North Kootenay Lake Water Monitoring Project:

Data Integration to April 2018 with Initial Analysis

Prepared for:

Management Committee, North Kootenay Lake Water Monitoring Project
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EXECUTIVE SUMMARY

This report provides an integration and initial review of data associated with the north Kootenay Lake Water Monitoring Project (NKLWMP), a community-driven program of action to prepare for climate change. Building on a previous program (started in 2013), NKLWMP monitors a network of hydrometric, snow course and 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 will serve as a template to guide other rural areas in addressing the information needs communities encounter in facing the climate crisis.

Water monitoring under NKLWMP was formalized in 2016 and the program has been strengthened each year. NKLWMP has three objectives:

1. To establish a long-term integrated scientific water, snow and climate monitoring program in the north Kootenay Lake region of British Columbia;
2. To facilitate community engagement and ownership of the NKLWMP monitoring system, including developing community responses to watershed and climate disruption; and
3. 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.

The monitoring network was completed in 2018 and now includes seven hydrometric stations, two snow courses and three meteorological climate stations, providing data of up to five years' duration (as of April 2018). All data available for the NKLWMP monitoring network to April 2018 are assembled in this milestone report including data sets inherited from the previous station owners and managers. Volunteer committees and staffing arrangements have evolved since 2016 and are now well established. Relationships with a cross section of funding organizations are in place. In addition to NKLWMP's aggregated data, regional data are available from government agencies, BC Hydro, and local stewardship activities in a larger Representative Area, defined based on having areas of similar elevational sequences of biogeoclimatic units (i.e., similar climates) and similar patterns of surface flow. Agency hydrometric and snow-course data are included in this compilation report to put NKLWMP data in context. As budgets allow, future reporting will include additional regional and comparative data (climate, physiography, terrain, etc).

The hydrometric program includes continuous monitoring of water quantity and targeted sampling for water quality at seven hydrometric stations. Contrasts in aspect (west/east and north/south) and elevation (high/low) are available in the network. Some of the hydrometric stations are streams held of priority interest to local communities. The transition is complete in creating a full network and in addressing legacy and routine maintenance issues. Availability of monitoring data ranges from one to five years. In addition to confirming general patterns expected based on landscape characteristics, results to date offer additional information. For example, despite the aspect contrast of the two high-elevation stations, they reach their annual maximum flow at the same time and at a timing that coincides with that of the maximum flow at NKLWMP's two largest monitored watersheds. Initial water-quality data show a wide range in turbidity across the monitored watersheds with Gar and MacDonald exhibiting the highest turbidity and Ben Hur and Carlyle potentially the lowest.

The snow and climate program includes monitoring of snow accumulation at two high-elevation snow courses and air temperature and rainfall at three climate stations. Two of the climate stations are situated at the snow-course sites. This component of NKLWMP's monitoring program was only recently completed in 2017 thus the reporting is limited. Rainfall is recorded every five minutes. During the brief period of monitoring, the highest five-minute rainfall intensity recorded was 0.40 mm/hr, the highest daily rainfall total was 21.6 mm, and the highest monthly total was 60.4 mm. Early results for snow depth, snow-water equivalent and snow density are available for the Kootenay Joe and Lost Ledge snow courses for 2016 to 2018. The pattern of change in snow depth is similar at the two monitoring stations, with Lost Ledge consistently showing greater depth than Kootenay Joe. The highest snow depth measured since the program began is 330 cm on April 1, 2017. Initial results at these two sites are consistent with the general provincial pattern that basin snow accumulation peaks around April 1. In 2017 and 2018, a sharp decline in snow depth occurred after May 1.

A review of other monitoring in the Representative Area shows six active hydrometric stations, five active snow courses, one snow pillow, six year-round climate stations and eight seasonal climate stations. The hydrometric stations record streamflow for drainages that are larger than all of the NKLWMP drainages. Whereas overall they exhibit increased streamflow over the period of record, there are inconsistencies including decreases and nested behavior that is opposite to the downstream counterpart. The complexity of runoff responses highlights the value of the NKLWMP monitoring in better understanding the controls on runoff and how runoff will change under future climates. Snow accumulation has changed little during the period of record and exhibits a strong relation with elevation. The NKLWMP snow courses are situated at an elevation that is higher than all the other provincial snow courses within the Representative Area, again highlighting their value in providing data otherwise outside the range of existing monitoring sites. Climate stations are inventoried here in support of analysis in a future reporting period. All non-NKLWMP year-round stations are situated at low elevation.

Three practical applications of streamflow data are introduced that highlight the value of the NKLWMP data. In the flood frequency analysis, the addition of data from NKLWMP's smaller basins hints at a trend in peak flow that may be different than larger basins. A ratio analysis looking at peak instantaneous flow in relation to mean daily flow suggests that the ratio commonly used in larger basins may be different in smaller ones. Last, the variability of low flows may be larger when data from NKLWMP's smaller basins are taken into consideration. These three practical hydrologic examples all indicate that the application to smaller basins of assumptions developed from larger basins may be inappropriate and lead to incorrect sizing of infrastructure (e.g., culverts), inappropriate allocations for environmental flow needs, and potential over allocation of streamflow for water supplies. These and other potential miscalculations will be ever more significant under a changing climate and underscore the importance of maintaining the NKLWMP network over the long-term.

This project is well established and on track to meet its long-term objectives and commitments in support of climate-change readiness. Priorities for future field activity and data analysis are indicated. These include exploring available technology for real-time data communication and additional steps to improve the measurement of low flows. Expanded data analysis may include water budgets and runoff dynamics in relation to meteorological conditions and quantification of the impact of community water withdrawals on the Bjerkness and Gar creek discharge time-series data. Opportunities for regional data analysis are suggested to better understand the context of NKLWMP's Representative Area. These steps will also assist in clarifying information gaps that NKLWMP monitoring addresses. There are opportunities to apply findings from NKLWMP monitoring to influence policy decisions.

1.0 INTRODUCTION

This report provides an integration and initial review and interpretation of data associated with the North Kootenay Lake Water Monitoring Project (NKLWMP). NKLWMP is a program of action to prepare for climate disruption, rooted in the community and region of Kaslo and Area D of the Regional District of Central Kootenay (RDCK), situated at the north end of Kootenay Lake in British Columbia's Columbia Basin. Extreme climate events in recent years have had significant impacts within large portions of the RDCK including this area. These events have contributed to the destruction of and damage to north Kootenay Lake homes and infrastructure, tragic loss of life at Johnsons Landing, disruption of transportation networks, stress to forested and aquatic ecosystems, damage to domestic water supply systems, and an array of additional impacts to the local economy, environment and quality of life. Drought and inadequate water supply during periods of extreme low precipitation have also been identified as concerns within the study area (Schreier *et al*. 2011).

The recent history of extreme climate and hydrologic events has catalyzed the community to take responsibility in preparing for the deepening climate crisis and the disruptions that it is bringing. An earlier monitoring initiative undertaken by the Kaslo and District Community Forest Society (KDCFS) and supported by Selkirk College seeded a network of hydrometric stations designed to take best advantage of regional information and data sets. The breadth and cost of the challenges faced by BC's small dispersed communities continues to grow and necessitates an efficient approach to spending scarce resources. NKLWMP is designed to provide scientific insights focused on small streams through monitoring integration and by complementing other monitoring work already in place in the larger local region. This project may also serve as a template to inspire and guide other rural areas in addressing the growing information needs communities encounter in facing the climate crisis.

1.1 Objectives

Recognizing the need to improve understanding of and responsiveness to changes in the region's water and climate systems, NKLWMP was formulated in 2016. Currently administered by a sub-committee of the Kootenay Centre for Forestry Alternatives Society (KCFA), the project is implementing a long-term water-monitoring program for north Kootenay Lake. The project is generating important and potentially life-saving data for use by planners and decision makers in sectors related to land use, development, forestry, water supply, emergency preparedness, transportation, agriculture, back-country recreation and more. NKLWMP builds on the earlier Area D Water Monitoring Program that had itself been transformed from the KDCFS's initial monitoring introduced above. The program has strengthened each year. An integrated and scientifically robust monitoring network was completed in 2017/18. Volunteer committees and staffing arrangements have evolved during the 2016/17 and 2017/18 monitoring years and are now well established. Relationships with a cross section of motivated funding organizations are in place. The project is furthering connections with knowledge partners and other parties interested in contributing to NKLWMP's composition and vision, and applying its information products.

NKLWMP has three objectives:

1. To establish a long-term integrated scientific water, snow and climate monitoring program in the north Kootenay Lake region of British Columbia;
2. To facilitate community engagement and ownership of the NKLWMP monitoring system, including developing community responses to watershed and climate disruption; and
3. 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

This milestone report supports these project objectives by providing an integration of a wide cross section of NKLWMP and selected regional data. Budget permitting, select annual reporting of future monitoring years will incorporate a broader array of information to strengthen the perspectives that the NKLWMP monitoring data provide. This report represents the first instalment of that long-term incremental vision.

1.2 Monitoring Network and Representative Area

Regional landscapes are areas of similar elevational sequences of biogeoclimatic units and similar patterns of surface water flow. Recent modeling (Wang *et al.* 2012) has shown that vegetation zonation is a very good representation of regional climate. Regional landscapes have been grouped to form hydrologic regions representing areas of similar streamflow patterns. The regional-landscape boundaries have been updated recently (Utzig 2018). The NKLWMP monitoring network is situated in the regional landscape shown in Figure 1, which, in this report, is referred to as the Representative Area.

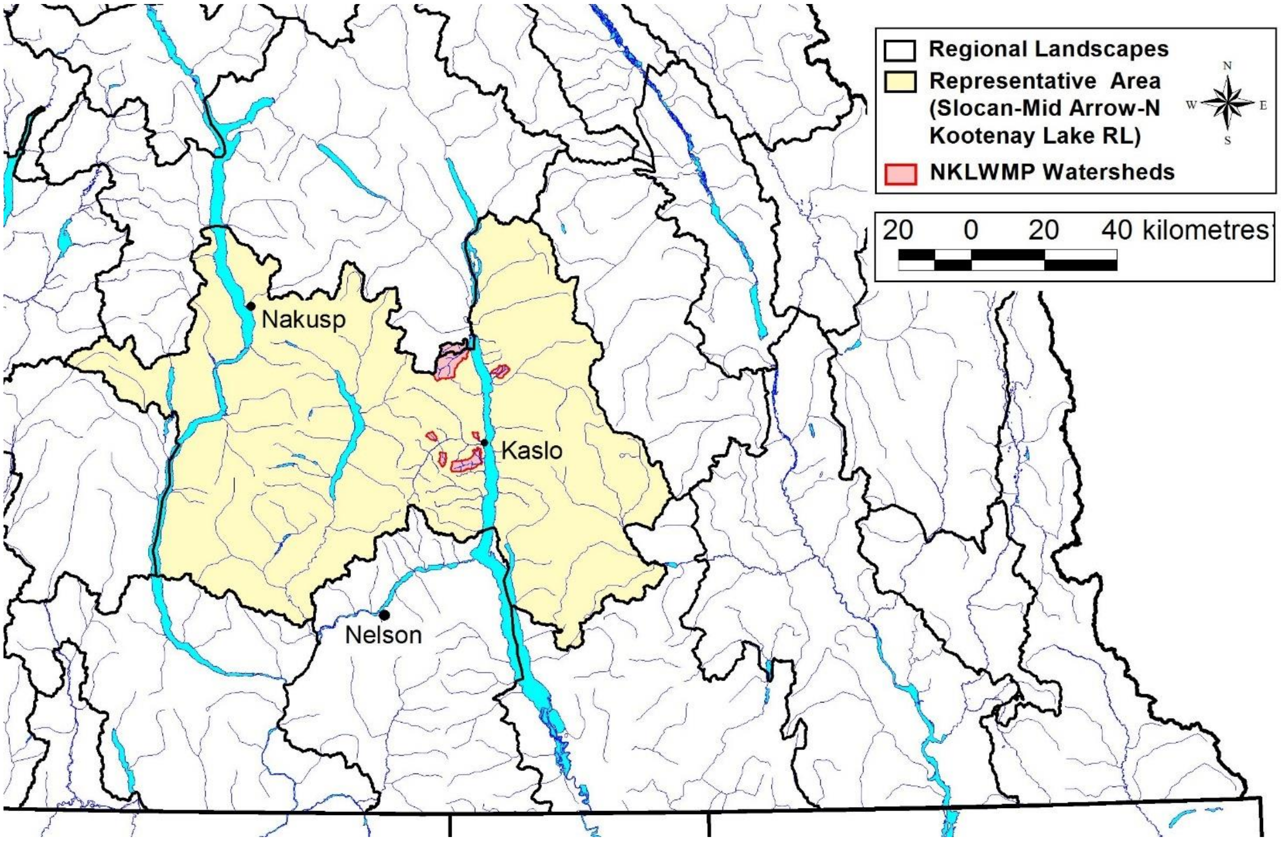

Figure 1. NKLWMP Representative Area showing spatial limits of area considered homogeneous with respect to hydrology and climate and within which the NKLWMP monitoring network is representative.

As of December 31, 2018, the monitoring network consists of seven hydrometric stations, two snow courses and three climate stations. Figures 2 and 3 show the locations of these monitoring sites, including the watershed boundaries associated with the hydrometric stations. Five of the monitored streams were originally included in the initial Area D Water Monitoring program, with two new creeks added in 2017 on the east side of Kootenay Lake to balance the network. Davis and Bjerkness creeks are the largest drainages in the network and are used as community water supplies. Lardeau has a community groundwater intake on the Davis Creek fan and the community of Mirror Lake takes water from

Bjerkness Creek. Ben Hur and Carlyle Creeks are paired sites (north-facing and south-facing) of small high-elevation drainages with limited impact from development. Gar Creek streamflow is shaped by significant inputs from calcareous bedrock springs sourced by water from outside the surface watershed and is the site of the 2012 Johnsons Landing landslide. MacDonald[1] Creek station drains a small watershed situated at lower elevation and has been an important water source to people living in or near the Village of Kaslo. Kootenay Joe Creek is a west-facing counterpart to the generally east-facing stations on the west side of Kootenay Lake.

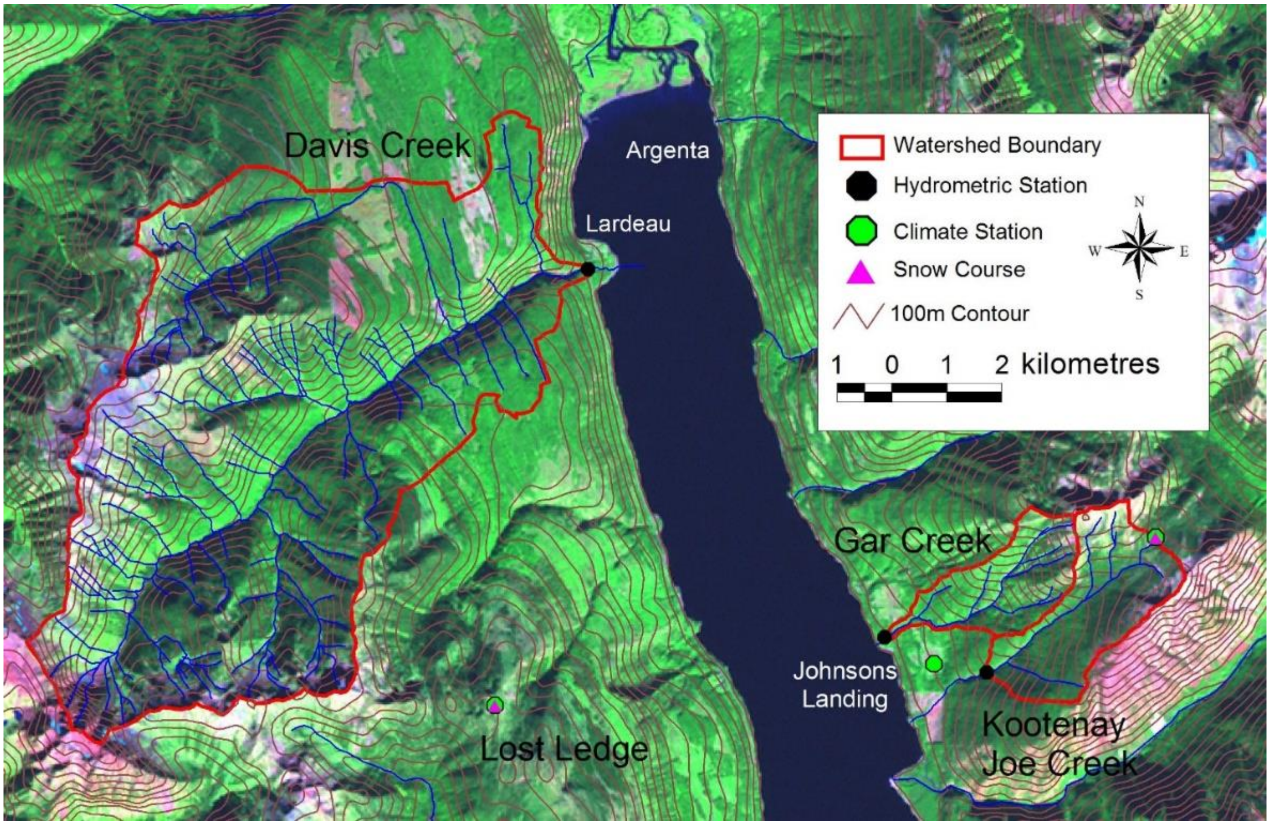

Figure 2. Northern portion of NKLWMP monitoring network showing Davis, Gar and Kootenay Joe hydrometric stations and associated drainage boundaries, Kootenay Joe and Lost Ledge snow course sites, and Kootenay Joe, Lost Ledge and Johnsons Landing climate station sites.

Snow courses are in place on each side of Kootenay Lake, above 2000 m elevation at nearby local ski cabins. The Kootenay Joe site was installed on October 23, 2015 while the Lost Ledge snow course was installed on October 3, 2016. In each case, a high-elevation climate station is situated within the snow course (both installed in the fall of 2017). An additional low-elevation climate station was installed on May 22, 2017 in Johnsons Landing at the base of the hillslope below the Kootenay Joe snow course. A

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[1] The spelling of MacDonald Creek is variable in many documents and on many maps, including NKLWMP records. In the book Kaslo – The First 100 years – The Oldest Incorporated Municipality in the Kootenays, Kaslo author/historian George McQuaig indicates that the correct spelling is "MacDonald". Elizabeth Scarlett, Archivist with the Kaslo Historical Society, suggests that the correct spelling may be "McDonald" Creek based on the name of the prospector and settler John "Lardo Jack" McDonald. In her opinion, the only verifiable, correct spelling would be his signature which may be available on mine claim registers. For now, this creek will continue to be spelled "MacDonald" however should a mine register be found, the spelling on that will be considered definitive and any changes will be made accordingly.

station at low elevation and on the west side of Kootenay Lake was deemed unnecessary due to the availability of suitable agency-provided climate data in that area.

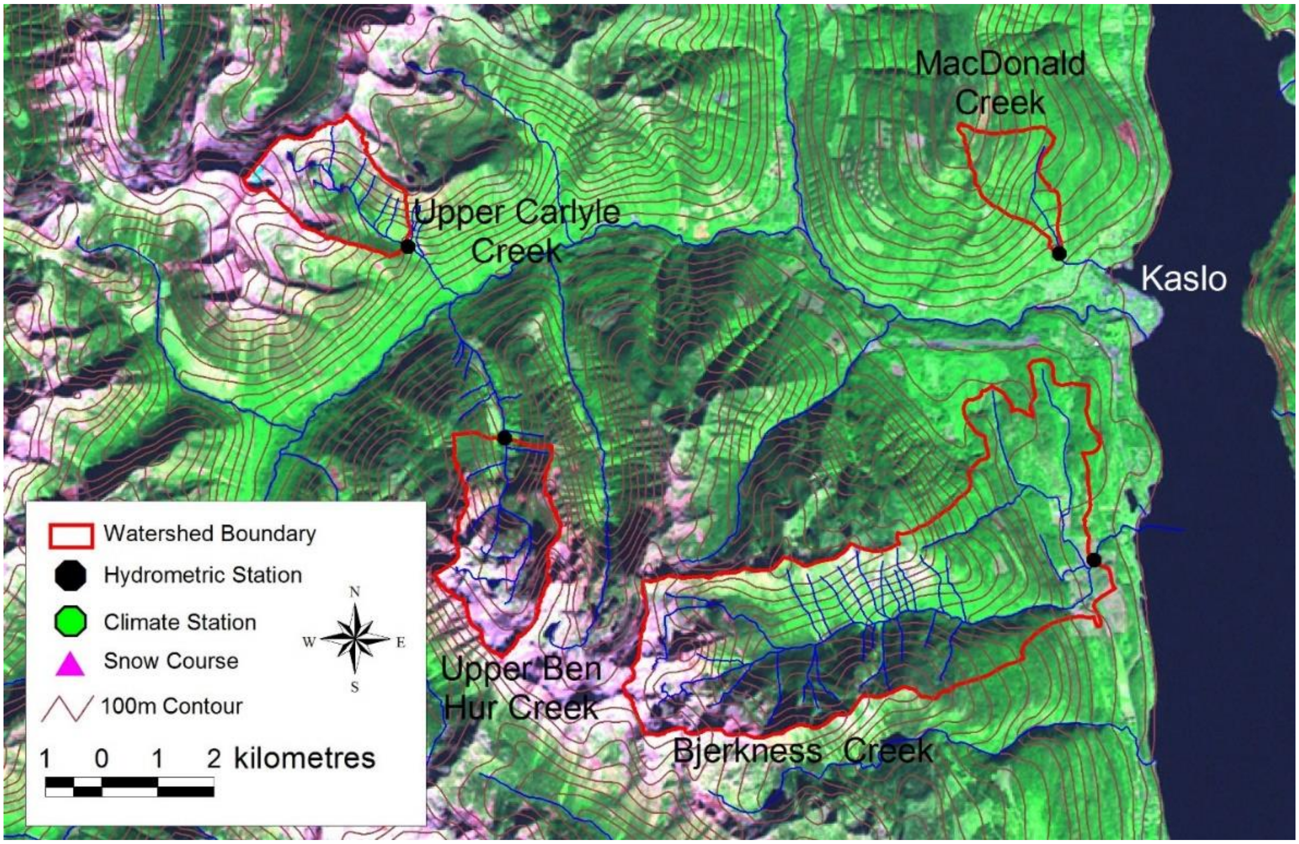

Figure 3. Southern portion of NKLWMP monitoring network showing Carlyle, Ben Hur, Bjerkness and MacDonald Creek hydrometric stations and associated drainage boundaries.

1.3 Project Administration

NKLWMP is a program of KCFA. KCFA acts as an overseeing financial body for NKLWMP, receiving funds and issuing payments. NKLWMP has recently established a project partnership with Living Lakes Canada[2]. Since NKLWMP's inception in May 2016, its administrative structure has evolved and matured. Two committees oversee and direct activities. NKLWMP's Management Committee oversees the ongoing function and delivery of NKLWMP commitments including fundraising, deliverables, contractors and volunteer participation. The Management Committee is composed of volunteers and is led by a Chair, or Co-Chairs. Day-to-day decisions are made by the Executive Committee (a subset of the Management Committee). These committees meet semi-regularly at a nominal quarterly or semi-annual frequency. Technical matters of the program are guided by the Scientific and Technical Advisory Group (STAG).

NKLWMP also hires three contractors to assist in the implementation of the project: a Senior Hydrologist, Junior Hydrologist and Project Coordinator. The Senior Hydrologist supervises the work of the Junior Hydrologist, organizes and facilitates STAG meetings and takes technical questions to the STAG for decision. The Junior Hydrologist supports the Senior Hydrologist in maintaining the hydrometric and climate stations, downloading the field data, managing and maintaining data sets, and

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[2] https://livinglakescanada.ca/projects/north-kootenay-lake-water-monitoring-porgram/

conducting basic data analysis. The STAG acts as a technical and scientific resource to support and assist the Senior Hydrologist. The Project Coordinator assists with project oversight, management and implementation under the direction of the Management Committee and Executive Committee and in coordination with the Senior Hydrologist, as necessary, along with assistance of volunteers. The Project Coordinator also works with and reports to KCFA. The Project Coordinator position was created in June 2017 to lessen the administrative burden of the Senior Hydrologist and to allow that person to emphasize field and technical matters. The detailed roles and responsibilities of each committee and position are available from NKLWMP, upon request.

Volunteers also carry out field-oriented functions outside of committees. In particular, the snow courses, hydrometric stations and climate stations each depend on participation of volunteers, often those living or recreating in proximity to the sites. Snow-course volunteers travel to the high-elevation sites to take measurements, providing the field data to the Senior Hydrologist. Hydrometric Station Guardians provide frequent and critical observations of the hydrometric stations, taking readings and water samples, and raising any concerns with the Senior Hydrologist. Climate Station Guardians observe the three climate stations, participating with the Senior Hydrologist in carrying out essential seasonal tasks of maintaining and monitoring the stations.

1.4 Project Recognition

The NKLWMP project and this report are made possible by the efforts and contributions of a wide range of groups and individuals, including community leaders and residents, professional and citizen scientists, contract staff and dedicated funders.

First, NKLWMP would like to acknowledge the individuals and organizations who had the initial vision for the project and initiated it in its former form, the Area D Water Monitoring Project. Erika Bird, Richard Marchand and the Board of the KDCFS, as well as Russell Smith, Robert Macrae and Frank Fowler from Selkirk College were integral to setting up the initial project. Ingrid Liepa worked as a contract coordinator during this time, with funding provided by the Columbia Basin Trust. Cheryl Hillier also worked as a contract water technician during the initial phase of the project.

NKLWMP has been able to continue monitoring and produce this report through the integrated contribution of funders, volunteers, organizations and contract staff. NKLWMP is grateful for their shared vision and commitment to supporting community preparedness and ecosystem resilience in the face of climate change.

1.4.1 Funding

Operational funding provides the capital essential to operate, including staffing and ongoing expenses.

- Columbia Basin Trust: 2016–2020.
- Kootenay Lake Local Conservation Fund, administered by Kootenay Conservation Program (KCP): 2017–2020.
- Affected Areas Program, funded by the Columbia Basin Trust and delivered by the Regional District of Central Kootenay (RDCK), with support from Area D Director, Aimee Watson: 2015 and 2018.

Equipment funding enables the project to establish and maintain hydrometric, climate and snow monitoring sites.

- Kootenay Savings Credit Union
- Nelson and District Credit Union
- Fortis BC
- Kootenay Country Store Cooperative

Equipment Loans on a seasonal basis reduces the scope of funding required by the project.

- Ministry of Forest Lands and Natural Resource Operations and Regional Development (MFLNRORD)
- Selkirk College
- Loans of personal equipment from volunteers

1.4.2 Operational Support

Selkirk Geospatial Research Centre reviewed the standards of NKLWMP's data parameters and advised on potential storage and dissemination technologies, with funding support from Columbia Power Corporation.

MFLNRORD has assisted with operational aspects of monitoring in the Johnsons Landing landslide area and continues to make its turbidity meter available for analyzing water samples.

1.4.3 Volunteer Support

Volunteers support NKLMWP through hundreds of hours annually of in-kind time toward both the management and field aspects of the project. Volunteers oversee project implementation and are active in field activities.

Project Oversight

- Kootenay Centre for Forestry Alternatives (KCFA) oversees the project, with outstanding contributions from Greg Utzig.
- The Management Committee provides general oversight, function and delivery of the program (2016-2018): Andy Shadrack, Bill Wells, Greg Utzig, Marlene Johnston, Don Scarlett, Charles Cuell, Mel Reasoner, Tara Clapp, Ross Lake and Martin Carver.
- The Executive Committee provides day-to-day support of the project, while also supporting the Senior Hydrologist and Project Coordinator (2016-2018): Bill Wells, Greg Utzig, Andy Shadrack, and Charles Cuell.
- The STAG guides and supports the technical aspects of the project (2016-2018): Peter Jordan, Greg Utzig, Bill Wells, Marlene Johnston, Don Scarlett, Pete Golden, Sarah Crookshanks, Mel Reasoner, Charles Cuell, Rob Macrae, Erin Rainey and Kyle Terry.

Field Activities

- Two high-elevation snow courses are made possible by community groups/residents who welcome project volunteers to stay in their backcountry cabins during field measurements. Snow-course measurements are taken by volunteers: Peter Jordan, Pete Golden, Samuel Lyster, Greg Utzig, Rob White, Isabel Desmarais, Carl Johnson, Chris Temple, Tom Duchastel, Osa Thatcher, Mark Elder, Martin Carver, Stu Heard, David Cunningham, Graham Collingwood, Clark Lyster, Jean-Michel Longval, Clayton Zacharias and Kristina Anderson. Peter Jordan maintains the snow tubes each season.
- Climate stations were installed by and continue to be maintained by volunteers: Martin Carver, Chris Hiebert, Greg Utzig, Chris Temple, Carl Johnson, Tom Duchastel, Mark Elder and Paula Owen.
- The Powder Bound Ski Club and John Lerbscher have supported NKLWMP's access to high-elevation snow-course and climate-station sites through the generous use and/or loan of ATVs and snowmobiles to access the sites.
- Seven hydrometric stations were installed by and continue to be maintained by volunteers: Greg Utzig, Don Scarlett, Martin Carver, Marlene Johnston, Joe Johnston, Bill Wells, Chris Hiebert, Darcie

Mathews, Andy Shadrack, M.L. Thomson, Tom Duchastel and JV Humphries students – Austin Tremblay (Cooper Creek) and Tyler Hearne and Will Halleran(Meadow Creek),.

- The following private landowners allow volunteers to access hydrometric sites through their land: Larry Badry (Bjerkness Creek), Jeff Mattes (MacDonald Creek), and Kate O'Keefe (Kootenay Joe Creek).

1.4.4 Project Endorsements

Government

Village of Kaslo, RDCK, RDCK Development Services, Ministry of Transportation and Infrastructure (MoTI), MFLNRORD, MoTI's West Kootenay District Provincial Approving Officer and the Interior Health Authority.

Community

Fletcher Creek Improvement District, Mirror Lake Water Users, KDCFS, Harrop-Proctor Community Forest, Columbia Basin Watershed Network, Johnsons Landing Community Association, Kaslo Outdoor Recreation and Trails Society, Kootenay Conservation Program, Friends of Kootenay Lake Stewardship Society and Perdue Geotechnical Services.

Additional Support

Bob Sandford, Epcor Chair for Water and Climate Security at the United Nations University's Institute for Water, Environment and Health. Hans Schreier, Professor Emeritus from the University of British Columbia, has supported the project from its beginning and with additional climate data from the Kaslo area; some of this work has been carried out in conjunction with the technical expertise of the Pacific Climate Impacts Consortium.

1.4.5 Contract Staff

The hard work and dedication of the contracting team has greatly contributed to the success of the project and the creation of this report.

- Senior Hydrologist, Martin Carver, provided ongoing oversight and expertise in the technical and field components of the project from May 2016 through September 2018, while also contributing to fundraising efforts and integration and oversight of project components. Martin has taken the lead in preparing this report.

- Senior Hydrologist, Samuel Lyster, stepped into the role of Senior Hydrologist in September 2018. He provides oversight and expertise in the technical and field components of the project, while also contributing to fundraising efforts and general project oversight.

- Junior Hydrologists, Paul Saso (current) and Laurence Chaput-Desrochers (former), have been engaged with field and data-analysis aspects of the project.

- Project Coordinator, Chris Hiebert, provided project oversight and fundraising leadership from June 2017 through March 2018. NKLWMP welcomes Mark Elder as the new Project Coordinator.

1.5 Acronyms

EFN	Environmental flow need
FFA	Flood frequency analysis
KCFA	Kootenay Centre for Forestry Alternatives
KCP	Kootenay Conservation Program
LLC	Living Lakes Canada
MoE	BC Ministry of Environment
MFLNRORD	BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development
MoTI	BC Ministry of Transportation and Infrastructure
NKLWMP	North Kootenay Lake Water Monitoring Project
RDCK	Regional District of Central Kootenay
RISC	Resource Inventory Standards Committee
STAG	Scientific and Technical Advisory Group
TSS	Total suspended solids
WMO	World Meteorological Organization
WSC	Water Survey of Canada

1.6 Report Acknowledgments

As the lead author of this report (Martin Carver), I would like to acknowledge the input of my co-authors. I am grateful to Samuel Lyster who assisted in writing sections of the report and in revising draft content as it became available. In particular, Samuel prepared the content of section 5. Paul Saso used the data sets to produce the original plots presented here. I am grateful for his capabilities in managing data sets in Excel and for his patience in carefully implementing many of my design requests associated with the preparation of the data plots.

I also recognize other contributions to the completion of this report. Chris Hiebert worked with Andy Shadrack, Rob Macrae and I in putting together the content of section 1.4. Greg Utzig and I worked together to develop the content and presentation of the report's maps. Greg used Geographic Information System software to generate the maps (shown in Figures 1, 2, 3, 32 and 33). Bill Wells provided the source information for the characterization of the NKLWMP drainages in relation to the Representative Area provided in section 2.3. The photos in the report are my own except where indicated. Sheila Roberts, Greg Utzig, Bill Wells, Marlene Johnston, Mark Elder, Chris Hiebert, and others provided helpful comments as reviewers that improved the report significantly. I am also grateful to the NKLWMP Management Committee for entrusting me with the responsibility of assembling this first milestone report. I acknowledge and am thankful to all these people, and the entire team of volunteers, funders, and contractors that has created and now sustains NKLWMP.

1.7 Report Limitations

As the first major reporting of NKLWMP's monitoring project, systems of data management, analysis, and presentation were needed for report completion that will create efficiencies in the project for years to come. Additionally, previous monitoring activities and data sets had to be updated and integrated with NKLWMP's modern systems. That burden on this first milestone report has required that some analyses be postponed. Notably, the integration of regional climate data with other regional and NKLWMP data is excluded from this reporting; however, associated meta-data are included here. Due to a lack of budget, regional data are introduced descriptively rather than analyzed quantitatively. The above limitations are associated with the incremental budgets available to this community-driven monitoring project.

The analysis presented in section 4 should not be used for establishing design flows or environmental needs in any real-life situation. These are theoretical examples demonstrating proof of concept to illustrate the potential value of long-term NKLWMP data sets.

2.0 NKLWMP STREAM PROGRAM

NKLWMP's stream monitoring program includes continuous monitoring of water quantity and opportunistic grab sampling for water quality at seven hydrometric stations for watersheds with contrasting aspect and elevation.

2.1 Methods, Standards and Instrumentation

Hydrometric monitoring follows the standards established in British Columbia (RISC 2018). Reference staff gauges installed at hydrometric monitoring cross sections are instrumented with continuous data loggers recording water level ("stage"). Water level is determined by recording changes in water pressure (every 30 minutes) with a Solinst Levelogger installed in a pipe below the water surface. A second Solinst Barologger installed nearby records changes in atmospheric pressure so that adjustment can be made for local variations in air pressure. (This second barologger also records air temperature – see section 3.3.) Water level is converted to discharge (stream flow) through an empirical exponential relation between stage and discharge, constructed through time by measuring streamflow at a range of stages.

To provide the data for the stage-discharge relations (also commonly called "rating curves"), creek discharge is measured using the salt-dilution method (Hudson and Fraser 2005; Moore 2005; RISC 2018). This technique is well established in British Columbia where it is optimal for applications involving steep boulder streams that are otherwise prohibitive to monitor using velocity methods. The salt-dilution method involves fully mixing a known quantity of salt in the streamflow, and then recording and analyzing the downstream conductivity pulse. The staff gauge reading is recorded. Background conductivity is determined to enable an appropriate adjustment during data processing. Field measurements of electrical conductivity are carried out using a WTW multi-parameter portable Multi 3620 IDS meter with TetraCon 925-P electrodes (graphite). Flow increments are summed up to yield the total flow during the known period of time. The computed discharge from the salt-dilution measurements is related directly to stage, forming the basis of the stage-discharge relation. Once a reasonable distribution of points has been gathered (Rainville *et al.* 2016), the functional relation between stage and discharge is determined statistically and applied to the stage time series. Office analysis of field data involves spreadsheet computations of short-term conductivity time series using statistical methods to ascertain corresponding flow.

To what extent do short-term salt elevated salt concentrations affect aquatic ecosystems? The maximum salt concentration measured throughout the period of NKLWMP monitoring was 225 mg/l at the Carlyle station, on June 11, 2016. This value is significantly lower than the allowable short-term maximum concentration of 600 mg/l, based on the BC Approved Water Quality Guidelines for standards to aquatic life (MoECCS, 2018). Also, the higher salt concentrations occur for only short periods and within short distances downstream, thus further limiting the potential for detrimental effects. Wood and Dykes (2002) provide additional insight into the potential ecological impacts salt-dilution gauging may have on the environment. That study focuses on the drift activities of benthic macroinvertebrates. Drift is defined as the entrance of organisms into the water column and their subsequent transport downstream (Matthaei et *al.*, 1998). The results of the study illustrate that the drift of macroinvertebrates in the two rivers studied increased with the introduction of the slug injection of salt under low and intermediate flows but under high flows, no appreciable increase in drift occurred in response to the slug injection. Overall, the study concluded that the effect on benthic macroinvertebrate community abundance is negligible.

Stage-discharge relations are developed following standard approaches (Rainville *et al.*, 2016). Based on the distribution of the data and a recognition of the nature of each hydrometric cross section, each relation can be characterized by the following simplified hydraulic equation:

$$Q = a\,(h - h_o)^{b}$$

where Q is the flow (m^3/s), h is the reading on the staff gauge (cm), h_o is an offset (axis intercept, cm), a is a channel calibration parameter and b is the rating exponent. The three unknowns (a, b, and h_o) are determined through linear regression supplemented by the objective of optimizing the distribution of computed departures (from the mean relation) and emphasizing the high-flow discharge measurements. See Rainville *et al.* (2016) for further information.

The continuous water-level records are converted to a time series of stream discharge using the stage-discharge relations. Data cleaning addresses issues associated with freezing, sedimentation and maintenance periods that may introduce uncertainties into the data logger records. The time series at MacDonald, Ben Hur, Carlyle, Davis and Bjerkness extend back to a period before monitoring began under NKLWMP. The stage-discharge relations and offsets applied in computing the time series from these earlier periods have been rectified using all available information. The time series provided in this report replace those previously published for these stations.

Water samples are taken using the standard depth-averaged grab-sampling technique (RISC 2006). At Davis, Carlyle, Ben Hur and MacDonald stations, grab samples are taken at or just downstream of the staff gauge. At Bjerkness station, the samples are taken well upstream of the staff gauge at the road crossing above the stilling pond. At Gar station, the samples are taken upstream of the staff gauge. The time and staff gauge reading of each water sample are recorded when the sample is taken. The samples are analyzed with a Hach 2100N Turbidimeter, made available to NKLWMP by FLNRORD at the Selkirk Resource District offices, near Nelson. Using the computed time series, discharge is identified based on the time and staff gauge reading noted when the sample was taken. The results are plotted as turbidity versus discharge.

2.2 Description and History of NKLWMP Hydrometric Stations

The NKLWMP hydrometric network consists of seven stations situated within the vicinity of the North Arm of Kootenay Lake (Figures 2 and 32). Table 1 provides metadata for the stations including locations, installation dates, and some basic characteristics of the watersheds they drain. Davis, Bjerkness, Carlyle, Ben Hur and MacDonald were installed by the KDCFS and were taken over first by the Area D Water Monitoring Committee and then by NKLWMP in May 2016. The Gar Creek and Kootenay Joe Creek stations were installed by NKLWMP, completing the network. All seven stations are equipped with a staff gauge, continuous water level loggers and nearby barometric pressure loggers. (The water level loggers are unvented and thus do not automatically compensate for barometric pressure acting on the water surface – see section 2.1.) As of December 2017, all stations were monitoring continuously with most operational issues addressed. However, the steep nature of these small mountain watersheds leads to ongoing maintenance demands at the hydrometric stations.

Table 1. Hydrometric stations within the complete NKLWMP monitoring network.

Station		Location			Watershed	
Name	**Established**	**Elev. (masl)**	**Easting**	**Northing**	**Area (km^2)**	**Max. Elev. (masl)**
Davis Creek	June 20, 2013	580	503193	5554441	63.58	2640
Bjerkness Creek	July 25, 2013	625	506221	5524072	26.72	2530
Carlyle Creek	October 11, 2012	1530	494021	5529644	4.13	2620
Ben Hur Creek	October 19, 2013	1550	495738	5526241	5.64	2580
McDonald Creek[1]	October 13, 2012	720	505601	5529514	2.20	1885
Gar Creek	June 8, 2015	570	508590	5547754	4.09	2290
Kootenay Joe Ck	Sept 7, 2017	890	510444	5547110	6.03	2360

1 – The sensor was removed on August 11, 2017 and reinstalled on September 25, 2018. The settling basin was excavated in May-June 2018.

The Davis Creek station is situated just south of the town of Lardeau near where Highway 31 crosses the creek. The original station (Figure 4a and 4b) was established in June 2013 at the site of an old diversion dam, located at the end of a short trail on the north side of the creek. According to Smith (2016), barometric loggers were installed at the Davis station on June 28, 2015. A site schematic of the original station is provided in Smith (2016). In November 2017, this station was relocated downstream due to severe natural decay of the wooden cross section and staff-gauge support at the original site. The current site is on the left bank just above the highway bridge (Figure 4c). When conducting salt-dilution gauging at this site, the salt is deposited in the splash pool immediately below the original site and the measurements conducted about 100 m downstream of the highway where water quality samples are also typically taken. The freshet here typically begins in late April reaching a peak in late May.

a) Davis station (2013-2017)

b) Davis station (2013-2017)

c) Current Davis station (2017-present) visible from bridge over Highway 31

Figure 4. Photographs of Davis Creek hydrometric station: a) staff gauge at original site b) wooden weir at original site, c) current site visible from highway bridge.

The Bjerkness Creek hydrometric station (Figure 5) was installed in July 2013 on the creek's south bank, at the Mirror Lake Water Users' dam and intake. An earlier hydrometric station on the creek at a different location was apparently washed out in the June 2013 freshet. This site is accessed by Birch Hill Lane, through private land, then up a steep hill and forest lane to a large concrete weir. The staff gauge and PVC pipe containing the datalogger is up the wooden stairs and near the south end of the weir. Due to the highly stable site associated with this installation, operational issues have been very limited. A site schematic is provided in Smith (2016). The freshet here typically begins in early April and peaks in late May. When conducting salt-dilution gauging at this site, the salt is deposited in the splash pool immediately below the weir and the measurements conducted about 100 m downstream. Water quality samples are typically taken below the weir or ~250 m upstream of the weir where the Back Road (Kaslo South Road) crosses Bjerkness Creek. Because the Bjerkness station is located at the dam and intake for the Mirror Lake Water Users' Community, the time-series recorded data do not reflect the flow reduction due to these removals. These withdrawals are likely of greatest relative significance during the summer low-flow period when temperatures climb and streamflow has dropped with the freshet's recent conclusion. The seasonal magnitude of introduced error should be determined by estimating seasonal withdrawals for the Mirror Lake community and comparing them with prevailing seasonal streamflow.

a) Bjerkness station – staff gauge

b) Bjerkness station – downstream reach

Figure 5. Photographs of Bjerkness Creek hydrometric station: a) staff gauge and stilling well and b) reach immediately downstream.

The Carlyle Creek hydrometric station (Figure 6) was installed in October 11, 2012 on the creek's left bank, about five km up a limited-use mining/logging road, accessed off the Keen Creek Road. The measuring station is about 80 m from the road. A site schematic is provided in Smith (2016). The freshet here typically begins in early May and peaks in late June. When conducting salt-dilution gauging at this site, the salt is deposited about 60 m upstream of the staff gauge and measurements taken about 10 m downstream of the staff gauge where water quality samples are also typically taken. This hydrometric station is located at high elevation and as a result, the logger data have shown some (very limited) evidence of freezing. Otherwise, operational issues have been very limited at this site.

Figure 6. Photograph of staff gauge and cross section at Carlyle Creek hydrometric station.

The Ben Hur hydrometric station (Figure 7) is located on the right bank in a wide bedrock section of the creek. The site is accessed up an old logging road accessed from the Keen Creek Road. The site is reached by walking about 1 km along the road from the parking spot for the Ben Hur hiking trail then a further 200 m through old-growth forest at the north boundary of Kokanee Glacier Provincial Park. A site schematic is provided in Smith (2016). The freshet typically begins here in early May and peaks in June. When conducting salt-dilution gauging at this site, the salt is deposited at a trail bridge about 50 m upstream of the staff gauge where measurements take place including water sampling. This hydrometric station is located at high elevation and the logger data have shown evidence of freezing. The station is located in a bedrock channel with good control, but is wide and, as a result, the instrument has experienced freezing at times, despite steps taken to winterize it. These periods typically correspond to daily minimum temperatures sustained below -10℃ in Kaslo. A barometric logger was installed here on Oct 22, 2015 to address variations in barometric pressure.

Figure 7. Photograph of Ben Hur hydrometric station.

The hydrometric station on MacDonald Creek (Figure 8) was originally installed in October 2012 at the site of an old water intake weir. It is found by walking from a private log landing, situated at the top of Brennand Street in Kaslo (west Village boundary). Although it has remained at the same site since that date, a higher level of operational maintenance (and associated service disruption) has been required here due to this site's sediment-filled settling pond caused by a debris flow in 2002. For example, the station has required additional maintenance to maintain good connection between the instrument and the streamflow. A barometric logger was installed on June 28, 2015 to allow more accurate correction of the automated water level recordings by including the variation in barometric pressure (Smith 2016). The station was temporarily decommissioned in the fall of 2017 due to liability and ownership issues. Once resolved, a legacy leak in the cross section was also repaired and the settling basin fully cleaned out after the 2018 freshet (May-June) so that the station became fully operational on September 25, 2018. The water level logger was also replaced at that time. When conducting salt-dilution gauging at this site, the salt is deposited into the splash pool immediately below the weir. Measurements take place about 50 m downstream. A site schematic is provided in Smith (2016). This station monitors a watershed generally situated at a lower elevation and, as a result, the freshet starts in early April and typically peaks in mid-May.

a) MacDonald station – staff gauge

b) MacDonald station – downstream reach

Figure 8. Photographs of MacDonald Creek hydrometric station: a) staff gauge and b) reach immediately downstream.

The hydrometric station at Gar Creek (Figure 9) was initially established in May and June 2015 with a staff gauge on the right bank, beside a V-notch weir. It is located close to Kootenay Lake, about 500 m downhill of the Argenta-Johnsons Landing Road, and a few metres upstream of a local access road. The Johnsons Landing landslide of July 12, 2012 severely disturbed Gar Creek and adjacent areas and, as a result, Gar Creek carries very high sediment loads, complicating station operations. Due to ongoing sedimentation and the creek's steep gradient at the hydrometric station, the station requires frequent cleaning throughout the freshet. Continuous monitoring began in the fall of 2017 when instrumentation became available (both level and barometric loggers). Detailed manual measurements are available during the first two years of operations.


a) Gar station – upstream reach b) Gar station – staff gauge and weir

Figure 9. Photographs of Gar Creek hydrometric station.

The installation of the Kootenay Joe station (Figure 10) on Sept 7, 2017 completed the NKLWMP hydrometric network. After its initial installation, it was dislodged by the freshet and was subsequently reinstalled and its anchoring strengthened. Operational issues have led to data gaps (largely affecting the low-flow period). Continuous monitoring for Kootenay Joe station is available for the 2018 freshet, which falls outside the scope of this report but will be included in subsequent reporting. When conducting salt-dilution gauging at this site, the salt is deposited at the hydrometric station with the conductivity measurements (and water sampling) taking place about 80 m downstream. Kootenay Joe's freshet starts in April and peaks in May.

Figure 10. Photograph of Kootenay Joe hydrometric station.

2.3 Preliminary Hydrologic and Geomorphic Descriptions of Monitored Drainages

Each of the seven NKLWMP streams rise and run in unique geologic regimes with the bedrock characteristics of each drainage determining much of each stream's general course and behaviour. Although the specific rock formations differ somewhat among the seven monitored drainages, the range of structural characteristics, terrain features and ecological processes found in the monitored drainages are comparable to those of the Representative Area. Relative erosion characteristics of bedrock formations are factors in steepness, rate, and direction of water flow. Repeated glaciation has not only carved the major geomorphic features and watersheds out of the main mountain ranges guided by gross geologic structures, but has also overlain the entire area with a variety of surface material deposits through which these mountain streams drain and shape the land.

Kootenay Joe and Gar creeks, both in the Johnsons Landing area, are examples of streams with contrasting bedrock characteristics resulting in different streamflow timing and behaviours, Kootenay Joe rises and runs entirely in intrusive granitic bedrock quick to respond to precipitation and thaw. Nearby Gar Creek runs in a contact zone between intrusive granitic and meta-sedimentary bedrock. It features springs emanating from strata crossed by the creek, some of which are karst, contributing to stream behaviour that is much less immediately responsive to weather-related inputs. The other five monitored streams have their own unique behaviours reflecting the structures, terrain materials and ecology in their particular locations. Together these seven drainages represent a range of watershed types that occur in parts of the North-Central Kootenay region.

The Representative Area contains portions of the Purcell and Selkirk mountain ranges, where the NKLWMP monitored streams are situated, in addition to a portion of the Monashee Ranges. The orogenic (mountain building) and glacial processes were similar across this portion of these ranges, resulting in similar geomorphic processes across the Representative Area. As discussed in section 1.2, the Representative area is defined to contain similar climate and patterns of surface flow. The similarities in structural qualities of the mountains, overlain by materials determined largely by glaciation, have provided NKLWMP with a significant spatial area that is also shaped by a similar geomorphic regime.

2.4 Previous Monitoring of Small Streams in the Vicinity of the NKLWMP Network

Well before the establishment of NKLWMP, other monitoring (focused on water quality) took place in the north Kootenay Lake area. In the 1980s Tony Salway (1983) completed a reconnaissance hydrologic assessment that included Gar and Kootenay Joe creeks. More recent activities are described by Quamme and Sundberg (2000), Sundberg (2001), Masse (2002), and Masse (2003a, 2003b, 2003c) and are briefly summarized in this section. Although this information is not directly applied to the analyses provided in the present report, it is made available here so that it may be of use in future reporting and analysis. The selected reporting provided in this section focuses on streams currently monitored in the NKLWMP network. Selected reporting from the previous monitoring of streams not in the NKLWMP network is given in Appendix A1.

From 1998 to 2002, the KDCFS carried out monitoring on two streams now monitored by NKLWMP - MacDonald and Bjerkness Creeks – and two other Kaslo-area streams, Wing and Kemp Creeks. The focus of this monitoring was water quality with monitored parameters including pH, conductivity, air/water temperature, turbidity/TSS, periphyton and benthic macroinvertebrates. Water quantity may have been monitored: although staff gauges were in place, this aspect of the program appears to have been discontinued and it does not appear that stage-discharge relations were developed. Quamme and Sundberg (2000) report watershed characteristics for these four monitored streams. That information is reproduced in Table 2 for two streams that overlap with the present NKLWMP network. (Information for the other two streams is given in Appendix A1.) Masse (2002) provides additional watershed descriptions for MacDonald and Bjerkness creeks. Excerpts from this information follow below. Further information from

Masse (2002) has been included in Appendix A1, including the personnel involved, data gaps, and additional details about Wing and Kemp Creeks.

Table 2. Selected characteristics of two hydrometric stations maintained by NKLWMP and previously monitored (1998-2002) under another program.

Characteristic	MacDonald[1]	Bjerkness
UTM coordinates of stations[2]- easting	501056	501062
UTM coordinates of stations[2]- northing	5512293	5512237
Stream order at station	2	3
Stream gradient at station (%)	3	3
Drainage area (km^2)	2.18	25.0
Maximum elevation (m)	1242	2554
Stream length (km)	7.68	6.46
Dominant aspect	SE	N

[1] This stream is called McDonald in the report. It has been changed to read "MacDonald" Creek - see explanation in footnote in section 1.2.
[2] There is doubt about the accuracy of the locations recorded by these authors. These locations of MacDonald Creek and Bjerkness Creek differ from those of the current stations by those names in the present report.

Masse (2002) provides descriptive information about the MacDonald Creek watershed, as summarized here. The headwaters of MacDonald Creek originate from the southern end of the Blue Ridge on the eastern edge of the Selkirk Mountains and consist of a small wetland located at an elevation of 1242 m. The creek flows southward until it reaches the Village of Kaslo, then turns east to discharge into Kootenay Lake. The upper parts of the watershed are steep with several avalanche chutes originating from the southeast side of the mountain. Small gravelly sediment flats and woody debris accumulations characterize the stream channel. Masse (2002) reports that the substrate appears highly mobile in parts of the channel, with unstable steps composed of small woody debris. Until 2002, MacDonald Creek was a domestic-use watershed providing water to local residents for domestic and irrigation purposes. In spring of 2002, a debris flow in the channel filled up the water intake pond with sediment and caused damage down through part of the Village and into the lake in Kaslo Bay. No fisheries information was available for this creek. It was designated as a Community Watershed. Quamme and Sundberg (2000) provide a plot showing electrical conductivity against discharge for their 1999 monitoring season, as shown in Figure 11.

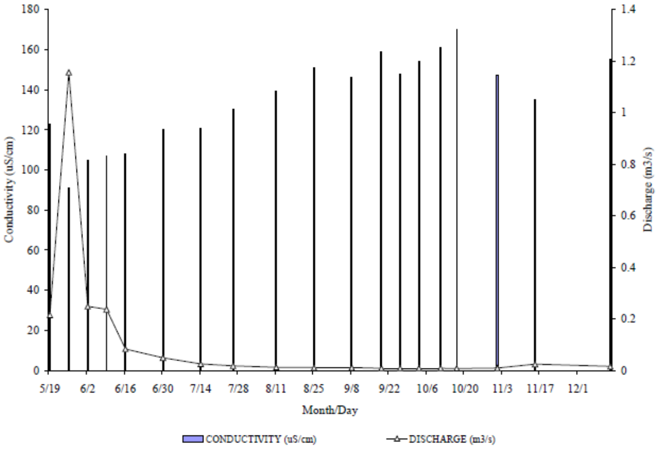


Figure 11. Discharge and conductivity versus in 1999 for MacDonald Creek (from Quamme and Sundberg 2000).

According to Masse (2002), forest harvesting took place in the watershed during the late 1980s and further harvesting was being planned within the next five years. In 2002, development within this watershed was limited but the channel's instability and steep slopes made it likely that further developments would increase its sediment load (Wells *et al.* 1999). An Interior Watershed Assessment Procedure was completed in 2000. The recommended level of Equivalent Clearcut Area for this watershed was 20% for the entire watershed and 15% for the eastern slopes (Green 2000). It was also recommended that road and trail construction be avoided on the steep slopes on the east flank of Mt. Buchanan. Vehicular access within this watershed made it a popular destination for local recreationalists.

Masse (2002) provides descriptive information about the Bjerkness Creek watershed, as summarized here. Bjerkness Creek is used by the community of Mirror Lake for domestic and irrigation purposes and had 54 registered water licenses at that time. The headwaters of Bjerkness Creek originate from a cluster of alpine lakes on Trafalgar Mountain at an elevation of 2554 m. Lofstedt Creek, a major tributary of Bjerkness Creek, enters the mainstem at 640 m elevation. The morphological characteristics of this tributary vary greatly between its upper and lower elevations. The upper reaches are characterized by shallow flows, steep gradients and bedrock substrate. The lower reaches, downstream of the Lofstedt Farm intake, have gentler gradients and a predominantly marshy substrate (Wells *et al.* 1999). According to the Fish Information Summary System, Bjerkness Creek was reported to support populations of kokanee and rainbow trout. These are part of adfluvial populations residing in Kootenay Lake and utilizing the lower reaches of Bjerkness Creek for spawning and juvenile rearing. Most of the logging activities within this watershed took place during the 1970s and the latest harvesting was completed in 2001 on private land by Cooper Creek Cedar. This logging is located along the lower reaches of Bjerkness Creek in the vicinity of the community water intake. Some sections of the cutblock were reported to be relatively close to the creek and within the riparian zone. Quamme and Sundberg (2000) provide a plot showing electrical conductivity against discharge for their 1999 monitoring season as shown in Figure 12.

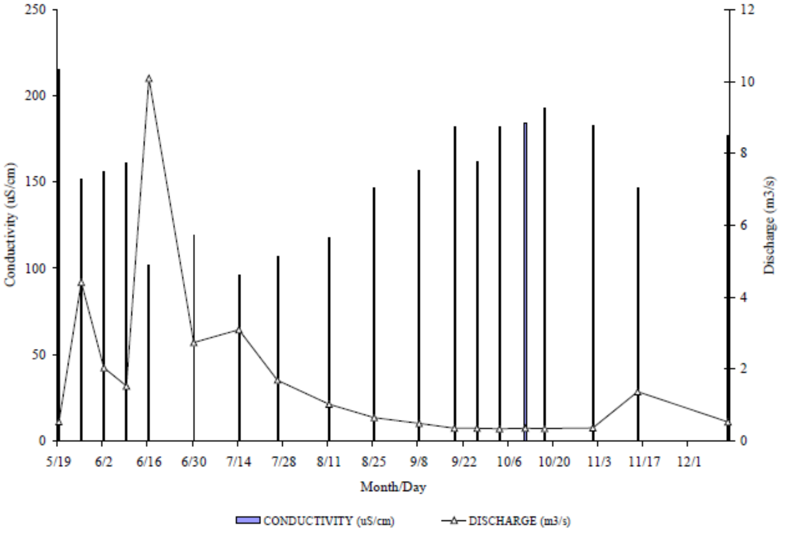


Figure 12. Discharge and conductivity versus date in 1999 for Bjerkness Creek (from Quamme and Sundberg 2000).

Data gaps in this monitoring program were noted as follows:

- MacDonald (1999): January 1 – July 8, July 13 - August 10
- MacDonald (2000): February 29 – April 28, May 30 to June 21, September 6-17, and October 25-31
- Bjerkness (1999): January 1 to April 7, June 16 to July 31

2.5 Stage-Discharge Rating Curves

Using the discharge data for each station gathered following the salt-dilution method, stage-discharge rating curves for Davis Creek, Bjerkness Creek, Carlyle Creek, Ben Hur Creek, MacDonald Creek and Gar Creek have been determined as summarized in Table 3. Parameter definitions are given in section 2.1. Appendix A2 provides plots of the field measurements at each station and the corresponding stage-discharge relations fitted to each data set. In addition to these, a second relation is required for each station to convert the pressure signal recorded by the pressure transducer into the corresponding reading on the staff gauge (vertical height of water). These are provided in Appendix A3. The flow-measurement data for Kootenay Joe Creek are insufficient at this time to determine a stage-discharge relation. In light of the station relocation at Davis that took place in November 2017 (section 2.2.1), a new rating curve at that site is now under development and the one shown in Figure A2.1 is completed.

Table 3. Stage-discharge rating curves (parameters) at six NKLWMP hydrometric stations.

Station	Coefficient (a)	Exponent (b)	Offset (h_o)	R^2
Davis	2.6147	4.4263	-0.6	0.9797
Bjerkness	5.1976	1.9695	0.10	0.9769
Carlyle	2.7145	0.8157	0.1	0.9548
Ben Hur	18.84	3.6622	0.05	0.9678
MacDonald	1.0161	1.1463	0.133	0.9362
Gar	8.0986	3.5257	0.14	0.8783

The NKLWMP stage-discharge rating curves as developed to date provide an excellent basis for determinations of discharge time-series at these stations. The best is the 2013-2017 Davis relation, with many well-distributed data points including data for some of the highest discharges occurring during the monitoring period. The relation also has the best R^2 in the data set. The Bjerkness relation is also good; however, the points could be better distributed and data are needed for discharges corresponding to staff gauge readings above 0.8. Both Carlyle and Ben Hur are good, particularly in light of the difficult access available for these sites, especially during the freshet. Further effort is warranted to get additional points at all staff gauge readings, though the greatest need is for data at higher flows (Carlyle above gauge 0.25; Ben Hur above gauge 0.3). The MacDonald relation would benefit from more data above gauge 0.19. The Gar relation should be considered preliminary given the shortage of data points, the limited data at high flow and the extent of scatter exhibited by the data so far. . In part, the scatter is a result of sedimentation issues, which will require some further data adjustment. Some stations will require additional measurements at lower flows; these are generally easier to accomplish and just require careful observation and coordination to time the measurement appropriately.

2.6 Discharge Time-Series Data

Discharge time-series data sets are available for Davis, Bjerkness, Carlyle, Ben Hur, MacDonald and Gar hydrometric stations. Figures 13-18 suggest that 2017 was the highest flow year during the period of record (excluding data prior to the Area D Water Monitoring Program). These plots also generally confirm what is already well known: that the lower and south-facing sites melt before their high-elevation and north-facing counterparts. The preliminary result for Gar confirms that Gar does not follow the typical pattern of the spring freshet and shows a later peak, potentially suggesting a groundwater connection to higher-elevation areas beyond its surface watershed. Overall, the data gaps are generally of limited concern (many relate to freezing at the high-elevation stations).

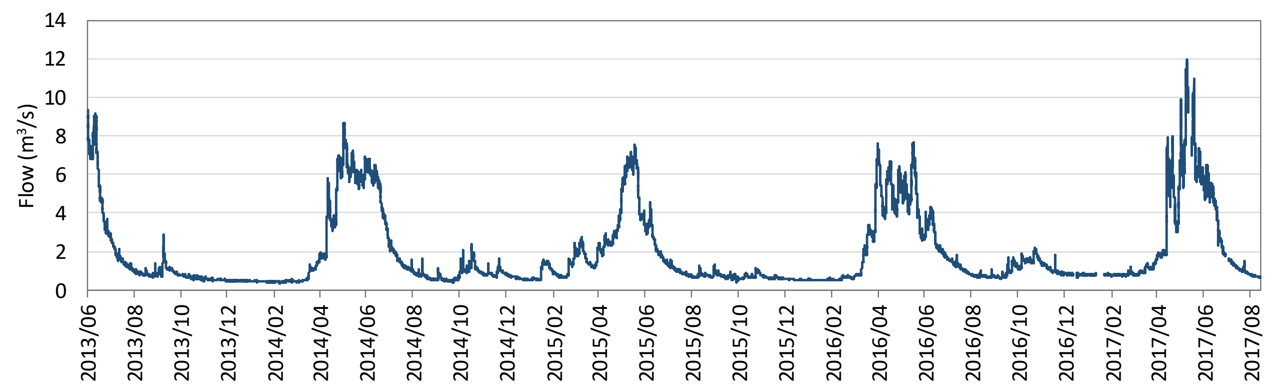


Figure 13. Discharge time-series data for Davis Creek hydrometric station.

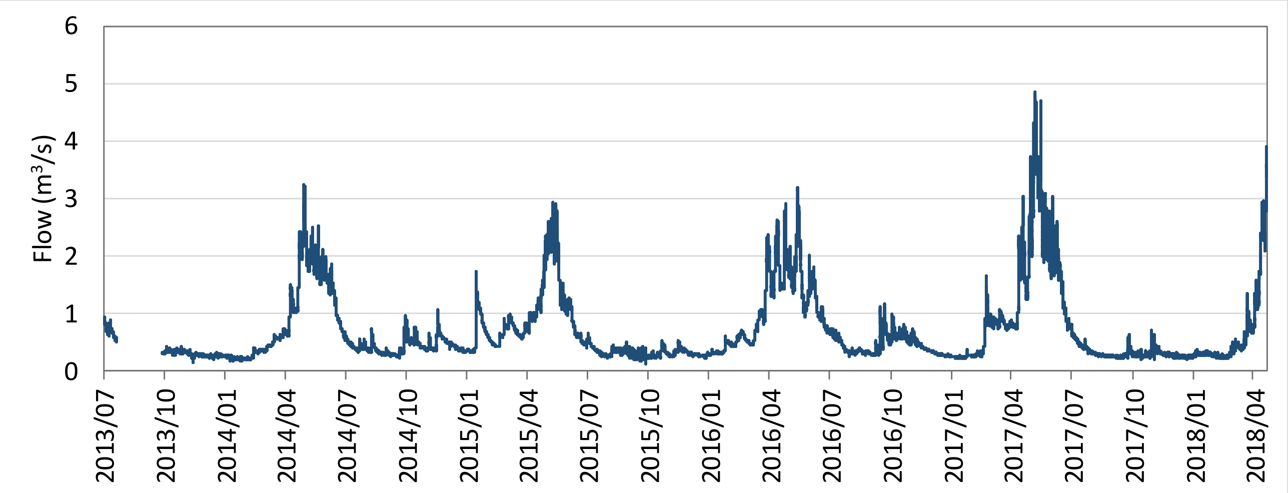


Figure 14. Discharge time-series data for Bjerkness Creek hydrometric station.

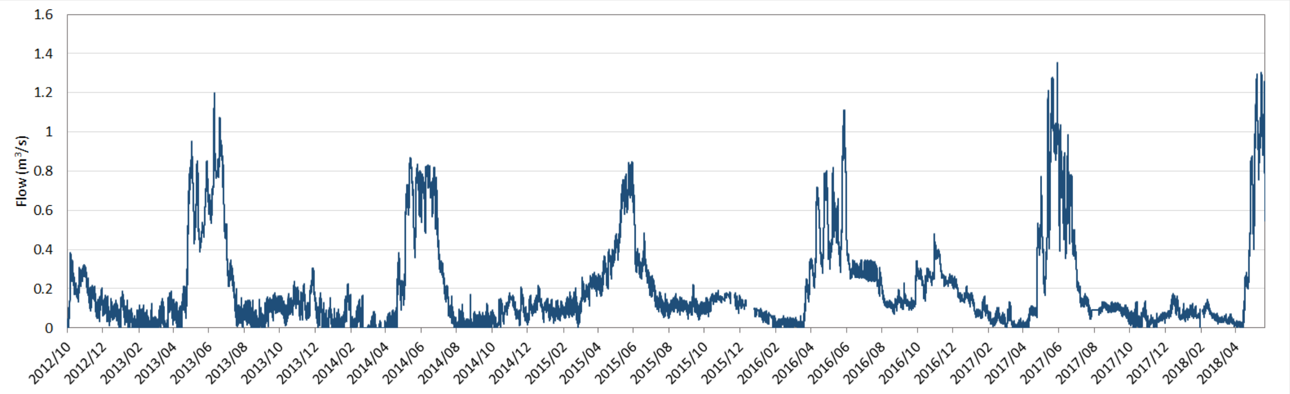


Figure 15. Discharge time series for Carlyle Creek hydrometric station.

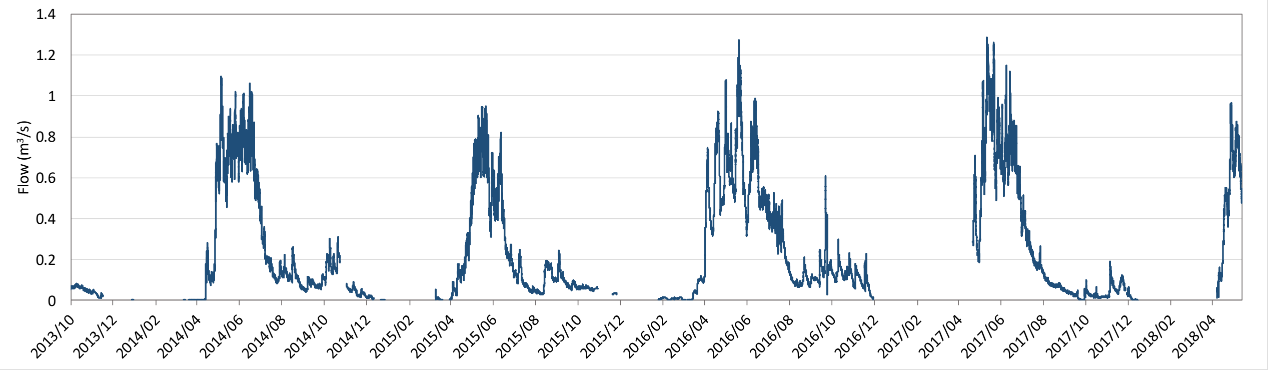


Figure 16. Discharge time-series data for Ben Hur Creek hydrometric station.

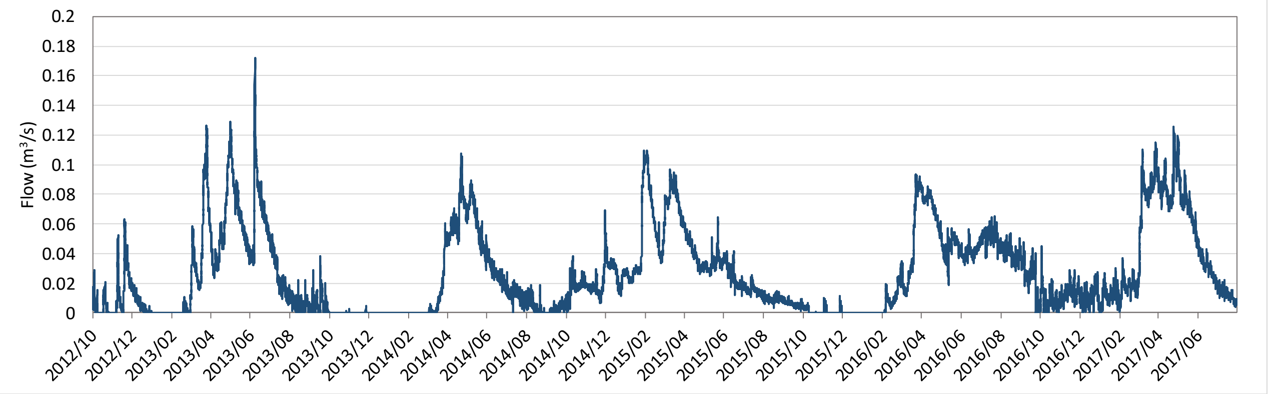


Figure 17. Discharge time-series data for MacDonald Creek hydrometric station.

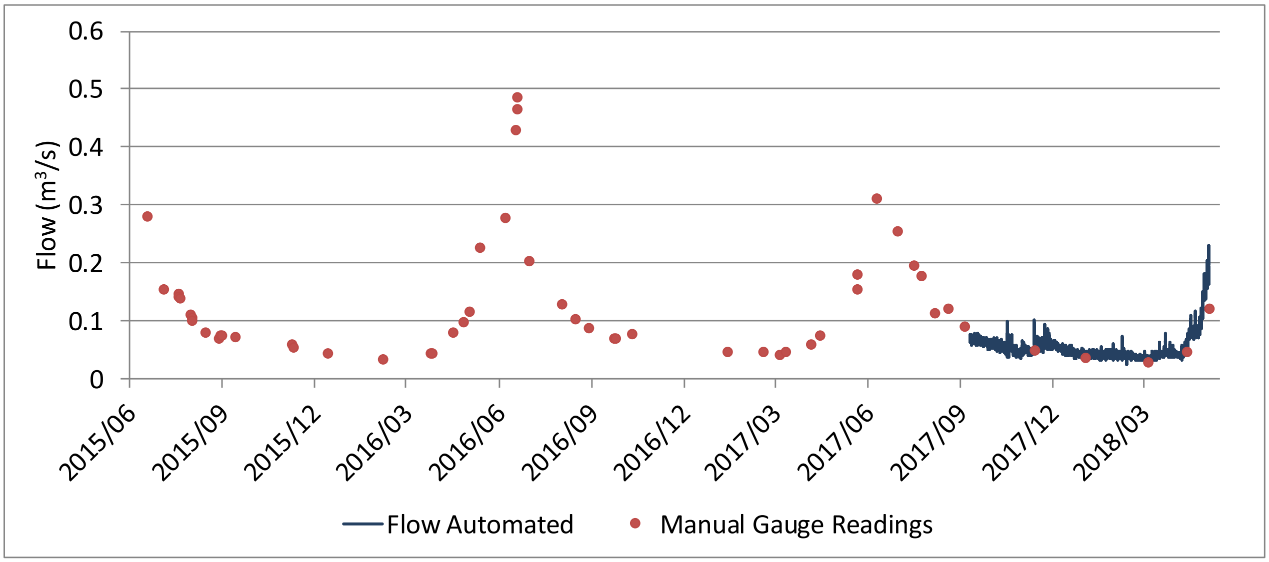


Figure 18. Discharge time-series data for Gar Creek hydrometric station.

Annual peak flow and low flow are extracted from available monitoring data (see Table 4). Carlyle and Ben Hur have peaked at the same time each year despite their contrasting north/south aspects. Their timing also coincides with that of the larger Davis and Bjerkness station,s highlighting the importance of the high-elevation source areas in shaping annual maximum flow at low-elevation monitoring sites. Peak-flow timing at MacDonald station is highly variable, occurring in February, April, May and June. With its low-elevation characteristic, this variability may reflect the increasing significance of rainfall events over low-elevation areas. Low-flow timing has been variable both at a station and between stations.

Table 4. Peak-flow, low-flow and annual-yield metrics derived from NKLWMP hydrometric time-series data.

Year	Station	Annual Peak Flow		Annual Low Flow		Annual Yield (m^3/s)
		m^3/s	Date	m^3/s	Date	
2013	Carlyle	1.197	June 20	0.000	January 7	0.195
	MacDonald	0.172	June 20	0.001	January 1	0.024
2014	Davis	8.661	May 23	0.352	March 1	1.877
	Bjerkness	3.232	May 23	0.166	February 1	0.663
	Carlyle	0.868	May 23	0.000	January 1	0.164
	Ben Hur	1.096	May 23	0.001	January 14	0.182
	MacDonald	0.107	May 3	0.001	March 15	0.020
2015	Davis	7.537	June 8	0.419	October 20	1.564
	Bjerkness	2.930	June 2	0.118	October 20	0.642
	Carlyle	0.852	June 8	0.000	October 1	0.203
	Ben Hur	0.951	June 8	0.001	January 11	0.136
	MacDonald	0.110	February 9	0.001	November 1	0.027
2016	Davis	7.664	June 7	0.495	February 7	1.850
	Bjerkness	3.184	June 6	0.225	January 20	0.755
	Carlyle	1.111	June 7	0.000	January 1	0.231
	Ben Hur	1.272	June 6	0.001	March 19	0.228
	MacDonald	0.093	April 4	0.000	October 6	0.030
	Gar	0.485	June 19	0.033	February 6	n/a[1]
2017	Davis	11.951	June 1	0.649	September 5	n/a[1]
	Bjerkness	4.840	May 30	0.199	November 7	0.781
	Carlyle	1.353	June 8	0.000	March 13	0.185
	Ben Hur	1.286	May 30	0.000	December 26	n/a[2]
	MacDonald	0.162	May 6	0.000	January 2	n/a[2]
	Gar	0.312	June 10	0.041	March 5	n/a[1]
2018	Gar	0.403	May 5	0.026	December 2	n/a[1]

1 Stage-discharge rating curves under development; annual yield will be determined in the future.
2 Insufficient data to calculate annual yield.

Although extreme events did not occur during the NKLWMP's period of monitoring, there was a significant rain-on-snow event in June 2013 which occurred during the "pre-NKLWMP" monitoring period. This event caused widespread damage in larger drainages, particularly in the Purcell Range. Nothing unusual was evident in the NKLWMP monitoring data however there were significant impacts to Kootenay Joe Creek causing the lower reach to alter course for a few years (Greg Utzig personal communication). Schroeder Creek, which has similarities to Davis Creek, also experienced impacts.

Preliminary estimates of basin yield are included in Table 4, calculated for those years where data gaps are considered insignificant (i.e., significant gaps are limited to periods of low flow). Normalized by drainage size, Figure 19 shows the change in annual basin yield during the period of monitoring. Basin yield has been highest at the Carlyle, Ben Hur and Davis stations, which is consistent with them draining the greatest amount of high-elevation areas where total annual precipitation is known to increase. The annual yield values are also reasonably consistent with Obedkoff (2002), which provides published values for regionalized runoff shown in Figure 20 (Kootenay Region, western subzone h). The pre-NKLWMP 2015 data for station Carlyle may require further examination in light of this plot (cf. Figure 15). In general, these preliminary calculations warrant further analysis in future reporting to strengthen the verification of the early (pre-NKLWMP) data sets.

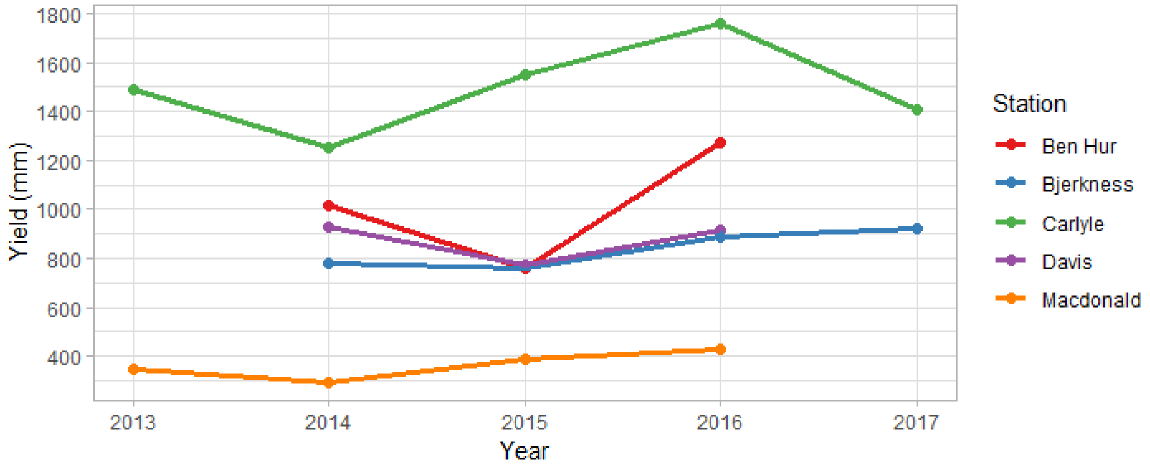


Figure 19. Annual variation in basin water yield at six NKLWMP hydrometric stations.

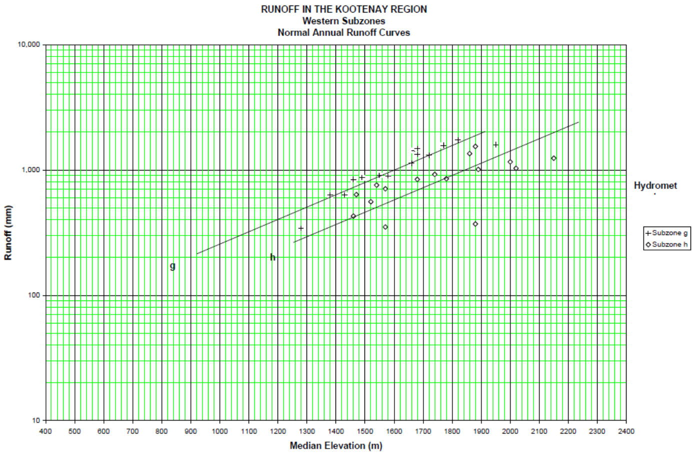


Figure 20. Runoff curves for Kootenay Region subzone "h" (from Obedkoff 2002, Figure 2).

2.7 Water Quality

To complement NKLWMP's monitoring of water quantity, the 2016-2018 monitoring period includes water quality monitoring of three physical parameters - turbidity, temperature, and conductivity. These measurements enable a preliminary baseline characterization of the drainages at the monitored cross sections. Whereas the hydrograph responds directly to changes in climate parameters, water quality responds to the changing hydrograph, new temperature regimes, and in some situations, variations in geomorphic activity, as hillslopes and channels adjust to new conditions. These primary, secondary and even tertiary responses to climate change may be associated with changes in water quality. Although not the primary emphasis of NKLWMP's monitoring efforts, changes in water quality can be very significant to aquatic ecosystems and to the water's utility for domestic purposes. Monitoring of basic water quality, particularly during the early years of the project, offers an opportunity to make additional comparisons later on as changes in climate become more pronounced and potentially influence sustained water quality.

Turbidity samples taken opportunistically during the freshet describe background and episodic sediment-transport fluxes at (and near) the hydrometric stations. In general, these systems are supply-limited, meaning that the level of sediment that is transported is less than what the water can sustain. Once sediment becomes available to the creek, it is normally transported, subject to fluvial processes. The snowmelt period and its resulting processes initiate a large proportion of the annual geomorphic activity that shows up as turbidity. Of this activity, a higher proportion is available for transport in the rising limb. Unless it is a chronic sediment source, the supply is often depleted before the falling limb commences. In addition, once the falling limb begins, there is often a decline in geomorphic activity. Based on these generic expectations, the rising limb is a focus of sampling effort.

Table 5 summarizes the sampling effort by limb of the hydrograph (rising vs. falling) for each station and year. (Sampling was not included in the monitoring until NKLWMP began in 2016/17.) Two-thirds of the samples derive from the rising limb, reflecting focused effort to capture this more active geomorphic period of the hydrograph. Generally, the samples are well distributed throughout the monitoring years. The remote stations are less intensively sampled. The stream grab samples have also been analyzed for conductivity but these are not analyzed in this report: in future reporting, those conductivity data may enable initial characterization of drainage geology and runoff dynamics (see also section 2.2).

Table 5. Distribution of water samples by year, station and hydrograph limb (R=rising; F=falling).

Station	Total			2016/17[1]		2017/18[1]		2018/19[1,2]	
	All	R	F	R	F	R	F	R	F
Davis	9	9		5		4			
Bjerkness	15	11	4	2		7	1	2	3
Carlyle	5	2	3	2			2		1
Ben Hur	4	1	3	1			2		1
MacDonald	16	9	7	3	2	6	5		
Gar	8	6	2	1		2	1	3	1
Total	**57**	**38**	**19**	**14**	**2**	**19**	**11**	**5**	**6**

[1] The hydrologic year is defined here to extend from March 1 to February 28.

[2] Some initial sampling from the 2018/19 hydrologic year is included in this year's report, as shown here.

Turbidity data from the six stations are plotted in Figure 21 in relation to respective stream discharges determined at the time of sampling. This integrated comparison following the standard form of the sediment rating curve (but based on turbidity) provides a preliminary opportunity to suggest comparative characteristics among the monitored NKLWMP drainages. There is a wide variation in turbidity across the basins. Within the range evident in this group of samples, those from Gar and MacDonald Creeks show the highest turbidity levels in relation to streampower (flow magnitude). Given the severely disturbed state of the Gar Creek gully and drainage, its high turbidity levels (in relation to its size) are not surprising. It is interesting to see that these initial samples from MacDonald Creek appear to show similar behavior to those of Gar Creek. Davis Creek provided the samples with the highest magnitude of turbidity (Figure 22) but these also correspond to higher streampower. Davis samples are also more variable, including many samples taken during the falling limb with very low turbidity.

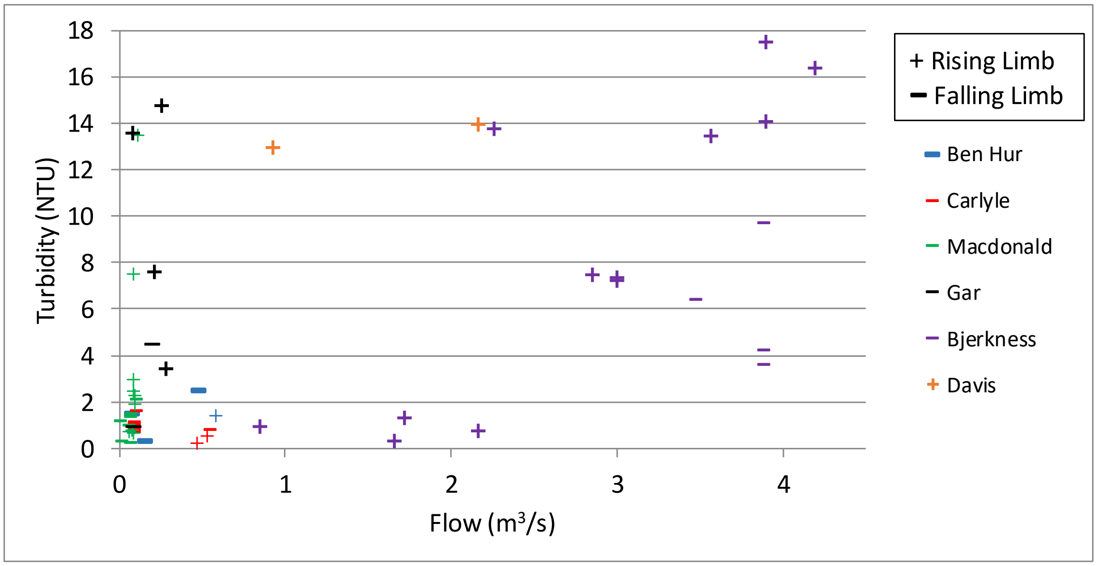


Figure 21. Turbidity-discharge plot based on water grab samples (< 18 NTU) taken during 2016-2018 at six NKLWMP hydrometric stations.

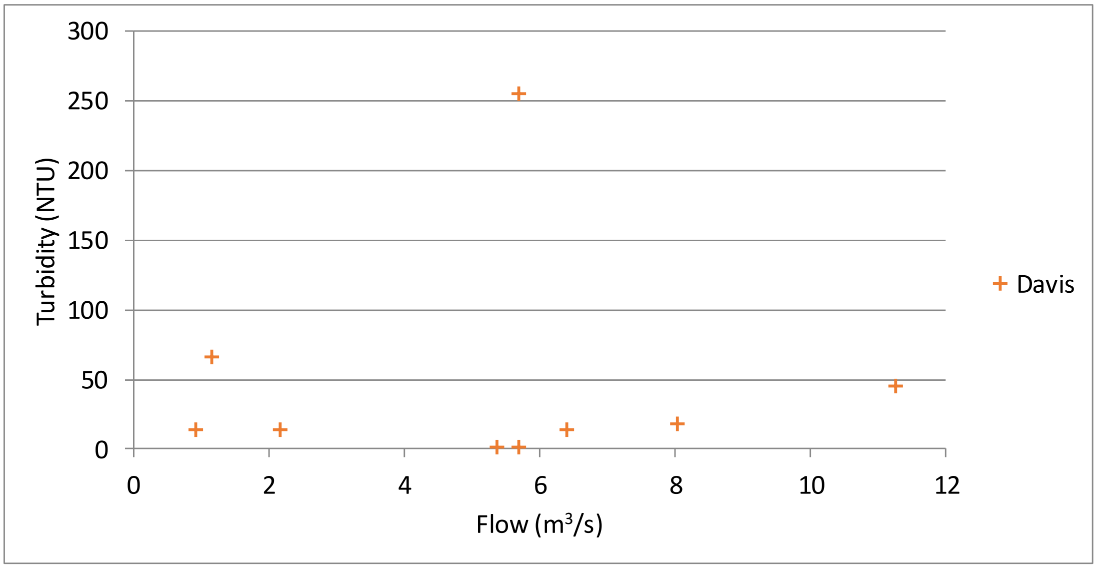


Figure 22. Turbidity-discharge plot based on water grab samples (> 18 NTU) taken during 2016-2018 at Davis Creek.

In the absence of additional information (and more sampling), it appears that Davis, being a larger drainage, offers a wider range of sediment-source opportunities in response to snowmelt/runoff events. In contrast, Gar and MacDonald creek drainages are less supply-limited. Sediment becomes available to Davis Creek then perhaps due to the power of this larger stream, the available sediment quickly becomes depleted as it is moved out of the drainage. The few samples that are available from Ben Hur and Carlyle creek show low levels of turbidity which are consistent with the relatively undisturbed condition of these drainages. Samples from Bjerkness Creek reveal a potential discharge threshold of about 2 m^3/s at which point turbidity begins to rise and above which there is a closer turbidity balance between the rising and falling limbs, though higher turbidity levels persist during the rising limb.

Stream temperature measurements provide a baseline against which to compare changes that may occur under future climates. They also provide supporting information to assist in interpreting issues that may arise regarding freezing of the year-round loggers (recording water depth) that are not intended to freeze. The available water temperature plots are shown in Appendix A4. Table 6 summarizes maximum and minimum temperatures associated with each station. Two findings are notable from this summary. Stream temperature is generally consistent across all the stations with the low-elevation MacDonald drainage demonstrating the highest maximum annual temperature and the north-facing high-elevation Ben Hur drainage demonstrating the lowest maximum annual temperature. In addition, all temperatures except those at MacDonald station went below freezing for some periods of most winters. Freezing was most severe at Ben Hur which resulted in some lost low-flow hydrometric data for short periods. For those stations experiencing freezing conditions, the number of days below 0°C was greatest at Ben Hur (206 days) and least at MacDonald, where freezing days were not recorded. These durations are reflected in the extent of lost data as shown earlier in Figures 13 to 18. These findings suggest that additional measures are justified in reducing the impact of freezing on the performance of the water-level sensors. For example, the sensors may need to be lower down under the surface of the water; however, this may mean moving the station at those sites where a deeper installation is not possible.

Table 6. Temperature characteristics measured during 2015-2018 for five hydrometric stations.

Station	Temperature (2015/16)			Temperature (2016/17)			Temperature (2017/18)		
	Max[1] (°C)	Min[1] (°C)	#Days[2] < 0°C	Max[1] (°C)	Min[1] (°C)	#Days[2] < 0°C	Max[1] (°C)	Min[1] (°C)	#Days[2] < 0°C
Davis	n/a	-0.645	20	12.408	-1.362	33	11.842	n/a	4
Bjerkness	n/a	0.269	0	12.427	-0.976	18	11.943	-0.900	13
Carlyle	n/a	-1.154[3]	61	12.545	-1.699	125	12.421	-2.763	174
Ben Hur	n/a	-1.086	106	11.032	-5.448	161	11.023	-3.218	206
MacDonald	n/a	1.025	0	13.698	-0.003	0	n/a	n/a	n/a

[1] Occurrences based on instantaneous temperature

[2] Occurrences based on mean daily temperature.

3.0 NKLWMP SNOW AND CLIMATE PROGRAM

NKLWMP's snow and climate program includes monitoring of snow accumulation at two high-elevation snow courses and air temperature and rainfall at three meteorological stations. Two of the climate sites are situated at the snow-course sites. This component of NKLWMP's monitoring program has only recently been completed thus the reporting available in this section is limited.

3.1 Methods, Standards and Instrumentation

NKLWMP's snow courses were established following protocols of snow monitoring and measurement in British Columbia (MoE 1981). Sites chosen for measuring snow accumulation are sheltered from the wind, representative of the area and generally without steep slopes. Ten plots were established at each snow course and monthly measurements are taken typically starting in early February. Measurement and analysis protocols follow MoE (1981). Federal metric snow sampling tubes are used to do the field measurements with six tubes able to measure up to 4.6 m snow depth. Measurements are taken at the start of each month to generally coincide with the survey pattern followed by the Province of British Columbia. Surveying continues until all the snow is gone, typically in May or early June. Snow depth, snow-water equivalent and snow density are calculated at each plot based on the field measurements. The results are averaged to yield one result for each parameter at each snow course.

NKLWMP's meteorological measurements focus on air temperature and rainfall. Air temperature is measured continuously using an Onset external Smart temperature sensor. Rainfall is measured with an Onset Hobo tipping bucket rain gauge (0.2mm resolution). Both are connected to a Hobo Micro Station Logger, set to record every five minutes. During each measurement period, temperature is averaged while rain is accumulated (total number of tips of the mechanism). The temperature sensor is situated within an Onset Solar Radiation Shield. The instruments are installed on a vertical pipe. At the high-elevation sites the pipe is anchored to a trimmed tree bole and at the low-elevation site the pipe is secured to a wooden post buried in a pile of large stones. Stabilizing wires or supports are employed as necessary to reduce vibration of the pipe.

Rain-gauge siting and installation are shaped by practical considerations and factors related to measurement error. Guidance from the World Meteorological Organization (WMO 2010) suggests that surrounding objects should not be closer to the gauge than a distance of twice their height above the gauge orifice and, ideally, the gauge should be sheltered from the wind. The best sites are often found in clearings within forests or among trees where other objects act as effective wind breaks. At the high-elevation locations, only sites within (or close to) the snow courses were considered. The low-elevation site at Johnsons Landing additionally reflects the significant constraint of private land and protection of the instrumentation from human disturbance. The selected sites reflect a reasonable compromise among all considerations. The instruments are installed at variable distances from the ground, depending on snow conditions at the station site. The soils and depth of snow at the high-elevation sites necessitated that the supporting pipe be mounted on a trimmed tree bole. Rainfall measurement error is influenced by many factors the most important of which can be wind speed at the gauge orifice. In turn, wind speed is influenced by siting factors and the orifice distance above ground level. Wind bias effects are reduced by using a ground-level gauge but that is not a practical option at the NKLWMP sites. At the selected high-elevation sites, the instruments are over three metres from the ground surface so that they remain above the snow surface throughout the winter season. At the Johnsons Landing site, the tipping bucket is located at ~3.5 m from the general ground level in the vicinity of the station (Greg Utzig personal communication 2019).

3.2 Monitored Sites and Station History

Two snow courses and three climate stations are included in the NKLWMP monitoring network as indicated in Table 7. The Kootenay Joe snow course was installed in October 2015 and the Lost Ledge snow course was established the following October. Both are situated above 2000 m in elevation. Figures 23 and 24 show typical forest cover within these snow courses.

Table 7. Snow-course and meteorological stations included in NKLWMP monitoring network.

Station Description			Location		
Name	**Type**	**Established**	**Elev (m)**	**Easting**	**Northing**
Kootenay Joe Mtn	Snow Course	October 23, 2015	~2060	513505	5549559
Lost Ledge	Snow Course	October 3, 2016	~2050	501495	5546500
Johnsons Landing	Climate	May 22, 2017	~670	509480	5547261
Kootenay Joe Crk	Climate	September 2017	~2060	513505	5549559
Lost Ledge	Climate	September 2017	~2050	501495	5546500

Three meteorological stations are included in the NKLWMP monitoring network as introduced in the previous section (see Table 7). The low-elevation site was established first at Johnsons Landing (Figure 25) in May 2017. The two high-elevation sites are within the snow courses and were installed in October 2017 (Figures 26 and 27). Only rainfall data from the Johnsons Landing meteorological station (summer/fall 2017) are available for review in this report.

Figure 23. Photograph of forest cover typical of the Kootenay Joe snow course.

Figure 24. Photograph taken within the Lost Ledge snow course.

Figure 25. Photograph of the Kootenay Joe climate station.

Photo credit: Chris Hiebert. (Note: rain gauge not installed.)

Figure 26. Photograph of the Lost Ledge climate station.

Photo credit: Greg Utzig.

Figure 27. Photograph of the Johnsons Landing climate station.

3.3 Temperature Time-Series Data

Temperature data are available from the Lost Ledge and Johnsons Landing climate stations, as shown in Figures 28 and 29. Maximum temperature at the Johnsons Landing station reached the mid-30s (°C) in 2017 and 30°C in late May (2018) at Lost Ledge. When the minimum temperature was about -15°C at Johnsons Landing in January 2018, it was about -23°C at Lost Ledge. The gap at the Lost Ledge site was due to snow burial. The different time periods of the available data prevent detailed comparisons in this report. (The instrumentation was subsequently raised higher to reduce likelihood of burial.) In future reporting, data from three stations will be available, enabling a fuller comparative picture of the relative temperature profiles.

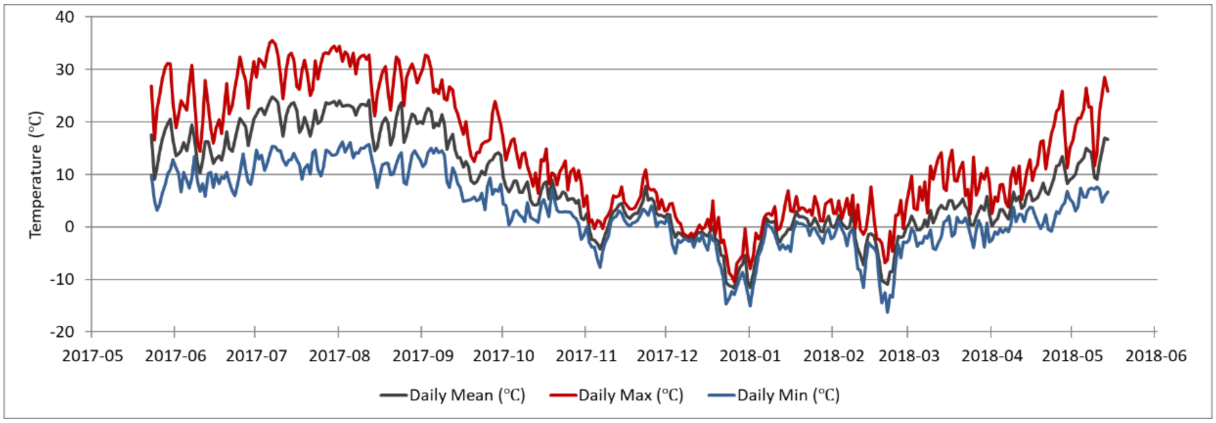


Figure 28. Temperature time-series data recorded at Johnsons Landing climate station.

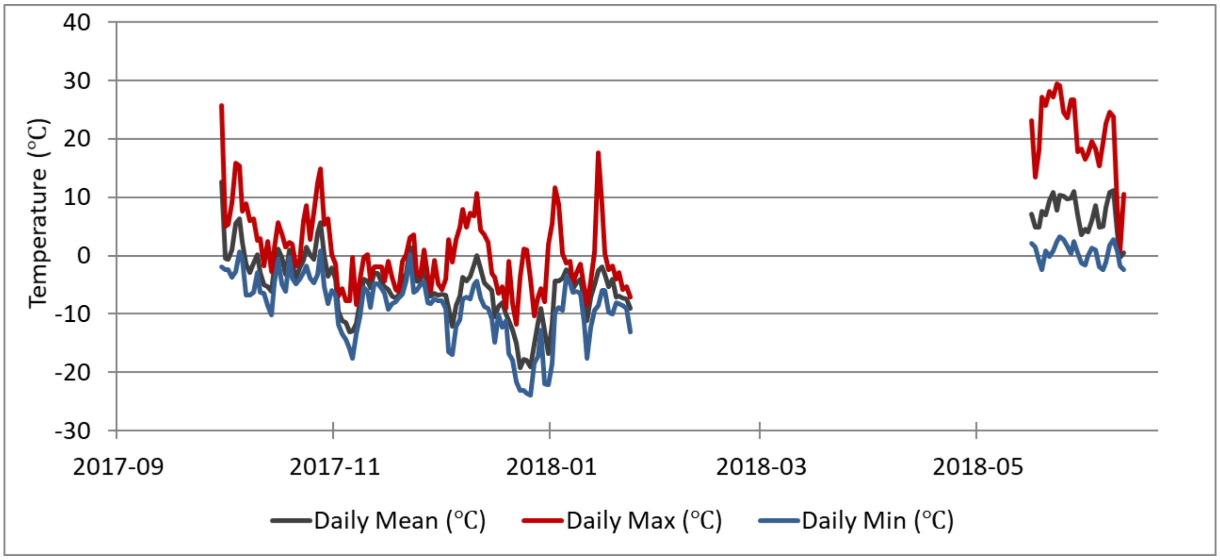


Figure 29. Temperature time-series data recorded at Lost Ledge climate station.

The barologgers that record atmospheric pressure at the hydrometric stations (see section 2.1) also record air temperature. Although these time-series data sets are available, they are not included here because those instruments are not installed to be representative of the watershed, tending to be in riparian areas (though generally unaffected by ultraviolet radiation given that they are well shaded). They have been retained in the data management system because they may offer additional valuable temperature data at low-elevation sites (*i.e.*, adjacent to the hydrometric stations) in future modeling work.

3.4 Rainfall Time-Series Data

Rainfall data within the present reporting timeframe (to April 2018) are limited to one year (May 2017 to May 2018) at one station, Johnsons Landing. It is presented here as a sample of what is recorded within the NKLWMP network and demonstrates initial calculations of how the data might be analyzed for future reporting. As indicated in section 3.1, total rainfall is recorded in each five-minute period. The rainfall during these samplings is totaled to indicate rainfall intensity over variable timeframes. For example, Figure 30 shows the daily rainfall at Johnsons Landing climate station in the station's first year of operation, including the winter period when freezing occurs. According to Figure 28, late October through early April is the period when the rainfall results may be affected by freezing conditions. Given the limited nature of the meteorological data available to this report, the full time series is presented for information. For future reporting, testing and analysis may be needed to ascertain the value of retaining the portion of the time-series potentially affected by freezing conditions.

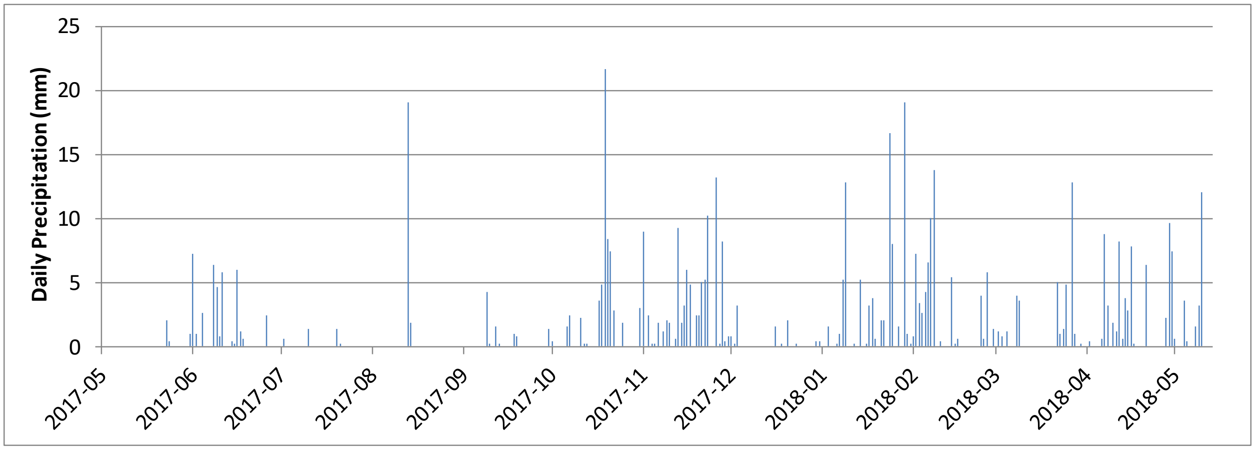


Figure 30. Daily rainfall measured at Johnsons Landing climate station.

Rainfall intensity and cumulative rainfall derived from the Johnsons Landing time series are provided in Table 8 to illustrate metrics that will be available to compare with other climate data from the Representative Area. These measures can also be used to supplement simulation modeling and other interpretations related to rainfall-runoff dynamics. During this brief period of monitoring, the highest short-term rainfall intensities recorded were 0.40 mm/hr (5-min) and 0.32 mm/hr (10-min) recorded in June 2017. The highest cumulative totals were 21.6 mm (one day) and 60.4 mm (one month) both of which occurred in October 2017.

3.5 Snow Course Measurements

Early results for snow depth, snow-water equivalent and snow density are available for the Kootenay Joe and Lost Ledge snow courses for 2016-2018. The pattern of change in snow depth is similar at the two monitoring stations (Figure 31), with Lost Ledge consistently showing greater depth than Kootenay Joe. The highest snow depth measured since the program began is 330 cm on April 1, 2017. Initial results at these two sites are consistent with the general provincial pattern that basin snow accumulation peaks around April 1. In 2017 and 2018, a sharp decline in snow depth occurred after May 1. In 2016, there is some indication that the decline may have begun earlier. Appendix A5 provides the results for mean snow depth, snow-water equivalent, and snow density at Kootenay Joe and Lost Ledge snow courses (2016-2018).

Table 8. Rainfall intensity (2017-18) as measured at Johnsons Landing climate station.

Time Period		Comparison of Rainfall Intensity			
Year	**Month**	**Max 5-min (mm/h)**	**Max 10-min (mm/h)**	**Max Daily (mm)**	**Monthly (mm)**
2017	5[1]	0.24	0.18	2	n/a
	6	0.40	0.32	7.2	39.2
	7	0.08	0.04	1.4	3.6
	8	0.2	0.16	19	20.8
	9	0.12	0.08	4.2	9.4
	10	0.12	0.10	21.6	60.4
	11[2]	0.20	0.16	13.2	92.2[4]
	12[2]	0.16	0.14	3.2	n/a
2018	1[2]	0.16	0.16	19	n/a
	2[2]	0.12	0.10	13.8	n/a
	3[2]	0.28	0.28	12.8	n/a
	4	0.32	0.24	9.6	65
	5[3]	0.32	0.28	12	n/a
Max recorded:		0.40	0.32	21.6	92.2

[1] Partial month starting May 21, 2018. [2] Periods of freezing limit reliability of results for total monthly rainfall. 5-min, 10-min and daily rainfall values may be higher than indicated. [3] Partial month ending May 15, 2018. [4] Monthly total rainfall for November included because extent of freezing was limited.

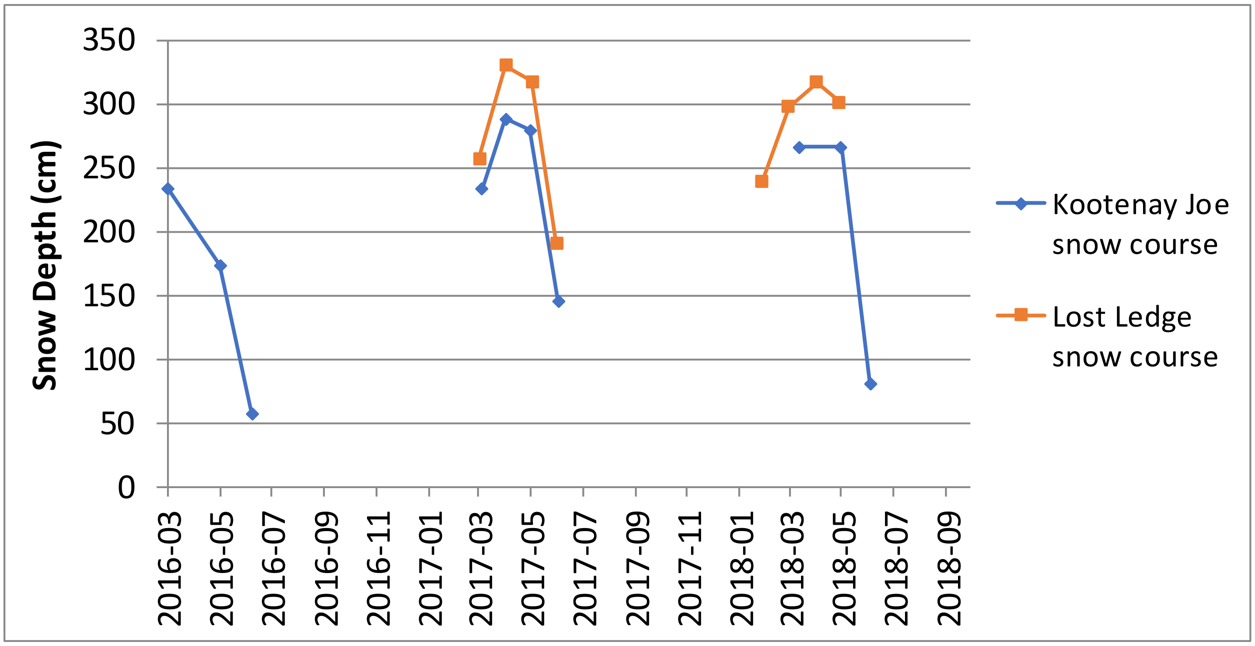


Figure 31. Snow depth as measured at Kootenay Joe and Lost Ledge snow courses.

4.0 MONITORING DATA ACROSS THE REPRESENTATIVE AREA

The Representative Area (introduced in section 1.2) illustrates the approximate landscape extents within which the NKLWMP monitoring network is considered hydrologically representative. Within this larger area, there remain significant heterogeneities related to topography (slope, aspect and elevation), surficial materials (type and depth), drainage area and shape, and a variety of related biological and chemical characteristics. Relating NKLWMP monitoring data and interpretations to characteristics across the Representative Area is a significant undertaking, particularly given that the NKLWMP hydrometric observations focus on small drainages whereas those of the larger area do not. This section describes hydrologic aspects of the Representative Area to begin placing in context the observations available from NKLWMP monitoring. In future reporting, climate, terrain and other landscape features can be compared.

4.1 Spatial Distribution of Monitoring Stations within the Representative Area

Figure 32 locates the NKLWMP stations within the Representative Area (Figure 3) alongside six active stations operated by Water Survey of Canada (WSC) that monitor larger drainages. Additional WSC stations located within this boundary are not included because they actually drain land outside the Representative Area. Discontinued WSC stations and monitoring of the Kootenay and Columbia Rivers are also not shown. (Discontinued stations are discussed in the context of practical applications in section 5.2.) Some limited hydrometric monitoring has been undertaken by three stewardship groups active in the Representative Area (see map), however it is unclear the extent to which those are ongoing. These stations are at Silverton Creek (Slocan Lake Stewardship Society), Crawford Creek (Eastshore Freshwater Habitat Society) and McDonald Creek.

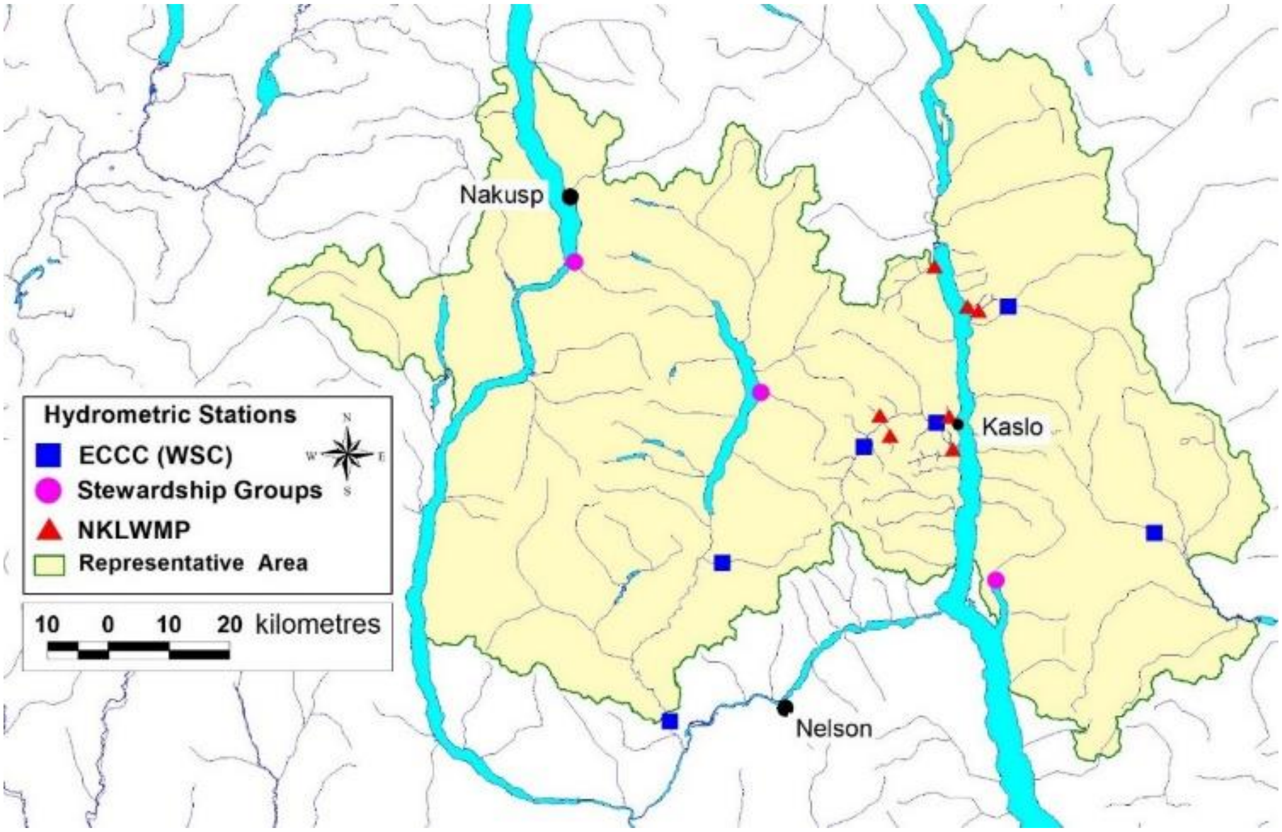


Figure 32. Locations of hydrometric stations measuring streamflow within the Representative Area.

Figure 33 locates the NKLWMP climate and snow stations within the Representative Area (Figure 3) alongside other active long-term monitoring of climate and snow. Climate stations include annual stations operated by ECCC (one is owned by BC Hydro) and a collection of seasonal stations operated by BC MoTI and BC FLNRORD. Commercial ski operations maintain snow poles that record snow depth and other basic meteorological measurements (see CAA 2016). Also shown are eight sites included in BC's snow survey network, six of which are snow courses and two of which (Redfish and Whatshan Upper) are snow pillows. A snow pillow is part of an automated snow weather stations providing real-time snow-water equivalent, snow depth, cumulative precipitation, and air temperature. Snow courses are visited monthly to measure snow accumulation in a manner similar to what is described earlier (section 3.1) for the NKLWMP monitoring.

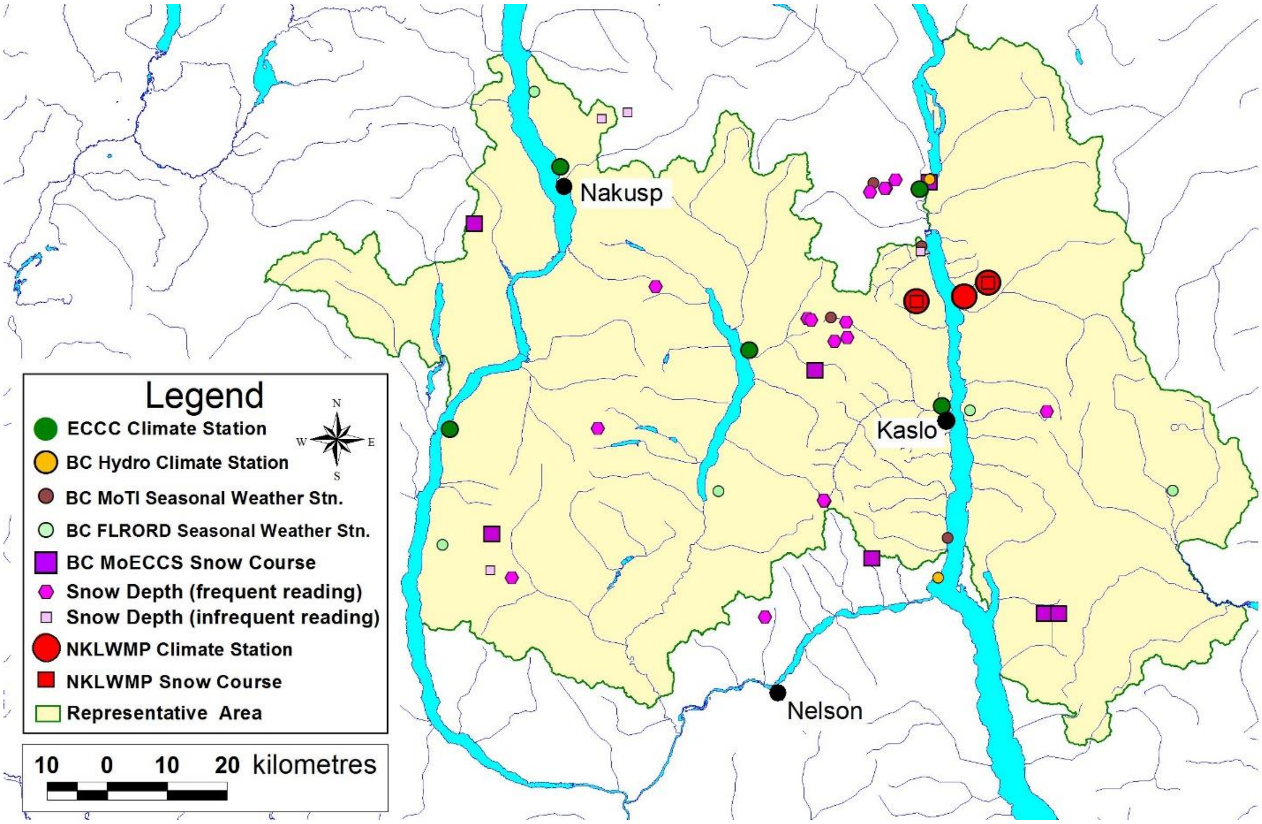


Figure 33. Locations of stations measuring snow and climate within the Representative Area.

To place NKLWMP's monitoring data in context, the following three sections (4.2-4.4) use data from these hydrometric and snow monitoring stations to provide introductory descriptions to some aspects of hydrology and snow accumulation in the Representative Area. Future reports will include an introduction to data from the long-term climate stations.

4.2 Long-Term Streamflow

Streamflow is shaped by many factors including geology, terrain, soils, vegetation, climate, and land-use. Meta-data are provided in Table 9 for the six active WSC hydrometric stations shown in Figure 32. Depending on the station, they drain watersheds ranging in size from 92 to 585 km^2 in addition to one drainage, the Slocan watershed, with an area of 3,330 km^2. The station locations are at elevations that range between 466 m and about 1200 m elevation. In contrast, monitored NKLWMP drainages range in size from 2.2 to 64 km^2 and include two locations at over 1500 m in elevation. The active WSC stations within the Representative Area have in place a discharge time series of between 42 and 105 years, providing the opportunity to examine trends and distributions of streamflow during this longer period.

Table 9. Active WSC hydrometric stations located within the Representative Area.

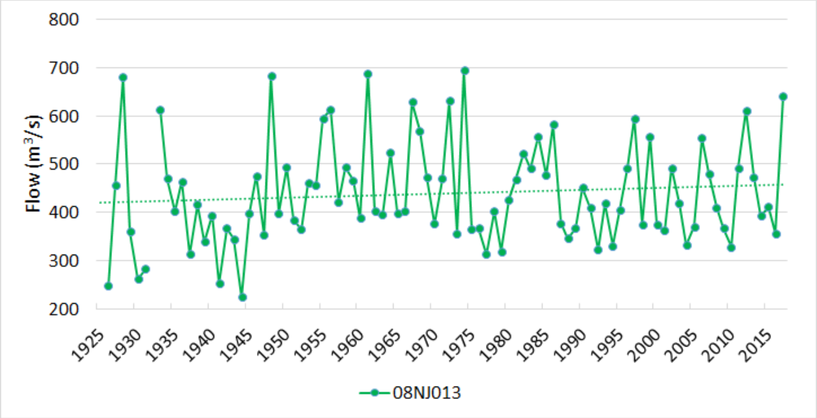
Name	Number	Elev. (masl)	Easting	Northing	Area (km^2)	Mean Watershed Elevation	Period of Data
Keen Creek	08NH132	~1206	491356	5524373	92	2080	1973-2019
Lemon Creek	08NJ160	635	467848	5505032	181	1788	1973-2019
St Mary River	08NG077	1177	539628	5510058	208	1991	1973-2019
Kaslo River	08NH005	768	503454	5528347	442	1872	1914-2019
Fry Creek	08NH130	947	515404	5547703	585	2133	1973-2019
Slocan River	08NJ013	466	459077	5478747	3330	n/a	1914-2019

Analysis of long-term changes in streamflow is a field of significant scientific interest around the world. Return-period flood flows, temporal trends in streamflow and other analyses are frequently carried out using long-term hydrometric data. Two related presentations are provided in this report. In this section, long-term trends in streamflow are examined for the larger monitored drainages within the Representative Area. This descriptive presentation provides hydrologic context to understanding changes in streamflow at NKLWMP's monitored stations. In section 5.2, short-term frequency distributions are examined for both the larger (WSC) and smaller (NKLWMP) monitored drainages within the Representative Area. The second example illustrates the value of NKLWMP data in practical applications.

Figures 33 and 34 present the long-term trends in annual maximum and minimum flows as measured at the six active ECCC hydrometric stations. While many of these plots display increasing flow overall during the periods of record (summarized in Table 10 and likely due to an overall increase in precipitation), there are notable exceptions. (See also Appendix A6.) Peak and low flows have both generally increased at the Slocan, Fry and Keen stations, while both have generally decreased at the Lemon station. Peak flow has increased at St Mary station, while low flow has remained relatively unchanged. The Kaslo station shows a decrease in peak flow with an increase in low flow. The trends at the Keen and Lemon stations, which are nested within the Kaslo and Slocan stations respectively, do not mirror the trends of their downstream counterparts. These contrasts in streamflow behavior highlight the complexity of the controls on streamflow and the importance of spatial scale in understanding this complexity. It is clear that the behavior of larger systems does not reliably reflect the behavior of the smaller systems of which they are composed, which indicates the importance of monitoring the smaller drainages to understanding how they are changing. Conversely, understanding the controls on the larger systems is enhanced by NKLWMP's monitoring of smaller drainages. See CBT 2017 (p40-41) for additional discussion of the complex response of streamflow to climate change and land use. The role of climate modes (e.g., ENSO and PDO) is beyond the scope of this discussion.

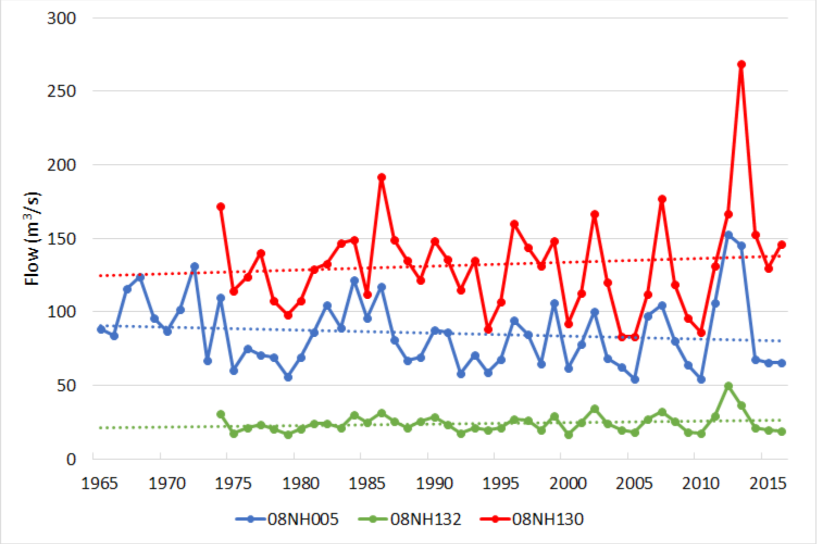
a)

green (Slocan)



b)

red (Fry)
blue (Kaslo)
green (Keen)



c)

blue (St Mary)
green (Lemon)

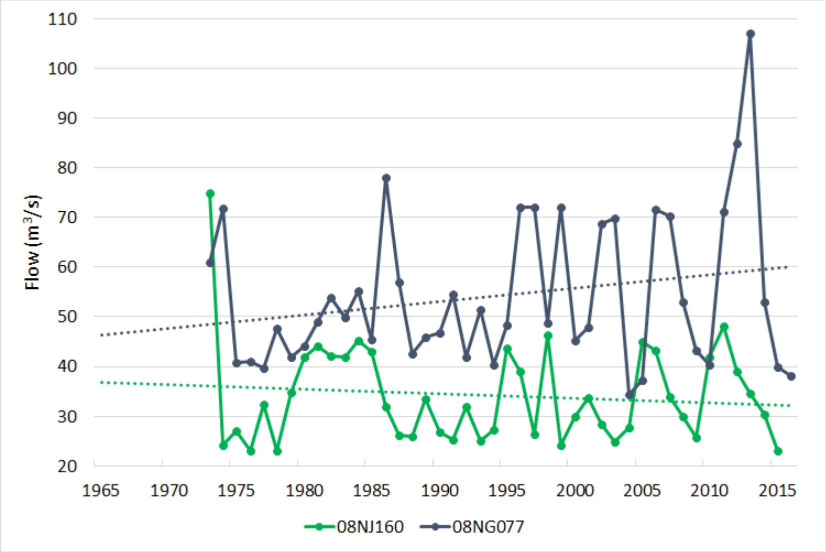
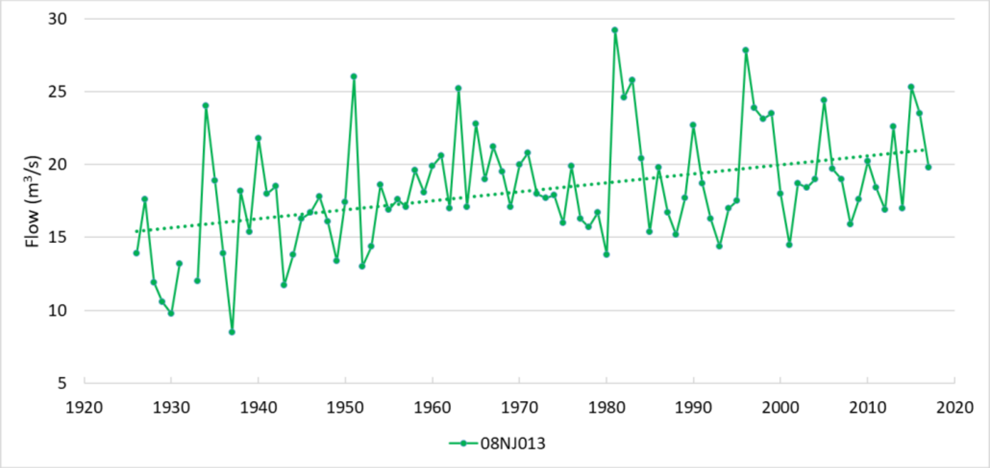


Figure 33. Annual peak flow at ECCC hydrometric stations within Representative Area: a) Slocan River b) Fry Creek, Kaslo River and Keen Creek; c) St Mary River and Lemon Creek.

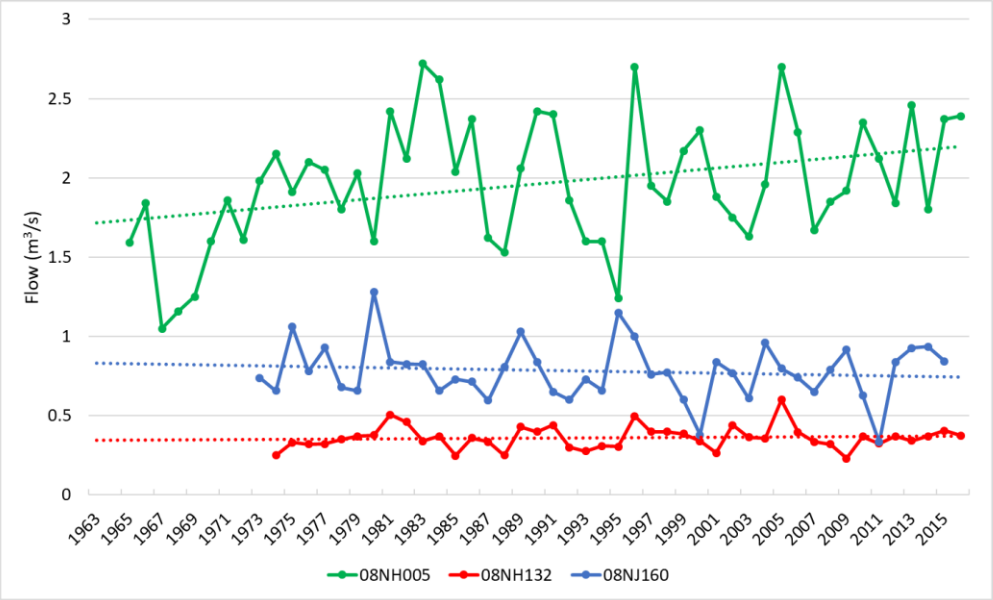
a)

green (Slocan)



b)

red (Keen)
blue (Lemon)
green (Kaslo)



c)

green (Fry)
red (St Mary)

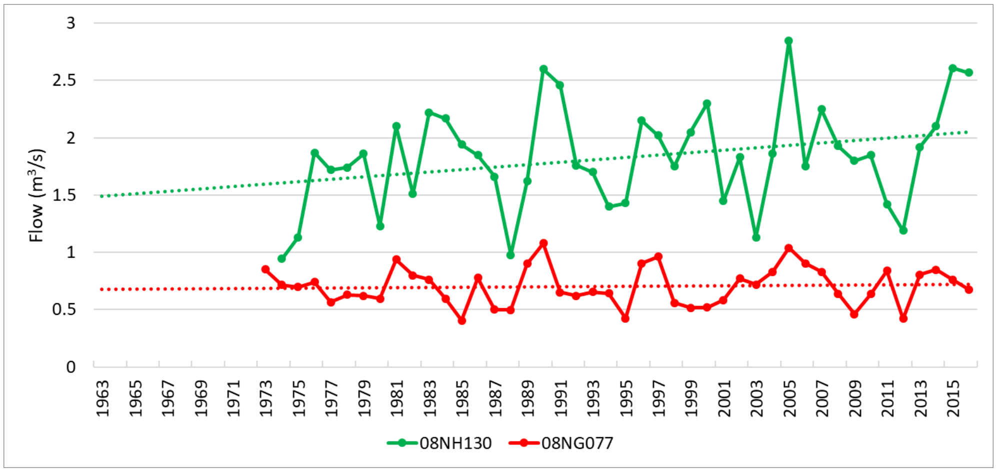


Figure 34. Annual low flow at ECCC hydrometric stations within the Representative Area: a) Slocan River b) Kaslo River, Keen Creek and Lemon Creek; c) Fry Creek and St Mary River.

Table 10. General preliminary observations of long-term trends of streamflow at active agency hydrometric stations within the Representative Area.

Stream Name	Overall Long-Term Change		Elev. (m)	Area (km²)	No. yrs
	Annual Peak Flow	Annual Low Flow			
Keen	Increasing[1]	Increasing	1598	92	53
Lemon	Decreasing	Decreasing	635	181	42
St. Mary	Increasing[1]	Unchanged	1177	208	43
Kaslo	Decreasing[1]	Increasing	768	442	51
Fry	Increasing[1]	Increasing	947	585	42
Slocan	Increasing	Increasing	466	3330	106

[1] Apparent increase in variability since about 2010.

4.3 Long-Term Snow Accumulation

In BC’s snow survey program, snow accumulation is measured at six sites located within the Representative Area at elevations ranging from 662 to 1926 m. As introduced in section 4.1, these sites are monthly and manually monitored, following the same standards followed at the NKLWMP snow courses (see section 3.1). One of the sites is a snow pillow at Whatshan Upper. Metadata for these sites are provided in Table 11. Just outside the boundary of the Representative Area is the Redfish snow pillow and snow course at St Leon, both of which are included in Table 11. The five snow courses have been monitored for 28 to 81 years providing the opportunity to describe long-term trends in snow accumulation at different elevations across the Representative Area.

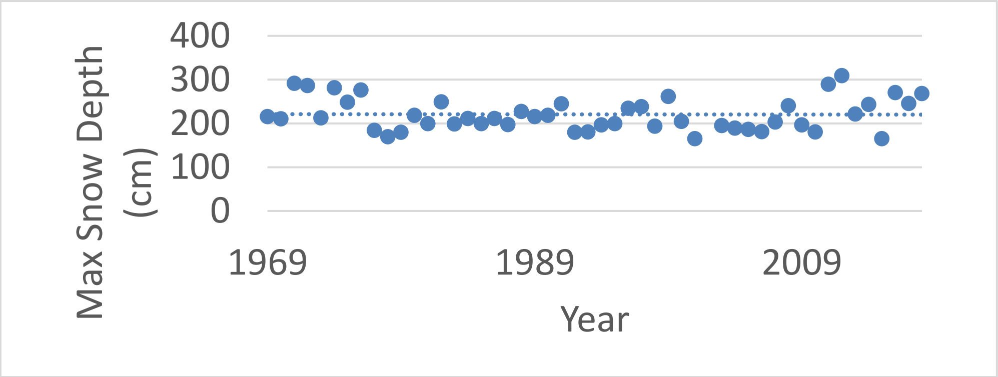
Table 11. Snow-monitoring stations within the Representative Area operated by the BC Ministry of Environment and Climate Change Strategy.

Station Description				Location		
Type	Name	No.	Period	Elev (m)	Easting	Northing
Snow course	Gray Creek (Upper)	2D10	1969-2019	1926	525291	5494217
Snow course	Koch Creek	2B07	1959-2019	1813	430316	5507578
Snow course	Gray Creek (Lower)	2D05	1948-2019	1558	522882	5494207
Snow course	Sandon	2D03	1938-2019	1072	484461	5534947
Snow course	Duncan Lake No. 2	2D07A	1991-2019	662	503565	5566429
Snow pillow	Whatshan (upper)	2B05	1959-2019	1476	427417	5559510
Snow pillow	Redfish Creek[1]	2D14P	2001-2019	2086	493989	5503427
Snow course	St. Leon Creek[1]	2B08	1967-2019	1828	450286	5587047

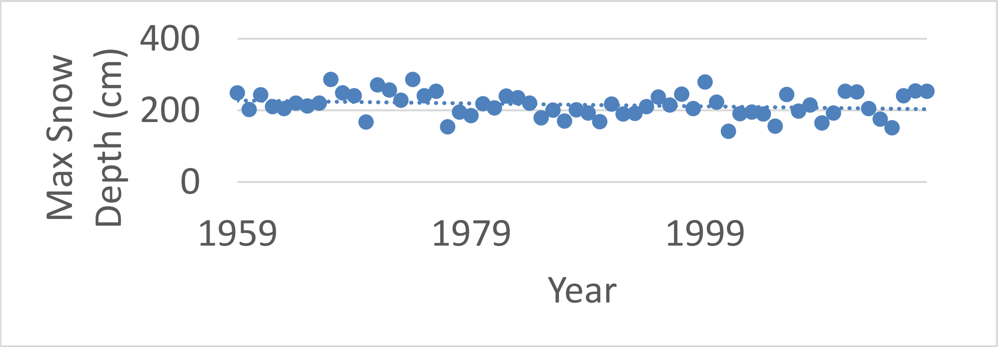
[1] – The St Leon and Redfish sites are outside of the Representative Area but are included here for discussion.

Figures 35 and 36 present the long-term trends in annual maximum snow accumulation as measured at the five snow courses situated within the Representative Area. Changes in maximum snow accumulation during the period of record are modest at these sites. Annual maximum snow accumulation varies considerably between the sites in relation to site elevation and other local factors. The highest depths occur at the Gray Creek (Upper) site and correspond to its highest elevation (1926 m) in the group. The lowest values correspond to the Duncan Lake No.2 and Sandon sites, which are at the lowest elevations (662 m and 1072 m, respectively). The two NKLWMP snow courses are situated at over 2000 m at elevations higher than those of the provincial snow-course sites. The maximum depths measured at the two NKLWMP sites are generally higher than the Gray Creek (Upper) site suggesting confidence in the measurements and the value of extending understanding of snow accumulation in the Representative Area to higher elevations than currently monitored.

a) Gray Creek (Upper)
1926 m



b) Koch
1813 m



c) Gray Creek (Lower)
1558 m

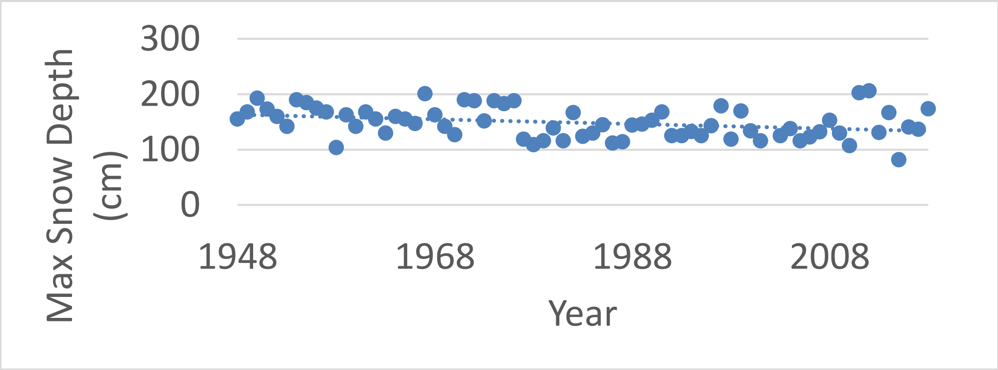
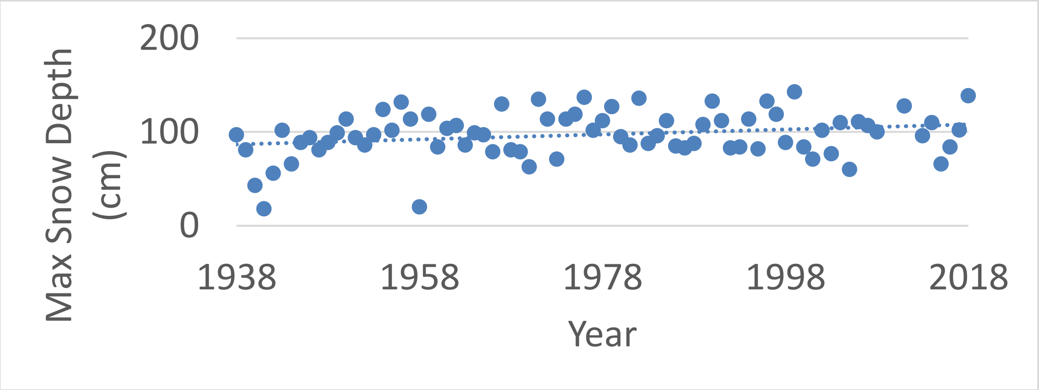


Figure 35. Annual maximum snow depth measured at three BC snow courses situated above 1500 m within the Representative Area: a) Gray Creek (upper) b) Koch c) Gray Creek (lower).

a) Sandon
1072 m



b) Duncan
Lake No. 2
662 m

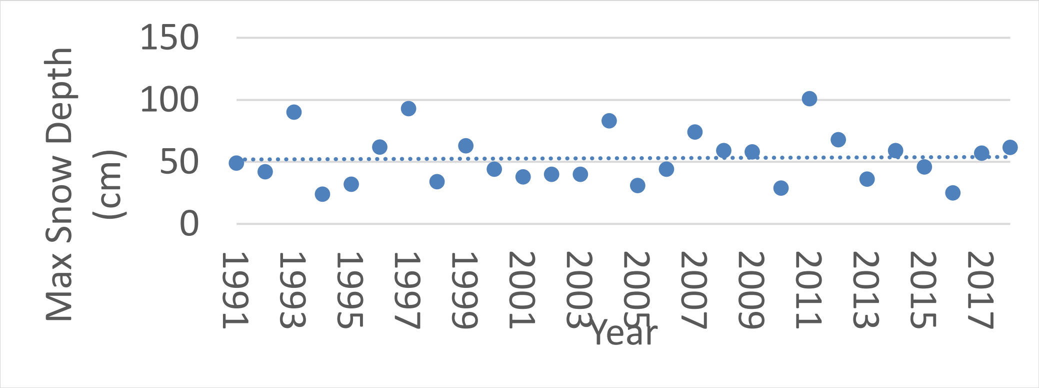


Figure 36. Annual maximum snow depth measured at two BC snow courses situated below 1600 m elevation in Representative Area: a) Sandon b) Duncan Lake No.2.

Figure 37 presents the annual maximum snow depth at the St Leon snow course, which is located slightly outside the boundary of the Representative Area. It is notable that the depths at this site (although at an elevation below the Upper Gray Creek site) are deeper. This is likely a reflection of the wetter conditions in the adjacent Regional Landscape unit.

b) St. Leon Creek
1828 m

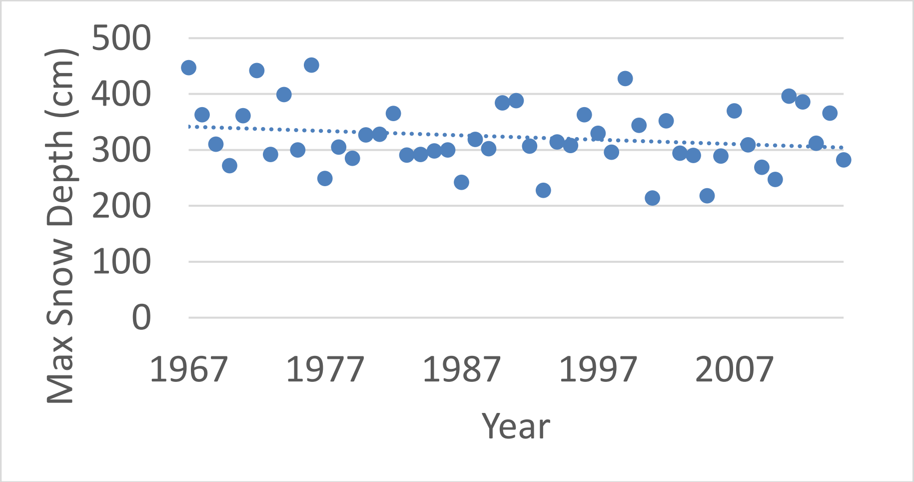


Figure 37. Annual maximum snow depth measured at the St. Leon snow course.

Long-term maximum and minimum snow depths measured at the provincial snow courses are provided in Table 12 with their occurrence dates. Snow accumulation ranges from 24 to 101 cm at the Duncan Lake No.2 site to 166-310 cm at the Gray Creek Upper site. Sites showed high snow accumulation in 1999, 2011 and 2012 and low snowpack depths in 1940, 1958, 2001 and 2010. These ranges place in context the values emerging from the NKLWMP snow courses. They also assist in interpreting variability that may take place as climate continues to change, potentially delivering more extreme precipitation inputs and melt rates.

Table 12. Magnitude and timing of largest and smallest annual maximum snow-water equivalent at agency snow-course sites in the Representative Area.

	Largest Annual-Maximum SWE (mm) mm < - > year						**Smallest Annual-Maximum SWE (mm) mm < - > year**					
	#1		**#2**		**#3**		**#3**		**#2**		**#1**	
Duncan Lake No. 2	101	2011	93	1997	90	1993	29	2010	25	2016	24	1994
Sandon	143	1999	139	2018	137	1976	43	1940	20	1958	18	1940
Gray Creek (Lower)	206	2012	203	2011	201	1967	107	2010	104	1958	82	2015
Koch Creek	287	1974	287	1967	280	1999	155	1977	152	2015	142	2001
Gray Creek (Upper)	310	2012	292	1971	290	2011	170	1978	166	2015	166	2001
Just outside the Representative Area:												
St. Leon Creek	452	1976	447	1967	442	1972	228	1993	218	2005	214	2001

4.4 Spatial Dynamics of Snow Accumulation

The Canadian Avalanche Association’s (CAA) Industry Information Exchange (InfoEx) database is a daily exchange of quantitative snow, weather, avalanche and terrain information between subscribers and ski operations. It was created to assist backcountry operations in making data-informed decisions, a goal aligned with NKLWMP objectives. NKLWMP has a data-sharing agreement with CAA to access data from backcountry ski operations that subscribe to InfoEx. These ski operations are located within (or near) the Representative Area and regularly collect snow depth and related climate information, following the Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches (OGRS) as described in CAA (2016). Through InfoEx, NKLWMP can access snow depth data (back to 2007) in addition to associated climate data from each operation: weather site coordinates, site elevation, daily maximum temperature, daily minimum temperature and 24-hour precipitation.

Under the data-sharing agreement, NKLWMP accesses data from eight ski operations monitoring snow depth at a total of 21 sites. (Data from Mount Carlyle Lodge may be included in the future.) Seventeen of these sites have measurements frequent enough throughout the winter to capture the season’s maximum snow depth. As indicated in Table 13, these 17 sites are located at elevations ranging from 1710 to 2195 m, with two at the much lower elevations of 1025 m and 1280 m. Their data periods are of variable duration as indicated in the table.

Table 13. Commercial backcountry-recreation snow-monitoring stations within (or near) Representative Area.

Station Description			Location		
Owner	**Site Name**	**Period (yrs)**	**Elev[1](m)**	**Easting**	**Northing**
Baldface	Lodge Study Plot	07-14	2036	476091	5493669
Baldface	Lodge Weather Plot	14-18	2036	476091	5493669
CMH KO	London Hi/Lo	14-18	2014	483243	5543675
CMH KO	Pleasure Centre	07-10,13-18	1964	453067	5578156
CMH KO	Too Deep wx	07-10,13-18	1942	448752	5577085
Ice Creek Lodge	Ice Creek Study Plot	09-18	1863	448098	5525278
Kokanee Glacier	Cabin	17-18	1956	486070	5513097
Kokanee Glacier	Kaslo Lake Wx Stn.	07-17	1966	485973	5513256
Powder Crk Lodge	Lodge Wx	15-18	2197	523364	5528061
Retallack	High Grade	07-18	2049	487767	5539841
Retallack	Lodge	07-13,17-18	1030	489708	5543067
Retallack	Robb Ridge	08-18	1874	489942	5540407
Selkirk Cat	A Frame Ridge	17-18	1898	496382	5565391
Selkirk Cat	Christmas Tree	07-16	1944	496224	5565400
Selkirk Cat	Lodge	07-18	1266	498017	5566835
Selkirk Cat	Meadows	07-18	2104	493752	5564826
Stellar HS	Lardeau	12-18	1090	502162	5554864
Stellar HS	London Low	12-18	1800	483887	5543419
Valhalla Mtn	Ruby Creek Lodge	11-18	1715	457780	5548992
Valhalla Powder	Center Lk	08,13-18	1932	430041	5501536
Valhalla Powder	Huckleberry	07-18	1761	433760	5500302

[1] Elevations are extracted from the Canadian Digital Elevation Data (CDED). CDED are taken from the Terrain Resource Information Management DEM converted to the Canadian Digital Elevation Data (CDED) format. Original source data (TRIM DEM) were captured at a 1:20,000 scale. The scale of the modified, CDED, data is 1:250,000. Resolution of the DEM is 25m.

The maximum annual snow depth is plotted for each year that monitoring was in place at each site. Given the range in elevations, the variety of spatial locations, and the inconsistent yearly coverage from site to site, the data require considerable sorting and analyzing to develop an integrated analysis. For the purposes of this initial report, the data are presented in Figures 38 to 40 for general review and comparison. The following preliminary observations are made from these plots:

- The InfoEx data indicate that snow accumulation varies greatly from year to year, consistent with ongoing experience from the provincial snow survey program.

- The InfoEx data show general consistency with the provincial snow survey data (Table 12). For example, 2012 and 2011 were years with high snow accumulation while 2009 and 2010 generally experienced lower snow accumulation.
- There is an overall trend among the InfoEx sites of increased snow depth with elevation, however there are exceptions that warrant further investigation.

Once these and other initial observations have been clarified and documented, the data can be explored in a spatial analysis and in conjunction with the data from the provincial network. The rate of snow accumulation through the season may also be of interest, particularly as mid-winter high-elevation rain-on-snow and other climate-related events come about.

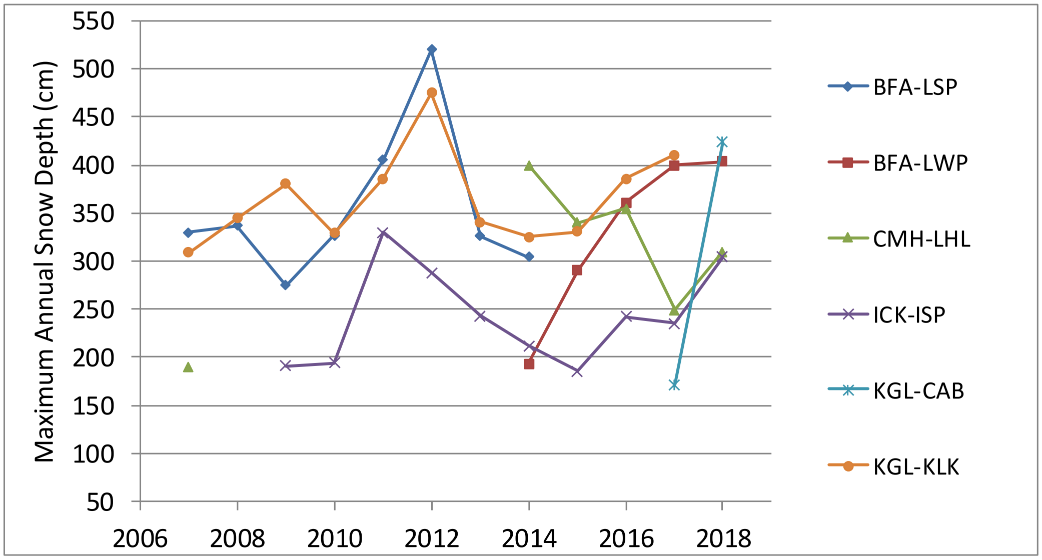


Figure 38. Maximum annual snow depth at six snow pole sites: a) Baldface Lodge b) Baldface Weather Plot c) CMH LHL d) Ice Creek Lodge ISP e) Kokanee Glacier Cabin f) Kokanee Glacier Kaslo Lake.

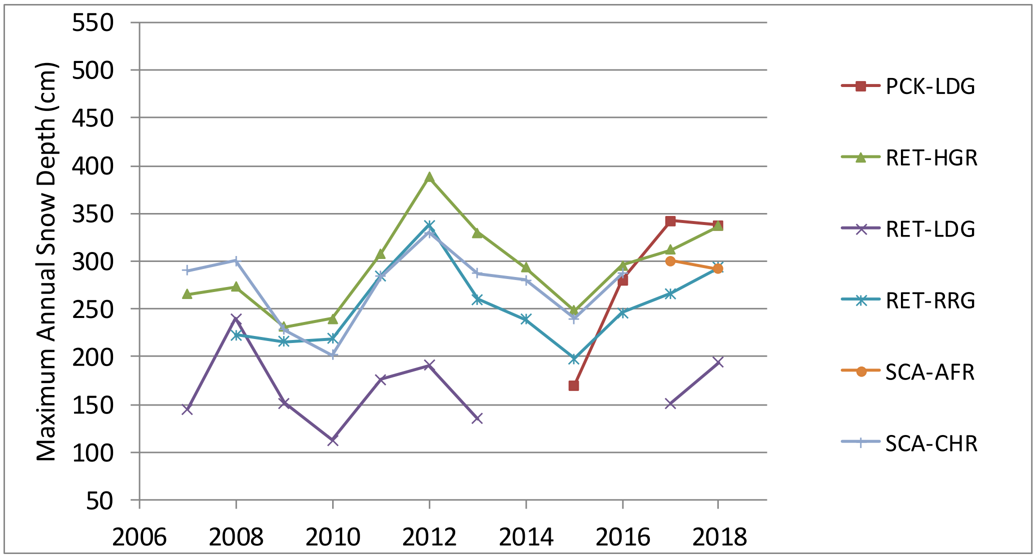


Figure 39. Maximum annual snow depth at six snow pole sites: Powder Creek Lodge, Retallack HGR, LDG and RRG; and Selkirk Cat Ski AFR and CHR.

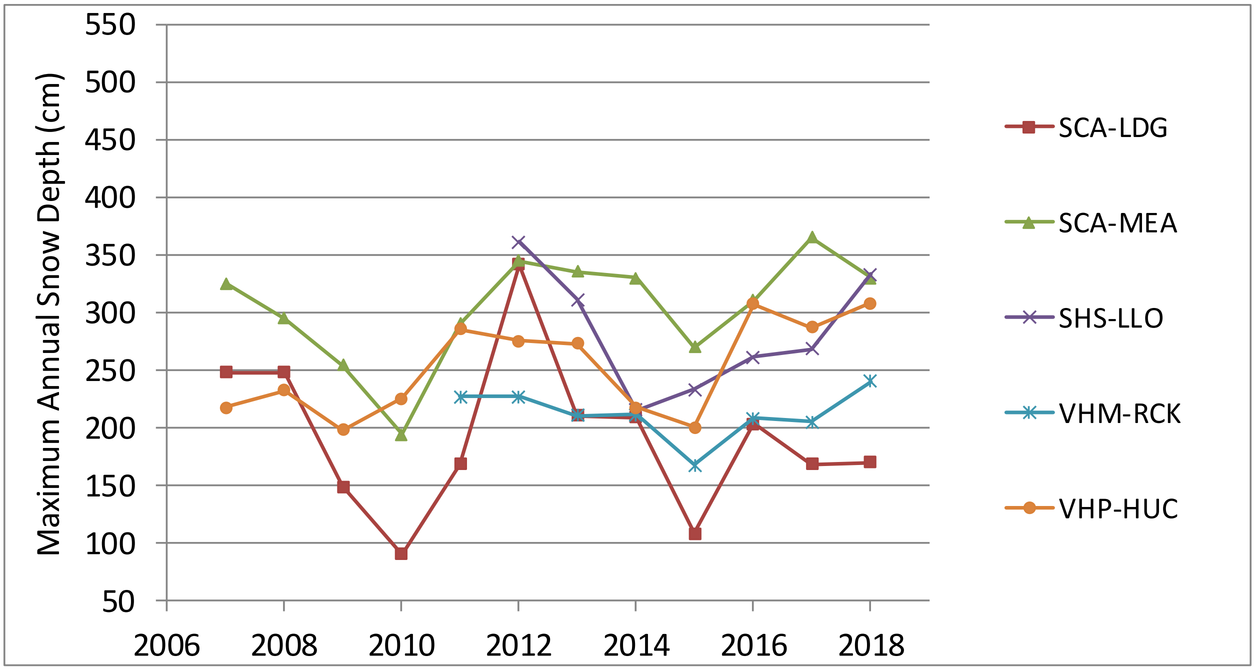


Figure 40. Maximum annual snow depth at six snow pole sites: Selkirk Cat Ski LDG and MEA; SHS-LLO; Valhalla Mountain RCk; and Valhalla Powder Huckleberry.

4.5 Climate Monitoring Stations

As shown earlier in Figure 33 (section 4.1), Canada, British Columbia, and BC Hydro currently monitor climate at 13 locations distributed within the Representative Area. Meta-data for these sites are provided in Table 14. Six are year-round stations and eight are seasonal (summer) stations. (An additional long-term year-round ECCC site in Fauquier was closed in 2015 and is included in the table due to its long record.) The long-term active year-round sites are at low elevations (512-600 m). The seasonal stations include sites at higher elevations operated by MoTI (up to 2518 m) and BC's Fire Management Branch (up to 1608 m).

Data from these stations are available to identify past trends in climate and explore the effects of climate on the trends in streamflow evident at regional and NKLWMP hydrometric stations (see section 4.2). In addition, future climate data from NKLWMP stations can be compared to data from these stations to clarify the uncertainty introduced by relying on regional climate to assess hydrologic dynamics of small local watersheds.

Table 14. Agency climate stations located within the Representative Area.

Station Description					Location		
Owner	**Station Name**	**Code**	**Estab'd**	**A/S**[1]	**Elev.**	**Easting**	**Northing**
ECCC	Fauquier	1142820	1913[2]	A	490	423293	5524940
ECCC	Nakusp CS	1145297	1991	A	512	441769	5568907
ECCC	New Denver	1145460	1924	A	568	473460	5538233
ECCC	Duncan Lake Dam	1142574	1963	A	549	502030	5565168
ECCC	Kaslo Cl	1143900	1994	A	600	505698	5528927
BC Hydro	Duncan Dam	DCN	1984	A	580	503683	5566985
BC MoTI	Fish Lake	34126	1999	S	1080	487174	5543795
BC MoTI	Lardeau High	34225	2012	S	2518	494276	5566307
BC MoTI	Lardeau C	34224	1995	S	1097	502322	5555773
BC MoTI	Coffee Creek	34621	1995	S	610	506687	5506882
FLNRORD[3]	Dewar Creek	421	1985	S	1608	544416	5514854
FLNRORD[3]	Slocan	406	1991	S	1230	468326	5514782
FLNRORD[3]	Falls Creek	383	2001	S	790	437443	5581586
FLNRORD[3]	Rory Creek	1092	2010	S	1580	514623	5606768

1 A – annual (year-round); S - seasonal.
2 Discontinued after 2015.
3: These are seasonal stations operated by the Fire Management Branch

5.0 PRACTICAL APPLICATIONS OF NKLWMP HYDROMETRIC DATA

This section provides a preliminary look at three practical applications of NKLWMP's hydrometric data. A flood frequency analysis (FFA) and a low-flow frequency analysis are performed with NKLWMP data and the results compared to regional historic WSC hydrometric data, from both discontinued and active stations. The L-moment method approach (Hosking, 1990 and 2019) is used to estimate the Generalized Extreme Value distribution parameters for the FFA, and the Pearson-III parameters are used for the low-flow frequency analysis. These distributions are commonly used in engineering hydrology to estimate extreme high or low flows of a given recurrence interval, in years. Many alternate methodologies exist and are employed on a case-by-case basis depending on project needs, available information, climate conditions and watershed characteristics.

The analysis presented here is not provided to establish a design flow or the environmental needs of a particular system and should not be used in that way. These examples are provided to demonstrate potential applications of NKLWMP's hydrometric data and to assess how the NKLWMP watersheds compare, hydrologically, to other watersheds in the region. The use of hydrometric data to inform decision makers, develop conservation guidelines, design infrastructure, etc, should always be done with additional rigour than is presented here. Potential additional rigour required includes critically evaluating the hydrologic compatibility of watersheds for regional analyses, evaluating the value of including historic hydrometric data, fine-tuning the FFA using paleo-flood information, filling data gaps using process-based modeling, and many other techniques.

5.1 Peak-Flow Frequency Analysis

Quantifying extreme flow events is of great practical importance for the design of infrastructure and stream restoration structures. Water supply systems, road ditches, culverts, bridges, bank erosion protection are all generally designed to withstand a 'design flood.' The design flood is a flood of a given probability of occurrence, often referred to in terms of a 'return period' (in years). For example, the 1-in-100-year design flood is the flood that has a 1-in-100 (1%) chance of exceedance in any given year. In the absence of a 100-year dataset, flood frequency analysis (FFA) methods are employed to fit a model to the observed data and to extrapolate it beyond the limits of the data in order to predict the magnitude of a flow event of a given, often 'rare,' probability. In the complete absence of flow data, a regional FFA can be undertaken to estimate the flood discharges of an ungauged basin by scaling the flood discharges of a gauged basin based on watershed area and characteristics.

Retrospective analyses of hydrologic behavior have become problematic due to climate change. The assumption of stationarity, *i.e.*, that future distributions will be similar to those of the past, is a potentially dangerous limitation of conventional FFAs and regional FFAs, especially in a period of climate change. Models not only have to look backward, but now have to look forward with *new data* and use climate projections, if they are to be of practical use in projecting future flood frequency and low flow frequency.

A flood frequency analysis of annual peak flow of mean-daily values is undertaken here for the Davis, Bjerkness, Carlyle, Ben Hur and MacDonald Creek stations. Results are compared with available WSC data from both active and discontinued stations. Section 4.2 did not include data from discontinued WSC stations. Figure 41 shows both the NKLWMP and WSC hydrometric stations within the project's Representative Area. Only WSC sites that are unregulated, have at least five years of consecutive data, and have a basin area under 600 km^2 are included in this analysis.

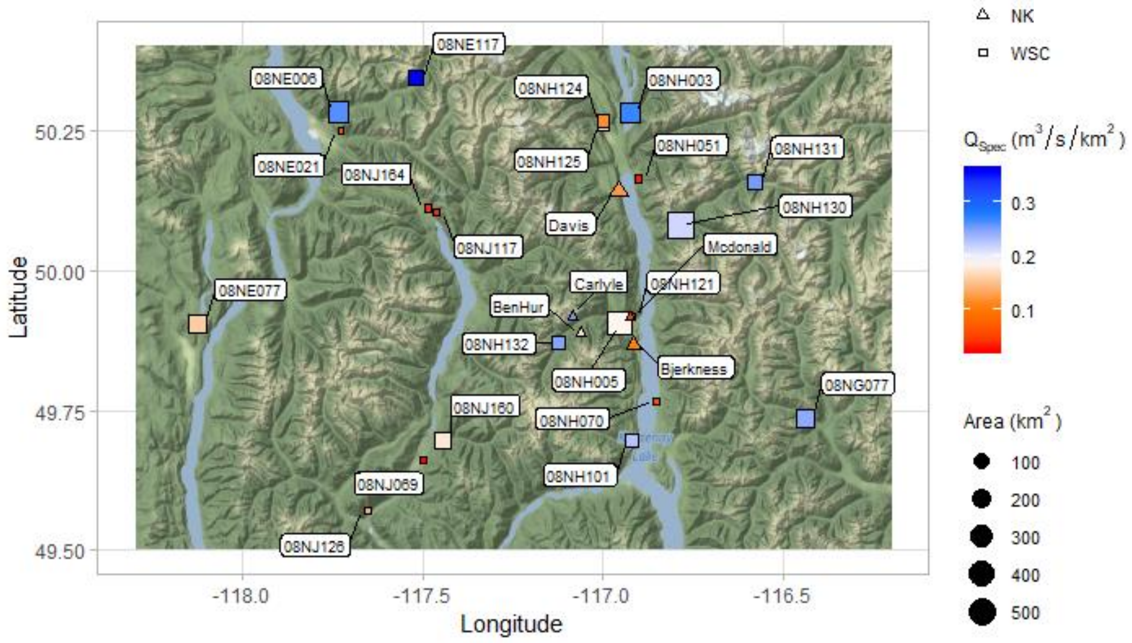


Figure 41. NKLWMP and WSC hydrometric stations considered for frequency analysis. Specific discharge (m^3/s per km^2) for the Q2 flood (two-year return period) is represented by the colour scale. Basin area (km^2) is represented by the size of the symbols.

Elevation range and dominant aspects of the gauged watersheds are also assessed to group the NKLWMP watersheds with similar WSC watersheds. Dominant valley orientation is used as a surrogate for slope aspect following three groupings: 1) north/south, 2) east/west and 3) other mixed aspects. See Figure 42. The NKLWMP sites belong to the first two groups so the WSC sites in the third group are excluded from the analysis removing six watersheds from consideration, leaving the WSC sites shown in Figure 43. Figure 44 displays the remaining watersheds (east/west and north/south) grouped by watershed size and elevation. *Note the WSC hydrometric network does not share the elevation range of Carlyle and Ben Hur stations*.

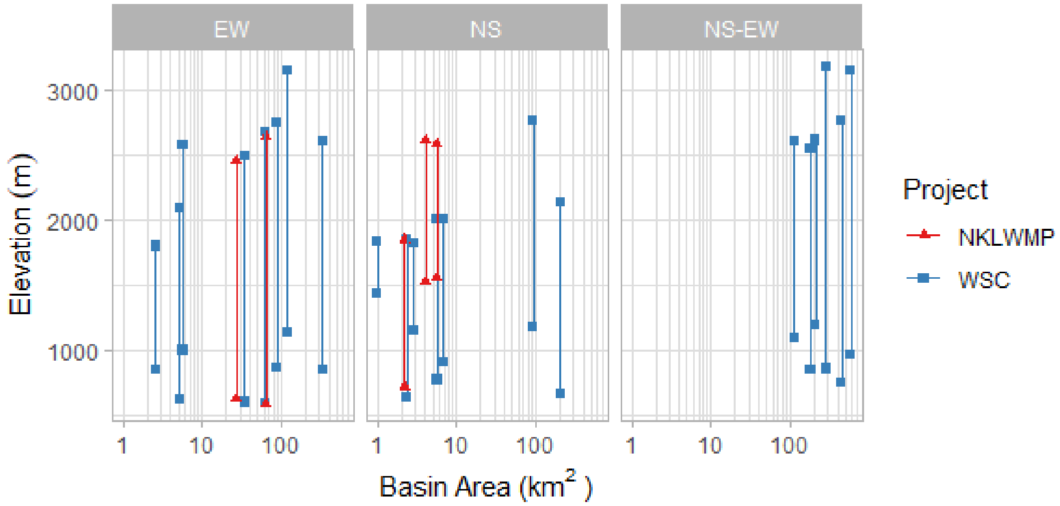


Figure 42. Dominant valley orientation (EW=East-West, NS=North-South, NS-EW = mixed NW/SE and NE/SW) and elevation range for the NKLWMP and WSC watersheds.

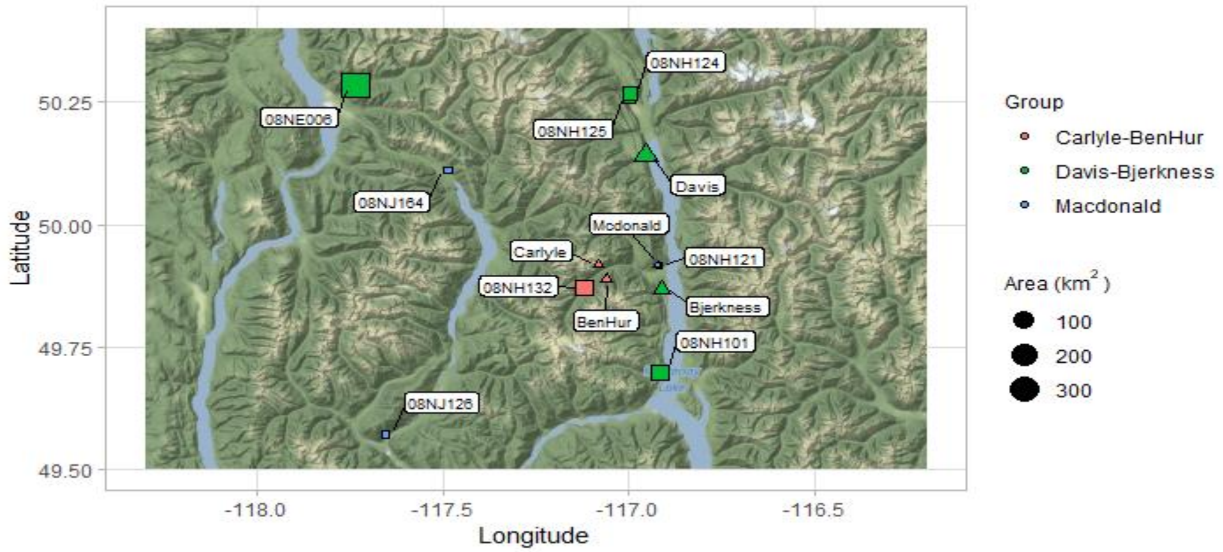


Figure 43. Map of grouped NKLWMP and WSC hydrometric stations used in analysis.

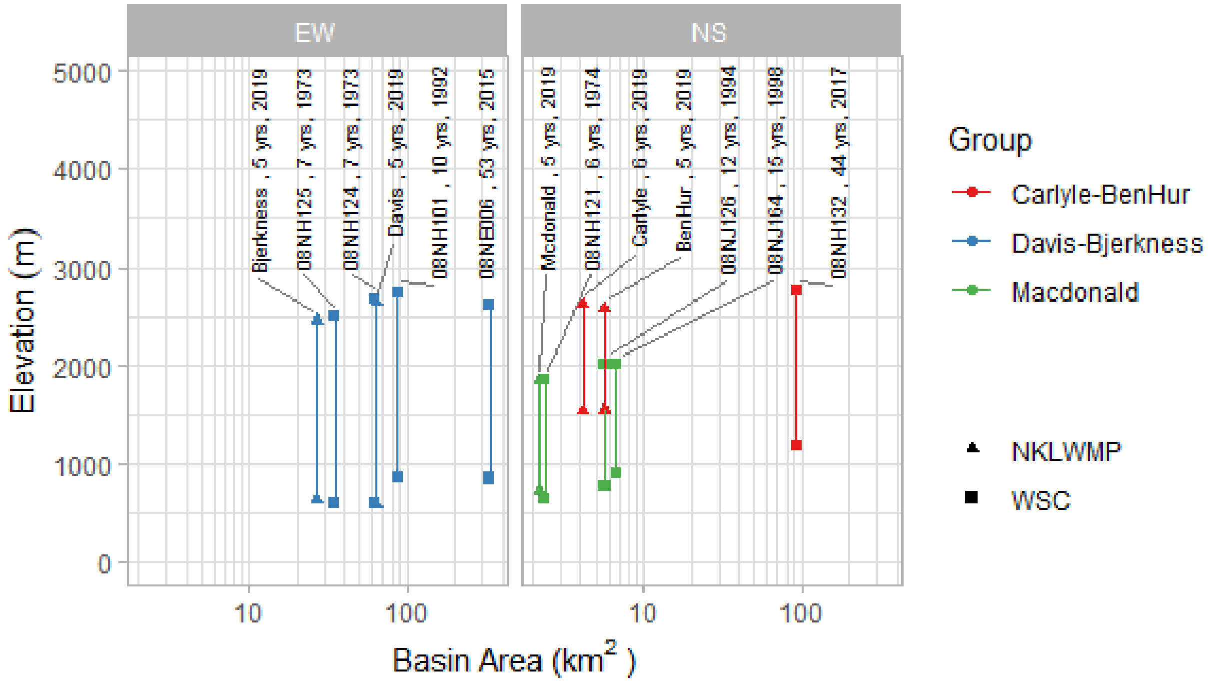


Figure 44. Dominant valley orientation (EW=East-West, NS=North-South) and elevation range for the NKLWMP and WSC watersheds. Each station is labelled with station name/number, number of years on record, and year of last recorded data.

The specific discharge of the two-year peak flood (Q2; flood with a return period of two years) is plotted against basin area for each of the grouped watersheds (Figure 45). Specific discharge (Q_{spec}; discharge per unit area) is presented to enable comparison across watersheds of different sizes. A return period of two years is selected due to the shorter time period of currently-available NKLWMP data (up to five years).

All three groups show a decreasing trend of $Q2_{spec}$ with decreasing basin area. This is contrary to conventional hydrologic theory that peak flows tend to increase, on a per unit area basis, with decreasing basin size. This observation, in conjunction with the fact that most of the WSC stations retained for the analysis have less than 15 years of data and do not have years which overlap with the NKLWMP stations, illustrates the need for continued monitoring at the NKLWMP sites to develop long-term datasets.

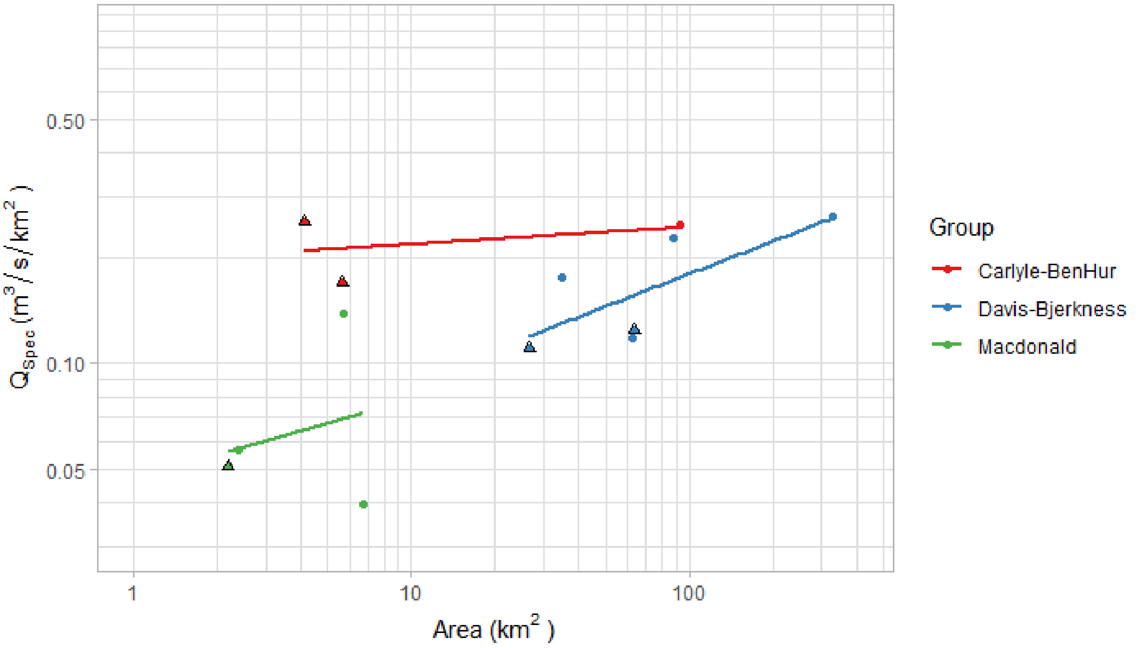


Figure 45. Specific discharge of the Q_2 for the grouped WSC-NKLWMP watersheds. Circles are WSC stations, and triangles are NKLWMP stations.

While longer datasets can generally result in more accurate predictions of low-probability floods, conventional methods for estimating these flood frequencies and magnitudes have two serious limitations. First, the fitting of any model requires an inferred assumption about the underlying distribution generating flood events. This is unknown for extreme hydrologic events beyond the observed record, and is untestable within human timescales (Klemes, 1989). Second, all FFAs assume conditions of statistical stationarity (Kidson and Richards, 2005) which are increasingly in doubt due to abruptly changing climate.

An alternative to the conventional FFA is to employ physically-based models to simulate precipitation-runoff. However, model calibration requires real data to produce accurate and robust model results, thus once again illustrating the paramount need for continued monitoring and development of long-term datasets, in this case for use in model calibration.

5.2 Ratio of Instantaneous to Daily-Mean Peak Flow

Another important metric for design and planning of water infrastructure is the ratio of instantaneous peak flow to daily-mean flow. Agencies collecting hydrometric information may publish only the daily-mean flow values, so in the absence of instantaneous values, the daily-mean values are multiplied by the ratio in order to estimate the instantaneous peak flow, which are then used in sizing critical infrastructure. Figure 46 illustrates the ratio of measured instantaneous flow to daily-mean peak flow for the NKLWMP stations and the full selection of WSC stations identified earlier (Figures 41 and 42). Published instantaneous peak-flow values are made available by WSC for only nine of these stations. The Representative Area does not have a WSC station with a drainage area under 20 km^2 against which to compare the NKLWMP values, highlighting the importance of the NKLWMP data in filling this important data gap for instantaneous flow values in small watersheds. The NKLWMP watersheds have an average ratio of Qpeak $_{\text{instantaneous}}$ to Qpeak $_{\text{daily}}$ of around 1.1 indicating that instantaneous flow values are typically 10% greater than the daily mean. However, the WSC data demonstrate that this ratio is high as 1.35. At this stage in NKLWMP monitoring, it remains unknown whether the ratio is smaller for smaller watersheds or is smaller due to the shorter period of available data, or both. Continued years of NKLWMP monitoring is required to confidently determine this ratio value for smaller watersheds in the Representative Area (the focus of NKLWMP monitoring).

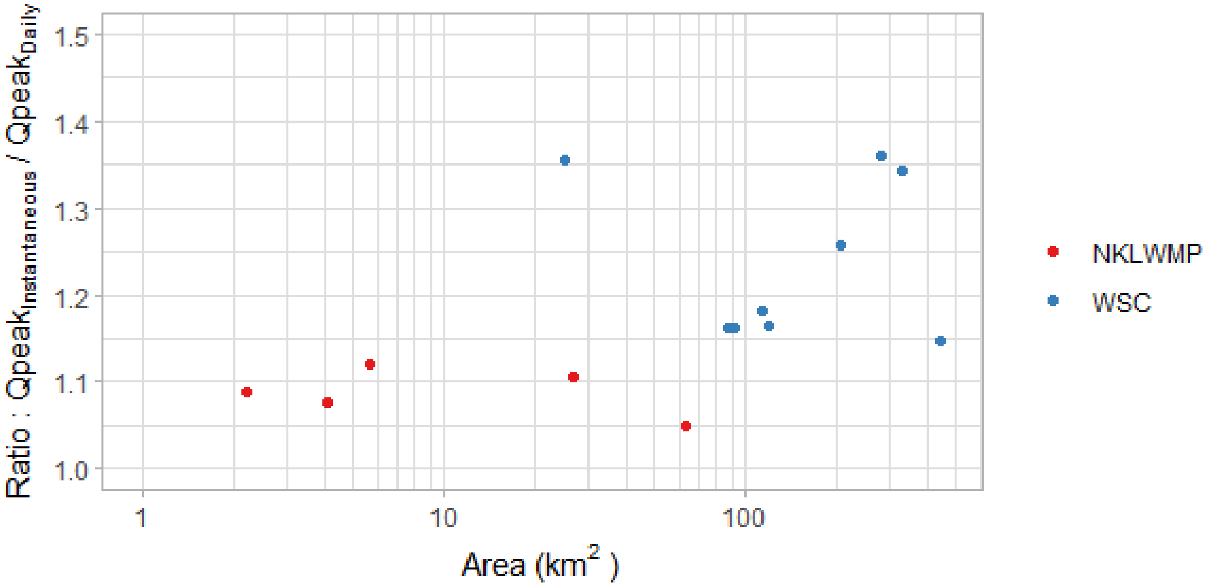


Figure 46. Ratio of instantaneous peak flow to daily-mean peak flow (Qpeak $_{\text{instantaneous}}$ / Qpeak $_{\text{daily}}$) for WSC and NKLWMP stations.

5.3 Low-Flow Analysis

Quantifying low flows is crucial for domestic, municipal, commercial and agricultural water supply management and for determining environmental flow needs (EFNs). A common metric used in establishing EFNs is the $Q_{7,10}$, which is the minimum discharge for a rolling seven-day average, with a return period of ten years. Because of the current limited timeframe of NKLWMP data, the $Q_{7,2}$ (rather than the $Q_{7,10}$) is calculated here for comparison with the full set of selected WSC stations (*i.e.*, those chosen in section 5.1, Figures 41 and 42). While the low-flow frequency analysis methodology is similar to that of flood-frequency analysis, the robustness of low-flow models is deemed better because low flows are generally truncated by some minimum value (in the extreme case, zero surface flow). This results in reduced uncertainty when extrapolating to unobserved events as compared to extrapolating to extreme high events. Figure 47 illustrates the seven-day, two-year return period low flows at both the NKLWMP and WSC stations. The WSC data show significant spread, with flows ranging from 0.0015 m^3/s/km^2 to 0.0115 m^3/s/km^2. The NKLWMP data add more spread to the WSC data, with a minimum value near zero.

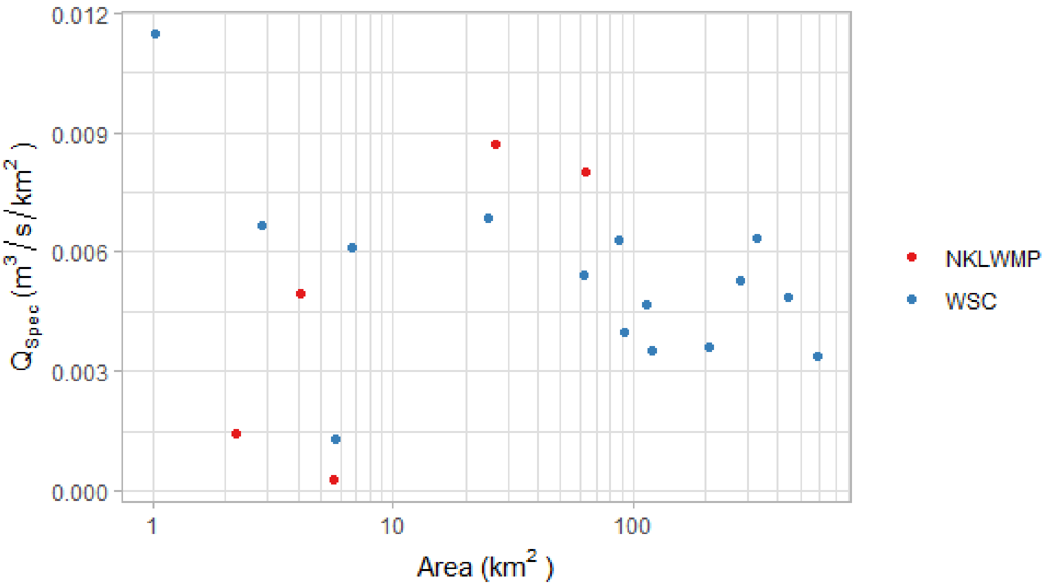


Figure 47. Specific discharge of the seven-day, two-year return period low flow event for the NKLWMP stations and the full set of selected WSC stations.

Figure 48 displays a subset of data from Figure 47 corresponding to WSC watersheds having similar basin size, elevation range and valley orientation to the NKLWMP watersheds (Figures 43 and 44). Despite controlling for these watershed attributes, the data continue to show significant variability. The hydrologic expression of watersheds is an aggregate of many complex biogeoclimatic factors, influencing watershed behavior across scales. The spread illustrated in Figure 48 is a reflection of these complexities, illustrating the limitations of regional extrapolation and emphasizing the need for continued development of long-term hydrometric data sets such as those being gathered by NKLWMP.

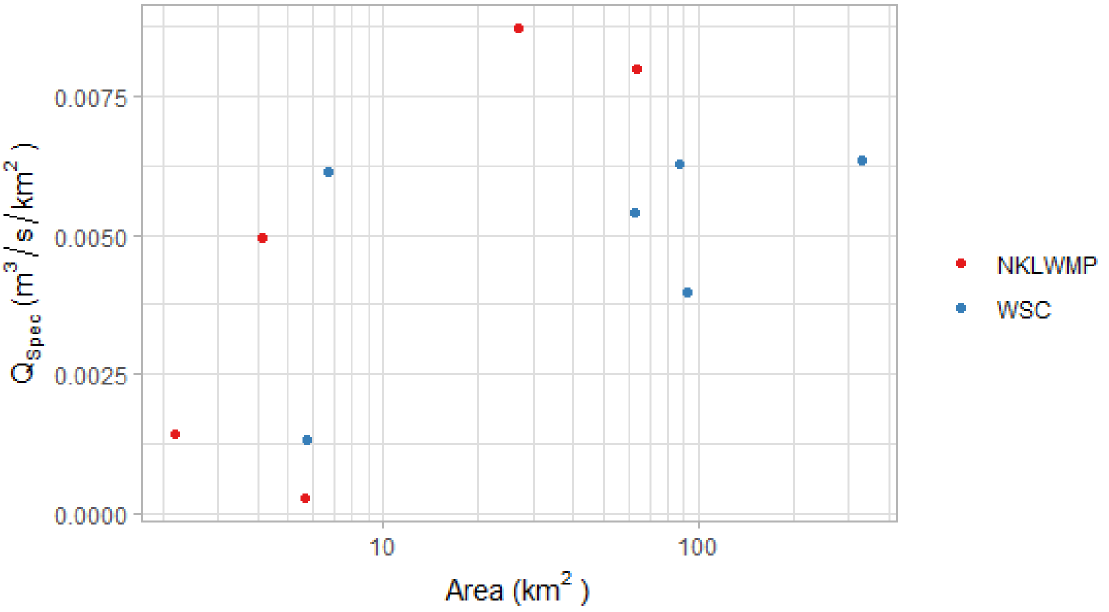


Figure 48. Specific discharge of the 7-day, 2-year return-period low-flow events for the NKLWMP and WSC stations.

5.4 Implications

Peak flows, the ratio of peak-instantaneous to peak-daily flows, and low flows are important metrics used in making water-management and infrastructure decisions. The analyses presented above illustrate the ‘messiness’ of hydrologic data, especially when considered at a regional scale. Conventional methods for determining the magnitude and frequency of rare events have performed adequately in the past but now face limitations imposed by a changing climate. The assumption of hydrologic stationarity (that future distributions will be similar to those of the past) over long timescales is increasingly unreliable and is reflected in the existence of *trends* now commonly observed in long-term data.

This new and changing reality of hydrologic systems implies:

- conventional methods employed for establishing design flows and EFNs need revisiting in light of climate change;

- hydrometric monitoring of smaller systems is essential in quantifying how these methods need to be adjusted; and

- hydrometric monitoring across scales - and reflective of evolving conditions - is necessary so as to provide the data needed to calibrate hydrologic models.

6.0 DISCUSSION AND NEXT STEPS

6.1 Discussion

The North Kootenay Lake Water Monitoring Project is well established and on track to meet its long-term objectives and commitments in support of climate-change readiness. A complete foundation is now in place for a strong and stable long-term monitoring project and initial results are shedding light on the characteristics of the study drainages within the Representative Area. The project's administrative structure is tested and effective, run by local people, and emphasizes those living regionally, especially at the north end of Kootenay Lake where the monitoring is taking place. The diversity of NKLWMP's funders indicates wide-ranging regional support for preparing communities for the evolving disruption of climate change, particularly in relation to its effects on water resources, aquatic ecosystems, and community water supply. This report provides an integration of accomplishments to date.

NKLWMP's monitoring design, parameters, and standards have been assembled to address critical gaps in scientific data and knowledge related to climate-change preparedness, while also facing the many practical challenges associated with environmental events, technical capacity, and funding availability. Maintaining and growing the monitoring network and meeting and exceeding required monitoring standards will be ongoing tasks through the project's life. Work to date has shown that to achieve successful and cost-effective environmental monitoring, particularly when it involves small streams and difficult sites, the program must rely on people who are in touch with the local environment and are available, sometimes at short notice, to address evolving circumstances. Additionally, NKLWMP's high-degree of volunteerism has been essential in delivering a cost-effective program.

Considerable site maintenance and technical improvements have been accomplished in NKLWMP's initial period. These include the completed network (hydrometric, snow, climate), acquisition of state-of-the-art monitoring equipment (salt dilution monitoring, continuous data loggers at all sites, Federal standard snow sampling equipment), successful resolution of inherited field issues, and establishment of logistical protocols that facilitate team efficiency. Current maintenance challenges include winter freezing at high-elevation hydrometric sites, sedimentation effects in settling ponds, and some practical winter considerations associated with the meteorological stations.

An important technical improvement moving forward is the establishment of elevation benchmarks at each station. Benchmarks are permanent fixed reference points of known elevation. They facilitate the confirmation or adjustment of gauge height or stage relative to a constant datum or reference elevation. Benchmarks were identified at the older NKLWMP stations when they were established (and should remain valid at Bjerkness, Carlyle and Ben Hur stations) however stable benchmarks are needed at all the NKLWMP hydrometric stations (RISC 2018). Station schematics (plan view) and cross-section diagrams should also be prepared to fully describe all NKLWMP monitoring stations. When a station is removed, reactivated, or damaged by extreme hydrologic and meteorological events, benchmarks can be used to recover the station datum.

It is too early in NKLWMP's monitoring of climate to say much about the program's climate data. The implementation of the tipping buckets in the climate stations warrants additional study. To what extent is rainfall catch being influenced by wind? To what extent are short-term episodes of freezing modifying the precipitation recorded by the tipping buckets? Continued monitoring and inspection of the data will shed light on these questions.

Although water quality is not the focus of NKLWMP's monitoring, the initial results presented in this report suggest that retaining the water quality program is worthwhile. Turbidity appears to distinguish the drainages to some extent. As melt and precipitation events become more severe under future climates, hillslope and channel responses should be reflected in patterns of turbidity.

An inventory has been carried out of other monitoring in the Representative Area, including long-term data sets. Those associated data sets have been assembled, and comparisons and preliminary interpretations have been carried out. Although NKLWMP data are currently somewhat limited (one to five years' duration) and thus do not support long-term comparisons with regional data, some interpretations are possible and have been included in this report. The preliminary presentation of data from other long-term monitoring within the Representative Area highlights the need for monitoring of smaller drainages. Patterns in the hydrometric data suggest complex interactions between the controls on runoff and imply that runoff behaviour of small basins is not necessarily reflected in that of their downstream counterparts. Snow-depth data are helpful in bracketing the range of depth expected based on elevation and provides added context for evaluating snow depth-measurements going forward. The NKLWMP snow courses are at higher elevations than those of the provincial snow survey network within the Representative Area, again highlighting the importance of these two snow courses. Snow-depth data from local ski operations offer a valuable resource to better understand spatial variability in snow accumulation and warrant a rigorous spatial analysis. Budget permitting, analysis of climate data from within the Representative Area will enable analyses of runoff dynamics and water balance calculations all of which are expected to adjust as the climate changes.

Internal systems of data management, basic protocols for data analyses, and preliminary reporting products are in place, which will allow for timely dissemination of NKLWMP's data products. At this time, NKLWMP data are housed internally and available on a case-by-case basis; however, dissemination and application of the data is one of the project's major next steps and aligns well with Living Lakes Canada's (LLC) initiative to develop and populate an Open Source Water Data Hub in the Columbia Basin (Mountain Labyrinths 2018). NKLWMP's strategic partnership with LLC allows its personnel to contribute directly to this initiative, along with other water stewardship groups, provincial government, local and regional government, and private industry. Participation in initiatives such as these supports NKLWMP's objectives in providing its data products (along with data products from other stakeholders in the Columbia Basin) housed in a public-access database maintained indefinitely and available to the public. NKLWMP's website is active[3] but remains under development.

Scope exists for a more detailed assessment of the terrain, land cover characteristics and land-use change of each monitored watershed, including vegetation cover, estimated average surficial material depth and water storage capacity, bedrock porosity/jointing, and topographical analyses. It may be possible to link these factors to the annual hydrograph and annual basin water yield to investigate the extent to which vegetation cover, land-use change, terrain/bedrock, surficial material characteristics and topography of each watershed could help explain differences in hydrologic response. This outcome could then be used to identify the other watersheds to which the data could be appropriately extended.

NKLWMP data add direct value to practical engineering/hydrologic analyses that require long-term records of streamflow. Although the examples reviewed in this report are based on short-term records, the same principles apply using long-term data. Furthermore, ongoing long-term data sets in these times of changing climate can be more important than historical long-term datasets, particularly in using flow data for design and risk-assessment purposes. Whereas recent short-term data are inadequate to confidently decipher hydrologic trends, their practical application is justified in conditions of changing climate. Historical hydrologic behaviour is less applicable in designing for *current* conditions; whereas, the use of current hydrologic data is, at a minimum, relevant for designing to current conditions, *and* can be used to calibrate models to assess future conditions. This does not, however, discard the importance of continued

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[3] http://www.kootenayresilience.org/nklwmp-water-monitoring

monitoring because, in times of changing climate, hydrologic variability is expected to increase and thus it is important to capture these data signals to make informed, data-driven, water-management decisions that can have long-term implications. As an example of the use of relatively recent data, Eaton *et al.* (2002) conducted an analysis of regionalization of flood flows and intentionally included only recent datasets (the 20 years of data prior to the time of publishing their paper) because the results would be more relevant to the current situation.

In examples involving estimates of maximum flood flows, minimum low flows, and maximum instantaneous flows, available NKLWMP data add spread to the calculated metrics beyond that from considering only the larger basins. This highlights the risks associated with extrapolating information from gauged watersheds to smaller ungauged watersheds, thus supporting the rationale of monitoring these small watersheds. Hydrometric monitoring, at a high standard, provides clear, unambiguous data that can be crucial for establishing correct requirements forEFNs of smaller basins, sizing infrastructure in response to escalating climate events, and generally managing community water supply needs under future climates.

6.2 Next Steps

The following actions are proposed for implementation.

Hydrometric Stations

1. Assess additional options to address freezing of instruments at high-elevation hydrometric stations.
2. Establish benchmarks for Gar, MacDonald, Kootenay Joe and Davis stations.
3. Create up-to-date site schematics for all stations, including measurement cross-section diagrams.
4. Explore available technology to deliver real-time data gathering.
5. Improve measurement of low flows particularly at MacDonald, Gar and Kootenay Joe stations.

Climate Stations

6. Assess uncertainty associated with rain measurement at the climate stations, including effects due to wind bias and freezing.

Data Analysis

7. Examine water budgets and runoff dynamics of NKLWMP drainages in relation to meteorological inputs. Use the information to assess the potential applicability of specific NKLWMP flow regimes to other drainages in the representative area.
8. Characterize bedrock geology, surficial materials and topography of each of the NKLWMP drainages. Examine water budgets and runoff dynamics in relation to bedrock, terrain and topography. Use the information to assess the potential applicability of specific NKLWMP flow regimes to other drainages in the representative area.
9. Review conductivity data to better understand runoff dynamics and characteristics of monitored drainages.
10. Adjust Bjerkness and Gar discharge time-series data to account for withdrawals by water users.
11. Adjust Gar water level readings for sedimentation issues in the weir pond.

Regional Data/Analysis

12. Assemble regional climate data and clarify regional climate behaviour in relation to NKLWMP climate stations and watersheds.
13. Expand water quality data by requesting data sets from stewardship groups monitoring within the Representative Area. Include these regional water quality data in future reporting.
14. Conduct a regional elevation-based analysis of snow accumulation and place in context of the Southern Interior and NKLWMP sites.

Data Applications

15. Work with hydrologic simulation modellers (*e.g.*, at a BC university) to create a pilot application to verify the value of NKLWMP and to recommend whether to include additional monitoring in the NKLWMP network.
16. Remain as an active contributor in Living Lakes Canada's initiative to develop and populate an open-source water data hub to disseminate NKLWMP data.

Policy Influence

17. Discuss further applications of NKLWMP data sets with policy makers and approval officers. For example, discuss applications with water-rights approval agencies, fisheries biologists, regional planners, subdivision approval agencies, forest management planners, engineers and geoscientists involved in forest road layout, MoTI, Fortis BC in relation to Kootenay Lake levels, water users associations, and others.

Funding

18. Secure long-term (decadal) sustained funding.

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APPENDIX A1. PREVIOUS MONITORING OF STREAMS IN THE VICINITY OF THE NKLWMP NETWORK

As introduced in section 2.3, prior to the commencement of NKLWMP some limited monitoring in the Kaslo area had taken place. These activities are described by Quamme and Sundberg (2000), Sundberg (2001), Masse (2002), and Masse (2003a, 2003b, 2003c). Excerpts from that work are provided here for Kemp Creek and Wing Creek, streams that are not monitored by NKLWMP but which are situated within the vicinity of the NKLWMP network. This information may be useful in relation to future analysis or potentially future monitoring. Table A1.1 provides the reported general characteristics of these streams.

Table A1.1 Selected characteristics of two small streams monitored during 1998 to 2002.

Characteristic	Kemp	Wing
Drainage area (km^2)	11.8	-
Maximum elevation (m)	2150	-
Stream length (km)	10.32	3.02
Dominant aspect	NE	E
Stream gradient (%) at station	>25	3
Stream order at station	4	3
UTM northing coordinates of stations[1]	5512272	5512334
UTM easting coordinates of stations[1]	501019	501059

[1] There is doubt about the accuracy of these recorded locations.

In 1999-2000, the following personnel were involved in this water monitoring project:

- Kara Sundberg (Community Forest) - field sampling, data compilation, reporting
- Darcie Quamme (Aquatic Resources) - supervision of analysis, benthic collection and reporting
- Danusia Dolecki - identification of benthic macroinvertebrates
- Dave Beringer - data collection

In 2001-2002, the following personnel were involved in this water monitoring project:

- Allan Law (Clearwater Environmental), Joanne Leesing (Surewood Consulting Ltd.), Jacquie Bastick, Kare Holmberg - data collection and site sampling
- MJ Jojic & Heidi McGregor (BC Ministry of Sustainable Resource Management) - technical support

According to Masse (2002), Kemp Creek flows northeast into the Kaslo River, fed by tributaries that cascade down its steep valley walls into two main sub-basins. The western sub-basin originates at an elevation of 2150 m, while the eastern sub-basin begins at 2010 m elevation. The upper parts of the watershed are characterized by steep, glacier-carved valley walls with avalanche-scarred slopes. The creek flows through a steep, V-shaped valley just upstream of the village water intake, where sediment deposits from erosion and debris slides accumulate. It was designated as a Community Watershed. In 2002, Kemp Creek provided water to the waterworks of the local authority (Village of Kaslo), which then distributed it to residents of Kaslo for domestic purposes. There were two registered water licenses. No fisheries information was available for this creek. Two blocks had been harvested downstream of the water intake in the watershed in 2000 and 2001. Quamme and Sundberg (2000) provide a plot (Figure A1.1) showing electrical conductivity during the 1999 monitoring of Kemp Creek.

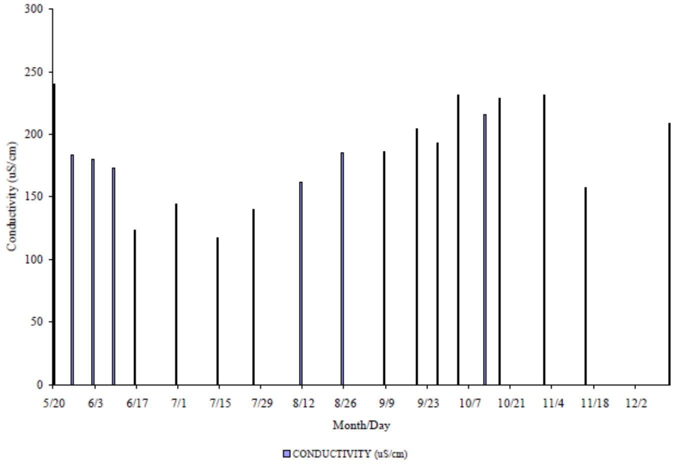

Figure A1.1. Variation in conductivity of Kemp Creek during 1999.

According to Masse (2002), Wing Creek flows eastward into Kootenay Lake and is characterized by generally steep gradients. Its headwaters are a series of small first-order tributaries that drain a steep (~70% gradient) catchment area covering 1-2 km^2. The middle reaches flow through a steep (~50% gradient), deeply incised channel, while the lower reaches have lower gradients (<20%) and are less confined (Wells 1995). Typical of high-relief drainage basins in the area, the Wing Creek watershed contains extensive debris slide scars and gullies. Debris slide scars, roughly 100 years old, are located along the middle portions of the watershed and appear to be related to an extensive forest fire that occurred around that time (Wells 1995). In 2002, Wing Creek was a domestic watershed providing water to local residents for domestic and irrigation purposes. There were nine registered water licenses. No fisheries information was available for this creek. Based on channel gradients downstream, Masse (2002) considered it probable that fish were unable to migrate upstream from Kootenay Lake. There had been no logging or development activities within this watershed as of 2002. Quamme and Sundberg (2000) provide a plot showing electrical conductivity during the 1999 monitoring season. See Figure A1.2.

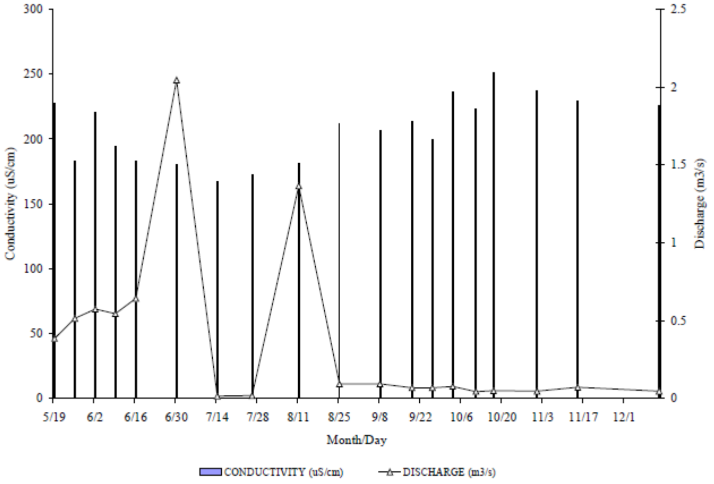

Figure A1.2. Discharge and conductivity for Wing Creek during 1999.

APPENDIX A2. STAGE-DISCHARGE RATING CURVES

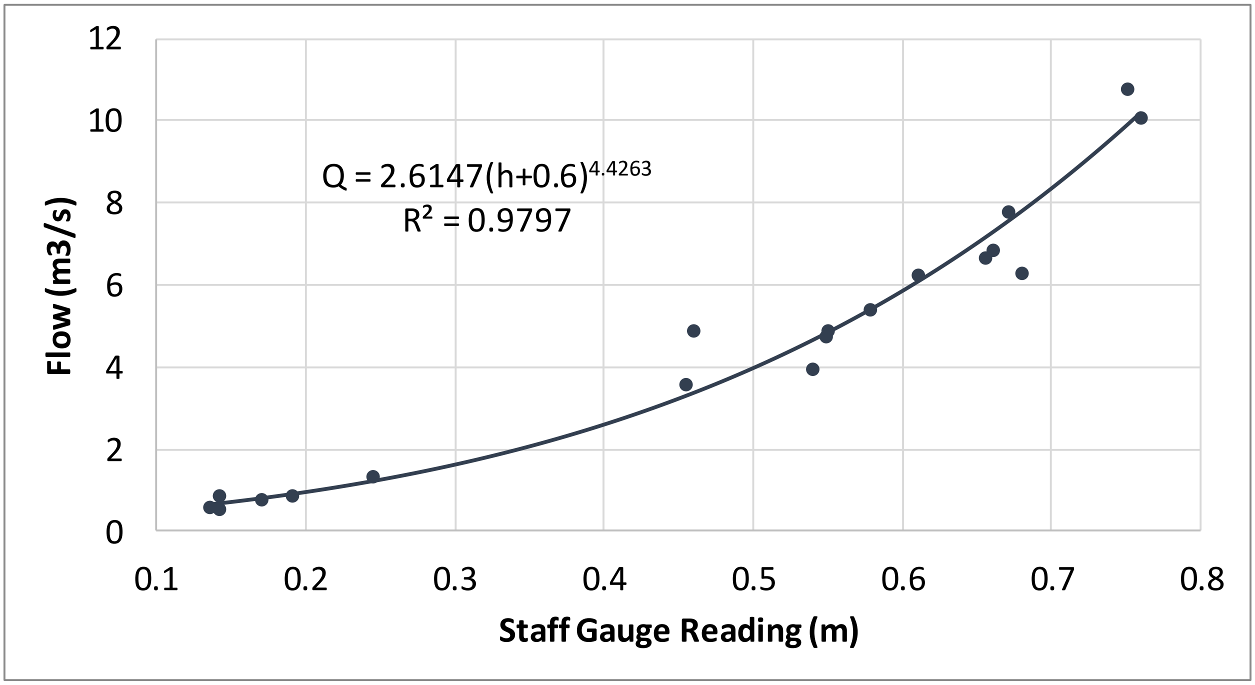

Figure A2.1. Stage-discharge relation for Davis Creek hydrometric station (closed November 2017).

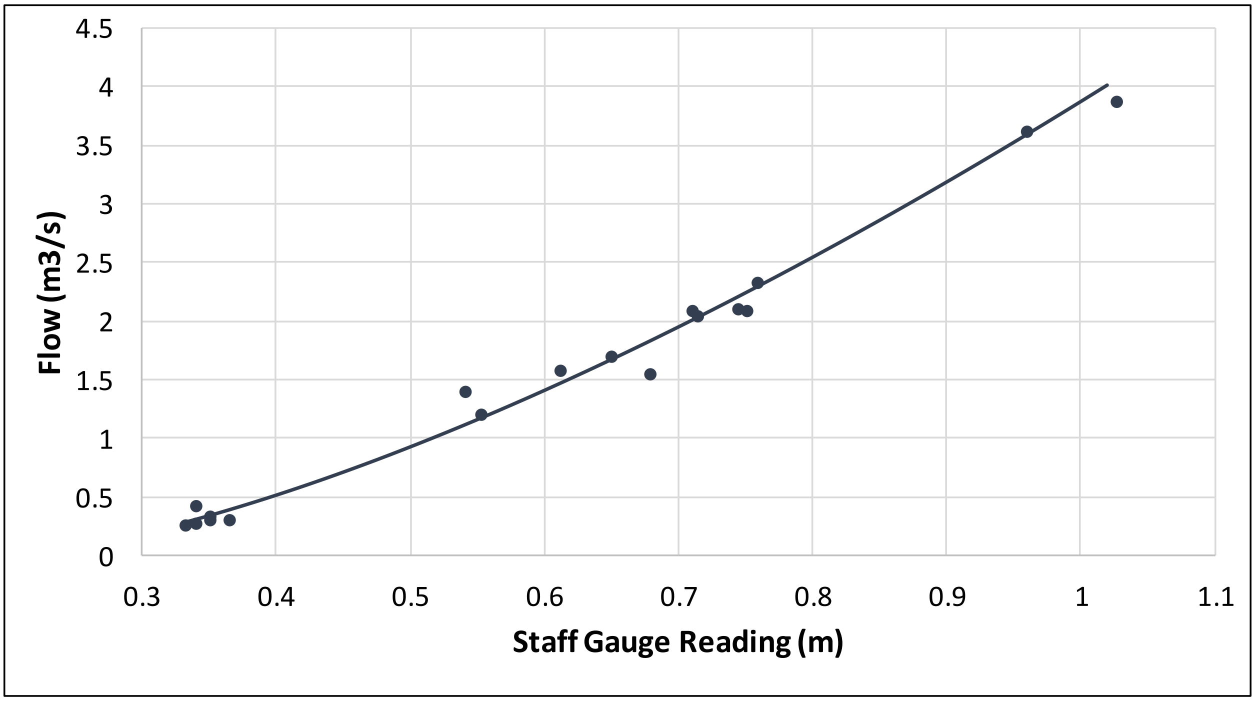

Figure A2.2. Stage-discharge relation for Bjerkness Creek hydrometric station.

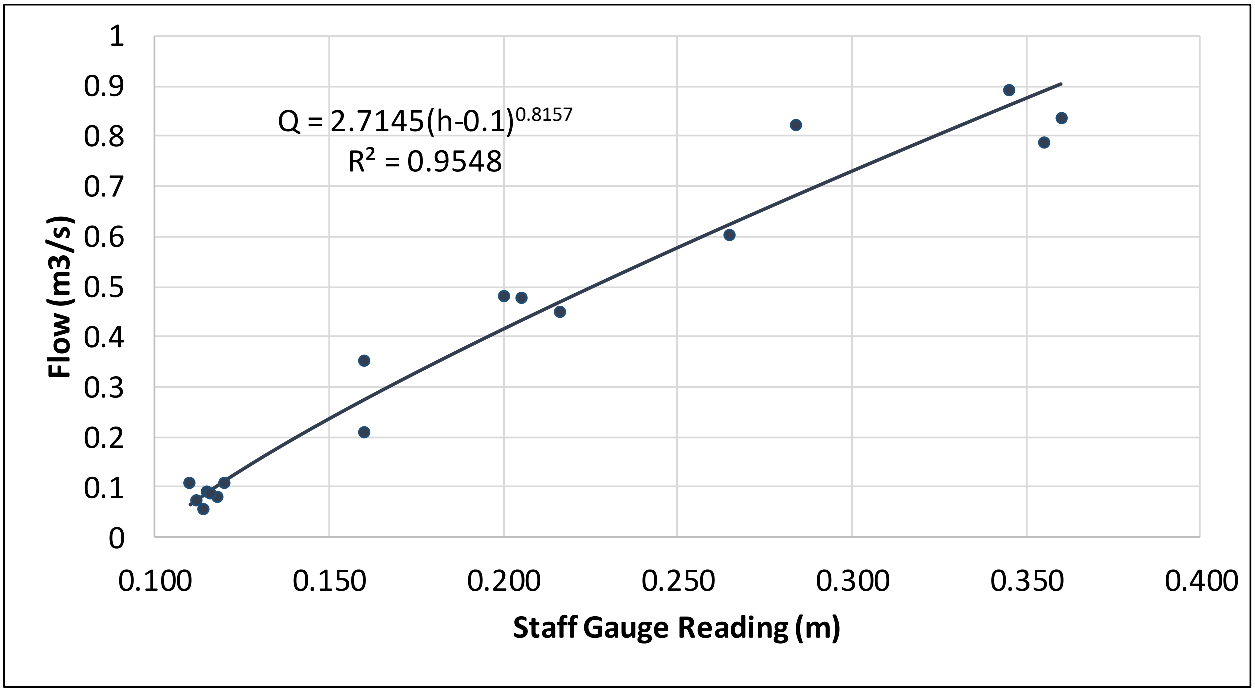

Figure A2.3. Stage-discharge relation for Carlyle Creek hydrometric station.

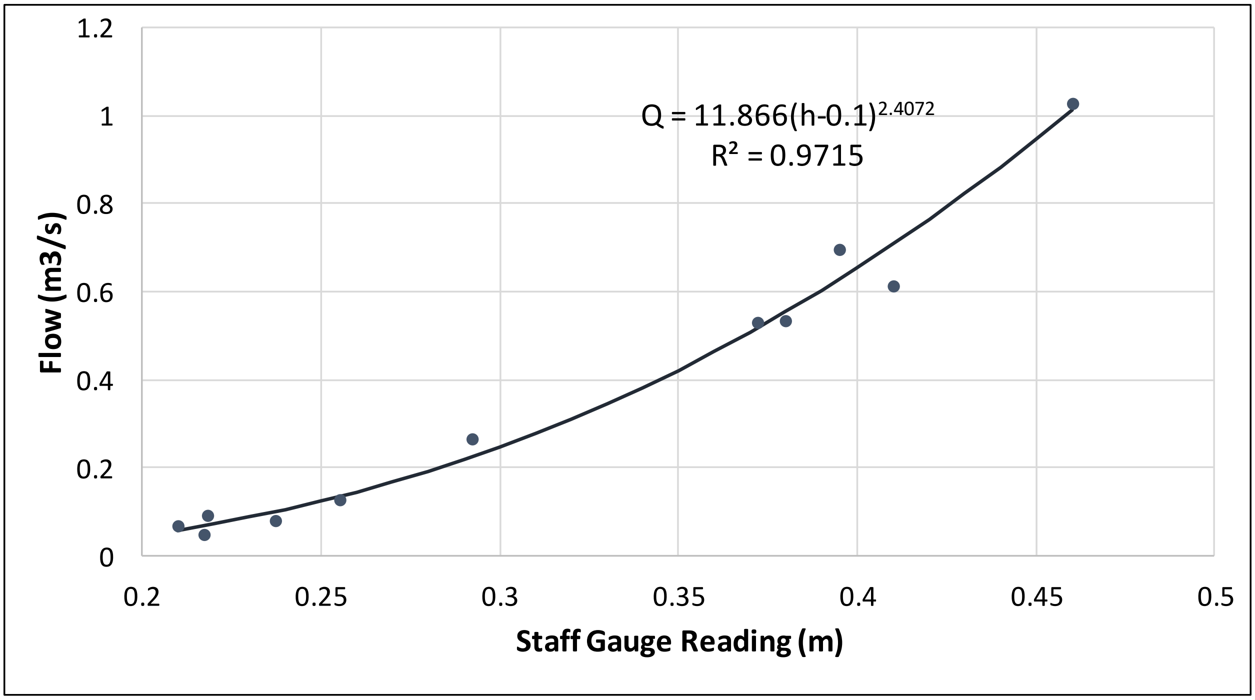

Figure A2.4. Stage-discharge relation for Ben Hur Creek hydrometric station.

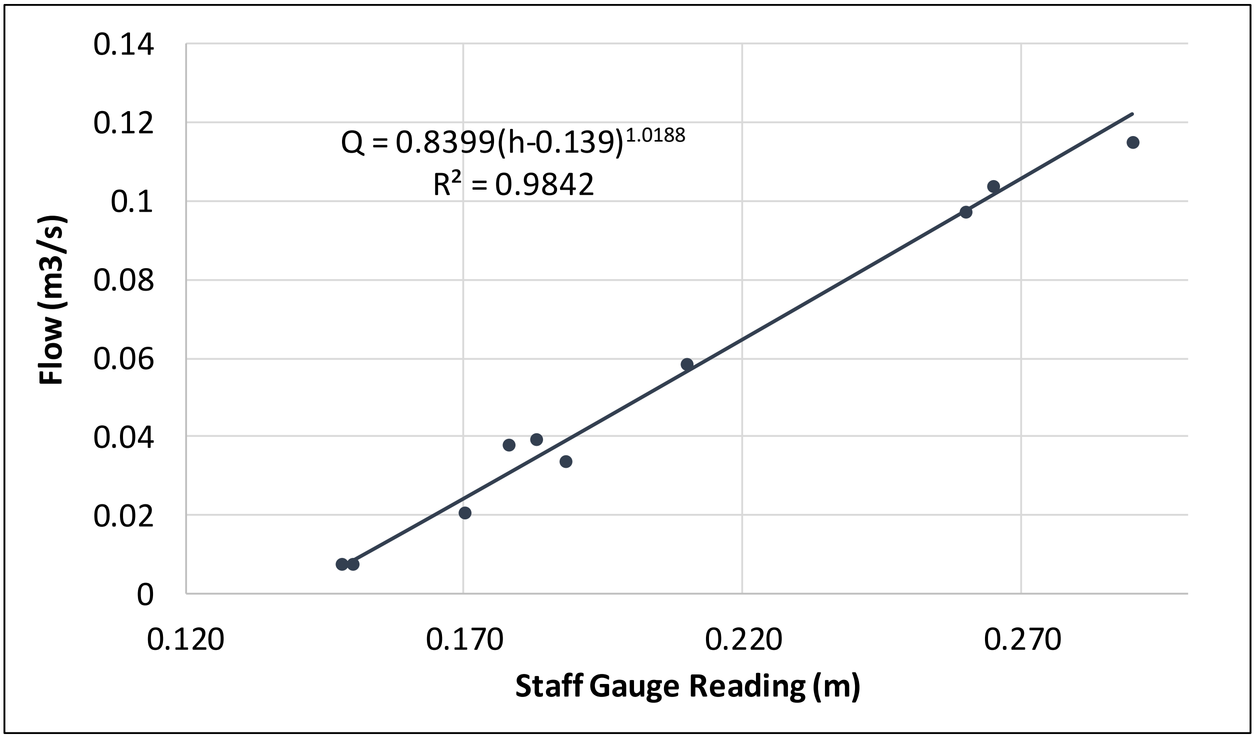

Figure A2.5. Stage-discharge relation for MacDonald hydrometric station.

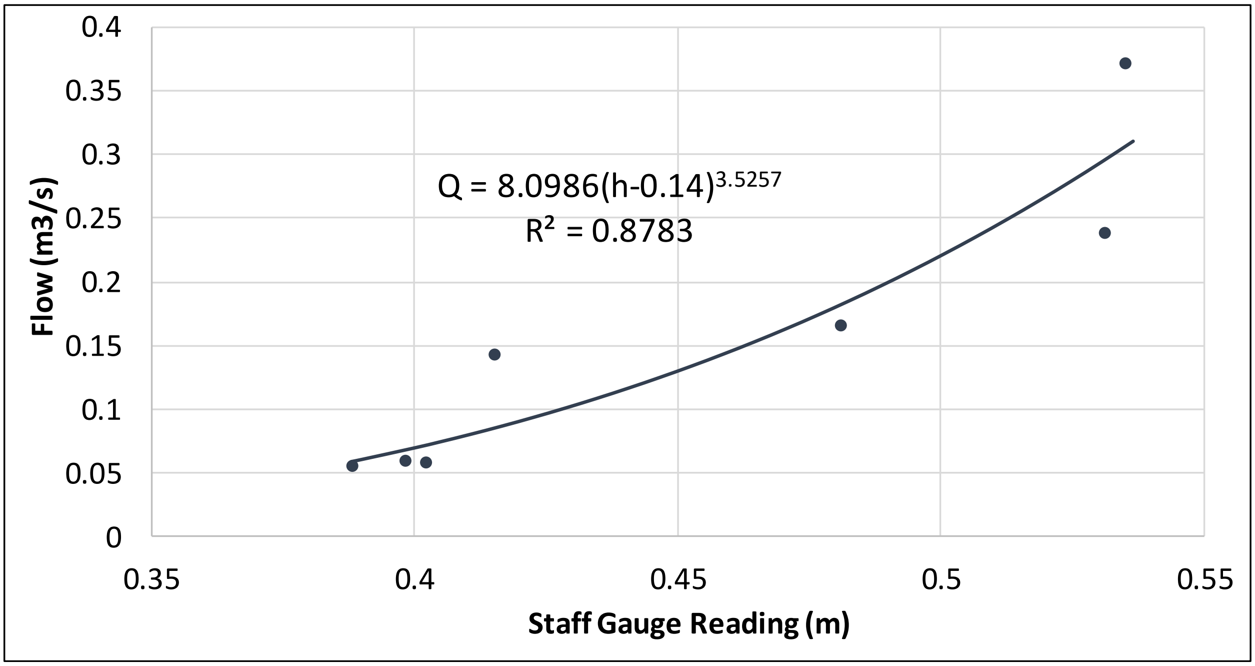

Figure A2.6. Preliminary stage-discharge relation for Gar Creek hydrometric station.

APPENDIX A3. RELATIONS BETWEEN AUTOMATED AND MANUAL WATER LEVEL READINGS

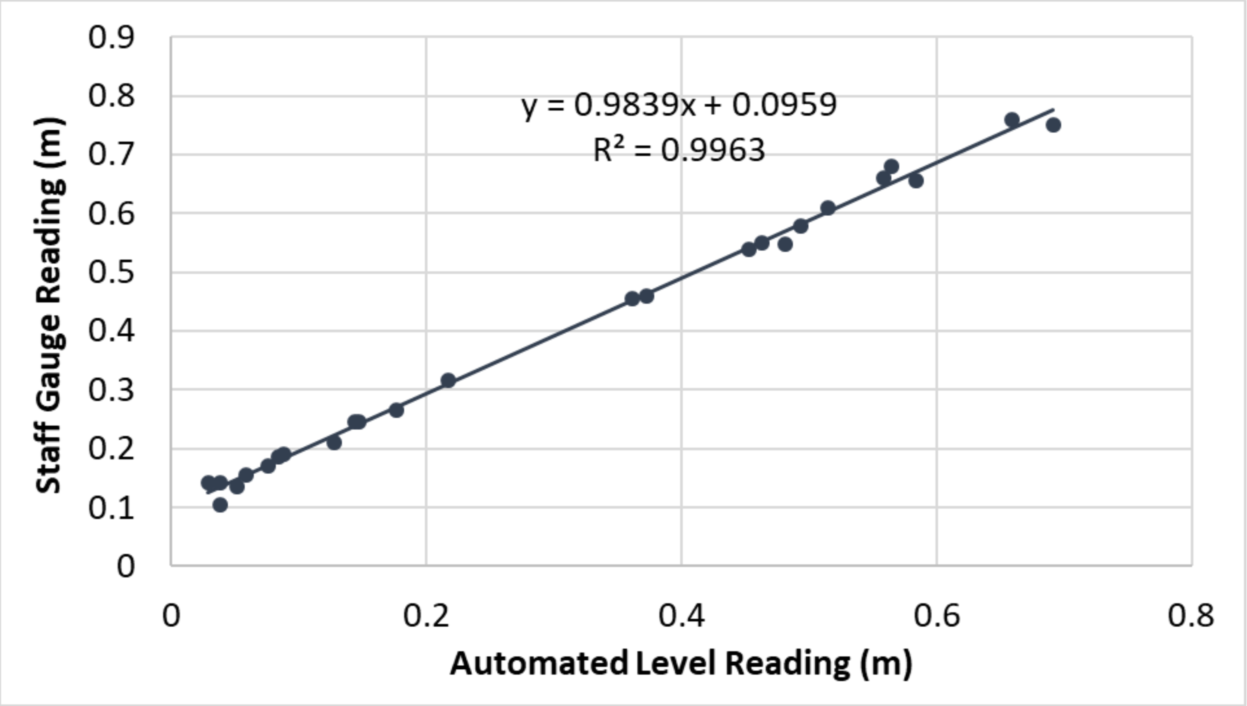

Figure A3.1. Relation between automated (data logger) and manual (staff gauge) level readings at the Davis hydrometric station.

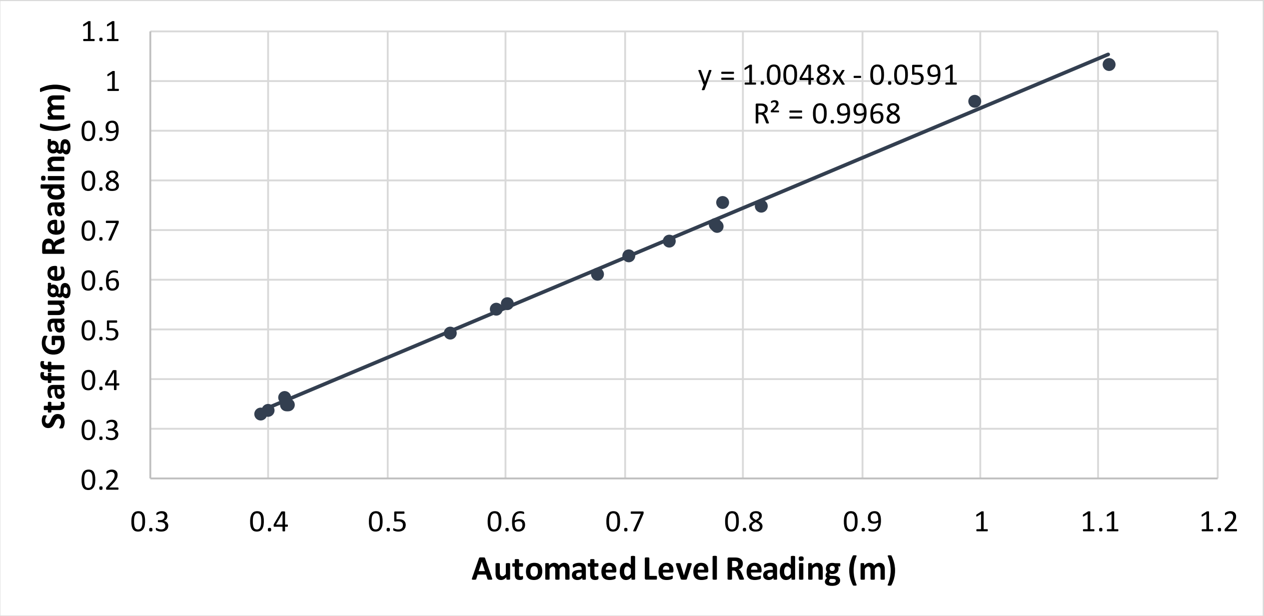

Figure A3.2. Relation between automated (data logger) and manual (staff gauge) level readings at the Bjerkness hydrometric station.

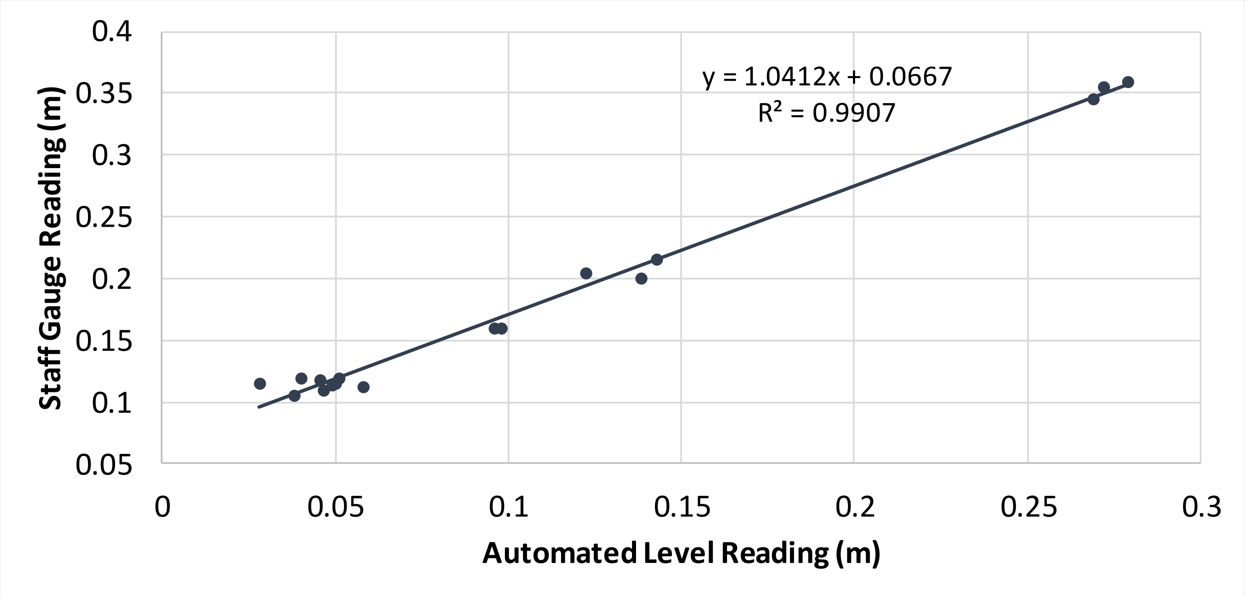

Figure A3.3. **Relation between automated (data logger) and manual (staff gauge) level readings at the Carlyle hydrometric station.**

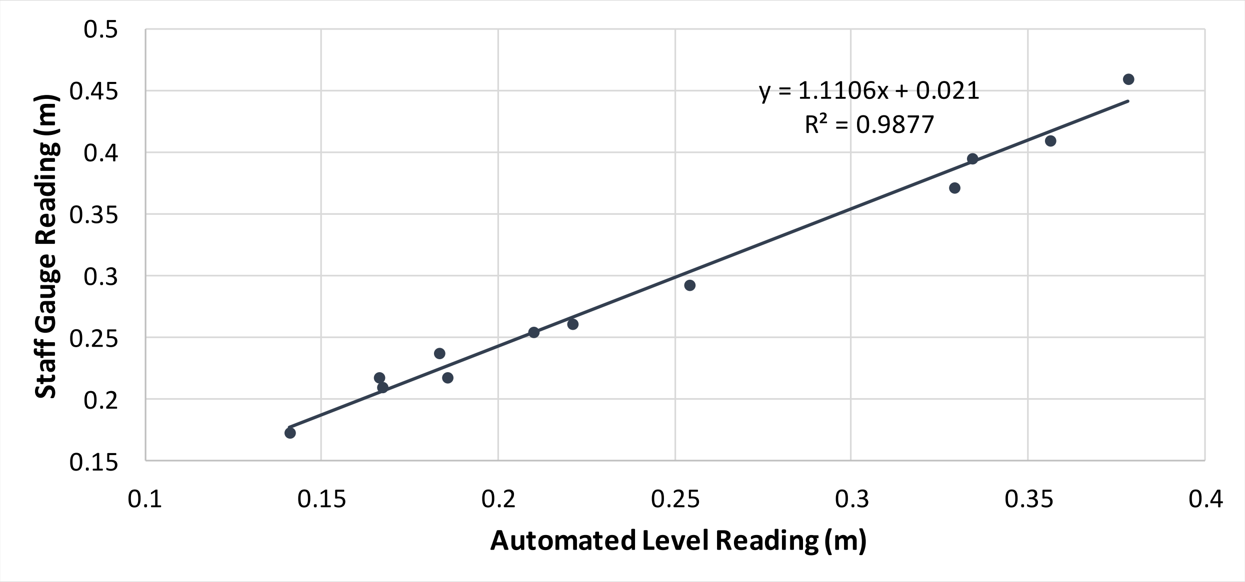

Figure A3.4. **Relation between automated (data logger) and manual (staff gauge) level readings at the Ben Hur hydrometric station.**

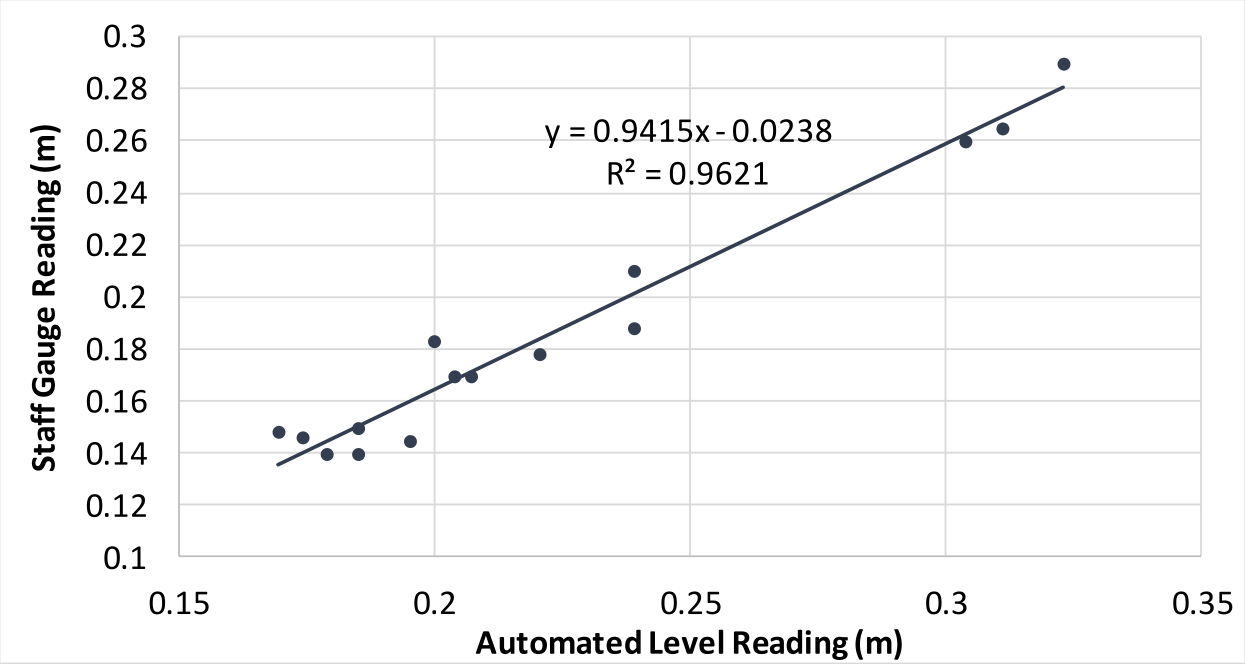

Figure A3.5. Relation between automated (data logger) and manual (staff gauge) level readings at the MacDonald hydrometric station.

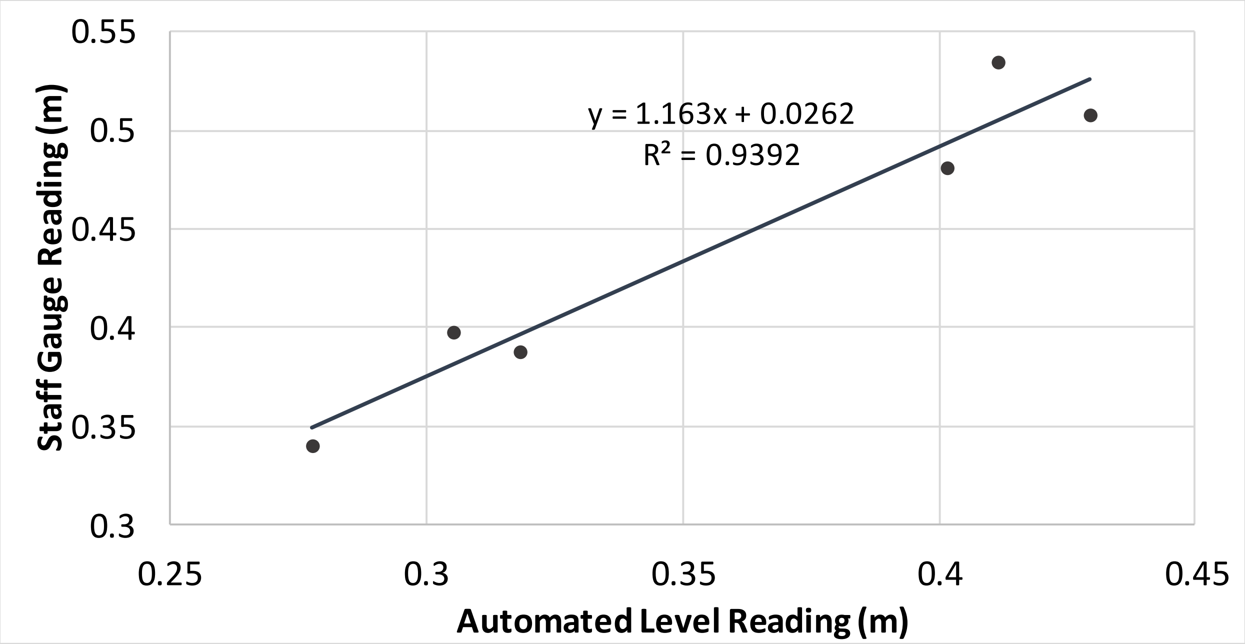

Figure A3.6. Relation between automated (data logger) and manual (staff gauge) level readings at the Gar hydrometric station.

APPENDIX A4. STREAM WATER TEMPERATURE

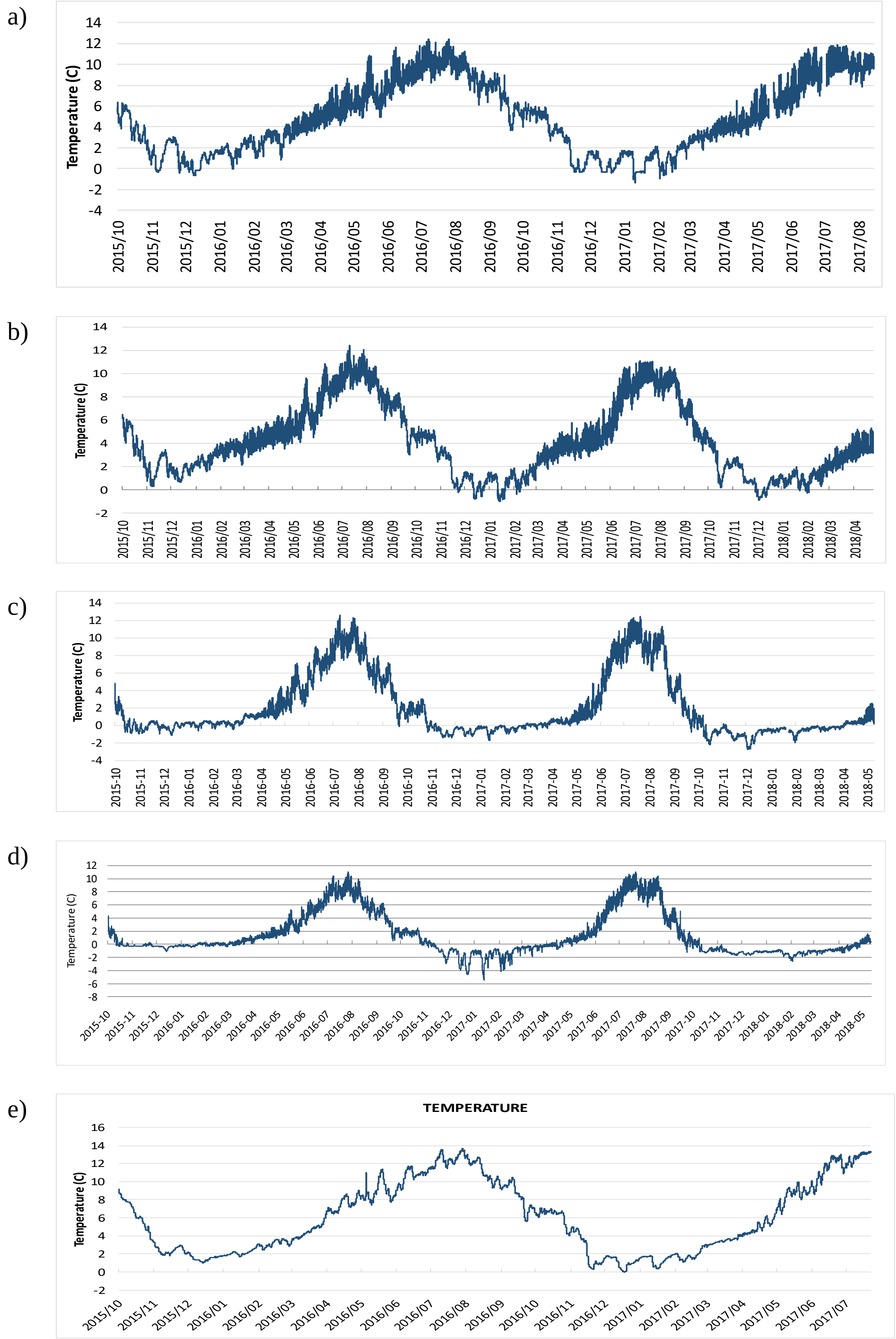

Figure A4.1. Stream temperature measured at five NKLWMP hydrometric stations: a) Davis b) Bjerkness c) Carlyle Creek d) Ben Hur Creek e) MacDonald Creek.

APPENDIX A5. SNOW COURSE DATA

Table A5.1. Mean outcomes for snow depth, snow-water equivalent, and snow density at Kootenay Joe and Lost Ledge snow courses (2016-2018).

Location	Year	Date	Snow Depth (m)	Snow Water Equivalent (cm)	Snow Density (%)
Kootenay Joe	2016	March 1	233	80.6	34.7
Kootenay Joe	2016	May 1	173	88.0	50.8
Kootenay Joe	2016	June 8	57	34.5	62.2
Kootenay Joe	2017	March 5	234	73.4	31.4
Kootenay Joe	2017	April 1	288	98.0	34.1
Kootenay Joe	2017	April 30	279	95.7	34.1
Kootenay Joe	2017	June 2	145	73.4	50.6
Kootenay Joe	2018	March 12	266	77.4	29.0
Kootenay Joe	2018	April 30	266	121.1	45.5
Kootenay Joe	2018	June 4	80	46.2	57.7
Lost Ledge	2017	March 1	257	77.1	30.0
Lost Ledge	2017	April 1	330	116.0	35.2
Lost Ledge	2017	May 2	318	121.0	38.2
Lost Ledge	2017	May 31	191	98.4	51.6
Lost Ledge	2018	January 28	240	70.7	29.5
Lost Ledge	2018	February 28	298	93.2	31.2
Lost Ledge	2018	April 2	316	99.3	31.4
Lost Ledge	2018	April 28	301	150.8	50.1

APPENDIX A6. ANNUAL HYDROMETRIC DATA FROM AGENCY STATIONS WITHIN REPRESENTATIVE AREA

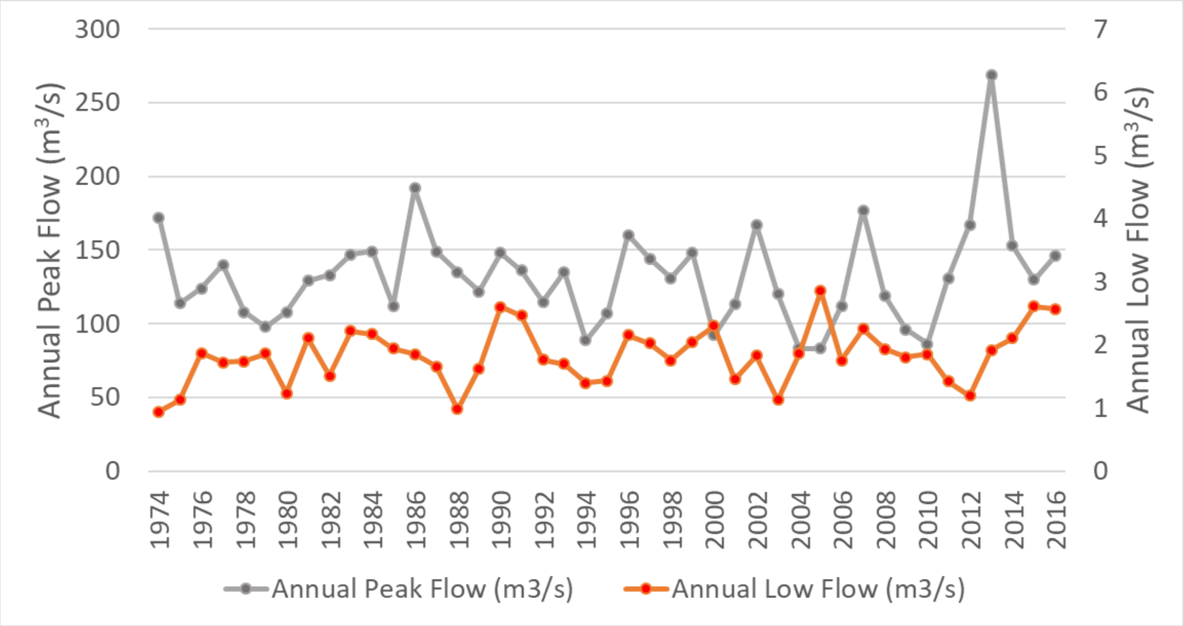

Figure A6.1. Peak-flow and low-flow time-series for Fry Creek below Carney Creek (WSC 08NH130) during period of record.

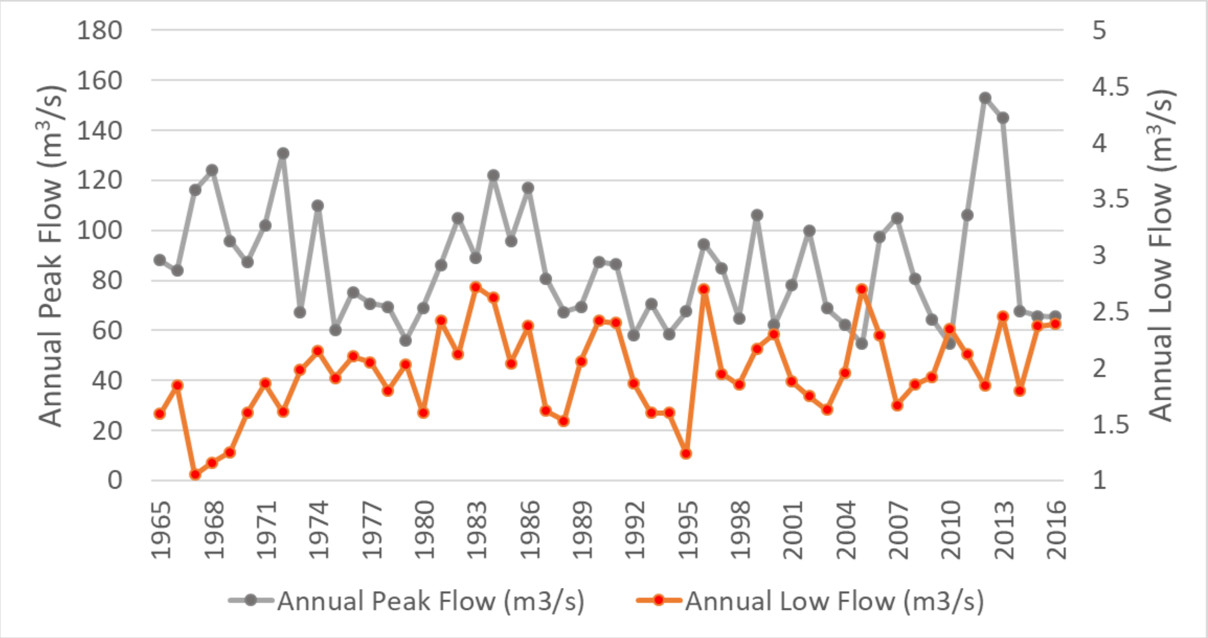

Figure A6.2. Peak-flow and low-flow time-series for Kaslo River below Kemp Creek (WSC 08NH005) during period of record.

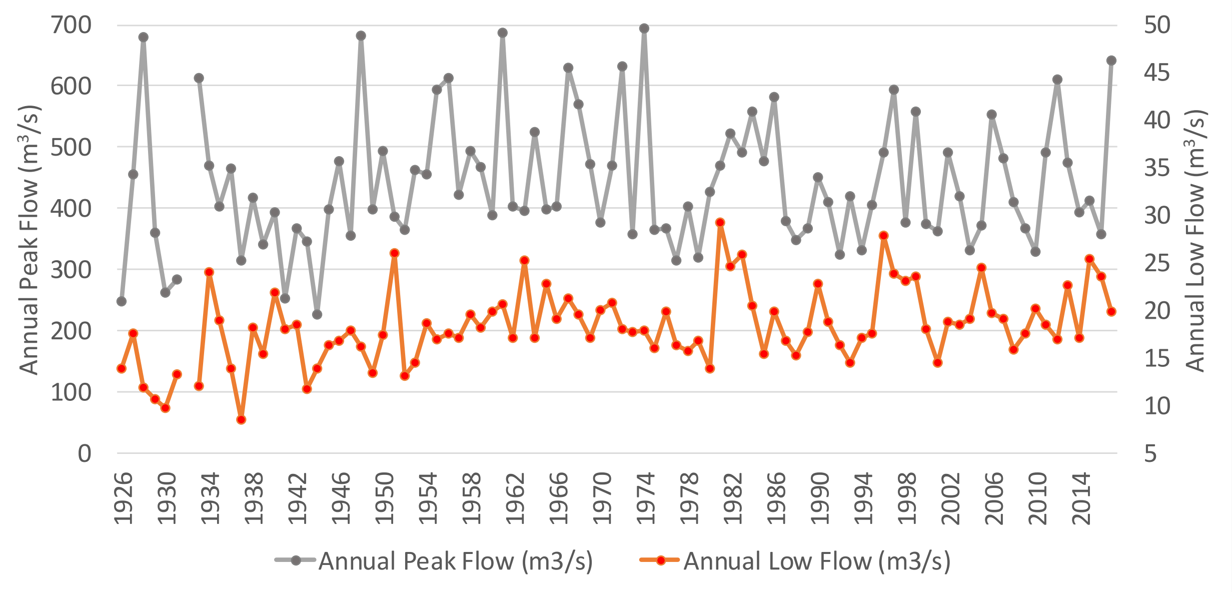

Figure A6.3. Peak-flow and low-flow time-series for Slocan River near Crescent Valley (WSC 08NJ013) during period of record.

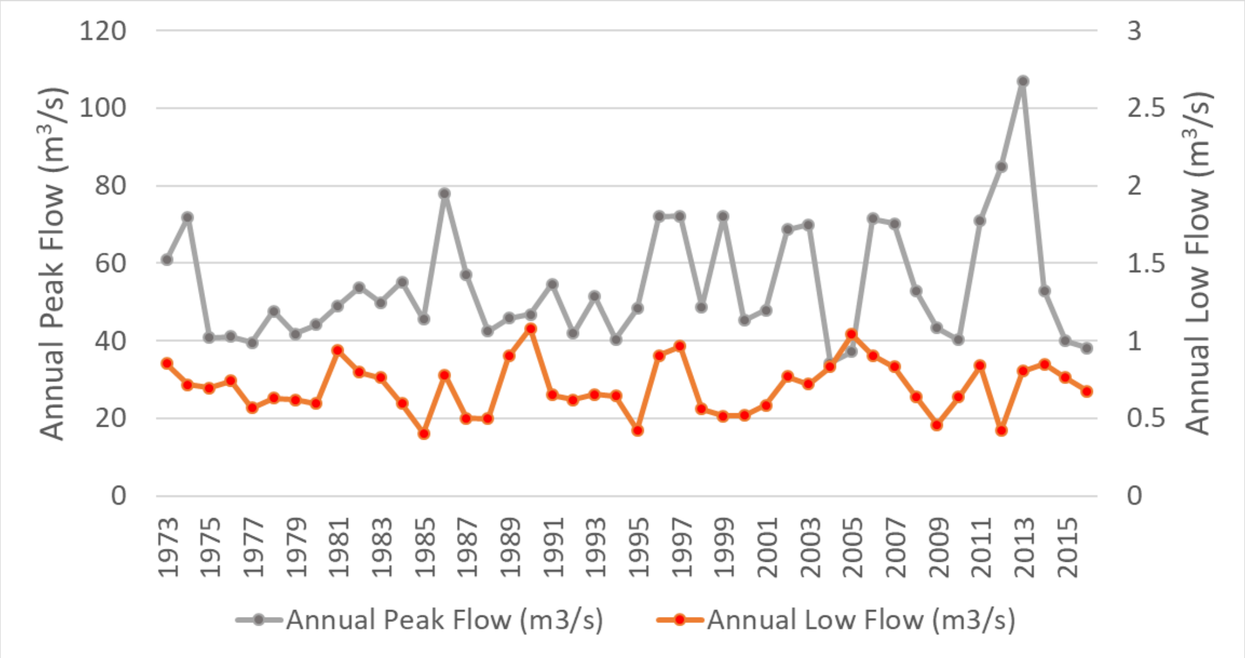

Figure A6.4. Peak-flow and low-flow time-series for St Mary River below Morris Creek (WSC 08NG077) during period of record.

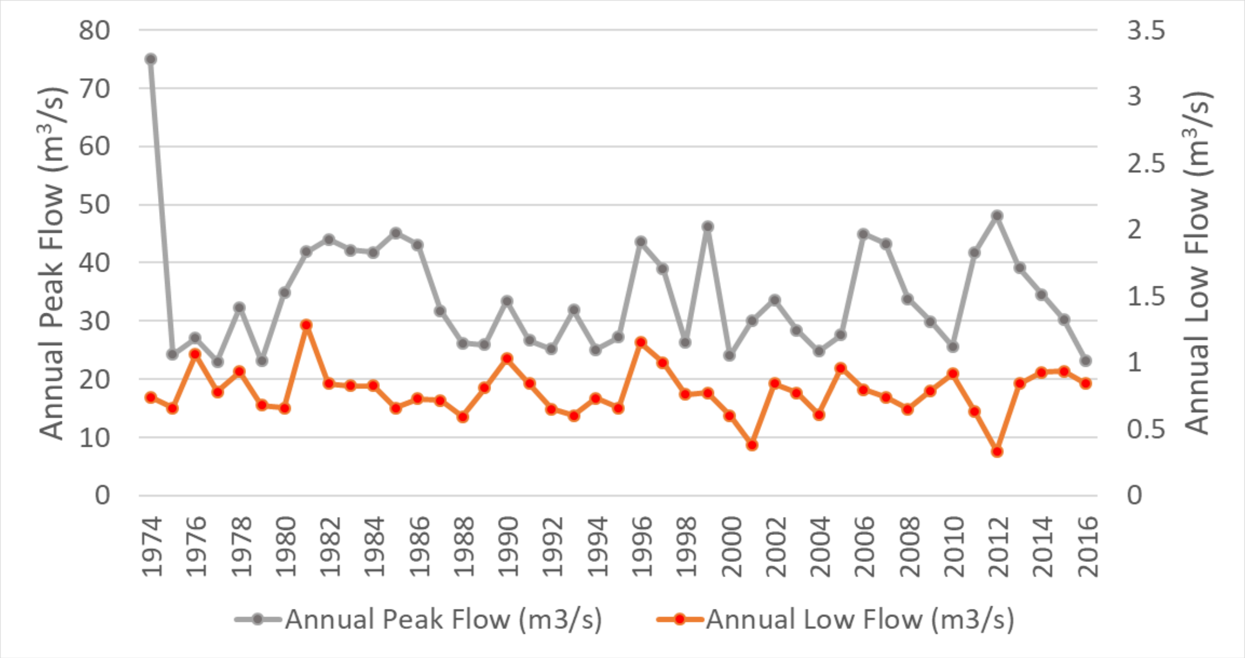

Figure A6.5. Peak-flow and low-flow time-series for Lemon Creek above South Lemon Creek (WSC 08NJ160) during period of record.

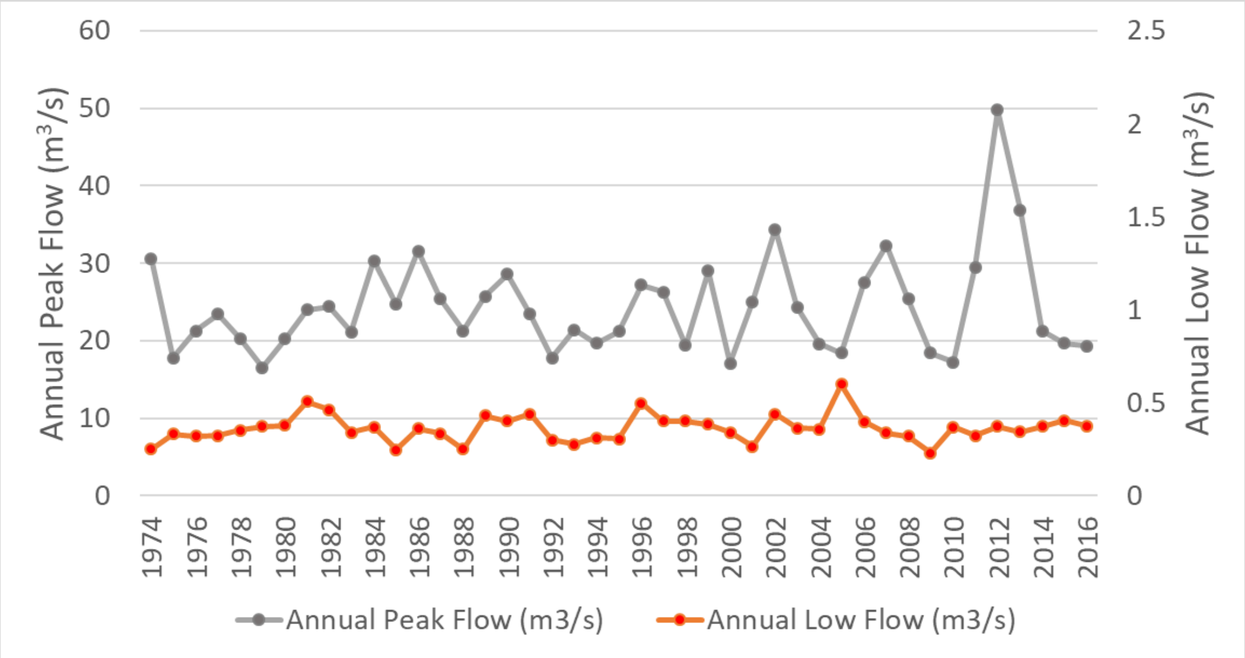

Figure A6.6. Peak-flow and low-flow time-series for Keen Creek below Kyawats Creek (WSC 08NH132) during period of record.