MacHydro

Addendum: Gap Analysis for Areas of Interest – CBWMF Expansion 2023

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1 Introduction

Living Lakes Canada (LLC) has served to spearhead the planning and implementation of hydroclimatic monitoring across the Columbia Basin since the late 2010's, when they conceived of the Columbia Basin Water Monitoring Framework (see Carver, M. and Utzig, G. (2020), Carver, M. and Utzig, G. (2021a) and Carver, M. and Utzig, G. (2021b) for a further history). 2022 marked the first year of implementation for the Columbia Basin Water Monitoring Framework (CBWMF), in which hydroclimatic monitoring stations were installed within three pilot Areas of Interest: the Columbia-Kootenay Headwaters, the Mid-Columbia Kootenay, and the Elk River Watershed. In 2023, Living Lakes Canada (LLC) expanded the CBWMF from three pilot Areas of Interest to two new regions: the Upper Kootenay (UK) and Lower Columbia Kootenay (LCK).

MacDonald Hydrology Consultants Ltd. (MacHydro) was approached by LLC to complete geospatial analysis to support the identification and prioritization of areas for expanded water monitoring. This was done alongside community and stakeholder consultation conducted by LLC to ensure that sites reflect the monitoring strategy outlined by Carver and Utzig (2021a); specifically, that monitoring reflect scientific and community concerns and priorities. This analysis was initially applied to the three pilot Areas of Interest, as detailed within Pilot Priority Matrix to Expand Water Monitoring in Upper Columbia Basin (Lapp et al, 2022); it was also applied to the two new Areas of Interest in 2023 with slight modifications based on review from the CBWMF technical panel.

This report details amendments made to the geospatial gap analysis. It is intended as an addendum to the previous report (Lapp et al. 2022) that outlines the gap analysis in detail and utilizes many of the same data sources and methods. To help guide the reader, this document references specific points within the 2022 document where additional detail could be useful.

This report thus describes:

- An overview of the geospatial gap analysis, including variables used to describe watersheds within the two new regions, and statistical analysis used to parse similarities in hydrologically important watershed characteristics (specifically, how this compares to the 2022 approach);
- A description of each of the clusters within the two new Areas of Interest as determined via the statistical analysis;
- The density of existing monitoring networks within each of the identified watershed clusters through the two new Areas of Interest;
- Future work to consider in continued geospatial gap analysis as the CBWMF potentially expands to new Regions across the Columbia Basin.

2 Cluster Analysis Update – 2023

2.1 Overview

This section contains a description of how watersheds were characterized and clustered by similarities in hydrologically important variables. It also contains a description of each of these clusters within the two new regions added to the CBWMF in 2023.

2.2 Details of Updated Cluster Analysis

2.2.1 Previous Analysis

The Columbia Basin Water Monitoring Framework (CBWMF) project was expanded into two new regions in 2023: The Lower Columbia Kootenay (LCK) and the Upper Kootenay (UK) regions. A gap analysis was undertaken to determine where additional monitoring would be most useful within these two regions. This gap analysis was built on the process used within the initial pilot phase of the project, a complete description of which can be found in Lapp et al. (2022). Briefly, Regional Landscapes within each Area of Interest were divided into smaller watershed units using the BC Freshwater Atlas Assessment Watersheds (BC FWA; BC Data Catalogue, 2022a). Each FWA watershed was characterized by variables that describe hydrologic function, including a range of climate, land cover and morphometric statistics (Table 1). These statistics were heavily informed by a pilot clustering study completed in the upper Columbia River (East Kootenay Area of Interest, MacDonald Hydrology Consultants, 2020). Further details regarding these variables, including details of how they were calculated and/or their data source, are available in Lapp et al. 2022.

Table 1 Data sources used to cluster watersheds (from Lapp et al., 2022).

Clustering Indicator	Units	Data Source	Citation
Infiltration Rating	none	Personal Communications	Carver and Utzig (2021)
Basin Shape Index	none	BC FWA	Spence et al. (2007)
Mean Elevation	m	CDEM	NRCan (2022), Hollister et al. (2021)
Maximum Elevation	m	CDEM	NRCan (2022), Hollister et al. (2021)
Slope-Aspect	rad	CDEM	NRCan (2022), Hollister et al. (2021)
Temperature	C	ClimateBC	Wang et al. (2016)
Precipitation	mm/year	ClimateBC	Wang et al. (2016)
Snow Fraction	%	ClimateBC	Wang et al. (2016)
Relative Humidity	%	ClimateBC	Wang et al. (2016)
Wetland Fraction	%	BTM - Present Land Use	BC Data Catalogue (2022b)
Forest Fraction	%	BTM - Present Land Use	BC Data Catalogue (2022b)
Glacier Fraction	%	BTM - Present Land Use	BC Data Catalogue (2022b)

Cluster Analysis

A cluster analysis was used to group FWA watersheds based on hydrologic characteristics shown in Table 1. Clustering was completed by first scaling (normalizing) all hydrologic variables; scaled variables were then classified using hierarchical cluster analysis on a set of dissimilarities using the `hclust` function in the R (R Core Team, 2023). Clustering within this function was performed using Euclidean distances via the 'ward.D' method. Clustering was also iterated to determine the optimal number of clusters within an Area of Interest, which was done by considering qualitative aspects such as the study goals (i.e., how many groups of watersheds could be monitored) and local knowledge (how "different" are these watersheds within the Area of Interest), as well as quantitative measures including the spread/distribution of clustering indicators between groups, significant differences between groups, and weighted sum of squares on the scaled dataset.

2.2.2 Updates to Cluster Analysis

Clustering analysis within the expanded Areas of Interest in 2023 was done using the same approach as briefly described above (and described in detail in Lapp et al., 2022). The significant departure in 2023 was that FWA watersheds within each Area of Interest were first grouped according to their Regional Landscape prior to clustering. Specifically, each region was first broken into their Regional Landscapes, defined as per Utzig (2019). Within each Regional Landscape (RL), watersheds were defined according to BC Freshwater Atlas watersheds. Hydrologically important variables describing landcover, elevation, and infiltration were collected for each of the FWA watersheds within a Regional Landscape (Table 1). Watersheds within a particular Regional Landscape were then compared to each other on the basis of these hydrologically important descriptor variables using the same clustering analysis as described above in Section 2.2.

This clustering approach used in 2023 can thus be described as:

Area of Interest -> Regional Landscapes -> FWA Watershed Clusters

2.3 Description of Clusters by Region

This section provides a description of each of the clusters by Regional Landscape within the LCK and UK Areas of Interest. These qualitative descriptions also include radar and density plots for each of the clusters that show quantitative similarities in terms of variables used to parse different clusters.

2.3.1 Lower Columbia Kootenay

This Area of Interest spans much of the West Kootenay area, a broad area that spans the south interior of BC along the Canada-USA border (Figure 1). The LCK contains three Regional Landscapes: Lower Arrow-Christina-Pend'Orielle (RL 2), West Arm-Salmo River (RL 3), and Goat-Moyie (RL 4). Clustering of both the Lower Arrow (RL 2) and Goat-Moyie (RL 4) Regional Landscapes resulted in three clusters, while the West Arm (RL 3) Regional Landscape resulted in two clusters of similar FWA watersheds. Figure 1 shows the locations of these clusters within the LCK.

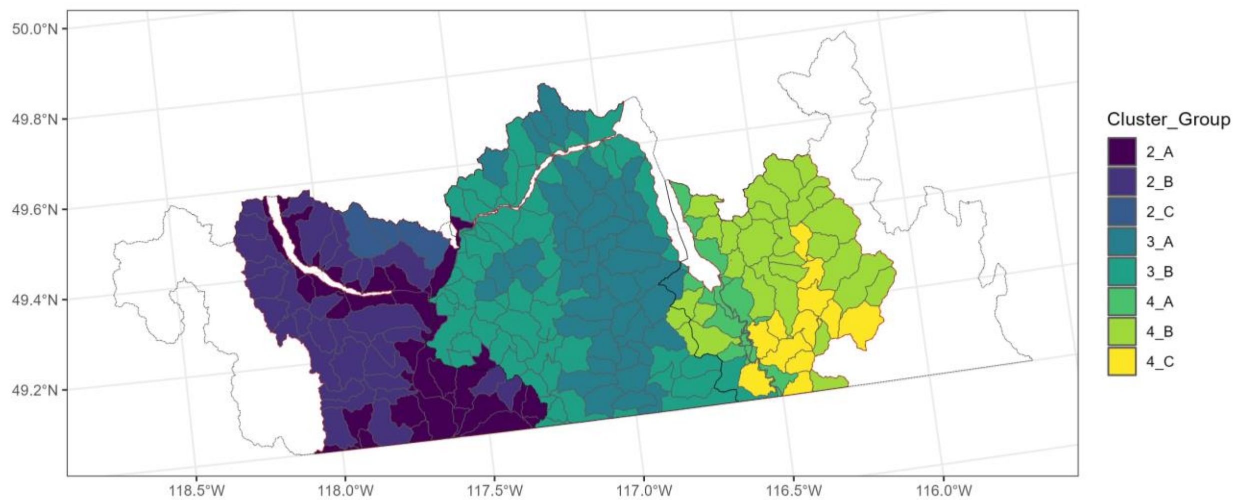

Figure 1 Clusters by Regional Landscape within the Lower Columbia Kootenay Region

These clusters can be described based on the characteristics of the watersheds that comprise each cluster. Here, we use radar and density plots to show qualitative similarities in clusters by variables examined (specifically, the distribution of each variable within a specific cluster group; Figure 2 and Figure 3).

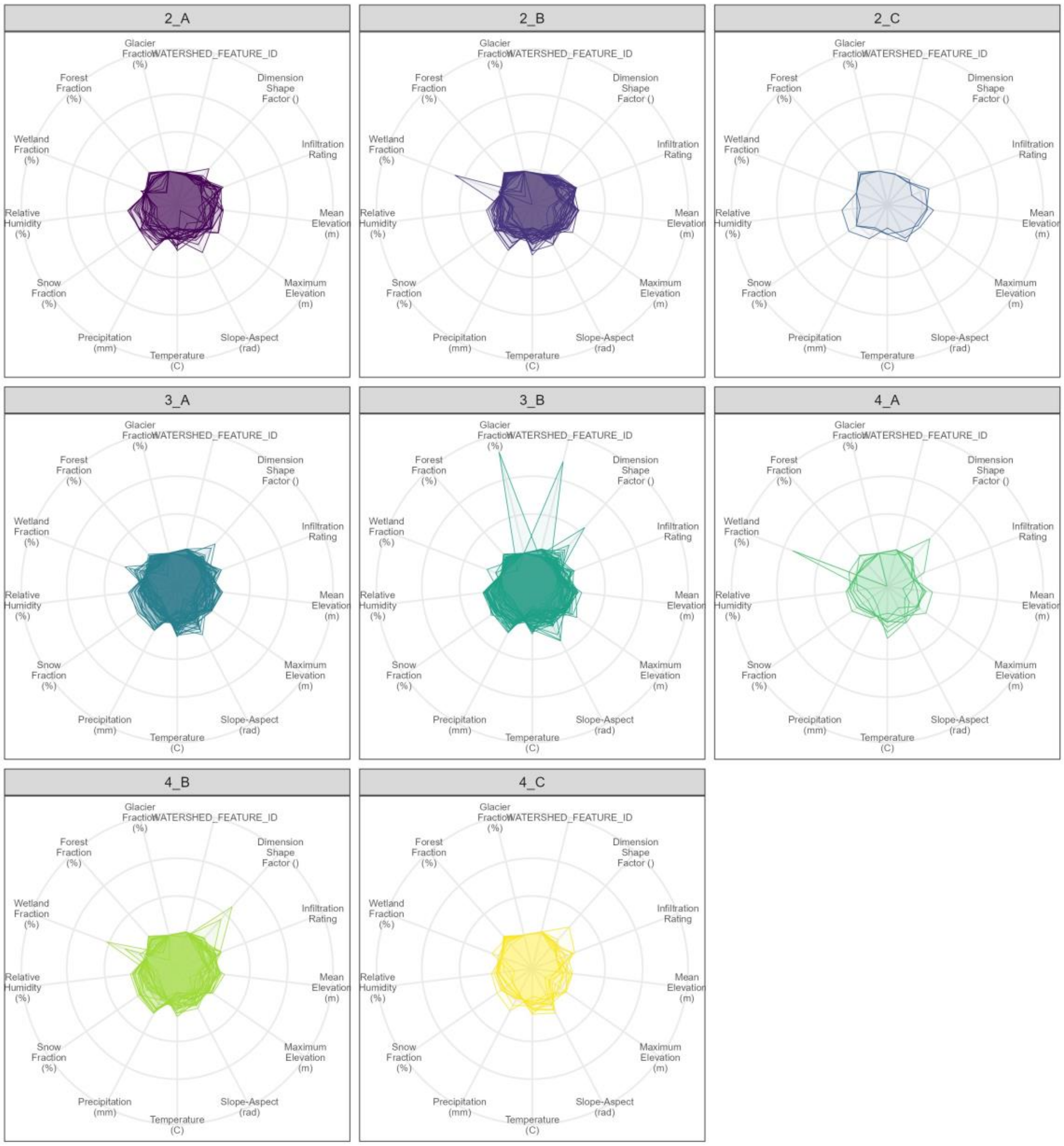

Figure 2 Radar plot for the LCK Clusters by Regional Landscape

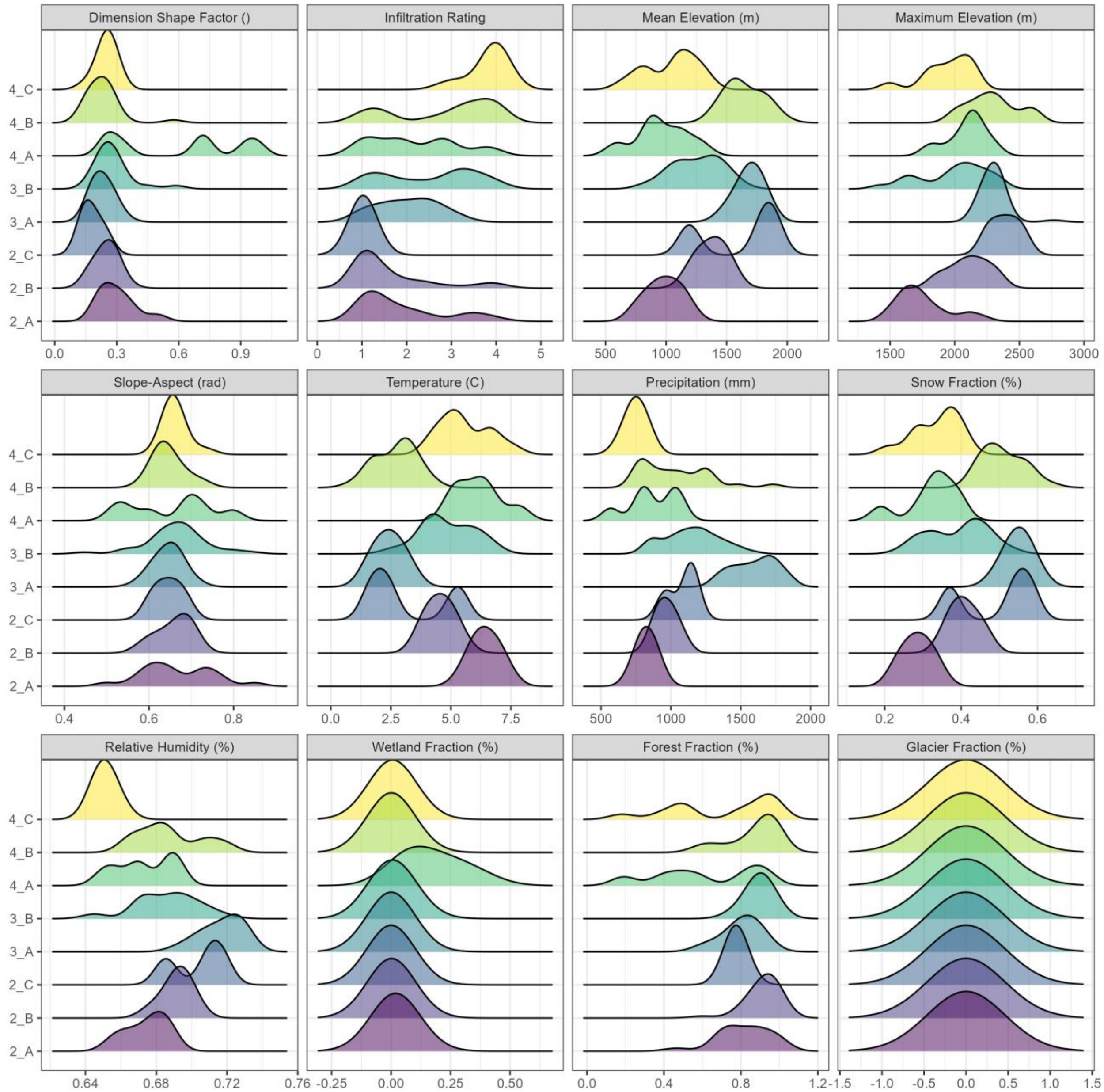

Figure 3 Density plots for the LCK Region by Regional Landscapes (2-4)

Each of the clusters were qualitatively described below using the characteristics of watersheds that comprise each cluster, including a description of each Regional Landscape (according to Utzig, 2019).

Lower Arrow-Christina-Pend'Orielle Regional Landscape (RL 2)

Regional Landscape characteristics: Moist, West-Kootenay Shuswap Climate Region.

Cluster analysis resulted in three (3) clusters:

- 2A: Low elevation, warm, dry, low snow fraction, predominantly forested watersheds.
- 2B: Mid elevation, warm-cool, dry, and predominately forested watersheds. Cooler temperatures than cluster 2A means a higher snow fraction (i.e., more precipitation that falls as snow versus rain).

- 2C: This is a small cluster of three watersheds in the very north of the cluster north of the Upper Arrow Lake. They tend to be mid to high elevation forested watersheds that are cooler, with more snow. The bimodal distribution within the density plots for this area is due to the small sample size (noting that there are only three watersheds within this cluster).

West Arm-Salmo River Regional Landscape (RL 3)

Regional Landscape characteristics: moist, West-Kootenay Shuswap Climate Region.

Cluster analysis resulted in two (2) distinct watershed clusters:

- 3A: High elevation, cold forested watersheds with a high snow fraction (most precipitation through the year falls as snow). Watersheds are relatively wet with a high relative humidity.
- 3B: Mid to high elevation forested watersheds warmer than 3A, with a lower snow fraction and less precipitation than 3A. High infiltration rating than watersheds in 3A.

Goat-Moyie River Regional Landscape (RL 4)

Regional Landscape characteristics: moist-dry transition, West-Kootenay Shuswap Climate Region.

Cluster analysis resulted in three (3) distinct watershed clusters:

- 4A: Low elevation watersheds near valley bottom around Creston. Warm and relatively dry watersheds with most precipitation falling as rain versus snow. Forest dominated with more significant wetlands at the low elevations.
- 4B: High elevation watersheds that are relatively dry and cold, with most precipitation falling as snow versus rain. Mostly forested, with non-forested areas at high elevations.
- 4C: Low to mid elevation watersheds with a high infiltration rating. Warm and dry watersheds where most of the precipitation falls as rain versus snow.

2.3.2 Upper Kootenay (UK)

This Area of Interest comprises the southeast corner of British Columbia (Figure 4). It excludes the Elk Valley as it was the subject of the pilot phase of the CBWMF, and so was not examined within this analysis. The UK Area of Interest contains four regional landscapes: Tobacco Plains Kootenay River (RL 10), Lower Elk-Bull Rivers (RL 11), Flathead-South Rockies (RL 12), and White River-Bull-Elk Headwaters (RL 13) (Figure 4).

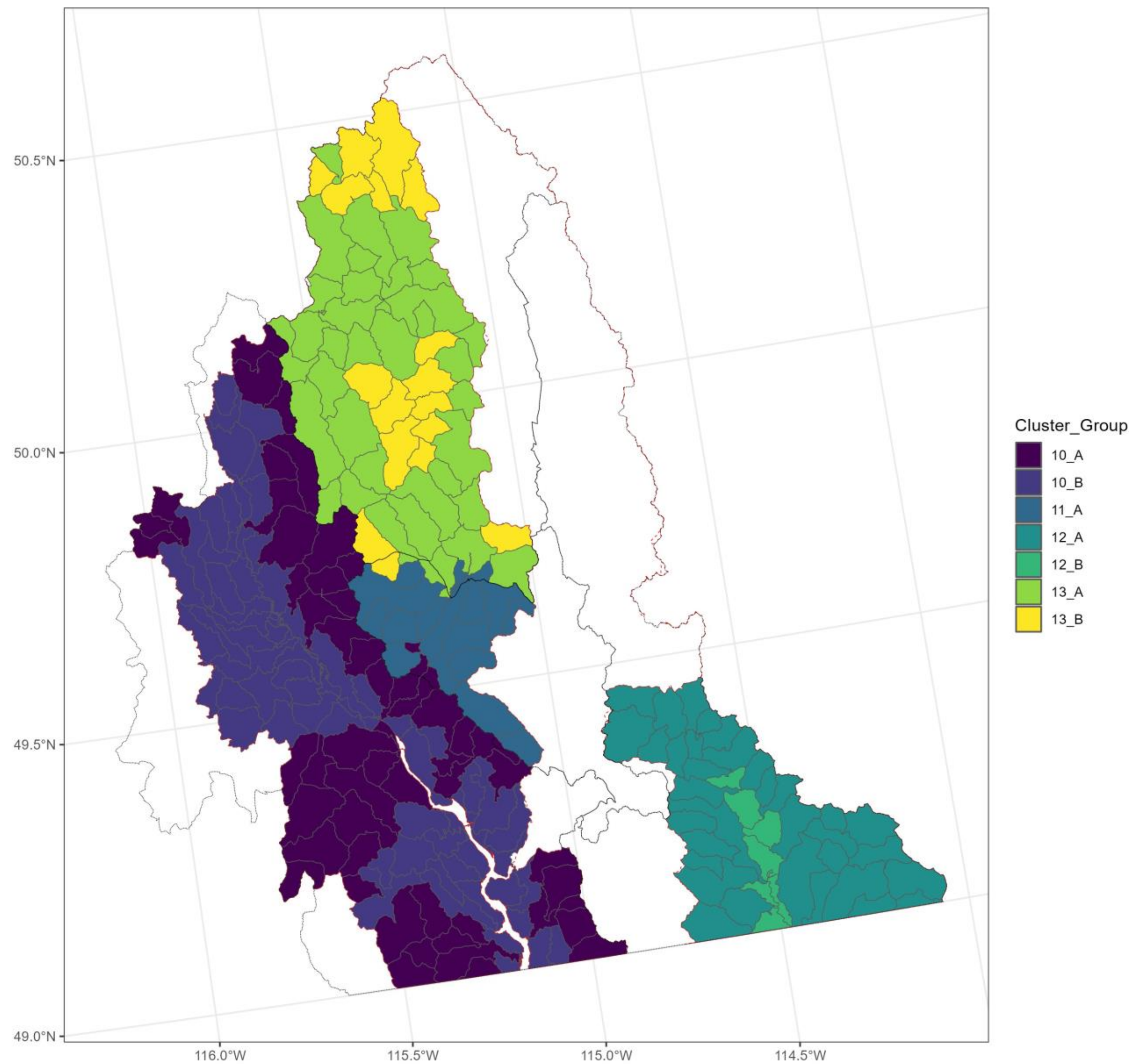

Figure 4 Clusters by Regional Landscape in the Upper Kootenay Region. Note the exclusion of the Elk Valley, contained within the pilot phase of the CBWMF.

As per the LCK, clusters within each Regional Landscape are described by the underlying characteristics of the watersheds they contain. The distribution of these watershed characteristics, grouped according to cluster, can be visualized by both radar (Figure 5) and density plots (Figure 6).

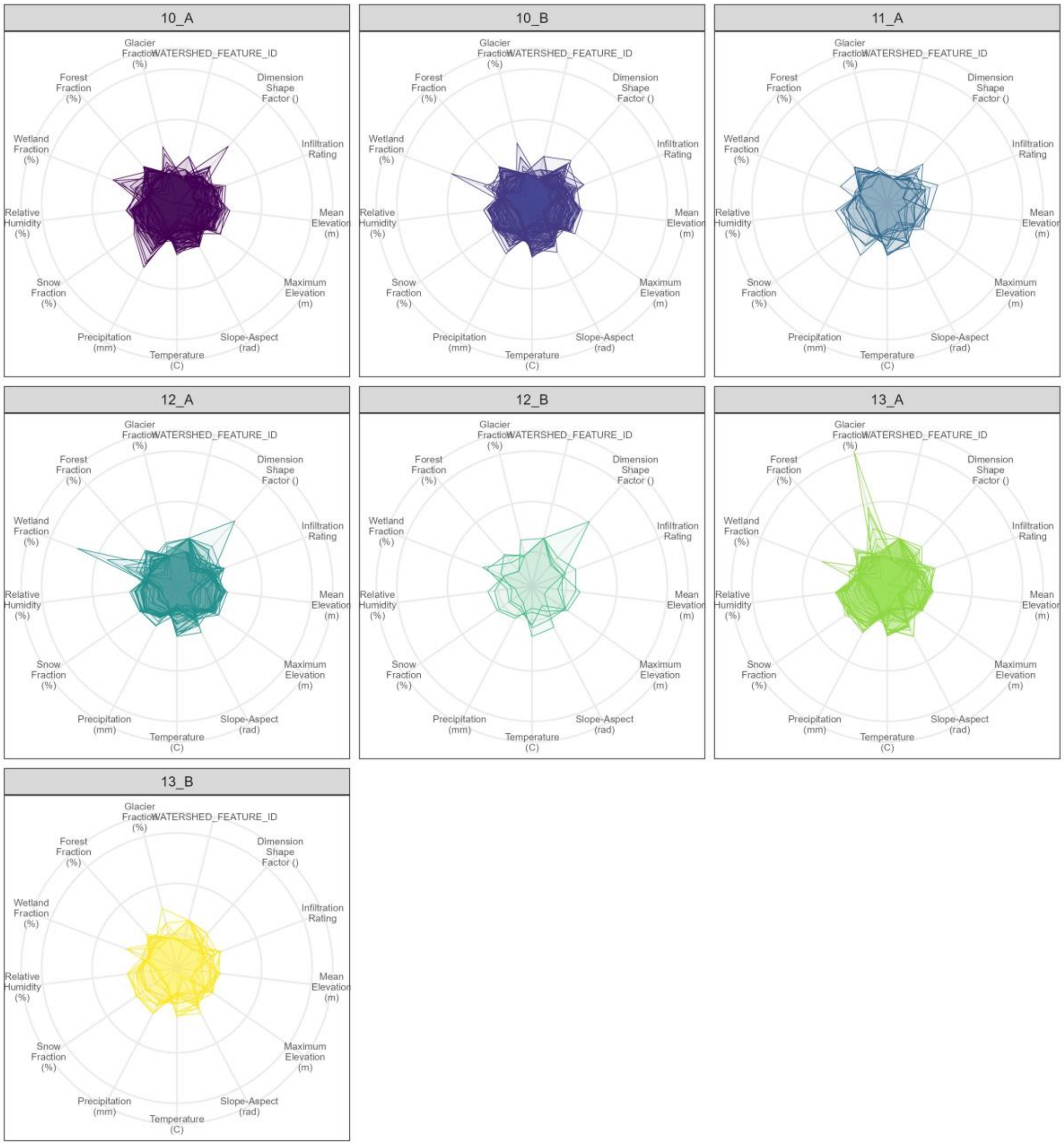

Figure 5 Radar plot for clusters within the Upper Kootenay region

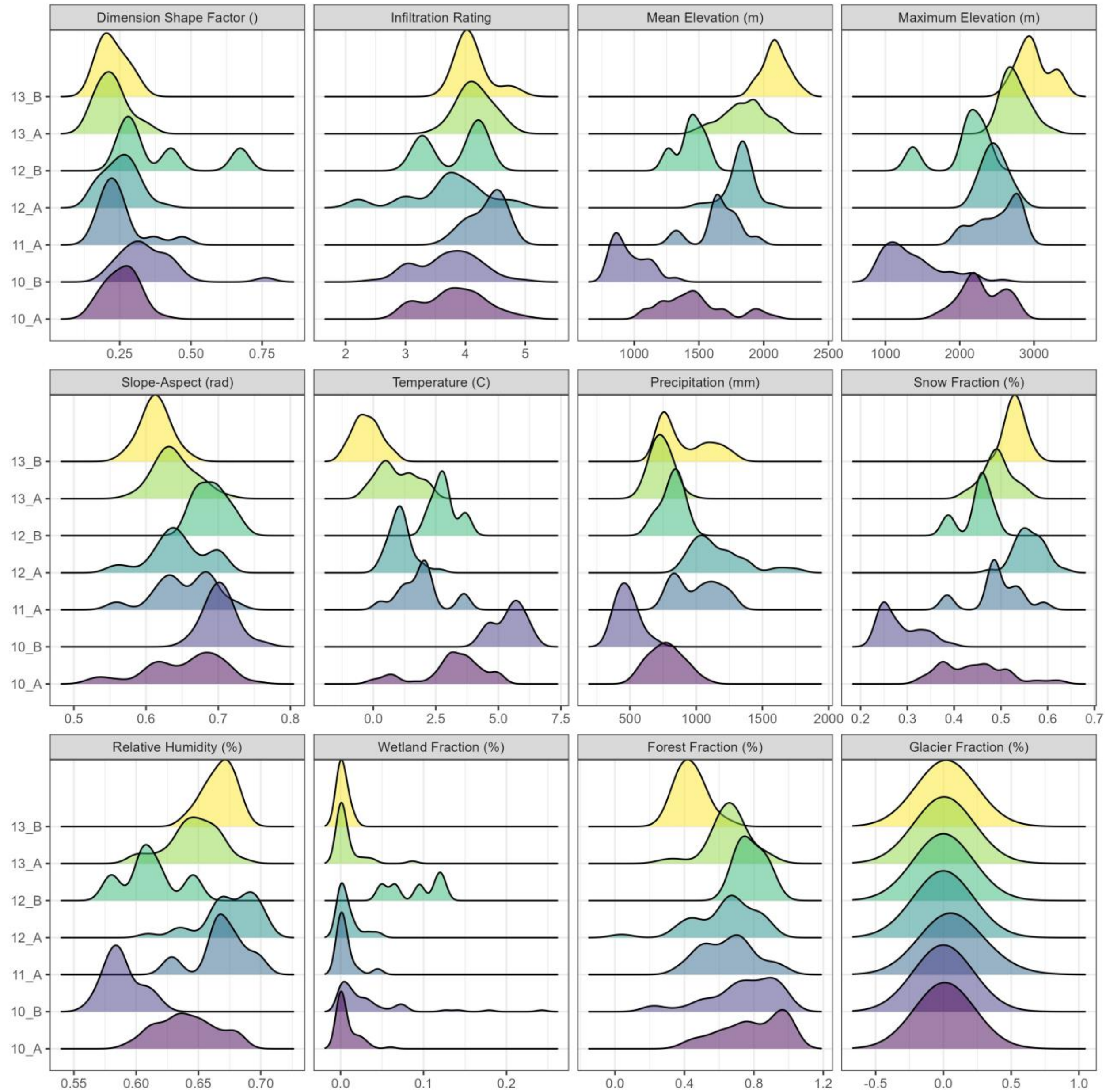

Figure 6 Density plots for clusters within the Upper Kootenay region

As per the LCK watersheds, qualitative descriptions of each cluster can be derived using the characteristics of the watersheds that comprise them (as shown in Figure 5 and Figure 6). A description of each cluster by Regional Landscape is provided below.

Tobacco Plains Kootenay River Regional Landscape

Regional Landscape characteristics: Dry, Southern East Kootenay Climate

Cluster analysis resulted in two (2) distinct watershed clusters:

- 10A: Mid to high elevation watersheds that are relatively dry and warm. Small segment of watersheds at high elevations with high snow fraction (i.e., most precipitation falls as snow versus rain). Mostly forested watersheds with non-forested areas at high elevation alpine areas.

- 10B: Low elevation watersheds that are warm and dry with a relatively low snow fraction (i.e., most precipitation falls as rain versus snow). Mostly forested with wetlands at the low elevations.

Lower Elk-Bull River Regional Landscape

Regional Landscape characteristics: Moist Southern East Kootenay Climate

Cluster analysis resulted in one (1) distinct watershed cluster:

- 11A: Relatively high elevation watersheds within proximity to the Bull River. Relatively cool and moist watersheds with higher relative humidity and high infiltration rating. Mostly forested watersheds with non-forested areas in the upper alpine areas. May have small remnant glaciers at the highest elevations.

Flathead-South Rockies Regional Landscape

Regional Landscape characteristics: Dry South Rockies Climate

Cluster analysis resulted in two (2) distinctive watershed clusters:

- 12A: Mid-high elevation watersheds that are relatively cool and moist. Most of the precipitation falls as snow versus rain within a year. Mostly forested with significant unforested area within the alpine elevations.
- 12B: Mid elevation watersheds that are warmer and slightly drier than watersheds in 12A, with a lower snow fraction than 12A. Mostly forested, with significant wetland areas at the lowest elevations.

White River-Bull-Elk Headwaters Regional Landscape

Regional Landscape characteristics: Dry South Rockies Climate

Cluster analysis resulted in two (2) distinctive watershed clusters:

- 13A: High elevation watersheds that are relatively cold and dry. Approximately 50% of the yearly precipitation falls as snow versus rain. Mostly forested watersheds with some small wetlands distributed throughout.
- 13B: High elevation watersheds that are cooler and wetter than 13A with a higher snow fraction and relative humidity. A lower forest fraction than 13A due to more alpine areas at high elevation.

3 Finding Monitoring Gaps: Existing Monitoring Networks

The next step within the gap analysis was to determine the location of existing hydroclimatic monitoring stations within each of the watershed clusters. Briefly, the intent of this analysis was to determine which clusters within the two Areas of Interest are underrepresented in terms of active hydrologic and climate monitoring, and thus would serve as good candidates for expanded monitoring.

This iteration used the same data networks as per Lapp et al (2022); briefly, active and inactive hydrometric and climate monitoring locations were determined by examining existing provincial and federal government networks. Active and inactive monitoring sites within each of the two new Areas of Interest were identified according to which watershed cluster they fall within.

Both hydrometric and climatic monitoring networks were examined. In terms of hydrometric monitoring, stations operated by the Water Survey of Canada (WSC) were considered within the gap analysis as they have well defined data quality protocols and procedures, with a known standard for resultant hydrometric data. Other entities may operate hydrometric monitoring stations within the Areas of Interest (for example, provincial and regional governments). However, these monitoring networks may have differing data availability, access, and quality. Although these stations were thus not included within the technical gap analysis, they were considered within the community engagement process undertaken by LLC.

Climate monitoring stations were considered from several different monitoring networks, including those operated by Environment and Climate Change Canada (ECCC), the provincial government (including networks maintained by the Ministry of Environment and Ministry of Transport), BC Hydro, and the Agricultural and Rural Development Act Network (see Table 4, Lapp et al., 2022). Climate monitoring networks are operated for different purposes, and thus comprise a range of data parameters and quality collected over different time periods, where the most directly comparable networks to the purpose of the CBWMF are likely ECCC and automated snow weather stations operated by the Ministry of Environment and BC Hydro. Other networks, such as those operated by the Ministry of Transport, may be comparable on a site-by-site basis depending on what parameters the station collects, data ranges, and data quality.

Within the 2023 analysis, the density of each type of active monitoring (hydrometric versus climatic) was calculated by dividing the number of active stations by the proportion of the total area within a particular cluster. This analysis focused on active stations as this is the closest comparison to data collected by stations implemented as part of the CBWMF program (i.e., stations will collect similar types of data over a similar time frame). The location of inactive stations of both types was examined as a subsequent consideration as they serve as potential locations for further monitoring (i.e., restoration of historic monitoring). Additionally, only WSC sites on unregulated streams were considered within the density calculation given that the behavior of regulated streams are dictated more by upstream storage and regulation versus natural processes.

Lastly, the relative density of stations within each of the clusters was used as the primary metric for recommending further monitoring but was not the only metric. Other considerations included those used within the previous analysis (Lapp et al., 2022):

- Was there an active climate station near the watershed that would be representative of precipitation, snow depth and air temperature?

- Does the recommended hydrometric network cover a range of watershed scales and elevations? Does it capture smaller watersheds (i.e., less than 100 km^2)?
- Does the recommended site within the representative watershed of each Watershed Group drain a large lake or wetland complex (store runoff) that would not represent discharge in another ungauged watershed?
- Was there a discontinued hydrometric station that could be re-activated?
- Does the proposed site location have road or easy access?

3.1 Lower Columbia Kootenay (LCK)

The section below describes the active monitoring network density for both hydrometric and climate stations within the Lower Columbia Kootenay (LCK) Area of Interest.

3.1.1 Hydrometric Monitoring Locations - LCK

Figure 7 shows active Water Survey of Canada stations within the LCK Area of Interest. Metadata describing these active stations is shown in Table 8 (Appendix 6.1).

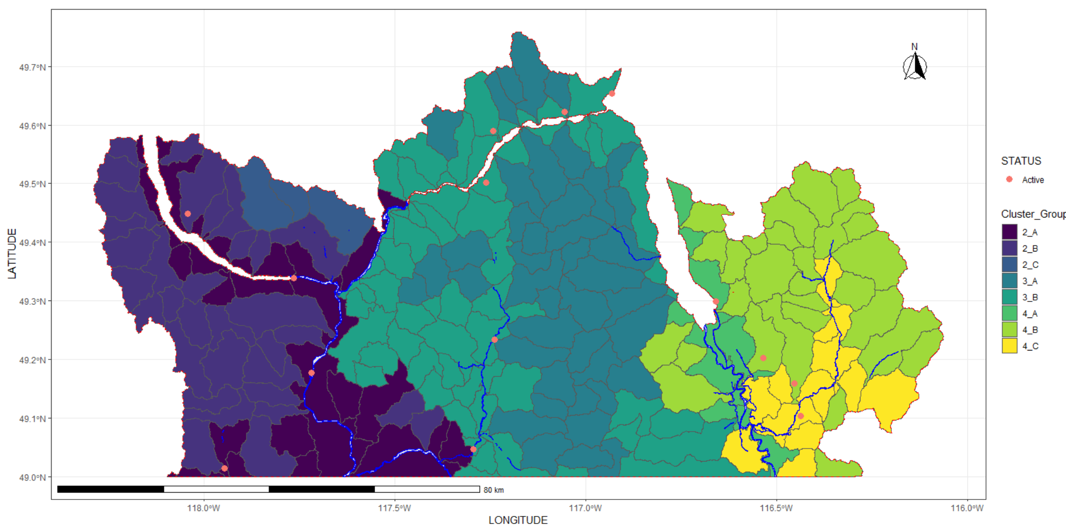

Figure 7 Active Water Survey of Canada Sites: LCK

Table 2 shows the number of active Water Survey of Canada sites within each of the clusters across all Regional Landscapes within the LCK. The density of WSC stations ranges from 0 stations/percent of overall region (in 2C and 4A) to 17 stations/percent of overall region (in cluster 4C). Both clusters 2C and 4A are relatively small both in terms of absolute area and percent of overall region.

Table 2 Water Survey of Canada Station density by watershed cluster: LCK

Cluster Group	Active Water Survey of Canada Stations	Cluster Area (km^2)	Percent of Overall Region (%)	WSC Station Density
2_A	3	1025	12	8
2_B	1	1442	17	6
2_C	0	209	2	0
3_A	2	1828	21	9
3_B	4	1981	23	13
4_A	1	304	4	0
4_B	2	1290	15	13
4_C	1	497	6	17

As previously discussed, station density was used as a broad metric to determine where additional monitoring could be most useful, given current gaps. Table 3 shows clusters ranked in terms of priority, based on the relative density of active stations along with the other considerations previously identified.

Table 3 Rationale for focusing further monitoring activities

Cluster Group	Priority	Justification
3_A	1	21% of the region; only 2 sites (density = 9).
2_B	2	17% of the region; only 1 WSC site (density = 6)
2_A	3	12% of the region; only 1 unregulated site (density = 8)
4_B	4	15% of the region, 2 unregulated stations

3.1.2 Climate Monitoring Locations - LCK

The density of climate active climate monitoring locations was also determined across the entire LCK. Figure 8 shows active climate monitoring locations across the LCK (active sites only), while Table 9 (Appendix 6.1) lists the metadata for all active climate sites within the LCK by cluster.

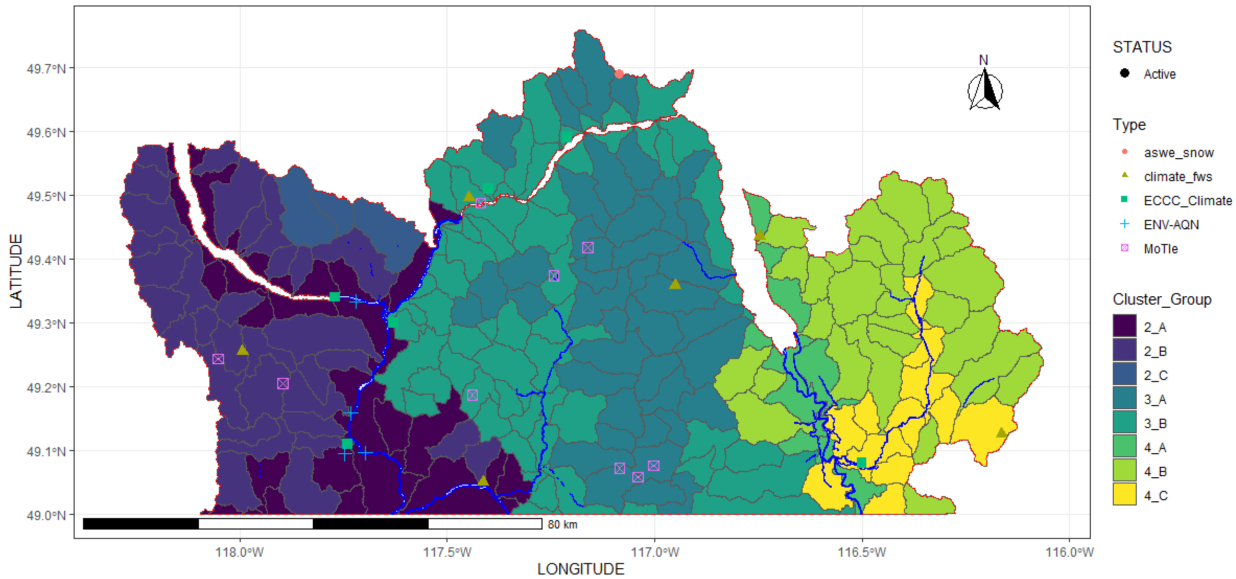

Figure 8 Active climate monitoring stations in the Lower Columbia Kootenay region

As per hydrometric stations, the density of climate monitoring stations within each cluster was determined by dividing the number of stations within a cluster by the percentage of area that that cluster represents of the total Area of Interest. The number of stations by cluster, along with climate station density, is shown in Table 4. Climate station densities ranged from 0 stations/percent of region in clusters 2C and 4B to 50 stations/percent of region in cluster 4C. Note that station densities were not the only considerations in determining placement of future monitoring stations, especially considering differences between monitoring networks in terms of data quality, data length, and biases in station location (for example, most ECCC stations are located at or near valley bottoms).

Table 4 Active climate monitoring stations in the Lower Columbia Kootenay region

Cluster Name	ECCC	Fire Weather Stations	MoTi (Electronic)	MoTi (Manual)	Automated Snow Weather Station	Cluster Area (km^2)	Percent of Total Region (%)	Climate Station Density
2_A	5	0	0	0	0	1025	12	42
2_B	1	2	2	0	0	1442	17	18
2_C	0	0	0	0	0	209	2	0
3_A	0	1	4	0	1	1828	21	10
3_B	2	1	3	0	0	1981	23	13
4_A	0	1	0	0	0	304	4	25
4_B	0	0	0	0	0	1290	15	0
4_C	2	1	0	0	0	497	6	50

3.2 Upper Kootenay (UK)

The section below describes the active monitoring network density for both hydrometric and climate stations within the Upper Kootenay Area of Interest.

3.2.1 Hydrometric Monitoring Locations - UK

Figure 9 shows active Water Survey of Canada stations within the Upper Kootenay Area of Interest. Metadata describing these active stations is shown in Table 10 (Appendix 6.2).

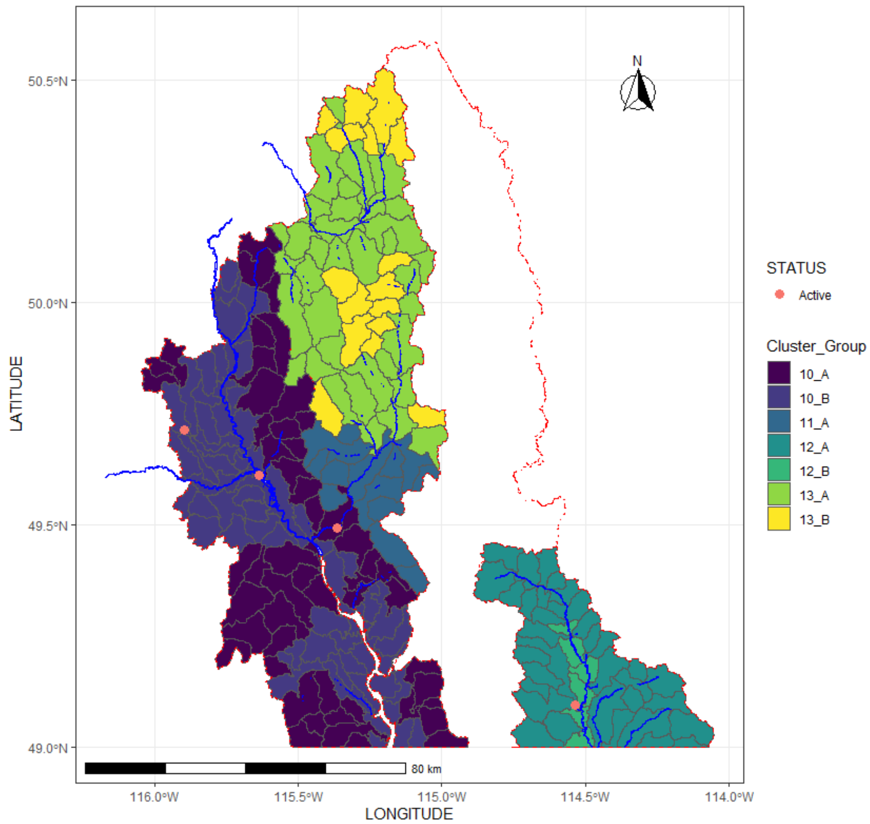

Figure 9 Active Water Survey of Canada sites: UK

There are only four (4) active WSC stations across the entire UK region, one of which is regulated (i.e., flows are controlled mainly by upstream reservoirs). Table 5 shows the number of active Water Survey of Canada sites within each of the clusters. The density of WSC stations ranges from 0 stations/percent of overall region (in 10A, 11A, 12B, 13A and 13B) to 9 stations/percent of overall region (in 10B).

Table 5 Water Survey of Canada Station density by watershed cluster: UK

Cluster Group	Active Water Survey of Canada Stations	Cluster Area (km²)	Percent of Overall Region (%)	WSC Station Density
10_A	1	2238.068	25	0
10_B	2	2091.296	22.96	9
11_A	0	627.3462	6.89	0
12_A	1	1407.778	15.45	6
12_B	0	163.5645	1.8	0
13_A	0	1850.607	20.31	0
13_B	0	731.6764	8.03	0

Station density was used as a broad metric to determine where additional monitoring could be most useful; however, many cluster groups have no hydrometric monitoring, given the low number of overall stations through the UK. Table 6 shows clusters ranked in terms of priority, based on the relative density of active stations, alongside a justification for the ranking.

Table 6 Monitoring priorities in the Upper Kootenay

Cluster Group	Priority	Justification
10_A	1	25% of the region; no monitoring of unregulated sites
13_A	2	20% of the region; no monitoring
13_B	3	8% of the region; no monitoring
11_A	4	7% of the region; no monitoring
10_B	5	22% of the region; 1 WSC station on small creek

3.2.2 Climate Monitoring Locations - UK

Next, the density of climate active climate monitoring locations was determined across the entire UK. Figure 10 shows active climate monitoring locations across the UK (active sites only), while Table 11 (Appendix 6.2) lists metadata for all active climate sites within the UK by cluster.

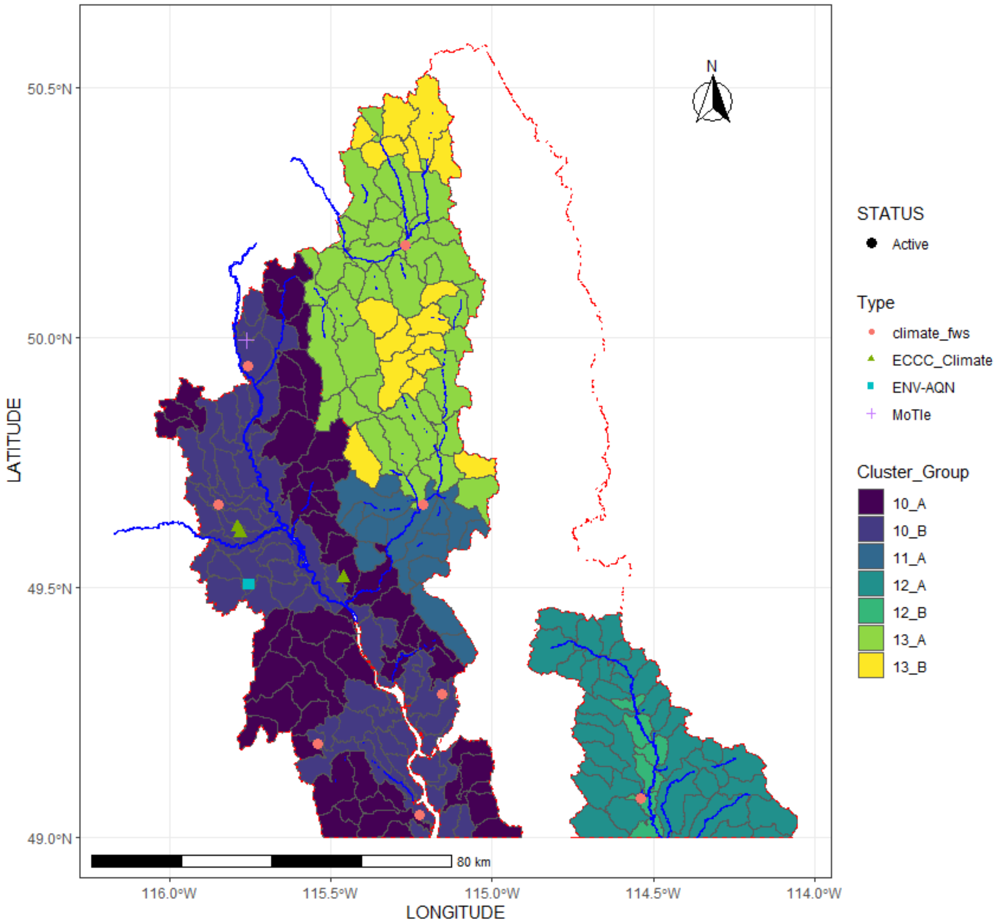

Figure 10 Active climate monitoring stations in the Upper Kootenay region

As per hydrometric stations, the density of climate monitoring stations within each cluster was determined by dividing the number of stations within a cluster by the percentage of area that that cluster represents of the total Area of Interest. The number of stations by cluster, along with climate station density, is shown in Table 7. Climate station densities ranged from 0 stations/percent of region (in clusters 12A and 13B) to 56 stations/percent of region in cluster 12B.

Table 7 Active climate monitoring stations in the UK region

Cluster Name	ECCC	Fire Weather Stations	MoTi (Electronic)	MoTi (Manual)	Automated Snow Weather Station	Cluster Area (km^2)	Percent of Total Region (%)	Climate Station Density
10_A	1	1	0	0	0	2238	25	8
10_B	2	4	1	0	0	2091	23	26
11_A	0	1	0	0	0	627	7	15
12_A	0	0	0	0	0	1408	15	0
12_B	0	1	0	0	0	164	2	56
13_A	0	1	0	0	0	1851	20	5
13_B	0	0	0	0	0	732	8	0

4 Next Steps

Hydroclimatic monitoring is a long-term commitment that requires a significant investment in resources and expertise. It is thus critical to ensure that the choice of where additional monitoring is implemented is made in a way that is scientifically robust, reflects community concerns, and does not replicate existing efforts to ensure resources are well spent over the long term. However, the hydrologic processes that monitoring seeks to examine are complex and can vary significantly spatially and temporally. Examining watersheds that are underserved by existing monitoring using their hydrologic characteristics is scientifically robust but can be difficult; many factors determine the hydrologic character and behavior of streams, and these factors can differ significantly over the landscape as well as change over time. Given this, any gap analysis is by nature a simplification of complicated natural systems with several different analytical approaches that could be appropriate, depending on monitoring aims and available resources.

The CBWMF is an evolving and expanding program, with the eventual aim of including all the Columbia Basin. Given this, we expect a continued need for analyzing gaps within hydroclimatic monitoring networks beyond the five Areas of Interest examined to date.

Continued dialogue between the many technical experts involved within the CBWMF have illustrated several opportunities for improvement within the current gap analysis approach:

- Firstly, it is important to understand the aims of the overall monitoring network in determining future monitoring locations. This dictates what is important to monitor; for example, is the aim of monitoring to understand how systems function generally across the Columbia Basin, or to monitor small watersheds that are relatively unique due to biophysical or anthropogenic circumstances?
- Examine the variables used to identify hydrologic characteristics within a watershed and identify whether additional variables are needed. There were two specific critiques of variables used within the current analysis. The first critique is that current variables correlate with watershed elevation, and the resultant analysis is thus too biased towards watershed elevation. The second connected critique is that variables describing underlying watershed geology (beyond the infiltration factor) need better representation within the gap analysis. Such data is not easily available for most watersheds and will have to be developed prior to integration within an updated clustering analysis.
- As the CBWMF expands there are benefits to looking at the basin, rather than on a region-by-region basis. Many Areas of Interest, especially those proximal to each other, are likely to have similar watersheds that are separated into different Areas of Interest used within the CBWMF. It would thus be useful to pre-plan the rollout of the monitoring program across the entire spatial scale of the Columbia Basin to ensure that monitoring is not duplicating effort across Areas of Interest.
- There is a relative paucity of hydroclimatic monitoring across the entire Columbia Basin. The UK is a good example of this, as it has only three WSC stations on unregulated streams. It is likely less consequential to understand minute differences between watersheds in scenarios where there is very little existing monitoring. Thus, the complexity of a future gap analysis must be weighed against the resources necessary to do so. A good gap analysis should provide scientifically robust guidance for watersheds best served by long-term monitoring without seeking to characterize hydrologic processes in all watersheds (a complex and difficult task).

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6 Appendices

6.1 Active Hydroclimatic Monitoring Station Metadata: LCK

Table 8 Active Water Survey of Canada Stations in the Lower Columbia Kootenay Region

Station Number	Station Name	Gross Drainage Area (km^2)	Cluster Group	Elevation (m.a.s.l)	LATITUDE	LONGITUDE	Regulation	Record Beginning	End of Record	RECORD LENGTH (years)
08NE039	BIG SHEEP CREEK NEAR ROSSLAND	347	2_A	2096	49.01465	-117.9453	FALSE	1929	2021	75
08NE049	COLUMBIA RIVER AT BIRCHBANK	87400	2_A	1856	49.17784	-117.7177	TRUE	1937	2021	85
08NE126	ARROW RESERVOIR OUTFLOW	NA	2_A	1565	49.33889	-117.7642	TRUE	1973	2019	46
08NE087	DEER CREEK AT DEER PARK	81.6	2_B	2333	49.44847	-118.042	FALSE	1958	2021	64
08NE114	HIDDEN CREEK NEAR THE MOUTH	56.7	3_A	2227	49.23454	-117.2392	FALSE	1973	2021	49
08NJ061	REDFISH CREEK NEAR HARROP	27.2	3_A	2321	49.62257	-117.0557	FALSE	1967	2021	50
08NE074	SALMO RIVER NEAR SALMO	1240	3_B	1632	49.04714	-117.2943	FALSE	1949	2021	73
08NH064	KOOTENAY LAKE AT QUEENS BAY	NA	3_B	2321	49.65404	-116.9303	TRUE	NA	NA	NA
08NJ026	DUHAMEL CREEK ABOVE DIVERSIONS	52.9	3_B	2326	49.59031	-117.2423	FALSE	1922	2021	30
08NJ130	ANDERSON CREEK NEAR NELSON	9.07	3_B	2070	49.50195	-117.2613	FALSE	1945	2021	62
08NH067	KOOTENAY LAKE AT KUSKONOOK	NA	4_A	2121	49.29882	-116.6596	TRUE	NA	NA	NA
08NH016	DUCK CREEK NEAR WYNNDEL	57	4_B	2158	49.20263	-116.5339	FALSE	1921	2021	57
08NH084	ARROW CREEK NEAR ERICKSON	78.3	4_B	2174	49.15912	-116.4525	FALSE	1945	2021	66
08NH115	SULLIVAN CREEK NEAR CANYON	6.22	4_C	2123	49.10427	-116.4368	FALSE	1958	2021	60

Table 9 Metadata for Active Climate Stations in the LCK

Cluster Group	Station Number	Station Name	Elevation (m.a.s.l)	Status	LATITUDE	LONGITUDE	Owner
2_A	1105	CASTLEGAR A	495.6	Active	49.3	-117.63	ECCC
2_A	1106	CASTLEGAR BCHPA DAM	435	Active	49.34	-117.77	ECCC
2_A	51458	CASTLEGAR A	495.6	Active	49.3	-117.63	ECCC
2_A	52938	CASTLEGAR A	495.6	Active	49.3	-117.63	ECCC
2_A	52938	CASTLEGAR A	495.6	Active	49.3	-117.63	ECCC
2_B	31067	WARFIELD RCS	566.9	Active	49.11	-117.74	ECCC
2_B	402	PENDOREILLE	725	Active	49.05056	-117.414	Fire Weather
2_B	407	NANCY GREEN	1397	Active	49.2545	-117.994	Fire Weather
2_B	2751	Strawberry Pass	1600	Active	49.20444	-117.897	MoTIe
2_B	2764	Paulson Summit	1535	Active	49.24368	-118.052	MoTIe
3_A	1203	DARKWOODS	1657	Active	49.35761	-116.95	Fire Weather
3_A	2D14P	Redfish Creek	2100	Active	49.69008	-117.087	ASWE
3_A	2746	Southridge	1990	Active	49.41778	-117.161	MoTIe
3_A	2825	Kootenay Pass	1780	Active	49.05806	-117.04	MoTIe
3_A	2826	Stagleap	2140	Active	49.07161	-117.084	MoTIe
3_A	12483	Crags Ridge	2054	Active	49.07644	-117.002	MoTIe
3_B	1095	NELSON RIXEN CREEK	760	Active	49.51	-117.4	ECCC
3_B	1137	NELSON NE	570	Active	49.59	-117.21	ECCC
3_B	404	SMALLWOOD	997	Active	49.49667	-117.448	Fire Weather
3_B	2742	Hall Creek	860	Active	49.37333	-117.243	MoTIe
3_B	11023	Beasley Bluffs	580	Active	49.48772	-117.42	MoTIe
3_B	12472	Meadows Junction	700	Active	49.18708	-117.44	MoTIe
4_A	838	AKOKLI CREEK	821	Active	49.4358	-116.746	Fire Weather
4_C	6838	CRESTON CAMPBELL SCIENTIFIC	640.7	Active	49.08	-116.5	ECCC
4_C	6838	CRESTON CAMPBELL SCIENTIFIC	640.7	Active	49.08	-116.5	ECCC

4_C	401	GOATFELL	1098	Active	49.12533	-116.164	Fire Weather

6.2 Active Hydroclimatic Monitoring Station Metadata: UK

Table 10 Active Water Survey of Canada Stations in the Upper Kootenay Region

Station Number	Station Name	Gross Drainage Area (km^2)	Cluster Group	Elevation (m.a.s.l)	Latitude	Longitude	Regulation Status	Record Beginning	End of Record	RECORD LENGTH (years)
08NG002	BULL RIVER NEAR WARDNER	1520	10_A	2572	49.49362	-115.366	TRUE	1914	2021	103
08NG065	KOOTENAY RIVER AT FORT STEELE	11500	10_B	1032	49.61203	-115.635	FALSE	1963	2021	59
08NG076	MATHER CREEK BELOW HOULE CREEK	135	10_B	2156	49.71366	-115.897	FALSE	1972	2021	50
08NP003	HOWELL CREEK ABOVE CABIN CREEK	145	12_A	2532	49.09472	-114.536	FALSE	1977	2021	2

Table 11 Metadata for Active Climate Stations in the UK

Cluster Group	Station Number	Station Name	Elevation (m.a.s.l)	LATITUDE	LONGITUDE	Owner
10_A	1186	FT STEELE DANDY CRK	856	49.52	-115.46	ECCC
10_A	791	CHERRY LAKE	1372	49.18778	-115.542	Fire Weather
10_B	50818	CRANBROOK A	940	49.61	-115.78	ECCC
10_B	51818	CRANBROOK AIRPORT AUTO	926.69	49.62	-115.79	ECCC

10_B	1075	KOOCANUSA	804	49.04694	-115.225	Fire Weather
10_B	412	ELKO	775	49.28767	-115.155	Fire Weather
10_B	426	CRANBROOK	996	49.6673	-115.848	Fire Weather
10_B	419	JOHNSON LAKE	853	49.94444	-115.758	Fire Weather
10_B	2783	Canal Flats	870	49.99444	-115.761	MoTIe
11_A	886	GOATHAVEN	1051	49.6673	-115.214	Fire Weather
12_B	418	FLATHEAD 2	1311	49.07914	-114.537	Fire Weather
13_A	790	WHITE RIVER	1357	50.185	-115.268	Fire Weather