Climate Indicators Methods Documentation

Acronyms

AHCCD - Adjusted *Homogenized Climate Change Data*

ECCC - *Environment and Climate Change Canada*

WSC – Water Survey of Canada

CFN – Critical Flow Needs

Contents

Purpose: This document records the methods and decisions made during the process of creating climate indicators for the Okanagan. The indicators are based on observed historical data and do not include projections or modelled data.

Inspired by the findings of the *2020 Climate Projections for the Okanagan Region Report*,[*] this project aims to identify to what extent Okanagan has experienced climate change, and to monitor changes going forward. This work was achieved by creating a set of indicators that each monitored a specific climate variable, such as daily mean temperature or the timing of the freshet into Okanagan Lake. Once in place, these indicators will be used to identify changes on an ongoing basis. While there are constraints and limitations based on the available data, a robust set of indicators was developed. This selection of indicators is not comprehensive, but it covers and broad scope of variables, and looks at shifts in average conditions and extreme events across all seasons and three important locations. With the observed extreme events in recent years[1] [2] [3] understanding and tracking changes in the climate extremely important.

Indicator Selection

Potential indicators were identified by:

- Identifying potential indicators based on data availability.
- Replicating the indicators used in the *Climate Projections for the Okanagan Region Report*[4] *where* possible.
- Identifying commonly used indicators from
  - Government Ministries such as B.C. Ministry of Environment[5], Environment and Climate Change Canada[6], the Environmental Protection Agency[7] [8], the United States Geological Survey[9], and the Water Survey of Canada[10].
  - Commonly used indicators from relevant organizations such as the Climate Data[11], the Intergovernmental Panel on Climate Change, and Atlas of Canada[12].
  - Peer-reviewed articles[13] [14].
- Speaking with local experts and knowledge holders.

The main criteria for indicator selection:

Once desired indicators were identified, we evaluated each based on the criteria from the World Meteorological Organization[15] and additional criteria relevant to this project:

1. ***Data Availability*** –is typically the main limitation for creating an indicator, especially at relevant temporal and spatial scales. Therefore, each indicator requires a high-quality, accessible, and long-term data source. To be included, data had to:
    - Have continuous records with minimal gaps.
    - Be at a relevant temporal resolution, in most cases daily.
    - Be at least 30 years long to capture natural variability.
    - Produced by a trusted source with known methods.
    - Be supported by a long-term stable entity to allow for ongoing use.

2. ***Replicability*** – the indicator could be used for multiple areas across the Okanagan and was not highly specific to one location.

[*] Pinna (2020). *Climate Projections for the Okanagan Region.* https://www.rdos.bc.ca/assets/PLANNING/AreaX/2020/ClimateProjections/FinalReport.pdf

3. ***Traceability*** – indicator could be calculated using known methods and accessible and verifiable data.

4. ***Interpretability*** - the indicator was easy to interpret. Some indicators are interesting but challenging to communicate to people without expert knowledge. However, separating the signal from the noise with climate trends is important, so some statistical methods were necessary.

5. ***Diversity/Representatives*** – as a package, the indicators should capture as many effects of climate change as possible. To present a diverse set, indicators were selected considering:
   - ***Climate Variables*** - rather than focus on one variable, such as precipitation, we identified a number of different variables, including stream flow, lake levels, temperature, and precipitation. Socioeconomic and ecological indicators were not within project this project's scope; however, they remain essential to understanding the effects of climate change on communities.
   - ***Timescale*** – the goal was to include more than just annual averages as indicators. Therefore, we also selected indicators that targeted different timescales or could be used on several timescales (e.g., weekly or seasonal).
   - ***Extremes and Averages*** - climate change is—and will continue to—change both the normal conditions, such as average temperature, and extreme events. It was important to include indicators designed to detect both types of shifts.

6. ***General Applicability*** – some indicators only have niche applicability. This project focused on prominent general trends using indicators that could be useful to many user groups.

7. ***Timeless*** – the indicator can be calculated at least annually and be frequently updated to allow for ongoing use.

Key Terms

Data Range – The range is the timeframe the indicator covers. The indicator starts when the data collection begins, and the last year is the last fully completed calendar year. Therefore, the current year included in a given indicator, but will be after the year is complete.

Baseline / Historical Average – The baseline is the period used as a reference point to define "normal" conditions. The indicator then highlights changes or deviations from those normal conditions. To account for natural variation in climate, a baseline must be calculated **using at least 30 years of data.** Although anthropogenic – human-caused - climate change began in the 1850s, the changes began accelerating in the 1970s[16]. Therefore, to make it easier to detect changes in the indicator from the baseline should be begore the 1970s. However, some locations do not have data that goes back past the 1950s. Furthermore, it was also necessary to balance data quality and the need for a constant date range across locations. Thus, the project used the following baselines:

- **1951 to 1980** for temperature, precipitation, and Okanagan Lake-level indicators.
- **1971 to 2000** for streamflow indicators.

Since the climate change signal is present in the baselines - especially for the hydrological indicators – trends reported here may be conservative (i.e., changes to climate may be greater than suggested).

Year - For data where a whole year is considered, the indicator is calculated using data from the same calendar year starting in January and ending in December. For example, January 1, 2023, to December 31, 2023. ***Seasons*** - In the case that an indicator is displayed for all seasons, the meteorological definitions of those seasons are used where winter is DJF (December, January, and February), spring is MAM (March, April, and May), summer is JJA (June, July, and August), and fall is SON (September, October, and November). In this case, winter starts in December of the preceding year, so in that case, winter 2023 would be made up of December 2022, January 2023, and February 2023.

30-year Rolling Average – a 30-year rolling average is used to detect long-term trends. This is done by taking the average of the 30 preceding years. For example, 1930 is the average of 1900 to 1929. With each new year, the window shifts to the right by one.

Late Season – For hydrology, some indicators are reported for the year's second half to understand low flow conditions better. For example, July 2023 to December 2023.

Indicators Data

Spatial Data Range

The indicators were created using observed data (i.e., data collected at specific weather stations), so the spatial distribution was dictated by data availability. Here, we report climate indicators for the cities of Kelowna, Penticton, and Vernon. Hydrological data is reported for specific unregulated streams, Mission Creek, and Okanagan Lake.

Temporal Data Range

Depending on the indicator, some can be created either annually and/or seasonally. Data is only presented for full years (i.e., 2023 data will not be added until the year ends). The range of start dates are based on the data available from specific locations. Most indicators are calculated from daily data, and then aggregated into months, seasons, or years.

Climate Data - Precipitation and Temperature

Temperature and precipitation data came from ECCC metrological stations. Climate data stations were selected based on the following criteria.

a) The station is still in operation, allowing indicators to be updated.
b) There has been at least 30 years of continuous daily data.

To provide the best data quality for temperature and precipitation indicators, the Adjusted *Homogenized Climate Change Data* (AHCCD)[17] daily from *Environment and Climate Change Canada* (ECCC)[18] was used to fill in the period between when the AHCCD data ends and the present. Daily ECCC data was downloaded using the weathercan package in R[19]. These data are of higher quality than raw ECCC data because they have been corrected to account for changes in methodology and station locations over time. The data is available at a daily resolution. The list of sites and stations used can be seen in Table 1.

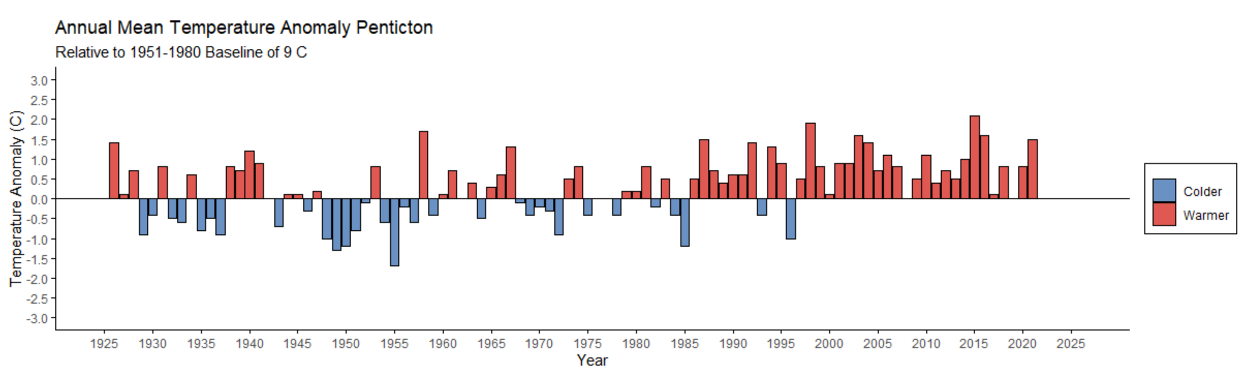
Some critical notes on the AHCCD data set

- **The currently available AHCCD dataset ends in 2021, so the remaining years were filled with raw daily ECCC data.** Where possible, this data came from the same station as the AHCCD data. That was sometimes impossible, and a new station next to the old one was used (Table 1 and Table 2). In the case the same station could not be used, the closest active ECCC metrological station was used. We intend to replace the raw ECCC data with the updated AHCCD data as it becomes available.

- A city's temperature and precipitation data may come from the same station or two separate stations, depending on site-specific conditions (Table 2).

- **To address data quality issues, we only used climate data collected after 1915.** The early temperature record, when reviewed, had large differences between the raw data and the corrected (AHCCD). Several years shifted from being cooler than normal to much warmer than normal. However, later in the record, the two data sets matched better. After consulting with experts at ECCC, no, the variation is possibly an issue with how the AHCCD correction was applied or because the weather stations moved multiple times during the data range, and a correction factor worked at one location better than another. For these reasons, we set the earliest start date to 1915, where available. However, nearly 100 years of daily temperature data is available even with this stipulation.

  For daily temperature indicators, Kelowna 2005 was interpolated due to data quality issues. Typically, Vernon, Kelowna, and Penticton—geographically quite close—had the same general temperature trends. However, this was not the case in 2005 (Figure 1). The 2005 temperature values in Kelowna were very cold, which was not seen in any other station. Furthermore, 2005 was when one of the weather stations in Kelowna moved, which may have affected the AHCCD data. For these reasons, 2005 was replaced by interpolating daily temperature values using the Vernon data set. This was done by comparing the daily temperatures in Vernon and Kelowna every day for ten years before and ten years after 2005. The average difference for each day of the year was calculated from the 20 years, and those were added to the daily temperature data for Vernon to estimate the daily temperatures in Kelowna. This was done individually for mean, minimum, and maximum temperatures.



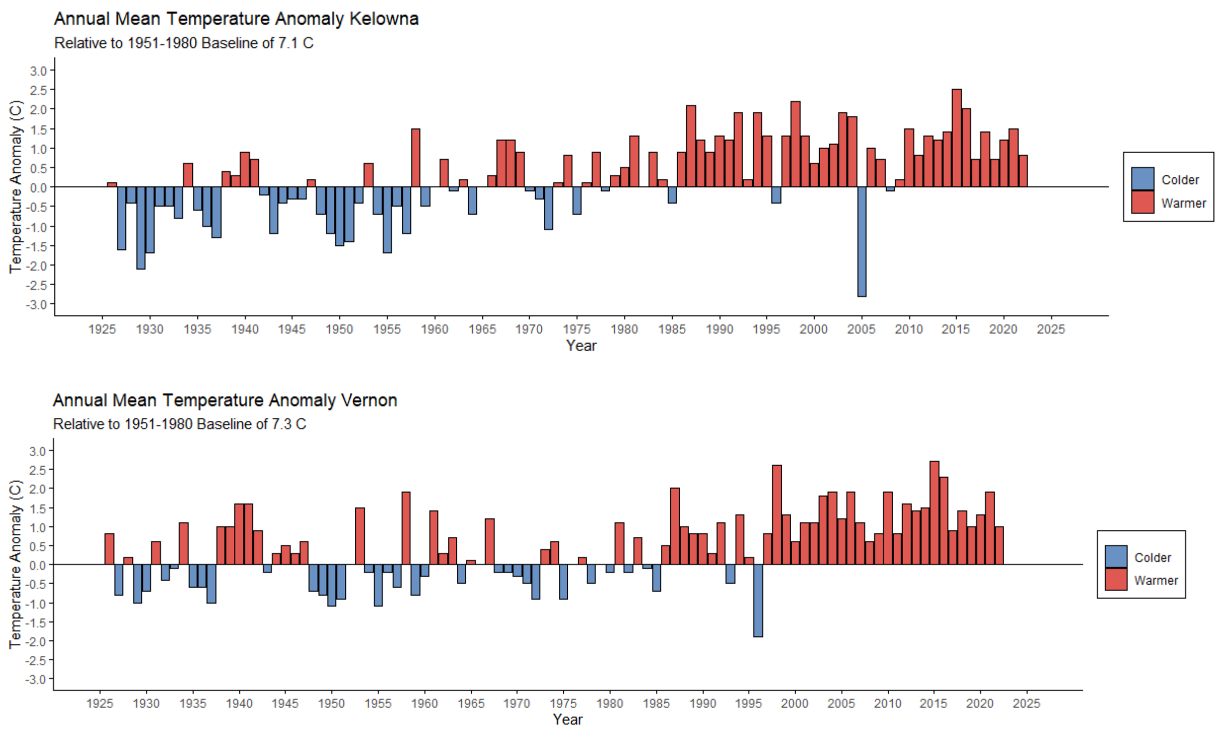


Figure 1: Average temperature anomalies in the Okanagan. Note 2005, where Kelowna has an extreme negative anomaly while the other cities do not, unlike other years where the cities are consistent.

- **For precipitation indicators, both Penticton and Veron had a year with a lot of missing data, and due to a large number of missing precipitation values, those years were removed. For Vernon this was 2010 and 2021 for Penticton (Figure 2).** This was because, in both cases, there were several months of missing data, and attempting to use the remaining data to calculate an indicator would have resulted in a bias toward dry conditions for that year. The data was not interpolated because, unlike temperature, precipitation is much more regional, and there was not a consistent trend across locations.

Figure 2: Missing precipitation data by year.

- For snow data, all AHCCD sites and most of the raw ECCC data did not have a record of the amount of snow that fell. Instead the data only recorded the amount of precipitation that fell each day regardless of if it fell as rain or snow. Therefore, temperature and precipitation data were used to create a form of snow data by assuming precipitation that occurred when the temperature was below 0˚C was snow.

Table 1 shows the locations in the Okanagan with AHCCD data and the data's start and end dates. Table 2 shows the stations that were used to infill the climate data. These are the same sites that will be used to update the climate data moving forward. However, as is apparent in Table 2, while there were 7 locations with AHCCD data (i.e., Okanagan Central, Osoyoos, Vernon, Oliver, Kelowna, Penticton, and Armstrong), most of those sites were not used for the final indicators report because there was no weather station precent to update them moving forward. **Therefore, the final sites we chose were Kelowna, Vernon, and Penticton.**

Table 1 Adjusted Homogenized Climate Change Data (Climate Data, 2023b) station identification and temporal range for temperature and precipitation data. Due to anomalies in the early temperature record, most indicators only use data from 1915 to avoid using data with calibration errors.*

Adjusted Homogenized Canadian Climate Data						
	Temperature*			Precipitation		
Location	**Station ID**	**Start Date**	**End Date**	**Station ID**	**Start Date**	**End Date**
Okanagan Central	1125700	1926-01-01	2021-12-31	1125700	1925-03-01	2017-12-31
Osoyoos	1125852	1954-04-01	2021-12-31	1125865	1954-04-01	2009-09-15
Vernon	1128582	1900-04-01	2021-12-31	1128553	1900-05-01	2015-06-30
Oliver	1125760	1938-06-01	2008-10-22	1125766	1924-01-01	2017-12-31
Kelowna	1123939	1900-01-01	2021-12-31	1123993	1900-01-01	2014-04-06
Penticton	1126146	1907-04-01	2021-12-31	1126150	1907-04-01	2012-05-09
Armstrong	1160483	1913-03-01	2021-12-31	1160483	1912-01-01	1998-12-31

Table 2 Raw Environment and Climate Change Data, (2023) station identification and temporal range for temperature and precipitation data. This is the data used to fill in climate variables moving forward.

Raw Environment and Climate Change Canada Data				
	Temperature	**Precipitation**		
Location	**Station ID**	**Station ID**	Notes	**Used?**
Okanagan Central	1125700	1125700	No station information past 2022	NO
Osoyoos	1125852	NA	No station or precipitation past 2009	NO
Vernon	1128582	1128582	No snow data. 2010 precipitation data removed seemed to be an anomaly; many NA values that year	Yes
Oliver	1125766	1125766	No station information past 2022	NO
Kelowna	1123939	1123939	The end date for the min temp was 2021-04-09, but I was able to use ECCC data to fill it in. No data for snow data. 2005 temperature data removed as it seemed to be an anomaly	Yes
Penticton	1126146	1126146	2021 precipitation data removed seemed to be an anomaly; many NA values that year	Yes

Hydrological Data - Streamflow

Hydrological indicators use discharge data from streamflow measurement stations. The hydrological stations were selected based on the following criteria.

- The station is still in operation, allowing indicators to be updated.
- There were at least 30 years of continuous daily data.
- The station provided daily discharge data (m^3/s).
- With the exception of Mission Creek, streamflow was for an unregulated stream.

Water Survey of Canada[20] stations were used for this analysis, as they typically have the longest records, the methods are consistent across all sites, and the data are easy to access. Table 3 show the list of all Water Survey of Canada Stations in the Okanagan that had a minimum of 30 years of data. Unregulated streams were used for the dashboard as they better represent the natural conditions, and the influence of climate change is more explicit. The extended list of stations is provided for background. The data was downloaded into R using tidyhydat[21].

The hydrological stations do not have as long a record as there is for climate data. Most consistent records for natural unregulated streams start in the 1970s and 1980s. Therefore, we used the baseline period of **1971 to 2000**.

Table 3 Streamflow (m^3/s) station identification (Albers, 2017a; Water Survey of Canada, 2023).

Discharge Data Natural Streams			
Station Name	**Station**	**Start Date**	**Notes**
Vance Creek Below Deafies Creek	08LC040	1978-05-31	Record too short
Siwash Creek Near Princeton	08NL039	1985-01-01	Record too short
Camp Creek At Mouth Near Thirsk	08NM134	1969-01-01	
Vaseux Creek Above Solco Creek	08NM171	1970-10-15	
Greata Creek Near The Mouth	08NM173	1970-09-30	
Whiteman Creek Above Bouleau Creek	08NM174	1971-01-01	
Forty-One Creek Near Penticton	08NM241	1983-11-01	Record too short
Dennis Creek Near 1780 Metre Contour	08NM242	1985-01-01	Record too short
Station Name	**Station**	**Start Date**	**Notes**
Mission Creek Near East Kelowna	08NM116	1967-01-01	Included with caveats

Snowfall

The Okanagan watershed's hydrological cycle is primarily driven by snowmelt; therefore, understanding snowmelt is vital to understanding the valley's hydrology. Unfortunately, data availability is a major issue for snow indicators. Records are often short or have many missing values.

The sources of the data are summarised in Table 4.

*Table 4 Source of snow data. Snowfall (cm) data was derived from weather data. *For the weather data, both minimum temperature (C) and total precipitation (mm) came from different stations.*

	Snow Fall Data			
Location	**Station ID***	**Data Source**	**Start Date**	**Notes**
Vernon	1128582 and 1128553	AHCCD and ECCC	1915-01-01	Temperature data was started in 1915 due to anomalies in the early record. 2005 interpolated for Kelowna, 2010 precipitation data for Vernon, and 2021 precipitation data for Penticton
Kelowna	1123939 and 1123993	AHCCD and ECCC	1915-01-01	
Penticton	1126146 and 1126150	AHCCD and ECCC	1915-01-01	

Snowfall (cm) was calculated from AHCCD and ECCC precipitation data. In many datasets, only total precipitation is reported; therefore, temperature and precipitation were combined to separate snow and rain. This was done by assuming that any precipitation that fell when the minimum daily temperature was above 0˚C was rain and precipitation when the maximum daily temperature was below 0˚C fell as snow. This method has the advantage of dramatically expanding available data but is based on a significant assumption.

Lake Inflows

The Government of B.C. Ministry of Water, Land, and Resource Stewardship has estimates of weekly inflows to Okanagan Lake discharge (kdam^3) going back to 1922-01-01. This is a remarkable data set because of the length of time (101 years) and because it integrates influences from the entire watershed.

Indicator Methods

The sections include a description of the calculations used to create each indicator Table 5.

Table 5 Full list of Indicators

Okanagan Climate Indicators				
Temperature				
Indicator Name	Unit	Annual	Seasonal	Notes
Daily Mean Temperature	C	X	X	
Daily Minimum Temperature	C	X	X	
Daily Maximum Temperature	C	X	X	
Days Over 30C	Days	X	X	
Days Over 35C	Days	X	X	
Ice Days	Days	X	X	
Frost Days	Days	X	X	
Days Below -20C	Days	X	X	
Date of Last Spring Frost	Date	X		
Date of First Fall Frost	Date	X		
Frost Free Length	Date	X		
Temperature Density Distribution	-	X	X	
Climate Normals	C	X		
Precipitation				
Indicator Name	Unit	Annual	Seasonal	Notes
Total Precipitation	mm	X	X	
Total Snow	cm	X	X	
Total Rain	mm	X	X	
Wet Days	Days	X	X	
Dry Days	Days	X	X	
Days with Effective Precipitation	Days	X	X	
Maximum Precipitation Event	mm	X	X	
Percent Precipitation as Snow or Rain	%	X		
Stream Flow and Mission Creek				
Indicator Name	Unit	Annual	Seasonal	Notes
Centre of Volume	Date	X		
Annual Average Streamflow	m^3/s	X		
Three-day High	m^3/s	X		
Days with High Flow	Days	X		
Days with Low Flow	Days	X		
Late Season Low Flow	Days	X		
Days Below Critical Flow Needs	Days	X		Only for Mission Creek
Okanagan Lake Inflows				
Indicator Name	Unit	Annual	Seasonal	Notes
Total Inflows	$Kdam^3$	X		
Center of Volume	Date	X		
Volume at the Centre of Volume	$Kdam^3$	X		

Weeks with High Flows	Weeks	X		
Weeks with Low Flows	Weeks	X		
Weeks with Net Losses	Weeks	X		
One Week Maximum	Kdam^3	X		
One Week Minimum	Kdam^3	X		

Temperature Indicators

All temperature indicators are derived from daily AHCCD and ECCC data. The indicators can be generated for annual values, or for each season (DJF, MAM, JJA, and SON). In all cases, the baseline for temperature data is 1951-1980. Anomalies are calculated by subtracting the calculated value of the indicator from the baseline. The trend line for a 30-year rolling average is taken by averaging the anomaly values for the preceding 30 years. The date runs from 1915, the last completed calendar year. As noted above, 2005 data was interpolated for Kelowna.

Mean Daily Temperature - takes the daily average temperature (C) and calculates its mean for each year and season. These mean values are compared to the 1951-1980 historical norm (30-year average) and shown as deviations from this norm. The result is a temperature anomaly in degrees C.

Maximum Daily Temperature – takes the daily maximum temperature (C) and calculates its mean for it for each year and season. These mean values are compared to the 1951-1980 historical norm (30-year average) and shown as deviations from this norm. The result is a temperature anomaly in degrees C.

Minimum Daily Temperature – takes the daily minimum temperature (C) and calculates its mean for it for each year and season. These mean values are compared to the 1951-1980 historical norm (30-year average) and shown as deviations from this norm. The result is a temperature anomaly in degrees C.

Days Over 30˚C – takes the sum of the days where the maximum daily temperature exceeds 30˚C for each year and season. These values are compared to the 1951-1980 historical norm (30-year average) and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Days Over 35˚C – takes the sum of the days where the maximum daily temperature exceeds 30˚C for each year and season. These values are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Frost Days – takes the sum of the days with a minimum daily temperature under 0˚C for each year and season. These values are compared to the 1951-1980 historical norm (30-year average) and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Ice Days – takes the sum of the days with a maximum daily temperature under 0˚C for each year and season. These values are compared to the 1951-1980 historical norm (30-year average) and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Days Below -20˚C – takes the sum of the days with a minimum daily temperature under -20˚C for each year and season. These values are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Date of Last Spring Frost – is the last day in the first half of the year with a minimum temperature below 0˚C. These dates are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly of the number of days before or after the normal date.

Date of First Fall Forst – is the first day of the year's second half with a minimum temperature below 0˚C. These dates are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly of the number of days before or after the normal date.

Growing Season Length – takes the number of consecutive days between the last spring frost and the first fall frost. These numbers are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days.

Temperature Density Distribution – Compares the distribution of the mean daily temperature for 1951-1980 to 1991-2020 for each. This is achieved by looking at all the temperatures found within the data set and looking at how often each one occurred to compute the probability of each temperature. This was done annually and for each season.

Climate Normals – Compares the average weekly temperature from 1951-1980 to 1991-2020. For each week in these two-time ranges, the average is calculated for mean, maximum, and minimum temperature.

Precipitation Indicators

All precipitation indicators are derived from daily AHCCD and ECCC data. The indicators can be developed annually or for each season (DJF, MAM, JJA, and SON). In all cases, the baseline is 1951-1980. Anomalies are calculated by subtracting the calculated value of the indicator from the baseline. The trend line in a 30-year rolling average is taken by averaging the anomaly values for the preceding 30 years. The time series begins in 1915, the first complete calendar year.

Total Precipitation – This is calculated by taking the total volume of precipitation (mm) that falls as snow or rain, over a given period. The precipitation totals are compared to the 1951-1980 historical average. The result is an anomaly in the amount of precipitation, given in mm.

Rainfall – is calculated by taking all the precipitation (mm) that falls when the minimum temperature exceeds 0˚C over a given period. The precipitation totals are compared to the 1951-1980 historical average. The result is an anomaly of the amount of precipitation, given in mm.

Snowfall – is calculated by taking all the precipitation (cm) that falls when the minimum temperature is below 0 C over a given period. The precipitation totals are compared to the 1951-1980 historical average. The result is an anomaly of the amount of precipitation in cm. Since temperature is used to derive the precipitation type.

Dry Days – takes the sum of the days where no precipitation fell. These values are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Wet Days – takes the sum of the days where at least 10 mm of precipitation fell. These values are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Days with Effective Precipitation – takes the sum of the days where at least 5 mm of rain fell. These numbers are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of days that meet the threshold.

Maximum One-Day Precipitation Event – identifies the greatest volume of precipitation that fell in one day during the calendar year. These values are compared to the 1951-1980 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly of the amount of precipitation in mm.

Percent Precipitation as Snow or Rain – identifies the percent of the precipitation that fell each year as rain (i.e., precipitation that fell on days with a minimum temperature above 0˚C) and the percentage of precipitation that fell as snow (i.e., precipitation that fell on days with a maximum temperature below 0˚C.

Streamflow Indicators

Streamflow indicators are calculated using daily discharge data (m^3/s) from the Water Survey of Canada (WSC). In all cases, the baseline is 1971-2000. Anomalies are calculated by taking the difference between the calculated value of the indicator and the baseline. The trend line in a 30-year rolling average is created by averaging the anomaly values for the preceding 30 years. The date runs from the start date for each station to the last completed calendar year. Initially, an indicator of seven-day low flows was considered, but this indicator was ultimately removed as it was not applicable for ephemeral streams or streams that consistently ran dry. Results from that indicator were confusing and inconstant so the decision was made to remove this indicator.

Centre of Volume – is used to identify the timing of the spring snowmelt, also known as freshet[22]. It identifies the date on which half of the flows between January 1st and June 30th have passed through the system. These dates are compared to the 1971-2000 historical norm (30-year average) and are shown as a deviation from this norm. The result is an anomaly in the number of days earlier or later than normal.

Annual Average Streamflow – is the mean discharge (m^3/s) for the entire year. These values are compared to the 1971-2000 historical norm (30-year average) and shown as a deviation from this norm. The result is an anomaly for flows in (m^3/s).

Three-Day High Streamflow – to derive this indicator, we took a three-day rolling average for all days in a year and the indicator is based on the highest annual value for these averages. These maximum values are compared to the 1971-2000 historical norm (30-year average) of the three-day high streamflow and are shown as a deviation from the norm. The result is an anomaly for flows in (m^3/s).

Days with Low Flow – counts the number of days in a year where flows are less than the 5th percentile for the 1971-2000 baseline. These counts are compared to the 1971-2000 historical norm (30-year average) and shown as a deviation from this norm. The result is an anomaly of the number of days that meet this low-flow threshold.

Days with High Flow – counts the number of days in a year where flows exceed the 95^{th} percentile for the 1971-2000 baseline. These counts are compared to the 1971-2000 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly of the number of days that meet this high-flow threshold.

Late Season Low Flow – counts the number of days from August to October—when drought conditions and the irrigation season are most likely to overlap—when flows are less than the 5th percentile for the 1971-2000 baseline. These counts are compared to the 1971-2000 historical norm (30-year average), and shown as a deviation from this norm. The result is an anomaly in the number of late-season days that meet this low flow threshold.

Days Below Critical Flow Needs for Mission Creek – are days where the discharge in Mission Creek was below a defined value for aquatic critical flow needs (CFN) for that time of year Associated Environmental[23]. Critical flow needs are defined by the Water Sustainability Act[24] as "*the volume of water flow below which significant or irreversible harm to the aquatic ecosystem of the stream is likely to occur*." Different fish species have different CFN depending on the species and time of year. The methods for calculating CFNs can be found in Associated Environmental[25] and Okanagan Nation Alliance[26].

For this indicator, the highest CFN (i.e., the largest discharge value, representing the greatest water demand) was taken for each week (Table 6). The indicator was then calculated by comparing daily average streamflow (m3/s) in Mission Creek to the CFN value threshold for that week. The number of days where flows were below that threshold were counted, and these counts are compared to the number of days the historical norm (1971-2000, 30-year average). The result is an anomaly of the number of days that meet this threshold.

Table 6 Weekly critical flow thresholds for Mission Creek (Okanagan Nation Alliance, 2020). Note that sockeye and chinook salmon have not yet been incorporated in this calculation and will change the Critical Flow Values used for the indicator.

Mission Creek Maximum Critical Flow Values		
Week Ending	**Fish Life Stage**	**Critical Flow (m3/s)**
Jan	*Rainbow rearing & over wintering*	*0.635*
Feb	*Rainbow rearing & over wintering*	*0.635*
Mar	*Rainbow rearing & over wintering*	*0.635*
1-Apr	*Rainbow rearing & over wintering*	*0.635*
8-Apr	*Rainbow rearing & over wintering*	*0.635*
15-Apr	*Rainbow spawning*	*1.118*
22-Apr	*Rainbow spawning*	*1.118*
29-Apr	*Rainbow spawning*	1.118
6-May	Rainbow spawning	*1.118*
13-May	Rainbow spawning	*1.118*
20-May	Rainbow spawning	*1.118*
27-May	Rainbow spawning	*1.118*
3-Jun	Rainbow spawning	*1.118*
10-Jun	Rainbow spawning	*1.118*
17-Jun	Rainbow spawning	*1.118*
24-Jun	Rainbow spawning	*1.118*
1-Jul	Rainbow spawning	*1.118*
8-Jul	Rainbow spawning	*1.118*
15-Jul	Rainbow rearing & over wintering	*0.635*
22-Jul	Rainbow rearing & over wintering	*0.635*
29-Jul	Rainbow rearing & over wintering	*0.635*
5-Aug	Rainbow rearing & over wintering	*0.635*
12-Aug	Rainbow rearing & over wintering	*0.635*
19-Aug	Rainbow rearing & over wintering	*0.635*
26-Aug	Rainbow rearing & over wintering	*0.635*
2-Sep	Kokanee spawning	*0.635*
9-Sep	Kokanee spawning	*0.635*
16-Sep	Kokanee spawning	*0.635*
23-Sep	Kokanee spawning	*0.635*
30-Sep	Kokanee spawning	*0.635*
7-Oct	Kokanee spawning	*0.635*
14-Oct	Rainbow rearing & over wintering	*0.635*
21-Oct	Rainbow rearing & over wintering	*0.635*
28-Oct	Rainbow rearing & over wintering	*0.635*
Nov	Rainbow rearing & over wintering	*0.635*
Dec	Rainbow rearing & over wintering	*0.635*

Okanagan Lake Indicators

Indicators for Okanagan Lake are calculated from weekly inflow data (kdam^3) produced by the B.C. River Forecast Centre. The baseline period is 1951-1980. The data is available from 1921 to the last completed calendar year. Anomalies are calculated by subtracting the calculated value of the indicator from the baseline, 30-year average value. The trend line is a 30-year rolling average, derived by averaging the anomaly values for the preceding 30 years.

Total Inflows – takes the sum of inflows (kdam3) for the entire year and compares each year to the 1951-1980 historical average. The result is an anomaly for each year in kdam3.

Centre of Volume – is used to estimate any change in the timing of freshet (spring runoff season). It identifies the week during which half of the total inflow volume has passed through the system, between the dates of January 1st and June 30th each year. Results are compared to the timing of the Centre of Volume given by the 1951-1980 historical average. The indicator shows anomalies in the number of weeks earlier or later than normal.

Volume at Centre of Volume – identifies the cumulative inflows (kdam^3) that have flowed into the lake up to the date of the centre of the volume. Results are compared to the volume at the Centre of Volume given during the 1951-1980 historical average. The result is an anomaly for each year in kdam3.

Weeks with High Inflows – counts the number of weeks where the inflows (kdam^3) exceed the 95th percentile for the 1951-1980 baseline. The result is a yearly anomaly for the number of weeks that meet this threshold.

*Weeks with Low Inflows –*counts the number of weeks where the inflows (kdam^3) are below the 5th percentile for the 1951-1980 baseline. The result is a yearly anomaly for the number of weeks that fail to meet this threshold.

Date of Maximum Inflow – identifies the calendar week each year (numbered 1 – 52) with the largest volume of inflows (kdam^3). The number of the week for each year is then compared to the 1951-1980 historical average. The result is an anomaly for each year of the volume in kdam^3.

Date of Minimum Inflow – identifies the calendar week each year (numbered 1 – 52) with the lowest volume of inflows (kdam3). The number of the week for each year is then compared to the 1951-1980 historical average. The result is then an anomy for each year of the volume in kdam$^{3.}$

Weeks with Net Negative Inflows – counts the total number of weeks each year during which the net inflow volumes (kdam^3) are negative. The number is then compared to the 1951-1980 historical average. The result is an anomaly for each year for the number of weeks that meet this threshold.

References

[1] White, R. H., Anderson, S., Booth, J. F., Braich, G., Draeger, C., Fei, C., ... & West, G. (2023). *The unprecedented Pacific Northwest heatwave of June 2021*. Nature Communications, 14(1), 727.

[2] Parisien, M.-A., Barber, Q. E., Bourbonnais, M. L., Daniels, L. D., Flannigan, M. D., Gray, R. W., Hoffman, K. M., Jain, P., Stephens, S. L., Taylor, S. W., & Whitman, E. (2023). *Abrupt, climate-induced increase in wildfires in British Columbia since the mid-2000s. Communications Earth & Environment*, 4(1), Article 1. https://doi.org/10.1038/s43247-023-00977-1

[3] Ishaq, S., Nahiduzzaman, K. M., Sultana, S. R., Rana, A., Mohammadiun, S., Yousefi, P., ... & Sadiq, R. (2022). *Flood-resilient governance in Okanagan valley of British Columbia: current practices and future directives. Environmental Reviews*, *31*(2), 327-347.

[4] Pinna (2020). *Climate Projections for the Okanagan Region.* *https://www.rdos.bc.ca/assets/PLANNING/AreaX/2020/ClimateProjections/FinalReport.pdf*

[5] B.C. Ministry of Environment (2016). *Indicators of Climate Change for British Columbia: 2016 Update.*

[6] Climate Atlas of Canada (2023). *Map.* https://climateatlas.ca/ (Accessed: 30.06.2023)

[7] United States Environmental Protection Agency (2023a). *Climate Change Indicators in the United States*. https://www.epa.gov/climate-indicators (Accessed: 15.05.2023)

[8] United States Environmental Protection Agency (2023b). *Climate Change Indicators: Streamflow.* https://www.epa.gov/climate-indicators/climate-change-indicators-streamflow (Accessed: 15.05.2023)

[9] United States Geological Survey (2015). *Hydrological Climate Change Indicators* https://www.usgs.gov/centers/new-york-water-science-center/science/hydrologic-climate-change-indicators (Accessed: 11.12.2023)

[10] Water Survey of Canada (2023). *Historical Hydrometric Data Search.* https://wateroffice.ec.gc.ca/search/historical_e.html (Accessed: 11.12.2023)

[11] Climate Data (2023a). *Download AHCCD.* https://climatedata.ca/variable/ (Accessed: 14.05.2023).

[12] Climate Atlas of Canada (2023). *Map.* https://climateatlas.ca/ (Accessed: 30.06.2023)

[13] Peters-Lidard, C. D., Rose, K. C., Kiang, J. E., Strobel, M. L., Anderson, M. L., Byrd, A. R., Kolian, M. J., Brekke, L. D., & Arndt, D. S. (2021). Indicators of climate change impacts on the water cycle and water management. *Climatic Change*, *165*(1), 36. https://doi.org/10.1007/s10584-021-03057-5

---

[14] Ombadi, M., Risser, M. D., Rhoades, A. M., & Varadharajan, C. (2023). A warming-induced reduction in snow fraction amplifies rainfall extremes. Nature, 619(7969), 305–310. https://doi.org/10.1038/s41586-023-06092-7

[15] Williams, M., & Eggleston, S., (2022). Using Indicators To Explain Our Changing Climate To Policymakers And The Public. *World Meteorological Organization. https://public-old.wmo.int/en/resources/bulletin/using-indicators-explain-our-changing-climate-policymakers-and-public (Assessed: 10.05. 2023).*

[16] Gulev, S.K., P.W. Thorne, J. Ahn, F.J. Dentener, C.M. Domingues, S. Gerland, D. Gong, D.S. Kaufman, H.C. Nnamchi, J. Quaas, J.A. Rivera, S. Sathyendranath, S.L. Smith, B. Trewin, K. von Schuckmann, and R.S. Vose, 2021*: Changing State of the Climate System. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, doi: 10.1017/9781009157896.004.*

[17] Climate Data (2023b). *Download AHCCD.* https://climatedata.ca/download/#ahccd-download (Accessed: 22.05.2023).

[18] Environment and Climate Change Canada (2023). *Daily Climate Data. https://climate-change.canada.ca/climate-data/#/daily-climate-data* (Accessed: 22.05.2023)

[19] LaZerte, S. E and Albers S. (2018). *weathercan: Download and format weather data from Environment and Climate Change Canada*. The Journal of Open Source Software 3(22):571.doi:10.21105/joss.00571.

[20] Water Survey of Canada (2018). *National Water Data Archive: HYDAT. https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey/data-products-services/national-archive-hydat.html*

[21] Albers S (2017). *"tidyhydat: Extract and Tidy Canadian Hydrometric Data."* The Journal of Open Source Software, 2(20). doi:10.21105/joss.00511, http://dx.doi.org/10.21105/joss.00511.

[22] López-Moreno, J. I., Pomeroy, J. W., Alonso-González, E., Morán-Tejeda, E., & Revuelto, J. (2020). Decoupling of warming mountain snowpacks from hydrological regimes. *Environmental Research Leters*, *15*(11), 114006. https://doi.org/10.1088/1748-9326/abb55f

[23] Associated Environmental (2020*). Okanagan Environmental Flow Needs Project – Phase 1 and 2 Summary Report*1.118

[24] Water Sustainability Act (2016). British Columbia

[25] Associated Environmental (2020*). Okanagan Environmental Flow Needs Project – Phase 1 and 2 Summary Report*1.118

[26] Okanagan Nation Alliance (2020). *Environmental Flow Needs Assessment in the Okanagan Basin: Appendix-B5 Mission Creek.* https://obwb.ca/efndocs/Appendix-B5.pdf

Land Acknowledgment

We would like to acknowledge this work was done on the traditional, ancestral, and unceded tm̓xʷúlaʔxʷ (land) of the syilx / Okanagan people who have resided here since time immemorial. The OBWB recognizes, honours, and respects the syilx / Okanagan lands upon which we live, work, and play; and the siwłk (water) which flows through the valley and connects us all.

Special Thanks

Thank you to the experts who provided advice on the project:

Dr. Jeremy Fyke,

Dr. Denies Neilsen,

Drew Lejbak,

Bob Hrasko,

Dr. Paul Whitfield,

Dr. Mel Reasoner,

Dr Brian Guy,

Robert Sandford,

Elinor McGrath,

Jamey Self