Tracking Climate Impacts on **Vulnerable High Elevation Environments**

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High elevation ecosystems in mountainous regions – often referred to as alpine and subalpine ecosystems – are more vulnerable to climate change than lower elevation ecosystems. Consequently, they are expected to experience climate impacts more rapidly (Minder and Letcher 2017).

Research suggests that small changes in climate can drive large shifts in alpine freshwater systems (Preston et al. 2016). Shorter winters, earlier freshet, and an increase in precipitation as rain versus snow will continue to have an impact on the health and function of alpine ecosystems, and subsequently, the human and biological communities that share these watersheds.

While high and low elevation areas differ in hydrology, biology, and ecosystem pressures, water security efforts require a holistic and integrated view of watersheds. High elevation areas are highly influential on downstream hydrology in the Columbia Basin as they contain the majority of headwaters. Moreover, high elevation areas may even become climate refugia for lower elevation species in the future.

There is an urgency to start collecting data as many high elevation areas in Canada have not been actively monitored. A comprehensive and science-based understanding of these sensitive ecosystems is needed to help fill important data gaps, inform water management and decision making, and support climate change adaptation. It is with this lens that Living Lakes Canada has developed its High Elevation Monitoring Program (HE Monitoring Program).

The HE Monitoring Program aims to collect baseline data and provide insight into how high elevation ecosystems are currently functioning. While some projections about future climate impacts can be made with baseline data, the continuous collection of alpine-specific data over a longer period will increase the accuracy and specificity of these projections.

In 2022, the HE Monitoring Program was piloted in two areas in the West Kootenay region of the Canadian Columbia Basin. A High Elevation Framework (HEF) was developed through considerable consultation with partner hydrologists and biologists, and the Living Lakes Canada's Advisory Board. The HEF outlines the methodologies and protocols required to collect meaningful scientific data in alpine areas. The success of the pilot year has led to an expansion of this project in 2023 (Figure 1).

Figure 1. Heather Shaw completing a bathymetric map survey on Upper Joker Lake from her inflatable Alpacka raft in August 2022.

High elevation monitoring program design

The Canadian Columbia Basin can be divided into ten Hydrologic Regions (HRs). Living Lakes Canada is working to implement a unified and nested monitoring network (known as the Columbia Basin Water Monitoring Framework, or CBWMF) across all ten HRs. As a component of the CBWMF, the HE Monitoring Program feeds into the broader monitoring network.

The data collected through the HE Monitoring Program and the CBWMF are made publicly accessible through the Columbia Basin Water Hub database. The "Water Hub" is a central repository where decision makers, researchers, students, professionals, and the public can access a wide variety of data and information about water in the Canadian Columbia Basin.

The HE Monitoring Program works collaboratively with the CBWMF to identify monitoring sites that will contribute valuable information to the broader project. Water monitoring sites are localized features within a monitoring area, such as a lake and the associated inflow and outflow streams. Where possible, a variety of monitoring sites within an area are selected to capture variability.

In Kokanee Glacier Provincial Park, monitoring sites include lakes that are snow-fed, glacier-fed, and differ in elevation, aspect, depth, and biogeoclimatic (BEC) zones. Collecting data from sites that differ in ecosystem features will generate a broader understanding of climate impacts on the various types of high elevation ecosystems. At each site, biological, physical, and chemical parameters are measured and analyzed, and photo plots are established to track changes at a landscape level. Through the HE Citizen Science Project, an inventory of flora and fauna information is gathered using iNaturalist (https://livinglakescanada.ca/project/high-elevation-monitoring-program/).

Other parameters not directly measured through the HE Monitoring Program, that are key components in understanding high elevation ecosystem health, include: climate, streamflow, snowpack, and glacier mass balance. The HE Monitoring Program tracks climate variability and streamflow parameters through climate and hydrometric stations installed by the CBWMF and in combination with existing climate stations operated by various ministries and other organizations. Snowpack parameters are shared by partnering backcountry lodge owners, and glacier mass balance is collected and published by the World Glacier Monitoring Service.

The HE Monitoring Program data are collected according to the appropriate standards and recognized protocols to ensure that they can be used for analysis, research, and decision-making support. Quality assurance and control are ensured by logging the calibration of equipment, following standardized water sampling protocols, field blanks, and data auditing.

2022 pilot implementation

The 2022 pilot areas included four lakes and two streams. The first area, Kokanee Glacier Provincial Park (KGP), is situated northeast of Nelson, B.C. Selected bodies of water in KGP were identified as a priority by the Integrated Lake Monitoring Framework for British Columbia (Zirnhelt et al. 2018). The park holds historical and cultural significance for Indigenous Peoples and the community of Nelson, and offers recreational activities such as mountaineering, skiing, fishing, and hiking. The second area is located north of Valhalla Provincial Park in the Selkirk Mountains.

Sapphire Lake, Lemon Creek, Tanal Lake, and Upper Joker Lake were selected as monitoring sites within the KGP area, and Shannon Lake and Huss Creek were selected as monitoring locations in the Valhalla/Selkirk area. Bathymetric, temperature, and lake level data were collected at Sapphire, Tanal, and Upper Joker Lake and bathymetric data on Shannon Lake was initiated. Biomonitoring was completed on the lower portion of Lemon Creek and the upper reaches of Huss Creek.

The expansion of the HE Monitoring Program will include the addition of temperature and light loggers, depth profiles, and water samples at each lake site. The program will also establish upper and lower biomonitoring locations at each stream site.

The following methods and results will focus on the data collected at Sapphire, Tanal, and Upper Joker Lake as part of the 2022 pilot implementation. Preliminary data on Shannon Lake, Huss Creek, and Lemon Creek will be available on the Water Hub this upcoming summer (Figure 2).

Methods used in lake data collection

Upper Sapphire Lake is located in the southwest regions of KGP at an elevation of 2,263 m above sea level. The lake is a deep blue sapphire colour as the name suggests and lies within the Interior Mountain-heather Alpine (IMA) biogeoclimatic zone (Government of British Columbia 2022). The lake is predominantly fed by snowmelt and marks the headwaters of Lemon Creek, a large fish-bearing tributary of the Slocan River.

In mid-August 2022, a level logger was installed off the lake's east shore and bathymetric map surveying was initiated. The level logger continuously tracked changes in lake level and temperature at 15-minute intervals from August 15th to October 7th, 2022. Bathymetric surveying was used to create a contoured map of the lake bottom and determine the locations where light and temperature sensors will be installed. Depth profiles will be completed in 2023 and onwards. This methodology applies to all the lakes monitored through the HE Monitoring Program. Site locations were also identified to complete the stream monitoring component of the HEF for 2023.

Tanal Lake sits approximately 500 m below Upper Sapphire Lake at 1,797 m. The dominant surrounding area is characterized by the Engelmann Spruce Subalpine Fir – wet cold (ESSFwc4) biogeoclimatic zone (Government of British Columbia 2022). The lake is predominantly fed by snowmelt and marks the headwaters of Enterprise Creek, another large tributary to Slocan Lake. The monitoring activities carried out at Tanal Lake for the 2022 monitoring season were consistent with those at Upper Sapphire Lake.

Joker Lakes are the only two lakes in KGP that are fed by Kokanee Glacier. Upper Joker Lake is a darker emerald colour, which is a stark contrast to the bright turquoise colour of Lower Joker Lake only 50 m away. The colour difference is due to the glacial stream from

Figure 2. An image of Upper Sapphire Lake in Kokanee Glacier Provincial Park.

Kokanee Glacier feeding mainly into Lower Joker, and only a small portion of the melt entering Upper Joker. Glacial streams carry significant amounts of glacial flour. These white particles reflect blue-green wavelengths and create the bright turquoise colour seen by the naked eye.

In August 2022, a lake level on the east side of Upper Joker Lake was installed as well as a string of temperature and light sensors spaced in 1-m intervals from the lake surface to the lake bottom. The sensors continuously tracked changes in light and temperature from August 11th to September 27th. Due to the technical nature of accessing Upper Joker Lake, monitoring sites will be moved to a more accessible area near Talus Lodge, B.C., in 2023. Two lakes near the lodge share similar characteristics to Upper and Lower Joker Lakes.

Preliminary results

This section outlines the results of the preliminary lake level and temperature data for the HE Monitoring Program pilot collected from Sapphire, Tanal, and Upper Joker Lake. We correlated the data with past 24-hour precipitation and temperature data from the nearby Redfish Creek climate station.

Sapphire Lake expressed the lowest water temperatures ranging from approximately 7º to 11ºC (46.6º to 51ºF). The highest water temperatures for all lakes occurred in August with the lowest temperatures observed in late September to early October.

The largest fluctuations in lake level are correlated with a decrease in water temperature, air temperature, and a precipitation event (Figure 3). The change in water level recorded by the level logger from August to September/October was approximately 10 cm at Sapphire Lake, 12 cm at Tanal Lake, and 20 cm at Upper Joker Lakes (Figure 1).

The graphs in Figure 3 express the relationship between lake level, water temperature, air temperature, and precipitation. While it's too early to identify a baseline condition for these lakes, the study can deduce that there is a strong relationship between the mentioned variables, lake level (quantity), and water temperature (quality). These variables are expected to change year to year due to climate variability. However, long-term monitoring will identify climate trends and large shifts in these variables that are predicted to have a negative impact on these lakes.

Expanded monitoring through collaboration

After a successful pilot implementation, Living Lakes Canada looks forward to expanding the HE Monitoring Program throughout the Canadian Columbia Basin. In 2023, the HE Monitoring Program will see the addition of four lake and ten stream sites.

Living Lakes Canada will continue to collaborate with the Alpine Club of Canada and the Backcountry Lodge of British Columbia Association to carry out monitoring efforts in 2023.

Preliminary data from the pilot project will be available on the Columbia Basin Water Hub in the summer of 2023. In the short term, the data collected help us to

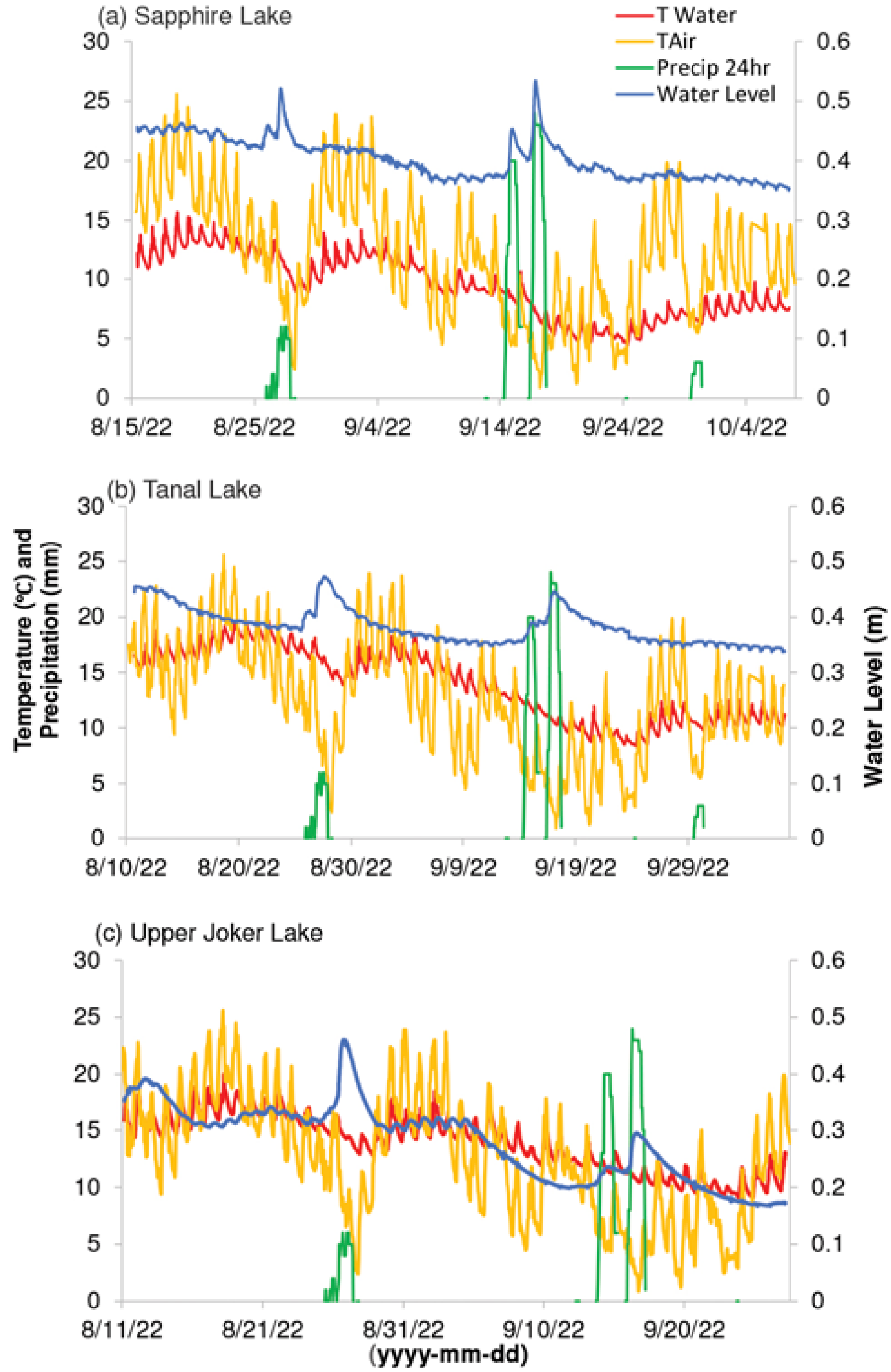

Figure 3. Values in lake level and water temperature (T water) for three high elevation lakes within the Canadian Columbia Basin, correlated with air temperature (T air), and past 24-hour precipitation data from the Redfish Creek, B.C., climate station from August-October 2022.

understand the current state of these lakes and to identify strategies for climate change adaptation and watershed security. Regional modeling will improve as more data are acquired year to year.

Given the hydrological, biological, and cultural importance of these mountainous ecosystems and their particular vulnerability to climate impacts, there is exceptional value in a continuous, long-term study. Such a study will provide the data required to more accurately model climate trends and events, which in turn can inform climate adaptation planning.

The HE Monitoring Program, in conjunction with the CBWMF program, will support these efforts towards water security.

Suggested references

Government of British Columbia. 2022. Biogeoclimatic maps. Available at: https://www.for.gov.bc.ca/hre/becweb/resources/maps/FieldMaps.html.

Minder, J. and Letcher, T. 2017. The Character and causes of elevation-dependent warming in high-resolution simulations of rocky mountain climate change. *J. Clim.*, 31: 2093-2113.

Preston, D., N. Caine, D. McKnight, M. Williams, K. Hell, M. Miller, S. Hart and P. Johnson. 2016. Climate regulates alpine lake ice cover phenology and aquatic ecosystem structure. *Geophys. Res. Lett.*, 43: 5353-5360.

Zirnhelt, N., R. Nordin, D. Roumieu, H. Lescheid and K. Hartwig. 2018. An Integrated Lake Monitoring Framework for British Columbia. Available at: https://www.bclss.org/wp-content/uploads/2020/11/ILMF-Final-Report.pdf.

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