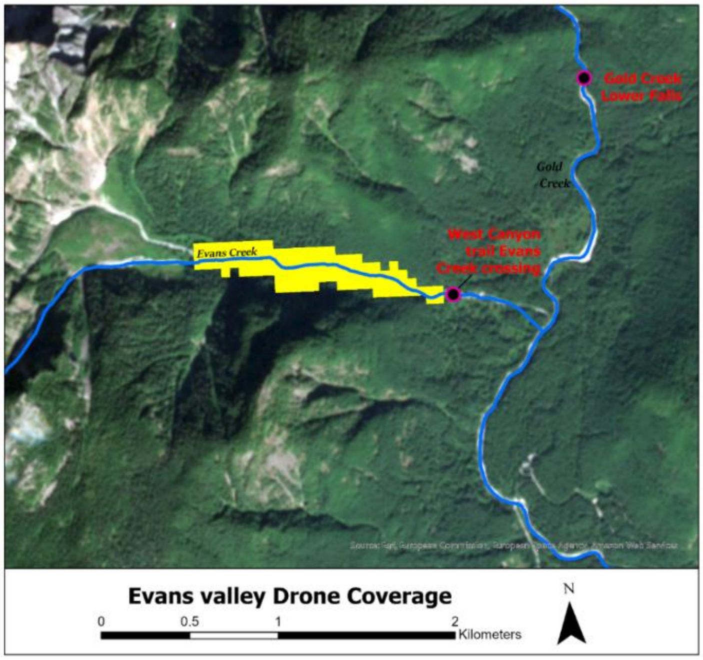

Figure 11: Mapped area in Evans Valley. Note that this map does not show the footprint of where the RPAS was flown. The RPAS footprint is smaller with coverage around the edges taken from oblique rather than nadir camera angles.

Data Processing

Post-mission processing involved downloading and organizing data from each mission into separate folders. Techniques from (Shupe, 2021) (Figure 12) were used for data analysis, summarized briefly below.

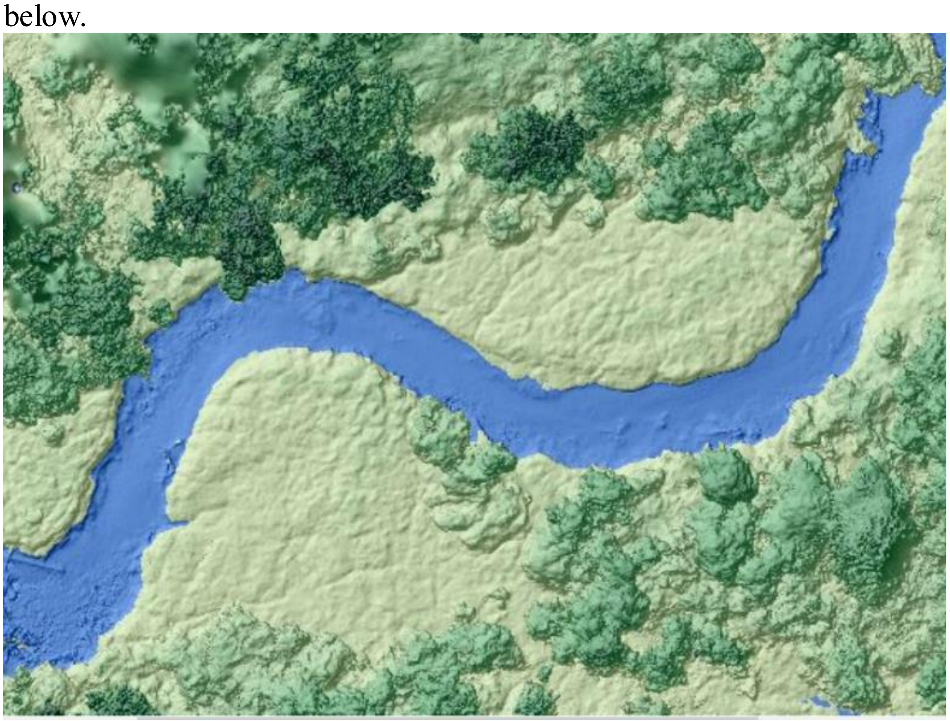

Figure 12: A portion of Kanaka Creek Watershed classified using a DSM.

For each mission, images were visually checked to ensure they fell within the project area and were correctly oriented. An algorithm in Agisoft Metashape (version 1.7.3) eliminated any out-of-focus photos. Next, the photos were aligned by identifying common points, using time-stamped WGS84 GPS coordinates for orientation. Photogrammetric methods within Metashape were then used to build a dense cloud of three-dimensional points, which were used to create a mesh model—a surface representation of the landscape using polygons. Flight photos were layered over the mesh to create a textured visualization. A DSM and a DTM were generated for each data set at 9 cm horizontal resolution. The DTM, representing the Earth's surface without vegetation or structures, was created by classifying the dense cloud model into ground and non-ground points using 1-m spacing. However, due to dense vegetation in the study area, DTMs were only used to show broad elevation changes upstream via contours (Figure 13). In contrast, DSMs reflect changes in elevation due to the tree canopy, useful for visually identifying cross-terrain routes where vegetation is a factor (Figure 14).

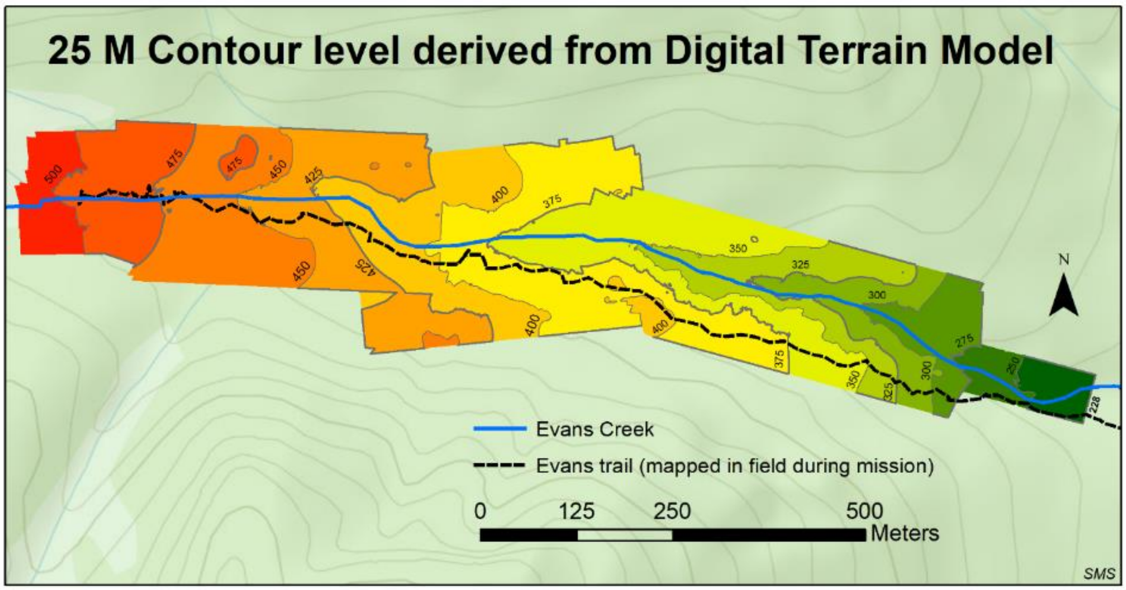

Figure 13: 25 m contour layer derived from DTM superimposed on a 40-m contour layer from an ESRI topographic basemap.

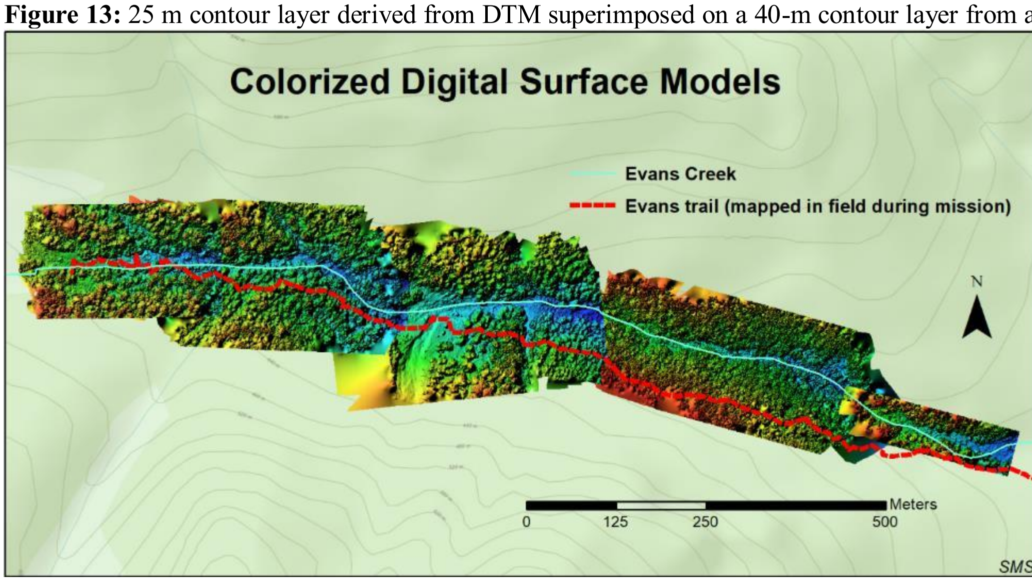

Figure 14: Overlapping Evans Valley digital surface model (DSM) layers. The source of the Evans Creek shapefile is the National Hydrographic Network (NHN). The Evans trail shapefile was generated in ArcGIS from point data recorded by a Garmin Forerunner watch (GPX formatted file) as I traversed the trail.

Orthophotos were created for each flight project at 3 cm resolution, producing a georeferenced map in a CSRS NAD83 UTM Zone 10 coordinate system. An algorithm integrated the photos with elevation data, but gaps appeared towards the edges due to differential shading, which complicates the derivation of common tie points. This effect is more pronounced at the image edges, where photos are often taken at an oblique angle rather than straight down.

The final step was stitching all the orthophotos into a single mosaic (Figure 15). Some data gaps in one mosaic were covered by adjacent mosaics, though overlapping areas often had gaps due to edge effects. The relative position of each orthophoto was suitable for the study; however, absolute positioning could be off by a few meters due to GPS signal variability and the absence of field GPS measurements. This led to degraded coverage and accuracy at the edges of the images. This absolute positioning error could be corrected by incorporating ground control points (GCPs) -precisely measured locations in the field- during the orthorectification process. However, this was beyond the scope of the present study. For the purposes of the SAR analysis, the relative spatial accuracy of the orthophotos was sufficient, as the study focused on spatial patterns rather than exact geolocations.

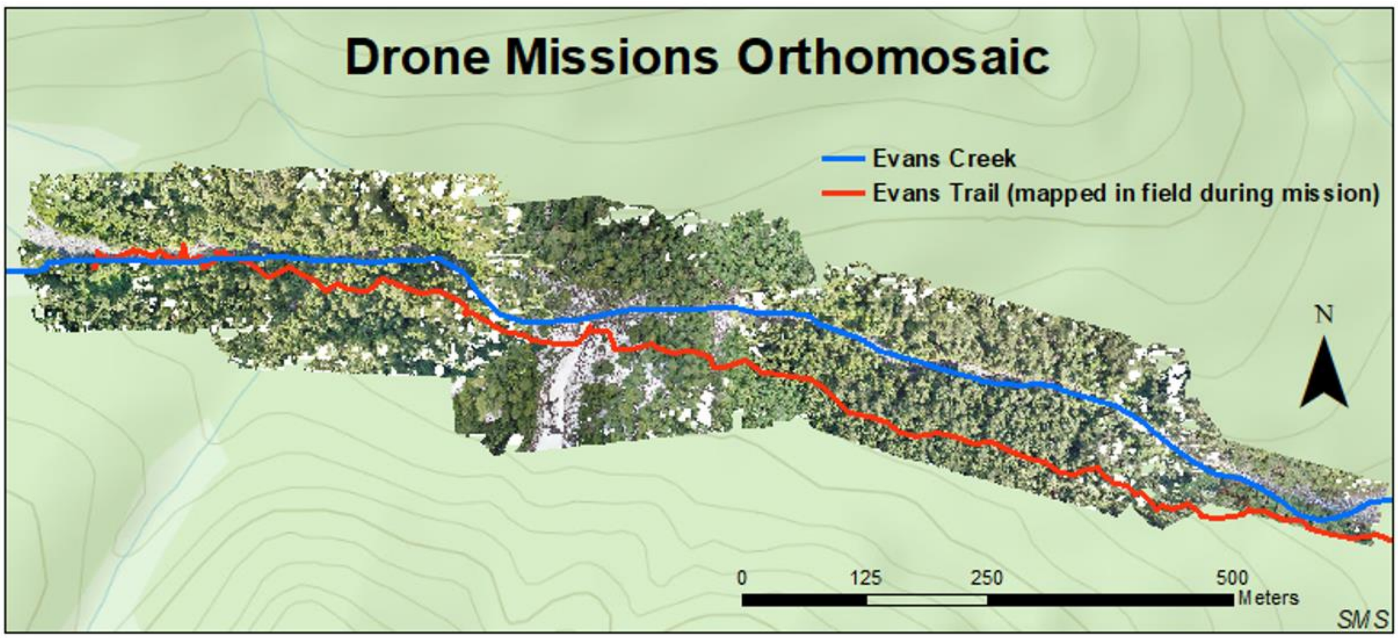

Figure 15: Orthomosaic of Evans Valley. The orthomosaic process fills in some of the gaps where there is overlapping coverage.

A scene layer package (SLPK format) was also generated for 3D terrain visualization. This layer was imported into ArcGIS Pro 2.8.0 and viewed in a 3D scene (Figure 16) for subsequent analysis. Processing these models required significant computing power and was limited by the model's size as some of mission data covered larger areas than others. Prior to creation of the SLPK, each model's resolution was reduced to 0.1 m, and the number of mesh faces from high to medium.

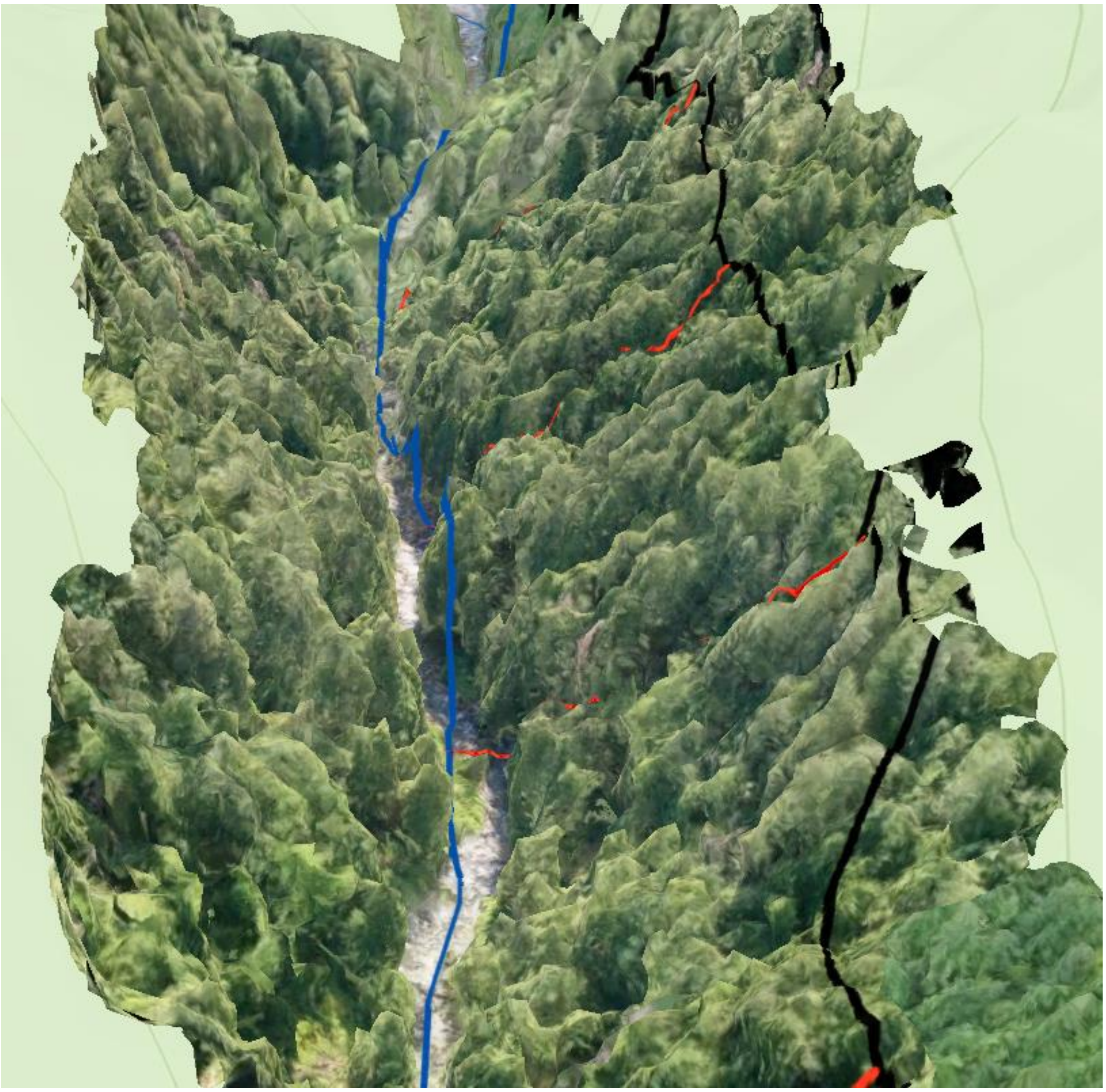

Figure 16: 3D visualization of a portion of Evans Valley. The blue line is the creek shapefile, the black line is the trail shapefile draped on top of the model, and the red lines are potential access routes from the trail to the creek.

Terrain Analysis

The orthophotos and data models were analyzed to assess potential paths for movement across the terrain, focusing on gaps in vegetation, slope breaks, and creek accessibility from the trail. A key objective was to evaluate the benefits of visualizing potential pathways using RPAS-based processing, specifically to define pathways between Evans Trail and Evans Creek.

Slope is a major determinant in terrain traversal. Contour layers at intervals of 1, 5, 10, 25, 50, and 100 meters were generated from the DTM to visualize slope changes at multiple scales. These intervals were chosen to provide a range of granularity for examining both localized and broad terrain features. Among these, the 25-meter contour layer derived from the DTM was found to offer the best balance, effectively minimizing extraneous detail while clearly illustrating elevation and slope differences across the valley (Figure 13).

Possible paths from Evans Trail to Evans Creek were digitized on orthophotos using visual cues like canopy gaps, where a possible path might be located. Potential digitized paths were modified, where possible, by close analysis of the DSM hillshade to further examine potential path obstacles like small trees or shrubs (Figure 17**)**. The paths were then visualized from different perspectives on top of the 3D terrain model to further assess their feasibility for actual traversal (Figures 16 and 18). Each path was then given a qualitative assessment of its potential to be traversable.

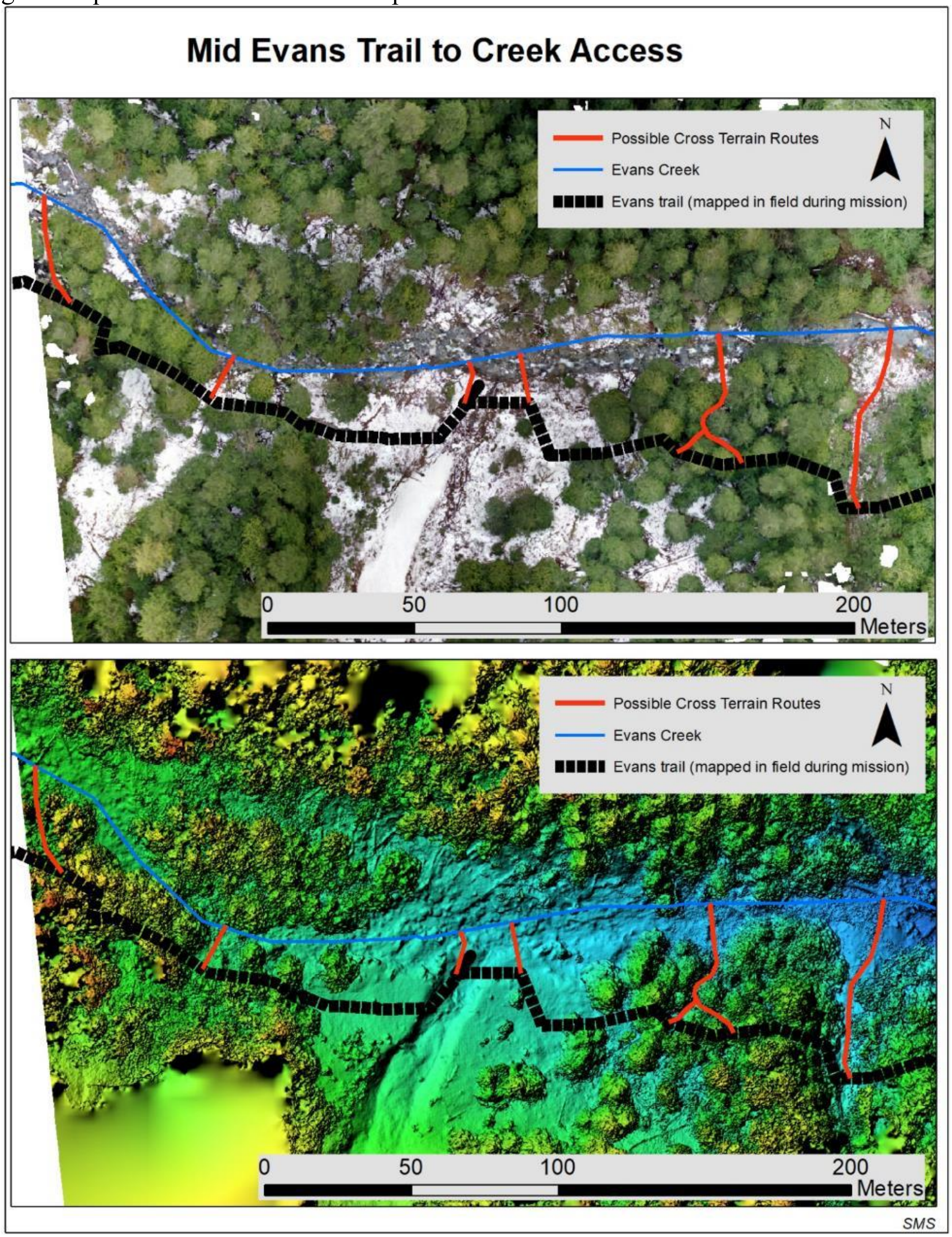

Figure 17: Potential cross terrain routes in mid-Evans Creek Watershed. Top image shows routes on model, bottom image shows routes on DSM.

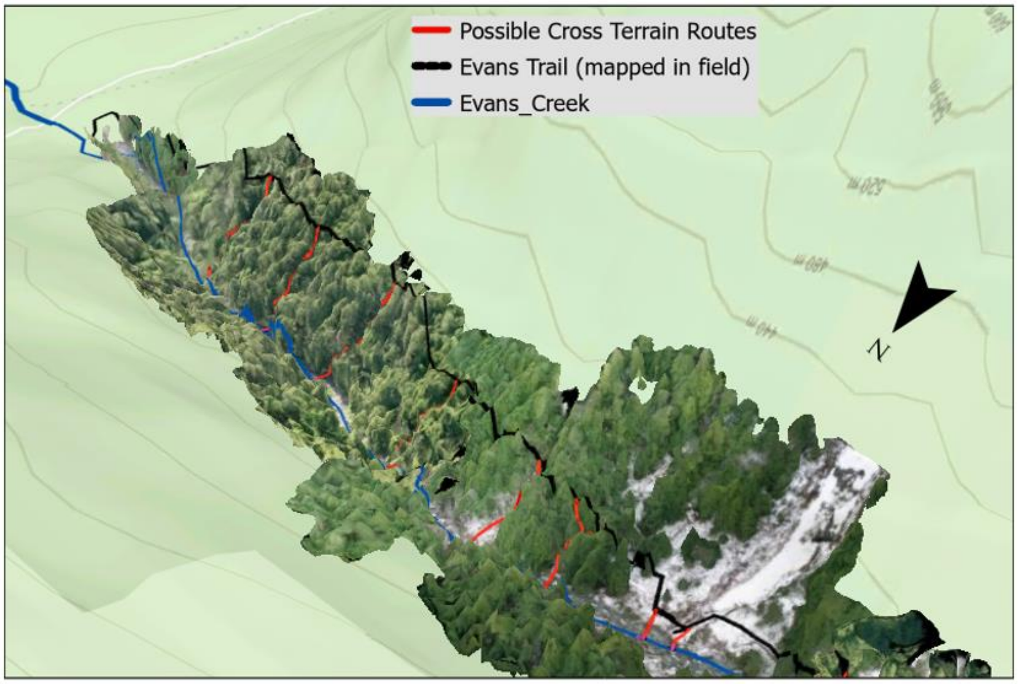

Figure 18: 3D visualization of potential cross terrain routes between Evans Trail and Evans Creek in the mid-portion of Evans Valley.

Discussion

The data generated in this project provided valuable insights into the topography and vegetation of Evans Valley, particularly around Evans Trail and Evans Creek. High-resolution maps and visualizations highlighted features of the terrain that could be used for planning SAR operations.
The contour map (Figure 13) effectively illustrates elevation changes along the trail and creek, highlighting steep areas, particularly in the lower to mid-valley, where slopes reach approximately 37° (e.g., Figures 2 and 3). This steep terrain is clearly visible in the visualizations, including the oblique RPAS photo in Figure 19.

Figure 19: Oblique view of steep slope seen in Figures 12, 13, and 15. Evans Trail has been drawn (non-georeferenced) on the photo (photo: Shupe, 2021)

3D terrain visualization provided the opportunity to assess and interpret the terrain from a variety of viewing angles, something which is difficult to automate. This approach made it easier to digitize potential routes on the orthophoto. The DSM hillshade proved to be invaluable for showing nuances of vegetation and terrain during path mapping. Continuous raster slope layers were less useful. The DSM-derived layer had too much variation due to varying canopy heights, and the DTM-derived layer did not adequately represent the bare earth.

Some mapped routes show good potential for human traversal due to gaps in vegetation, shallower slopes, and shorter distances, while others are less viable due to thicker vegetation, steeper slopes, and longer distances. Field analysis is necessary to accurately evaluate these routes and explore others not mapped but visible in the data. Additionally, these routes could also be compared with those derived from a least cost path analysis (Douglas, 1994, Atkinson et al., 2005; Bagli et al., 2011; Taylor, et al., 2023). This type of analysis uses algorithms found in most GIS packages to model the least cost ("easiest") paths by incorporating slope, vegetation, and other factors into a cost raster that must be traversed between the creek and the trail.

Challenges in this study included steep terrain with few open areas for safe launches, rapidly changing elevation along the valley sides that exceeded Transport Canada's height limits (especially when flying from downstream), and thick tree canopies that obscured line-of-sight, risking loss of radio control (Figure 5). Significant time was spent searching for safe launch areas. During some flights, the RPAS came dangerously close to the canopy, risking crashes (Figures 4, and 5). DroneDeploy's terrain-adjusted functionality performed poorly, likely due to the coarse elevation data it uses for planning. Alternative RPAS planning and flight software applications could be tested, though they require monthly subscriptions. UgCS, for example, has a Terrain following functionality (SPH Engineering, n.d.). However, it also uses the course SRTM database, though there is an option to import custom DEMs. Dronelink does have a Terrain Follow functionality that uses ESRI's World Elevation Services (Dronelink, n.d.), but the resolution ranges from 0.25 m to 1000 m (ESRI, 2022).

Collaboration with RMSAR was crucial in analyzing the data and providing feedback, guiding future mapping efforts. Their insights underscore the practical applications of RPAS-based processing in terrain analysis and route planning. Additional research, however, needs to be done to refine these analyses given the lack of route mapping research in SAR.

Future work could improve data products and better define the terrain and potential routes by:

- Planning flights using terrain awareness mode based on higher-resolution elevation data models, though current options may still be too coarse for steep, vegetated valleys.
- Seeking out additional launch sites, particularly when creek flow is low, and conducting additional flights at different heights to increase coverage and reduce data gaps, improving the accuracy of elevation models and orthophotos, especially along higher valley walls.
- Using improvements in SfM software, e.g., improved point cloud classification, to increase the accuracy of 3D data models (Nebula Cloud, 2023; Agisoft, 2024).

Conclusion

This study successfully utilized RPAS-generated data to map and analyze the topography of Evans Valley, offering valuable insights into elevation changes and potential routes along Evans Trail and Evans Creek. The contour maps, orthophotos, DSM layers, and 3D visualizations revealed significant variations in slope, terrain, and vegetation particularly in the lower to mid-valley, where steep slopes pose navigation challenges. The collaboration with RMSAR emphasized the practical applications of this data in route planning and terrain analysis, highlighting the need of field verification to assess the safety and viability of potential routes.

The findings demonstrate the effectiveness of RPAS-acquired data in understanding complex terrains. Future research should focus on utilizing higher-resolution elevation data, if possible, in terrain awareness functionality of mission planning and flight software, expanding flight coverage, and improving SfM outputs. These enhancements will refine terrain mapping precision and broaden the applicability of RPAS technology in similar environments.

Overall, this research contributes to the growing body of work demonstrating the utility of RPAS in environmental mapping and SAR planning, with significant implications for both practical applications and future technological advancements.

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Research Notes:

2023 Geographic Indigenous Futures of the Salish Sea Symposium

Authors:

Shirley Williams/Kusemaat (Lummi)
Whiteswan Environmental

Jeannine Georgeson (Coast Salish/Santu Dene)
Institute for Multidisciplinary Ecological Research in the Salish Sea

Aidan Gowland
Geographic Indigenous Futures Collaboratory, University of Victoria

Jugal Patel
Geographic Indigenous Futures Collaboratory, University of Victoria

Maya Weeks
Geographic Indigenous Futures Collaboratory & University of California, Davis

Niiyokamigaabaw Deondre Smiles (Ojibwe)
Department of Geography, University of Victoria

Abstract:

This paper provides a report on a 2023 symposium regarding Indigenous geographies in the Salish Sea bioregion. The presenters spoke on topics ranging from animal movement analysis and quantitative research to the permeability of boundaries in the Salish Sea. Through their talks, the participants provided potential glimpses into what a 'geographic Indigenous future' of the Salish Sea might look like. In this article, the presenters reflect on their contributions, and further interrogate what this future may mean for the broader region, given the ongoing effects of climate change. The article also speaks to the creation of a research group at the University of Victoria which is devoted to these efforts.

Introduction:

RDK Herman (2008) wrote that the critical component of Indigenous geographies centers on their interconnectedness with land (and water). Indigenous geographies differentiate themselves from broader European/Western conceptions of geography by recognizing that we relate to the spaces surrounding us, and that space is deeply embedded with meaning (Herman, 2008; Wong et. al, 2020). Language, culture, history, and emotions are all part of the land. This suggests that even our *love* of a place can guide how we relate to it.

In July 2023, a group of academic researchers, students, and community members began a conversation about what can happen when they are brought together to share their love of a place/space. The result, the 1st Geographic Indigenous Futures symposium, "The Salish Sea," sparked meaningful connections among its attendees and led to further conversations and collaboration. We, the Symposium speakers, present this progress report to share what happened and what has happened since.

We begin this report by briefly introducing readers to the Salish Sea region, the ways in which boundaries shape its lands and waters, and the ways in which the communities and Indigenous nations that call the region home contend with and transcend these boundaries. We then briefly attend to how anthropogenic climate change/crisis has placed and will continue to place environments and spaces within the region at risk.

We then introduce the research collective that hosted the first Geographic Indigenous Futures symposium, discussing how the lab's values guided its work in hosting the event. We then outline the speakers' contributions to the event and reflect on how the various foci they brought to the Symposium reflect the ability of the Salish Sea and its people, particularly Indigenous nations, to continue to move beyond boundaries when relating to the land.

Finally, we contemplate the broader lessons of what we can take away from this event. We reflect on how we can continue our work towards creating better futures for Indigenous nations and their environmental relations in the Salish Sea and beyond.

Introduction to the trans-boundary Salish Sea region:

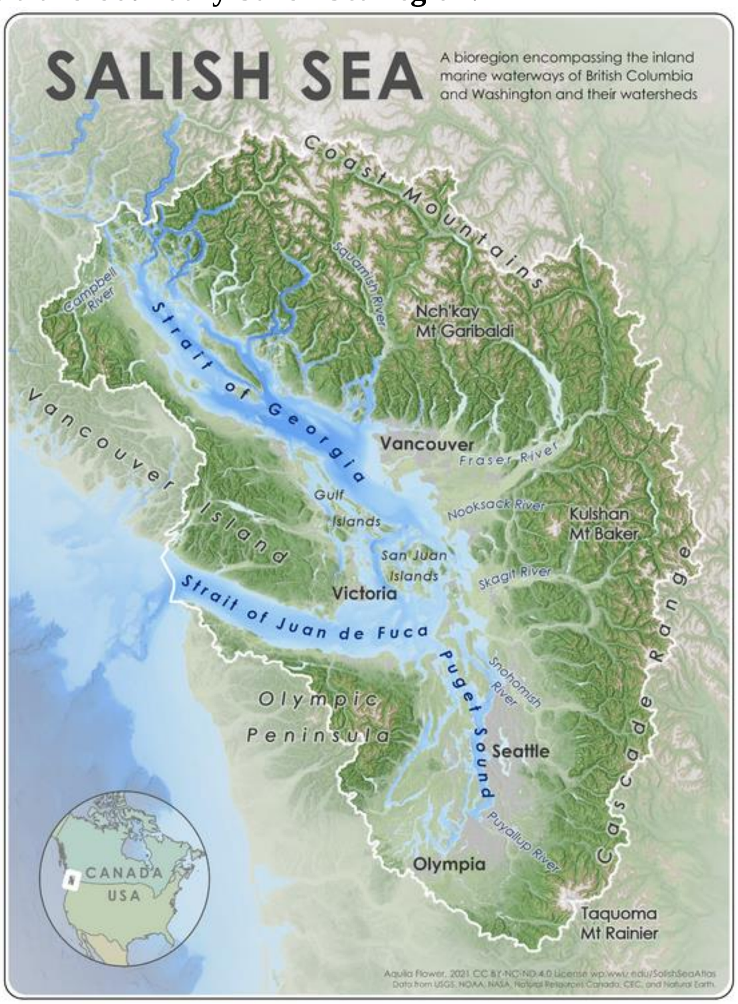

Figure 1: Map of the Salish Sea region. (Aquila Flower/Western Washington University, 2021)

The Salish Sea is a body of inland/marginal Pacific Ocean waters, broadly defined as including the Strait of Juan de Fuca, the Strait of Georgia, Puget Sound, and the waters surrounding the Gulf and San Juan Islands. The waters are shared between the United States and Canada, and include the province of British Columbia and the State of Washington.

According to the Salish Sea Institute at Western Washington University (Salish Sea Institute, 2024) the name Salish Sea was coined in the late 1980s to tie together the different areas of these waters based on shared cultural and environmental traits, including shared cultural relationships with the water among Coast Salish nations, and shared ecosystems between the different branches of the Sea.

The naming of the Salish Sea also points to the ways in which understandings and connections to the broader waters of the Salish Sea can transcend political boundaries imposed upon these lands by settler colonial structures and legal orders.

Part of this comes from the multitudes of Indigenous nations that live on and near the Sea, including (in no particular order) the Lummi Nation, Tulalip Nation, WSANEC Nation, Songhees Nation, Esquimalt Nation, T'Souke Nation, Pacheedaht Nation, Makah Nation, S'Klallam Nation, Suquamish Nation, Muckleshoot Nation, Musqueum Nation, Sechelt Nation, and many others (Native-Land.ca, 2024).

Their lands and territories overlap with each other and the broader lands of the transboundary region, obscuring the colonial boundaries placed upon them and impacting their relationships with the land to the present day (Norman & Cohen, 2016; Jones & van der Flier, 2021).

Climate/Environmental Change and the Salish Sea:

Within geographic and, more broadly, environmental literature, it is no secret or surprise—we are entering a period of rapid climate change, primarily driven by human factors. Lewis and Maslin (2015) define this period as the Anthropocene. Others, such as Moore (2014; 2016) or Donna Haraway (2015), define it as the 'Capitolocene,' or 'Plantationocene,' to point the finger of blame away from humanity writ large and towards the culprits of capitalism and imperialism.

Regardless of how it is defined, the effects of this rapidly growing climate crisis can be observed here in the Salish Sea. In recent years, the region has seen damage, destruction, and disruption from a variety of causes. These include wildfires, disastrous floods and landslides driven by rainfall from atmospheric rivers, alongside ncreasing pollution and damage to the aquatic and land ecosystems that comprise the Salish Sea region (Western Washington University, 2024). Indigenous nations in the broader region are, and have been, often front and center regarding the consequences of climate and environmental change.

For example, the Semiahmoo First Nation, located right on the border between the United States and Canada, struggled for 25 years to gain access to clean, safe drinking water (Ryan, 2021), while the nearby Tsawwassen First Nation has battled against expansion of the Roberts Bank superport (a major shipping port for Vancouver, BC), which will bring more pollution to its surrounding waters and species that move through the area, such as orca (CBC, 2023; Wood, 2024). On the opposite end of the spectrum, Indigenous communities in the interior of BC grappled with wildfires, which not only affected the air quality in the broader region but led to the destruction of several Indigenous communities, including most notably, those in Lytton, BC.

The waters of the Salish Sea are at particular risk. According to Khangokar et al. (2019), the average temperature of the Salish Sea could rise by a degree and a half Celsius by the year 2095, leading to changes in the oxygenation and acidity in the Sea. Although the authors note in this paper that the overall changes in the Salish Sea might not be as devastating as other coastal waters, this is still a very rapid increase in temperature and could result in shifts to the ecosystem in the Sea, an assessment shared by other scholars (Khangokar, 2019; Wilson, 2020; Government of Canada, 2020; Sobocinski, 2021; Baker 2023; Baloy & Pipp, 2024).

Indigenous academics such as the Citizen Potawatomi scholar Kyle Whyte (2017) have pointed out that to Indigenous peoples, what is viewed from non-Indigenous perspectives as a climate apocalypse represents yet another end of the world for Indigenous communities. Whyte argues that Indigenous communities often avoid the fatalism that is tied to climate crisis not because they do not understand the gravity of the situation but rather because they have faced apocalypses themselves through the loss of their lands, the attempted destruction of their cultures, histories, and languages, and how their connections to their broader environment have been eroded via settler legal orders and settler histories. Whyte continues his argument by asserting that if we are to try to find a path forward out of the climate apocalypse that we are creating for ourselves, it may be essential to listen to Indigenous voices and Indigenous worldviews because of their resilience and survivance in the face of colonial apocalypses (Whyte, 2017).

Introduction to the Geographic Indigenous Futures Collaboratory:

To address Whyte's provocation from a geographic perspective, we must approach space and place from an Indigenous perspective. We would like to introduce the research group that hosted the Symposium, which is driven by such principles.

The Geographic Indigenous Futures Collaboratory, or GIF Lab, is a research group based out of the Department of Geography at the University of Victoria. The Collaboratory was founded in 2022 by current lab director Niiyokamigaabaw Deondre Smiles as a research space focused on bringing Indigenous geographic praxis and thought into the geography department at the University, into the University as a whole and into the broader community spaces that the Collaboratory works within. As of the writing of this article, the Collaboratory is engaged in research projects and collaborations across North America, ranging from the west coast of Vancouver Island to the Great Lakes, in a variety of different topic areas focusing on various aspects of Indigenous geographies.

The GIF Lab consists of 20 members, including Director Smiles, eight graduate students, one undergraduate student, and ten community members. These community members represent a variety of primary affiliations, including the University of California Davis, Michigan Technological University, and several alumni of the University of Victoria. Historically, collaborators have come from across North America, from Alaska to British Columbia, to Quebec, and even beyond North America, including Aotearoa/New Zealand.

As mentioned, the GIF Lab focuses almost exclusively on community-engaged work with the Indigenous communities it partners with, particularly emphasizing work that furthers Indigenous environmental resurgence from cultural, political, and social perspectives. The communities almost always initiate projects the Collaboratory works with, which ensures that their input and desires for the scope of the work being done are upheld throughout the life of the projects being carried out on their territories. The GIF Lab adheres firmly to Indigenous principles of research ethics and data sovereignty, as defined by leading Indigenous scholars such as Renee Pualani Louis (2007) and Linda Tuhawai Smith (2019), as well as established trainings on the topic, including the First Nation Governance Centre's OCAP (Ownership, Control, Access, Possession) training.

The GIF Lab was borne out of the desire to further the resurgence of Indigenous relationships to space and place within the discipline of Geography; such relationships are increasingly being centered in Geographic scholarship, but without the input or meaningful participation of Indigenous communities themselves (Louis, 2007; Smiles, 2023). Rather than performing 'top-down' based work or 'parachute research' that objectifies Indigenous nations and their territories, the GIF Lab embraces a model of research that places the community and their needs and wants at the centre of the proposed projects and recognizes that relationships to land, places, and space are indispensable in any Indigenous geographic work (Smiles, 2023). To the members of the Collaboratory, a successful project can be turned over to the community/nation to be managed and continued by them without the need for the GIF Lab to be involved, which is guided by the Collaboratory's commitment to the self-determination of Indigenous nations in all spheres.

The Symposium:

Keeping in mind the goal of facilitating conversations between all stakeholders in the broader Salish Sea region, Director Smiles and their Geographic Indigenous Futures Collaboratory organized a symposium titled 'Geographic Indigenous Futures of the Salish Sea,' held on July 6th, 2023, in the First Peoples' House at the University of Victoria. The event drew an attendance of nearly 40 people (both in-person and virtually via Zoom) from Vancouver Island, the broader Salish Sea region, and as far away as the Netherlands. Besides facilitating conversations and fellowship over connections to the Salish Sea region, several speakers presented their work, which broadly related to the Salish Sea region and Indigenous geographies. We were fortunate to open the event well with a welcome to the territory and prayer by Songhees Nations member Jessica Joseph.

Highlights from the speakers' presentations are as follows:

Dr. Maya Weeks

The first presentation was from Dr. Maya Weeks, a writer, artist, and geographer on the California coast. Dr. Weeks presented a series of poems that focused on her relationships to water and the ways in which colonialism, pollution, and climate change have impacted water and the broader ocean. While not explicitly focused on the Salish Sea itself, Dr. Weeks' work spoke of how our relationship with the water can transcend boundaries and bring us into various relationships, both good and bad.

Ongoing/Future Work: Dr. Weeks is continuing their work in California, focusing on marine pollution, gender, and feminist political ecology. Dr. Weeks and GIF Lab Director Smiles have had conversations about future collaborations between the two, including art-based and land-based education.

Aidan Gowland

Following Dr. Weeks' presentation, Aidan Gowland, a master's student in the GIF Lab, followed up with a presentation on their ongoing research surrounding the relationships between Parks Canada and local First Nations, particularly around stewarding and protecting Indigenous interests in Parks lands and working with First Nations in governance and oversight. Within the Salish Sea region is one Canadian national park, the Gulf Islands National Park Reserve.Parks Canada has formed relationships with local First Nations in the area, including the WSANEC nations, among others (Parks Canada, 2024). Given stated commitments to reconciliation by the Canadian government, Gowland outlined how Parks Canada has recognized—and in some cases, not recognized historic Indigenous claims and title to the lands and provided recommendations for Parks Canada to follow to live up to its commitment to reconciliation.

Ongoing/Future Work: Gowland is continuing their MA research. As a result of the conference, Aidan and Kusemaat/Shirley Williams entered into conversations about how Gowland's skill with mapping can assist Whiteswan Environmental in their efforts to educate community members in the Salish Sea regarding Lummi relationships to land and water.

Jugal Patel

Jugal Patel, a member of the GIF Lab who most recently was a master's student in the Department of Geography at McGill University, presented his research on participatory research in animal movement analysis. In the talk, Patel argued that community-engaged, participatory work is vital for animal movement analysis, as it can bring critical perspectives on migration, animal distribution, and how human relationships with animals can impact how animals move through space and place. While Patel's paper was more general in its focus, analysis of animal migration and habitation patterns in the Salish Sea is not new, particularly when it comes to work on critical species such as orca (Osborne, 1999; Olson et al., 2018; Trimbach et al., 2021; Thornton et al., 2022). This, combined with Indigenous community relationships to animal species in the region (Claxton et al., 2018), means that Indigenous communities and their perspectives must be considered in any animal movement analysis research in the Salish Sea.

Ongoing/Future Work: As of the writing of this article, Jugal has taken a job in California with Esri. He and GIF Lab Director Smiles have begun developing a project on animal movement analysis and its connections to Indigenous knowledge systems, with a particular focus on orca movement near Vancouver Island.

Niiyokamigaabaw Deondre Smiles

GIF Lab Director Smiles followed up with a presentation about the artificial nature of colonial boundaries across Indigenous lands. They spoke on the ways in which these boundaries could and often do become very rigid, but also could become porous when brought into contact with Indigenous relationships to land. Smiles spoke to how Indigenous ties of kinship and inter-community connections already transcended colonial boundaries in the Salish Sea region. Smiles also outlined the continued and increasing importance of these community ties, considering the risks that the climate crisis would bring to the transboundary Salish Sea region in the future.

Ongoing/Future Work: Smiles continues to collaborate with the participants of the symposium in various ways through the GIF Lab. In particular, Smiles is beginning to develop ideas for field schools and geography camps in the Salish Sea in collaboration with organizations such as Whiteswan Environmental and IMERSS, along with ecocultural mapping. Smiles has also joined the board of Whatcom Intergenerational High School in Bellingham, WA, a school which is focused on the resurgence of Indigenous/Lummi knowledge. Smiles plans to hold another GIF Symposium in 2025 in Anishinaabe lands in Minnesota.

Shirley Williams and Jeannine Georgeson

Following Smiles' presentation, the co-keynote speakers of the Symposium, co-founder of Whiteswan Environmental, Kusemaat/Shirley Williams, and transboundary partner Jeannine Georgeson from the Institute for Multidisciplinary Ecological Research in the Salish Sea (IMERSS) based on Galiano Island in the southern Gulf Islands of British Columbia, presented on their mission, vision, and collaborative work to support thriving cultures and environments for all in the Salish Sea.

Whiteswan Environmental (WE) is a Indigenous-led nonprofit located in the uppermost corner of the Pacific Northwest in Washington State on the federally reserved lands of the Lummi Nation. According to their website, Whiteswan "[supports] community healing through the natural, cultural and historical restoration to the Salish Sea for 7th generations sustainability as a measure of ecological health protection for all (Whiteswan Environmental, 2024)."

Readers can watch the MIT Indigenous Communities Fellowship Solver/ WE - Digital Ecocultural Mapping Project video here to learn about why the collaborative efforts of Whiteswan Environmental participants are significant and what people who attend gatherings such as the Geographic Indigenous Futures of the Salish Sea symposium could/can do to join these efforts.

Kusemaat/Shirley Williams added that Whiteswan Environmental, as an Indigenous-led organization, understands that ecocultural stories must be preserved for future generations. WE and IMERSS invite readers, and all interested peoples in the Salish Sea, to contact them to learn more about how to get involved and share their stories.

Ongoing/Future Work: Whiteswan Environmental and IMERSS continue to pursue community-engaged scholarship, research, and collaboration in the trans-boundary Salish Sea region. Whiteswan has hosted two journeys within the San Juan Islands, in Summer 2023, and Spring 2024. They are also engaged with the National Park Service surrounding storytelling of Indigenous presences in NPS sites on San Juan Island. IMERSS is currently developing an ecocultural map of Galiano Island, BC, and is in the process of applying for funds for workshops to bring together stakeholders to conduct further work.

Broader Implications and Conclusions: Towards promoting a geographic Indigenous future of the Salish Sea:

It is clear from the presentations at the Symposium and the conversations that were had during and after the event that the challenges that face the transboundary Salish Sea region are numerous. This is a sentiment shared by scholars who have longstanding research interests in the bioregion (Jones & van der Flier, 2021).These challenges could have severe implications for the environmental health of the waters and lands of the region going forward, to say nothing of the impact to the Indigenous communities and their cultural and political practices by environmental and climate change.

However, the question is raised—what exactly can a symposium held on a university campus do to help solve these issues? We argue that the solution is not just the event itself but rather what it represents, and the connections forged from the event. To the GIF Lab and the participants of the Symposium, our participation was driven by our deep commitment and love for the Salish Sea, a region that many of the participants and attendees in the Symposium call home.

Whether we are originally from these lands or have come to live here from elsewhere, we are obligated to do what we can to ensure that our home remains healthy. This obligation and accountability becomes even more important when the interests of Indigenous communities in the region are considered. Visitors and guests upon these lands must recognize that our connections and relationships with the land must be upheld above all.

To us, a geographic Indigenous future of the Salish Sea lies in amplifying Indigenous voices and relationships to land in ways that center their perspectives while leveraging our institutional privilege to bring these perspectives into spaces that may not historically have been open to them. This potential future focuses on the connections and the generative power of conversation and collaboration to move work forward in a good way—the GIF Lab is pleased to have engaged in ongoing conversations with Whiteswan Environmental and IMERSS with an eye on future collaborations that can further the goals of these organizations and the Indigenous communities they work with and represent.

A geographic Indigenous future centers on our love and connections with the land and waters of the Salish Sea, recognizing that we are intertwined with the land and that we must lean into our relationships with it rather than holding ourselves apart from it.

Ultimately, we hope that this work, even if it is small and ongoing, can help ensure that future generations can enjoy and relate to the Salish Sea and that the Indigenous nations who call the area home can remain resurgent.

Acknowledgements
We would like to thank everyone who could attend, including community members across the Salish Sea and beyond. In particular, we wish to thank the presenters, including Aidan Gowland, Jugal Patel, Maya Weeks, Kate Herchak, Hilary Ronald and the VIDEA team working with T'Souke First Nation, Shirley Williams from Whiteswan Environmental, and Jeannine Georgeson from IMERSS. We also wish to thank Jessica Joseph from the Songhees Nation for providing a welcome to the territory.

Last but not least, we want to extend a special thanks to Ginny Broadhurst, Ruth Musonda, Natalie Baloy, and all of the good people at the Salish Sea Institute at Western Washington University for providing the funding to make this Symposium through their Salish Sea Fellows program.

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A Better Understanding of CO2 Fluxes within Canadian Boreal Forests through Satellite-Based XCO2 Data

Authors: Saba Asadolah, Dr. Peter L. Jackson

Abstract

This research seeks a better understanding of carbon fluxes in the Canadian boreal forest in recent years due to the profound impacts of climate change and recent increases in wildfire occurrences. These forests play a significant role in the global carbon cycle, acting as major carbon sinks by absorbing carbon dioxide from the atmosphere. However, the balance between carbon absorption and release is delicate and can be easily disrupted by climate change, leading to increased temperatures, changes in precipitation patterns, and more frequent and severe wildfires. These environmental changes have direct consequences on the carbon balance of the boreal forests. Wildfires, not only release large amounts of stored carbon back into the atmosphere but also alter the forest landscape, affecting its future ability to store carbon.

Canadian boreal forests are significant carbon reservoirs, with approximately 28 pg of carbon across biomass, dead organic matter, and soil. This includes both aboveground biomass and belowground components like roots and soil organic matter. The dynamics of these pools are subject to growth rates, mortality, and disturbances such as fires and insect infestations. This research focuses on quantifying the levels and fluxes of carbon dioxide within Canada's boreal forests.

Fig.1
Adapted from Natural Resources and Environment Canada

With integrating top-down satellite observations with bottom-up field measurements, the research seeks to provide a comprehensive quantification and modeling of CO2 fluxes, enhancing our understanding of carbon sequestration mechanisms. Key objectives include identifying the primary drivers of CO2 exchange variability, assessing the impact of wildfires on forest carbon balances, and assess post-fire forest recovery and its implications for carbon sequestration. Methodologically, the research leverages an array of satellite data, including bias-corrected XCO2 values from OCO-2/3 Lite File, Solar-Induced Fluorescence data, and vegetation indices such as NDVI from MODIS and Landsat satellites. These space-based observations will be coupled with in-situ measurements from networks like FluxNet for validation.
An inverse modeling approach using the Global Earth-system Monitoring model (GEOS-Chem) will assist in interpreting the data to identify the CO2 fluxes and their association with vegetation dynamics and climate conditions.

Furthermore, the study will utilize satellite imagery to analyze land cover changes, fire disturbances, and post-fire regeneration. The research aims to combine top-down satellite observations with bottom-up ground measurements to address the frequency, extent, and intensity of wildfires and their subsequent effect on the forest carbon balance. Furthermore, the study will utilize satellite imagery to analyze land cover changes, fire disturbances, and post-fire regeneration. The research aims to combine top-down satellite observations with bottom-up ground measurements to address the frequency, extent, and intensity of wildfires and their subsequent effect on the forest carbon balance.

Methodology

Satellite Data (OCO-2/3 Lite File, Solar-Induced Fluorescence, NDVI from MODIS and Landsat):

- Utilization of OCO-2 Data for XCO_2 Measurements
The approach to measure CO_2 fluxes in this study is based on XCO_2 data, representing the column-averaged concentrations of carbon dioxide. These data are sourced from the Orbiting Carbon Observatory-2 (OCO-2) satellite, global measurements of atmospheric CO_2 with a spatial resolution of 1.29 square kilometers (2.25 km x 0.70 km footprint). Its orbit allows it to revisit any point on the Earth's surface approximately every 16 days at the equator under nominal operation conditions. However, due to its orbit and operational modes, the actual temporal resolution for a specific location can vary.
The satellite employs spectrometers to measure the intensity of sunlight reflected by the Earth's surface and absorbed by CO_2 molecules, facilitating the calculation of CO_2 concentrations across different atmospheric columns. It employs three high-resolution spectrometers to measure the molecular absorption of sunlight by CO_2 and molecular oxygen (O_2) across three specific bands of the electromagnetic spectrum. These spectrometers are tuned to the near-infrared region where CO_2 and O_2 have strong absorption lines.

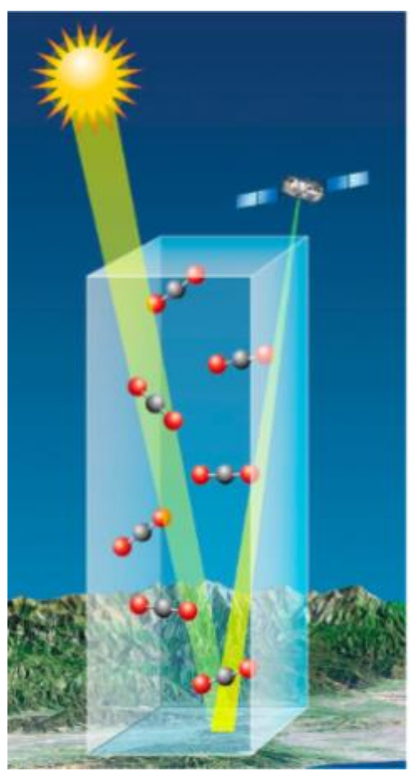


Fig.2
Adapted from NASA Applied Remote Sensing Program, 2023.

- Incorporation of NDVI Data from MODIS
The methodology also incorporates the Normalized Difference Vegetation Index (NDVI) data obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites. MODIS provides NDVI data with a spatial resolution of up to 250 meters, enabling detailed monitoring of vegetation health and biomass across the boreal forests. This research utilizes NDVI to identify areas of active photosynthesis and to assess the health and density of forest vegetation, which are critical for understanding the forests' role in carbon absorption and sequestration.

- Application of Solar-Induced Fluorescence (SIF) Data
Additionally, this study employs Solar-Induced Fluorescence (SIF) data to evaluate the photosynthetic activity of the boreal forests. SIF data are extracted from observations made by the OCO-2 satellite, complementing its CO_2 measurements. SIF serves as a proxy for photosynthetic efficiency and plant productivity, reflecting the amount of light energy converted into chemical energy during photosynthesis. By analyzing SIF data, the research aims to quantify the photosynthetic capacity of the boreal forests and to understand how this capacity influences their ability to act as carbon sinks.

In-Situ Measurements (FluxNet):

Ground-based measurements from FluxNet stations are integrated to validate and complement satellite observations. These measurements offer precise data on CO2 fluxes at specific locations, enabling a detailed examination of carbon exchange processes at the microscale. This helps in understanding how local factors influence carbon dynamics, providing a ground truth for satellite data.

Inverse Modeling (Global Earth-system Monitoring Model):

The inverse modeling approach is applied to interpret the combined satellite and in-situ data, aiming to identify specific CO2 fluxes and their association with various environmental factors. This modeling helps in deducing the net carbon exchange rates, distinguishing between sources and sinks of carbon within the boreal forests. It's particularly valuable for analyzing how vegetation dynamics and climate conditions affect carbon fluxes.

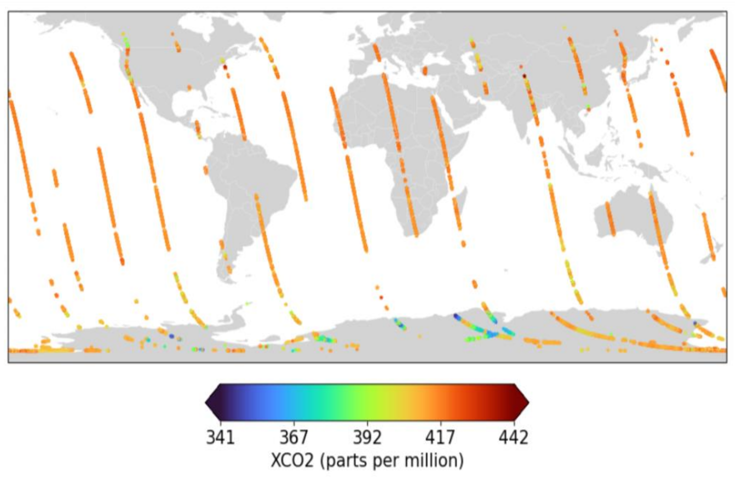


Fig.3
OCO-2 spatial resolution in 1 day.

Satellite Imagery Analysis:

Satellite imagery is analyzed to track land cover changes, fire disturbances, and post-fire regeneration. This aspect of the methodology is crucial for assessing the impact of wildfires on the carbon balance of boreal forests. It allows researchers to quantify the extent, frequency, and intensity of wildfires and their subsequent effects on forest carbon stocks. This analysis helps in understanding the regenerative capacity of the forest and its role in carbon sequestration post-disturbance.
Furthermore, the study will utilize satellite imagery to analyze land cover changes, fire disturbances, and post-fire regeneration. The research aims to combine top-down satellite observations with bottom-up ground measurements to address the frequency, extent, and intensity of wildfires and their subsequent effect on the forest carbon balance.

Objectives

1- Quantify Spatial and Temporal CO2 Exchanges:
Identifying and analyzing the specific periods and geographic areas within Canada's boreal forests where there is a shift between acting as a net carbon sink (absorbing more CO2 than it emits) and a net carbon source (emitting more CO2 than it absorbs). By utilizing satellite-based XCO2 (atmospheric carbon dioxide) data, this research aims to map out and understand the temporal (seasonal, annual) and spatial (location-specific) variations in CO2 fluxes. This involves analyzing satellite imagery and data over time to detect patterns and trends in carbon exchange, thereby identifying key areas and times when the forest's carbon balance tips from negative (sink) to positive (source). This detailed mapping will provide a clearer picture of the forest's role in global carbon dynamics and help identify regions and times that are critical for targeted conservation and management efforts.

2- Identify Drivers Influencing CO2 Exchanges Variability:
The second objective aims to dissect and understand the various factors that cause fluctuations in the CO2 exchange rates of the boreal forest. This includes an in-depth analysis of how the health of vegetation, changes in land cover (such as due to logging or industrial development), and the impacts of wildfires influence the forest's ability to sequester or release carbon.

By examining these drivers, the research intends to uncover the underlying causes of variability in the forest's carbon exchange processes. This could involve studying changes in tree health and density, the extent and recovery of areas affected by wildfires, and how these factors correlate with changes in carbon fluxes.
The goal is to identify actionable levers that can help manage or mitigate these drivers to maintain or enhance the forest's role as a carbon sink.

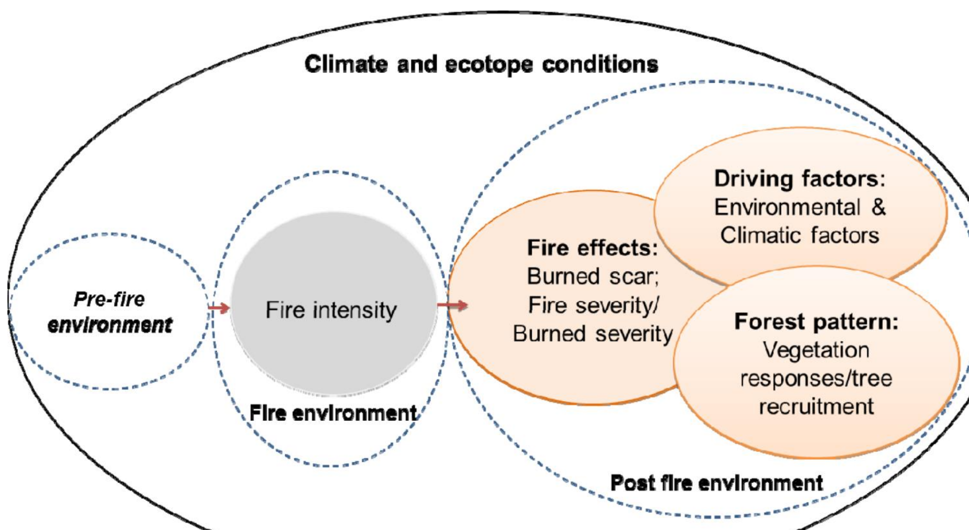


Fig.5
Schematic representation of fire-related environments and assessment of post-fire effects on forest conditions concerning this comprehensive review. This review will particularly focus on studies of post-fire environments with respect to remote sensing approaches.

Adapted from : Chu, T., & Guo, X. (2014). Remote Sensing Techniques in Monitoring Post-Fire Effects and Patterns of Forest Recovery in Boreal Forest Regions: A Review. Remote Sensing, 6(1), 470-520. https://doi.org/10.3390/rs6010470

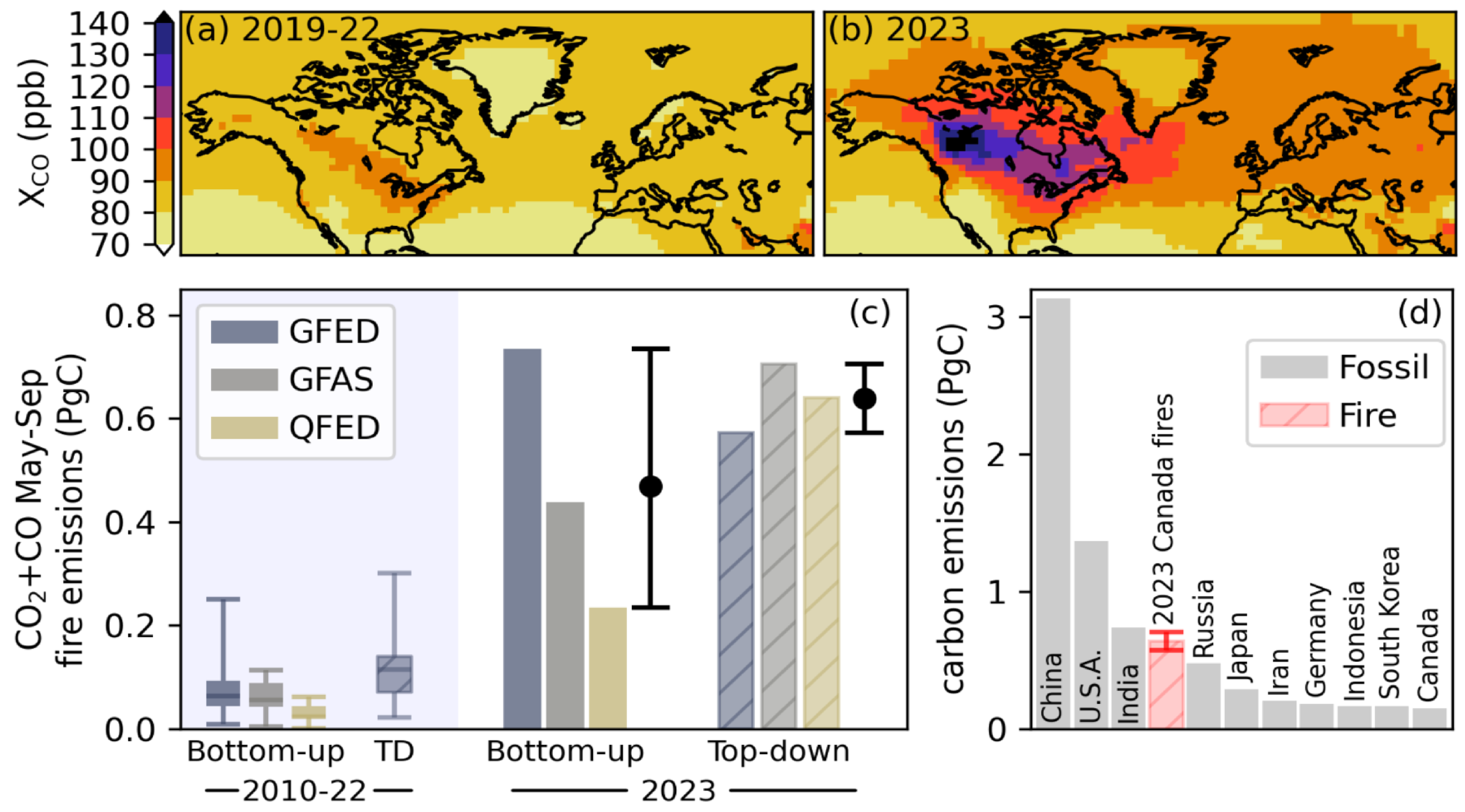


Fig.4. May-Sep TROPOMI XCO (a) averaged over 2019–2022 and (b) for 2023 aggregated to a 2◦ × 2.5◦ grid. (c) Canadian forest fire carbon emissions (from CO and CO2) for the 2023 May-Sep fire season, compared with fire emissions during 2010-2022 (distribution shown by box-and-whisker plots). Top-down emissions over 2010-2022 are estimated from MOPITT (2010–2021) and TROPOMI (2019-2022) CO retrievals. (d) A comparison of May-Sep Canadian fire emissions with 2022 territorial fossil carbon emissions for the 10 largest emitting countries, obtained from Global Carbon Budget 2022.
These estimates are performed using three different prior bottom-up fire emission inventories: the Global Fire Emissions Database (GFED4.1s) , the Global Fire Assimilation System ver- sion 1.2 (GFAS), and the Quick Fire Emissions Data set version 2.6r1 (QFED) inventories.

Adapted from Byrne et al., 2023, Physical Sciences - Article, DOI: 10.21203/rs.3.rs-3684305/v1.

3- Assess Post-Fire Forest Recovery:
The final objective centers on understanding the impact of wildfires on the boreal forest's carbon balance and its recovery process post-disturbance. Wildfires are a natural part of boreal forest ecology but affect the carbon balance by releasing stored carbon and altering the landscape. This research aims to evaluate how these fires impact the forest's carbon sequestration capabilities and to monitor the recovery and regrowth of vegetation using satellite observations. This includes tracking the speed and extent of vegetation regrowth after a fire and how effectively the new growth can sequester carbon compared to pre-fire levels. The aim is to gain insights into the resilience of the forest ecosystem, understand how long it takes for the forest to return to being a net carbon sink after a disturbance, and identify strategies to aid and hasten recovery, thereby mitigating the long-term impact of wildfires on the forest's carbon balance.

Local Impacts of Climate Change: Investigating the past and future of glacier ice and melt processes in the North Shuswap

Tay Powrie

Dr. Thomas Pypker, Dr. David Hill, Crystal Huscroft, Dr. Brian Heise

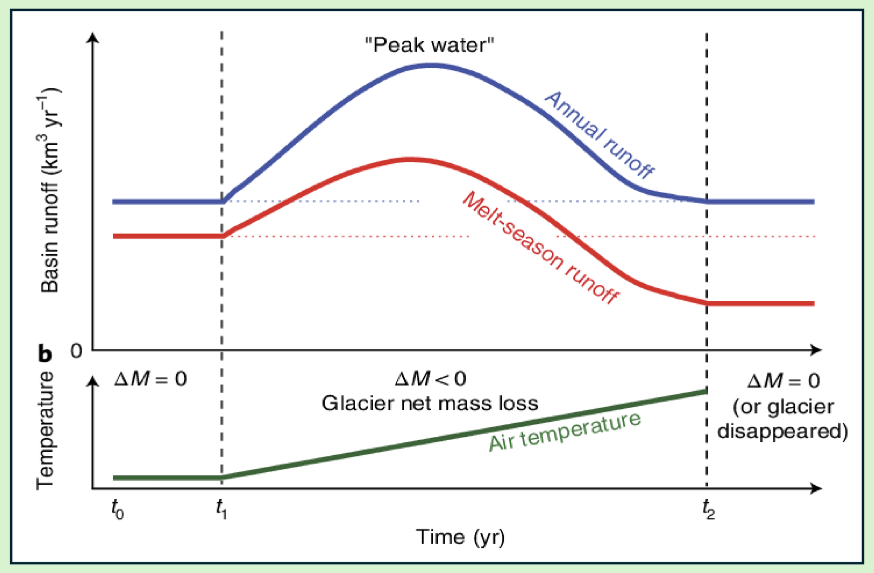
NSERC CRSNG · Adams Lake Indian Band · SHUSWAP watershed council · Mike Wiegele Helicopter Skiing

INTRODUCTION

Globally, glaciers of all sizes are receding, linearly correlated to an increase in average global temperature (Rounce et al. 2023). **Hydrological response to glacier recession may pose significant ecological and socioeconomical risks** (Spehn et al. 2002; Milner et al. 2009).

The contribution of glacier melt to the annual drainage of a catchment is generally dependent on the percent of glaciated area and the current rate of recession (Jansson et al. 2003). A glaciated area as little as 1% in a macroscale basin (100,000 km²) can account for 25% of late summer (August) river flow (Huss 2011).

Glaciers in Western North America have generally been receding since the Little Ice Age, resulting in an increasing contribution of glacier runoff in glacially influenced basins (Moore et al. 2009).



The above diagram from Huss & Hock (2018) demonstrates that annual discharge within a catchment is not influenced by glacier runoff when glaciers are in a state of equilibrium or when there is negligible glacier coverage - annual discharge is only influenced when glacier mass balance is in a state of flux.

The 'peak water' phase for glaciers located within Western Canada is expected to occur between 2020 – 2040 (Clarke at al. 2015).

It is important to assess the impact of glacier change within distinct hydrological systems.

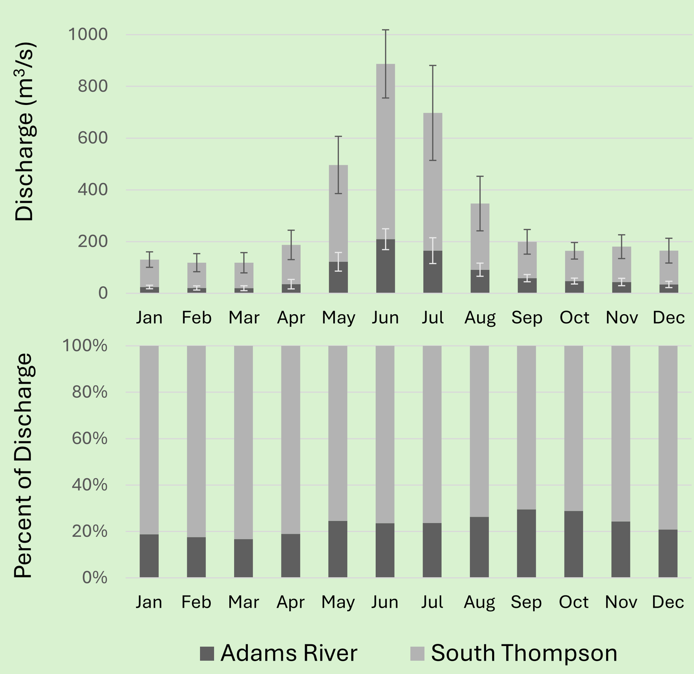
The Adams River catchment is a glaciated sub-drainage of the South Thompson River. The South Thompson is the main source of water for the community of Kamloops (*Tk̓emlúps te Secwépemc*). Furthermore, Adams River has immense socio-economic and ecological importance, providing critical habitat for salmonids and native aquatic species (Kruger & Saayman 2017).

Is the Adams River hydrology glacially influenced?

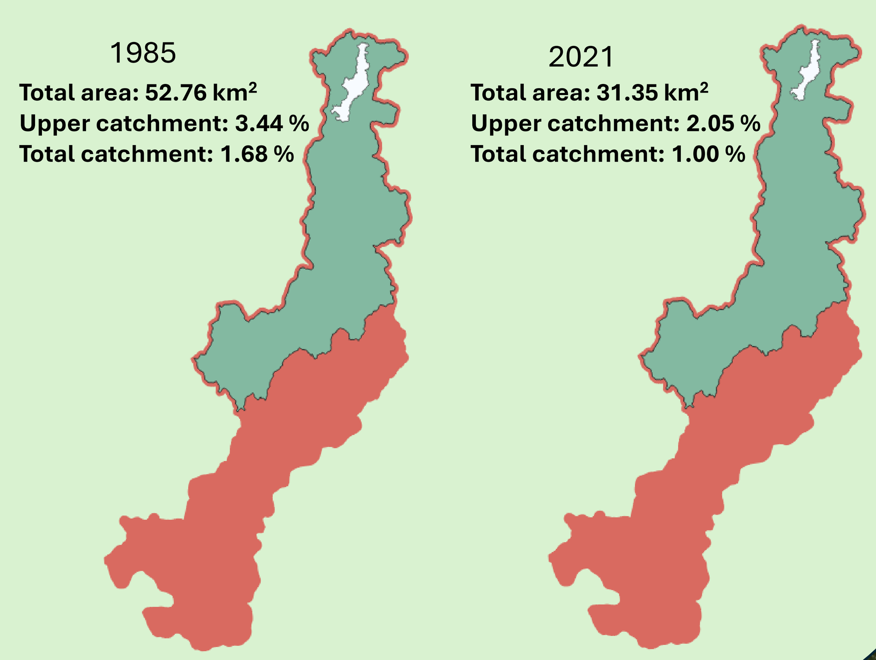
If so, how will glacier change affect the quantity of river discharge on a decadal, annual, or seasonal time scale?

INITIAL INVESTIGATION

The top figure portrays the average monthly flow, over the past 23 years, at the outflow of Adams River and at a South Thompson River hydrometric station near Chase, BC. **Adams River flow is especially important in the late summer and fall, reaching up to 29% of the South Thompson River discharge in September.**



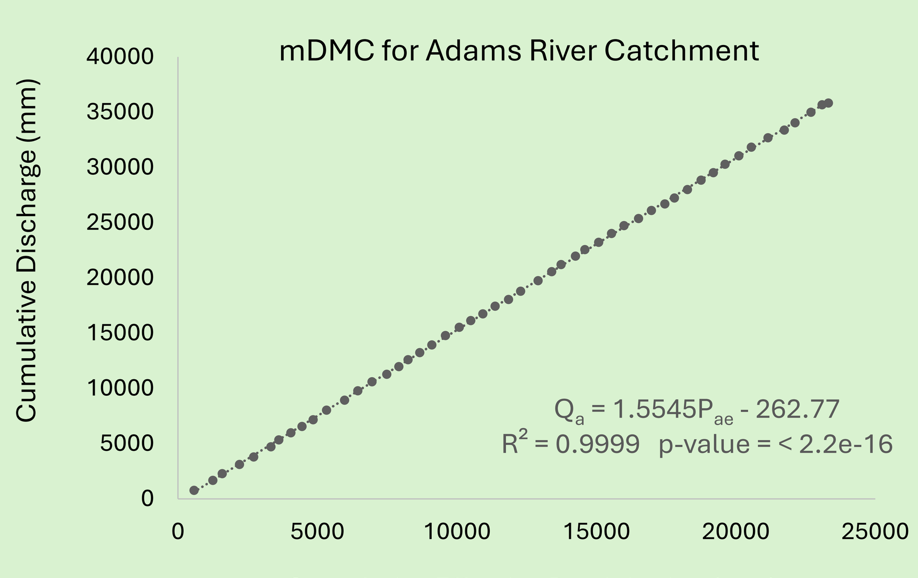
Satellite imagery was utilized to quantify the total glaciated area of the Adams watershed in 1985 and 2021 (Sever & Pypker unpublished). The upper catchment area (1532.75 km²) is shaded in green. The total catchment area (3137.13 km²) is shaded and outlined in red. Only glaciers > 0.01 km² were considered.



ANNUAL DISCHARGE TREND ANALYSIS

A modified Double Mass Curve (mDMC) detects any changes in cumulative annual discharge due to shifts in non-climatic variables when a breakpoint or change in slope occurs (Wei & Zhang 2010). In a glaciated watershed, a change in the rate of glacier recession should be depicted by a shift in the mDMC curve.

No significant break point or slope change suggests **there has not been a significant change in the quantity of annual discharge within the Adams watershed between 1971-2021; however, this does not account for any shifts in seasonal patterns or potential compensatory factors.**



Pettitt test:
Changepoint in 2009
p-value = 0.204

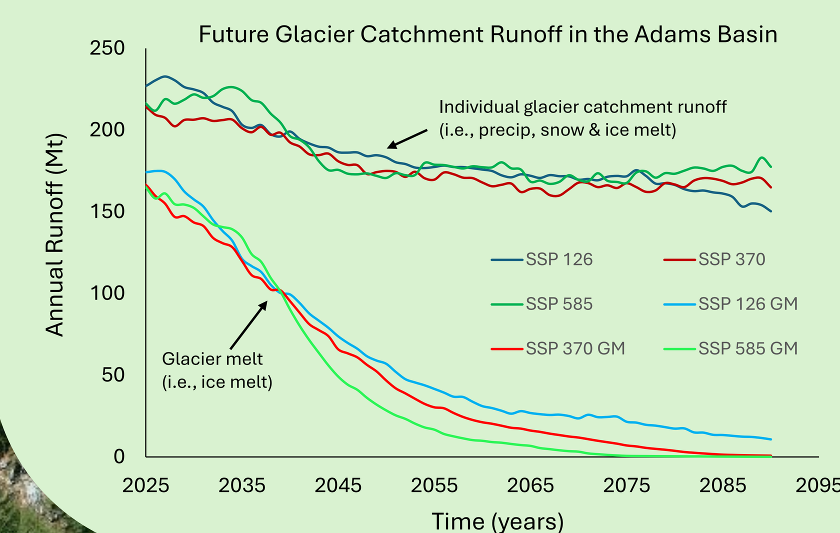
Davies' test:
Best at 13380 P_{ae}
p-value = 0.3307

ISOLATING GLACIER RUNOFF

The Open Global Glacier Model (OGGM) was utilized to project future glacier runoff and seasonal melt patterns.

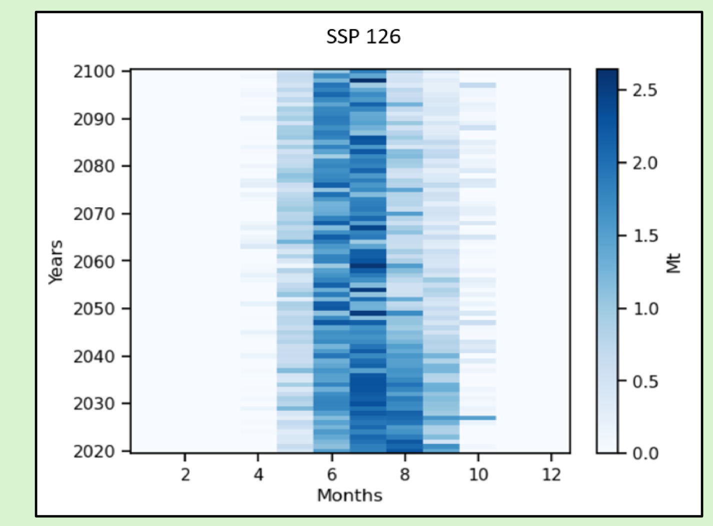
The figure below depicts projected annual runoff from all glaciers within the Adams watershed based on three climate scenarios.

- **Glacier recession in the Adams watershed is at or just past 'peak water'**
- **Glacier melt is currently equivalent to 14% of Adams River June – September flow**
- **Glaciers will recede completely or become negligible by 2100 in all climate scenarios**
- **Annual flow may be buffered by increase in precipitation**



The previous figure does not account for a change in seasonal timing. The figure below depicts the projected change in seasonal runoff from a representative glacier in the watershed for the 'best-case' climate scenario.

- **Currently, most glacier runoff occurs in July, August and September. Over time, glacier catchment runoff will occur earlier in the season due to a shift towards precipitation dominated runoff**
- **This trend is more pronounced and at a faster rate for the SSP 370 & SSP 585 climate scenarios**

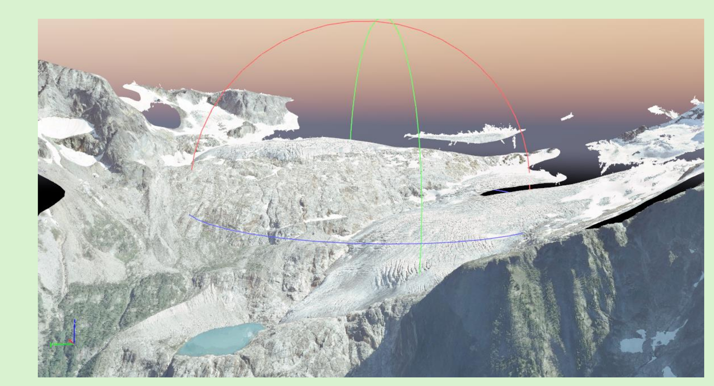


FUTURE WORK - MODEL CALIBRATION

The OGGM utilizes remote sensing data to model glacier geometry, mass balance, and volume from which water melt equivalence can be calculated (Maussion et al. 2019). ***In situ* data is important for model calibration and refining model error at a single basin scale.**

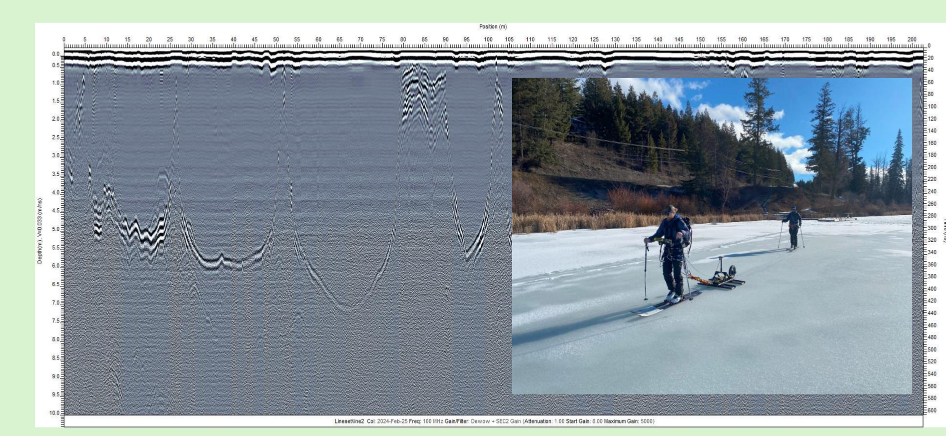
Photogrammetry

High resolution aerial images were obtained from the BC photo archives for 2011. Overlapping frames, by at least 60% form stereopairs, where the difference in photo perspective allows for 3D modelling of the surface. Photos from 1997 and 2005 will be obtained and used to fmodel the surface elevation of two representative glaciers over time within the Adams Watershed.



Ice Penetrating Radar (IPR)

Pelto et al. (2020) utilized IPR to measure thickness of glaciers that had previously been estimated with inversion models and found, on average, a 38% difference in modelled and measured ice thickness. IPR measurements from two representative glaciers within the Adams watershed will be collected in April 2024 and integrated into the OGGM model to refine ice thickness estimates.



CONCLUSIONS & FURTHER CONSIDERATIONS

- **Glaciers with the Adams Watershed have reached the 'peak water' phase and are projected to recede completely by 2100 under any climate scenario.**
- **Adams Lake has a large water holding capacity with a volume of 40.96 km³ . This may work to buffer any significant fluctuations of annual or seasonal discharge** at the outflow of the Adams watershed. This may account for no significant change in annual discharge at the Adams River hydrometric station between 1971 - 2021 despite glaciers within the catchment receding and contributing an equivalence of 14% of the Adams River late summer and early fall flow.
- **The upper Adams River does not have the same buffering system and has a higher proportional glaciated area.** The upper Adams River once provided critical spawning habitat for thousands of salmon; however, the Upper Adams sockeye run was decimated in the early 20th century due to the construction of a splash dam (Hume et al. 2003). There have been reintroduction efforts, as well as nutrient supplementation programs to re-establish a thriving Upper Adams River salmon run. **It is crucial to understand the future hydrological effects of glacier recession in the Upper Adams catchment specifically to plan for future management.**
- As glaciers have dominantly been in a state of flux since the LIA, **water allocation and management within glacially influenced basins has been developed within a period of elevated flows. As we lose this long-term water storage, it is necessary to reassess management practices within these watersheds.**

Adams watershed hydrometric station

City of Kamloops
Tk̓emlúps te Secwépemc

This study is being conducted on the traditional and unceded lands of the Adams Lake First Nations Band, within Secwepemcúl'ecw.

"Tmícw - the rough translation of this Secwepemctsín word is land, waters, and everything on Earth. Tmícw reflects layers of meaning and interrelation to the landforms, places, and beings within Secwepemcúl'ecw." – Qwelmínte Secwépemc Tmícw cumulative effects plan:

"The Adams Lake Indian Band is currently working on a draft Land Management Framework for the Adams Lake drainage system. This project will be focused on water and forestry development and will look at the cumulative effects on these resources as well as create an ALIB specific scenario for management in these areas."

References · mDMC Methods & Script · OGGM Methods · 'Cool' Glacier Photos