# KOKSILAH REGULATORY RESPONSE TO LOW FLOWS EFFECTIVENESS ANALYSIS

## FINAL REPORT

Prepared for:

Ministry of Forests, Lands, Natural Resource Operations & Rural Development
Nanaimo, British Columbia

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5 May 2020

NHC Ref No. 3005650

nhc

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# 1 INTRODUCTION

The Koksilah River is located on Vancouver Island south of the City of Duncan. The river connects in the tidal reach of the south arm of the Cowichan River before it drains into Cowichan Bay. The Koksilah River runs through agricultural lands where many users extract surface and groundwater for irrigation and/or domestic purposes. In recent years, low flows on the Koksilah River have degraded aquatic habitat conditions and threatened fish populations (FLNRORD, 2019). FLNRORD imposed a water extraction curtailment on specified licensed surface water and groundwater users, as well as unlicensed groundwater users in August 2019 in an effort to temporarily improve flows in the river.

This study uses available data sets, including measured low flows on the Koksilah River, to assess the effectiveness of the 2019 extraction curtailment.

## 1.1 Study Area, Watershed Characteristics, and Hydroclimate

The Koksilah River watershed has a gross drainage area of 209 km$^2$, and 80% of the land use is designated forestry. The downstream-most 17 km river reach flows almost entirely through agricultural lands, which make up 14.9% of the land use in the watershed (Pritchard et al., 2019). By volume, most of the licensed water use on the Koksilah River is for agricultural purposes.

The Koksilah watershed is rain-dominated with a wide range in annual precipitation over its area. The basin area in the 300 to 800 m elevation range is considered to be in the mixed rain-snow regime. The headwaters can receive more than twice the annual average amount of precipitation compared to the mouth. The average annual precipitation at the headwaters and mouth of the Koksilah River is 2850 mm and 1119 mm, respectively (PCIC, 2020). The average annual precipitation for the Koksilah watershed is 1975 mm (PCIC, 2020). Multiple wetlands and four small lakes, the largest of which is Grant Lake at 0.28 km$^2$, are at the headwaters and middle elevations of the watershed. Dougan Lake (0.10 km$^2$) and Keating Lake (0.05 km$^2$) are the two largest in the lower reaches. The sub-watershed of Kelvin Creek contains at least 10 small wetlands (Fishnbc, 2018; BC Ministry of Environment, 1985). However, because the Koksilah River does not have a large lake or any significant water storage, summer flows are very low, and the river is more responsive to rainfall inputs. Groundwater flows are also important inputs to the Koksilah River, which has three overlapping sand and gravel aquifers and three bedrock aquifers (Pritchard et al., 2019).

The Chemainus River was used for comparison in this analysis, as it has similar watershed characteristics and is relatively close to the Koksilah watershed, but had no curtailment imposed. With a gross drainage area of 355 km$^2$, the Chemainus River watershed is 1.7 times the size of the Koksilah. The highest elevation within the Chemainus watershed is Mount Whymper at 1,541 m. Waterloo Mountain at 1,070 m is the highest in the Koksilah watershed. Similar to the Koksilah, the majority of the land-use in the Chemainus watershed is forestry, while the lower reach is mainly agricultural (BC Ministry of Environment, 2014). Lack of major lakes and water storage on the Chemainus similarly contribute to higher flow variability and sensitivity to rainfall. The larger drainage area of the Chemainus generally causes low flow discharge to be greater than on the Koksilah.

## 1.2 Estimated Flow Gains Resulting from Regulatory Curtailment

Approximations of the volumes and flow rates available for return from specific curtailed users to the Koksilah River are provided in **Table 1**. The differences between the licenced demands and total approximated benefits result from determining if the user was drawing water. Benefits were only anticipated if the user had been extracting water. Returns to the river from curtailing groundwater users were anticipated to be a fraction of what was being pumped due to the recovery period and delay in returns. **Map 1** provides approximate locations benefiting from curtailment, and the gauges used to analyze those benefits.

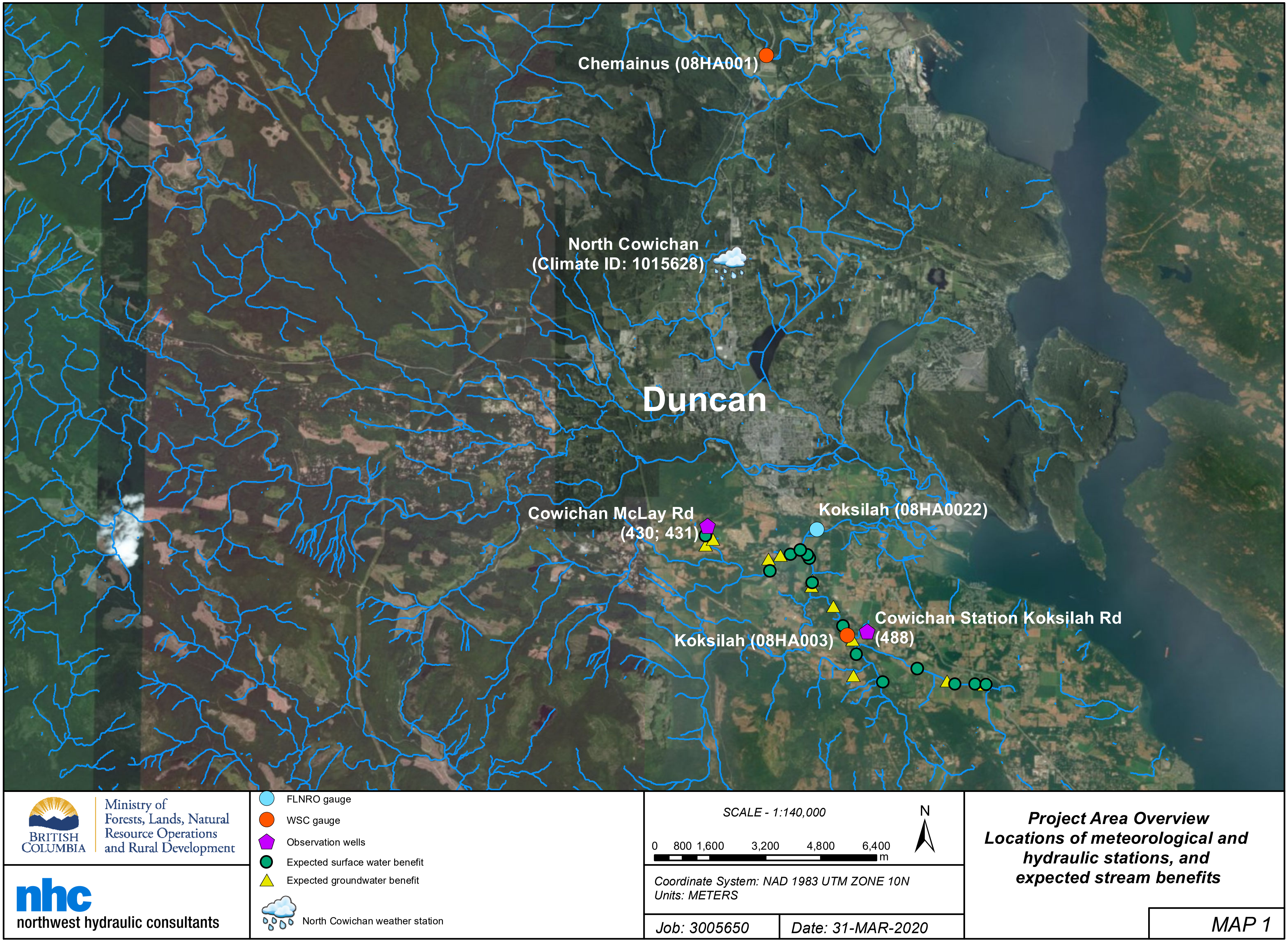
**Table 1 Approximate post-curtailment volumes and flow rates available for return to the Koksilah River from select curtailed users as determined by FLNRORD.**

| Gauge Name | Gauge ID | Gauge Ownership | Type of Benefit | Total Licenced Demand Upstream of Gauge | | Total Approximated[1] Benefit at Gauge Location | |
|---|---|---|---|---|---|---|---|
| | | | | [m³/d] | [m³/s] | [m³/d] | [m³/s] |
| Koksilah River at Cowichan Station | 08HA003 | WSC[2] | SW | 3434 | 0.040 | 1383 | 0.016 |
| | | | GW | 328 | 0.004 | 135 | 0.002 |
| Unknown inflow location | | | SW | 554 | 0.006 | 0 | 0 |
| | | | GW | 913 | 0.011 | | |
| Koksilah River at Trestle[3] | 08HA0022 | FLNRORD | SW | 12165 | 0.141 | 3738 | 0.04 |
| | | | GW | 3052 | 0.035 | 636 | 0.01 |
| **Maximum upstream demand/benefit for furthest downstream gauge[3] (08HA0022)** | | | | **15218** | **0.176** | **4374** | **0.05** |

**Notes:**

1. If the user was not irrigating, there was no anticipated benefit from that source.
2. Water Survey of Canada.
3. Flows measured by Koksilah River Trestle (08HA0022) include flow measured by Koksilah River at Cowichan Station (08HA003) as well as the unknown inflow locations, which were assumed to be upstream in order to determine a maximum approximated benefit.
4. Red text indicates approximated benefits at the principal gauge used for analysis

Approximate groundwater returns were calculated by FLNRORD using the aquifer properties, the distance of pumping wells to inferred hydraulic connection points on the nearest stream, and assumptions such as modelling aquifers as homogeneous (M. Wainwright, personal communication, March 27, 2020). Inflows presented in **Table 1** are from curtailing the selected water users and do not include estimates for the total water users that were additionally asked to limit extraction. Therefore, the maximum anticipated returns from all water users to the Koksilah River are unknown.


Chemainus (08HA001)
North Cowichan
(Climate ID: 1015628)
Duncan
Cowichan McLay Rd
(430; 431)
Koksilah (08HA0022)
Cowichan Station Koksilah Rd
(488)
Koksilah (08HA003)
Ministry of Forests, Lands, Natural Resource Operations and Rural Development
BRITISH COLUMBIA
nhc
northwest hydraulic consultants
FLNRO gauge
WSC gauge
Observation wells
Expected surface water benefit
Expected groundwater benefit
North Cowichan weather station
SCALE - 1:140,000
0 800 1,600 3,200 4,800 6,400 m
N
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METERS
Job: 3005650
Date: 31-MAR-2020
Project Area Overview
Locations of meteorological and hydraulic stations, and expected stream benefits
MAP 1
ABC, \\mainfile-nan\Projects\Active\3005650 Koksilah Regulatory Response to Low Flows - Effectiveness Analysis\95 GIS\3005650.Map1.DataStationsUsed.mxd

# 2 METHODOLOGY AND DATA

Much of this analysis uses discharge data reported by Water Survey of Canada (WSC) from Koksilah River at Cowichan Station (08HA003). Thirty-five percent of the total anticipated curtailment benefits were upstream of this gauge location, and of those curtailments, 90% were from surface water and 10% from groundwater (**Table 1**). Surface water extraction curtailment is expected to more quickly affect flows in the river.

Discharges recorded at the WSC gauges on the Koksilah and Chemainus rivers begin in 1914. Koksilah River seasonal summer low-flow data are available from 1914 to 1916, 1955 to 2011, and 2013 to 2018. Provisional low-flow discharge data are available for 2019. On the Chemainus River, summer low-flow data are available from 1914 to 1916, 1952 to 1971, and 1973 to 2019. Discharge and precipitation data from the following stations and owners were used in this analysis:

- Koksilah River at Cowichan Station(08HA003); Water Survey of Canada
- Chemainus River Near Westholme (08HA001); Water Survey of Canada
- Koksilah River at Trestle (08HA0022); Water Authorizations, FLNRORD
- North Cowichan (Climate ID: 1015628); Co-operative Climate Network

Groundwater levels from the following observation wells from the Provincial Groundwater Observation Well Network were also used in this analysis:

- OBS Well 431 - Cowichan (McLay Rd shallow)
- OBS Well 430 - Cowichan (McLay Rd deep)
- OBS Well 488 - Cowichan Station (Koksilah Rd)

**Map 1** provides the location of these stations in addition to the locations benefiting from curtailment. The weather station at North Cowichan was used for this analysis, as data from most other stations were limited and not recent. North Cowichan was the only station with available data for 2019 and was in a central location for covering both the Chemainus and Koksilah rivers in the area of anticipated inflow benefits. Cowichan Lake Forestry had data available up to 2018; however, the station location was not representative for the study purposes.

Precipitation data from the North Cowichan gauge dated back to 1981 with 30-year climate normals available for 1981 to 2010. These data were used to determine the type of season (e.g. wet, average, or dry) experienced in 2019 for comparison of low flows on the Koksilah and Chemainus rivers with similar past seasons.

This comparison provided the basis for a qualitative relationship in low flows for the two rivers. It is noted for example that when low flows on the Chemainus River increased or decreased, the Koksilah River low flows were similarly rising or falling. Any change in this general pattern in 2019 after curtailment could be indicative of the effects of the water use restrictions.

Additionally, it should be noted that precipitation influences river flows both from direct watershed inputs and through influencing agricultural practices. Drier seasons, such as experienced in 2019, are believed to result in increased withdrawals for irrigation and hence a greater impact on low flows in the river.

The 7-day, 15-day and 31-day average low flows on the Koksilah River were assessed to determine if the 2019 low flows were significant compared to the last ten years. Trends in annual low flow over the period of record were also estimated. The 7-day low flows were used in a low flow frequency analysis to determine the return period of the 2019 drought.

# 3 RESULTS

Discharge on the Koksilah River is from WSC gauge Koksilah River at Cowichan Station (08HA003) unless otherwise stated.

## 3.1 Seasonal Patterns

Daily precipitation data for 2019 were obtained from the North Cowichan gauge. Comparison with climate normals and more recent historic conditions provided context for the 2019 season. The months of August through September were used to determine which years were similar to 2019. July 2019 had average rainfall; however, August 2019 had less than half the average rain compared with 30-year climate normal, and September 2019 had nearly three times the average rain. **Table 2** provides the climate normals for 1981-2010, and recent historic years with similar precipitation totals to 2019 in July, August, and September.

**Table 2 Monthly precipitation (mm) for 2019 and previous similar seasons for highlighted months**

| | Climate Normals | 2019 | 2016 | 2015 | 2009 | 2007 | 2005 | 2003 | 1998 |
|---|---|---|---|---|---|---|---|---|---|
| **January** | 194.3 | **218** | 229.4 | 152.5 | 37.6 | 188.7 | 235.4 | 246.9 | 251.2 |
| **February** | 125.4 | **112.6** | 177.3 | 142.8 | 22.1 | 107.1 | 53.4 | 32.4 | 146.4 |
| **March** | 110.4 | **14** | 178.5 | 125.1 | 39.3 | 141.6 | 133.2 | 188.8 | 80.4 |
| **April** | 69 | **68.8** | 1.2 | 41.4 | 23.6 | 68.8 | 89.4 | 96.5 | 9.7 |
| **May** | 50.5 | **21** | 8.8 | 9.3 | 47.4 | 35.7 | 68.4 | 22 | 38.9 |
| **June** | 37.4 | **31.8** | 25.6 | 4.6 | 12.2 | 33.4 | 33 | 4.1 | 27.1 |
| **July** | 23.3 | **25.8** | 26 | 20.2 | 8.1 | 36.1 | 25.2 | 30.6 | 41.7 |
| **August** | 30 | **11.2** | 14.4 | 26.8 | 12.3 | 13.4 | 21.9 | 7.1 | 11 |
| **September** | 36.2 | **98.6** | 51.6 | 60 | 45.3 | 95.2 | 32.5 | 30 | 13.6 |
| **October** | 108.8 | **96** | 292.6 | 109.7 | 97.8 | 96.9 | 114.3 | 282.1 | 97 |
| **November** | 191.5 | **81.4** | 228.6 | 124.3 | 283.9 | 122.8 | 103.2 | 160.5 | 339.2 |
| **December** | 176.3 | **148.4** | 123.4 | 312.1 | 38.5 | 191 | 189.1 | 140.5 | 256.1 |
| **Total Annual** | 1153.1 | **927.6** | 1357.4 | 1128.8 | 668.1 | 1130.7 | 1099 | 1241.5 | 1312.3 |

Numerous similar seasons (based on precipitation records) were appropriate for comparison, thus discharges on the Chemainus and Koksilah rivers focussed on the records from 1998 onwards. Relative difference in land and water use changes for the watersheds were not considered for this study.

**Figure 1** presents a visual comparison of flow patterns between the Chemainus and Koksilah rivers. Discharge from each river follows a similar pattern over the summer. This allows changes in discharge on one river to be more apparent. For similar past seasons (based on precipitation records), low flow daily discharge on the Chemainus was never less than the Koksilah. This changed in 2019 following the curtailment in August. The relative flow pattern began to change around August 24, 2019. At this point, discharge on the Koksilah remained constant and then began to increase, while discharge on the Chemainus decreased from 0.39 $m^3/s$ on August 24 down to 0.25 $m^3/s$ on September 8, 2019. Based on flow patterns from previous years, an increase in low flow on the Koksilah River when low flow is decreasing on the Chemainus River is unexpected. Koksilah River low flow increasing above Chemainus River low flow in late August and early September 2019 was likely due to the curtailment.

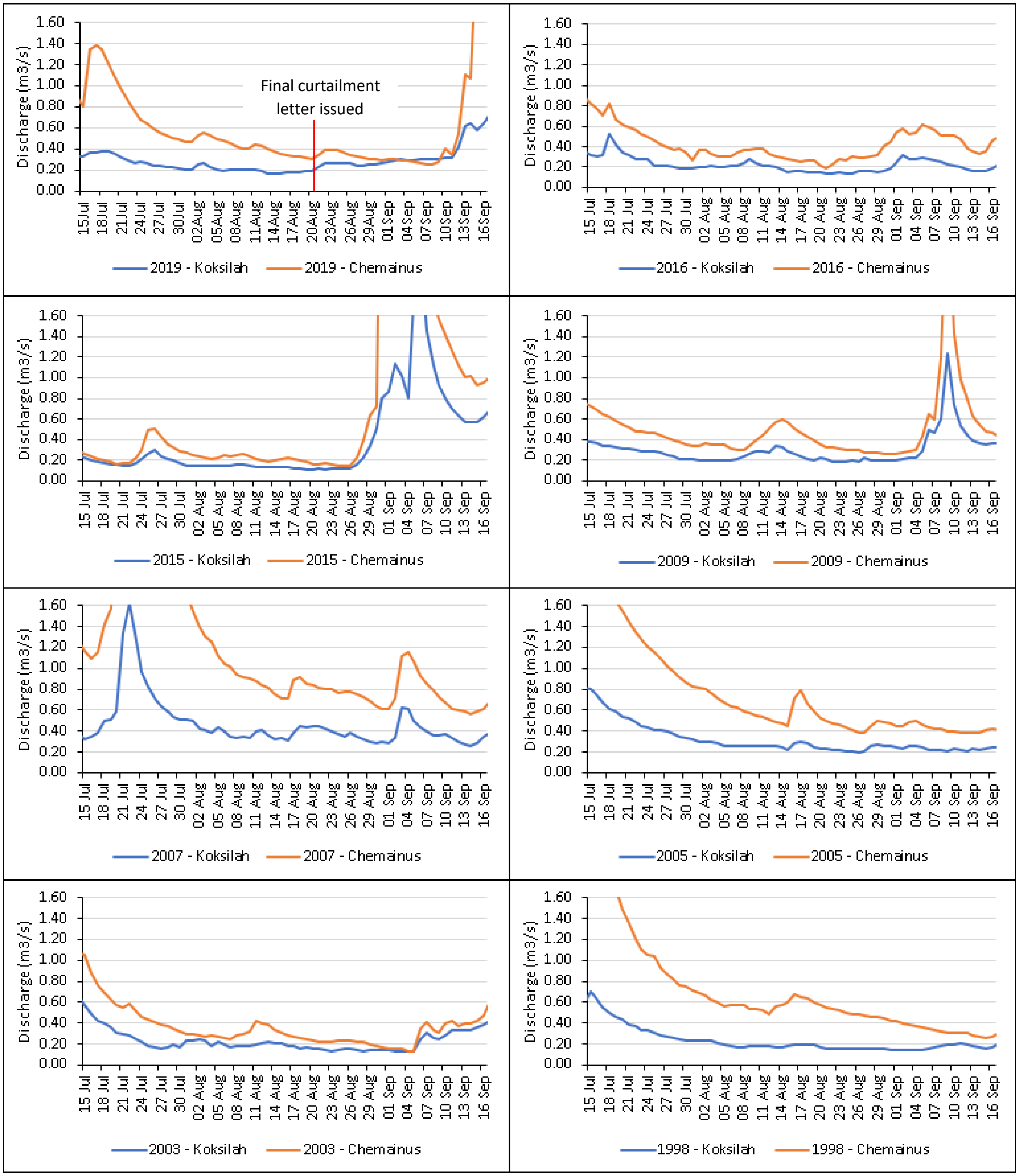



**Figure 1** **Comparison of daily discharge on the Chemainus River (08HA001; WSC) and Koksilah River (08HA003; WSC) for years with similar rainfall in August through September**

## 3.2 Groundwater

Groundwater benefits resulting from the curtailment would be gradual and most likely would not cause immediate changes in surface flow. The affect of the curtailment on groundwater levels and the effect of groundwater inflows on the discharge in the Koksilah River were investigated. This was completed by reviewing discharges on the Koksilah River in conjunction with water temperature and groundwater levels in the area of anticipated benefits (**Figure 2**).

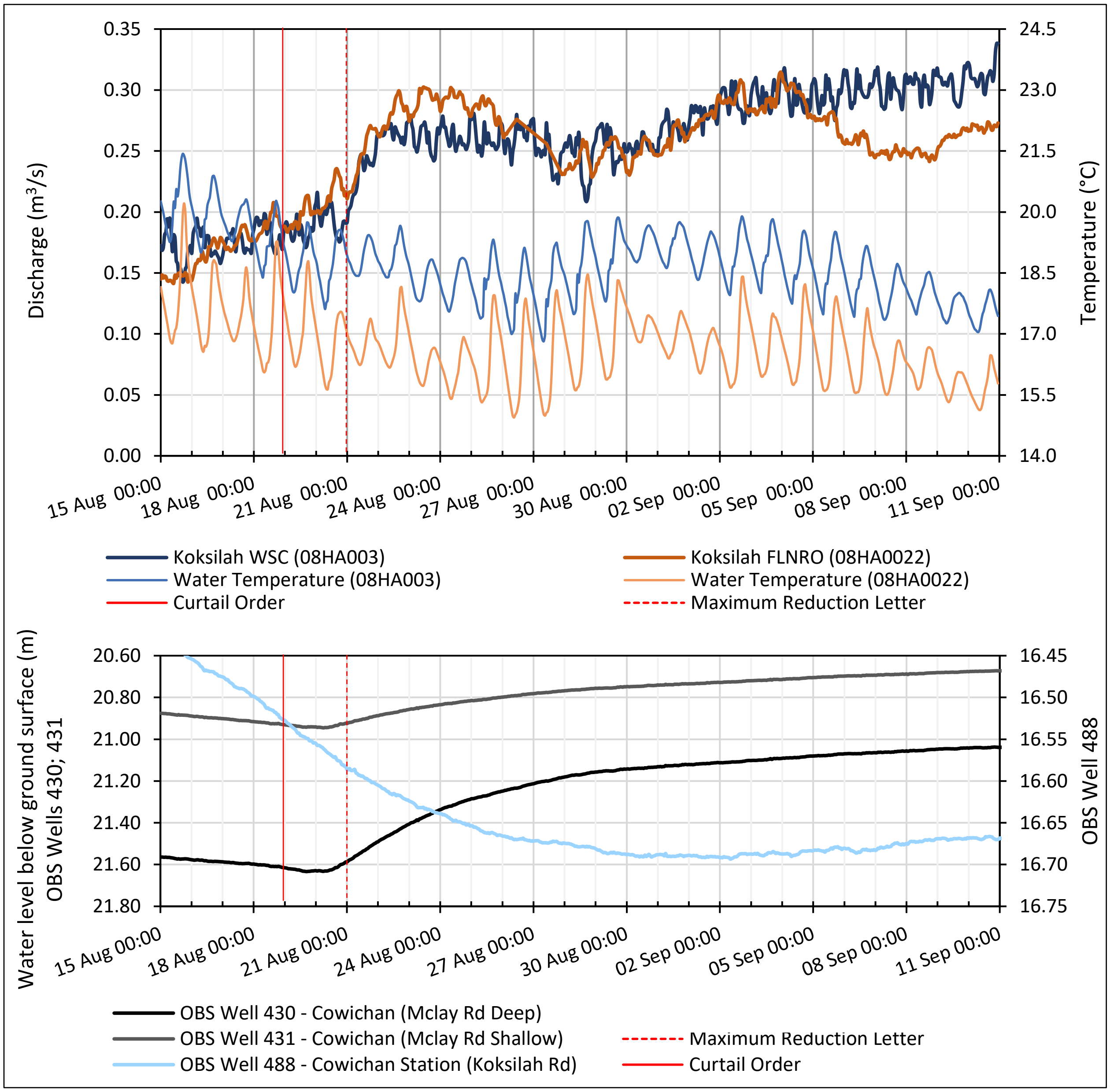



**Figure 2 Hourly discharge on the Koksilah River compared to water temperature and groundwater levels near the mouth of the watershed**

On August 21, 2019 there was a visible spike in discharge on the Koksilah River at both the FLNRORD and WSC gauges leading to discharges increasing at a greater rate compared to the days prior. Discharge also increased on the Chemainus River on this date, as seen in **Figure 1**. After August 24, 2019, flows on the Chemainus River began to decrease, while flows on the Koksilah River continued to increase. Upon review of precipitation records from Shawnigan Lake (Climate ID: 1017230; elevation: 159.0 m), Chemainus (Climate ID: 1011500; elevation: 75.0 m), Lake Cowichan (Climate ID: 1012055; elevation: 171.0 m), and North Cowichan (Climate ID: 1015628; elevation: 45.7 m) weather stations, there was no significant rainfall in the area. It is possible that the headwaters experienced greater volumes of rainfall due to the higher elevations. The reason for the temporary increase on the Chemainus River is uncertain and would require further investigation beyond the scope of this study.

This increase in discharge on the Koksilah River occurred approximately one day after the increase in groundwater levels. The groundwater inflection occurred approximately one day after the August 19 curtailment and resulted in an increase relative to average groundwater fluctuations. As the discharges and groundwater levels increased, the water temperature decreased. This may indicate additional groundwater was influencing the Koksilah River. Air temperatures were similarly declining during this time, which also likely affected water temperature.

If the groundwater levels are below the river stage, the water loss from the river to groundwater is reduced as the hydraulic gradient from the river to groundwater decreases. Groundwater inflow to the Koksilah River would occur if the groundwater levels are above the river stage. Based on the available data, it could not be assessed whether the river was losing or gaining water from the groundwater system. Further investigation into the groundwater levels relative to Koksilah River stage would be required to confirm the flow path. However, the increase in groundwater levels after curtailment would benefit Koksilah River flows due to either reducing water loss or contributing to inflows.

Groundwater levels at the Cowichan Station at Koksilah Road had been steadily decreasing since the middle of May. However, the rate of decrease began to slow on August 22, and groundwater levels began rising by the beginning of September. There was only sporadic and minimal precipitation between August 19 and September 11. Therefore, these significant changes in groundwater and discharges on the Koksilah River are likely a result of the curtailment.

The response of monitoring wells (430, 431, and 488) to the curtailment and resulting cessation of pumping depends on multiple factors such as proximity of the monitoring well to pumping, rate of pumping by each user which governs local drawdown, and aquifer properties. Further investigation of these characteristics and data from additional monitoring wells would be required to more definitively assess the affect of the groundwater levels on river flows.

## 3.3 Average Low Flows

A centered moving average was used to calculate the 7-day, 15-day, and 31-day low flows on the Koksilah River. For the past six consecutive years, the 7-day low-flows on the Koksilah River have been at or below 2% of the mean annual discharge. This threshold of 0.18 $m^3/s$ severely degrades aquatic habitat conditions and threatens fish populations (FLNRORD, 2019). **Table 3** provides a comparison of the 7-day, 15-day, and 31-day low flows for the last 10 years with available summer discharge data.

**Table 3 Koksilah River low flows for the previous 10 years. Highlighted values are below 2% of the mean annual discharge**

| Date | 7-day low flow ($m^3/s$) | Date | 15-day low flow ($m^3/s$) | Date | 31-day low flow ($m^3/s$) |
|---|---|---|---|---|---|
| 26 Aug 2009 | 0.19 | 27 Aug 2009 | 0.20 | 18 Aug 2009 | 0.23 |
| 27 Aug 2010 | 0.27 | 24 Aug 2010 | 0.27 | 24 Aug 2010 | 0.31 |
| 11 Sep 2011 | 0.19 | 10 Sep 2011 | 0.21 | 03 Sep 2011 | 0.26 |
| 24 Aug 2013 | 0.20 | 21 Aug 2013 | 0.24 | 12 Aug 2013 | 0.26 |
| 15 Sep 2014 | 0.18 | 15 Sep 2014 | 0.19 | 06 Sep 2014 | 0.22 |
| 22 Aug 2015 | 0.12 | 20 Aug 2015 | 0.12 | 13 Aug 2015 | 0.14 |
| 23 Aug 2016 | 0.14 | 23 Aug 2016 | 0.15 | 17 Aug 2016 | 0.18 |
| 28 Aug 2017 | 0.18 | 31 Aug 2017 | 0.19 | 24 Aug 2017 | 0.21 |
| 11 Aug 2018 | 0.13 | 15 Aug 2018 | 0.14 | 23 Aug 2018 | 0.15 |
| 16 Aug 2019 | 0.18 | 13 Aug2019 | 0.19 | 09 Aug 2019 | 0.21 |

The lowest annual flows are generally in late August or early-mid September, making August a critical time on the Koksilah River. The average 7-day low flow for the last 10 years with available summer discharge data is 0.18 $m^3/s$. While the 7-day low flow for 2019 was below 2% of the mean annual discharge, it was one of the highest in the last six years. The curtailment likely allowed flows to recover and increase in late August and early September (**Figure 1**, top left).

The 15-day and 31-day low flows indicate drawn-out low flows over the summer, particularly in August. Even at the 31-day average, three of the last five years have been below 0.18 $m^3/s$. **Figure 3** shows the general trend in 7-year low flows on the Koksilah River from 1955 to 2019. There is a statistically significant downward trend in 7-day low flows on the Koksilah River since the beginning of continuous record in 1955. Only very slight downward trends in precipitation were noted for July and August (**Figure 4**). The significant decrease in low-flows in comparison to slight change in summer precipitation could indicate significant increases in water withdrawals since the early 1980's.

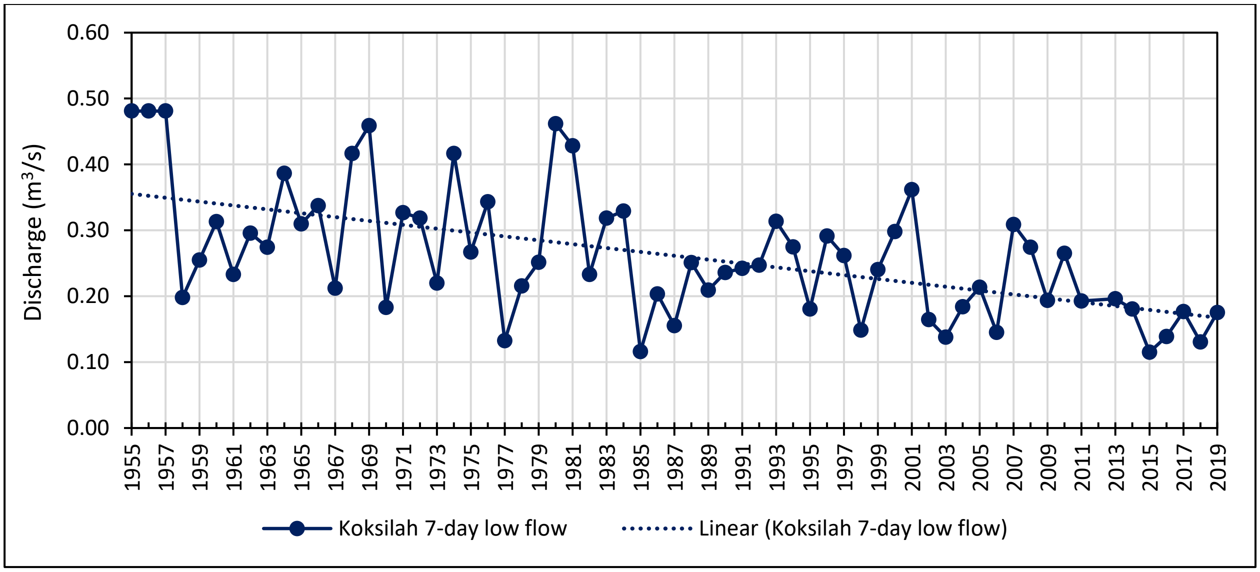



**Figure 3 Annual 7-day low flows on the Koksilah River from 1955 to 2019**

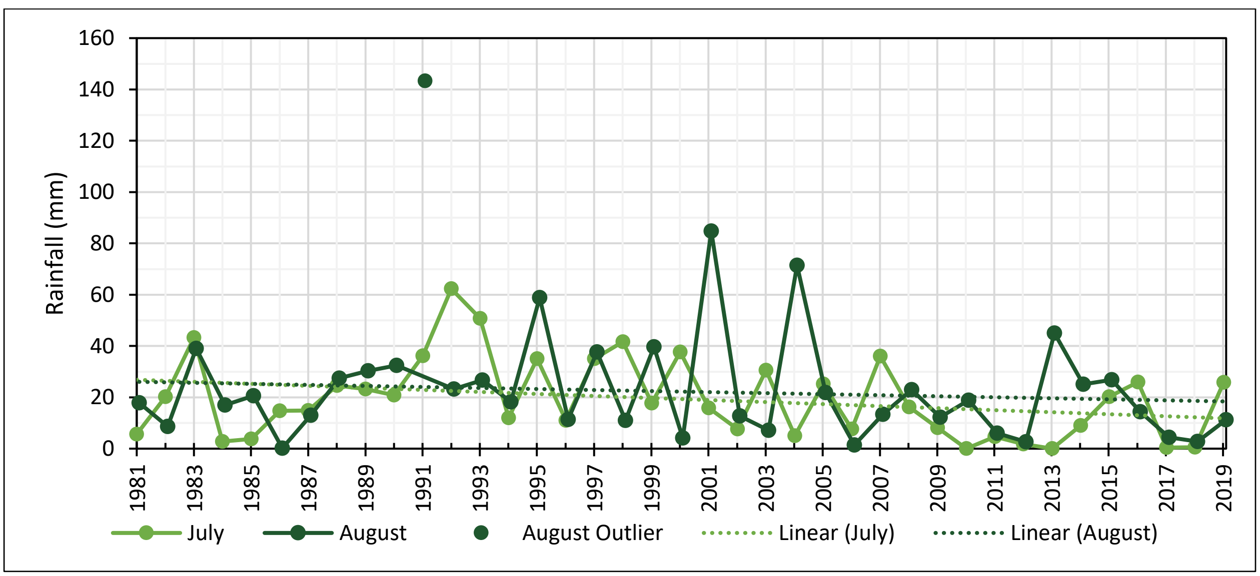



**Figure 4 Monthly rainfall for July and August measured at the North Cowichan Weather Station (Climate ID: 1015628) from 1981 to 2019**

Using the relationship between the daily low flows on the Chemainus and Koksilah rivers, the approximate annual low flow was investigated for the Koksilah River without the curtailment. The daily low flows from the Koksilah and Chemainus rivers were used for years where August had similar amounts of rainfall (+/- 5 mm). These years were further refined to years where the low flow recessions were similar: 2016, 2009, 2003, 1998. **Figure 5** provides a visual of the range in theoretical Koksilah River low flows without curtailment.

It was theorized that without curtailment the Koksilah River discharge would have increased similar to the Chemainus River between August 20 and 24, 2019. The rise in discharge on the Chemainus River is likely the result of rain at the headwaters, which was negligible near the mouth. Part of the reason for the rise in discharge on the Koksilah River may be attributed to rainfall at the headwaters. Therefore, low flow without the curtailment was theorized to be similar to the measured daily discharge on the Koksilah River up to August 24, 2019.

From August 24 to August 29, the Koksilah River flows without curtailment were assumed to follow a pattern similar to the Chemainus, with flows decreasing to the pre curtailment low flow of 0.19 $m^3/s$ recorded at the start of August 20. On August 29, 2019 the average low flow recession rates from 2016, 2009, 2003, and 1998 were used to approximate a range in possible low flows for the remainder of the dry period through early September. Of these years, 2016 and 2009 gave the least and greatest recession rates, respectively. Therefore, these were the years used to determine a maximum range in theoretical daily low flow on the Koksilah River without curtailment. Low flow recessions were projected to September 11, 2019. September 12, 2019 was the first day with significant recorded rainfall (32.8 mm) and therefore Koksilah River flow recession would cease. The range in theoretical low flows at the end of the dry period was 0.16 $m^3/s$ to 0.18 $m^3/s$. From this analysis, the curtailment resulted in approximately a 50% increase in flows relative to estimated flows without the curtailment for a substantial period of the post-curtailment duration.

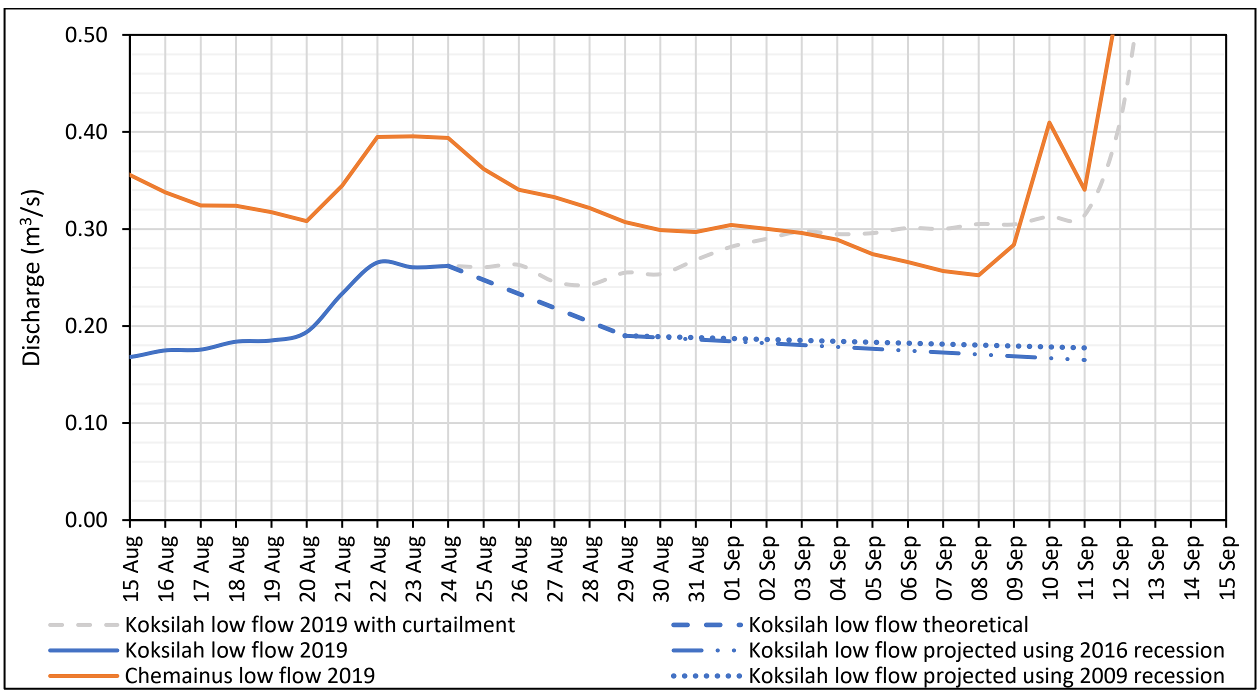



**Figure 5** **Koksilah River estimated low flows using recession rates from previous years with similar August rainfall (+/- 5mm)**

## 3.4 Frequency Analysis

The return period of the 2019 annual 7-day low flow was calculated for the Koksilah and Chemainus rivers using the Log Normal approximation and estimated graphically. The Log Normal approximation was determined to be the best fit for extreme low flow approximations. **Table 4** provides the 7-day low flows for given return periods. From the graphical (**Figure 6**) and Log Normal approximations, the 2019 7-day low flow had a 2 to 3-year return period on the Koksilah River, and a 2-year return period on the Chemainus River.

The 2019 annual minimum 7-day low flow occurred on August 16 on the Koksilah River. This is most likely due to the curtailment order yielding direct benefits from reduced surface water extraction and allowing groundwater levels to recover. The range in return period for the estimated theoretical annual low flow on the Koksilah River without curtailment was also assessed. The range in return period for this approximation ($0.16 m^3/s$ to $0.18 m^3/s$) was a 2- to 4-year event.

Due to the significant trend in low-flow data, this frequency analysis was completed using 7-day annual low flows from 2002 to 2011 and 2013 to 2019. Insufficient summer data were available for 2012. Because this frequency analysis was conducted using only 17 years of data, the results are only provided as a general approximation.

**Table 4 Return periods for annual 7-day low flows on the Koksilah and Chemainus rivers using data from 2002 to 2011 and 2013 to 2019**

| Return Period (years) | Koksilah River low flows ($m^3/s$) | Chemainus River low flows ($m^3/s$) |
|---|---|---|
| 50 | 0.10 | 0.09 |
| 20 | 0.12 | 0.11 |
| 10 | 0.13 | 0.13 |
| 5 | 0.14 | 0.17 |
| 2 | 0.18 | 0.26 |
| 1.25 | 0.23 | 0.41 |
| 1.11 | 0.26 | 0.53 |
| 1.05 | 0.28 | 0.64 |
| 1.02 | 0.32 | 0.80 |
| 1.01 | 0.34 | 0.92 |
| **2019 (with curtailment)** | 0.18 | n/a |
| **Return Period** | (2 to 3) | n/a |
| **2019 (approximation without curtailment)** | 0.16 – 0.18 | 0.27 |
| **Return Period** | (2 to 4) | (~2) |

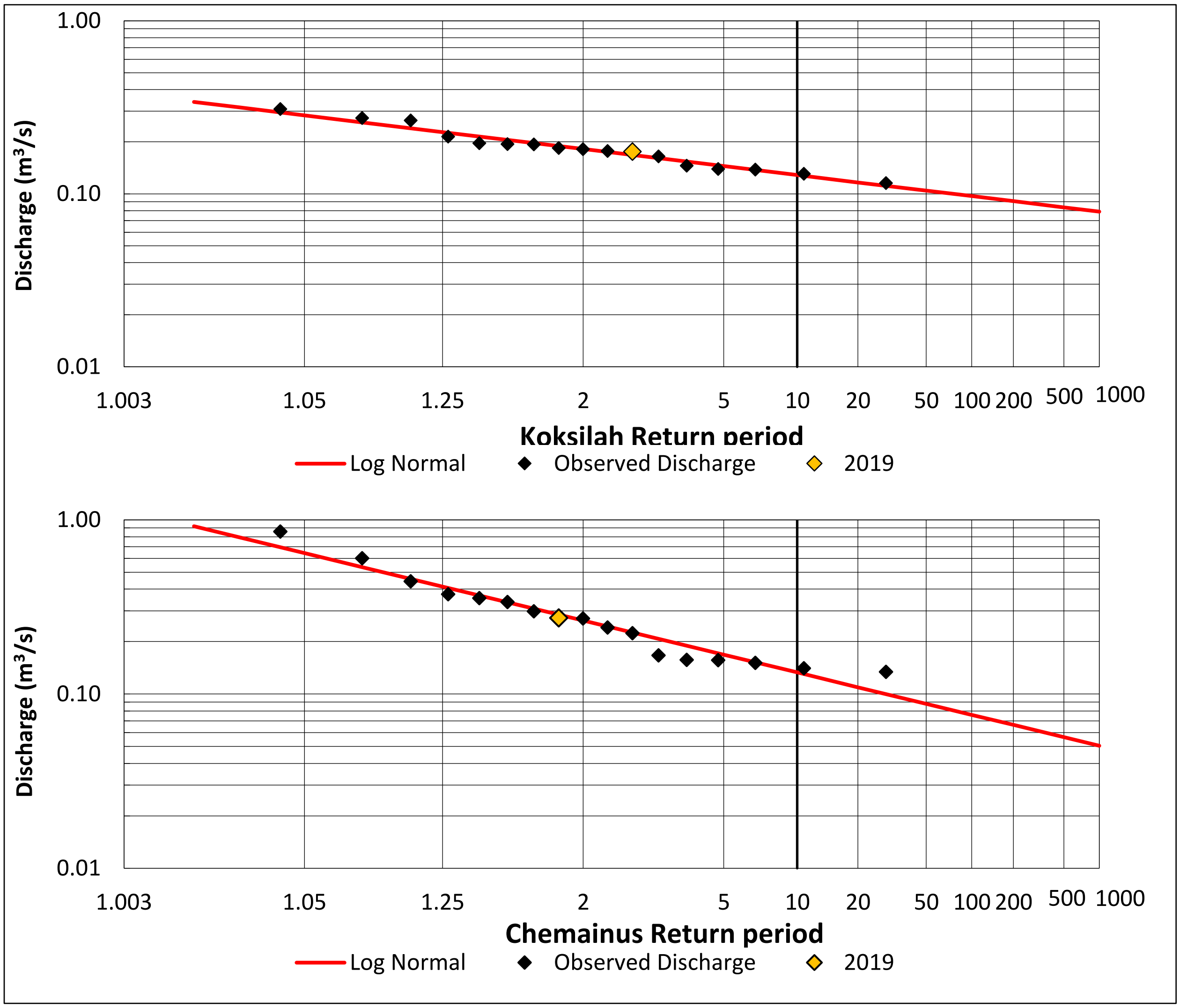



**Figure 6 Frequency analysis of annual 7-day low flows from 2002 to 2011 and 2013 to 2019**

# 4 LIMITATIONS

This analysis uses preliminary discharge data for 2019 from WSC gauge Koksilah at Cowichan Station (08HA003). It was noted by the WSC (Leigh Sinclair, personal communication, March 26, 2020), that reported discharges on the Koksilah River could have significant changes due to deviations from the current rating curves. WSC may revise discharges that deviate from the rating curve by more than 5% due to possible inaccuracies (WSC, 2020). NHC obtained the rating curves and shifts for the 2019 year, recalculated discharge, and completed a quality control and quality analysis of the preliminary data.

The frequency analysis was limited to a small subset of available annual low flow data due to the significant decades-scale downward trend in 7-day annual low flows. Additional data and further analysis of low-flow hydrology would be required for more accurate 7-day low flow return periods. Further future analysis, after establishing long-term gauges, could include determination of trends, or lack of, in 7-day annual low flows on significant tributaries (Kelvin Creek on the Koksilah River, and Nugget and Banon Creeks on the Chemainus River) and calculation of return periods on these tributaries for reference to the Koksilah and Chemainus rivers. The return periods provided in this analysis are only approximations.

# 5 CONCLUSIONS AND RECOMMENDATIONS

A water extraction curtailment was ordered by FLNRORD in August 2019 to alleviate stress on fish populations due to aquatic habitat degradation from low flows in the Koksilah River. Analysis of the available data indicates the curtailment allowed flows to increase in the following weeks until the drought period ended.

The annual 7-day low flow of 0.18 $m^3/s$ occurred on August 16 and had an approximately 2- to 3-year return period. The 7-day annual low flows show a decreasing trend since 1955. For the past six years including 2019, the 7-day low flows have been less than 2% of the annual mean discharge. In comparison, the 7-day low flow on the Chemainus river occurred on September 6, 2019. Without the curtailment, the Koksilah River low flow could have been between 0.16 $m^3/s$ and 0.18 $m^3/s$ by September 11, 2019. The measured Koksilah River discharge post-curtailment on September 11, 2019 was 0.31 $m^3/s$, which is approximately 50% greater than estimated low flows without curtailment.

The curtailment also resulted in a significant recovery of groundwater levels, which may have further contributed to the increased flow on the Koksilah River. However, further analyses of groundwater levels and river levels, as well as hydrogeologic assessments, would be required to assess if the river is gaining water from or losing water to the groundwater system.

The following are recommended for future consideration:

- Conduct field reviews of the gauging locations, as well as review the discharge measurement and data processing procedures.
- Continue discharge measurements focussed on low flows for at least ten years to facilitate stronger statistical trends and analyses. The Chemainus River is a good comparison watershed; consideration should be given to obtaining high quality low flow measurements in the lower reaches.
- Complete a detailed hydrogeological study of the groundwater system and groundwater data to better understand surface water/groundwater interactions.
- Develop/expand a targeted public education initiative about water use and environmental impacts.
- Increase monitoring of groundwater and surface water extraction volumes and rates.

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