polar geoscience ltd.
1005 Balsam Place
Squamish, BC, V8B 0W1
(604) 815-4548
www.pgeo.ca

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Mr. Pierre Aubin, RPF
Practices Forester
BC Timber Sales, Chinook Business Area
7077 Duncan Street
Powell River, BC, V8A 1W1

Dear Mr. Aubin:

Re: Response to Dr. Alila's Review of the Mt Elphinstone South Watershed Assessment

1.0 BACKGROUND

On August 25, 2023, Tom Johnson, Woodlands Manager of BC Timber Sales (BCTS) Chinook Business Area (TCH) received an email from Ian Moore, Barrister & Solicitor, serving as legal counsel for Elphinstone Logging Focus (ELF), an environmental group based in Roberts Creek, BC. Ian Moore notified Mr. Johnson that ELF had recently retained Dr. Younes Alila of the University of British Columbia Faculty of Forestry to review a multi-phased watershed assessment report, completed by Polar Geoscience Ltd. (Polar) (Polar, 2023a and 2023b). Alila's (2023) review was critical of the approach and methodology applied in Polar's assessment. As such, BCTS TCH subsequently requested that Polar review Alila (2023) and provide a response to the comments made. A revision to Alila (2023) was subsequently received by BCTS on September 19, 2023. The review herein was based on the initial Alila (2023) document, delivered August 25, 2023. However, Alila's (2023) revision was also reviewed upon receipt, and given no substantive changes, did not warrant any notable changes to our evaluation. This letter outlines our overall and detailed comments of Alila (2023). Figures referenced in our response are attached below.

2.0 OVERALL COMMENTS

We appreciate the time and effort Dr. Alila has spent to review our report, and welcome all comment and constructive criticism. We recognize the importance and strive for continual improvement in all aspects of our work[1]. It should be noted that in accordance with EGBC (2021), prior to Alila's (2023) review, Polar's assessment report was independently reviewed by subject matter expert Dr. William Floyd, PhD, RPF, Research Hydrologist for the Coast Area Research Section, BC Ministry of Forestry and Adjunct Professor, Vancouver Island University. In addition to his independent review, Dr. Floyd also provided technical advice during the course of the assessment.

Through the use hyperbole, Alila (2023) presents several criticisms of Polar's watershed assessment of eight watersheds in the Mt. Elphinstone area (the assessment watersheds). Many of these criticisms, however, are unfounded and flawed or focus on the hypothetical with no reference to actual conditions within the assessment watersheds. Moreover, some comments made by Alila (2023) suggest that he may not have fully reviewed the final draft of the assessment report which incorporated useful suggestions and comments received during the public consultation period. Instead, it appears Alila (2023) based much of the review on an earlier out-of-date draft that was released prior to the public consultation period. According to Principle 13 of the Engineers and Geoscientists British Columbia Code of Ethics (EGBC, 2022), in order to maintain professionalism and as a professional courtesy, reviewing professionals "should endeavor to contact the originating professional prior to reviewing their work". This would provide the opportunity for exchange of pertinent information and prevent review of out-of-date drafts. Unfortunately, Dr. Alila neglected this step.

One of the fundamental criticisms of Alila (2023) is that Polar's assessment failed to utilize a probabilistic framework. While we agree that this could be a useful approach for a portion of our assessment, to our knowledge, the only means by which such an approach could be used is to develop deterministic models for each of the assessment watersheds and apply the probability framework on the model outputs. Polar is actively utilizing and testing such model development (e.g., utilizing the Raven hydrologic modelling platform) in other applications. While they do show promise and have been demonstrated in a number of data-rich locations to be insightful, they have yet to become fully accessible, cost effective, and reliable tools in operational forestry planning and watershed management. As such, deterministic model development and application in support of watershed risk assessment is currently not standard practice in British Columbia (EGBC and ABCFP, 2020).

Further, given a lack of suitable streamflow data in the assessment streams, any model developed in the assessment area would be rife with uncertainty and be unreliable. As such, the source of error and uncertainty in model outputs would yield indefensible results under any assessment framework.

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[1] Continual improvement is fundamental to professional practice and is expressed in Polar's Professional Practice Management Plan, a document that is audited and endorsed by Engineers and Geoscientists British Columbia.

Moreover, installing hydrometric stations and monitoring streamflow at each of the eight assessment watersheds would require years (perhaps decades) of monitoring to develop a streamflow time series with a record length suitable for model development. Alila (2023) unfortunately offers no solutions regarding how this major limitation could be addressed or overcome.

As such, Polar's assessment approach, referred to as "old" or "antiquated" by Alila (2023), remains consistent with terms of reference established by BC Timber Sales and current guidelines for watershed assessment and management of hydrologic and geomorphic risk in the British Columbia (EGBC and ABCFP, 2020). While Polar's report does not explicitly utilize a probabilistic framework as identified by Alila (2023), it follows a risk-based approach[2] supported by extensive field review and considers the large body of research relevant to the assessment area, including the work of Alila et al. Furthermore, Polar's report is based on a thorough examination of the assessment area including field observation by the report's senior author who has 30 years of operational forest hydrology and fluvial geomorphology experience. Alila's claim that the report is "microscale" in scope as a result of not explicitly utilizing a probabilistic framework, is a mischaracterization of the assessment. Contrary to Alila's claims, and consistent with EGBC and ABCPF (2020), the watershed assessment findings and recommendations are based on more than a single metric (i.e., ECA). This includes, but is not limited to, a detailed understanding of the physiography, bedrock and surficial geology, soil conditions, forest cover (including growth rates), current and projected climate, hydrology, fluvial geomorphology, groundwater-surface water interactions, aquifer characteristics, fisheries, water users, land uses, and past disturbances (e.g., wildfire). Watershed assessments cover more than just an evaluation of runoff response, which Alila (2023) is focused on, but also includes consideration of the processes of sediment yield, riparian function and stream channel stability, all of which are done so at the watershed level utilizing a risk-based approach.

It should be stressed that Polar respects Alila et al. and their research and has considers it along with others in completing our watershed assessments in the Mt. Elphinstone area. We suggest that if Dr. Alila believes the watershed assessment (risk-based) framework currently used in British Columbia requires revision, that he constructively engages with Engineers and Geoscientists British Columbia

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[2] A risk-based approach to watershed management acknowledges that risk is integral to any land use activity, including forestry. It recognizes that watersheds are valuable resources that provide water for drinking and domestic use, for irrigation, and stream flow that supports aquatic habitats while moderating the effects of climate variability and change on the hydrologic cycle in a watershed. Furthermore, it understands that water is a sacred resource to Indigenous Peoples who rely on it for health and well-being, culture, customs and traditions, sustenance, and economic opportunities (FPB, 2022). It should be understood that many watersheds, including the assessment area, are subject to integrated resource management under provincial law, which permits multiple land uses, including forestry. These activities have the potential to influence hydrologic and geomorphic processes that can affect water quality, water quantity, and/or timing of flow, which may pose a range of risks to downstream elements and values. Such risk is managed by BC Timber Sales through appropriate assessment, monitoring, treating, and transferring of risk, while also consciously retaining residual risk at an appropriate level. It should be stressed that while zero residual risk is an ideal goal, it is rarely achievable and unrealistic in most watersheds. With this understanding, BC Timber Sales is committed to reduce risks wherever practically possible, and this includes implementing control measures identified following watershed assessment.

and Forest Professionals BC[3] to assist in any refinement to their guidelines and more importantly offer practical, defensible and cost-effective solutions to implementing the concepts he promotes.

3.0 DETAILED COMMENTS

3.1 Deterministic (microscale) vs. Probabilistic (macroscale) Approaches

One criticism of Polar (2023a) is its utilization of the current watershed assessment framework in BC as a whole. Alila (2023) maintains that the current framework focusses on the hydrology at the microscale, which is stated as being a deterministic approach. Alila (2023) claims that as a result, Polar (2023a; 2023b) fails to account for hydrology at the macroscale. This argument is used to claim that the assessment does not effectively address cumulative effects, nor does it capture the true risk of forest harvesting. It should be recognized that Polar was retained by BCTS and subject to terms of reference consistent with the *Joint Professional Practices Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector* (EGBC and ABCFP, 2020).

Despite Alila's (2023) criticism of the current watershed assessment framework, Polar (2023a) was completed in accordance with the current standards of professional practice as outlined in the *Joint Professional Practices Guidelines,* which make no reference to using a probabilistic approach. Moreover, given the nature of the urban-interface assessment watersheds, the analysis and evaluation of hydrogeomorphic hazard was conducted at a higher level of detail than is normally practiced in the province. Recommendations provided in Polar (2023a) on opening size, retention levels and overall extent of harvesting were provided with the specific objective of minimizing risk within each of the assessment watersheds and conserving watershed values. These recommendations incorporated a degree of conservatism beyond what previous assessments have identified in the assessment area.

We recognize the sensitivity of forest harvesting suggested by the probabilistic approach, and have described this in the literature review. However, to conduct an assessment using the probabilistic approach would require hydrologic models be developed for each of the eight watersheds in the assessment area. None of these catchments have recorded streamflow data that would satisfy the development of a model. Furthermore, the streamflow data recorded at the neighboring Roberts Creek is not representative of the much smaller assessment streams[4]. Moreover, installing hydrometric stations and monitoring streamflow at each of the eight assessment watersheds would require several years of monitoring to acquire time series with a record length suitable for model development. Alila (2023) offers no solutions regarding how this major limitation could be addressed or overcome.

3.2 Influences on Peak Flow Variability

Alila (2023) claims that the flood frequency curve (FFC) of Roberts Creek is mild in slope, which is characteristic of rain-on-snow environments. Using the peak flow time series from Roberts Creek Water Survey of Canada (WSC) station 08GA047 as an example, they further claim that the

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[3] Previously the Association of British Columbia Forest Professionals

[4] Several of the assessment streams also interact with an alluvial aquifer, which is not prevalent in Roberts Creek.

shallowness of the slope at Roberts Creek is further amplified by the process of meltwater drip, which increases baseflow. According to Blöschl & Sivapalan (1997), an increase in baseflow decreases the coefficient of variation (CV) of the peak flow frequency distribution. However, according to Blöschl & Sivapalan (1997), the effect of baseflow on the CV of the peak flow frequency distribution is most notable on larger watersheds (> 1,000 km^2), and appears minimal for smaller watersheds (1 km^2 to 10 km^2)[5]. Moreover, the research conducted by Blöschl & Sivapalan (1997) is based on watersheds in Austria. We recognize that the general findings on the effect of baseflow on the CV of the peak flow frequency distribution are noteworthy, and agree that baseflow can play a role in reducing the CV in the assessment area. However, it is unclear to what extent baseflow would serve to reduce CV in the (1 km^2 to 11 km^2) assessment watersheds.

To replicate the normalized FFC presented in Alila (2023), annual maximum mean daily peak flows from Roberts Creek at Roberts Creek (WSC hydrometric station 08GA047) were scaled to the mean annual flood (Q_2) and fit to a generalized extreme value (GEV) distribution[6] (FIGURE 1). The hypothetical scenario assumed by Alila (2023), where peak flow magnitudes are increased by 15%, are also presented in FIGURE 1. Using the 71-year peak flow time series from Roberts Creek, the FFC developed herein appears to deviate from what is presented in Alila (2023). Although the FFC's are similar, one notable difference is that the FFC calculated herein is steeper than the FFC presented in Alila (2023). The difference in slope has implications on the projected changes in frequency associated with the hypothetical 15% increase in peak flow magnitude, whereby smaller changes in frequency are expected with a steeper slope. Alila (2023) did not provide any details on the methodology used to fit the normalized streamflow data to a GEV distribution. As such, the reason for the discrepancy between the FFC calculated herein and Alila's (2023) FFC is unknown.

Alila (2023) claims that the blue line in their Figure 3 (similar to the blue line shown in FIGURE 1) represents "pre-logging" conditions. However, this is incorrect given that Roberts Creek watershed has been subject to land use disturbances for over a century including wildfire and logging. They provide no explanation as to how the FFC under "pre-logging" conditions may have been altered by historic land-use changes to date, and how that might influence any potential changes associated with future forest development. Making inferences on how the FFC has changed in the past and is expected to change following future forest development would require a more thorough analysis, whereby the drivers of change are isolated from other confounding factors such as climate and other land use disturbances (e.g., wildfire, insect infestation, and residential and commercial development). Further, the <u>assumed</u> 15% increase in peak flow magnitude that is presented in Figure 3 of Alila (2023) should be carefully considered, as it could easily mislead readers to believe such an increase is fact when it is not.

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[5] The drainage area for Roberts Creek at the mouth (near WSC Station 08GA047) is 26.6 km^2. The drainage areas of the eight assessment streams varies from 0.95 km^2 to 10.7 km^2.

[6] Peak flow data were fit to a GEV distribution using the "extRemes" package developed by Gilleland and Katz (2016) in the R programming language (R Core Team, 2023).

Nonetheless, we agree that the nature of the FFC for the assessment watersheds tend to be relatively mild in slope and consistent with the Beckers (2002) coastal watershed curve. However, the influence of past disturbances on the FFCs for both Roberts Creek and Beckers (2002) are unknown. In other words, it remains unclear how the FFC would have appeared under baseline conditions (i.e., truly pre-logging). Regardless, we fully recognize that small increases in magnitude can translate to large increases in frequency, and increases in frequency are expected to be greater for larger peak flow events. Given the discrepancy between the FFC's calculated herein and those in Alila (2023), increases in frequency are expected to be somewhat less than what is proposed in Alila (2023) under the assumed conditions.

3.3 Significance of Meltwater Drip

Alila (2023) maintains that meltwater drip is a critical component of the hydrologic regime in the assessment area, and that it provides sustained groundwater recharge from October through mid-spring. He further criticizes Polar (2023a), stating that the watershed assessment "overlooked this vital feature". In both cases, Alila (2023) is incorrect.

We suspect that Alila (2023), at least in part, based his criticism on an earlier, out-of-date draft. Section 3.1 of Polar (2023a) provides a background discussion on the process of meltwater-drip within coastal watersheds, and demonstrates that authors are aware of the process and its potential to contribute to groundwater under certain circumstances, as demonstrated in several studies cited. However, Alila's (2023) contention that meltwater drip is "crucial for the renewal and recharge of groundwater" in the assessment area is false and his argument to support this statement is flawed.

Alila (2023) attempts to use the Chapman Creek Community Watershed, which is located 20 km north-northwest of the assessment area, as an analogue for the assessment area. However, there are two problems with his argument, as follows, that demonstrate a poor understanding of the assessment area and the hydroclimatic gradients on the Sunshine Coast:

1. Meltwater drip is not a crucial process in the Chapman Creek watershed as Alila (2023) claims, and
2. Chapman Creek is not representative (i.e., it is poor analogue) of the assessment area.

Both points are discussed below.

3.3.1 Meltwater Drip in Chapman Creek

Chapman Creek serves as a community water supply for the Sunshine Coast Regional District (SCRD), and supplies over 90% of the regional water service area[7]. Chapman Lake (elevation 980 m) and Edwards Lake (elevation 1,073 m) are the largest headwater lakes in the Chapman and Gray Creek

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[7] https://www.scrd.ca/wp-content/uploads/2022/12/2016-SCRD-Water-Quality-Report.pdf

drainages; both are regulated and have control gates to allow water storage for controlled release during low streamflow periods. Edwards Lake naturally drains to Gray Creek, but an excavated channel and control gate allow discharge into the Chapman Creek watershed (Horel, 2014).

Alila (2023) asserts that Chapman Lake levels are maintained by groundwater recharge through meltwater drip during the winter months, and claims the dates of water restrictions in 2022 (e.g., Stages 1-4)[8] set by the Sunshine Coast Regional District (SCRD), and particularly the lifting of restrictions in 2023, provides evidence of the importance of meltwater drip. To support his argument, Alila (2023) uses the Chapman Lake provincial snow survey station 4B04 (which he incorrectly describes as an automatic snow pillow station) to illustrate the amount of snow in the watershed. He states that 138 cm of snow was measured during the snow survey in February 2023, and uses this to suggest that precipitation at mid to high elevations from the months of October to February could have only fallen as snow. The Chapman Lake 4B04 manual snow survey location, however, is roughly 650 km north of the assessment area (i.e., near Smithers) and thus is not representative of conditions in the Chapman Creek watershed[9]. We suspect that Alila (2023) confused the Chapman Lake snow survey station with the Chapman Creek snow survey station 3A26 (elevation 1,022 m), which is located in the Chapman Creek watershed.

One reason that Chapman Creek was developed as a community water supply is the deep snowpack typically found in this mountainous watershed, with elevations that rise to over 1,600 m. This is demonstrated by recorded snow data collected at the Tetrahedron automatic snow weather station 3A28P located north of Chapman Lake at an elevation of 1,420 m. This station commonly records maximum snow depths of 5 m +/-, which are some of the deepest recorded on the BC south coast (Floyd, pers. comm., 2023). As a result, snow in the contributing area to Chapman Lake often persists into July.

Meltwater drip does not play a significant role in the maintenance of water levels in Chapman Lake. In almost every year, other than the exceptionally dry fall of 2022, Chapman Lake is filled by rain by late November, and stays full due to snowmelt. Meltwater drip that occurs would be stored in a deep snowpack, and when meltwater is dripping, it most often occurs when the reservoir is full. Further, the dates that SCRD implemented and lifted water restrictions has nothing to do with meltwater drip or lack thereof. These restrictions resulted from an unprecedented dry period in summer and fall 2022, which may have been even worse had the snowpack the previous winter (i.e., 2021-2022) not persisted a month later than usual. The water restrictions set by the SCRD were entirely due to the extended lack of rain well into November, and when precipitation arrived, it was in the form of snow at elevations above Chapman Lake. As a result, the reservoir remained very low until snow began to

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[8] https://www.scrd.ca/water-regulations/

[9] Although no snow surveys were conducted at the Chapman Creek snow survey 3A26 in February 2023, a survey conducted on March 7, 2023 measured a depth of 342 cm of snow. This contrasts the incorrect value of 138 cm reported by Alila (2023).

melt. Such conditions were not unique to Chapman Creek, but were observed in several watersheds on the south coast (Floyd, pers. comm., 2023).

3.3.2 Use of Chapman Creek as an Analogue for the Assessment Area

Notwithstanding the insignificance of meltwater drip above Chapman Lake, Alila's (2023) argument regarding meltwater drip from October to mid-spring is predicated on the belief that a significant snowpack is present in the assessment area for a majority of this period. This belief is false and further demonstrates a poor understanding of the assessment area.

Assuming that the Chapman Creek snow survey station 3A26 was intended to be used to demonstrate the snowpack in the area (not Chapman Lake station 4B04), Alila (2023) erroneously assumes that snow conditions at Chapman Creek are representative of (or analogous to) those of the assessment area. As noted above, Chapman Creek and specifically the location of the snow survey station represents a high relief inland mountainous location, which has some of the deepest snowpacks on the south coast of BC. The assessment area, by contrast, is located in a mild and maritime climate (adjacent to the ocean) with considerably less relief. As such, the assessment area, even at the highest elevations, receives much less snow than the headwaters of Chapman Creek.

To demonstrate this, we obtained information from the Snow Data Assimilation System (SNODAS) snow depth data product produced by the U.S. National Operational Hydrologic Remote Sensing Center (NOHRSC). The SNODAS dataset provides hourly modelled estimates of snow cover variables, assimilated from nearby empirical meteorological observations. We fully recognize there are several limitations or uncertainties associated with the use of this product, including its relatively course resolution (estimates are downscaled to 1 km^2 grid cells). However, the snow depth estimates are considered sufficient for demonstrating differences in snow depth between the assessment area and the Chapman Creek snow survey station. Furthermore, the data highlights the highly transient nature of the snowpack in the assessment area.

SNODAS-derived snow depth estimates from October to June for the years 2021 to 2023 are presented in FIGURE 3. The SNODAS data illustrates the significant differences in snowpack between the location of the Chapman Creek snow survey station and the assessment area. Relative to the highest elevations in the assessment area, SNODAS-estimated snow depths were roughly two to three times deeper at the location of the Chapman Creek snow survey station (FIGURE 3). Over the 2021-2022 winter period, the assessment area remained snow-free until January 1, at which point nearly 200 cm of snow is estimated at the Chapman Creek snow survey. By February 1, 2022, snow had disappeared in all but the uppermost portions of the assessment area, while the snowpack at Chapman Creek continued to develop. From March, 2022 through to the beginning of June, 2022, the assessment area remains snow-free[10], while the Chapman Creek snow survey remains covered by a deep snowpack. Over the 2022-2023 winter period, the assessment area is snow-covered beginning December 1, is largely snow-free by January 1, and snow covered from February 1 to at least March 1. By April 2023, the assessment area is nearly snow-free and is effectively snow-free by May 1, 2023. At the location of the Chapman Creek snow survey, a continuous snowpack is present from November 1, 2022 to at least June 1, 2023. This clearly shows that the Chapman Creek snow survey station is not remotely representative of snowpack conditions in the assessment area.

The transient nature of the snowpack was discussed in Polar's (2023a) report, stating that middle and upper elevations experienced transient snowpacks and snow on the ground occurred occasionally down to sea level, although lower elevations are predominantly snow-free throughout the winter. Daily SNODAS snow depth estimates serve to validate the transient nature of the snowpack in the assessment area (FIGURE 3). To illustrate the transient nature of the snowpack over shorter time scales, SNODAS-estimated snow depths for select days throughout February 2023[11] are presented in FIGURE 4, and can be accessed here[12].

The SNODAS data shows the assessment area covered in trace amounts of snow (i.e., < 5 cm) on February 1, 2023 (FIGURE 4). By February 5, 2023, the majority of the assessment area is snow-free, although more snow is present on the ground at high elevations. Snow-covered area continues to decrease until February 17, 2023, at which point the lower portion of the assessment is covered by trace amounts of snow. Nearly all of the low elevation snow disappears by February 21, 2023, and is completely gone by February 25, 2023. The data indicates that the assessment area received another snowfall down to sea level (i.e., the entire watershed is snow-covered) on February 26, 2023, which disappears by mid-March, 2023.

Alila (2023, p. 9) states that meltwater drip is "…crucial for the renewal and recharge of groundwater during ROS months from October to mid-spring in mid to high-elevation coastal environments." However, this statement further shown to be incorrect for the assessment area as demonstrated by the SNODAS snow depth estimates. From 2002 to 2023 (the entire SNODAS record length), no snow is present at any elevation within the assessment area by November 1. Moreover, snow has been estimated to cover a portion of the assessment area on December 1 for only nine of the years from 2002 to 2023.

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[10] It is possible that the assessment area received snowfalls between the first of each month, which has melted by the following month. This would give the appearance of a continual snow-free period.

[11] This month was selected as it is the month discussed in Alila (2023).

[12] Readers are encouraged to follow this website link and view other years and months of snow cover data in the assessment area using the Interactive Snow Information tool on the NOAA website.

We maintain that the significance of meltwater drip in renewing groundwater in the assessment area is minimal. This notion is further supported by modelled and empirical temperature and precipitation data, as described below.

Climate normals, mean daily temperature, and mean daily precipitation for the assessment area are presented in Polar (2023a). Climate normals for 1991-2020, estimated using ClimateBC (version 7.30) indicate that the median elevation of the assessment area (approximately 550 m) receives 1,943 mm of precipitation on average, only 6% (124 mm) of which falls in the form of snow. At upper elevations (1,000 m), the area is estimated to receive 2,442 mm of precipitation, 13% (325 mm) of which falls in the form of snow. This indicates that a vast majority of the precipitation in the assessment area occurs as rainfall.

According to the TS Elphinstone (FLNORD-WMB 1002, El. 593 m) meteorological station, mean daily temperatures at 593 m elevation are above freezing for all months of the year, while daily minimum temperatures are below freezing from early November to early April, on average [Polar, (2023), Section 4.6]. Year-round above-freezing mean daily temperatures support the notion that mid-elevations experience a transient snowpack.

To better illustrate the variability in temperature throughout the year, minimum daily temperature from 2009-2022 are presented in FIGURE 5. This data indicates that temperature fluctuates significantly throughout the winter months, with above-freezing minimum daily temperatures occurring multiple times throughout even the coldest months. Precipitation data from the same meteorological station indicates that temperature is typically warmer during precipitation events, suggesting a majority of precipitation is in the form of rain. Below-freezing precipitation does occur occasionally, likely in the form of snowfall.

While we acknowledge that meltwater drip can occur occasionally, particularly at higher elevations over the winter months, its occurrence is only intermittent during periods when snow is present. The SNODAS-derived snow depth estimates and empirical meteorological data suggest that the relative contributions to groundwater recharge from meltwater drip are minor compared to recharge sourced from direct rainfall. Furthermore, even if meltwater drip were assumed significant, the majority the assessment watersheds will always remain forested and the process will continue.

3.4 Regenerating Forest and Drought

With respect to the effects of regenerating forests on late-summer low flows, Alila (2023) discusses the results from Perry and Jones (2017). They state that the implications from Perry and Jones (2017) must be considered regarding the potential reduction in late-summer streamflows associated with regenerating forest stands following harvesting. Polar (2023a) considered and implemented the results of Perry and Jones (2017), as well as more recent research by some of the same authors presented in Segura (2020). Results from both Perry and Jones (2017) and Segura (2020), among other literature, were used to develop the risk management options presented in Polar (2023a), including implementing alternative silviculture systems, such as small openings and thinning, to mitigate potential reductions in late-summer flows following forest development activities. BCTS's forest development plans within the assessment area were in accordance with the risk management options presented in Polar (2023a; 2023b). As such, it is unclear whether Alila (2023) is seeking additional mitigative measures or simply reiterating what was described and implemented in Polar (2023a; 2023b).

3.5 Forest Roads

Alila (2023) reiterates many of the same influences that forest roads can have on watershed hydrology that were discussed in Polar (2023a). Alila (2023) criticizes Polar (2023a), stating that the HJ Andrews watershed study of Jones (2000), highlighted in the Polar (2023a) report, fails to isolate the effect of roads on peak flows. Alila (2023) states that the study of Rong (2017), which evaluated several study watersheds including HJ Andrews, isolated the effect of roads on peak flows using a probabilistic framework.

The results from Jones (2000) were discussed in Polar's (2023a) literature review; however, it was stated in Polar (2023a) that Jones (2000) used an analytical method unsuitable for the evaluation of peak flows, citing Alila et al. (2009) which called for abandoning this approach. Findings from Rong (2017) were also described in the Polar (2023) literature review, and in greater detail than Jones (2000), despite it being a Master's thesis and not having undergone the peer review process required for scientific literature.

The results from Jones (2000) were not used to make any inferences on the potential effect of forest roads and peak flows and was only cited twice in the literature review; once to summarize their findings and once to state that there have been calls to abandon this approach due to the analysis framework used. It is therefore unclear why Alila (2023) states that Jones (2000) was highlighted in Polar (2023a).

Although Rong (2017) evaluated the effect of forest harvesting and roads on peak flows at the Fox Creek study watersheds, Rong (2017) did not isolate the effect of roads as claimed by Alila (2023). Rong (2017) evaluated the effect of 25% harvest and roads at the two Fox Creek treatment watersheds, but did not attempt to isolate the effect of roads from the harvesting treatment. Instead, Rong (2017) made inferences as to how roads might have affected the peak flow frequency distribution.

The sensitivity to harvesting and roads in the two Fox Creek treatment watersheds is attributed to their low peak flow CV. Despite the gently sloping watershed physiography, which was expected to result in higher peak flow CV due to runoff synchronization, Rong (2017) posited that the watershed characteristics (e.g., elongated watershed shape), wet climate, and the occurrence of fog interception were responsible for the unexpectedly low CV. The CV in the Fox Creek control watershed[13] was reported as 0.38 (Rong, 2017). The CV for peak flows at Roberts Creek from 1960 to 2021 is 0.62. The drainage area of the Roberts Creek watershed ranges from 2.5 to 28 times larger than the drainage areas of the assessment watersheds. As such, it is expected that the CV of peak flows in the assessment area would be greater than 0.62 (Blöschl & Sivapalan, 1997). Using the rational presented in Rong, (2017), this suggests that the assessment streams would be less sensitive to increases in peak flows as a result of roads, relative to the Fox Creek treatment watersheds. Moreover, the Fox Creek experimental watersheds are located roughly 140 km east of the Oregon coast with a minimum watershed elevation roughly 800 m higher than the minimum elevation of the assessment watersheds. The Fox Creek watersheds range in elevation from 840 m to 950 m (Rong, 2017). Therefore, the hydrology and climate of the Fox Creek watersheds is not considered representative of the assessment area.

Polar (2023a) acknowledges that a road network can increase runoff generation potential by increasing the rate at which runoff water is delivered to streams. However, the potential for roads to induce runoff synchronization/desynchronization is also dependent on the nature of the roads, the road network, watershed characteristics, and climate. A comprehensive field-based review of roads in the assessment area was conducted as part of Polar (2023a; 2023b). Road surfaces were observed to be in good condition, and current road alignments are commonly on low gradient terrain with relatively shallow road cuts. As stated in Polar (2023a), Hudson and Anderson (2006), which is in part based on the work of Anderson et al. (2009)[14], found shallow groundwater and surface flow rates to be similar in a nearby BC coastal watershed, due to relatively rapid preferential flow[15] and high drainage densities. As such, road-related effects (e.g., interception of shallow groundwater flow and conveyance as ditch flow) on drainage patterns and rates are expected to be small.

In relation to the road alignments associated with planned block G043B4P8, Alila (2023) raises the concern of cutbanks intercepting groundwater, which could inhibit groundwater recharge. However, as per the recommendations put forth in Polar (2023b), out sloping the road in the northeast portion of planned block G043B4P8 should serve to mitigate the potential for groundwater recharge to be markedly affected by intercepted shallow groundwater along cut banks.

3.6 Hydroclimate Regimes: Rain-on-snow in comparison to Rain

Alila (2023) presents observed peak flow data from the Roberts Creek at Roberts Creek WSC station 08GA047 (1960-2022) and from Chapman Creek. There are three WSC hydrometric stations along Chapman Creek. It is not stated which of these three hydrometric station was used in their analysis.

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[13] CVs for the two Fox Creek treatment watersheds were not reported in Rong (2017).

[14] Dr. Alila was a co-author of this paper.

[15] Preferential flow refers to rapid shallow groundwater flow through preferential flow pathways. These pathways typically occur above low permeability soils/surficial materials (i.e., basal till), and through macropores (e.g., from decaying roots, cracks in the soil, and worm/insect holes).

However, based on the 18 years of peak flow data used to plot the FFC, it is assumed that the Chapman Creek above Sechelt Diversion WSC station 08GA060 was used, which has an 18 year record from 1970-1988. Probability density functions (PDFs) are also provided for Roberts Creek and Chapman Creek in Alila (2023).

Alila (2023) states that step changes observed in the Roberts Creek FFC and three populations observed within its PDF can be attributed to different runoff generation mechanisms. He claims that the two upper populations observed at Roberts Creek can be attributed to rain-on-snow processes. They do not, however, offer any empirical evidence or literature to support this argument, meaning that this conclusion is purely speculative and can not be considered attribution. The second largest peak flow of record at the Roberts Creek WSC station, which is claimed to fall within the population of rain-on-snow events, occurred on October 2, 1964. Meteorological data recorded at the Gibsons (Environment Canada, 1043150, El. 62 m) meteorological station from September 1 to October 10, 1964 are presented in FIGURE 6. Since the station is located near sea level, maximum and minimum daily temperature representative of the upper portion of the assessment area were estimated assuming a adiabatic lapse rate of 7 °C/1,000 m (Fitzharris, 1975; Bunnell et al., 1985), which is considered conservative, particularly during large fall storms (Floyd, pers. comm., 2023). The empirical data indicates that temperatures leading up to the October 2, 1964 peak flow event were predominantly above 0 °C across all elevations of the assessment area (FIGURE 6). As such, it is highly unlikely that a substantial snowpack was present in late September 1964, suggesting the peak flow event was driven by rainfall and wet antecedent conditions in late September 1964 as corroborated by Septer (2007).

This invalidates the suggestion presented in Alila (2023) that the upper population observed in the Roberts Creek FFC represents rain-on-snow events. While we agree that there appears to be multiple populations in the PDF of peak flows recorded at Roberts Creek, further investigation is required to effectively attribute the causes of these populations.

Alila (2023) attempts to use rain and snow pillow measurements to evaluate the likelihood of rain-on-snow event occurrence in the assessment area. They state that rain-on-snow events occur over three winter months: "Furthermore, it was decided by the authors that ROS events occurred in the months of <u>November, December, and January</u>." (Alila, 2023, p. 23). However, this contradicts what is stated in their executive summary: "Meltwater drip is a key component of ROS-dominated environments and is crucial for the renewal and recharge of groundwater during ROS months from <u>October to mid-spring</u> in mid to high-elevation coastal environments." (Alila, 2023, p. 9).

Nonetheless, Alila (2023) analyzed antecedent precipitation index (API)[16] for the months of November, December, and January alongside snow pillow data in an attempt to determine the percentage of peak flows that occurred as a result of rain-on-snow. They found that 75% of peak flows occurred between November and January, and that 73% of all peak flows were associated with at least 40 mm of rain leading up to the event. As mentioned previously, there are no snow pillow stations within close proximity of the assessment area. It is assumed that Alila (2023) intended to use snow measurements from the Chapman Creek (3A26) snow survey, but instead evaluated data from the Chapman Lake (4B04) snow survey station located roughly 650 km north of the assessment area (i.e., near Smithers). Notwithstanding the use of the incorrect snow survey data, the claim that a snowpack was present during a vast majority of these peak flow events is inconclusive.

Polar (2023a) does acknowledge that rain-on-snow events can be the principal driver of peak flows in the assessment area, and that forest harvest has an effect on rain-on-snow processes (i.e., the removal of the forest canopy increases snow depth on the ground, and the energy fluxes that drive snow melt - mainly the turbulent ones). Further, while rain makes up the majority of the precipitation that drives the hydrology of the assessment area, we are aware that snowmelt can enhance contributions, potentially turning a small runoff event to a larger one, or making a large event even greater.

Using stochastic physics, Alila (2023) reasons that harvesting at mid-elevations will result in the synchronization of melt with lower elevation melt processes. Such snowmelt synchronization is then posited to cause increased peak flows. They do not, however, offer any insight regarding how urbanization in the lower portion of the assessment area has influenced the CV of the peak flow frequency distribution, and consequently how urbanization may influence the synchronization of melt and runoff. Rosburg et al. (2017) used a probabilistic framework (i.e., flow duration curves) to evaluate the effect of urbanization on streamflow in several watersheds in coastal Washington. They also evaluated how urbanization affected the flashiness[17] of these watersheds. In addition to finding that urbanization increased the magnitude of the entire flow duration curve, Rosburg et al. (2017) also found that urbanization increased the flashiness of a watershed, in accordance with previous literature cited therein. Urban interface watersheds, such as those in the assessment area, are understandably complex, and thus the synchronization or desynchronization of runoff is watershed and event specific. Recognizing this complexity, Polar (2023a) identifies several control measures for BCTS consideration, including conservative harvest limits and non-conventional silvicultural practices.

Using the rationale presented in Alila (2023), an increase in the efficiency of water delivery to the outlet (i.e., increased flashiness) would result in an increase in the CV of peak flows. From a purely

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[16] There is no description of the methodology used to calculate API presented in Alila (2023). For example, it is unknown where the data was sourced (i.e., which station), or how many days of precipitation data were used to determine the amount of precipitation leading up to the event. As such, these results could not be reproduced for verification.

[17] Flashiness describes how quickly a watershed responds to precipitation inputs.

theoretical standpoint and again using the reasoning presented in Alila (2023), a steepening of the FFC as a result of urbanization would render the hydrologic regime to be less sensitive to disturbance. Alila (2023) offered insights on how stochastic physics can be used to understand melt and runoff generation in the forested portions of the assessment area. However, they failed to consider entire watersheds by not considering the lower third of the assessment area, which has been subject to various levels of residential and commercial development.

3.7 Geomorphic Sensitivity

Alila (2023) raises concerns regarding the implication that an increase in peak flow magnitude, frequency, and duration might have on channel morphology and infrastructure. We agree that an increase in frequency of even small magnitude peak flow events (i.e., the 2-year flood) can influence the geomorphology of sensitive channel reaches. Similarly, we agree that many crossings in the urban areas and on Ministry of Transportation and Infrastructure (MOTI) roads were installed several decades ago and may be undersized in light of climate change projections. As such, recommendations were provided in Polar (2023a) for BCTS to share this information with MOTI and the SCRD. Polar (2023a) also recommended that the appropriate party consider a stream crossing review to pre-emptively identify and replace and improve undersized or potentially non-functional crossings, especially those which pose higher social or environmental risks with failure. However, we maintain that if BCTS incorporates the recommendations put forth in Polar (2023a; 2023b), a low peak flow hazard[18] can be maintained within BCTS chart area.

Alila (2023) raises particular concern regarding erosion potential along the 60% slopes within planned block G043B4P8. However, as described in Polar (2023a), sediment hazard can be mitigated if BCTS follows recommendations outlined in Polar (2023a), which include but are not limited to:

- continuing to retain qualified professionals to identify terrain-related and blowdown risks;
- deactivating or seasonally deactivating existing and/or new roads;
- continuing to employ best management practices around streams and riparian zones as identified in BCTS Environmental Management System and environmental field procedures; and
- retaining a Qualified Professional to monitor works involving potential soil disturbance or large cuts and fills within 50 m of a stream channel and installation of bridges or major culverts.

Alila (2023) states that to fully appreciate the sensitivity of current channel conditions, FFC's should be developed and causal inference should be utilized, although offers no indication as to how such an analysis could be conducted for the assessment streams. As noted above, such an analysis would require the development of deterministic models to produce a simulated streamflow time series for

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[18] As presented in TABLE 2.1 of Polar (2023a), a low hazard rating is defined as the hazard occurrence being unlikely; meaning the event or sustained change to watershed process is unlikely. Probabilities of occurrence for a low hazard rating are also presented in TABLE 2.1.

each of the assessment streams, which could then be evaluated using a probabilistic framework. As mentioned previously, none of the assessment streams have a gauged streamflow record suitable for model development. We maintain that thorough field review of channel morphology and conditions affecting channel sensitivity, as was performed in the assessment area, remains the most effective practical approach at understanding future channel stability.

The use of the Delcan (2009) report in Polar (2023a) is criticized by Alila (2023), claiming that Delcan (2009) significantly underestimated projected increases in peak flow magnitude associated with climate change. This criticism is simply incorrect. As described in Polar (2023a), the projected increases in peak flow magnitude presented in Delcan (2009) are a result of future land development scenarios, not a result of future climate change. It is therefore unsurprising why Alila (2023) found these results to be inconsistent with the findings of Gillet et al. (2022). Projected changes to peak flows as a result of climate change are presented in Section 4.7.2 and Section 7.7 of Polar (2023a), which includes a summary of the findings from Gillet et al. (2022).

3.8 Equivalent Clearcut Area (ECA)

We recognize that there are several pitfalls and limitations associated with the use of equivalent clearcut area (ECA) in relation to identifying peak flow hazard. However, Alila (2023) is incorrect in assuming the assessment of peak flow hazard is solely based on this single metric.

As described in Section 3.1 and again in Section 6.1 of Polar (2023a), peak flow hazard is evaluated by considering runoff generation potential (RGP) and runoff synchronization. RGP describes the propensity by which precipitation and/or snowmelt are converted to surface runoff and ultimately streamflow within a given spatial area of interest (i.e., drainage area or catchment). It is influenced by physical watershed characteristics as well as meteorological factors. Physical characteristics that affect runoff generation include, but are not limited to, vegetation (e.g., forest type), soil type, geology, stream density, presence of lakes and wetlands, surface water and groundwater interactions, and physiography. Meteorological factors affecting RGP include the type of precipitation; rainfall/snowmelt intensity, amount and duration; distribution of rainfall over the stream catchment, antecedent precipitation (as rain and as snow stored on the ground), and melt factors such as wind, humidity, radiation and air and rain temperature, and other conditions that affect evapotranspiration such as temperature, wind, relative humidity and season.

Forest management has the potential to influence RGP with the removal of forest cover and development of roads. ECA was used by Polar (2023a) as a metric to represent the level of past forest disturbance and regrowth within the assessment watersheds. ECA is one factor used in evaluating the influence of forest cover disturbance on RGP at the watershed scale. In the assessment watershed, Current ECAs are not the primary factor in the identified RGP. Rather the physical and meteorological factors listed above are responsible for high RGP in all watersheds with exception of End/Walker

Creek above Highway 101, Smales Creek below Highway 101[19], and Higgs Brook. As stated previously, evaluating the effects of past disturbances using a probabilistic approach may have been useful; however, a lack of streamflow data in the assessment area render this approach unpractical and beyond the terms of reference for this assessment.

Alila (2023) states that "it would have been appreciable to have a greater level of transparency" with regards to the tree growth modelling and associated assumptions used in Polar (2023a). Appendix B in Polar (2023a) provides a detailed description of the methodology, assumptions, and limitations associated with the ECA modelling. The following is a quote from Appendix B (Polar, 2023a): "It is important to recognize, however, the complexities and uncertainties in applying stand-scale recovery estimates (i.e., ECA indices) to the evaluation of hydrologic change at the watershed scale (Winkler et al., 2010b)." As a result, Polar (2023a) has taken into full consideration the specific characteristics in the assessment watersheds, confirmed by field review, and has forwarded conservative planning recommendations to BCTS (e.g., harvest levels and silvicultural systems).

In line with the above quote, we agree with Alila (2023) that ECA is a metric developed at the stand-level (and cumulatively applied at the watershed level). We recognize that other factors need to be considered (i.e., RGP) when evaluating forest harvesting effects at the watershed scale. It is somewhat surprising that Alila (2023) calls for greater transparency with respect to tree growth modelling assumptions. As stated in Appendix B (Polar, 2023a), the provincial tree growth modelling tool "SiteTools" was used to synthetically grow tree heights into the future, and associated assumptions are provided therein. This is the same tree growth modelling tool used in the ECA analysis of Dr. Alila's recent publication (Johnson and Alila, 2023), where fewer details on assumptions and methodology with respect to tree growth modelling are provided, relative to Appendix B of Polar (2023a).

Alila (2023) claims that the peak flow hazard thresholds used in Polar (2023a) are derived from Winkler et al. (2010), which is incorrect. As stated in Section 6.1.1 of Polar (2023a), these thresholds were based on 30 years of assessment experience (including field review) in BC and previous literature, which indicate that the detectable limit of forest harvesting's effect on peak flows is approximately 20% ECA. This threshold is lower (i.e., more conservative) than that recommended by Madrone (2015) in their assessment of some of the same watersheds in the area.

We understand that some newer research suggests that there may be instances where peak flow effects are identified at lower thresholds. It should be noted that these are thresholds where changes in peak flow may be detected or inferred, and not necessarily where adverse impacts on stream channels have occurred. Although one may debate whether a specific flow threshold is correct, attention should be

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[19] The RGP for Smales Creek above Highway 101 is considered high.

focused on identifying sensitive stream channels, riparian areas, alluvial fans and ensuring these are not harvested or otherwise impacted, which is what watershed assessments are intended to provide.

We agree with Alila (2023), that peak flow hazard does not increase by step changes, rather it increases incrementally with disturbance. This is a downside of the current risk assessment framework in BC and is a topic that deserves attention at the provincial level. The hazard and consequently risk thresholds reported in Polar (2023a) are consistent with BC Timber Sales' Watershed Risk Management Framework (Polar, 2022), which was developed in response to the guidelines of the *Joint Professional Practices Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector* (EGBC and ABCFP, 2020).

4.0 SUMMARY & CONCLUSIONS

Dr. Alila was retained by the Elphinstone Logging Focus to conduct a review of the Mt Elphinstone South Watershed Assessment Report: Phases 1, 2 & 3 (Polar, 2023a; 2023b). Alila (2023) presents several criticisms of Polar's watershed assessment, which are responded to herein. Many of these criticisms, however, are unfounded. Moreover, several comments articulated in Alila (2023) suggest that Dr. Alila reviewed an old draft. Unfortunately, Dr. Alila neglected to contact Polar prior to his review, a common professional courtesy, that would have avoided this issue.

Based on our review of Alila (2023), we have the following concluding points:

- Our report meets or exceeds the terms of reference identified by BC Timber Sales and the Joint Practices Guidelines of EGBC and ABCFP (2020). Alila (2023) provides no evidence to the contrary.
- Our report is comprehensive, watershed-based, and meets or exceeds the standard of practice in British Columbia. The report is informed by not only the research literature, including that of Alila et al., but also field review of the assessment area.
- Our report was externally reviewed by Dr. William Floyd, Research Hydrologist for the Coast Area Research Section, BC Ministry of Forestry and Adjunct Professor, Vancouver Island University. All recommendations provided by Dr. Floyd were incorporated into the assessment report.
- We suggest that Alila's criticisms on the standard practices for watershed assessment might be better directed to the professional associations (i.e., Engineers and Geoscientists British Columbia and Forest Professionals BC) and provincial agencies that provide guidance hydrology practitioners in these matters.
- Many of the statements made by Alila (2023) are incorrect or misleading.
    - Alila (2023) does not appear to have or refer to any direct knowledge of the assessment area or streams. As a result, much of his argument appears to stem from an office-based exercise, which utilized data that does not represent conditions in the assessment area.

    - Alila's (2023) contention that meltwater drip is "crucial for the renewal and recharge of groundwater" in the assessment area is false and his argument to support this statement is flawed. As detailed herein, not only is meltwater drip insignificant to the recharge of Chapman Lake over winter, but it is also not crucial to groundwater recharge in the assessment area as Alila (2023) claims.
    - Although the research of Rong (2017) provides valuable insights in relation to the effect of forest development on peak flows in ROS environments, the study did not isolate the effect of roads, as claimed by Alila (2023). Furthermore, the study watersheds are located roughly 140 km east of the Oregon Coast with a minimum watershed elevation 840 m higher than the minimum elevation of the assessment watersheds. As such, the hydrology and climate of the study watersheds are not considered representative of the assessment area.
    - Alila (2023) claims that the upper two populations of the probability density function of peak flows at Roberts Creek can be attributed to ROS events. Empirical meteorological data presented herein disproves this claim.
  - Alila (2023) makes inferences in relation to how runoff synchronization might be influenced by forest development; however, failed to incorporate a holistic, watershed-scale approach, by not considering the lower third of the assessment area, which has been subject to various levels of residential and commercial development.
  - Alila (2023) claims that the HJ Andrews watershed study of Jones (2000) was highlighted in the Polar (2023a) report in relation to the effect of forest roads on peak flows. This claim is unfounded as discussed herein.
  - Alila (2023) criticizes the use of use of the Delcan (2009) report in Polar (2023), claiming the report significantly underestimated projected increases in peak flow magnitude associated with climate change, relative to Gillet et al. (2022). This is unsurprising given that Delcan evaluated future land development scenarios and not climate change.
  - Alila (2023) calls for greater transparency with regards to the tree growth modelling and associated assumptions used in Polar (2023a). This is surprising given that Appendix B in Polar (2023a) provides a detailed description of the methodology, assumptions, and limitations associated with the ECA and tree growth modelling.
  - Alila (2023) claims that the peak flow hazard thresholds used in Polar (2023a) are the same thresholds created by Winkler et al. (2010), and claims that the work of Winkler et al., (2010) was not directly referenced. This is incorrect. The basis of the peak flow hazard thresholds used in Polar (2023) is described herein.
- No direct evidence is provided to demonstrate that our findings or recommendation are in error. Reference is made only to hypothetical examples including presenting FFCs (Figure 3) that prove little, and are misleading. For example, a 15% increase in magnitude is assumed not proven.

- We recognize and respect the research of Alila et al. and also agree that a probabilistic approach would be useful. However, it is not standard practice and based on our understanding, is dependent upon development of deterministic hydrologic models, which have yet to be demonstrated to be practical, defensible and cost-effective in an operational forestry setting, particularly in watersheds with little to no hydroclimatic data.
- We agree that some coastal watersheds are sensitive (i.e., have shallow FFCs), but the data represented does not represent the assessment area.

5.0 CLOSURE

We trust that this letter meets your requirements at this time.

Yours truly,
Polar Geoscience Ltd.

2023-11-30

Lars Uunila, M.Sc., P.Geo., P.Geol., P.H., CPESC, CAN-CISEC, BC-CESCL
Senior Hydrologist & Geoscientist

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FIGURES

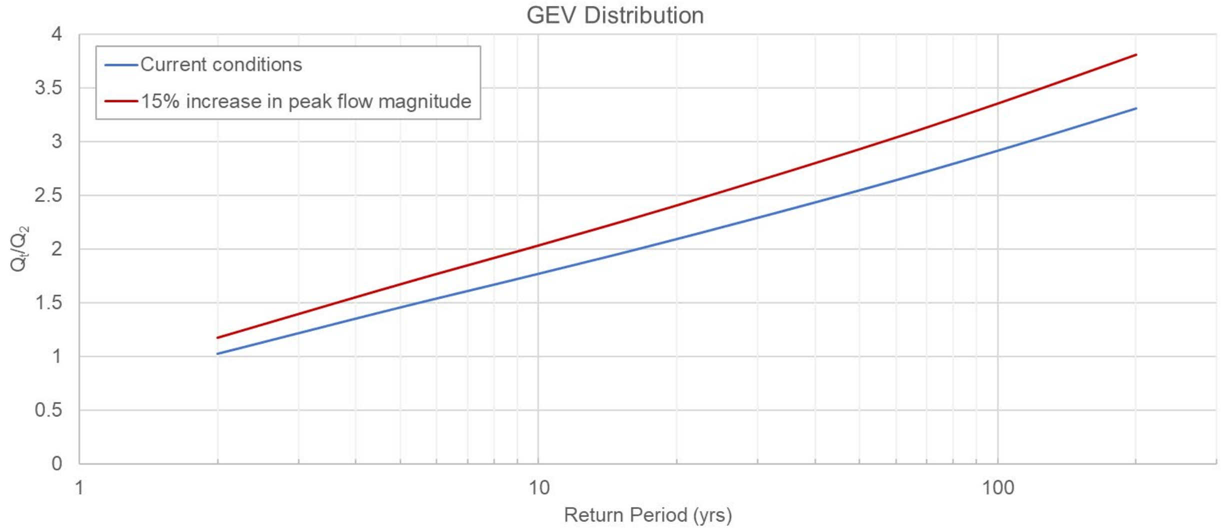
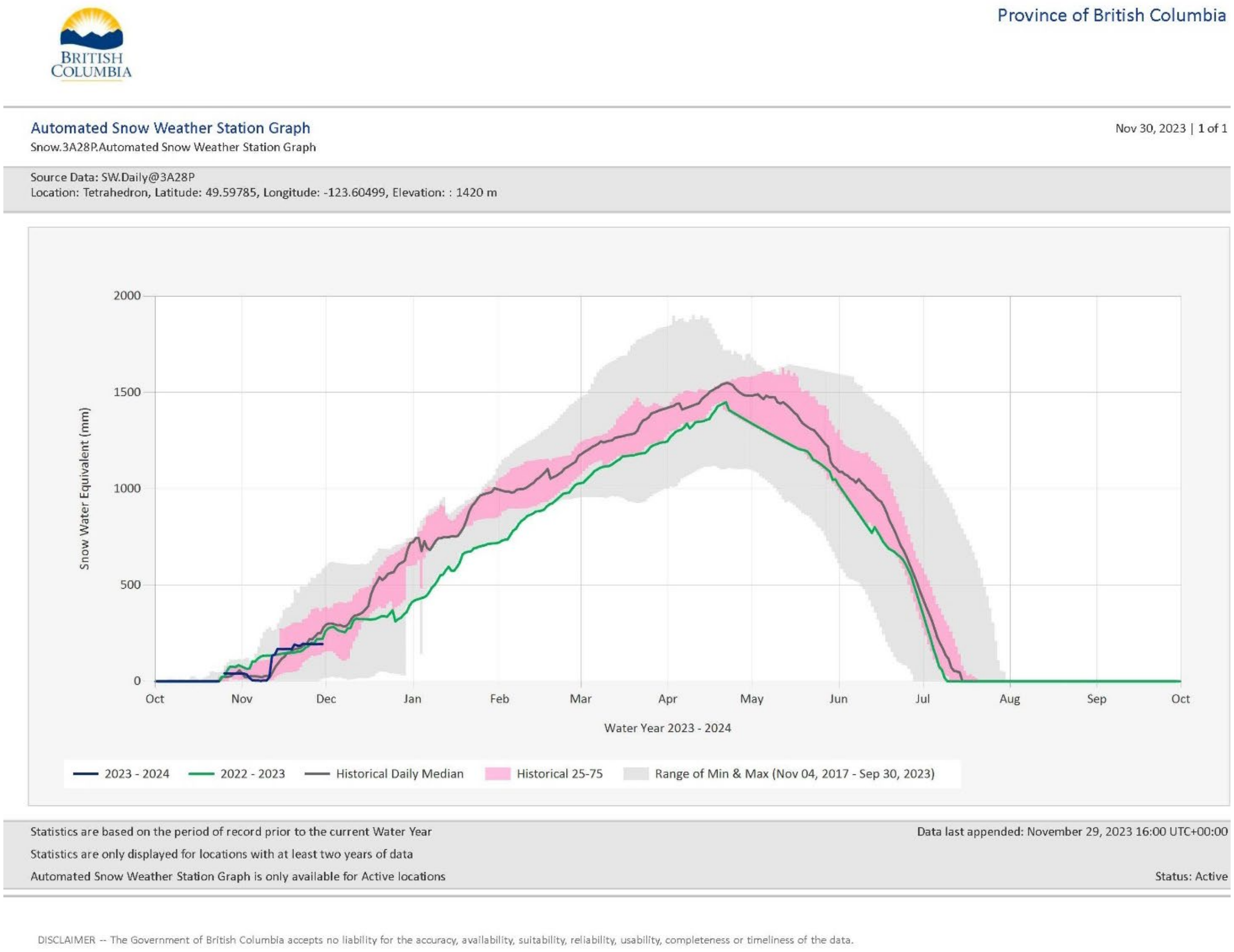


FIGURE 1 *Normalized flood frequency curve of annual maximum mean daily peak flows from the Roberts Creek at Roberts Creek Water Survey of Canada hydrometric station 08GA047 fit to a GEV distribution. The blue line indicates current conditions and the red line indicates a hypothetical increase in peak flow magnitude of 15%.*



Province of British Columbia

BRITISH COLUMBIA

Automated Snow Weather Station Graph

Snow.3A28P.Automated Snow Weather Station Graph

Nov 30, 2023 | 1 of 1

Source Data: SW.Daily@3A28P

Location: Tetrahedron, Latitude: 49.59785, Longitude: -123.60499, Elevation: : 1420 m

Statistics are based on the period of record prior to the current Water Year

Statistics are only displayed for locations with at least two years of data

Automated Snow Weather Station Graph is only available for Active locations

Data last appended: November 29, 2023 16:00 UTC+00:00

Status: Active

FIGURE 2 *Automated snow weather station graph for Tetrahedron (3A28P), located north of Chapman Lake at an elevation of 1,420 m.*

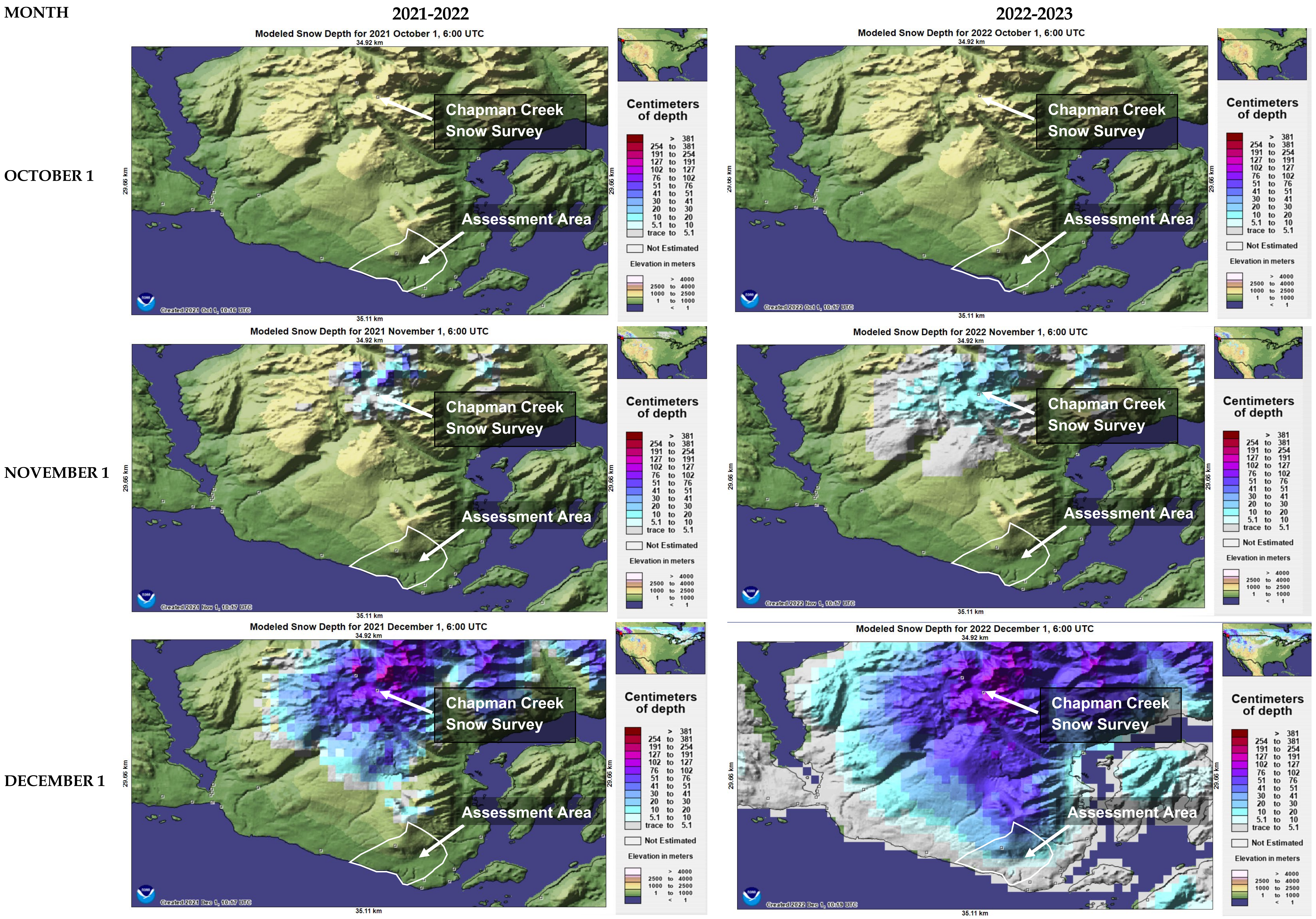


FIGURE 3 *Monthly remotely sensed SNODAS-derived snow depth estimates from October to June for years 2021 – 2023. The assessment area and location of the Chapman Creek snow survey station 3A26 are presented on each plot.*

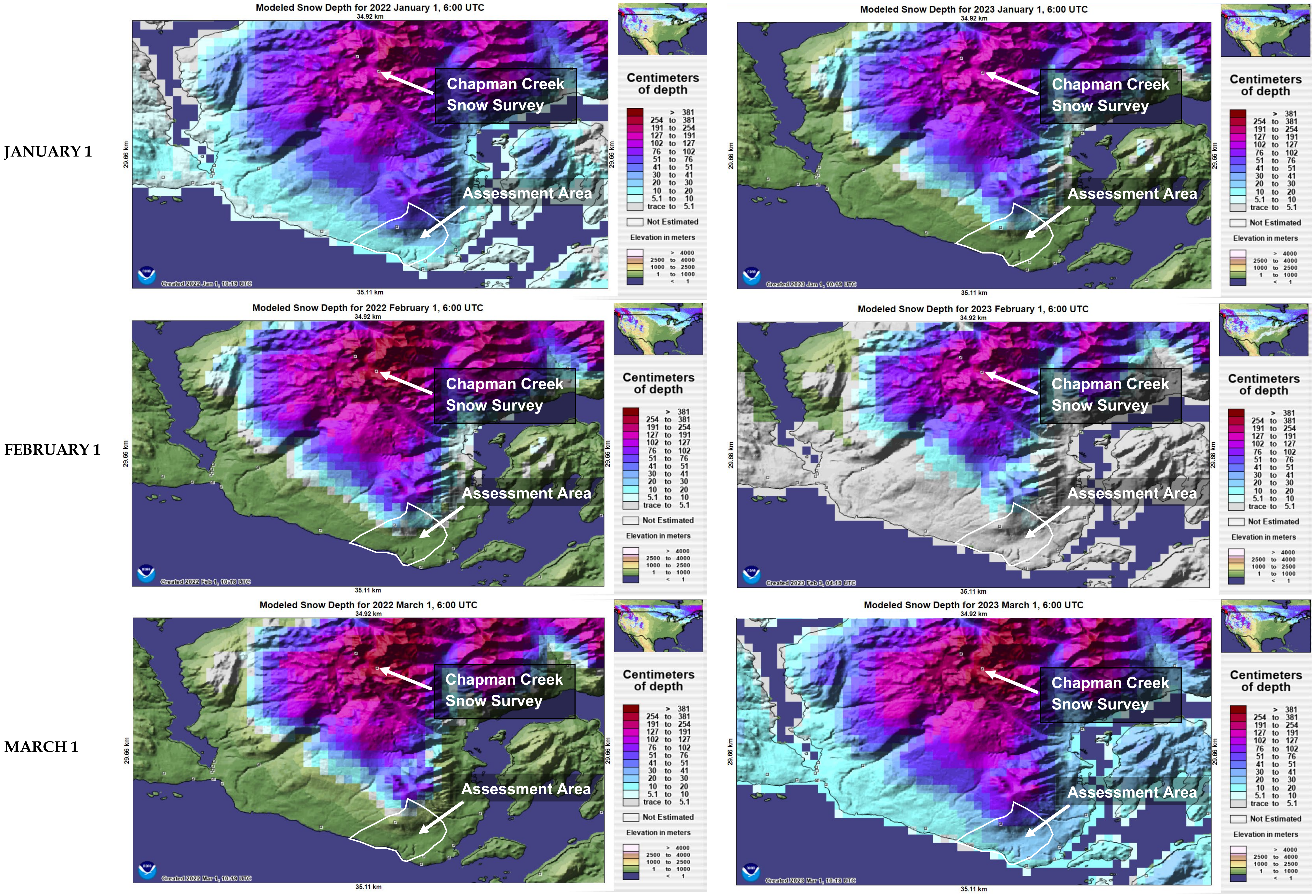
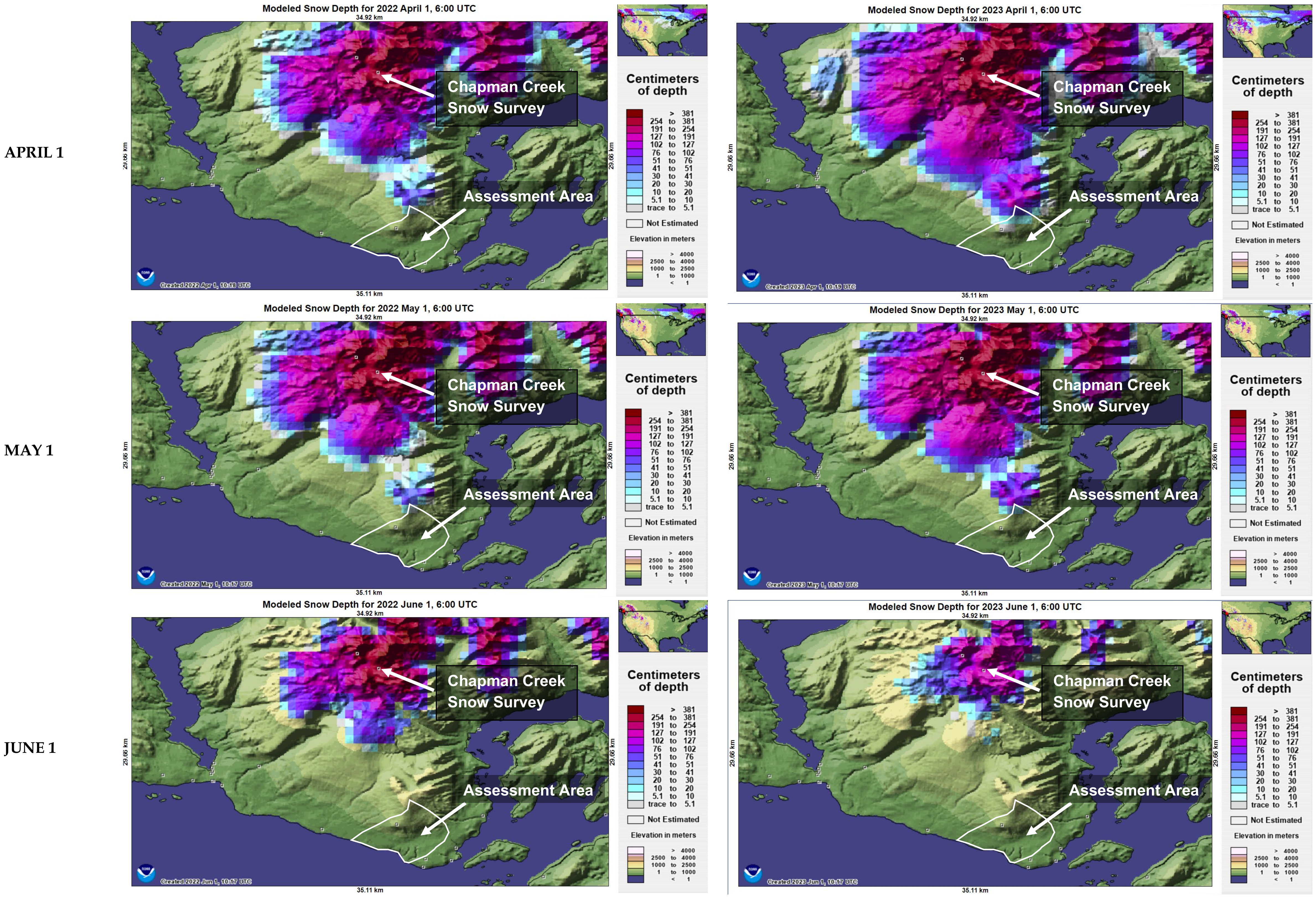


FIGURE 3 *Cont'd.*



Modeled Snow Depth for 2022 April 1, 6:00 UTC

Modeled Snow Depth for 2023 April 1, 6:00 UTC

Modeled Snow Depth for 2022 May 1, 6:00 UTC

Modeled Snow Depth for 2023 May 1, 6:00 UTC

Modeled Snow Depth for 2022 June 1, 6:00 UTC

Modeled Snow Depth for 2023 June 1, 6:00 UTC

FIGURE 3 *Cont'd.*

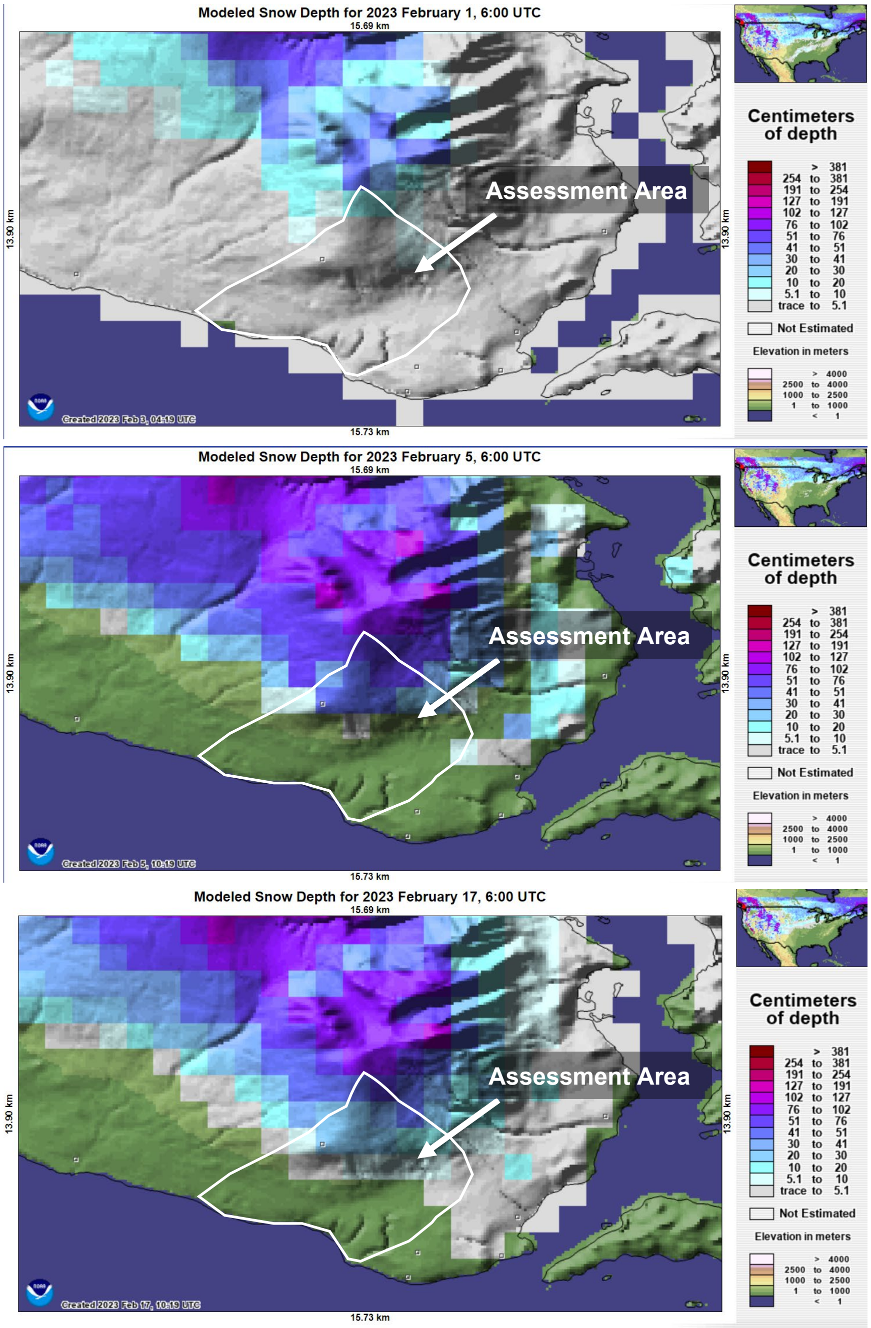
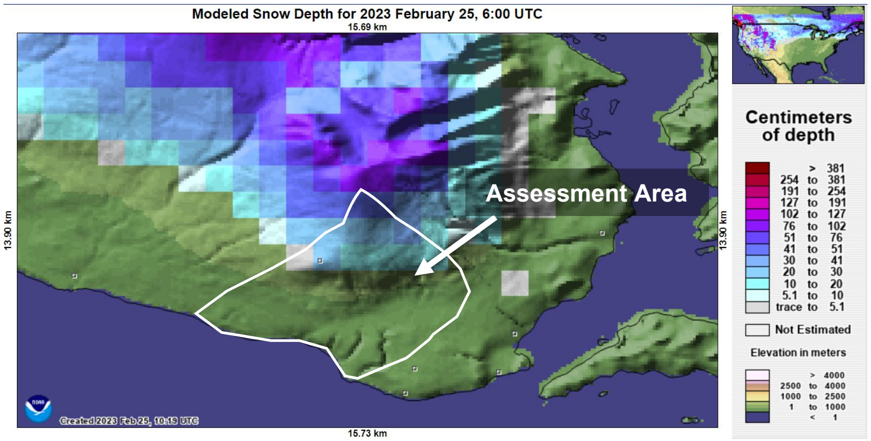
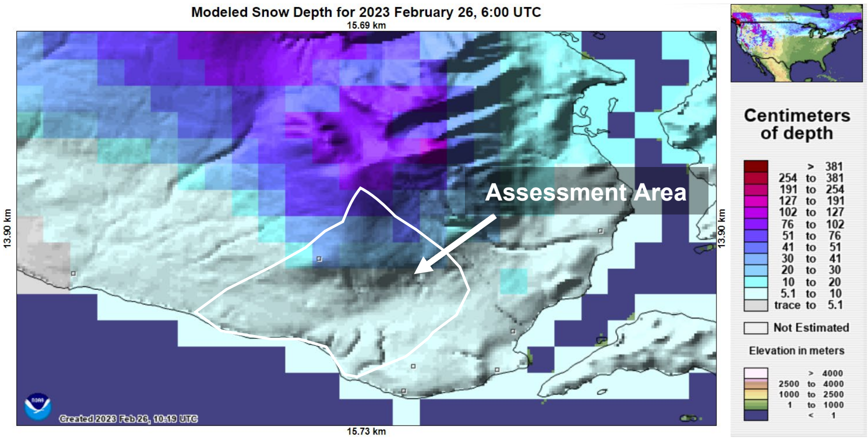


FIGURE 4 *SNODAS-derived snow depth measurements for the assessment area from February 1, 2023 to March 15, 2023.*


Modeled Snow Depth for 2023 February 25, 6:00 UTC


Modeled Snow Depth for 2023 February 26, 6:00 UTC

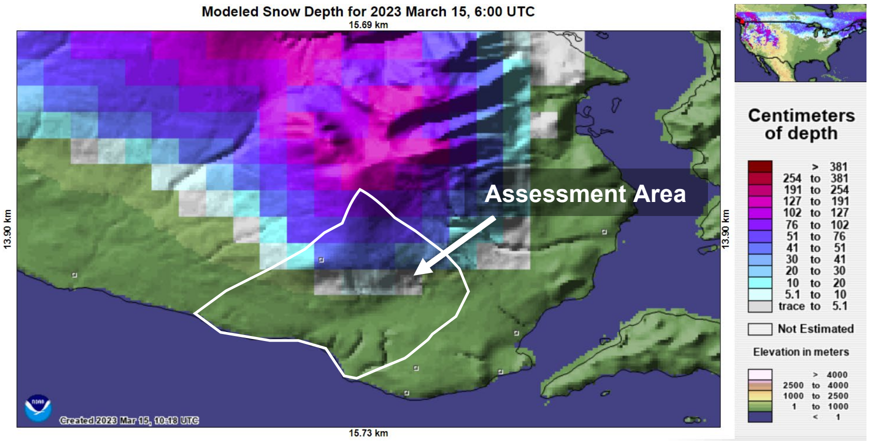

Modeled Snow Depth for 2023 March 15, 6:00 UTC

FIGURE 4 *Cont'd.*

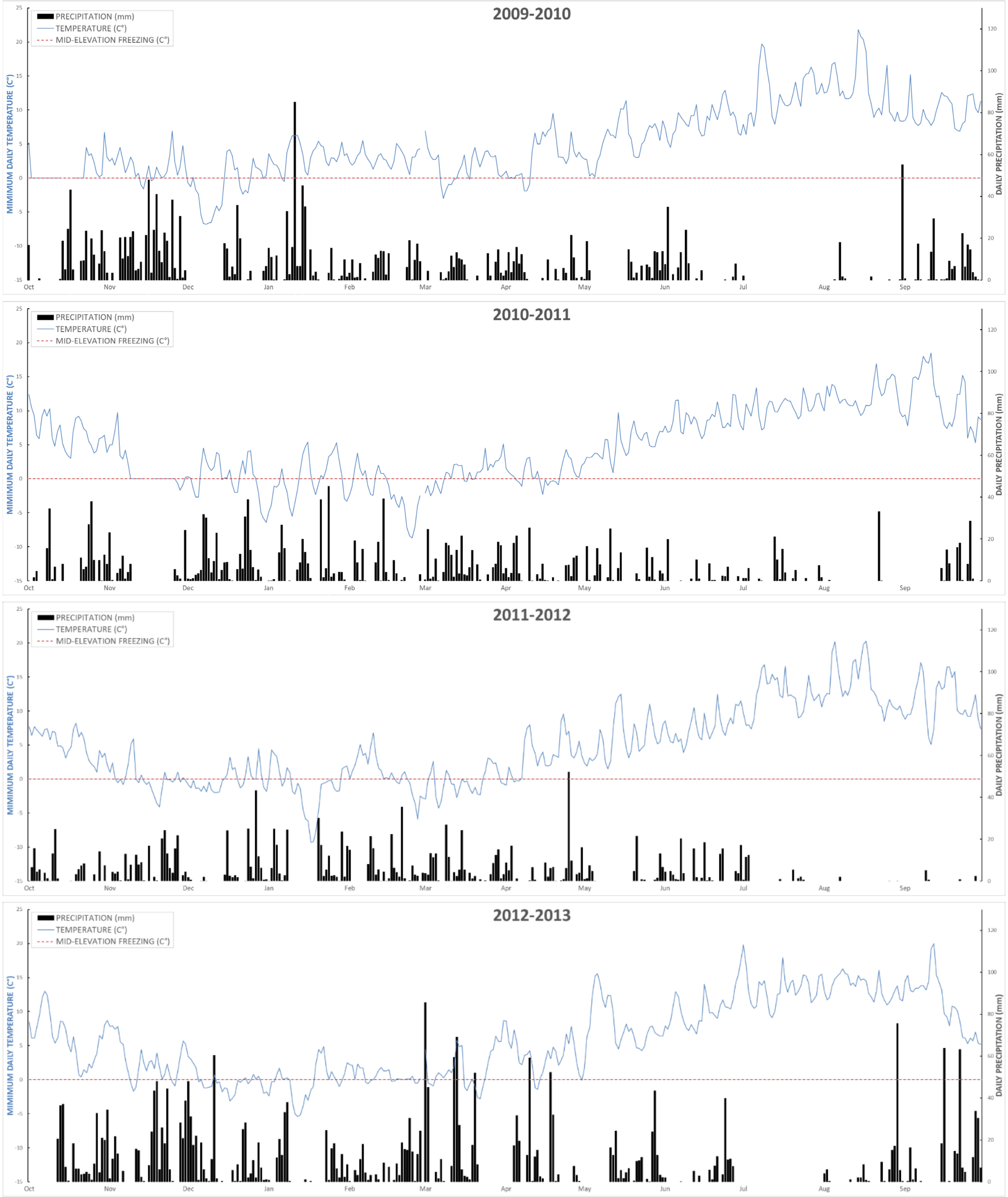


FIGURE 5 *Minimum daily temperature and daily precipitation recorded at the TS Elphinstone (FLNORD-WMB 1002, El. 593 m, 2009-2023). The red horizontal line indicates the line below which precipitation is expected to fall as snow at an elevation of 593 m. Data was incomplete for 2017 and not included.*

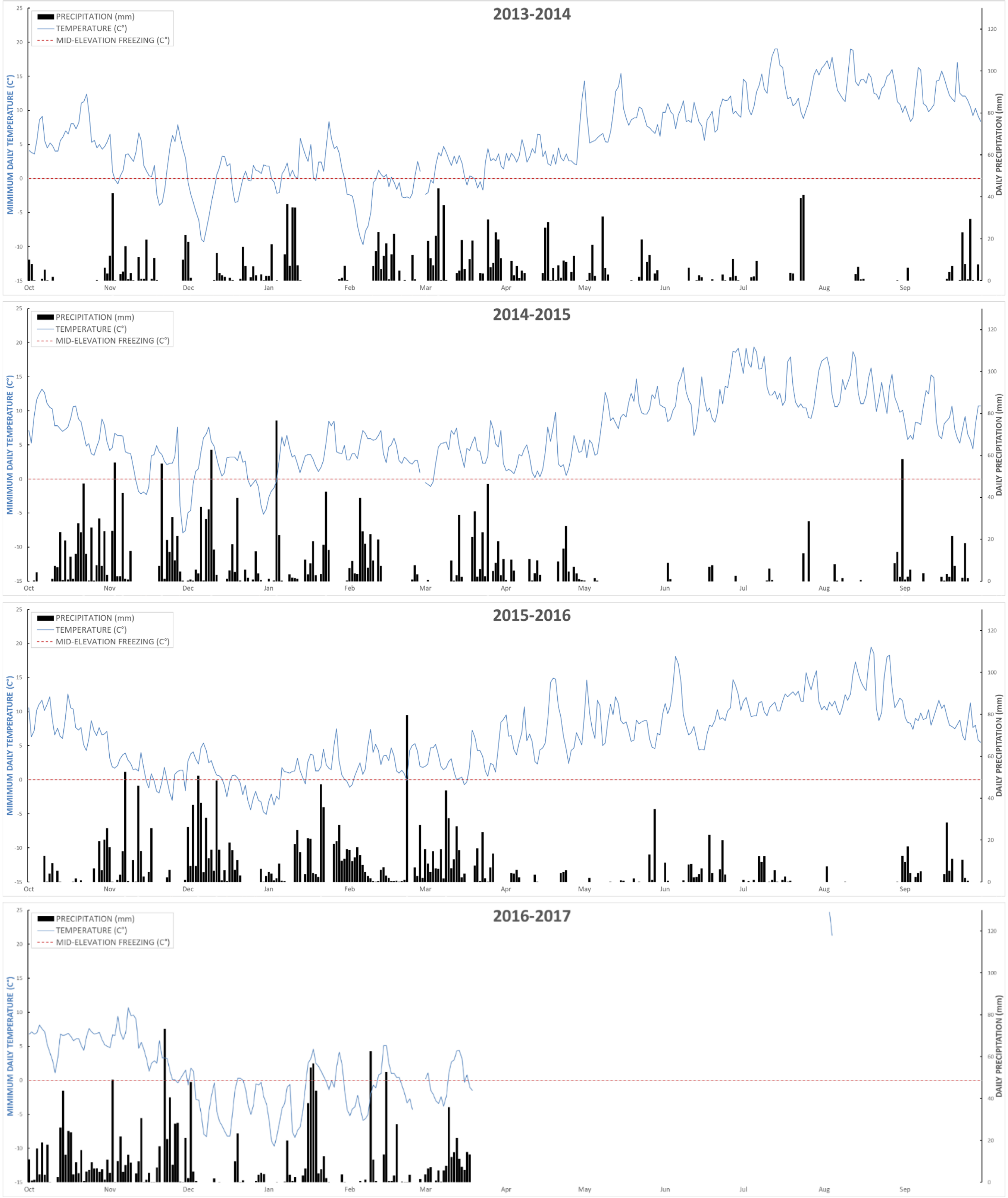


FIGURE 5 *Cont'd*

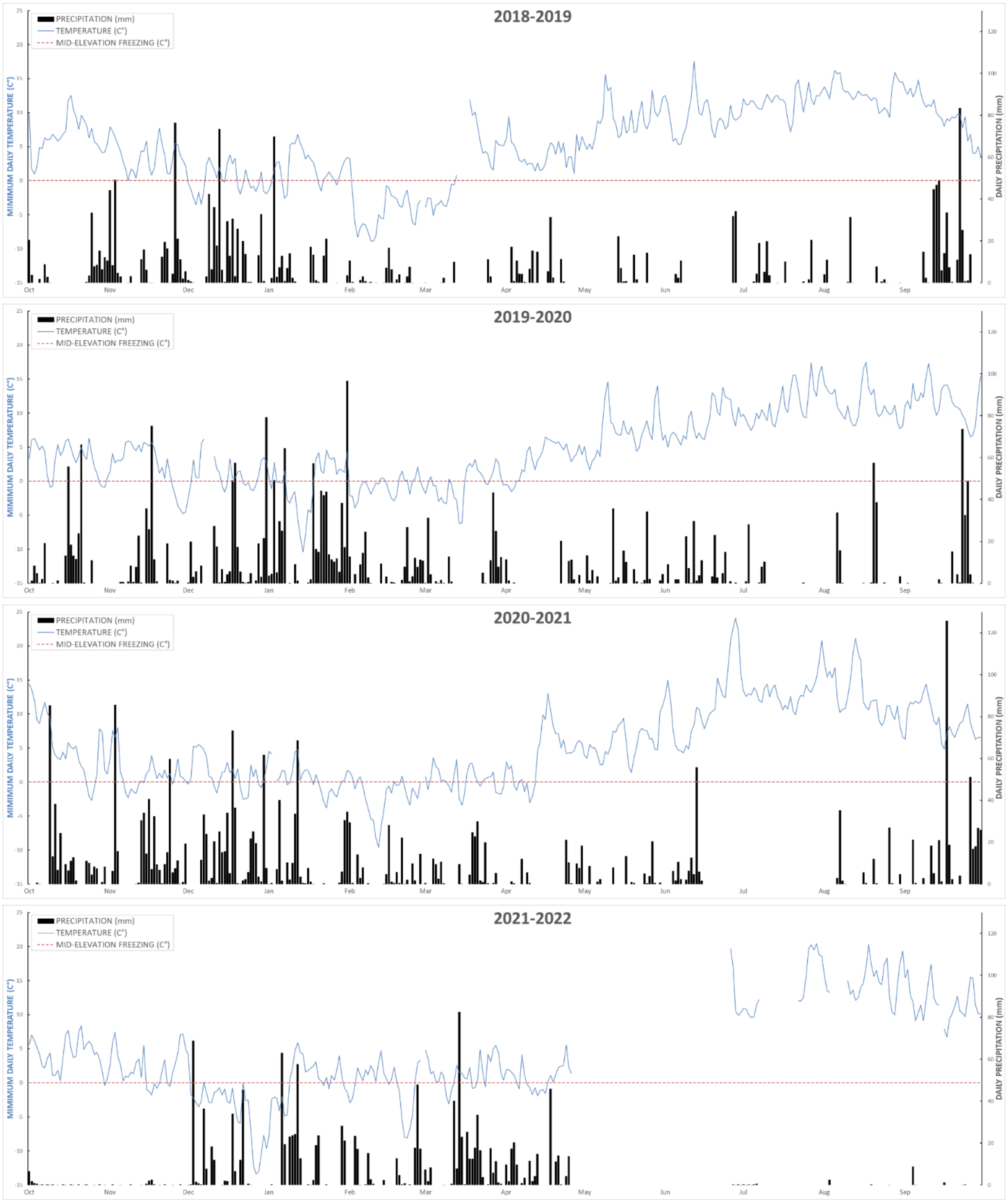


FIGURE 5. *Cont'd.*

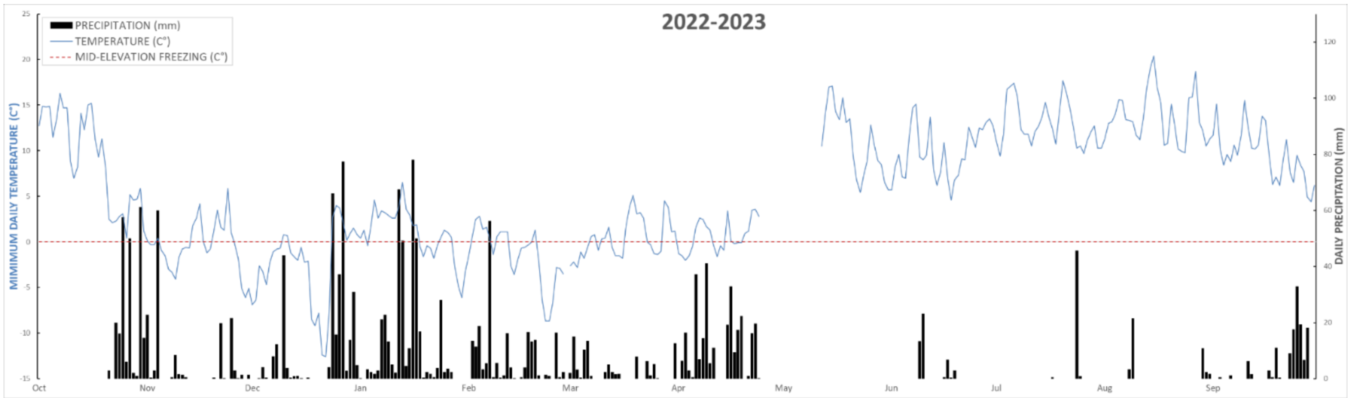


FIGURE 5 *Cont'd*

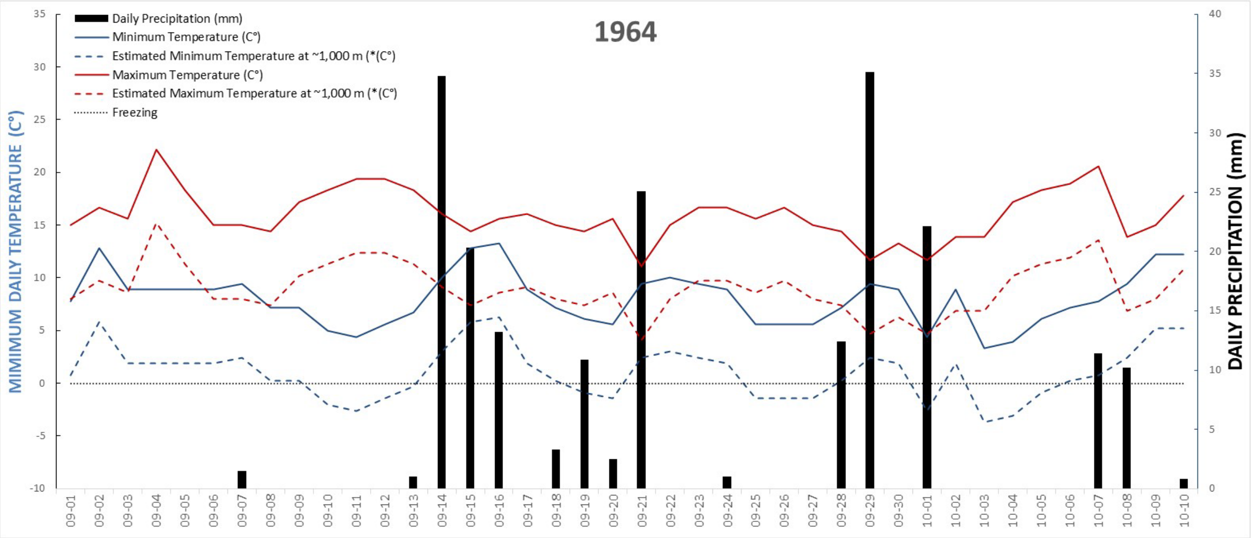


FIGURE 6 *Minimum and maximum daily temperature and daily precipitation recorded at the Gibsons (Environment Canada, 1043150, El. 62 m) meteorological station from September 1 to October 10, 1964. Daily maximum and minimum temperature at an elevation of roughly 1,000 m was estimated assuming an adiabatic lapse rate of 7 C°/ 1,000 m.*