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

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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.

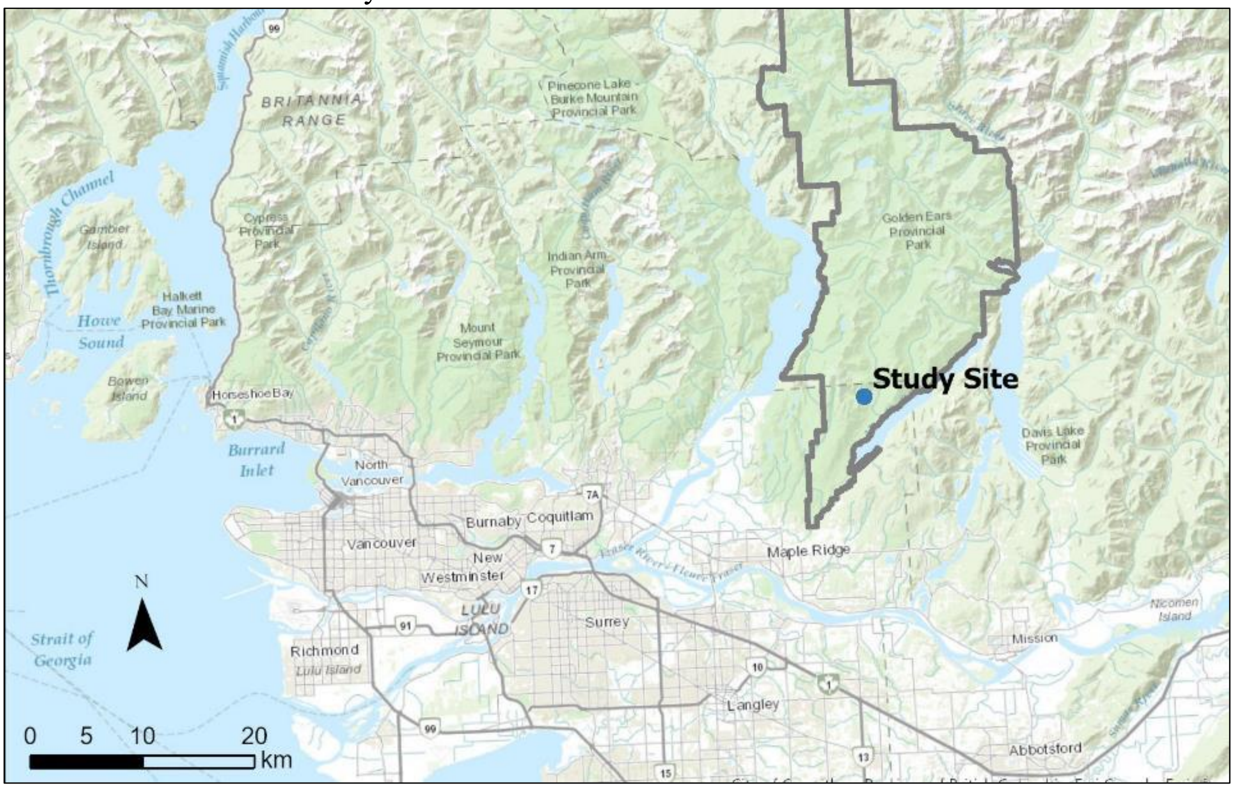

Figure 1: Location Map of Golden Ears Provincial Park in British Columbia.
The Evans Valley study site is in the southern portion of the park.

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.

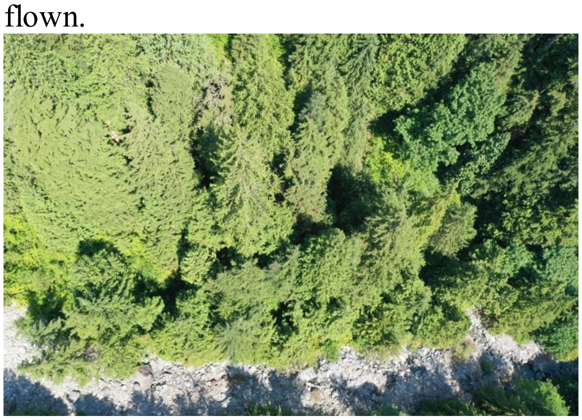

Figure 5: With rapidly climbing elevation in narrow valleys, a RPAS can get very close to the tree canopies, as seen here as the RPAS crosses Evans Creek (photo: Shupe, 2021)

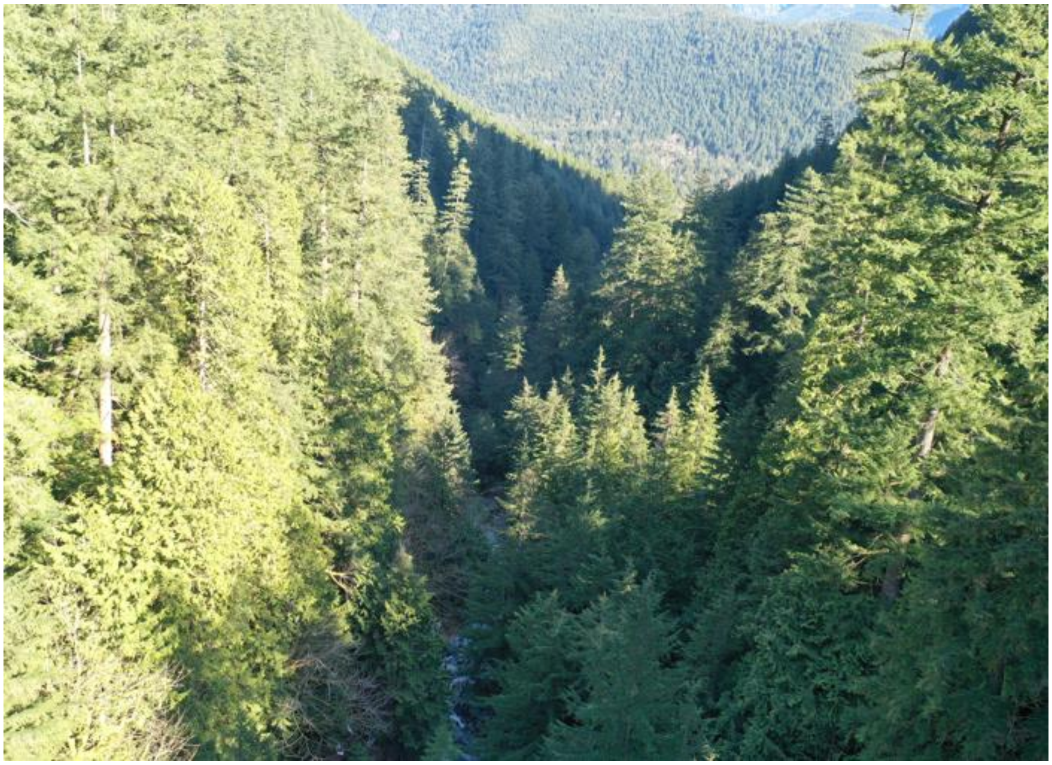

Figure 6: Portions of the valley narrowed making it a challenge to have a consistent flying height that captures detail (lower flying heights without impacting the canopy) (photo: Shupe, 2021)

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.

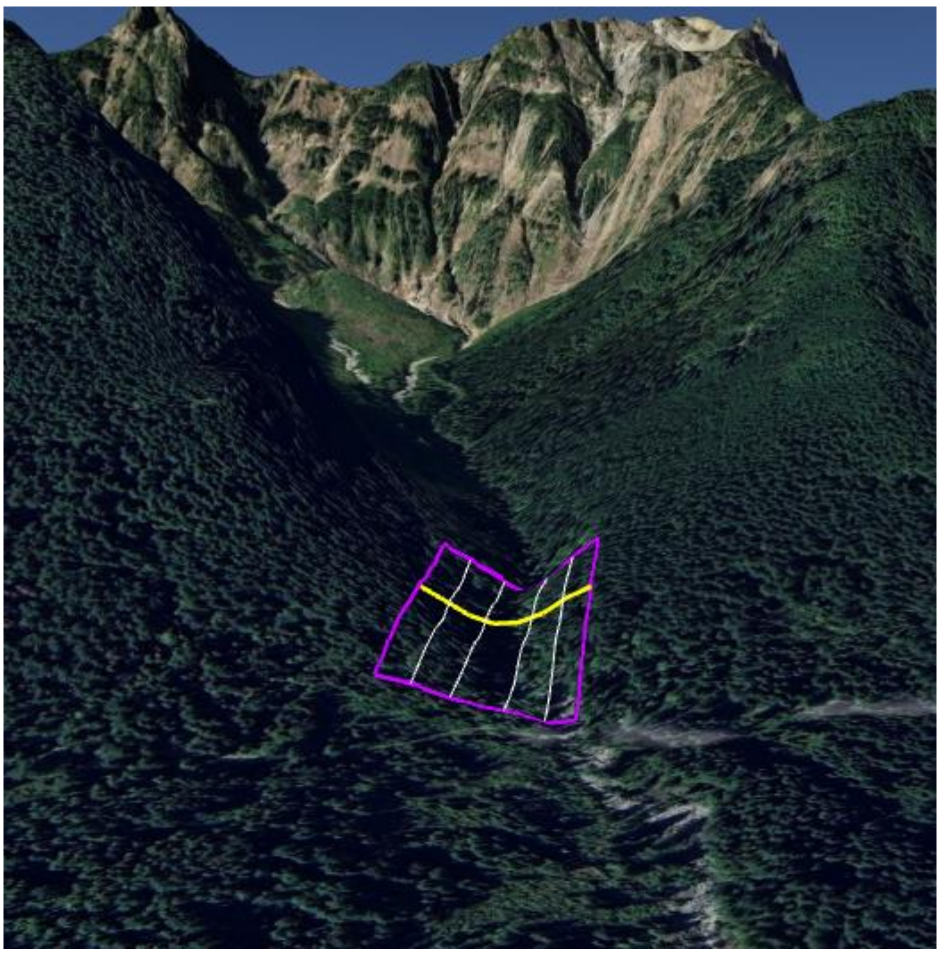

Figure 8: View Looking Upstream in Lower Evans Creek. The areas upstream of this location have less favorable conditions for RPAS launching sites and surrounding terrain compared to Lower Evans Creek. White and magenta lines here represent the approximate midpoint of the flight path.
The yellow line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

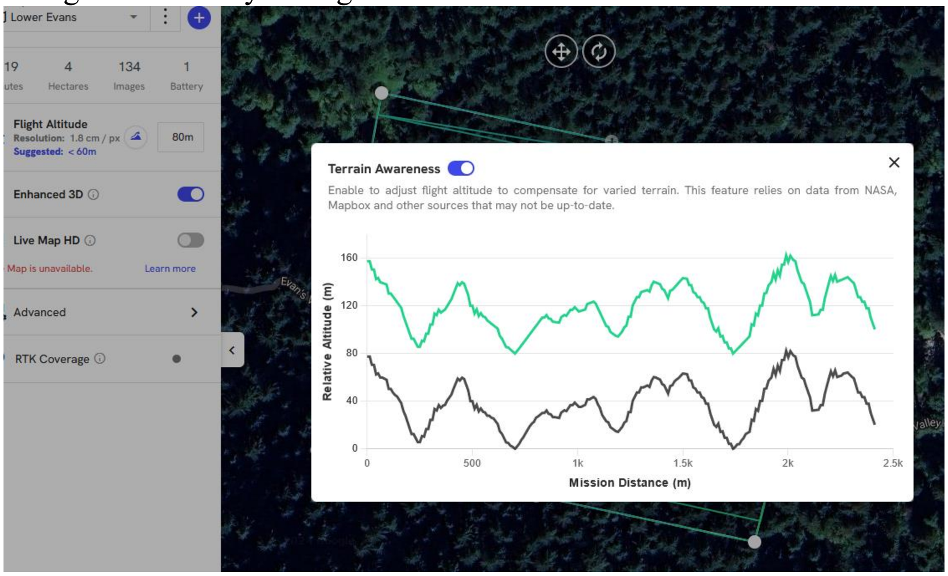

Figure 9: Terrain Awareness Settings. The black line represents the terrain height, automatically sourced from online elevation datasets by DroneDeploy. The green line indicates the terrain-adjusted flight paths.

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

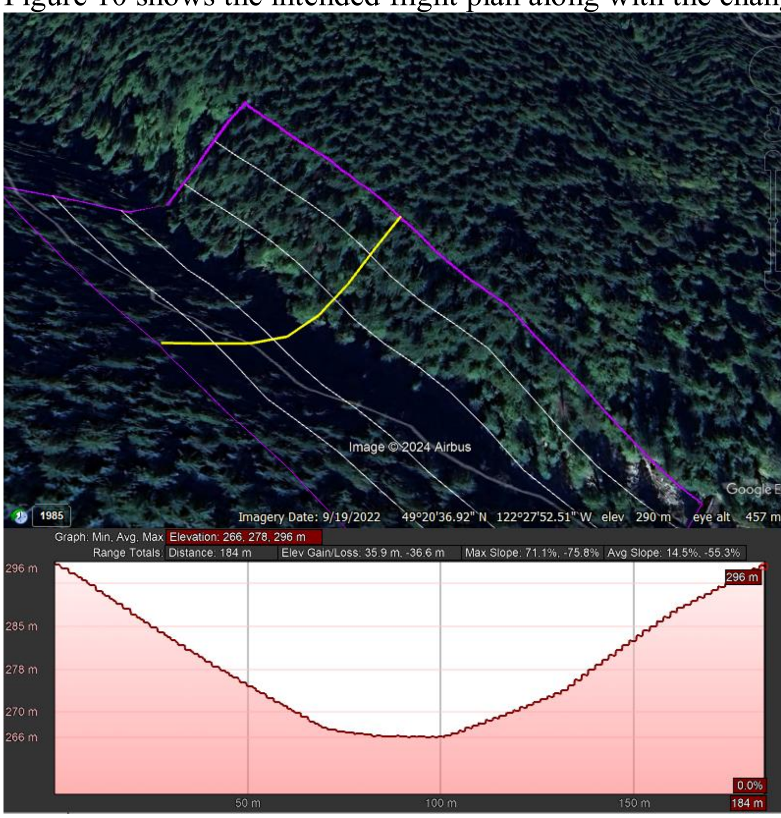

Figure 10: Cross-Section View of the Planned Lower Evans Creek Mission Area Using Google Earth (yellow line). Field observations suggest that the elevations shown on Google Earth for the study area are approximate and are likely not inclusive of tree heights. White and magenta lines show planned flight 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.

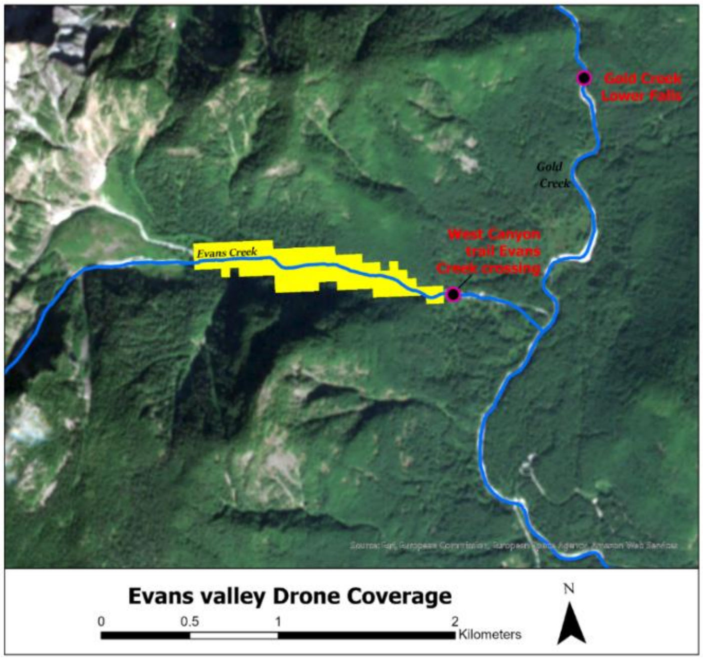

Figure 11: Mapped area in Evans Valley. Note that this map does not show the footprint of where the RPAS was flown. The RPAS footprint is smaller with coverage around the edges taken from oblique rather than nadir camera angles.

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.

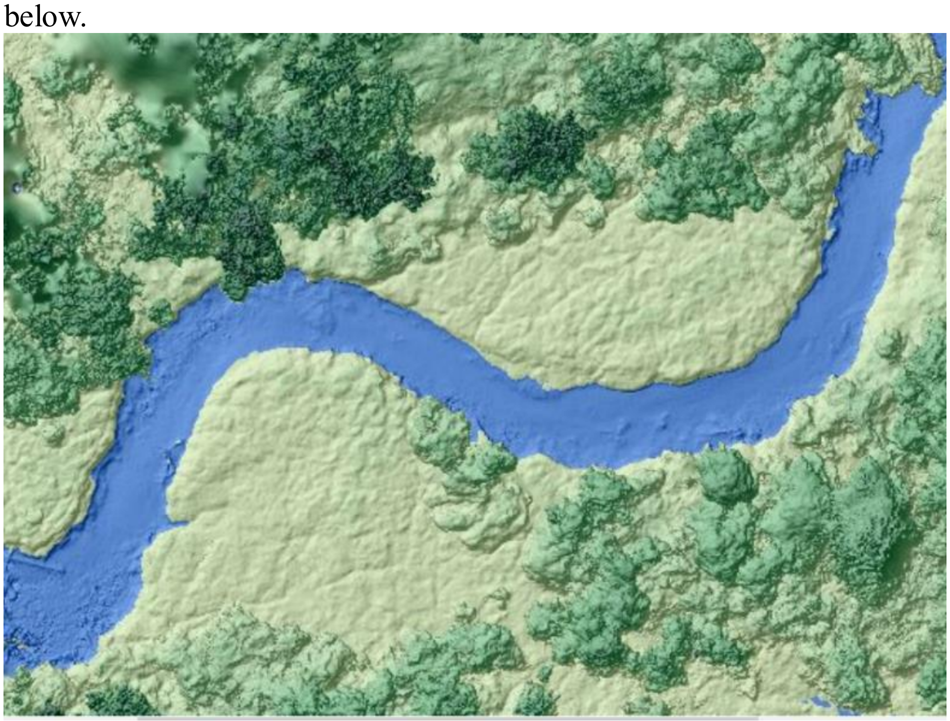

Figure 12: A portion of Kanaka Creek Watershed classified using a DSM.

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).

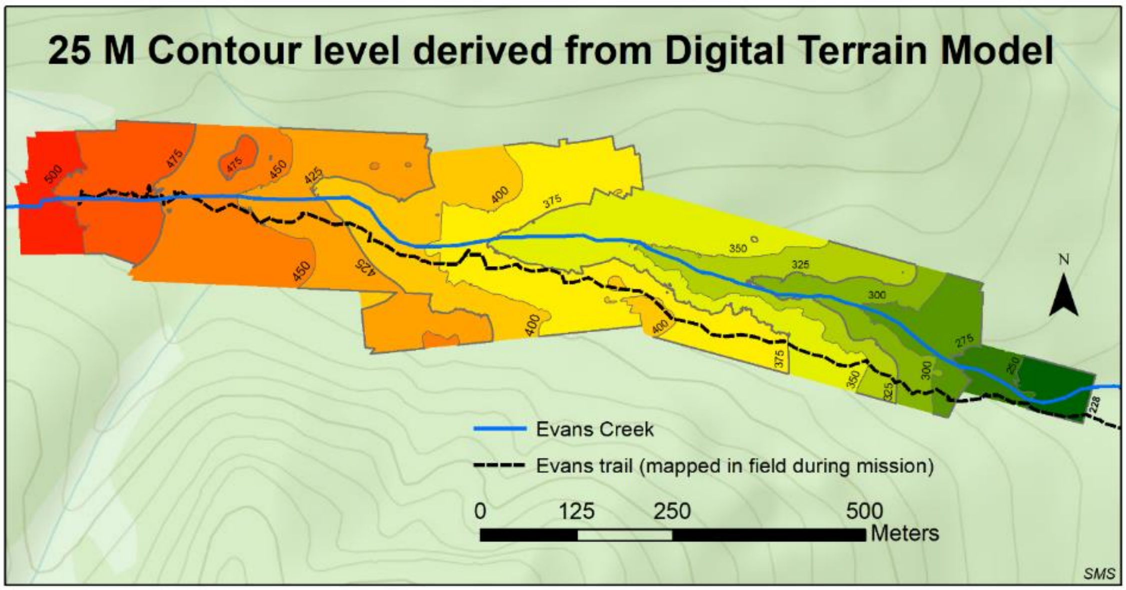

Figure 13: 25 m contour layer derived from DTM superimposed on a 40-m contour layer from an ESRI topographic basemap.

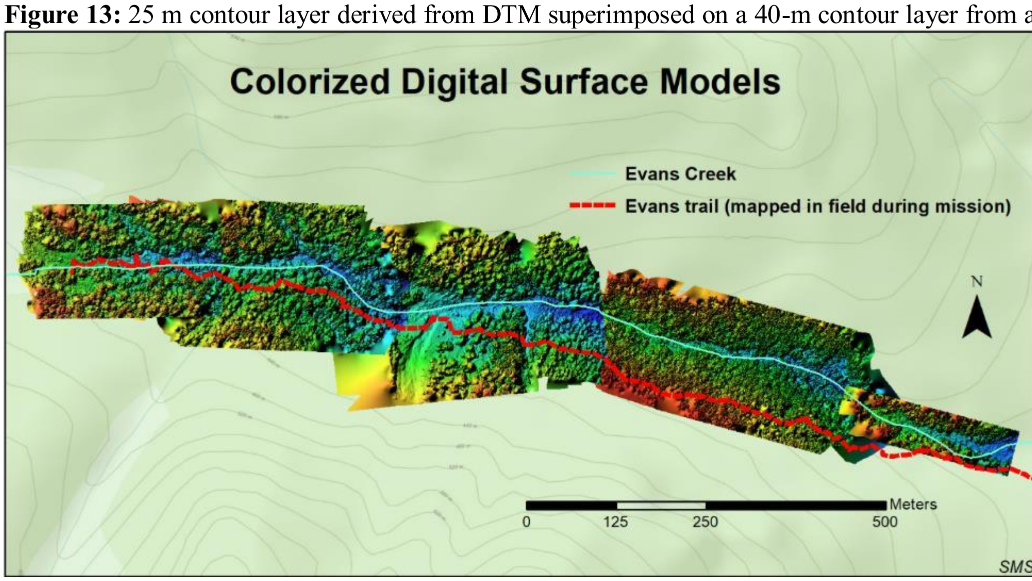

Figure 14: Overlapping Evans Valley digital surface model (DSM) layers. The source of the Evans Creek shapefile is the National Hydrographic Network (NHN). The Evans trail shapefile was generated in ArcGIS from point data recorded by a Garmin Forerunner watch (GPX formatted file) as I traversed the trail.

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.

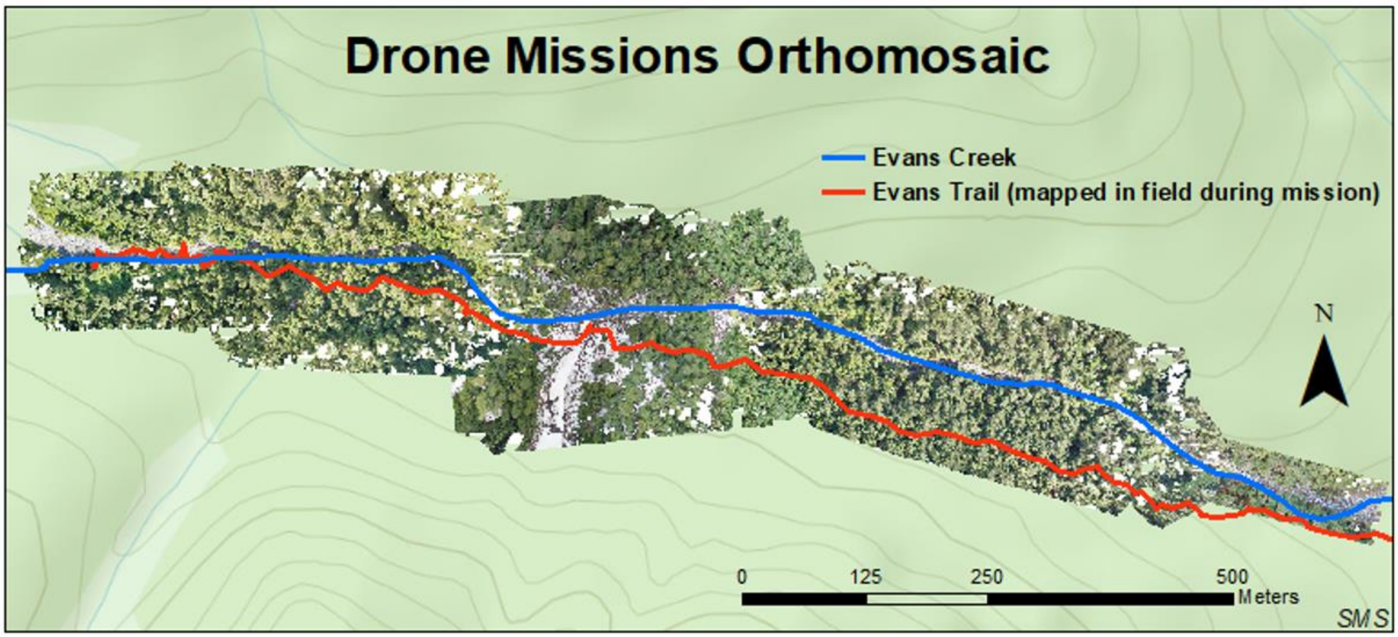

Figure 15: Orthomosaic of Evans Valley. The orthomosaic process fills in some of the gaps where there is overlapping coverage.

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.

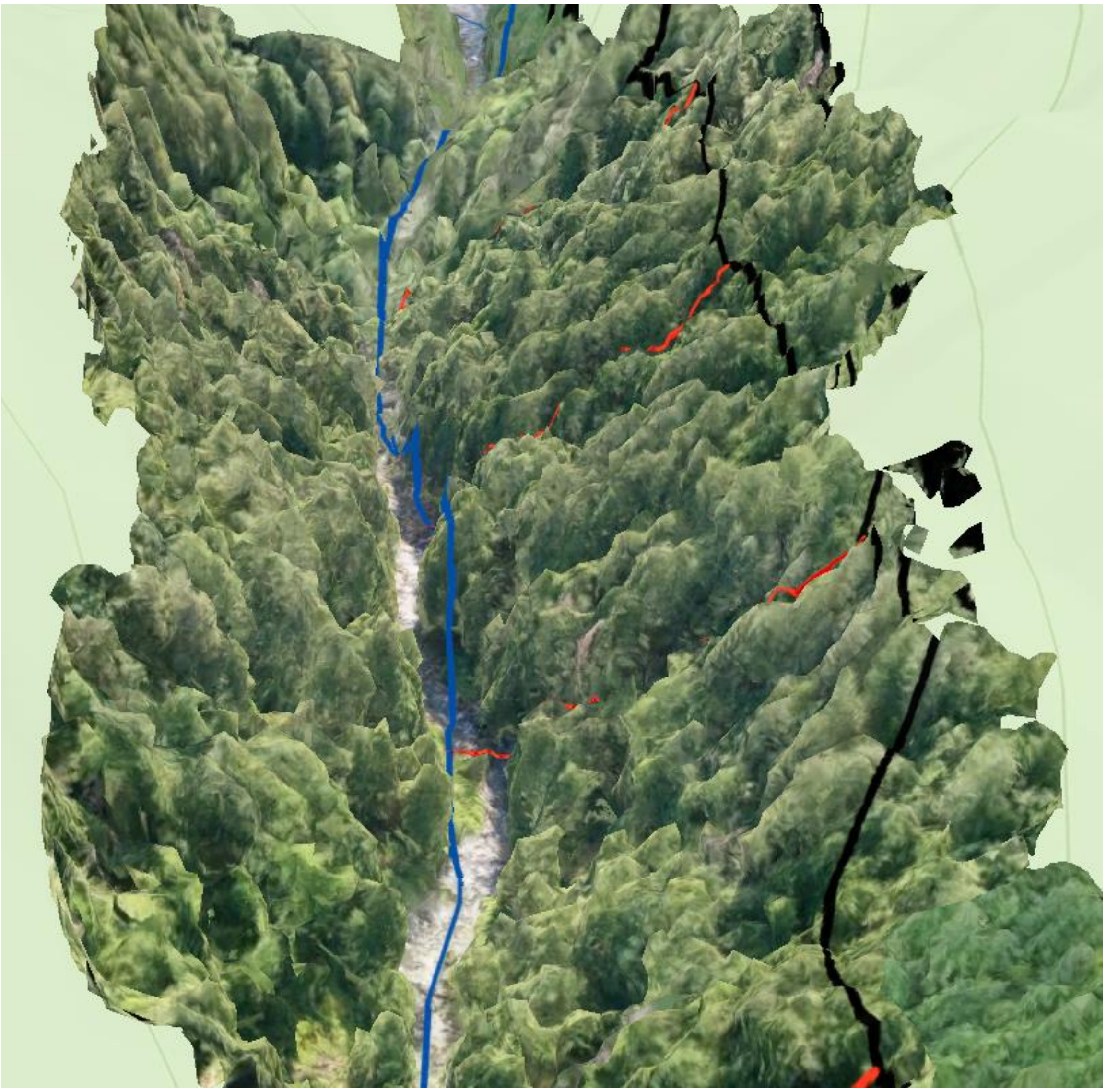

Figure 16: 3D visualization of a portion of Evans Valley. The blue line is the creek shapefile, the black line is the trail shapefile draped on top of the model, and the red lines are potential access routes from the trail to the creek.

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.

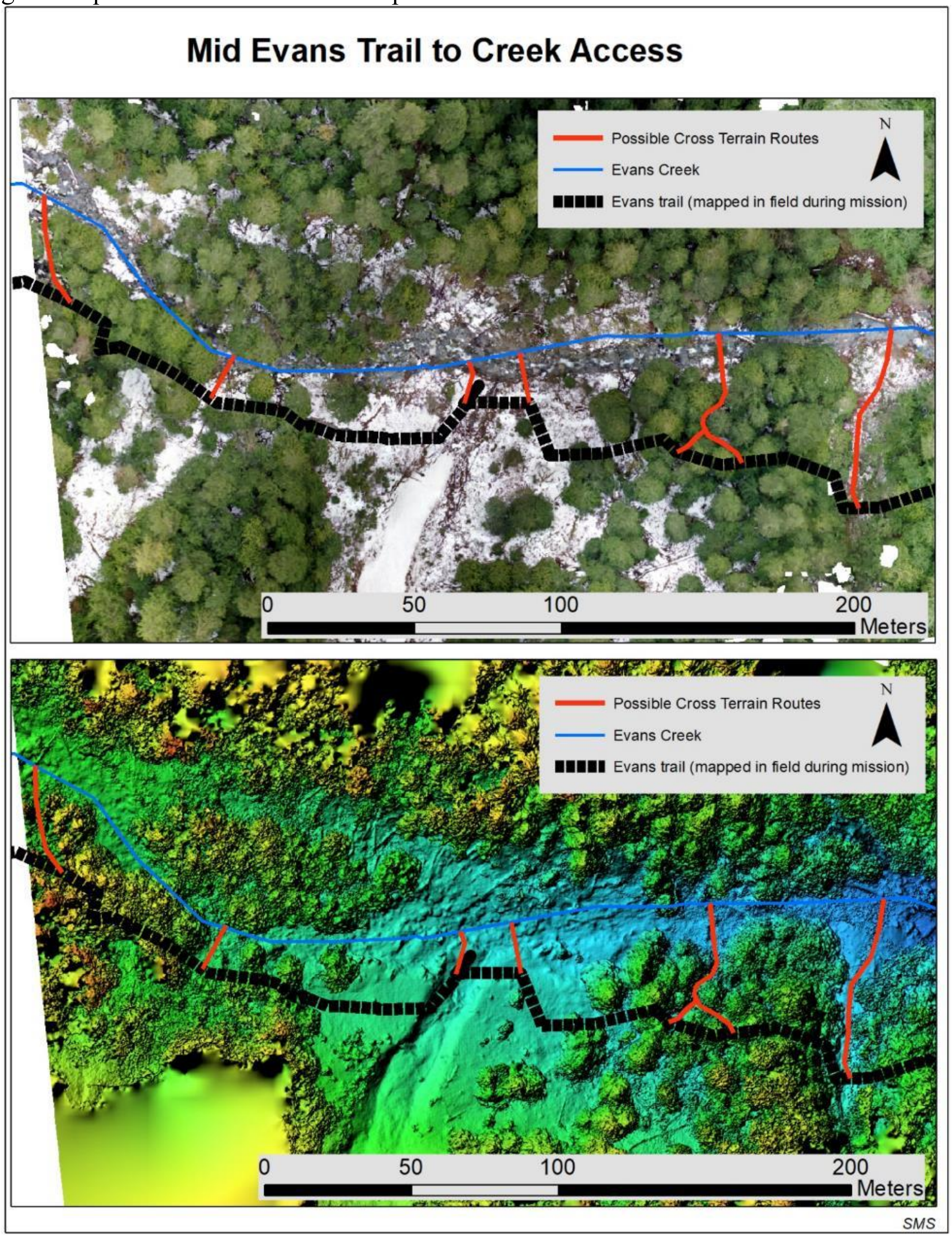

Figure 17: Potential cross terrain routes in mid-Evans Creek Watershed. Top image shows routes on model, bottom image shows routes on DSM.

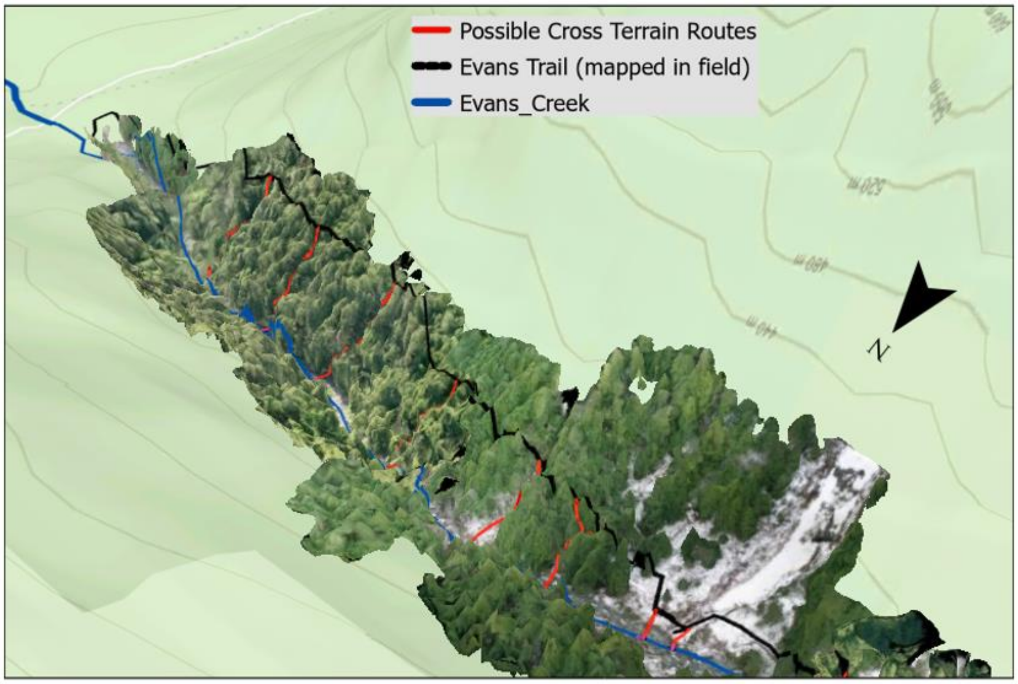

Figure 18: 3D visualization of potential cross terrain routes between Evans Trail and Evans Creek in the mid-portion of Evans Valley.

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.

Acknowledgements
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