AN ONLINE WORKSHOP:

# EXPANDING WATER MONITORING WITHIN CANADA'S UPPER COLUMBIA BASIN

Hosted by Living Lakes Canada • June 8, 2020 • 9 a.m. - 3 p.m. PT

PHOTO: DAMIEN RICHARD
LAKE OF THE HANGING GLACIER, PURCELL MOUNTAINS

# WORKSHOP PROCEEDINGS

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## EXECUTIVE SUMMARY


The Columbia Basin Water Monitoring Collaborative (Collaborative) exists as a collective effort to help answer questions about hydrologic conditions affecting communities and ecosystems. Its impetus came out of reports published by the Columbia Basin Trust in 2017 and 2019 detailing how Basin water data are inadequate for managing and protecting the region's water resources in response to climate change. The Collaborative was created to coordinate water data collection with a focus on clarifying 'why' monitoring is needed, 'what' data are needed and 'who' will be responsible for actually doing the monitoring. The vision for the Collaborative is that it becomes an independent, stand-alone entity with a provincially-legitimized governance structure. It is recognized that cooperation among various levels of governments including First Nations, community water-stewardship groups, industry sectors and academia is needed for this vision to be realized. Currently, the Collaborative is finalizing an open source data hub as a repository for housing and accessing water monitoring data collected by groups operating within the Basin. The increased frequency of extreme events and the projected decreases in low flows both suggest some urgency to get a scientifically-based monitoring system in place so that we can understand these changes and mitigate the growing risks.

On June 8th 2020, Living Lakes Canada convened and facilitated a hydrology workshop with the purpose of developing recommendations for a phased expansion of the monitoring network for the Upper Columbia Basin (UCB). The workshop objectives were: to develop criteria for selecting (priority) watersheds to be included in a regional watershed monitoring network; identify monitoring needs related to scientific objectives; to develop a process for ranking monitoring needs in terms of both site locations and measured parameters; and describe a potential phased implementation. Greg Utzig, PAg, and Dr. Martin Carver, PEng/PGeo, PAg, provided a proposed approach to expanding the UCB monitoring network, and then the 27 workshop participants actively engaged with the proposal, providing feedback on how it might be improved and implemented.

Priorities for monitoring were identified within a scientific framework that distinguishes hydrologic variability according to known variations in climate within the UCB. Within this broad framework of the UCB's 10 hydrologic regions (CBT 2017), workshop participants discussed setting priorities based on hydrologic and terrain characteristics, compelling scientific questions, and prevailing resource issues. Discussions concluded that the monitoring network should take into account the full range of variation of potential watershed response within the UCB, while also emphasizing watersheds critical to biodiversity conservation, community sustainability, and ecosystem resilience in the face of climate disruption. Potential monitoring is effectively infinite but resources are limited, thus the proposed network build-out must carefully balance the relative importance of site locations and monitoring parameters. That balance should efficiently address climate and landscape variability while recognizing the need to increase understanding of ecosystem requirements and risks, community sustainability and hydrologic impacts of climate change. Implementation of the approach will require the further refinement of the overarching Collaborative, including active participation of various levels of government including First Nations.

It is expected that implementation of the approach will involve a two-stage technical process. A standing scientific advisory committee could be established to identify subregions and provide preliminary descriptions of the individual hydrologic responses of the subregions to disturbance and change. This stage would focus on initial landscape stratification criteria. The second stage would involve subregional groups with localized expertise and knowledge. These groups would identify the shortlist of actual proposed monitoring sites. This work would be shaped by Traditional Ecological Knowledge, Western science, and local socio-economic priorities, and could be funded through the Collaborative after it has adopted a governance model that supports implementation of the recommendations arising from this report.

# 1.0 INTRODUCTION

## 1.1 Meeting Purpose and Objectives

Water resources are changing rapidly during a general and long-term decline in monitoring effort. Pressing water-resource issues present at local and regional scales reflect a range of escalating pressures on resources and include climate impacts such as extreme precipitation, flooding and fire events. Site-specific reactive monitoring can never satisfy the myriad of data requirements of all local water issues. Variability in hydrologic response across the Columbia Basin is too great to be sufficiently understood based on current monitoring. Additionally, under the Water Sustainability Act, current regulatory tools such as water objectives and Water Sustainability Plans (WSPs) both depend on appropriate long-term monitoring data for success. As a result, there is a growing need to refocus when planning future monitoring to carefully allocate limited resources to meet multiple scientific objectives.

On June 8th 2020, Living Lakes Canada (LLC) convened and facilitated a senior hydrologist workshop. The workshop was by invite, with the purpose of developing recommendations for a phased expansion of the water (and water-related) monitoring network of the Upper (Canadian) Columbia Basin (UCB). Priorities for monitoring were identified within a scientific framework that distinguishes hydrologic variability according to known variations in climate within the UCB. Within this broad framework of the UCB's 10 hydrologic regions (CBT 2017), workshop participants discussed setting priorities based on hydrologic and terrain characteristics, compelling scientific questions, and prevailing resource issues.

These considerations go beyond what is needed to serve the Columbia River Treaty and its renegotiation because the monitoring network must address and support a wider array of issues and activities. It was intended that the workshop outcome support the subsequent design of a monitoring strategy for the UCB. Ultimately, the UCB monitoring network should take into account the full range of variation of potential watershed response within the UCB, while also emphasizing watersheds critical to biodiversity conservation, community sustainability, and ecosystem resilience in the face of climate disruption.

The workshop objectives were:

1. Develop criteria for selecting (priority) watersheds to be included in a regional watershed monitoring network.

2. Identify monitoring needs related to scientific objectives that can be part of an expanded watershed monitoring network.

3. Identify a process to rank the implementation of potential water-related monitoring in terms of both the site locations and measured parameters and describe a potential phased long-term implementation.

Potential monitoring is effectively infinite but resources are limited, thus the proposed network build-out must carefully balance the relative importance of site locations and monitoring parameters. That balance should efficiently address climate and landscape variability while recognizing the need to increase understanding of ecosystem requirements and risks, community sustainability and hydrologic impacts of climate change.

## 1.2 Participants

The following individuals attended the workshop:

- Alan Thomson, Mountain Station Consultants
- Antonio Barroso, GW Solutions
- Avery DeBoer Smith, Living Lakes Canada
- Bill Coedy, Rossland Streamkeepers
- Bill Thompson, Columbia Lake Stewardship Society
- Carol Luttmer, Living Lakes Canada
- Chad Hughes, Elk River Alliance, Columbia Basin Watershed Network
- Dr. R.D. (Dan) Moore, University of British Columbia
- David Hutchinson, Water Survey of Canada
- Dr. David Wilford, BC Ministry of Forests Lands and Natural Resource Operations & Rural Development
- Ed Gillmor, Columbia Lake Stewardship Society, Columbia Basin Watershed Network
- Dr. Gilles Wendling, GW Solutions
- Greg Utzig, Kutenai Nature Investigations
- Dr. Janice Brahney, Utah State University
- Jeff Burrows, BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development
- Kat Hartwig, Living Lakes Canada
- Kyle Prince, Living Lakes Canada
- Dr. Martin Carver, Aqua Environmental Associates
- Dr. Natasha Neumann, BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development
- Neil Goeller, BC Ministry of Environment and Climate Change Strategy
- Dr. Paul Bach, Living Lakes Canada Board
- Raegan Mallinson, Living Lakes Canada
- Ryan MacDonald, MacDonald Hydrology Consultants
- Samuel Lyster, BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development
- Stephanie Merrill, Global Water Futures
- Stephen O'Hearn, Global Water Futures
- Dr. Suzanne Bayley, University of Alberta, Columbia Wetlands Stewardship Partners
- Tom Dance, Columbia Lake Stewardship Society

## 1.3 Acronyms and Abbreviations

| | |
|---|---|
| BBC | Bonanza Biodiversity Corridor |
| FLNRORD | BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development |
| MoE | BC Ministry of Environment and Climate Change Strategy |
| MoTI | BC Ministry of Transportation and Infrastructure |
| Collaborative | Columbia Basin Water Monitoring Collaborative |
| CBM | Community-based monitoring |
| CBT | Columbia Basin Trust |
| CBWN | Columbia Basin Watershed Network |
| CLSS | Columbia Lake Stewardship Society |
| DEM | Digital Elevation Model |
| ECCC | Environment and Climate Change Canada |

| | |
|---|---|
| FWCP | Fish & Wildlife Compensation Program |
| GW | Groundwater |
| LLC | Living Lakes Canada |
| MCK | Mid Columbia-Kootenay (Hydrologic Region) |
| NKLWMP | North Kootenay Lake Water Monitoring Project |
| PCIC | Pacific Climate Impacts Consortium |
| QA/QC | Quality assurance, quality control |
| RL | Regional Landscape |
| UCB | Upper Columbia Basin |
| WSA | Water Sustainability Act |

## 2.0 BACKGROUND

### 2.1 Living Lakes Canada

Living Lakes Canada (LLC) is a not-for-profit, charitable non- governmental organization, whose work on water stewardship has its roots in the UCB. LLC bridges the gap between science and action to help normalize and enhance water stewardship ethics and practices across Canada. LLC engages communities and decision makers to better understand the interdependence between land use, biodiversity, climate change, water quality, water quantity, and the actions required to maintain ecosystem health to build climate resilient communities. For further information about LLC, see livinglakescanada.ca.

### 2.2 Columbia Basin Water Monitoring Collaborative

In the past few decades, the federal and provincial governments have reduced their hydrometric monitoring, especially on smaller streams. Because existing monitoring networks predate the need for regional climate impacts monitoring, the current network does not represent an optimal configuration for tracking and understanding the full range of implications of climate change on water supply for UCB ecosystems and people.

Two Columbia Basin Trust (CBT) reports — *Water Monitoring and Climate Change in the Upper Columbia Basin: Summary of Current Status and Opportunities* (CBT 2017) and *Guidance Information for Planning Monitoring Programs* (Carver 2019) — identify water-related knowledge gaps in the UCB and outline preliminary guidance for steps required to fill those gaps. These CBT-sponsored reports revealed that Basin water data is inadequate for managing and protecting the region's water resources in response to climate change.

These reports were also the premise and impetus for the Columbia Basin Water Monitoring Collaborative (Collaborative), a collective effort to build a coordinated approach to help answer local and regional scale questions about current and future hydrologic conditions affecting communities and ecosystems.

A monitoring collaborative for the UCB is an endeavor particularly relevant to the region's higher-volume users such as communities and municipalities, hydropower operators, agricultural producers, industrial operations, ski resorts (snowmaking), as well as commercial and residential users. It was envisioned that this monitoring framework would coordinate water data collection within the Basin through a collaborative process that clarified 'why' monitoring was needed, 'what' data were needed, 'who' would be responsible for the tasks outlined within the framework, and to provide guidance on how to choose 'where' to monitor. It is recognized that cooperation among governments including First Nations, community water stewardship groups, industry sectors and academia is needed for this vision to be realized.

A collaboratively designed structure for water monitoring can clarify why monitoring is needed and what the immediate, medium, and longer term priorities are, who is responsible for managing the framework and collecting data, as well as storing and making data/information easily accessible. Currently the Collaborative is finalizing an open source data hub as a repository for the many water monitoring groups within the UCB to house and access data. Monitoring groups will be supported in adhering to metadata standards, training, equipment and be provided with professional advice and in their ability to mobilize water data knowledge to decision makers for sound, sustainable policies in provision for healthy ecosystems that support healthy human and non- human communities. There are approximately 20 active water monitoring groups in the Columbia Basin and more than 30 groups that are members of the Columbia Basin Watershed Network. The vision is for the Collaborative to become an independent, stand-alone entity with a provincially-legitimized governance structure.

## 3.0 UCB WATER MONITORING AND HYDROLOGIC PRACTICE

The Collaborative is, in part, a response to the intensifying degree of climate disruption reshaping UCB water resources and geomorphic hazards as a result of extreme precipitation events, floods, droughts and landslides. The UCB has already experienced increases in temperature over the past decades, and these are projected to accelerate significantly over the coming decades (PCIC 2013). Climate modelling also projects decreases in summer precipitation, which combined with increased summer evapotranspiration, will result in decreased late summer stream flows (CBT 2017). These will impact fisheries in those streams, as well as water availability for domestic and irrigation users. Climate change will also significantly alter the vegetation communities within the basin watersheds (Holt *et al*. 2012).

Although winter precipitation is projected to increase, warmer temperatures mean that this precipitation will increasingly fall as rain rather than snow. In general, spring runoff will occur earlier than in the past, and may be more rapid. Extreme precipitation events may lead to local flooding, especially when they occur as rain-on-snow events. The June-2013 flooding in the Elk Valley, Buhl Creek, Fry Creek, Campbell Creek and other areas is an excellent example of the potential damage than can be associated with such events. Rapid snowmelt and spring precipitation in the Kettle/Granby area resulted in unprecedented damage to the Grand Forks area. Another extreme rainfall even in the spring of 2020 resulted in numerous evacuation alerts in the West Arm of Kootenay Lake. The text box below summarizes another impact on water availability in the UCB related to the decline of glaciers.

### 3.1 UCB Monitoring and Data Situation

The UCB network of water and water-related monitoring has ebbed and flowed over the past century in response to agency priorities. Hydrometric monitoring undertaken by the Water Survey of Canada (WSC) has generally been in decline since its peak in the 1980s and now focuses largely on larger watersheds. Largely situated in valley bottom locations, Environment Canada's climate network is supplemented by BC Hydro climate stations some of which are located at somewhat higher elevations. Water quality monitoring is carried out largely by Environment and Climate Change Canada and BC's Ministry of Environment and Climate Change Strategy, many sites in collaboration through the CABIN program. Additional sites are monitored for water quantity and/or water quality through community-based monitoring (CBM), and reflect local priorities. Monitoring at these CBM sites is vulnerable to the vagaries of funding. The combined monitoring network as it existed in 2017 has been compiled and provided in CBT (2017). Maps from that report are reproduced here in Appendix A3. Originally initiated in the UCB in the 1930s, the current extent of snow-survey sites has also declined somewhat from its 1980s peak.

Carver (2019) has evaluated the 2017 patchwork of monitoring sites resulting from this history. That compilation of monitoring sites is reproduced here in Tables 1, 2 and 3, according to hydrologic region and elevation. It is evident from this compilation (and further discussion in Carver 2019) that the site locations are not evenly distributed across the hydrologic regions and they are not suited well to address priority scientific questions, including many related to climate disruption. In particular, monitoring is inadequate at high elevation and there is very little monitoring of small- and medium-sized watersheds.

**Pace of Decline of Glaciers in the Upper Columbia Basin – findings from Moore *et al.* (2020)**

As glaciers melt due to global heating, downstream streamflow generally first increases, eventually peaking and then declining as glaciers retreat until they disappear or reach a new equilibrium. The duration of the rising phase can last from decades to over a century, varying with climatic conditions and basin slope. The duration of the phases of change is important for ecosystem management, land-use planning, water allocation and infrastructure development.

In 2005, 2078 glaciers were identified in the UCB, covering 1,750 $km^2$ (Bolch *et al.* 2010). These glaciers have experienced widespread retreat over recent decades, with implications for downstream streamflow. Moore *et al.* (2020) have carried out a regional statistical study of the relative effect of recent glacier changes and the streamflow changes from the unglacierized portions of these catchments. Between 1985 and 2013, glacier coverage decreased by up to 2% of catchment area for their 35 studied catchments. Their study design focused on a set of stations with a range of glacier cover, but with similar patterns of climatic variability over a common period of record, facilitating the partitioning of observed streamflow trends into components associated with climate-driven trends from unglacierized areas and those associated with glacier changes.

Glacier-melt flows generally occur in the summer and fall, thus augmenting critical low flows required for irrigation and domestic use. Using streamflow and climate data and information on glacier area and mass change, they found that the portion of annual catchment water yield from glacial melt increased with glacier coverage and decreased with catchment water yield. For catchments with over 10% glacier cover, glacier melt contributed 6% of the annual water yield from the mid-1980s to 1999. For more heavily glacierized catchments, the proportion increased to 10-15% of annual water yield during 2015–2019.

Trend analyses suggest that glacier-melt contributions to streamflow have already passed peak water in the UCB. Their analyses also indicated that there is a clear declining trend in the streamflow that would have been observed if glaciers had not retreated with clear implications for streamflow forecasting and summer water temperature response during hot, dry weather. Overall, they conclude, it appears that the Columbia River headwaters region is already in the process of beginning a post-peak decline in runoff. The magnitude and significance of the declines may get stronger over the coming decades, unless there is an increase in summer rainfall to compensate for reduced glacier melt.

Related background on changes to UCB glaciers can be found in chapters 4 and 5 of *Glaciers of the Columbia Basin, Technical Report* (Canadian Columbia Basin Glacier and Snow Research 2020).

If the network is to be expanded, how is that to be accomplished? A first step with any monitoring is to be clear on the monitoring objectives. If it is a composite network that is being expanded, it may need to address a wide range in objectives including status and trends, baseline and reference conditions, water quality objectives, calibration/validation of predictive models, emerging natural hazards/risks, water supply planning, guidance for land and water management, and even economic development and regulatory compliance. However, given that the impetus of the Collaborative (section 2.2, above) is shaped by climate disruption, it may be reasonable to establish the following objectives for the expanded monitoring: a) assessments of natural hazards, b) protection/restoration of ecosystems, c) safeguarding community stability, and d) sustainable economic development.

Tackling variability of water resources is the central scientific challenge in designing a monitoring network and particularly in an area like the UCB where variability is high. Climate is a fundamental driver of this variability due to it influencing the UCB's wide range in mean annual and seasonal patterns of temperature and precipitation, and the spectacular diversity of ecosystems that results. There are Pacific, continental and boreal climate influences in the UCB in addition to climate-mode effects particularly those resulting from the El Nino Southern Oscillation and the Pacific Decadal Oscillation. The UCB's north-south trending mountains strongly shape the region's climates with drier environments in the east, wetter ones in the north and hotter ones in the south. Land use complicates the evaluation of monitoring data by adding further variability related to impacts from diverse activities that are variable in their magnitude, breadth, persistence and reversibility.

Climate disruption amplifies these challenges. Rising temperatures, changing precipitation patterns, an increased frequency and magnitude of extreme events, a retreating cryosphere, and other changes are collectively changing both mean behaviour and variability of water resources in the UCB. In addition, given the trajectory of greenhouse gas emissions and the lag times inherent in the climate system, current changes will escalate long before they can stabilize.

Across a landscape as variable as the UCB, and now forced by an increasingly non-stationary climate, characterization of the UCB's contrasting and dynamic water resources places considerable demands on the design of the monitoring network. Given the reduced variability that tends to exist across larger basins and the ease of access of lower-elevation sites, it is perhaps not surprising that the current network emphasizes larger basins (streamflow; water quality) and lower-elevation sites (various parameters including climate metrics). Residents, resource managers, developers and others use available data sets to address their needs through a variety of means (introduced in section 3.3), however, these methodologies are increasingly being pushed to - and potentially beyond - their limit due to climate disruption.

The related workshop presentations are found at:

http://livinglakescanada.ca/wp-content/uploads/2020/10/LLC-hydro-monitoring-wkshp_Carver_Design-Challenges.pdf

http://livinglakescanada.ca/wp-content/uploads/2020/10/LLC-hydro-monitoring-wkshp_Carver_Scope-of-Scientific-Objectives.pdf

Table 1. Climate, snow and glacier monitoring sites (as of January 2017).

| Data Group | Provider | Status /Type | Hydrologic Region[1] | | | | | | | | | | | Elevation Range[2] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | All | CKH | UPK | UPC | NEC | NWC | MCK | LCK | SMM | CR | KI | lo | mid | hi |
| Climate | All | Annual | 122 | 13 | 28 | 7 | 6 | 25 | 10 | 29 | 3 | | 1 | 60 | 40 | 22 |
| | All | Seasonal | 32 | 5 | 1 | 1 | | 11 | 6 | 7 | 1 | | | 8 | 8 | 16 |
| | ECCC | Discontinued | 147 | 25 | 33 | 4 | 4 | 18 | 16 | 37 | 3 | 7 | | 46 | 66 | 33 |
| Snow | All | All | 53 | 8 | 3 | 4 | 2 | 15 | 6 | 7 | 5 | 1 | 2 | 4 | 11 | 37 |
| | MoE | Pillows | 9 | 1 | | 2 | 1 | 3 | 1 | | | | 1 | | | 9 |
| | MoE | Courses | 39 | 7 | 3 | 2 | 1 | 11 | 4 | 4 | 5 | 1 | 1 | 3 | 10 | 26 |
| | CBM | Course | 2 | | | | | | 1 | 1 | | | | | | 1 |
| Glacier | CBSGRN | Mass Balance | 5 | | | 2 | 1 | | 1 | | | 1 | | | | 5 |
| | CBSGRN | Supersite | 3 | 1 | | | | 2 | | | | | | | | 3 |

Table 2. Water-quantity monitoring sites for streams, lakes, reservoirs and groundwater wells (as of January 2017).

| Group | Provider | Status | Hydrologic Region | | | | | | | | | | | Elevation Range | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | All | CKH | UPK | UPC | NEC | NWC | MCK | LCK | SMM | CR | KI | lo | mid | hi |
| Stream discharge | All | Active | 45 | 2 | 20 | 6 | 2 | 4 | 17 | 14 | 3 | | | 49 | 17 | 2 |
| | ECCC | Active | 45 | 1 | 10 | 5 | 2 | 4 | 7 | 13 | 3 | | | 29 | 16 | |
| | CBM | Active | 23 | 1 | 10 | 1 | | | 10 | 1 | | | | 20 | 1 | 2 |
| | ECCC | Discontinued | 38 | 9 | 5 | 3 | 1 | 4 | 4 | 11 | | | 1 | 28 | 6 | 4 |
| | CBM | Discontinued | 56 | 2 | 7 | 4 | 1 | 3 | 29 | 6 | 4 | | | 37 | 19 | |
| Lake level | All | Active | | | | | | | 2 | | | | | 2 | | |
| Reservoir level | All | Active | 6 | | | | | 1 | 4 | 1 | | | | 6 | | |
| Groundwater (2020 update) | All | Active | 6 | 4 | 5 | 1 | | | | 7 | | | | 5 | 1 | |
| | MoE | Active | 5 | | 3 | 1 | | | | 1 | | | | Largely at low elevation | | |
| | CBM | Active | 1 | 4 | 2 | | | | | 6 | | | | | | |

Table 3. Water-quality monitoring sites for streams, lakes, reservoirs, wetlands, & groundwater wells (as of January 2017).

| Group | Provider | Status | Hydrologic Region | | | | | | | | | | | Elevation Range | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **All** | **CKH** | **UPK** | **UPC** | **NEC** | **NWC** | **MCK** | **LCK** | **SMM** | **CR** | **KI** | **lo** | **mid** | **hi** |
| Stream | All | Active | 66 | 5 | 28 | 3 | 1 | 6 | 10 | 6 | 7 | | | 35 | 24 | 7 |
| | MoE/ECCC | Active | 26 | 2 | 10 | 1 | | 5 | | 1 | 7 | | | 7 | 14 | 5 |
| | WQMSD | Active | 12 | 2 | 3 | 1 | 1 | 1 | | 4 | | | | 8 | 4 | |
| | CBM | Active | 28 | 1 | 15 | 1 | | | 10 | 1 | | | | 20 | 6 | 2 |
| | All | Discontinued | 144 | 14 | 24 | 13 | 4 | 12 | 40 | 29 | 7 | | 1 | 97 | 43 | 4 |
| Lake | All | Active | 32 | 5 | 6 | | | 1 | 10 | 7 | 3 | | | 25 | 6 | 1 |
| | MoE | Active | 10 | 2 | 1 | | | 1 | 4 | | 2 | | | 7 | 2 | 1 |
| | CBM | Active | 14 | 3 | 5 | | | | 1 | 4 | 1 | | | 10 | 4 | |
| | FWCP | Active | 8 | | | | | | 5 | 3 | | | | 8 | | |
| Reservoir | FWCP | Active | 9 | | | | | 4 | 3 | 2 | | | | 9 | | |
| GW | MoE | Active | 3 | | 2 | 1 | | | | | | | | 2 | 1 | |
| Wetland | CBM | Active | 21 | | | | | | 20 | 1 | | | | 13 | 5 | 3 |

**Reference for Tables 2-4**

| | |
|---|---|
| CKH | Columbia-Kootenay Headwaters |
| UPC | Upper Columbia |
| NEC | Northeast Columbia |
| CR | Canoe Reach |
| NWC | Northwest Columbia |
| MCK | Mid Columbia-Kootenay |
| KI | Kettle Inonoaklin |
| UPK | Upper Kootenay |
| SMM | St. Mary-Moyie |
| LCK | Lower Columbia-Kootenay |

| | |
|---|---|
| Lo | < 900 m |
| Mid | 900-1500 m |
| Hi | > 1500 m |

## 3.2 Overview of Selected UCB Projects

A collection of UCB projects were profiled at the workshop to shed light on how water monitoring can be used and to highlight typical challenges associated with that monitoring. The descriptions below are summarized from recent publications.

### ***Bonanza Biodiversity Corridor Project Summary***

Authors: Slocan Lake Stewardship Society

Wetlands in the Bonanza Biodiversity Corridor (BBC), along Bonanza Creek between Slocan and Summit lakes, are sensitive ecosystems with high biodiversity values. These wetlands support a wide range of critical aquatic and terrestrial habitats, and contribute significantly to the hydrologic functioning of the Slocan Lake Watershed. At a landscape level, the wetland complexes targeted in this project are vitally important to the BBC, providing this region of long lakes and steep terrain one of the key hydrologic corridors in the Slocan Lake Watershed. The historic Canadian Pacific Railway railway berm that runs the length of the BBC's valley bottom acts as a linear dam and over time has negatively impacted the dynamic wetland-riparian-floodplain system of Bonanza Creek and its tributaries.

This summary is compiled with extracts from the BBC Restoration Management Plan (Mar 2020, Durand, EcoLogic Environmental Consulting) and the 2020 Progress Report (Apr 2020 prepared by SLSS).

http://slocanlakess.com/wp-content/uploads/2019/11/SLSS-Announce-BoWep-Summary-Timeline.pdf\

### ***Columbia Basin Groundwater Monitoring Program***

Author: Carol Luttmer, Living Lakes Canada

The goal of the Upper Columbia Basin Groundwater Monitoring Program is to help effectively manage and protect groundwater resources by: (1) Filling important knowledge gaps about groundwater resources; (2) Providing information to decision-makers to assist with land use and water planning for sustainable and water smart communities; and (3) Engaging citizens to develop groundwater knowledge and conservation ethic. The Upper Columbia Basin Groundwater Monitoring Program is increasing our understanding of groundwater systems to ensure long-term water sustainability for nature, communities, and watershed stakeholders. The program facilitates the collection, management and sharing of groundwater level data. Information, data, training needs, priority areas, and suitable wells for monitoring are identified in collaboration with watershed stakeholders. Existing wells are monitored in partnership with the well owners. The Program secures, installs, and maintains monitoring equipment, provides training, field support, and data management and analyses. Data are shared publicly so they can be used to effectively inform water management and protection and ensure human and ecological needs can be met under changing climate conditions.

http://livinglakescanada.ca/projects/groundwater/

***Hydrologic Assessment of the Upper Columbia River Watershed (2020)***

MacDonald Hydrology Consultants Ltd.

The purpose of this study is to provide information on the current and projected status of hydrologic conditions in the upper Columbia River watershed and Columbia Wetlands with the goal of informing priorities in the development of the Columbia Wetlands Strategic Plan. These objectives include identifying and addressing “gaps in monitoring locations by hydrologic region” while also focusing on elevation bands and other site characteristics including “region, period of record, and landscape, etc.”. In addition, the report highlights the need to use available data to describe the condition and status of waterbodies within the region, with particular focus on smaller streams, lakes, and wetlands. Some of the findings from the study include an assessment of the available hydro-climatic data and a first order estimate of current and future conditions in the upper Columbia River Basin and its tributaries and wetlands.

This study identified hundreds of sub-basins within the study area, and an approximate estimate is that 1-2% of the stream are monitored. Water levels in naturally-drained wetlands (those with surface water connections to the Columbia River floodplain) followed a seasonal pattern of increasing late spring/early summer, concurrent with snow melt, and were highly correlated to streamflow on the Columbia River. Conversely, naturally Isolated wetlands (those without surface water connections to the Columbia River floodplain) were not correlated with streamflow at any WSC stations in the region. Clustering was applied in order to identify sub-basin ‘hydrological types’ and how these types affect water levels in wetlands within the Columbia River valley. Clustering identified two sub-basin types: Cluster A; characterized by high elevations, cold air temperatures, high precipitation, and glaciers. Cluster B; characterized by low elevations, less snowfall, and no glaciers. Further analysis was conducted to determine if Cluster B could be broken into additional sub-groups; however, it was determined that smaller-scale data are required to differentiate between sub-basin types.

https://wetlandstewards.eco/wp-content/uploads/2020/02/CWSP_Hydrology-CV-Watershed-Report_Final-Jan-31-2020.pdf

***Columbia Lake Stewardship Society Water Quantity and Quality Monitoring***

Authors: Bill Thomson, Tom Dance, Columbia Lakes Stewardship Society

The Columbia Lake Stewardship Society (CLSS) vision is that the current pristine nature and ecological health of Columbia Lake be maintained and preserved for future generations. The immediate goals are to continue to conduct water monitoring of Columbia Lake, maintain best water sampling practices to ensure accurate and defensible data collection and build a database of water data to allow comparison of current conditions to the recorded baseline as a means to measure potential effects. CLSS has been monitoring water levels and water quality since 2014. The purpose of measuring water level has been to better understand the hydrology of Columbia Lake. A current meter was later purchased in 2016 and following that flow was measured on inflowing and outflowing streams. The results showed that the annual summer rise in lake water level is due to overflow from Dutch Creek following spring runoff. During the winter the lake relies on local inflow. Early indications are that it contributes less than two cubic metres per second pointing to a water supply issue in the face of increasing demands for water. Water quality results demonstrate a noticeable variation in water quality from season to season. South to north profiles along the lake suggest that the south end of the lake contains a higher concentration of chloride believed to be from groundwater discharge to the lake. There are no natural sources of chloride in the soil and rock formations surrounding the lake.

http://columbialakess.com/reports/

***Improved Climate-Change Readiness through Water Monitoring in North Kootenay Lake***

Author: Martin Carver, Samuel Lyster, Paul Saso

The North Kootenay Lake Water Monitoring Project (NKLWMP) is a community-driven program of action to prepare for climate change. Building on a previous program (started in 2013), NKLWMP monitors a network of seven hydrometric, two snow course and three climate stations designed to maximize insights gained from a local monitoring network and taking best advantage of regional information and data sets. Extreme climate and hydrologic events in recent years in the north Kootenay Lake area have had significant impact within large portions of the Regional District of Central Kootenay. These events have catalyzed citizens to take responsibility in preparing for the deepening climate crisis and its associated disruption by generating important and potentially life-saving data for use by planners and decision makers in sectors related to land use, development, forestry, conservation, water supply, emergency preparedness, transportation, agriculture, back-country recreation and more. Given the breadth of growing challenges that small and rural communities face in British Columbia, this project serves as a template to guide other rural areas in addressing the information needs communities encounter in facing the climate crisis.

NKLWMP has three objectives:

- To establish a long-term integrated scientific water, snow and climate monitoring program in the north Kootenay Lake region of British Columbia;
- To facilitate community engagement and ownership of the NKLWMP monitoring system, including developing community responses to watershed and climate disruption; and
- To engage funding and knowledge partners and facilitate application by decision makers at all levels of NKLWMP outputs to inform decisions that support climate preparedness.

NKLWMP's monitoring sites are situated within the Mid Columbia-Kootenay (MCK) hydrologic region which was used in the workshop as the example application of the proposed approach to expanding the UCB monitoring network (as described in section 4 below). A review of the MCK region showed that in 2019 there were six active hydrometric stations, five active snow courses, one snow pillow, six year-round climate stations and eight seasonal climate stations in place through agencies. These monitoring stations do not emphasize the small- and medium-sized watersheds that form the focus for NKLWMP's monitoring.

This summary was prepared from a 2019 NKLWMP summary report of all monitoring up to April 2018, available at www.kootenayresilience.org.

## 3.3 Hydrologic Methodologies for Addressing Data Challenges

Widespread data deficiencies are not unique to the UCB. Throughout the world, data challenges have led to hydrologic approaches that make do with what is or can be made readily available. Site-specific monitoring may be gathered over a short period to gain a preliminary understanding of the hydrologic behaviour of a stream of interest. However, because this approach does not capture the full range of long-term variability at a site, it cannot reliably provide return period flows for durations longer than its own period of record. In the absence of direct monitoring data for a stream of interest, other approaches are generally pursued to estimate its hydrologic behaviour.

In situations where regional data are available but not for the drainage of interest, statistical relations may be developed that use available data to generalize local or regional stream behaviour. Streamflow metrics are extracted, pooled and statistically analyzed from time-series data of nearby monitored drainages with similar characteristics. Dominant controls on runoff (typically area or elevation) may be used as a basis for estimating expected long-term behaviour of a focal stream in terms of hydrologic metrics such as annual yield, peak low and low flow.

Using a streamflow inventory compiled in the late 1990s, this type of regional statistical approach has been applied across BC to characterize regional variability of streamflow parameters within BC hydrologic zones. Obedkoff (2002) provides graphical outputs from its application to subzones (*i.e.*, subregional hydrologic zones) within zones 13 and 14 of the Kootenay region. With increased statistical modelling capacity and internet capabilities, an updated and more sophisticated version of this approach is available through the regional "Water Tools" developed by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). The Kootenay-Boundary Water Tool is available at: https://kwt.bcwatertool.ca/watershed. Chapman *et al*. (2018) describe the methodology behind the Water Tools, using the NE BC region as an example. Although provided to assist in determining design streamflows for ungauged watersheds, the value of these regional relations remains limited by the input data and particularly by the size, elevation and characteristics of the monitored drainages. For example, limited UCB data are available for small drainages (Carver *et al.* 2019). The approach to zonation may also affect the effectiveness of the subregional relations.

In situations where suitable climate and physiographic data are available, simulation modeling may be undertaken to compute expected hydrologic response rather than estimating it based on statistical analysis of past performance. In some of these situations, short-term monitoring data may also be needed to calibrate and validate model outputs. Although hydrologic modeling may be the best option where appropriate long-term data are unavailable, its key disadvantage is the time and cost generally required to get such models up and running. However, as long-term streamflow data records become increasingly ill-suited to projecting future streamflow due to the nonstationary nature of present climates (Milly *et al.* 2008), simulation modeling is of increased value where resources are available because they can take into account climate changes.

As long as unifying theories of watershed classification remain unavailable (Wagener *et al.* 2007), it appears that regional and simulation approaches will dominate in addressing streamflow estimates in ungauged watersheds. However, the success of both groups of methodologies rests on having adequate data on which to base the methodology. Appropriate grouping or zonation of watersheds is also important to support the most effective application of the approach and broad applicability of the outputs and with acceptable variance. For example, too coarse a grouping generalizes too much leading to excessive variability in the relations whereas outputs may be unavailable if the grouping is too fine due to data constraints. The zonation also needs to be physically appropriate.

MacDonald (2020) illustrates typical challenges faced in the UCB in acquiring data required for managing ecosystems in the face of climate change. Wetlands within the Upper Columbia River valley constitute a Ramsar wetland of international significance, however, the reliability of the source water for these wetlands is in question because of the changing climate. This overview hydrologic study shows that available tributary streamflow data are highly correlated and derive only from large drainages. Yet it appears to be the small- and medium-sized drainages which source the water needed by the wetlands. As a result, the available hydrologic data are of limited value in developing projections supportive of long-term management. Slides presented by Ryan MacDonald at the June 8 workshop are provided in Appendix A2 and illustrate the monitoring gaps existing in this part of the UCB.

Section 4 proposes an approach to designing an expanded monitoring network in the UCB. With its intended monitoring design configured to take into account streamflow variability across the UCB, the proposed approach is structured to meet a broad number of data needs across the UCB. In so doing, standard approaches to determination of design flows should be rendered more effective under the proposed approach.

# 4.0 PROPOSED APPROACH TO DESIGNING AN EXPANDED MONITORING NETWORK

Opportunities to monitor water in the UCB are essentially unlimited. The size of the UCB, the magnitude of present monitoring gaps, the compelling questions that need to be answered, and the ongoing changes in climate and development now underway, together mean that tough choices will have to be made among competing options when expanding the monitoring network. Section 3 provided some scope for potential additional monitoring and introduced some challenges to creating a systematic network, particularly in light of the variability in ecosystems that is a notable feature of the UCB. In this section, a new approach is introduced for designing an expanded monitoring network. It includes a selection process guided by Traditional Ecological Knowledge, local social and cultural priorities and Western scientific questions, directed toward addressing watershed variability within a scientific framework. It is fundamentally collaborative, reflecting the overall goals of the Collaborative.

## 4.1 The Approach

The primary focus here for establishing a monitoring network is to better understand watershed behaviour, with emphasis on the magnitude and timing of peak flows, low flows and, more generally, the potential response of watersheds to climate disruption. Given that it is not feasible to monitor all watersheds, the intent of this approach is to ensure that the watershed selection process for monitoring is efficient and covers the range of watershed response within the UCB. In addition to attempting to cover the range of natural variation, the approach incorporates considerations such as fisheries values, access and cost, societal priorities such as water demands and flood risk, and the potential for addressing research questions such as watershed response to disturbance.

The approach uses the concept of the hydrologic water balance as its basic scientific principle. An expanded monitoring network that provides the data required to quantify the catchment water balance is a strong general foundation for responding to society's key environmental water concerns associated with the climate disruption. The process is initiated by delineating a study area of relatively homogeneous regional climate to consolidate a major source of variation in watershed behaviour. The next step is to select an appropriate range of watershed size to focus on, based on locally determined priorities and gaps in historic and current monitoring. Focal watersheds can then be stratified into groups based on criteria related to watershed response. Within each grouping, specific watersheds for monitoring are then based on locally available information such as First Nations Traditional Knowledge and other local priorities (see Figure 1).

In situations where sediment loads are of concern, an expanded approach can incorporate consideration of a sediment budget as a component of the stratification process. A sediment budget approach requires the identification of active and potential sediment sources within the watershed, the connectivity between those sources and the stream network, as well as assessing the potential for the stream network to store and transport sediment. Extreme sediment delivery events are often coincident with extreme precipitation and snow-melt events, and hence sediment delivery is closely associated with the water balance and watershed response.

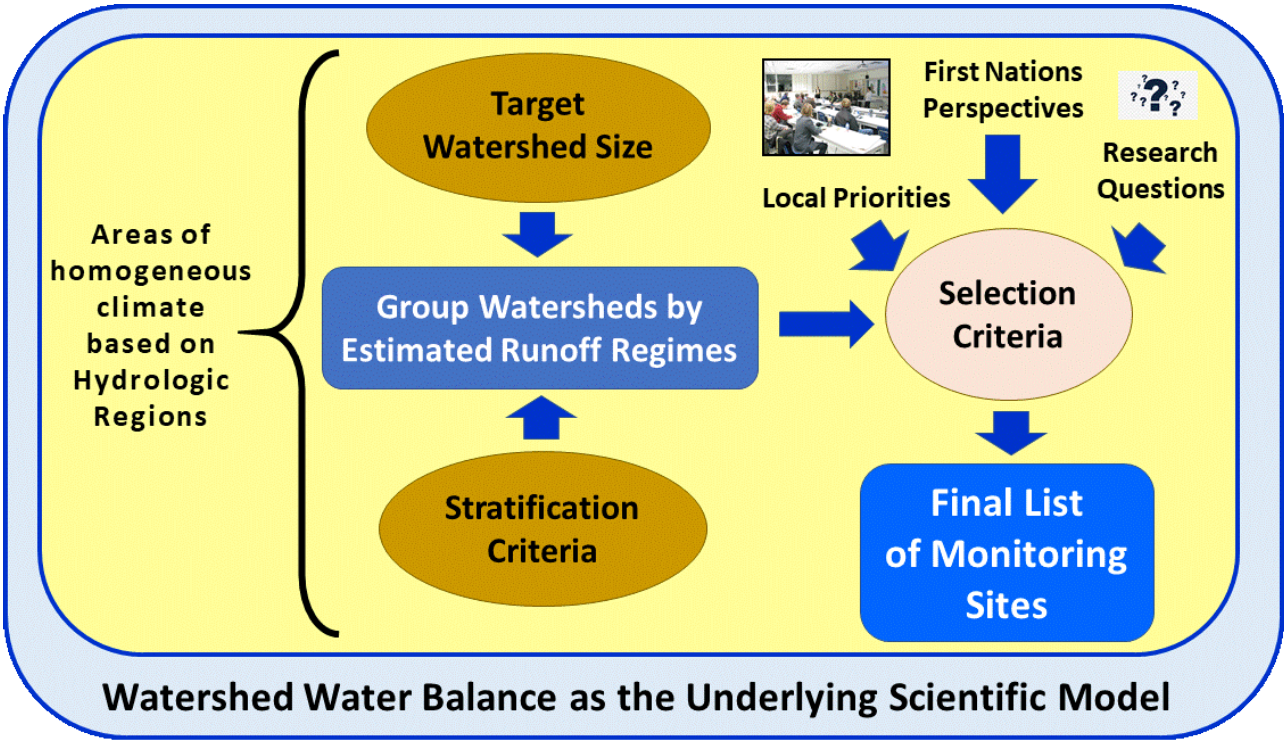


**Figure 1. Proposed approach for planning a scientifically-based watershed monitoring network that efficiently represents the range of natural variation in watersheds, and meets local needs.**

## 4.2 Watershed Stratification Factors and Selection Criteria

Watersheds are complex systems with many interacting processes and functions. A water balance analysis is a typical approach in determining watershed response, where the main factors considered are water inputs, storage, stream discharge, and losses due to evapotranspiration and/or inter-basin transfer, over the time period of a single year (see Figure 2, and descriptions below). The approach uses variation in these factors, or surrogates for these factors, as the primary criteria for stratification of watersheds for the selection of monitoring candidates. This approach attempts to stratify the full range of watersheds across a study area into groups that are likely to have similar flow regimes and responses to a changing climate and/or disturbance. The basic assumption is that watersheds with similar expressions of these characteristics will likely respond in similar ways, and monitoring results from one watershed in a group can be extrapolated to other watersheds within that group. Groupings can be established with statistical methods that carry out grouping and differentiation among populations (*e.g.*, cluster analysis and discriminant analysis). A list of potential stratification criteria is provided in Table 4, including which of the water balance factors each criterion is potentially linked to.

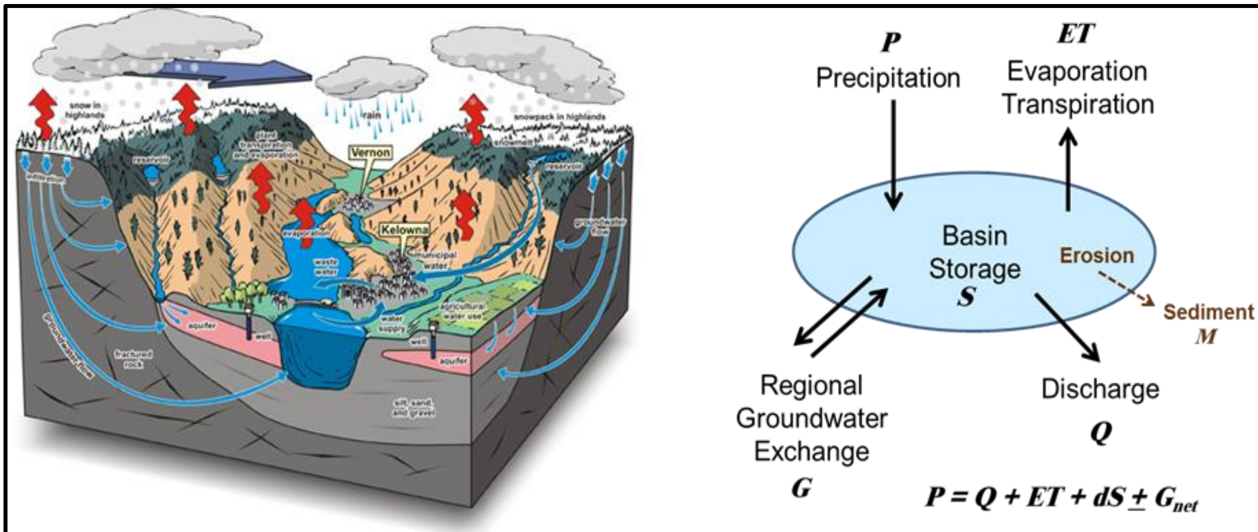


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**Figure 2. An example of watershed complexity and how water balance analysis attempts to simplify that complexity into measurable quantities of water fluxes over time. Although erosion and sediment transport are not direct factors in the water balance, they are included here as they are often of significant interest in relation to watershed response.**

**Precipitation (P)** In the first stage of stratification, the approach characterizes water inputs using regional climate mapping as represented by Hydrologic Regions and Regional Landscapes (see Figure 3). Regional Landscapes (RLs) are areas of similar regional climate, as indicated by the occurrence of similar elevational sequences of Biogeoclimatic Subzones (Utzig 2019). Each RL has a relatively uniform elevational sequence of seasonal temperature and precipitation. Hydrologic Regions (CBT 2017) are either individual RLs, or groupings of them, with slight boundary adjustments to make them coincide with major watershed boundaries. The actual amount of precipitation and snow regime will also depend on the topographic characteristics of the watershed itself. Watersheds that include greater percentages of higher elevations will receive proportionally greater precipitation input due to orographic effects, and have increased influence of snow accumulation and melt on seasonal flows.

**Evaporation and Transpiration (ET)** Evaporation and transpiration rates are driven primarily by climate, however, they are also influenced by topography through the effects of aspect and slope on solar radiation inputs. ET is also influenced by vegetation cover and type, as well as soil storage and its seasonal availability to the vegetation.

**Storage (S)** Storage within a watershed is influenced by the texture and depth of surficial materials. Where available, terrain and soil mapping can be interpreted to find this information. Where soil and terrain mapping is unavailable, bedrock type can be used as a less precise estimate of soil and terrain textures and their influence on storage. The occurrence of lakes and wetlands within a watershed can also provide seasonal storage and buffer peak flows, especially when located at mid-to-lower elevations on the mainstem stream channel. Glaciers also provide a type of long term storage that can impact seasonal flows, especially low flows.

Table 4: Proposed criteria for watershed stratification and their links to basic water balance components.

| # | Core Criterion | Justification (Factor[1]) | Comment / Reference |
|---|---|---|---|
| 1 | Hydrologic Regions | These provide broad-scale representation of regional climate and are tied to large watersheds (P; ET) | CBT (2017) |
| 2 | Regional Landscapes | These are a finer subdivision of regional climates and provide a higher degree of homogeneity with regard to regional climate (P; ET) | Utzig (2019) |
| 3 | Watershed size and stream order | Classes appropriate to the distribution within Regional Landscapes (Q) | BC's Assessment Watersheds provide starting point - Carver and Gray (2010) |
| 4 | Watershed type | Classes to ensure homogeneity of groupings (Q) | Primary watersheds, tributary watersheds, face units |
| 5 | Percentage of glaciation | Affects seasonal flow distribution and sediment production (Q; M) | |
| 6 | Wetlands percentage | Support low flows and flood dissipation through buffering (Q; M) | Wetlands also have conservation value |
| 7 | Lakes percentage | Affects sedimentation, stream nutrient status, and flow regime (Q; M; ET) | |
| 8 | Dominant bedrock type | Affects permeability and hydrologic response and potential sediment production (S; Q; G; M) | Examples include intrusive, sedimentary, metamorphic and calcareous rock types |
| 9 | Surficial material depth and distribution | Direct effects on storage and hydrologic response and potential sediment production (S; M) | Need to estimate material texture and depth and their distribution (1:50,000 soil/terrain) |
| 10 | Vegetated percentage | Affects snowmelt, evapotranspiration, and hydrologic response (ET) | Typical classes are non-vegetated, alpine, forested, grassland, etc. |
| 11 | Drainage Density | Affects peak flow response (Q) | Ratio of stream length to area |
| 12 | Hydrometric Index/ Hypsometric Integral | Provides an elevational weighting that affects distribution of precipitation and snow (P) | Ratio of upper and lower elevation areas |
| 13 | Aspect Index | Affects snowmelt and evapotranspiration (ET) | Distribution by slope and elevation |
| 14 | Circularity Ratio | Correlated with size and duration of peak flow (Q) | Ratio of watershed area to a circle with the same perimeter |
| 15 | Relative Relief | Correlated with sediment production (M) | Ratio of relief to area |
| 16 | Melton Ruggedness Index | Correlated with sediment production and sediment transport (M) | Ratio of relief to perimeter |
| 17 | Evidence of channel and slope instability | Correlated with sediment production (M) | Consider generalized risk based on slope characteristics (*e.g.*, wetness, hillslope/channel gradients, materials) |
| 18 | Channel type | Related to flow regime (Q; M) | *e.g.*, bedrock vs alluvial |

1 - See definitions provided for Figure 2.

**Discharge (Q)** On an annual basis, stream runoff, or discharge, is primarily controlled by precipitation inputs and evaporation and transpiration losses. However, the presence of seasonal and long-term storage within a watershed has significant influence on seasonality of flows. Stream responses to extreme precipitation events are further influenced by the stream network itself, including factors such as stream gradient, stream channel density and shape of the watershed.

**Regional Ground Water Exchange (G)** Net inflow/outflow for smaller primary watersheds is generally not a significant concern in the UCB's mountainous areas. However, for watersheds located on the lower slopes and valley bottoms of larger valleys, these exchanges may be a significant factor. Areas with the occurrence of karst features or highly jointed bedrock will also have a higher likelihood of inter-basin water transfers. Bedrock mapping and topographic information can be used to identify watersheds with increased potential for this factor.

**Sediment (M)** Although sediment production is not part of water balance analysis, it is a factor of interest from the perspective of water quality and natural hazards. Many of the factors that are significant to water balance analysis are also factors in sediment production, although they have to be applied differently. Potential sediment production could also be a primary criterion for grouping watersheds, if desired.

The workshop presentation introducing the proposed approach is found at:

http://livinglakescanada.ca/wp-content/uploads/2020/10/LLC-hydro-monitoring-wkshp_Utzig_Proposed-Approach.pdf

## 4.3 Stratification Factors Applied to the Mid-Columbia Kootenay Hydrologic Region

The Mid Columbia-Kootenay Hydrologic Region (MCK) is selected to demonstrate how the criteria could be applied in a real-world situation (see Figure 3). The MCK is a typical West Kootenay mountainous landscape with seasonal precipitation, the majority of which comes in the winter as snow and increases with elevation. Streamflow generally peaks in late spring and early summer coincident with snowmelt at higher elevations. Low flows generally occur in late summer or early fall. Examples of the application of stratification criteria within the MCK's primary and nested Assessment Watersheds can be found in Appendix A4.

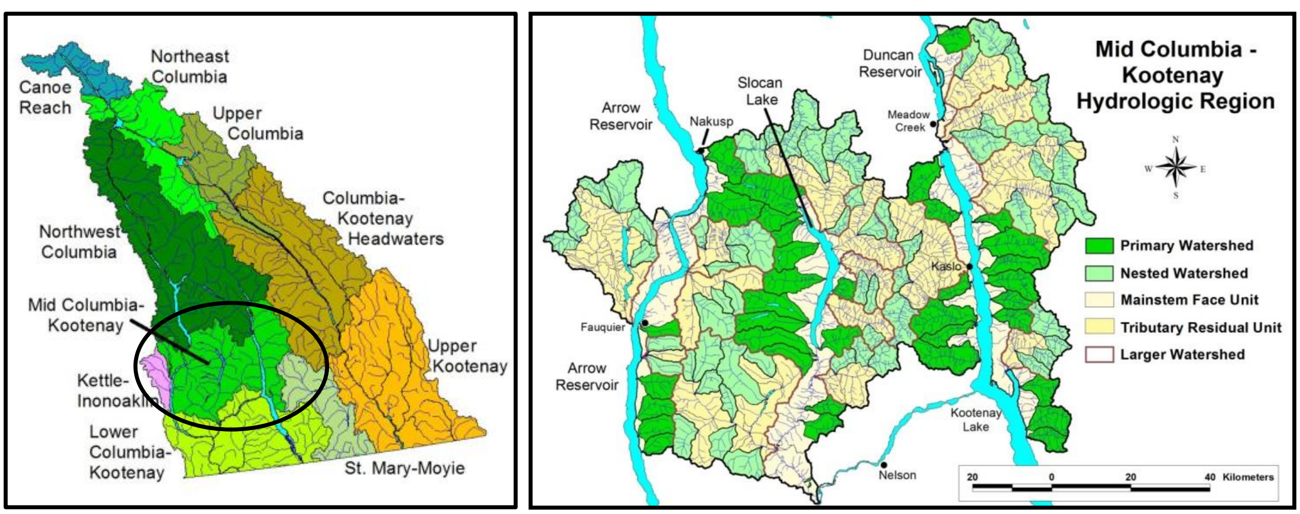


**Figure 3. The Mid Columbia-Kootenay Hydrologic Region and constituent Assessment Watersheds, with a focus on primary and nested watersheds.**

### 4.4 Watershed Selection Criteria

The stratification criteria and groupings provide a starting point for understanding the variation within a region. Local concerns, social and cultural priorities, research questions and practical considerations can then be utilized to select specific watersheds for installation of monitoring equipment, and determination of monitoring parameters for each site. This stage of the approach includes incorporation of First Nations' priorities and Traditional Knowledge and identification of issues of local concern such as flooding, water-use demands, fisheries and sediment levels. It also allows for incorporation of potential research priorities such as the impacts of disturbance or climate change. Availability of funding and volunteer support will have to be taken into account. Logistical issues such as ease of access and availability of appropriate monitoring sites will also have impacts on final site selection. Table 5 lists examples of selection criteria for consideration.

Table 5. Potential selection criteria when choosing among candidate monitoring watersheds/sites.

| # | Selection Criterion | Justification | Other Comments |
|---|---|---|---|
| 1 | Complementarity to existing monitoring networks | Efficiency | Avoid duplication of existing monitoring networks |
| 2 | Sites of importance to Indigenous people | | Sites of Indigenous importance for cultural, spiritual, and other purposes |
| 3 | Sediment issues | Water quality; debris flood/ flow risks | Requires sediment budget analyses |
| 3 | Fisheries significance | | Fisheries habitat values |
| 4 | Resource significance | | Domestic, industrial or irrigation demand |
| 5 | Degree of disturbance | | Wildfire and/or forest harvesting (distribution and percentage), road density, etc. |
| 6 | Access | Access requirements affect monitoring costs | |
| 7 | Availability of local sponsors | Shared interests can enable increased monitoring scope | |
| 8 | Nested watersheds | Provide information at range of scales | Strategically nesting smaller drainages within larger ones |
| 9 | Geographic distribution | Ensure coverage | A wide distribution of sites is preferred |

Examples of local priorities that may influence the selection of specific monitoring watersheds within a watershed response group may include watersheds with flooding risks for communities located on alluvial fans, watersheds where water licensees are concerned about low flows and water availabilities, streams with high fisheries values and watersheds with Indigenous cultural sites. Figure 4 illustrates some of the potential issues within the MCK Hydrologic Region.

Scientific questions that may drive watershed selection may include pairing watersheds with differing levels of road construction and/or forest harvesting. Ensuring that all relevant groups, including First Nations, are involved in the selection of watersheds for monitoring may suggest the need for a regional coordinating organization to ensure a full range of input into the process.

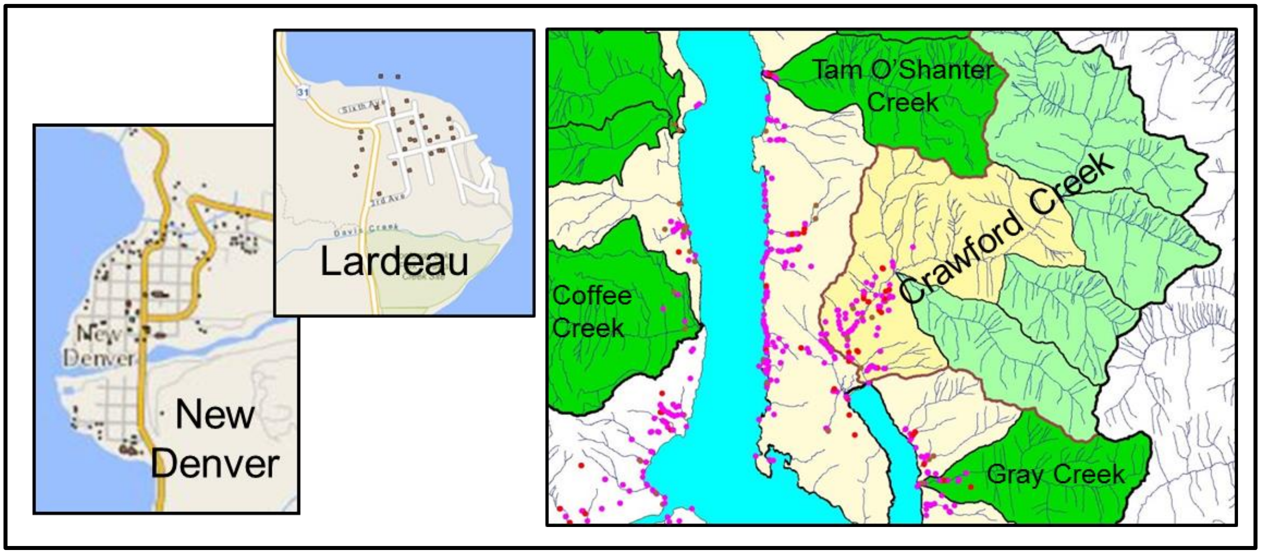


**Figure 4. Examples of potential local priorities: communities located on alluvial fans and concentrations of water licenses.**

The workshop presentation describing the application of the approach to the MCK Hydrologic Region is found at:

http://livinglakescanada.ca/wp-content/uploads/2020/10/LLC-hydro-monitoring-wkshp_Utzig_Example-Area.pdf

## 5.0 PARTICIPANT FEEDBACK ON POTENTIAL DEVELOPMENT OF PROPOSED APPROACH

Two 45-minute break-out sessions and additional discussions and question-and-answer periods provided opportunities during the workshop for participants to provide direct feedback on the proposed approach. In presenting the ideas that were provided in those interactive sessions, this section integrates the input given across sessions to enhance the feedback's value here in advancing the development of the proposed approach. In addition, section 5.3 combines overall points of consensus from the break-out sessions with feedback provided at other times during the workshop.

The views presented here do not represent those of any particular individual who attended the workshop nor do they necessarily represent the views of the authors or of LLC. Rather, this summary represents a grouped synthesis of all the comments provided during the workshop, as understood and summarized here by workshop's scientific coordinators.

### 5.1 Breakout Session #1

In the first set of small-group discussions, three questions were posed, one for each of the groups (Group 1 - Q1; Group 2 - Q2; Group 3 - Q3). If time remained after the primary question had been addressed, the groups were asked to also respond to the other two questions. Participants were distributed in this break-out session as follows:

**Group 1** – Martin Carver (science lead and facilitator), Kyle Prince (note-taker), Bill Thompson, Chad Hughes, David Hutchinson, Gilles Wendling, Janice Brahney, Ryan MacDonald, and Stephen O'Hearn

**Group 2** – Greg Utzig (science lead and facilitator), Raegan Mallinson (note-taker), Antonio Barroso, Dan Moore, Dave Wilford, Ed Gillmor, Jeff Burrows, Natasha Neumann, and Suzanne Bayley,

**Group 3** – Carol Luttmer (science lead and facilitator), Avery DeBoer-Smith (note-taker), Alan Thomson, Bill Coedy, Kat Hartwig, Neil Goeller, Samuel Lyster, Stephanie Merrill, and Tom Dance

The participant input has been pooled here by question and is grouped below by the topics suggested by the participants' comments themselves.

**Question #1: What priority or compelling water and water-related scientific and societal questions in the Upper Columbia Basin require monitoring data?**

Changes related to water quantity are seen as a priority because water quantity shapes changes in the fluxes of other parameters such as sediment and nutrients. Issues associated with climate change are seen as a related priority, especially with respect to floods, droughts and fires. The pace of glacial recession and its effects on water quality need further study in addition to the decline of (previously) permanent snow fields. While measuring streamflow rates is critical, it is also essential that shifts in timing be well described. In addition to monitoring at the site (*e.g.*, at a location of a glacier) and at the far downstream outlet of the site's drainage, intermediate (nested) hydrometric sites are needed to identify how far downstream effects remain significant. It is important to describe associated thermal regimes because these are also changing, with consequences for water quality and aquatic habitats. It was suggested that a greater integration of monitoring of both water quantity and quality is needed in these situations and more generally.

Information to support management of water supply systems is a priority. Climate change is increasing demand on water supply systems. Which watersheds are stressed and which are comfortable? Requirements for environmental flows are needed across spatial scales, particularly in those drainages where the changing water budget is resulting in an inadequate supply available for human use. Greater understanding is needed of the magnitude of evapotranspiration both in terms of the instantaneous rates across the landscape and its effects on water budgets over seasonal and annual timeframes. Higher rates of evapotranspiration, and in conjunction with longer growing seasons, affect water budgets and may undermine water supplies.

In addition to direct monitoring data, other sources of information and knowledge should be pursued to expand understanding about water in the UCB. First Nations historic knowledge, particularly from Elders and frequent land-users, may be made available by First Nations. This is of particular value in understanding and describing pre-industrial baseline conditions. There may be value in integrating paired watersheds and other experimental approaches into the expanded monitoring network. Distinguishing those data types that cannot be gathered later on (*e.g.*, river flows) from those that can be (*e.g*., remotely-sensed data and interpretations) can assist in prioritizing what monitoring is implemented first. In general, less is known about ephemeral streams, wetlands and sedimentation than the water dynamics themselves. Regardless of the approaches taken to expand water data and knowledge, these scientific initiatives and outcomes must also be communicated effectively to decision makers.

Would expanded monitoring be useful in helping to evaluate how adaptive management might unfold under the Columbia River Treaty? It is recognized that if greater flexibility is built into a renegotiated treaty it will require its own adequate monitoring. However, additional monitoring may be useful in leveraging monitoring funds that may become available under a renegotiated treaty.

**Question #2: Are the correct factors included in the criteria tables and which are most critical?**

Stratification factors and selection criteria are shown in Tables 1 and 2 in section 4. There was general support for the factors included in these criteria tables, however, some aspects need greater detail while others are missing. Discussions focused on groundwater, climate, and other miscellaneous topics.

Groundwater is not yet included in the proposed approach. Various suggestions were made on how groundwater may be included as a criterion for selecting watersheds to be monitored. Stream temperature (or salt content) may provide evidence of groundwater discharging into surface waters. Can remote sensing be used to develop thermal images that can be subsequently linked to indicate where groundwater discharge is occurring? In some systems, an upstream/downstream change in temperature can be used to indicate a groundwater discharge and potentially its relative volume. Locally, drones may be able to assist in locating points of groundwater discharge. In the northern portion of the UCB, it may be possible to use ice-free zones in the channel system as indicators of groundwater discharge sites. An index of topographic wetness, based on a Digital Elevation Model (DEM), can identify storage and can be used with bedrock to identify areas of flow contribution from groundwater. Although recognized as an effective approach, it is difficult to implement it computationally over large areas. In the criteria tables, bedrock is sorted by its erodibility and texture, however, it could also be classified by structure. By stratifying bedrock in this way, it would indicate the types that are more fractured and thus more likely to contain groundwater. Given available mapping, this could be pursued easily only on a gross scale.

All climate-related factors in the proposed approach are expressed through the one factor called “regional landscapes”. The application of regional landscapes is used to provide a basis for generalizing watershed characterization. Could these watershed groupings be broken down further or supplemented with additional information to reflect a range of climate characteristics? Meteorological parameters such as short-term rainfall intensity, solar radiation, and degree days may also add further value as stratification criteria.

There is a long history of discontinued hydrometric stations in the UCB. These station data may be helpful in improving the design of the expanded monitoring network. On the other hand, the climate has shifted considerably since the period when many of these data sets were gathered, with some stations dating back to the early 1900s. As a result, these data would have to be carefully assessed to avoid misinterpretations associated with climate change.

Wetlands are included in the proposed approach as a reflection of flow buffering. If this correlation is not appropriate for both upland and riparian wetlands, wetlands may need to be partitioned by type. Although not originally included in the proposed approach, wetlands (and lakes) have also been weighted by elevation to better reflect the individual waterbody's influence in flow buffering (and potentially sediment buffering).

The Kootenay-Boundary Water Tool can be used to add licensed allocation volume to the total licensing numbers. Although defining water use remains an ongoing challenge, suitably capturing allocation volume should be a criterion. One approach might be to focus on those licenses used for irrigation.

The criteria related to watershed shape reflect gradedness and drainage maturity in an attempt to distinguish key basin types. Concern is expressed for the potential subjectivity of the criteria, especially for channel and slope stability. Channel gradient may be a useful additional criterion, and perhaps be less prone to subjectivity.

Additionally, can a time dimension be built into the criteria so that cumulative effects can be tracked to feedback into how and where to further monitor?

**Question #3: Which parameters should be monitored (climate, streamflow, water temp. etc) & how best to set relative priorities among these?**

Selection of priority monitoring parameters should not be strictly a scientific exercise. It should also carefully consider the interplay between who wants/needs the data and who is collecting the data. Station longevity, monitoring/staffing capacity, local oversight, and presence of data champions are among key considerations that will influence the long-term value of monitored data. Funders, agencies, researchers, cities/towns, resource and environmental managers, watershed groups and other stakeholders are interested in data for a range of purposes which should be considered. The reasons for a declining support for monitoring, the discontinuation of specific sites, and a persistently low site density should be well understood when considering scientific priorities. A scientific framework for siting stations and establishing parameters has to be responsive to these social, economic and political priorities while suitably retaining direction from the scientific framework. The criteria need to strike the right balance between scientific requirements and societal demands and be responsive to guidance from First Nations. While the scientific framework may need modification, adequate scientific standards and rigour need to be maintained and the monitoring data need to remain connected to explicit questions to which First Nations and stakeholders need answers.

In terms of scientific guidance for parameter selection, primary hydrologic processes and their net outcome in the water budget (*e.g.*, streamflow) both need monitoring. Hydrologic models need to be parameterized using reliable data on basic processes. Water temperature (presence of groundwater; aquatic ecosystem health) and solar radiation (rate of snow melt) are generally inexpensive to monitor. Monitoring water level is more difficult than these basic process parameters but still far less complex than measuring streamflow. Expanded measurement of streamflow is needed, particularly on small- and medium-sized streams, however, selection of sites should likely come after site establishment for other less-expensive parameters. Larger entities such as government agencies are more likely to be able to set up, carry out and/or scientifically oversee those more complex monitoring efforts. Over time, the relative complexity (usually related to cost) among monitoring parameters needs to be traded off so that the optimal mix of parameters is pursued.

Given the prevalence of hydrologic models, especially for small- and medium-sized streams, attention is needed for their parameterization. In this sense, which parameters are most needed depends on the size of watershed one is interested in. Increasingly, we will see investment in hydrologic models; although they have large upfront costs, the efficiencies of application are very powerful. It is suggested that monitoring a range of watershed types and scaling up broadly using models may be less expensive than monitoring across all types. Also, any monitored parameters which can help resolve water deficits within the water budget should be useful (*e.g.*, evapotranspiration).

Climate stations remain a priority, however, siting them and determining the scope of each site's monitoring parameters remains an open discussion. In the 1970s and 1980s, there were elevational transects established in or near the northern portion of the UCB which may be worth examining again (FLNRORD's Vanessa Ford may have information in this regard.) One complete climate station may be expensive but can provide considerable data able to serve many purposes.

Concerns regarding the reliability of using monitoring data collected by citizen scientists can be addressed by involving scientists to set up the stations and the methodologies to be followed in gathering the data, then engaging locally-based citizen scientists to do the data gathering.

## 5.2 Breakout Session #2

In the second set of small-group discussions, three groups were asked to each respond to three questions. Participants were distributed in this break-out groups as follows:

**Group 1** – Martin Carver (science lead and facilitator), Kyle Prince (note-taker), Alan Thomson, Antonio Barroso, Dan Moore, Dave Wilford, Neil Goeller, Samuel Lyster, and Stephanie Merrill

**Group 2** – Greg Utzig (science lead and facilitator), Raegan Mallinson (note-taker), Bill Coedy, Chad Hughes, Ed Gillmor, Gilles Wendling, Janice Brahney, Jeff Burrows, Natasha Neumann, and Ryan MacDonald

**Group 3** – Carol Luttmer (science lead and facilitator), Avery DeBoer-Smith (note-taker), Bill Thompson, David Hutchinson, Kat Hartwig, Stephen O'Hearn, Suzanne Bayley, and Tom Dance

The participant input has been pooled here by question and is grouped below by the topics suggested by the participants' comments themselves.

**Question #4: Is the approach reasonable? What issues do you have with it and how would you improve upon it?**

Overall, the participants indicate support for the approach to expanding the monitoring network as presented in section 4. Using the water balance as the scientific organizing principle addresses the interests of most groups and provides an effective tool for communication. In the water balance approach, there are many details that can be difficult to acquire. It will be important to provide means for data at every scale and from every group so that they can be put to work in the water balance. There is an important role for coordination so that data from one regional use can be put to use in another. If the regional landscapes reflect differences in the water balance, then they are suitable for configuring the monitoring network.

The approach emphasizes the measurement of variability in the UCB. An alternative would involve supporting the development of hydrologic models so that they can be applied across the UCB with appropriate sensitivity analyses. Opportunities to support model development include measurement of basic processes, research into watershed dynamics using experimental catchments, and applications of tracers such as isotopes and other aspects of water chemistry. This type of consideration is perhaps even more relevant for groundwater given the costs associated with groundwater monitoring and the challenges with the associated interpretations. Three-dimensional groundwater models provide an excellent opportunity to visualize what is happening below the ground and to communicate this to stakeholders. Like their surface water counterparts, these models require parameterization data.

Regardless of whether or not model development is emphasized in the monitoring network, the question was raised as to which data from one area can be transferred to another. Transferable data should be identified due to the potential cost savings. Not all processes differ between regional landscapes. The Kootenay-Boundary Water Tool provides public access to map-based information on natural water supply, existing water rights, and environmental flow needs of rivers, lakes and streams in southeastern British Columbia. It models streamflow and applies assumptions about water use rates and environmental requirements to available data, providing the outputs as watershed reports. It also uses a water balance approach. Where it is appropriate to transfer data from one area to another, the Kootenay-Boundary Water Tool may provide efficiencies in generating selected transferable data. Where model data are transferable (or are available elsewhere), calibration is still needed. Can the approach include transferable data and a protocol to tweak the data to the new region of application?

We need to be careful not to chase unrealistic parameters where gaps exist. For example, rather than pursuing high-elevation instantaneous precipitation, thereby attempting to sustain difficult interpretation at remote sites, it may be more suitable to monitor snow-pack depth or glacier change using LiDAR data. Airborne remote sensing may be useful for other surrogate data. Reporting uncertainty is generally greatest in the small watersheds but, fortunately, many of these are highly accessible. Groundwater data tend to be available only where people are living. Although they are expensive to gather, more deep groundwater data are needed.

**Question #5: How would you choose what to emphasize in monitoring in a particular hydrologic region or individual watershed?**

Once variability is addressed scientifically at larger/landscape scales, local priorities can be established within this scientific framework at local scales. First Nation Elders may be available to provide their own knowledge about issues in their landscapes and in key watersheds. Watershed and site connections can be made through local groups, water champions and other experts within each watershed, providing opportunities to listen to local residents, community leaders and monitoring groups about their concerns and perspectives. Good communication is needed to foster effective priority setting. The Columbia Basin Watershed Network (CBWN) may be helpful in identifying monitoring gaps. Levels of government possess valuable information that can assist in local site selection. Comparing or trading off monitoring ambitions with sharply different objectives (*e.g.*, long-term baseline flow monitoring vs short-term monitoring of lake water quality) may require difficult choices and quasi-arbitrary rationales. There is likely no generally-defined approach that can be formulated at this scale but an emphasis on local priorities is recommended. Within this, a multi-scale approach should still be encouraged. There may be preferred sites that can be identified across the landscape - sites of high monitoring impact and best value for resources spent. Previously-monitored sites may be potential candidates. Once these low-hanging fruit are tagged for monitoring, as appropriate, selection decisions may become more challenging thereafter.

Local priority setting can be enabled by assessing the sensitivity of key waterbodies to disturbance and assessing and communicating other issues such as the level of cumulative effects present in the local watersheds. Are there technologies available that can support identifying monitoring requirements or in determining components of the water balance? Universities may be helpful because they often use leading monitoring technologies. If there are basin-wide monitoring priorities (*e.g.*, mid-elevation snow-pack data), these priorities should be communicated locally so that they may be implemented alongside local priorities. Considerations related to the Columbia River Treaty and potential salmon reintroduction may suggest specific basin-wide criteria. If there are efficiencies that can be gained by undertaking monitoring across larger areas simultaneously (*e.g.*, remotely-sensed data), this can be communicated at the local level to gain funding support. When monitoring glacier change, findings should be interpreted in light of the watershed boundaries associated with the glaciers under study.

One widely-recognized and fundamental gap is the monitoring of small streams. Due to the unlimited opportunity to monitor these systems, we need to narrow down what monitoring is needed and what data can be transferred among this subset of monitoring or found elsewhere altogether. Given the resulting limitations in understanding small streams, we don't know well what data would be transferable. This may justify a more intensive level of monitoring for a number of areas to assess transferability. Once we know what can be transferred, the next phase of monitoring can eliminate the transferable ones. Given that this is an evolution, we don't need to be concerned about making these decisions upfront. Instead, an adaptive approach to monitoring may be required.

Overall, it is better to do some monitoring well than to be spread too thinly. Also, no matter what ends up being chosen to be monitored, metadata should be well documented.

**Question #6: Who should be involved in rolling out this program? How do you get them involved and in what sequence or timeframe?**

Resource monitoring is largely considered the responsibility of the provincial government. Although Professional Reliance remains entrenched in provincial governance, there is a move away from it and a move to local government managing water. However, decisions made on Crown land can have repercussions for local government downstream. There is a mix of attitudes among the BC's Regional Directors. If local government is going to manage water, it needs support from provincial government. Is there a way that local government can create a tax model similar to the Kootenay Lake Local Conservation Fund?

How will decisions be reached about allocating funds to specific monitoring? An independent decision-making body is needed, made up of hydrologists and geologists who are from the area of interest and who have local government support. Nanaimo is cited as an example where the role of local government has been significant and successful. Generally, the most effective approach is to have roundtables with all stakeholders and First Nations at the table because this model creates a sense of ownership and control.

There are funds available through FLNRORD set aside to support of Water Sustainability Act implementation, however, it is champion driven. It needs a strong force to make it happen. Currently, BC has the goal of one funded WSA watershed in each of the East and West Kootenay. The Province is available to help with training and equipment. CBT also has a strong mandate for water monitoring and a long history of support. It should be approached to become involved once again.

WSC should have a role when a long-term hydrometric station is being established. Typically, local sources identify the need for the monitoring then provincial and federal authorities get involved to provide the funds once it is deemed valuable. The challenge is in securing the money, given the costs typically involved in installing and operating one hydrometric station. Additionally, it may be preferable that funding for long-term hydrometric stations come exclusively from the provincial and federal sources because of the difficulty of relying on funding from a third party that may back out. Partnership opportunities may best lie in involving the community in installation, using experts to calibrate it to the standard, and engaging community members again to run it. Data would be sent away for QA/QC. Varied perspectives were expressed about the potential for community members to be engaged in streamflow monitoring at this level due to the complexities involved. Data post-processing can be challenging when WSC does not initially gather the data. To be successful, a shared work approach would require strong coordination. It was noted that similar issues apply for monitoring of snow-pack and high-elevation climate. Note that WSC gathers water temperature data and has an agreement in place for collecting data outside of their mandate and this agreement involves additional funds and instructions.

There are untapped resources available across the UCB. Ski lodges may share their data on snow depth. LLC (with Kootenay Centre for Forestry Alternatives) oversees the NKLWMP which has established an agreement with ten commercial ski lodges in the area surrounding the northern portion of Kootenay Lake to have access to their snow-depth measurements. This type of cooperation could be expanded. Where they exist regionally, local hydrologists and other science experts should be engaged to provide training and mentorship, thereby ensuring the best possible quality of data is collected.

Selkirk College and Vancouver Island University have programs related to community data. Selkirk College should be involved as a recipient of the data to then teach students. This should also help make the data available for future generations and for multiple purposes. Researchers working with neural networks (which are data hungry) could also be rolled in as data users. Ideally, these applications would be coupled with those working with more traditional modelling approaches.

There are many apps for water monitoring that could assist in implementation. Examples include those of the North America Lake Management Society, Water Rangers, and Alpine Club of Canada. We don't want these to be in competition so coordination and direction are required.

## 5.3 Integration of Workshop Feedback and Ideas

Overall, workshop participants indicated support for the approach to expanding the monitoring network as presented in section 4, an approach rooted in stratifying and measuring hydrologic variability across the UCB. It was agreed that using the water balance as its scientific organizing principle, the interests of most groups are addressed. Determining the components of the water balance would also be an effective basis for subsequent communication with the public and policy makers. Quantifying the water balance over multiple scales requires considerable data so regional coordination would be needed to transfer data between regions wherever scientifically acceptable. The Kootenay-Boundary Water Tool may provide efficiencies in generating selected transferable data.

Supporting intensive model development is seen as an alternative to the proposed approach, however, these approaches are not mutually exclusive: a monitoring network optimized to quantify water balances would also be of great value in the development and/or application of hydrologic models in the UCB. Supporting the application of hydrologic models in the UCB may best emphasize three-dimensional groundwater models given the costs associated with groundwater monitoring and the challenges of the associated interpretations.

The stratification factors and selection criteria of the proposed approach were generally supported by workshop participants, however, some aspects need greater detail while others are missing. Factors representing groundwater need to be expanded. Proxies for groundwater monitoring include stream temperature and salt content and remotely-sensed and drone-based data may each be useful in making data affordable. Expanded interpretation of bedrock characteristics beyond erodibility and texture to include structure may be useful in indicating likelihood to contain groundwater. Further characterization of regional landscapes in terms of specific weather parameters would strengthen the climate representation in the approach. Including additional meteorological parameters such as short-term rainfall intensity, solar radiation, and degree days may add further value as stratification criteria. Further additions and modifications to the preliminary factors were discussed related to wetlands, water licensing, channel slope and stability, and cumulative effects. A thoughtful review of the factors is warranted with due consideration to data availability, incremental improvement, minimizing subjectivity, and the degree of complexity in the outcome.

Although there are clearly many compelling water-resource issues, it was agreed by workshop participants that those associated with climate change – and in particular, water quantity – are an overarching priority, especially in relation to floods, droughts and fires because quantity shapes changes in the fluxes of other parameters such as sediment and nutrients. Immediate support for setting management priorities would be valuable. For example, requirements for environmental flows are needed across spatial scales and in highly stressed catchments. Greater understanding is needed of the effect of evapotranspiration rates both across the landscape and on water budgets. The site-selection step should emphasize a greater integration of both water quantity and quality monitoring.

In addition to direct monitoring data, other sources of information and knowledge would expand understanding of water in the UCB. First Nations historic knowledge, particularly from Elders and frequent land-users, would be valuable, for example, in understanding and describing pre-industrial baseline conditions. Depending on resources available and interest by research partners, there may be value in integrating paired watersheds and other experimental approaches into the expanded monitoring network. In general, less is known about ephemeral streams, wetlands and sedimentation. Regardless of the approaches taken to expand water data and knowledge, scientific initiatives and outcomes must also be communicated effectively to decision makers.

Selection of priority monitoring parameters should not be strictly a scientific exercise. A scientific framework for siting stations and establishing parameters has to be responsive to social, economic and political priorities while suitably retaining direction from the scientific framework. The criteria need to strike the right balance between scientific requirements and societal demands and be responsive to guidance from First Nations. The historic reasons for and against monitoring in any particular area should be well understood when considering scientific priorities. Station longevity, monitoring/staffing capacity, local oversight, and presence of data champions are among key considerations that will influence the long-term value of monitored data. Funders, agencies, researchers, cities/towns, resource and environmental managers, watershed groups and other stakeholders are interested in data for a range of purposes which should be considered. While the scientific framework may need modification, adequate scientific standards and rigour need to be maintained and the monitoring data need to remain connected to explicit questions to which First Nations and stakeholders need answers.

In terms of specific parameters to monitor, workshop participants indicated that rates of hydrologic processes and the main components of the water budget both need monitoring. Given the prevalence of hydrologic models and their powerful efficiencies of application, attention is needed for their parameterization especially for small- and medium- sized streams which have little monitoring.

Monitoring cost should play a role because it varies strongly by parameter. Water temperature and solar radiation, for example, are inexpensive to monitor. Monitoring water level is more difficult than these basic process parameters but still far less complex than measuring streamflow. The relative complexity (usually related to cost) among monitoring parameters needs to be traded off so that the optimal mix of parameters is determined. It is suggested that monitoring a range of watershed types and scaling up broadly using models may be less expensive than monitoring across all types. Although climate parameters are clearly a priority, the best selection of them to pursue remains unclear.

Workshop participants point to the value of existing agencies such as FLNRORD and WSC having lead responsibilities in carrying out expanded resource monitoring. Local government, Selkirk College, non-government organizations (such as LLC) can also play roles in the actual monitoring. Collaboration across sectors and with universities is also important. Universities may be helpful in identifying monitoring requirements or in determining components of the water balance because they often use leading monitoring technologies. If there are basin-wide monitoring priorities, these priorities should be communicated locally so that they may be implemented alongside local priorities. If the fundamental gap in monitoring of small streams is to be addressed, a thoughtful winnowing down of what data are needed from small streams will be essential alongside clarity on what can and cannot be transferred among monitoring sites.

## 6.0 PATH FORWARD / NEXT STEPS

It is expected that implementation of the approach will involve a two-stage technical process.

As introduced above, a standing scientific advisory committee would need to be established to identify subregions and provide preliminary descriptions of the individual hydrologic responses of the subregions to disturbance and change. This stage would focus on the stratification criteria as introduced in Table 4. The second stage would involve subregional groups with localized expertise and knowledge. These groups would identify the shortlist of actual proposed monitoring sites. This work would be shaped by Traditional Ecological Knowledge, western science, and local socio-economic priorities.

Prior to actual implementation and subsequent streamlining of the process, considerable technical work would be required to develop the procedure's content. To do this, a focal hydrologic region would need selecting to work through the next steps of its development. This work would require engagement of First Nations and identification of an appropriate group of stakeholders and resource experts with knowledge of the selected region. Available current and historic watershed monitoring data and GIS layers to cover the range of stratification criteria outlined in Table 1 would need to be collated for the region (or potentially for the UCB in general) as background material for the parties participating and consulted groups. This involved group should identify the watershed issues of concern within the region and identify any specific questions that need to be addressed. Based on those priorities, stratification criteria should be reviewed and updated as necessary, and the appropriate size and types of watersheds identified for final stratification. The range of watershed groupings for the region can then be examined against the selection priorities for the region, specific watersheds for monitoring can be chosen, and monitoring parameters defined for each. The final step is to ensure that adequate financial and human resources and technical expertise are available to maintain the sites over the medium term (ten years and beyond) while recognizing that there are shorter-term monitoring needs associated with assessment of development proposals and environmental impacts.

To this end, LLC envisions the existing Columbia Basin Water Monitoring Collaborative (see section 1) as the likely vehicle for directing funds to meeting these requirements. In order to achieve this, a governance structure for the Collaborative is required. LLC is in the process of developing such a governance structure to support the technical recommendations in this report, and will be preparing a detailed governance proposal using the workshop outcomes as supporting rationale.

The workshop presentation on this topic is found at:

http://livinglakescanada.ca/wp-content/uploads/2020/10/LLC-hydro-monitoring-wkshp_Carver_Path-Forward.pdf

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## APPENDIX A1. WORKSHOP AGENDA

Expanding the Water Monitoring network of Canada's Upper Columbia Basin
*An online workshop hosted by Living Lakes Canada*
June 8, 2020 • 9 a.m. PT / 10 a.m. MT

### Access Details

Meeting starts promptly at 9 a.m. Pacific Time / 10 a.m. Mountain Time on June 8, 2020.
Please join Zoom meeting at **8:50 a.m. Pacific Time / 9:50 a.m. Mountain Time**, at:

- *https://us02web.zoom.us/j/81482544681*
- *Meeting ID: 814 8254 4681*

Or for telephone only, call: 778-907-2071, 81482544681#

### Background

Water resources are changing rapidly during a general and long-term decline in monitoring effort. Pressing water-resource issues present at local and regional scales reflect a range of escalating pressures on resources and include climate impacts such as extreme precipitation, flooding and fire events. Site-specific reactive monitoring can never satisfy the myriad data requirements of all local water issues. Variability in hydrologic response across the Columbia Basin is too great to be sufficiently understood based on current monitoring. Additionally, under the Water Sustainability Act, current regulatory tools such as water objectives and Water Sustainability Plans (WSPs) both depend for success on appropriate long-term monitoring data. As a result, there is a growing need to refocus in planning future monitoring to carefully allocate limited resources to meet multiple scientific objectives.

The purpose of the Living Lakes Canada (LLC) Water Monitoring Workshop is to develop recommendations for a phased expansion of the water (and water-related) monitoring network of Canada's Upper Columbia Basin (UCB). Priorities for monitoring will be identified within a scientific framework that distinguishes hydrologic variability according to known variation in climate within the UCB. Within this broad framework of the UCB's ten hydrologic regions (CBT 2017), workshop participants will discuss setting priorities based on hydrologic and terrain characteristics, compelling scientific questions, and prevailing resource issues. These considerations go beyond what is needed to serve the Columbia River Treaty and its renegotiation because the monitoring network must address and support a wider array of issues and activities. It is intended that this workshop outcome support the subsequent design of a monitoring strategy to be used in rolling out a phased expansion of the UCB monitoring network that takes into account the full range of variation of potential watershed response within the UCB while also emphasizing watersheds critical to biodiversity conservation, community sustainability, and ecosystem resilience in the face of climate disruption.

## Objectives

Workshop objectives are:

1. Develop criteria for selecting (priority) watersheds to be included in a regional watershed monitoring network.
2. Identify monitoring needs related to scientific objectives that can be part of an expanded watershed monitoring network.
3. Rank the implementation of potential water-related monitoring in terms of both the site locations and measured parameters and describe a potential phased long-term implementation.

Potential monitoring is effectively infinite but resources are limited, thus the proposed network build-out must carefully balance the relative importance of site locations and monitoring parameters. That balance should efficiently address climate and landscape variability while recognizing the need to increase understanding of ecosystem requirements and risks, community sustainability and hydrologic impacts of climate change.

*Session 1: Background to Designing the Monitoring Network* ***(9 am-10:40 am Pacific Time)***

1. Welcome, introductions and regional perspectives (55 min)
2. The challenge of designing a monitoring network (20 min)
3. Hydrologic assessment in the Columbia-Kootenay Headwaters hydrologic region (20 min)
4. Overview of proposed approach and introduction to reference example (5 min)

*Session 2: Proposed Approach* ***(11 am-12:30 pm Pacific Time)***

1. New approach to building out the Upper Columbia Basin's water monitoring network (15 min)
   - Current UCB monitoring and typical hydrologic practice
   - Concept and details of proposed approach
2. Reference example for discussion (15 min)
3. Break-out groups for detailed discussion of reference example. Each group responds to their own question below then responds to the other groups' questions with any time remaining (40 min)

   **Group 1**. What priority/compelling water/water-related scientific and societal questions in the Upper Columbia Basin require monitoring data?

   **Group 2**. Are the correct factors included in the criteria tables and which are most critical?

   **Group 3**. What parameters should be monitored (climate, streamflow, water temperature, etc) and how best to set relative priorities among these?
4. Debrief and group sharing on break-out discussions (20 min)

*Session 3: Broader Scientific Issues* ***(1 pm-2:20 pm Pacific Time)***

1. Summary of input from previous session (10 min)
2. Scope of scientific objectives to be supported by expanded monitoring (10 min)

3. Break-out groups for detailed discussion of three questions. Each group responds to all three questions below (40 min)

   **Question 1**. Is the approach reasonable? What issues do you have with it and how would you improve upon it?

   **Question 2**. How would you choose what to emphasize in monitoring in any particular hydrologic region or individual watershed?

   **Question 3**. Who should be involved in rolling out this program? How do you get them involved and in what sequence or timeframe?

4. Debrief and group sharing on break-out discussions (20 min)

*Session 4: Workshop Outcomes and Next Steps* ***(2:20 pm-3 pm Pacific Time)***

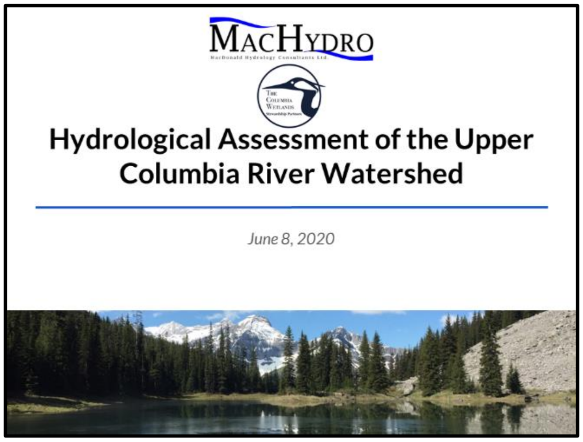
1. Summary of input from previous session (5 min)
2. Key elements of a path forward (5 min)
3. Final round of comments from participants (1-2 min each) (25 min)
   - What was useful, what are the gaps, and what was not addressed in the workshop?
   - What are your remaining overarching concerns?
4. Final comments from Living Lakes Canada (5 min)

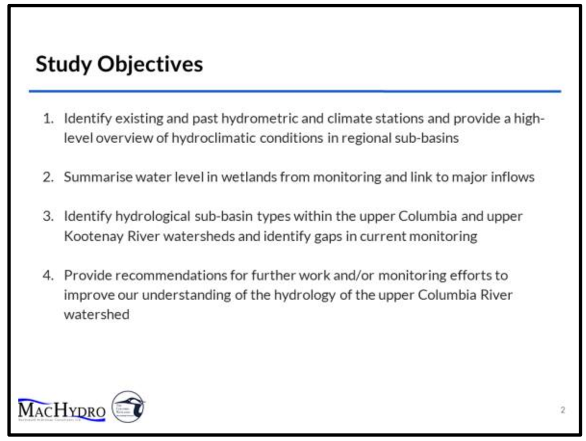
Invitees who accepted the workshop invitation but, later, could not attend:

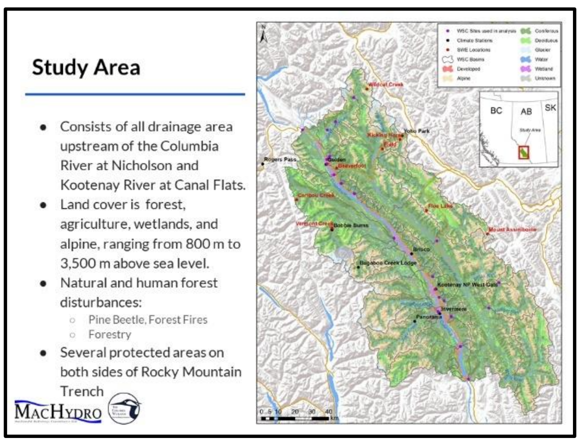
- Dr. John Pomeroy, Global Water Futures
- Paul Bauman, WorleyParsons
- Richard Bussanich, Okanagan Nation Alliance
- Richard Johnson, Arrow Lakes Environment Stewardship Society

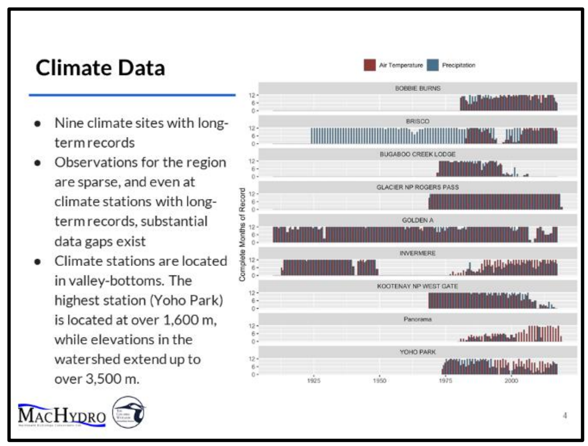
## APPENDIX A2. CASE STUDY OF UCB MONITORING GAPS IN COLUMBIA RIVER WETLANDS

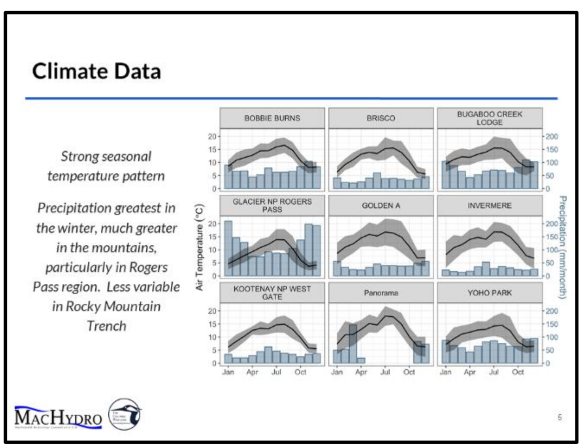
This appendix contains a presentation given during the workshop by Ryan MacDonald on assessing monitoring gaps in the upper Columbia River drainage. It is drawn from MacDonald (2020) and provides an example of the typical challenges faced in the Columbia Basin in acquiring data required for managing ecosystems.

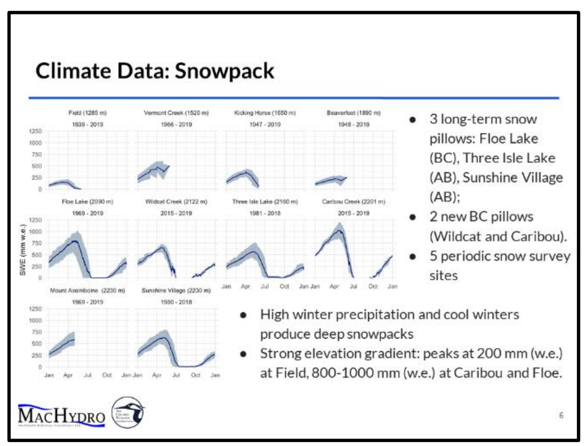


## Streamflow Data Selection

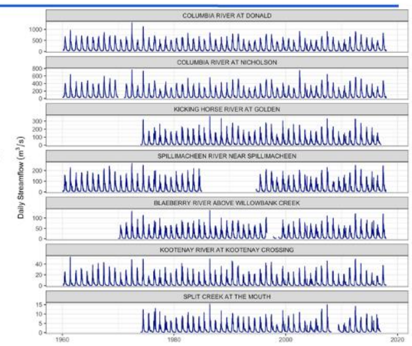
- Water Survey of Canada data for all sites in the upper Columbia River (above Donald, BC) and upper Kootenay River (above Canal Flats, BC) watersheds,
  - Resulted in 70 hydrometric stations with streamflow observations
- From this dataset, we then selected all discharge observations that occurred since 1960;
  - Consisted of 39 hydrometric stations
- Then we filtered for stations that had at least 5 years of complete summers, where a complete summer was defined as containing at least 180 days of observation per year between April and October
- This method identified 24 WSC hydrometric stations that were used for further analysis, 7 of which had active records

MACHYDRO 7

## Streamflow Data

*7 WSC sites with long-term, active records*

*These 7 sites are highly correlated (r = 0.87-0.99)*




MACHYDRO

## Streamflow Trend Analysis

*Mann-Kendall statistics for the six long-term, uninterrupted, hydrometric stations. Tau is the magnitude of the trend, while the p value represents its significance (**bolded** if p < 0.10). Only modest indication peak flows decreasing at Columbia River at Donald.*

| Station Name | Mean Annual Flow | | Max Annual Flow | |
|---|---|---|---|---|
| | *Tau* | *p* | *Tau* | *p* |
| BLAEBERRY RIVER ABOVE WILLOWBANK CREEK | 0.12 | 0.26 | 0.02 | 0.89 |
| COLUMBIA RIVER AT DONALD | -0.14 | 0.12 | **-0.16** | **0.08** |
| COLUMBIA RIVER AT NICHOLSON | -0.10 | 0.29 | -0.10 | 0.26 |
| KICKING HORSE RIVER AT GOLDEN | 0.01 | 0.92 | -0.05 | 0.64 |
| KOOTENAY RIVER AT KOOTENAY CROSSING | -0.12 | 0.20 | -0.08 | 0.36 |
| SPLIT CREEK AT THE MOUTH | 0.07 | 0.51 | -0.11 | 0.32 |

MACHYDRO 9

## Watershed Cluster Analysis: Motivation

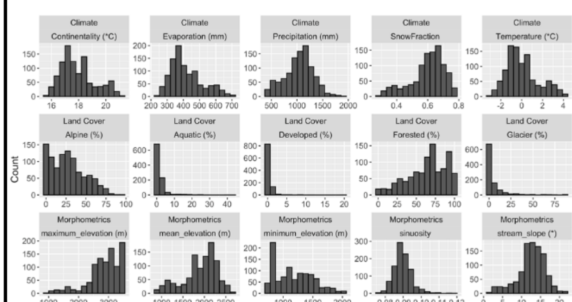
*Identify sub-basin 'hydrological types' and how these types affect water levels in wetlands within the Columbia River watershed.*

Two sub-basin datasets were used:

- **WSC:** All Historical WSC hydrometric station sub-basins in the upper Columbia and Kootenay River watersheds, for a total of 70 sub-basins.
- **Comprehensive:** All sub-basins greater than 5 km$^2$ in the upper Columbia and Kootenay River watersheds, for a total of 991 sub-basins.

MACHYDRO 10

## Watershed Cluster Analysis




## Watershed Cluster Analysis: Parameter Importance

- Since the full parameter set is unlikely to fully (and equally) characterize the hydrological conditions within each sub-basin, parameters were paired down and selected based on their:
  - Ability to predict hydrological characteristics
  - Process understanding
  - To minimize parameter overlap and collinearity
- Input all 17 parameters into a linear regression model to predict mean annual runoff (mm) from the 24 WSC hydrometric stations
- Calculated the relative importance of each parameter in predicting runoff

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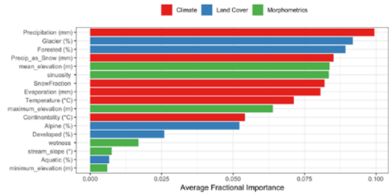
## Watershed Cluster Analysis: Parameter Importance




*Strong overlap with some parameters (i.e. Alpine and Forest anti-correlated, Temperature, Evaporation, Continentality highly correlated)*

Final Parameters:

- 3 climate variables: precipitation, snow fraction, and temperature
- 2 land cover variables: glacier cover and forested cover
- 3 morphometric variables: maximum elevation, mean elevation, and sinuosity

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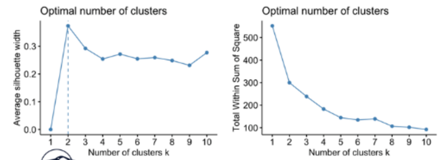
## Watershed Cluster Analysis: Clustering

We clustered sub-basins using three approaches:

- k-means
- agglomerative hierarchical clustering
- divisive hierarchical clustering

Number of clusters was chosen using average silhouette (first maximum value) and the sums of squares (inflection point)

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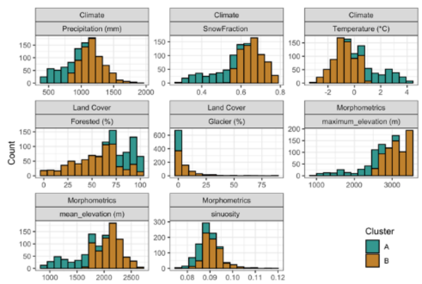
## Watershed Cluster Analysis

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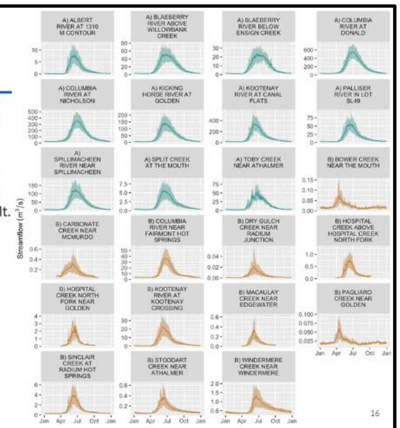
## Cluster Hydrographs

Cluster hydrographs are distinctive:

A) Large freshet; drawn-out high flow due to high snowpack and glacial melt. Low variability (little rainfall effect)

B) Shorter freshet; low late-summer flows (less snow, no glaciers).



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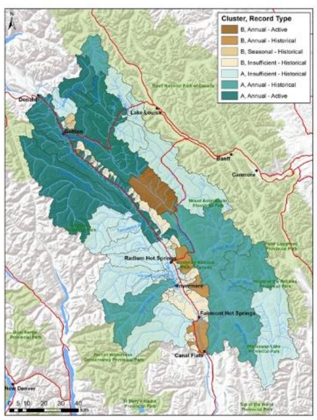
## Data Gaps (WSC)

- Six active hydrometric stations in cluster A, only one in cluster B (Kootenay River @ Kootenay Crossing),
  - Note: clustering algorithms were undecided of whether this sub-basin was cluster A or B
- Active hydrometric stations all have sub-basin drainage areas > 79 km²
  - All but 3 WSC stations in cluster B have drainage areas ranging from 2 km² to 93 km²
- No sub-basins along Rocky Mountain Trench are active




## Limitations

- Used Water Survey of Canada hydrometric gauge sites to determine sub-basins
  - Arbitrary and relies on the initial WSC gauge site selection being representative
- Clustering limited by data availability
  - Many WSC hydrometric records were insufficient to derive more hydrometric statistics
- Clustering results sensitive to parameter set chosen
  - Could get different results with other parameters or different target (i.e. mean annual flow)
  - This methodology is flexible and could be easily adapted for other objectives

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## Conclusions

- Nine sites in the study region have long-term climate records
  - All are located in valley-bottom locations
- Seven active WSC hydrometric stations exist in the study region, including six in the upper Columbia River watershed, and one in the upper Kootenay River watershed
  - Only one of these stations (Spillimacheen River) measures streamflow on the west side of the Rocky Mountain Trench
- Cluster analysis using morphometric, climate, and land cover variables identified two sub-basin types:
  - Cluster A; characterized by high elevations, cold air temperatures, high precipitation, and glaciers
  - Cluster B; characterized by low elevations, less snowfall, and no glaciers
  - Long-term, active hydrometric records are currently only available for cluster A

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## Recommendations

1. Identify regions, sub-basins, or sub-basin types of concern
2. Determine if streamflow records for cluster B are important data for hydrological understanding in the region/implement monitoring program
3. Quantify water use (irrigation, municipal, other industrial uses) in the watershed, and determine what percentage of current and future streamflow is allocated

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## APPENDIX A3. UCB MONITORING NETWORK IN 2017

**Figure A3.1. UCB climate, snow and glacier monitoring sites established by agencies and regulated industry (as of 2017).**

Map reproduced courtesy of CBT (2017).

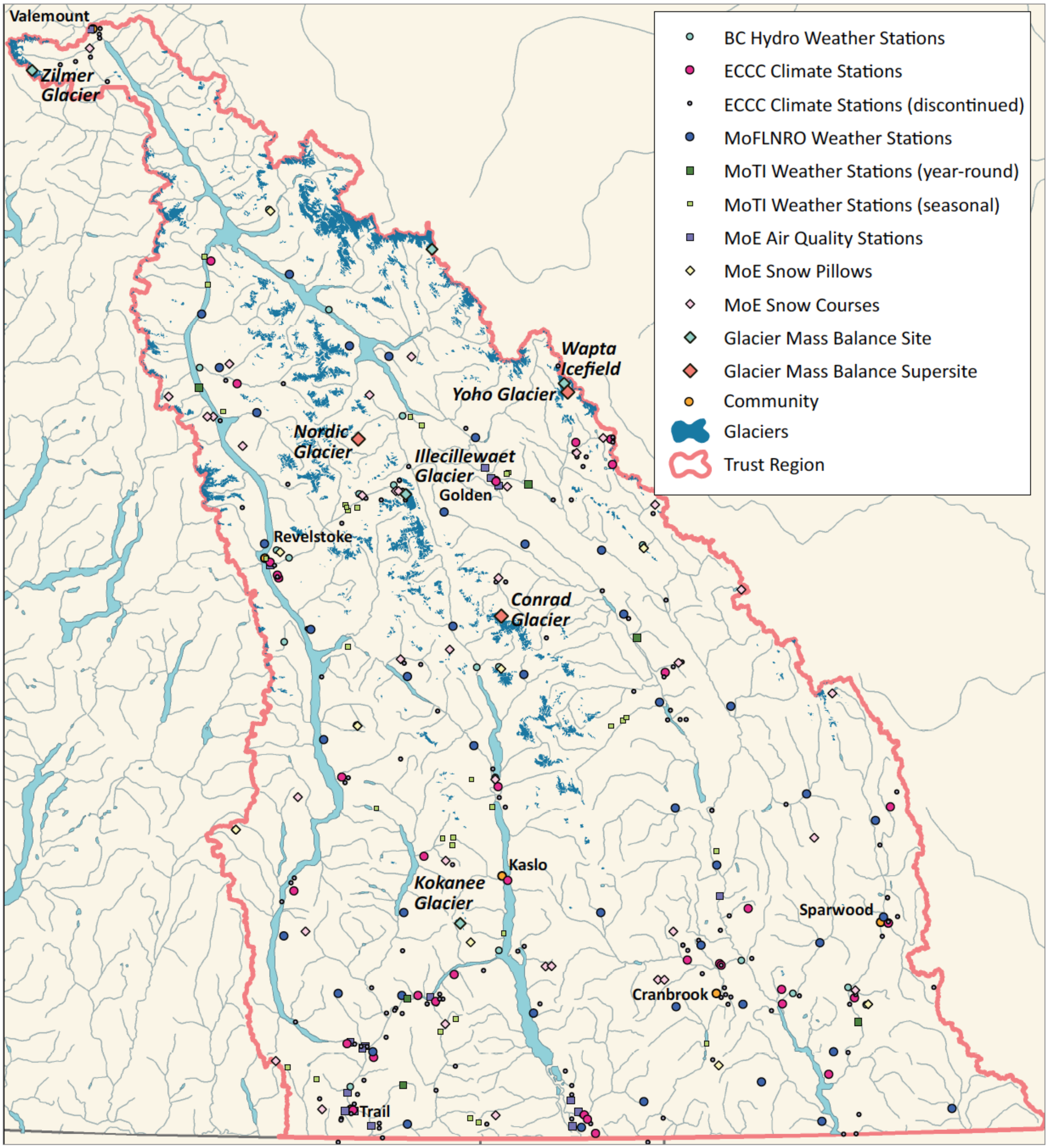


**Figure A3.2. UCB hydrometric stations and lake/reservoir and groundwater monitoring sites, established by agencies and regulated industry (as of 2017).**

Map reproduced courtesy of CBT (2017).

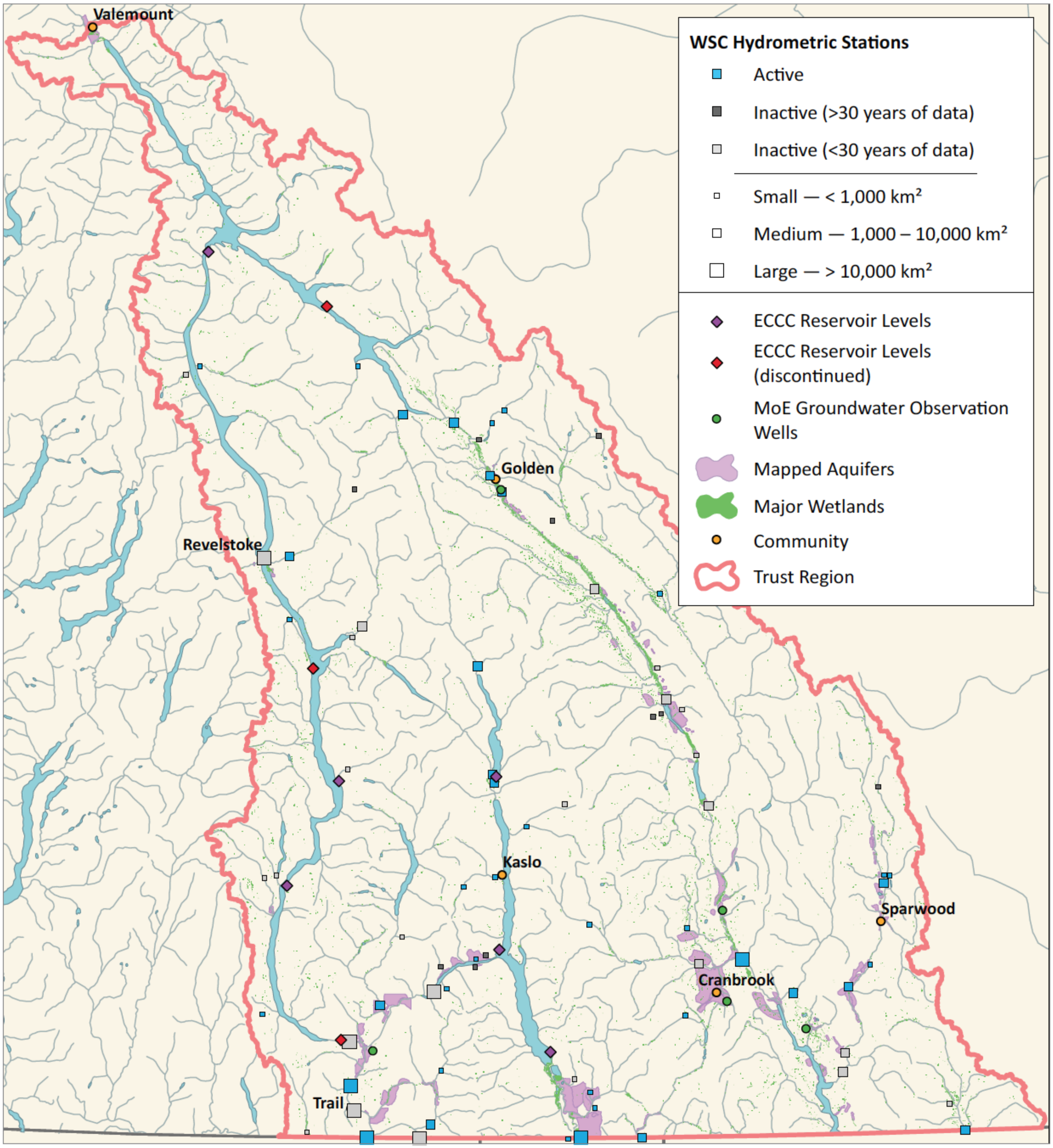


**Figure A3.3. UCB water quality monitoring sites, established by agencies and regulated industry (as of 2017).**

Map reproduced courtesy of CBT (2017).

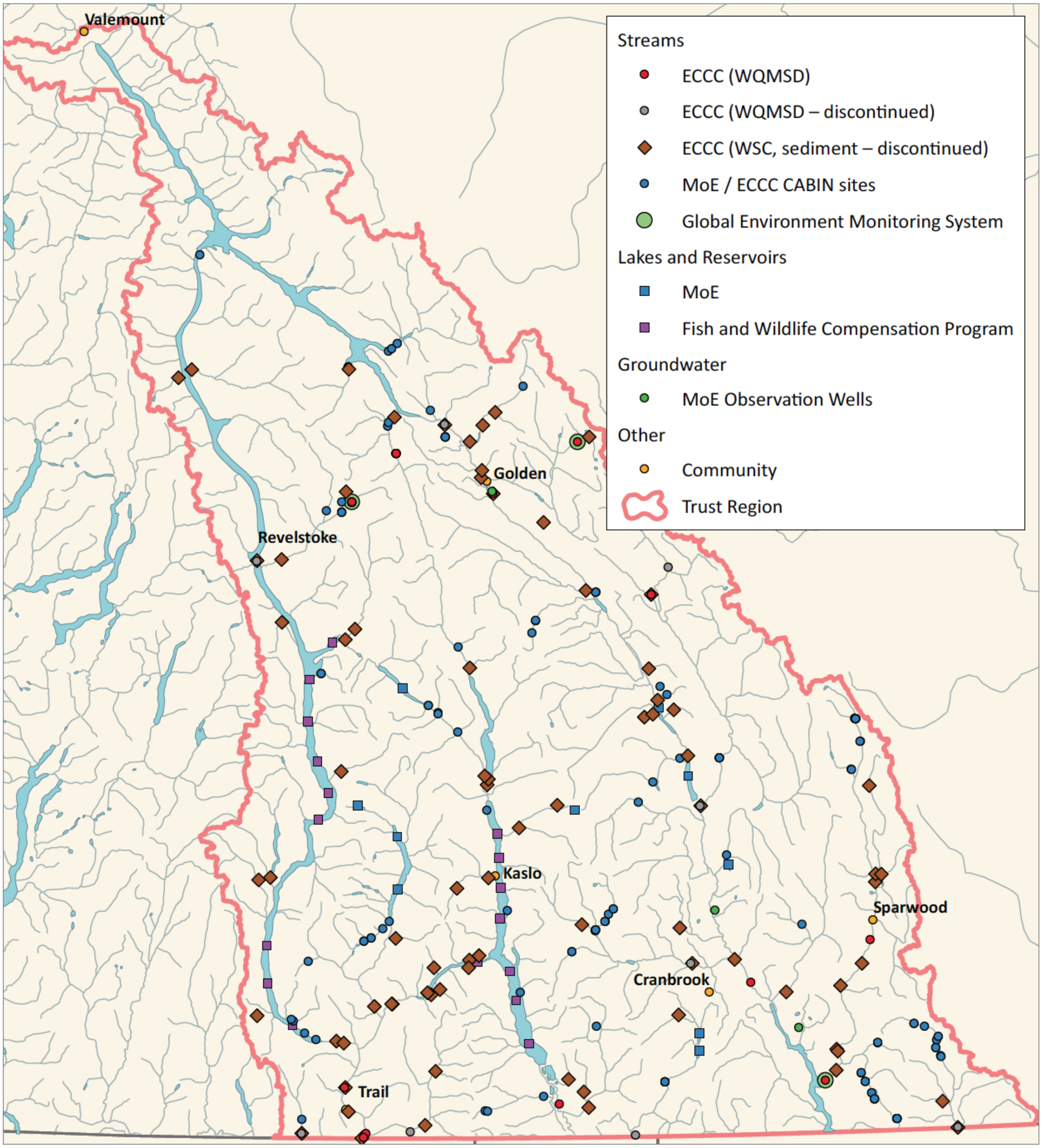
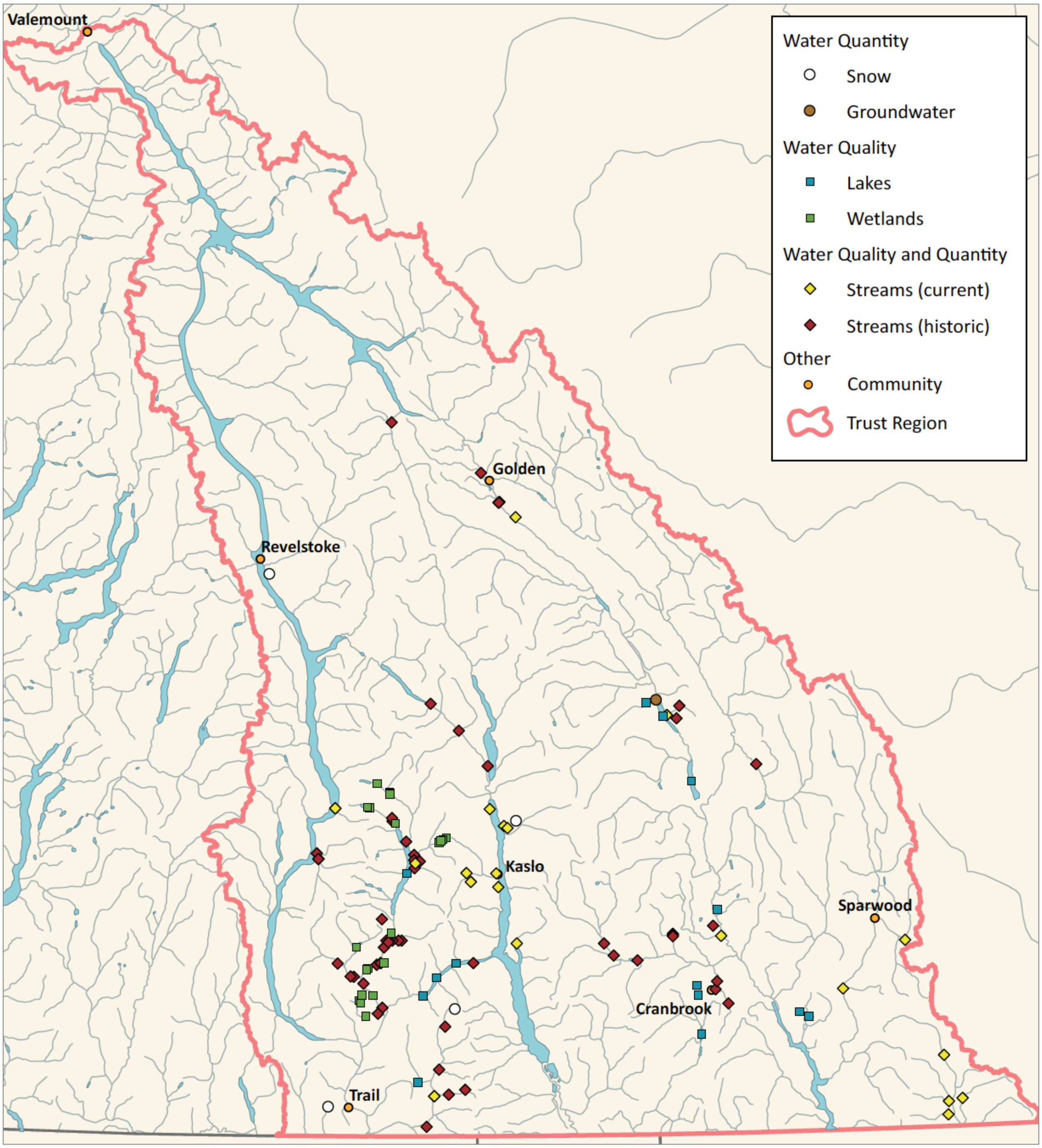


**Figure A3.4. UCB water monitoring sites, operated through community-based monitoring (as of 2017).**

Map reproduced courtesy of CBT (2017).



## APPENDIX A4. MAPS FROM EXAMPLE APPLICATION OF PROPOSED APPROACH

Examples of stratification criteria for the Mid-Columbia Kootenay Hydrologic Region.

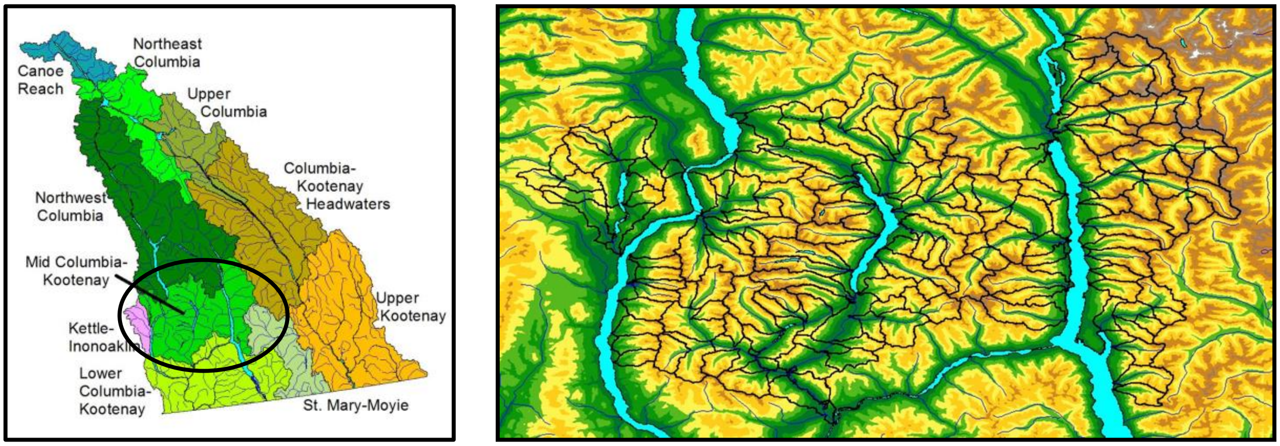



**Figure A4-1. The Mid Columbia-Kootenay Hydrologic Region and topography in relation to potential Assessment Watersheds.**

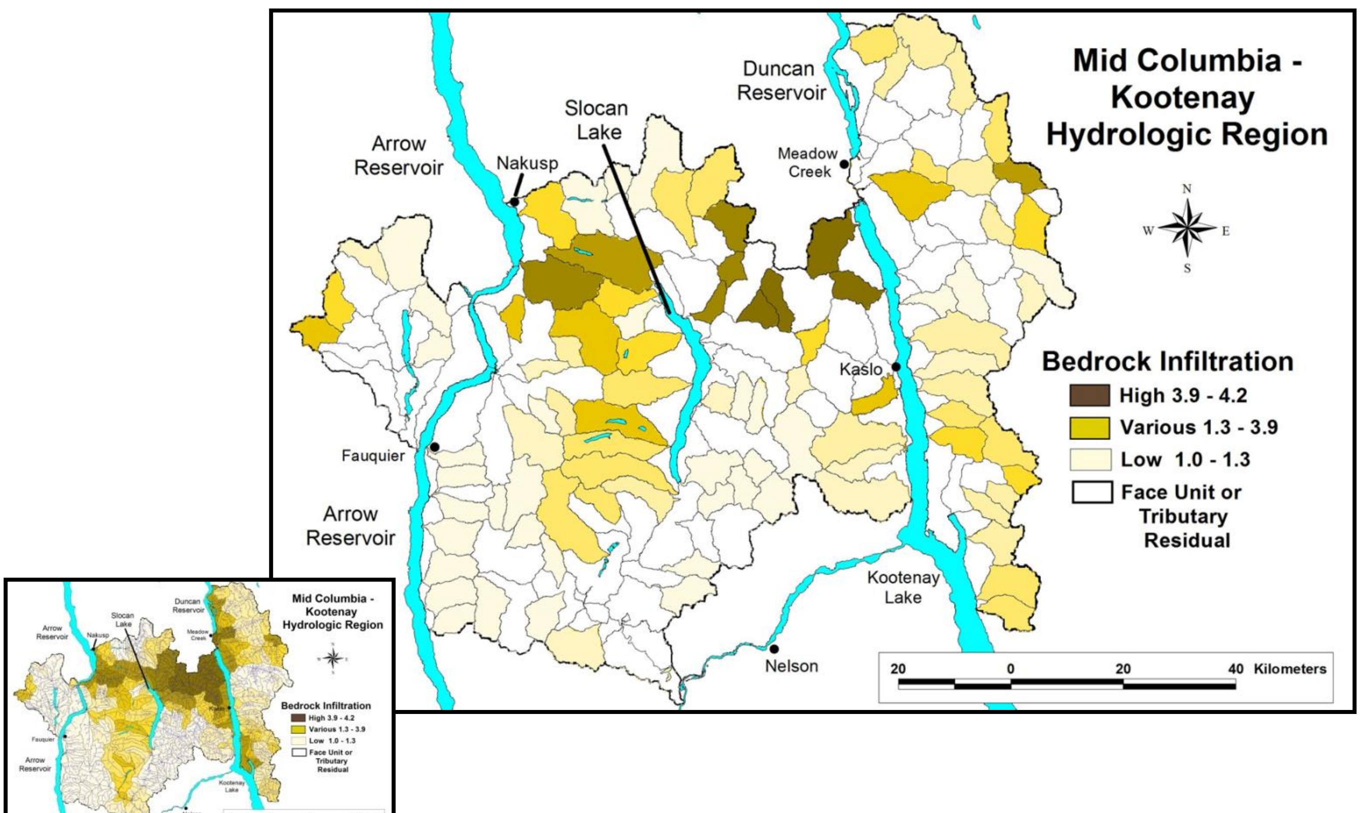



**Figure A4-2. Bedrock infiltration index for primary and nested Assessment Watersheds. Inset shows infiltration index for all Assessment Watersheds.**

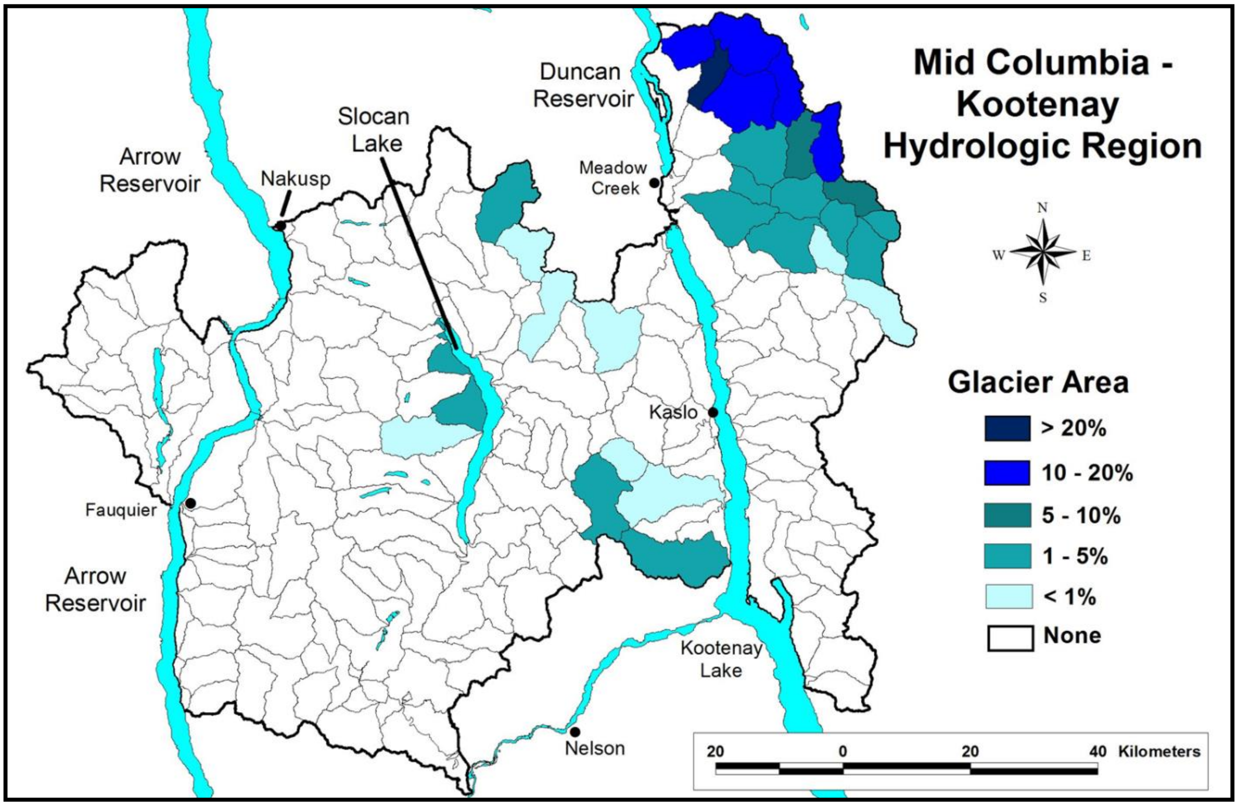



**Figure A4-3. Glacier area percentages for all Assessment Watersheds.**

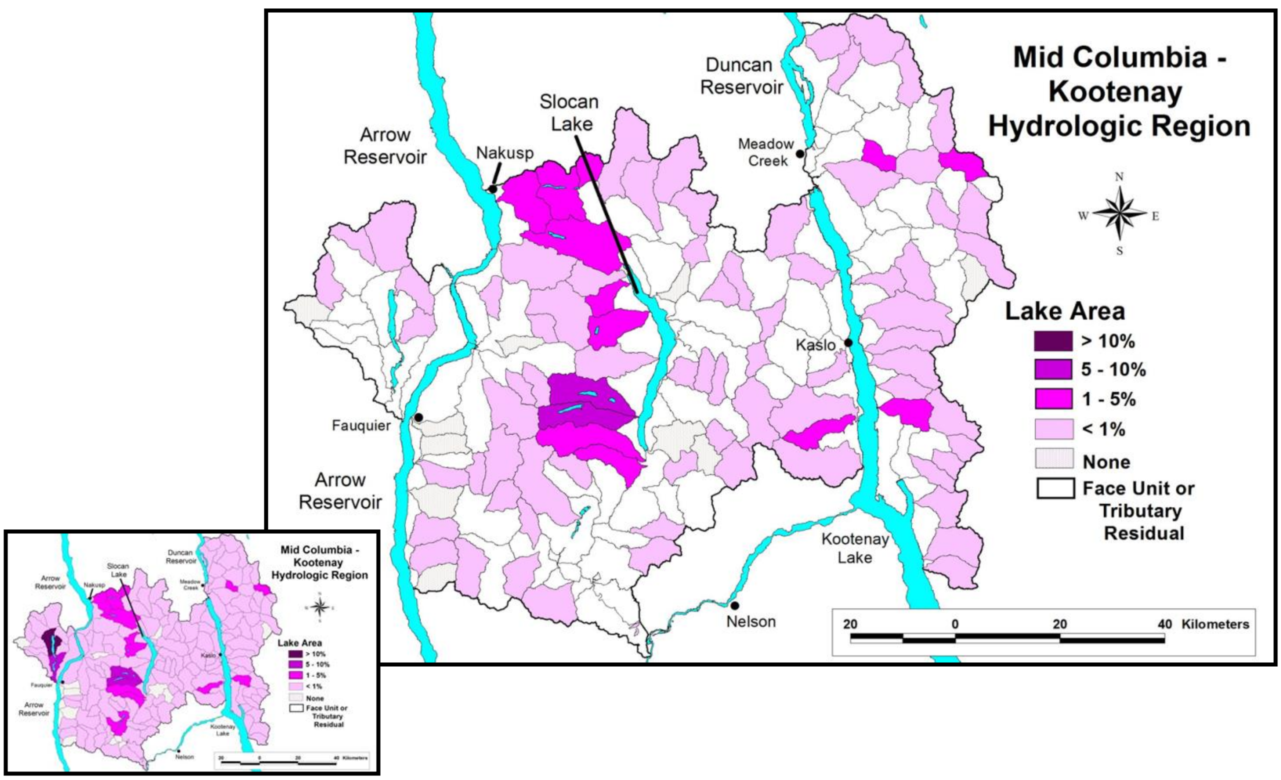



**Figure A4-4. Lake area percentage for primary and nested Assessment Watersheds. Inset shows lake area percentage for all Assessment Watersheds.**

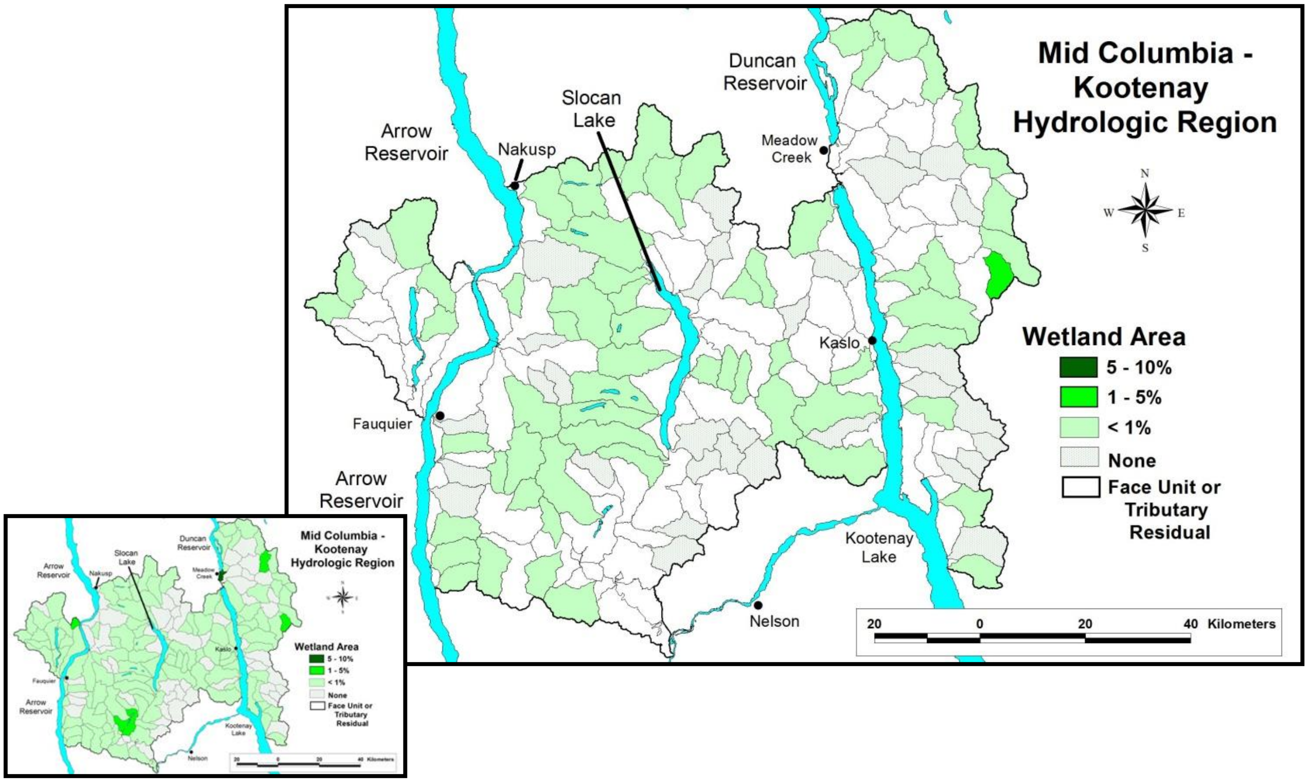



**Figure A4-5. Wetland area percentage for primary and nested Assessment Watersheds. Inset shows wetland area percentage for all Assessment Watersheds.**

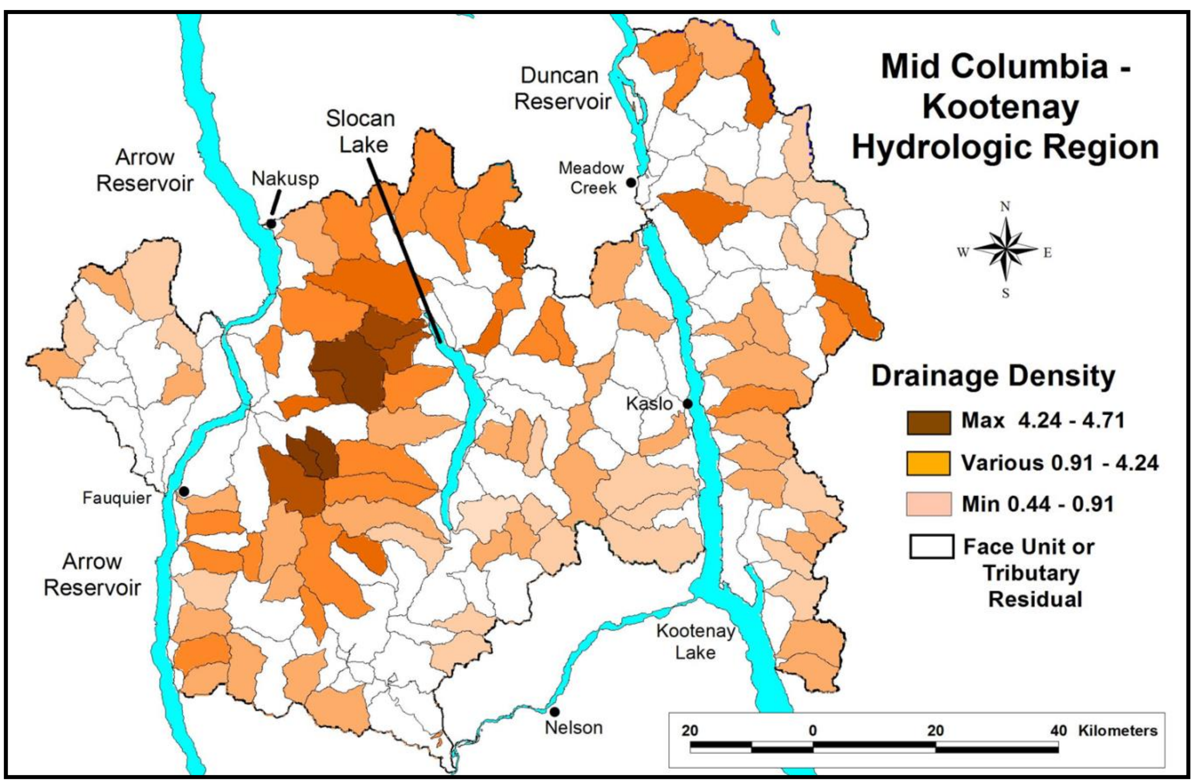



**Figure A4-6. Drainage density index for primary and nested Assessment Watersheds.**

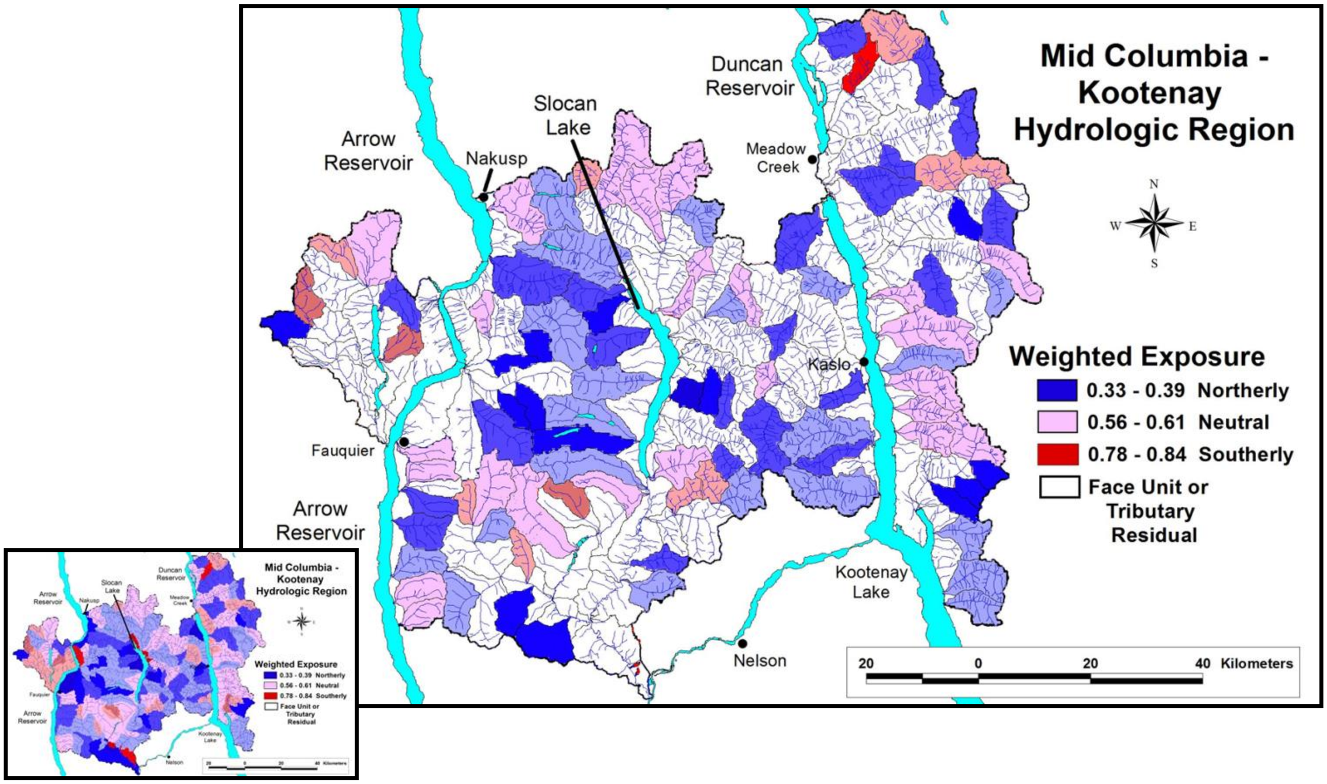



**Figure A4-7. Weighted exposure (aspect) for primary and nested Assessment Watersheds. Inset shows weighted exposure for all Assessment Watersheds.**

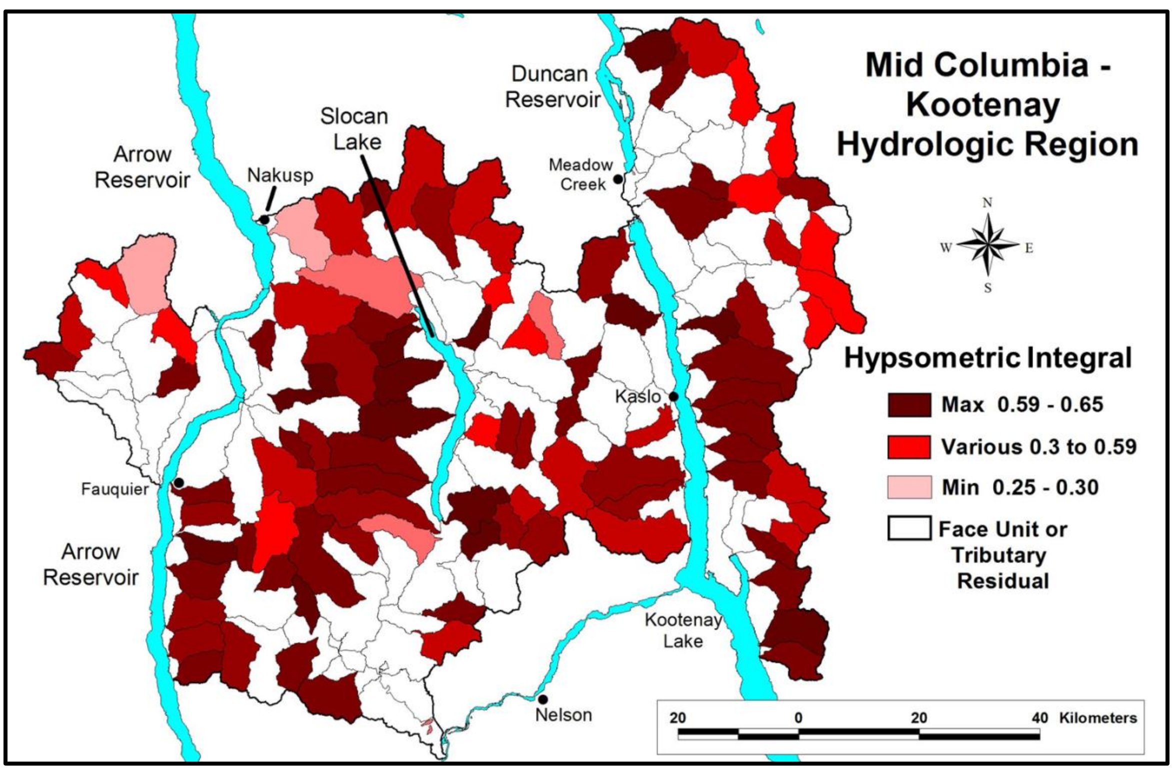



**Figure A4-8.Hypsometric Integral for primary and nested Assessment Watersheds.**

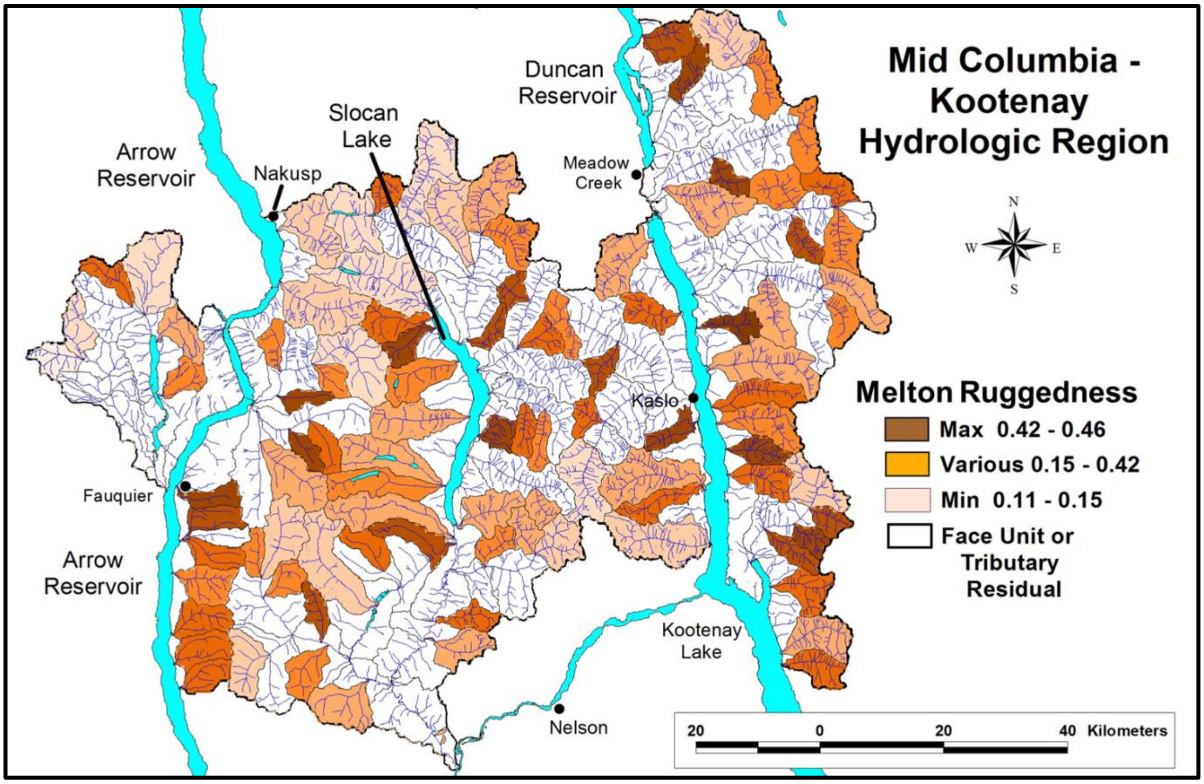



**Figure A4-9. Melton Ruggedness for primary and nested Assessment Watersheds**

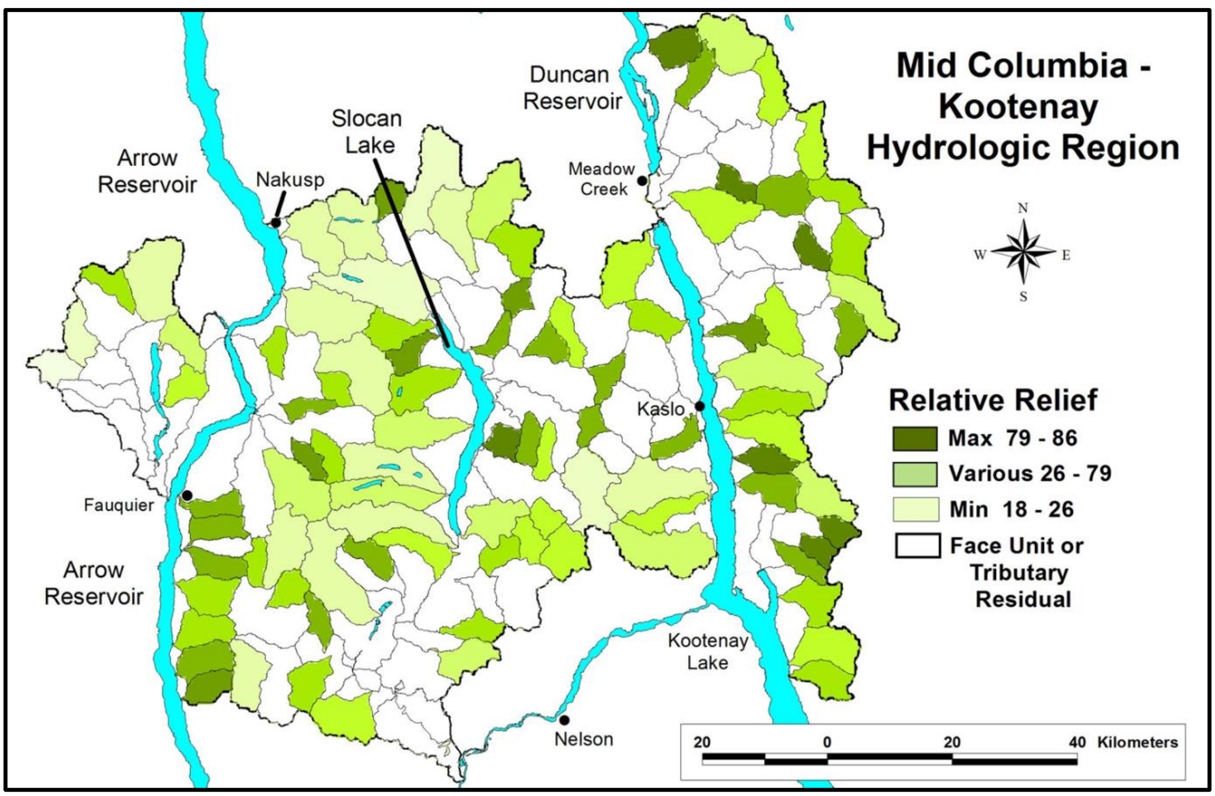



**Figure A4-10. Relative Relief for primary and nested Assessment Watersheds**