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Water Use and Management in the Koksilah River Watershed

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EXECUTIVE SUMMARY

The Koksilah River on southeastern Vancouver Island is prone to low flows during the summer dry season, potentially affecting habitat suitability and the survival of aquatic life including salmonid species. Enactment of B.C.'s *Water Sustainability Act* (WSA) in February 2016 provides new tools for integrating surface and groundwater management. Along with licensing of non-domestic groundwater use, the Act enables protection of environmental flow needs, requires consideration of potential hydraulic connection between groundwater and surface water sources, and contains tools to regulate water use during times of scarcity to protect fish and aquatic life, and to protect the rights of senior rights holders. A major change within the WSA is the recognition that surface water and groundwater sources are integrally linked, and that groundwater extraction can influence availability of water in hydraulically connected surface water systems. This report examines some of the questions involved in implementation of the Act in the Koksilah watershed including quantification of groundwater demand after years of unregulated groundwater development, and identification of where and how groundwater use may be influencing surface water flows.

Although a restriction on issuing surface water licences on the Koksilah River and tributaries was imposed in 1980, total water demand in the watershed increased since that time due to unregulated groundwater development (pre-2016). Groundwater flux to the Koksilah River is understood to be an important influence on environmental flow needs, providing base flow and maintaining instream conditions, such as cooler water temperatures, that benefit aquatic species. Aquifers and wells in the watershed have been interpreted to be hydraulically connected to the Koksilah River and associated sub-tributaries, and groundwater pumping is therefore believed to be contributing to impacts on streamflow. Inferred stream depletion is concentrated within the middle and lower sections of the watershed where there is the greatest usage of water, coincident with areas historically associated with preferred aquatic habitat for salmonid species. Cumulative impacts from many wells distributed across large aquifer areas, uncertainty regarding water use volumes, and variable lag times between the period of pumping and depletion effects, contribute to the challenges associated with water management in this watershed.

In recent years, flows in the Koksilah River have diminished to levels where the healthy condition of aquatic habitats and the survival of fish populations are likely threatened. A groundwater curtailment model was developed to identify groundwater use that, if stopped temporarily, would help improve instream flows should they reach a critical point where significant harm to survival of aquatic species was likely. Community outreach, compliance enforcement, and the requesting of voluntary reductions in surface and groundwater use have been implemented in the watershed in attempts to improve instream flows. Despite these efforts, a Temporary Protection Order (TPO) under WSA section 88 was issued in 2019 that required specified users to curtail groundwater and surface water use. Monitoring results demonstrated that the TPO likely resulted in an increase in streamflow compared to historical conditions and anticipated seasonal streamflow recession in the absence of rainfall.

This report summarizes the current understanding of surface and groundwater use in the Koksilah watershed and details the science used to guide management actions during the summer low-flow period in 2019 and required to undertake management of water resources in the watershed in subsequent years. Recommendations are provided for future monitoring, technical assessment and planning, needed to address equitable water resource distribution and protection of Indigenous water rights, while maintaining minimum streamflow for the protection of aquatic life. This case study will be of interest to the public, researchers and water managers in this region and in other areas of B.C. facing similar water resource challenges.

CONTENTS

FIGURES

TABLES

ACRONYMS

BED	Bedrock aquifer
CPD	Cumulative Precipitation Departure
CEFT	Critical Environmental Flow Threshold
DEM	Digital Elevation Model
DTSID	Distributed Temperature Sensing to Identify groundwater Discharge
EFN	Environmental Flow Needs
ENV	Ministry of Environment and Climate Change Strategy
FITFIR	First in Time First in Right
FLNR	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GWELLS	Groundwater Wells and Aquifers Database (https://apps.nrs.gov.bc.ca/gwells/)
LWSA	Local Water Service Area
m	metres
masl	metres above sea level
MAD	Mean Annual Discharge
MAF	Mean Annual Flow
OW	Observation well
PAU	Primary Actual Use
PET	Potential Evapotranspiration
PGOWN	Provincial Groundwater Observation Well Network
PID	Parcel Identifier
PoHC	Point of Hydraulic Connection
SDF	Stream Depletion Factor
SDM	Statutory Decision Maker
TPO	Temporary Protection Order
UC	Unconsolidated-confined aquifer
UU	Unconsolidated-unconfined aquifer
WSA	*Water Sustainability Act*
WSP	Water Sustainability Plan
WSR	Water Sustainability Regulation

1. INTRODUCTION AND PROJECT OUTLINE

The Koksilah River on southeastern Vancouver Island (Figure 1) is prone to low flows during the summer dry season, potentially affecting habitat suitability and the survival of aquatic life including salmonid species. Historically, the Koksilah watershed has provided habitat for fish species including Chinook and Coho salmon, and steelhead, rainbow and cutthroat trout (Marshall, et al., 1976; Lister, et al., 1981); however, based on limited data, the populations of many of these species have declined over the last several decades (Tutty, 1984; Department of Fisheries and Oceans, 2019). While salmonid population declines in streams in North America's west coast have been linked to factors such as land use, water pollution, surface and groundwater extraction, climate change, overharvesting, predation, and declining marine survival (Grant, et al., 2019), the relative importance and impacts of these factors in the Koksilah watershed is still not fully understood (Pritchard, et al., 2019).

The Koksilah watershed is within the traditional territory of the Coast Salish peoples, including Quw'utsun' (Cowichan) Tribes, Malahat Nation, Halalt First Nation, Ts'uubaa-asatz (Lake Cowichan) First Nation, Lyackson First Nation, Stz'uminus First Nation, Penelakut Tribe, and T'sou-ke First Nation (FLNR, 2020b). Koksilah River has cultural and spiritual importance within the oral and written histories of the Cowichan people (Marshall, 1999). The origin story of the Quw'utsun' people describes how the first man, *Syalutsa*, fell from the sky at *Quwutsun* (Koksilah Ridge). *Hwulqwselu* was a traditional village site on lower Koksilah River, and the river was a source of food fisheries and location of spiritual bathing (Marshall, 1999; Pritchard, et al., 2019). The ancestral and present link between indigenous peoples and the Koksilah River watershed underpins current collaborative efforts to understand the pressures influencing the health of the watershed and associated fisheries.

The Koksilah River does not have a dam structure or large lake that could provide storage to augment streamflow during periods of low precipitation. Flows in the river respond to inputs from rainfall and are naturally low during in the summer period (Northwest Hydraulic Consultants Ltd., 2020). As described in this report, licensed and unlicensed use of surface water from the Koksilah River and its tributaries and groundwater diversions from hydraulically connected aquifers are suspected to impact the volume of seasonal and daily river flow. Peak demands for surface and groundwater are greatest during the dry season (summer months), which correspond to the time of year when water availability in the stream is naturally low.

Reduced water availability during the summer months in the Koksilah River has been documented as early as 1980, when surface water allocation restrictions were imposed and the first water management plan was developed that focused on surface water use in the watershed (Tutty, 1984; Ministry of Environment and Parks, 1986). With the enactment of the *Water Sustainability Act* (WSA) in 2016, attention toward the watershed was renewed as requirements to consider impacts of both surface and groundwater use on stream health were introduced (Province of B.C., 2018a). Work began to determine a critical environmental flow threshold (CEFT) (Szczot, 2020), the daily minimum discharge established for a particular reach or section of the stream, below which significant irreversible impacts on aquatic life and fish populations could occur. At the same time water managers considered actions that could be taken to maintain or restore minimum streamflow requirements to prevent detrimental impacts to aquatic species.

Streamflow at the existing hydrometric station was closely observed in the summer of 2017, and in 2018 additional surface water monitoring stations were installed. During these periods provincial water authorizations staff focused on communicating with water users and requesting voluntary reductions in surface and groundwater use when stream discharge was declining to a level of concern. At the same time management actions, such as curtailment of surface and groundwater use under a Temporary Protection Order (TPO), were explored should streamflow decline below critically low levels. In order to determine which groundwater users might be considered for curtailment, a groundwater curtailment model was developed in 2018 that compiled information on aquifers within the watershed and the locations and estimated quantities of groundwater use (Barroso & Wainwright, 2018).

In 2019, declining flows in the Koksilah River during the late spring and summer period were observed. A revised groundwater curtailment model was developed using additional data inputs and approaches, which incorporated learnings from the 2018 study and other recent work on the hydraulic connection of surface and groundwater (Sivak & Wei, 2019). In August 2019, provincial biologists believed that flows in the Koksilah River were so low that the survival of populations of resident and anadromous fish species, including steelhead, could be threatened. On August 16, 2019, a TPO under section 88 of the WSA was issued in the Koksilah watershed. It was the first time in British Columbia that this section of the WSA was applied to both surface and groundwater users to mitigate low flows for the protection of aquatic ecosystems and fish populations.

In February 2020, in recognition of the importance of the Koksilah River to Indigenous rights, economic interests, and employment, a historical agreement was signed between Cowichan Tribes and the Minister of Forests, Lands, Natural Resource Operations and Rural Development (FLNR) to scope the development of a plan for water sustainability in the Koksilah watershed. Initial work for the scoping project involves developing a shared understanding of the factors contributing to the low flows in the river as well as stakeholder and community outreach.

This report provides a summary of the best available information on surface and groundwater demand in the watershed and the technical analysis which informed management options during the low-flow summer periods in 2018 and 2019, needed to guide future work in this area.

1.1 Objectives

A key element required to understand influences on streamflow and seasonal water availability in the Koksilah River watershed is an estimation of the volume and timing of surface and groundwater use. The objectives of this study were to:

a) Compile information on licensed surface water use by sector and review the history of water allocation in the watershed;
b) Use available information to estimate groundwater use by sector, and catalogue the methods used to develop and verify these estimates;
c) Describe new requirements and approaches to water management under the WSA including licensing of non-domestic groundwater use, understanding hydraulic connection between aquifers and streams, considering environmental flow needs in management decisions, and considering mechanisms for addressing water scarcity;
d) Outline strategies such as communication, outreach and regulatory actions taken in the watershed in 2018 and 2019;
e) Describe the methods, technical considerations, and results of the groundwater curtailment model; and,
f) Summarize identified data gaps and recommendations for additional work.

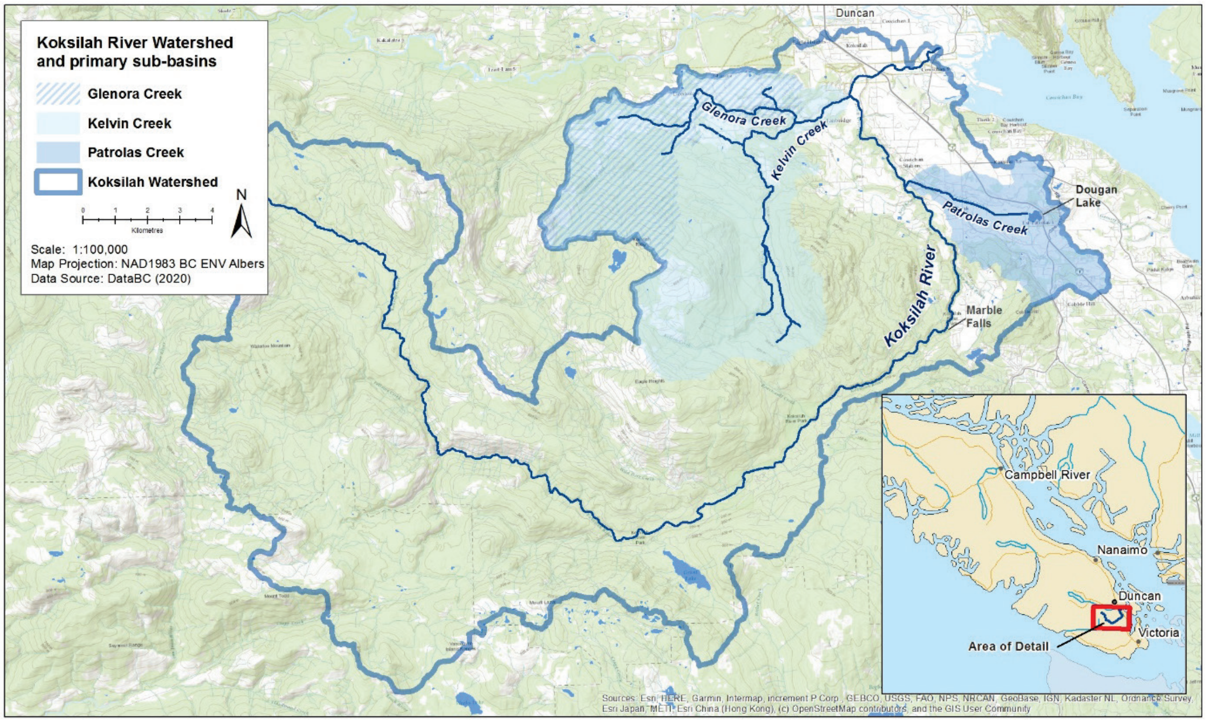


Figure 1: Koksilah River watershed and primary sub-basins, Vancouver Island.

1.2 Study area

1.2.1 Climate

The Koksilah watershed is located within the Coastal Douglas Fir moist maritime (CDFmm) biogeoclimatic zone (Ministry of Forests, Lands and Natural Resource Operations, Research Branch, 2014) and has a climate characterized by warm dry summers and cool wet winters (Peel, et al., 2007). Precipitation patterns are influenced by the rain shadow of the Vancouver Island Range to the west and the Olympic Mountains to the south. Most of the annual precipitation in the watershed falls as rain between November and March. With elevations around 800-1000 metres above sea level (masl), the upper watershed receives approximately twice the precipitation (average 2850 mm per year at the headwaters) compared to the lower watershed (average 1119 mm per year at the mouth). On average, 1975 mm of precipitation falls over the watershed annually (Northwest Hydraulic Consultants Ltd., 2020).

The longest climate record available for this area is from the Shawnigan Lake station (Environment Canada EC 1017230, elevation 159 masl), 3 km southeast of the watershed. Climate normals (1981-2010) for the Shawnigan Lake station are shown in Figure 2. During the period of record from 1913-2019, on average, 93% of total precipitation was rainfall. The statistical variation (mean, median and quartile spread) of monthly precipitation during the 1913 to 2019 period is presented in Figure 3, which illustrates there is greater variability in precipitation during wetter months (October to March) compared to drier months (April to September). As shown in Figure 4, total annual precipitation measured for a water-year (October 1 to September 30) is primarily dependent on rainfall during the winter season (October to March); winter precipitation is also the major source of groundwater recharge which maintains river baseflow in the summer.

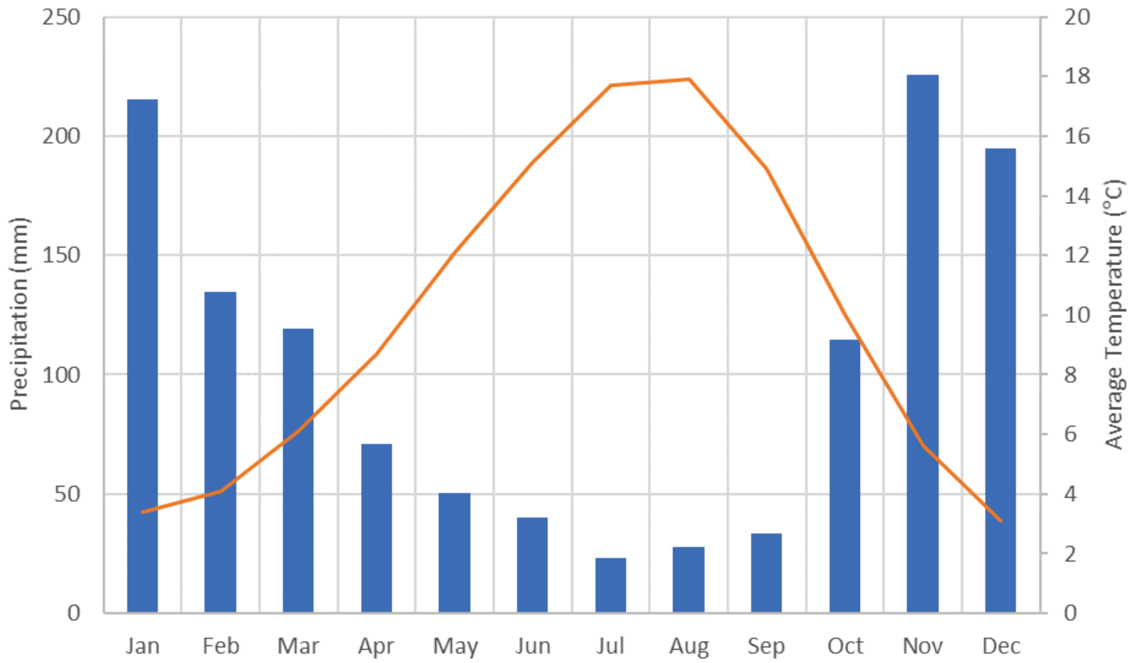


Figure 2. Average monthly temperature and precipitation for Shawnigan Lake station (EC1017230) for the period 1981 to 2010 (Environment Canada, 2020).

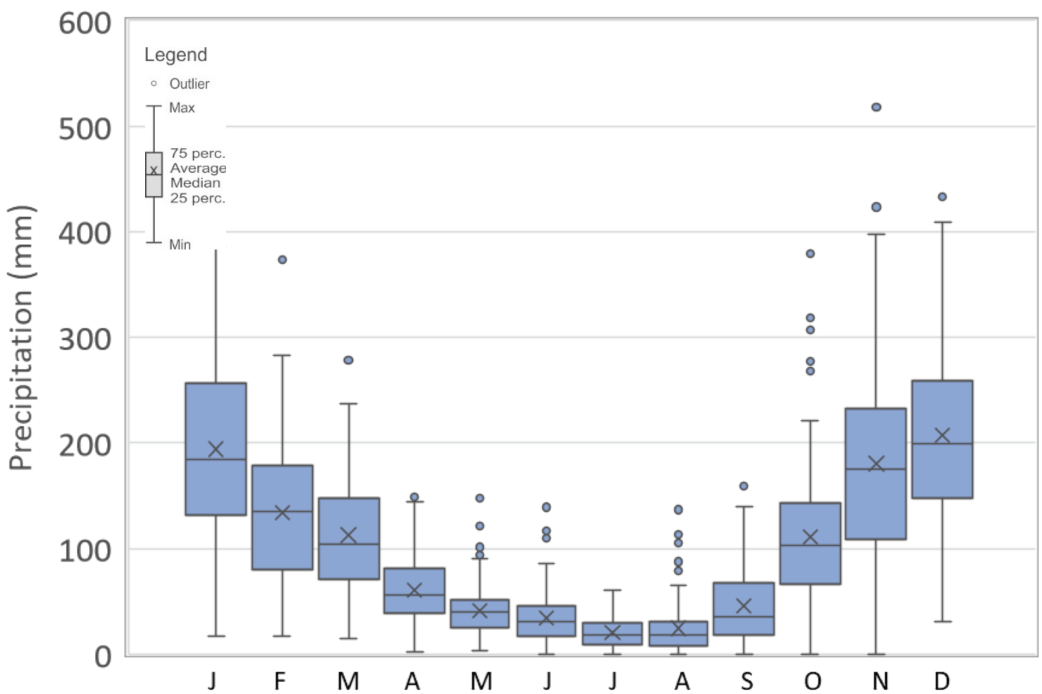


Figure 3. Quartile boxplots of monthly precipitation Shawnigan Lake climate station (1017230) 1913-2019. (Blue box outlines the 1st, 2nd (median) and 3rd quartile of the data, X indicates average, whiskers or lines above and below the box show maximum-minimum spread of the data, and small circles indicate potential outliers).

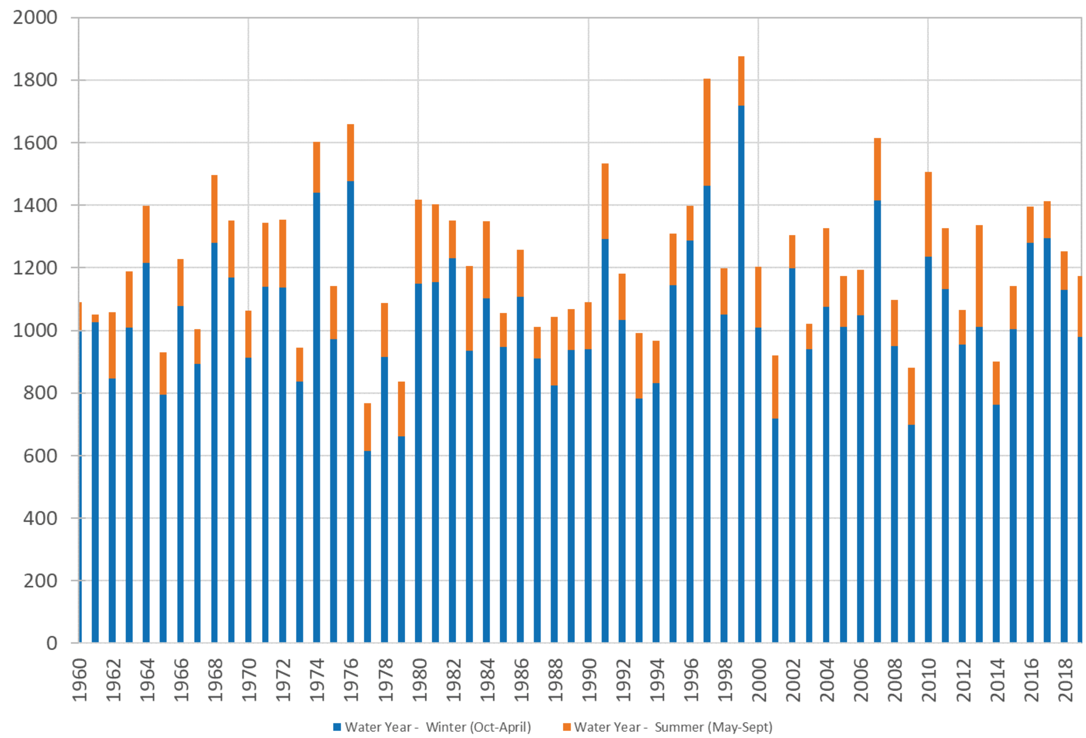


Figure 4. Total annual precipitation during water year (October 1 to September 30), separated into winter and summer periods. Data from Shawnigan Lake station (EC1017230) for period 1960-2019.

Since the start of climate monitoring, significant changes have occurred to forest cover and land-use in both Koksilah and Shawnigan watersheds, potentially influencing the measured temperature and precipitation. Additional statistical analysis of the climate record that could be completed include regression analysis, t-tests, Mann-Kendall tests, and consideration of factors affecting annual water balance in the watershed and in this region (Weber & Stewart, 2004). Climatic conditions during the spring and summer are expected to influence water demand, for example irrigation is likely to start earlier, continue longer, and require greater inputs based on a longer duration dry season and higher temperatures (Cowichan Valley Regional District, 2017). While differences in air temperature and land cover (e.g. forest seral stage, crop type) influence potential evapotranspiration and runoff (Smerdon, et al., 2009; Brown, et al., 2004; Hargreaves & Samani, 1985).

1.2.2 Surficial and bedrock geology

Based on terrain classification mapping for Vancouver Island, surficial geology within the uppermost Koksilah watershed consists mainly of shallow colluvial and deep moraine deposits (Blyth, et al., 1993; Guthrie, 2005). Fluvial and glaciofluvial materials are found along the major river drainages such as Koksilah mainstem, while marine and glaciomarine deposits are found along the coast at Cowichan Bay, Satellite Channel and Saanich Inlet. The surficial geology mapping as shown in Figure 5 represents a simplified summary of regional characteristics, as material types and thicknesses vary at the site-scale. Aquifers in this region, discussed further in section 2.1, may be made up of unconsolidated or loose sedimentary materials, such as the fluvial and glaciofluvial deposits with a relatively high permeability; wells in these types of materials tend to be more productive. Moraine deposits typically composed of compact gravelly clay and silt, with low permeability, form confining layers that overly and provide protection to aquifers from contaminants introduced at the land surface. Movement of groundwater through fine lacustrine and marine clays is also slower, and these materials can provide some confinement and protection from contamination if present over an aquifer.

Bedrock in the Koksilah watershed is divided into three primary classes that are separated by major fault structures (Cui, et al., 2017) as shown in Figure 6:

a) Metamorphic and intrusive igneous: At the highest elevations on the south side of the watershed, metamorphic and intrusive igneous rocks are found such as quartz diorite, tonalite, gneiss, amphibolite, diorite, gabbro, marble and metasedimentary rock (West Coast Crystalline Complex);
b) Volcanic basalt: In the central watershed the bedrock is mainly volcanic basalt including basaltic pillowed flows, pillow breccia, hyaloclastite tuff and breccia, massive amygdaloidal flows, minor tuffs, interflow sediment and limestone lenses (includes Vancouver Group Karmutsen Formation);
c) Sedimentary: Bedrock in the lower part of the watershed to the north, included conglomerate, sandstone, siltstone, shale, and coal (Nanaimo Group); and,
d) Limestone: Interspersed across the central part of the watershed, smaller deposits of limestone are mapped, which are part of the Buttle Lake Group-Mount Mark Formation (light green in Figure 6). Marble Falls is one location on the Koksilah River where limestone is present, however the degree or presence of permeable karst formations associated with the limestone deposits and their interrelationship to the river is not known.

In aquifers made up of bedrock, discussed further in section 2.1, groundwater is stored and moves mainly through cracks and fractures in the rock. Weathering along fractures and holes in the limestone can increase the velocity and movement of groundwater through these types of rocks.

1.2.3 Land use

The Koksilah watershed encompasses portions of the Cowichan Valley Regional District electoral areas B, C, D, E and F, which include the communities of Shawnigan Lake, Cobble Hill, Cowichan Bay, Cowichan Station/Sahtlam/Glenora, and Cowichan Lake/Skutz Falls, respectively (CVRD, 2020). Land use within the watershed is predominantly private managed forest, which encompasses approximately 66% of the watershed (B.C. Assessment Authority, 2018a). Within the developed areas in the lower watershed, the primary land uses are residential and agricultural as described in Table 1 and Figure 7 (B.C. Assessment Authority, 2018a).

Table 1: Inferred area and land use categories in the Koksilah watershed (B.C. Assessment Authority, 2018a).

Actual Use Code (AUC) Category*	**Total area (km^2)**	**Percent of total**
Residential	29	46.8
Agricultural	20.7	33.4
Civic/Institutional/Recreational	9.7	15.6
Industrial	1.7	2.7
Commercial	0.6	1
Transportation/Communication/Utility	0.4	0.6
Total non-vacant/known parcels (categories above)	62	20
Vacant parcels	218	70
Unknown (no data)	32	10
Total	312	

*Excludes private managed forest lands (66%) and other parcels categorized as vacant and unknown (14%).

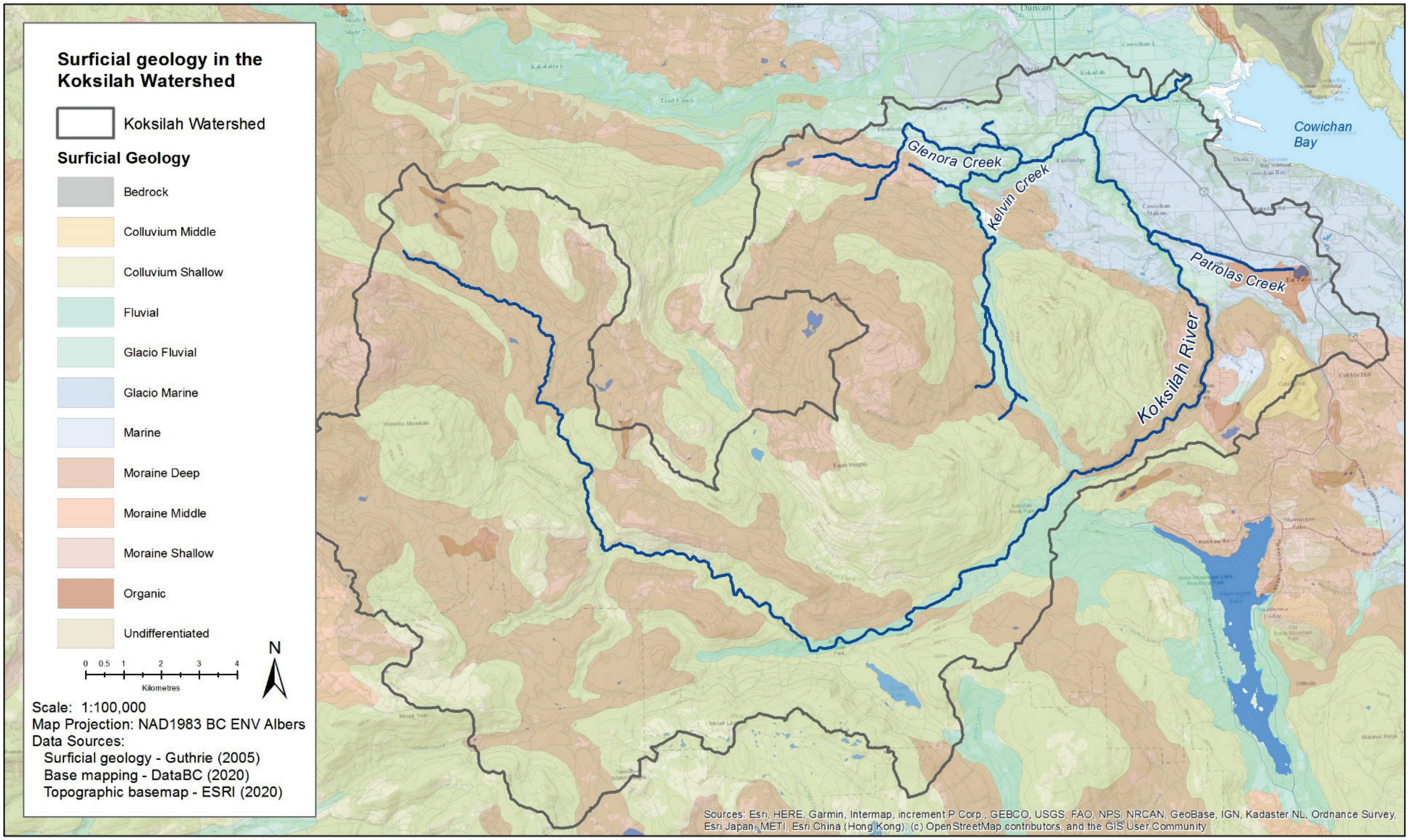


Figure 5. Surficial geology in Koksilah watershed (Blyth, et al., 1993).

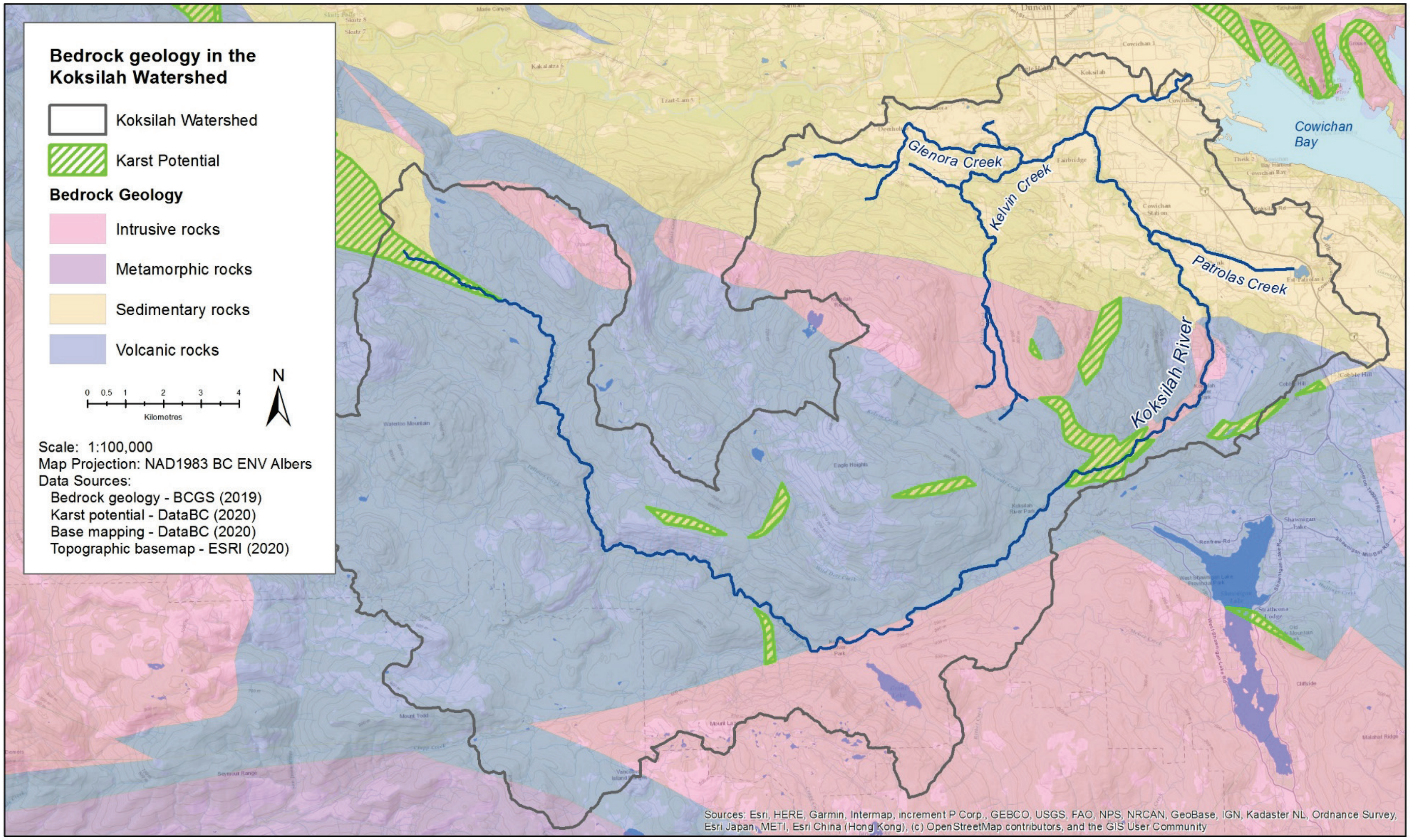


Figure 6. Bedrock geology in Koksilah watershed (Cui, et al., 2017).

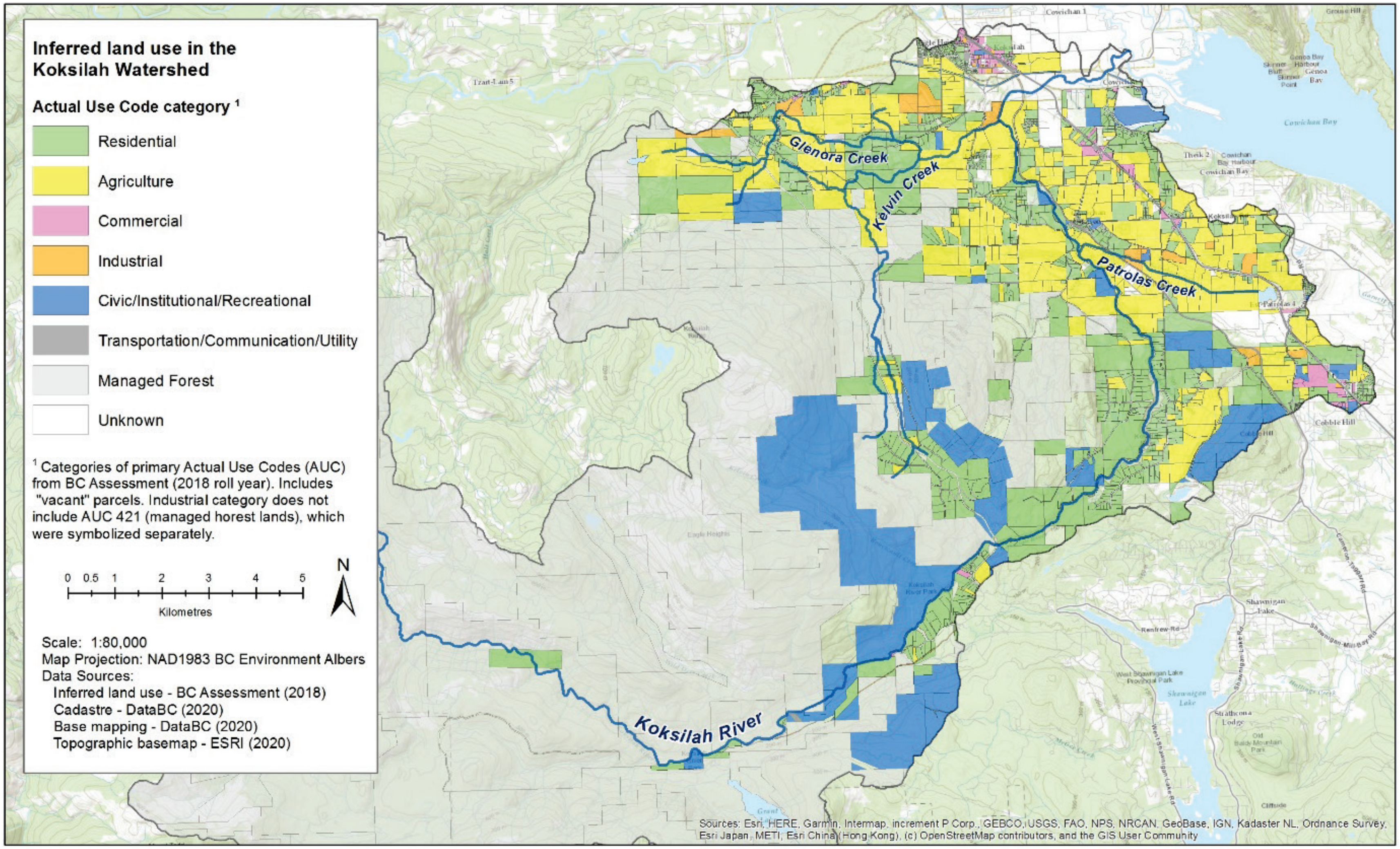


Figure 7: Inferred land use in the Koksilah watershed.

1.3 Hydrology

The Koksilah River watershed has a drainage area of 312 km^2 and contains three major sub-tributaries (shown in Figure 1): Patrolas Creek, Glenora Creek, and Kelvin Creek. Flows in the river are predominantly influenced by rainfall inputs, with the greatest discharge observed in winter months, and the lowest flows observed from June to September annually (Government of Canada, 2020; Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2020a). Historic and recent hydrologic monitoring in the watershed has included stream gauge (level), discharge, and temperature measurements, which have been collected continuously year-round and periodically during the low-flow period. Monitoring stations in the Koksilah watershed are shown in Figure 9.

Based on the long-term streamflow record (1960-2018) from Koksilah River at Cowichan Station (08HA003) (Figure 9 and Figure 10), discharge is greatest November to April, and lowest June to September. A statistical summary of the long-term record based on station data summarized using the BC Water Tool (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2020a) is provided in Table 2 (Note: Statistics exclude January 1979, July-Aug 2012 and 2019 due to incomplete record, or unverified data). Figure 11 shows mean discharge during August, separated by decade from 1960-2018. Average, median and quartile (25^{th}, 75^{th}) August flows at this station appear to have declined over time; minimum flows in August have diminished overall and have declined below 200 L/s within the past four decades despite annual precipitation increasing slightly. Observed minimums in the 1980's reached lows similar to what was observed in the most recent decade (2010-2018). A detailed analysis of the hydrology of the Koksilah watershed including evaluation of low flows is included in a report by Hatfield Consultants (2021).

*Table 2: Koksilah River at Cowichan Station (08HA003) mean monthly discharge statistics (1960-2018).**

	Discharge (m^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Max	42.18	59.15	35.09	20.36	8.97	5.77	7.19	2.28	2.23	47.32	48.46	46.22
75th Percentile	30.02	23.37	19.89	12.22	4.79	1.84	0.79	0.47	0.75	5.18	24.64	30.56
Average	22.97	18.19	15.18	9.04	3.70	1.53	0.74	0.39	0.64	5.26	17.79	22.10
Median	21.55	16.23	13.97	8.51	3.59	1.23	0.56	0.33	0.44	3.20	15.57	21.63
25th Percentile	15.94	11.16	9.21	5.90	2.22	0.90	0.42	0.23	0.31	1.16	9.80	14.10
Min	4.75	5.41	4.08	2.71	0.89	0.30	0.19	0.15	0.18	0.21	2.39	3.20
StDev	8.84	9.51	7.09	4.00	1.89	0.95	0.92	0.29	0.53	7.45	11.43	10.12

**Excludes data from January 1979, and July-Aug 2012.*

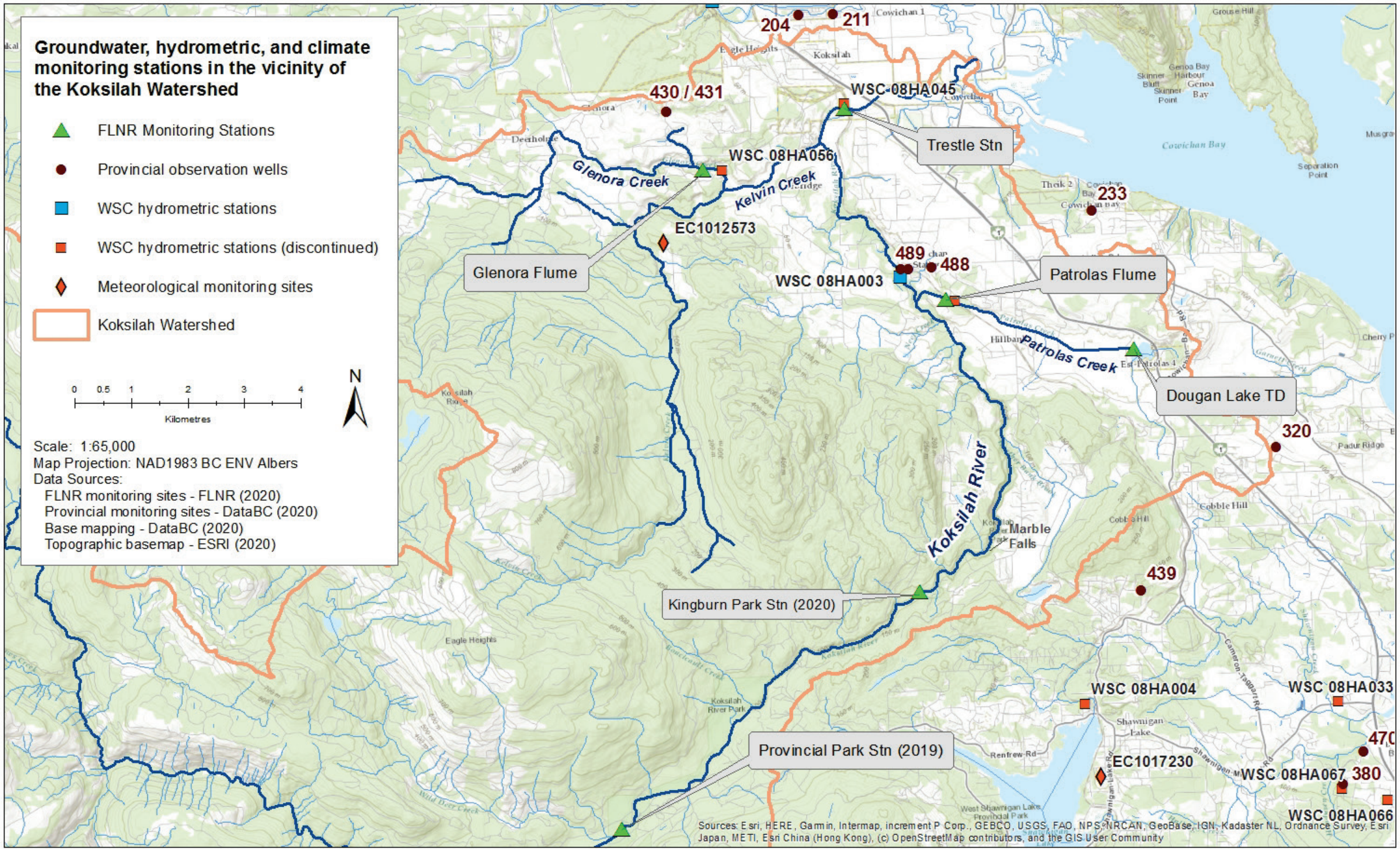


Figure 8: Monitoring stations in the Koksilah watershed.

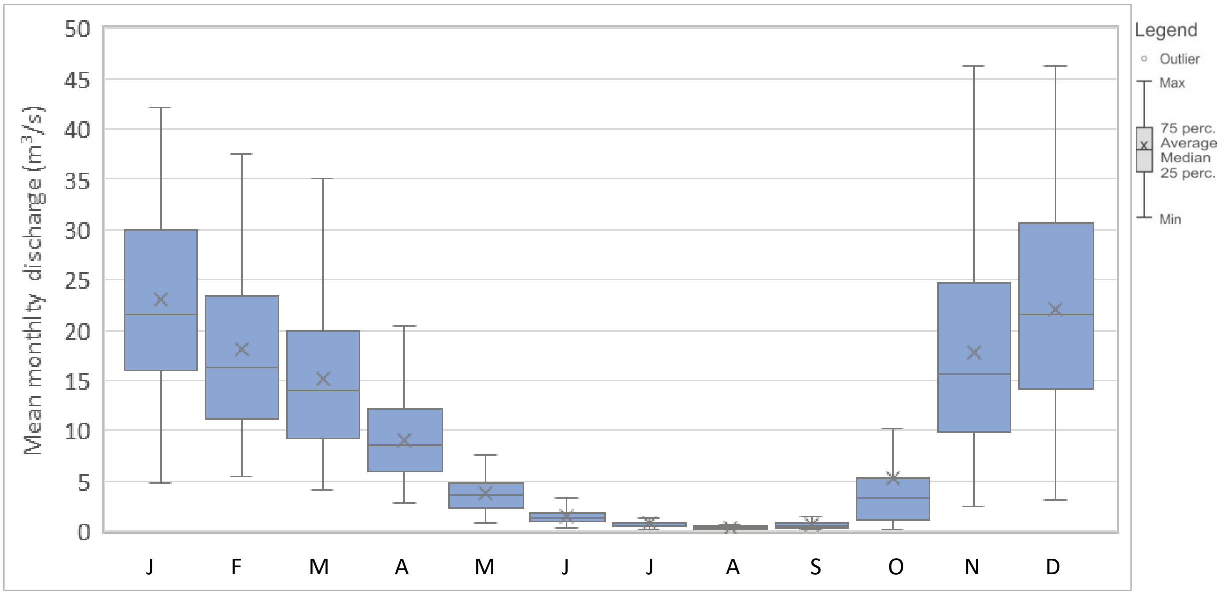


Figure 9: Koksilah River at Cowichan Station (08HA003) box-whisker plots of mean monthly discharge (1960-2018).

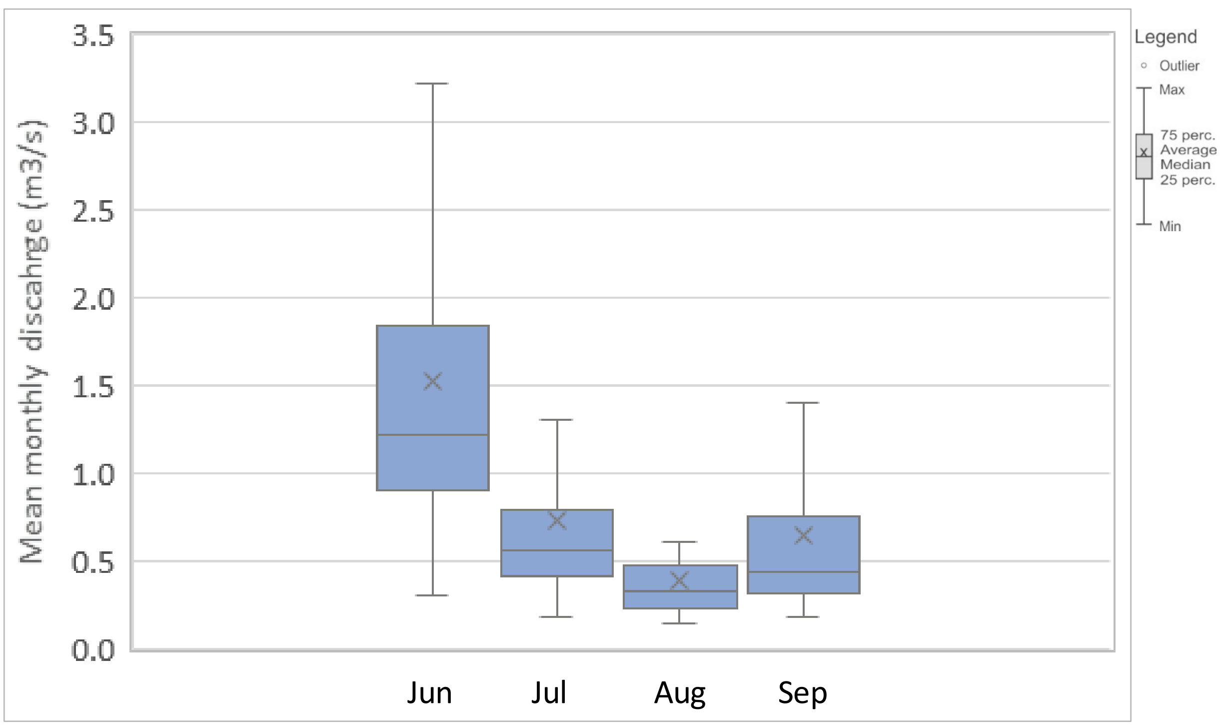


Figure 10: Koksilah River at Cowichan Station (08HA003) box-whisker plots of mean monthly discharge, June-September (1960-2018).

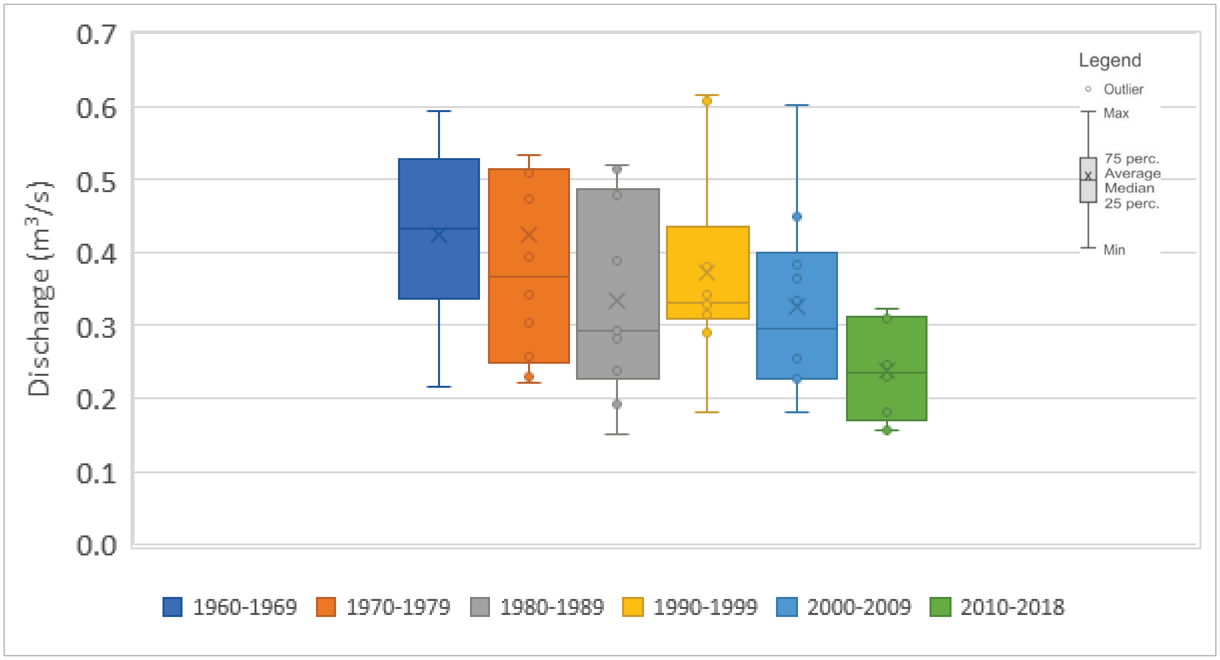


Figure 11: Koksilah River at Cowichan Station (08HA003) box-whisker plots of mean monthly discharge in August by decade (1960-2018).

1.4 Salmonid populations and habitat

The Koksilah River has populations of salmonid species including Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), Chum (*Oncorhynchus keta*), and steelhead (*Oncorhynchus mykiss*) (Marshall, et al., 1976; Tutty, 1984; Pritchard, et al., 2019). Within historical studies the locations of greatest habitat suitability were identified primarily within the lower watershed, including near the Cowichan-Koksilah River estuary and within the Glenora Creek and Kelvin Creek sub-watersheds and lower Koksilah mainstem (Marshall, et al., 1976). Marble Falls, shown in Figure 8, was considered a barrier to upstream migration and inaccessible by most species apart from steelhead and some Coho; a fish passageway at the falls was built in 1980 to increase access to upstream habitat (Marshall, et al., 1976; Pritchard, et al., 2019).

As a tributary to the Cowichan River, the Koksilah River was historically included within fisheries habitat studies, population estimates, and flow needs assessments for the Cowichan River system and eastern Vancouver Island watersheds. Pritchard et al. (2019) summarized the numerous evaluations and projects aimed at improving habitat conditions and colonizing streams and lakes in the Koksilah watershed with hatchery stock, dating back to the 1920s. Based on limited data, populations of Coho, Chinook and steelhead in the stream have declined since the 1980s in comparison to historic numbers (Szczot, 2020). For example, Figure 12 displays historic data for escapement (the estimated number of adult spawning fish returning to the stream) for the Koksilah River showing greater overall decline in numbers of Chinook and Coho, compared to Chum (Kevin Pellet, Department of Fisheries and Oceans, personal communication, September 11, 2019). Recent fish counts are not available, apart from steelhead population estimates from snorkel surveys (data not shown), which also indicate declines in steelhead population compared to historic numbers (Szczot, 2020).

Several recent studies discuss the impacts of climate-change related factors on Pacific salmon, including increased vulnerability of species which inhabit freshwater streams for a longer duration, or whose critical life stages (spawning, rearing, migration) are being impacted by variability and timing of seasonal flows (Crozier, et al., 2019; Grant, et al., 2019; Neilitz, et al., 2007).

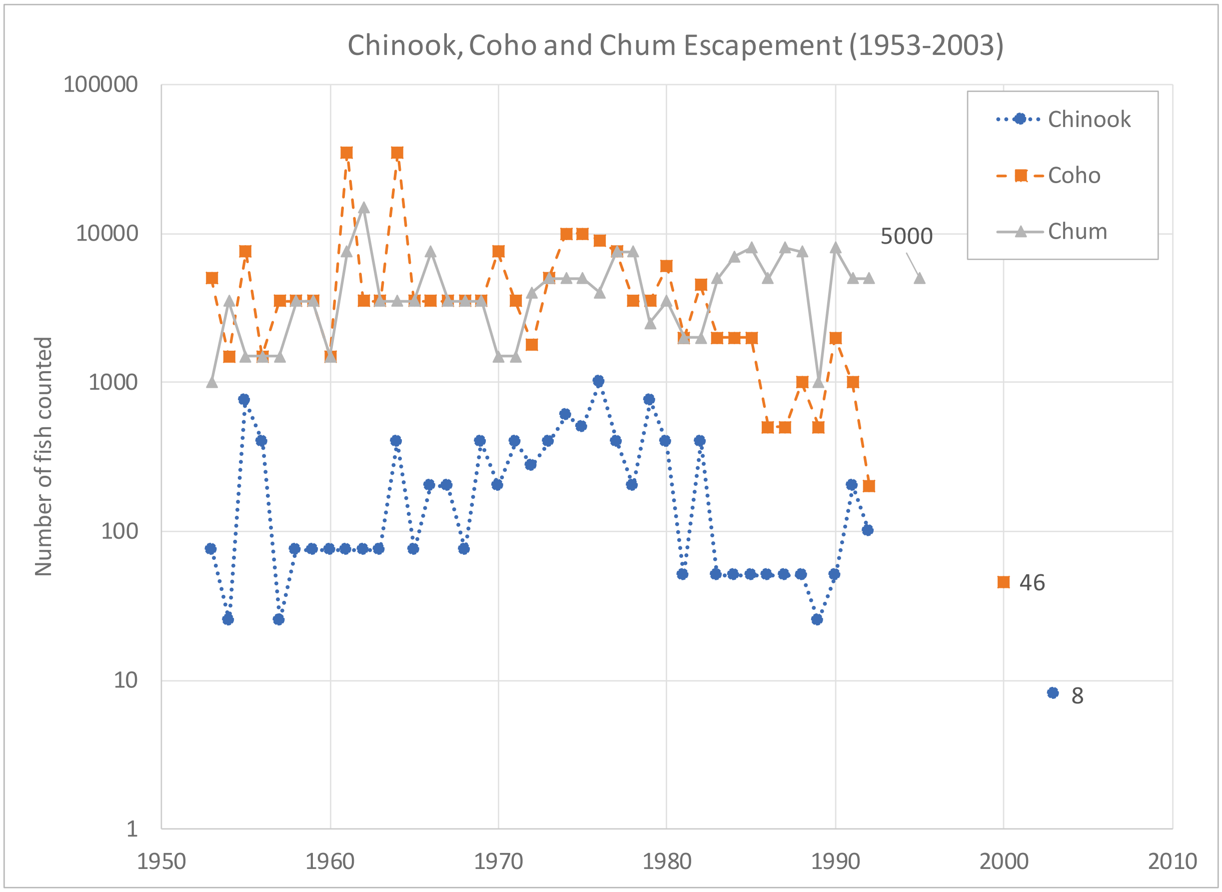


Figure 12: Chinook, Coho and Chum escapement recorded by Department of Fisheries and Oceans (1953-2003).

Concerns related to low summer streamflow and impacts on fish habitat and survival were identified in a 1984 report by Brian Tutty (Federal Department of Fisheries and Oceans) entitled "The Koksilah River: Streamflows and Salmon Production." Tutty (1984) reported that seasonal flows in the river were insufficient to sustain salmon populations and that no further licensing, unless supported by off-stream storage, should be considered. Furthermore, it was recommended that water allocations be compared to actual use and licenses be amended accordingly. The report also made mitigation recommendations including development of a water management plan, consideration of headwater storage for fish flow releases, maintenance of a minimum fish flow of 15 cubic feet per second (425 L/s), and implementation of a salmon colonization plan.

A Cowichan-Koksilah water management plan developed in 1986 concluded that low seasonal flows from June to October were adversely impacting the availability of aquatic habitat for critical life stages such as rearing, migration and spawning. Decreased rearing productivity was linked to high water temperatures, reduced dissolved oxygen and increased predation and mortality in dewatered reaches. Cumulative impacts from land use (e.g., change in drainage patterns, water pollution, and channel modification) were also identified as concerns impacting fisheries productivity (Ministry of Environment and Parks, 1986).

When the WSA came into force in 2016, it defined environmental flow needs as "the volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream" (Province of B.C., 2018a). In comparison, a critical environmental flow threshold (CEFT) is defined in the WSA as the flow of water in a stream "below which significant or irreversible harm to the aquatic ecosystem of the stream is likely to occur." The new Act requires decision makers to consider the impacts on environmental flow needs caused directly through surface water withdrawals, or indirectly from groundwater diversions from hydraulically connected aquifers. To assist in understanding potential impacts of water allocation on environmental flows, work began in 2018 to estimate the minimum flow needed to maintain suitable habitat for anadromous fish species during instream life stages. A preliminary analysis of minimum environmental flow requirements for the Koksilah River watershed is outlined in Szczot (2020); see also further discussion in section 5, below.

Standards for environmental flows in B.C. are based on a modified Tennant method, which links seasonal variations in ecological, hydrologic and geomorphologic conditions in a stream to different levels of flow as a percentage of mean annual discharge (Ptolemy & Lewis, 2002). Methods for development of environmental flow guidelines and assessment of impacts to aquatic ecosystems are summarized in Hatfield, et al. (2003a; 2003b; 2007) and Lewis, et al. (2004). The Provincial policy and framework for considering impacts of surface and groundwater diversion on environmental flows is included in the Environmental Flow Needs Policy (Ministry of Forests, Lands and Natural Resource Operations and Ministry of Environment, 2016).

2. GROUNDWATER SOURCES AND HYDRAULIC CONNECTION TO SURFACE WATER

2.1 Aquifers

There are seven mapped aquifers within the Koksilah watershed. The uppermost part of the watershed is primarily private managed forest land where there is limited groundwater development, thus no aquifers have been mapped. In the central part of the watershed, the Koksilah River is bordered by bedrock canyons; here, the sedimentary overburden is thin or absent. Several bedrock aquifers have been mapped in this area, which border and underly the stream (grey shaded areas in Figure 13). Overlying the bedrock in the lower part of the watershed are thicker unconsolidated deposits including layered unconsolidated aquifer systems (orange shaded areas in Figure 13). Table 3 summarizes the characteristics of the mapped aquifers in the watershed including factors influencing whether the aquifers are considered hydraulically connected to the river system.

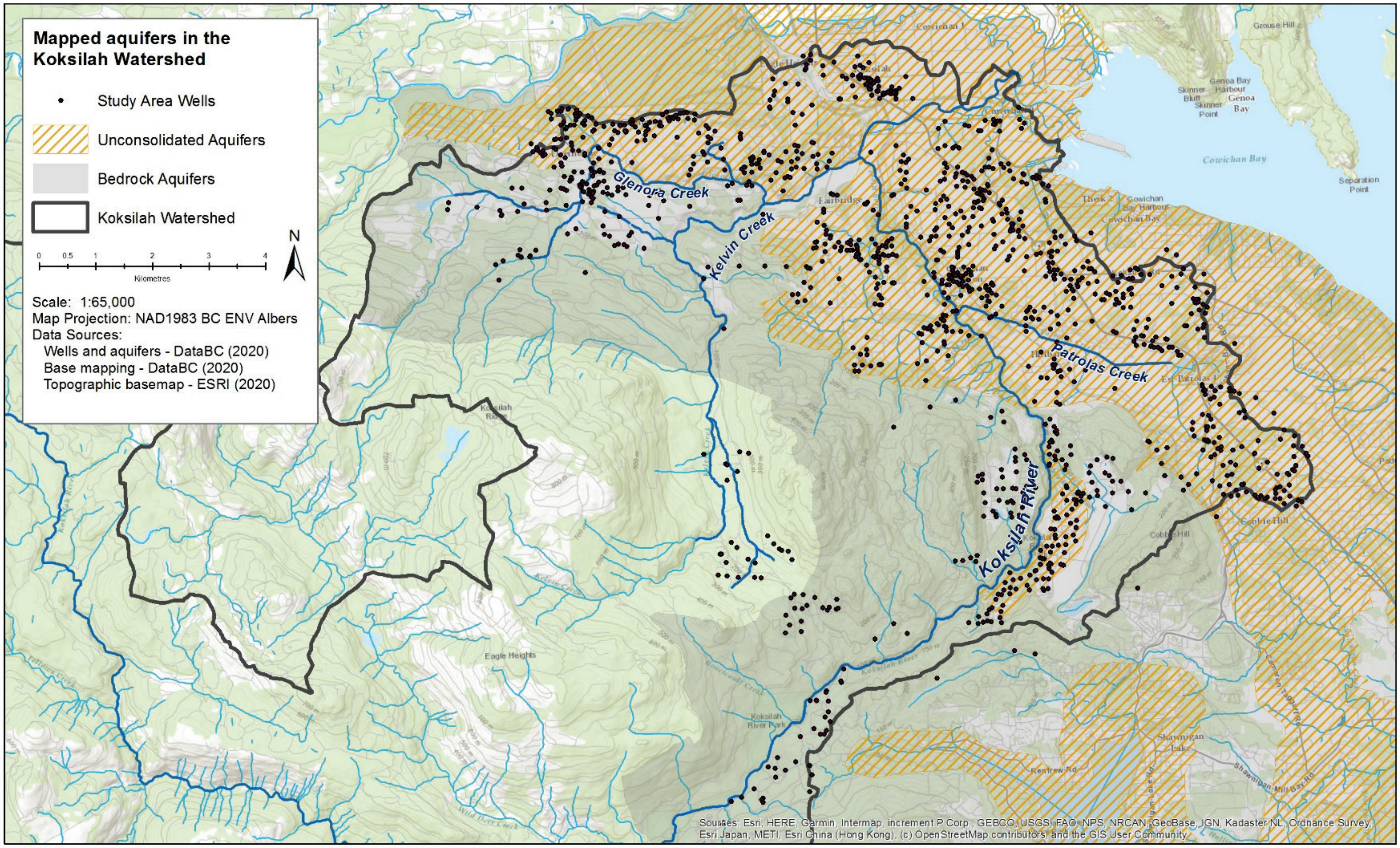


Figure 13: Aquifers mapped within the Koksilah watershed (categorized as either unconsolidated or bedrock).

Table 3: Aquifers in the Koksilah River watershed.

Aquifer Number	Aquifer Materials	Descriptive Location	Litho Stratographic Unit	Aquifer Subtype Code*	Size (km^2)	Likelihood of hydraulic connection to Koksilah River and rationale
186	Sand and Gravel	Duncan (Cowichan River, Upper and Middle Aquifer)	Salish and Capilano Sediments	1b	17.4	Unconfined to partially confined, unconsolidated; hydraulically connected in lower reaches of Koksilah River and Cowichan River (Aquifer complex formerly referred to as Aq186 and Aq187)
188	Sand and Gravel	Duncan Lower Cowichan River A	Vashon Drift	4b	8.6	Confined, unconsolidated, relatively thick grey silt-fine sand layer overlying much of aquifer extent. Aquifer footprint not extensive within Koksilah watershed. Not likely hydraulically connected.
197	Sand and Gravel	Cowichan Bay / Cobble Hill	Vashon Drift	4b	48.6	Partially confined, unconsolidated aquifer. Borders east side of Koksilah River from south of Patrolas Creek confluence and downstream. Hydraulic connection likely through regional groundwater flow system. Disconnected locally where water table relatively deep compared to surface water elevation (stream perched relative to aquifer level).
199	Sand and Gravel	Cowichan Station-Fairbridge	Vashon Drift	4b	27.7	Partially confined, unconsolidated aquifer. Borders west side of Koksilah River from Hillbank Rd/Patrolas Creek area and downstream. Likely hydraulically connected. Borders Aq185 in Glenora area which is hydraulically connected to Cowichan River system.

* Refer to (Province of B.C., 2018b) and (Wei, et al., 2009) for a description of aquifer sub-types

Aquifer Number	Aquifer Materials	Descriptive Location	Litho Stratographic Unit	Aquifer Subtype Code*	Size (km^2)	Likelihood of hydraulic connection to Koksilah River and rationale
201	Sand and Gravel	Cobble Hill, Heather Bank	Vashon Drift	4b	1.9	Unconfined, unconsolidated aquifer with smaller spatial extent, borders west side of Koksilah River near Heather Bank Brook. Likely hydraulically connected.
198	Bedrock	Cowichan Station / Duncan	Nanaimo Group Sedimentary bedrock	5a	104.7	Partially confined, fractured bedrock. Underlies lower reaches of Koksilah River, Kelvin Creek, Glenora Creek and Patrolas Creek. Northern aquifer boundary at Cowichan River. Potentially hydraulically connected where overburden is thin or absent and via regional groundwater flow systems.
202	Bedrock	Koksilah River Valley (Cobble Hill)	Bonanza Group and Sicker Volcanics	6b	39.6	Partially confined, fractured bedrock. Borders east and west side of Koksilah River in central part of watershed. Potentially hydraulically connected to Koksilah River mainstem and headwater tributaries, where overburden is thin or absent and via regional groundwater flow systems. Potentially disconnected where river system is perched relative to groundwater table.

* *Refer to* (Province of B.C., 2018b) *and* (Wei, et al., 2009) *for a description of aquifer sub-types*

2.2 Hydraulic connection between surface and groundwater

Over the past several decades understanding of the interconnectedness of surface and groundwater systems has increased. In the simplest sense, groundwater and surface water share the same origin in the water cycle. Rainfall (and snowmelt) either runs off the land into creeks and rivers, infiltrates into underground aquifers or dissipates through evaporation and plant use (Winter, et al., 1998). Extraction for human use temporarily or permanently removes water from its source in a stream or aquifer, and in the process changes its location and quality in comparison to natural conditions (Sophocleous, 2002).

Streams can be described in relation to the direction of water movement into or out of the stream from an adjacent aquifer. When a stream provides a source of water that infiltrates into an underlying aquifer, the stream is said to be losing. When groundwater flows from an aquifer into the stream, the stream is described as gaining. Gaining or losing conditions can vary seasonally, and in different locations or reaches along a stream (Winter, 2007).

An aquifer is considered hydraulically connected if groundwater pumping from a well in the aquifer has the potential to affect the quantity and timing of flows within an adjacent surface waterbody (Barlow & Leake, 2012). Unconfined aquifers with a shallow water table are considered more likely to be hydraulically connected to an adjacent stream, whereas aquifers that are overlain by thick deposits of very fine-grained, low permeability sediments (such as clay or till), and bedrock aquifers in lowland areas overlain by unconsolidated deposits, may be considered less likely to be hydraulically connected to a stream (Province of B.C., 2016a). Bedrock aquifers in upland areas, where surficial sediments are thin or absent, may be hydraulically connected to headwater streams where the groundwater table and the river water level intersect (Winter, 2007). In practice, unconsolidated or bedrock aquifers are often partially confined, with gaps in the confining sediments or places where a stream channel has incised the confining layer, thereby increasing the likelihood of hydraulically connection between the aquifer and the stream (Fleckenstein, et al., 2006).

The pumping of a well located close to a stream can cause movement of water from the stream into the aquifer, referred to as induced infiltration. Similarly, pumping of groundwater from a well can capture or remove water that would otherwise flow toward and discharge to the stream. Stream depletion is the combined change in flow in a stream resulting from capture and induced infiltration (Winter, et al., 1998). Depending on the pumping rate, the effect of one well pumping on streamflow depletion could be very small in comparison to total discharge in the stream; however in areas of high groundwater development, and during periods of the year when surface water levels are at their lowest, the cumulative impacts of depletion from multiple wells could represent a significant component of streamflow (Barlow & Leake, 2012).

The 1986 Cowichan-Koksilah water management plan identified the potential for impacts on river levels of groundwater usage from the highly productive industrial and municipal well fields in the lower Cowichan River area southeast of Duncan (Ministry of Environment and Parks, 1986). Unconsolidated aquifers of moderate or unknown productivity were identified along the Cowichan River and lower Koksilah River system as potential sources for agricultural and municipal water supplies. Bedrock aquifers in the uplands of both watersheds were considered to have a lower overall potential for development and were not identified as being hydraulically connected to the river system. Presciently, the plan stated that "if surface water supplies are fully allocated (licensed), there may be potential for surface water-groundwater conflicts if aquifers which are hydraulically connected to surface waters are further developed."

In 2019 the hydraulic connectivity of aquifers and wells in the Koksilah River watershed was evaluated within the study titled, "Koksilah River Watershed: Preliminary Assessment of hydraulic connection" (Sivak & Wei, 2019). This work estimated the potential hydraulic connection of registered wells to stream reaches of the Koksilah River and sub-tributaries using subsurface geology, groundwater levels, and topographic elevations. Based on the well lithology, each well within the watershed was determined to be constructed within one of four aquifer sub-types (Wei, et al., 2009):

a) Unconsolidated, unconfined: wells in sand and gravel aquifers without an overlying confining layer, including fluvial and glaciofluvial deposits along moderate-order rivers (i.e., sub-type 1b and 4a);
b) Unconsolidated, confined: wells in sand and gravel aquifers, where a confining layer of clay, silt or till > 3 m thick is present, including glacial and pre-glacial deposits (i.e., sub-type 4b);
c) Fractured sedimentary: wells in sedimentary bedrock including shale, sandstone, and conglomerate (sub-type 5a); or,
d) Crystalline bedrock: wells in fractured bedrock including volcanic and granitic rock types (sub-type 6b), and limestone (sub-type 5b).

As illustrated in Figure 14, using this approach, segments along the stream were determined to be either:

a) Open to hydraulic connection, where confining sediments were absent, and the elevation of groundwater and of water in the stream intersect;
b) Open to hydraulic connection, where confining sediments pinch out prior to reaching the stream or where the stream channel is believed to incise through the confining layer, and the elevation of groundwater and of water in the stream intersect;
c) Perched, where stream elevation was >3 m above estimated groundwater elevation; or
d) Blocked, where confining sediments were contiguous below the stream.

Sivak and Wei (2019) determined the point of hydraulic connection (PoHC) of each well to the closest "open" stream segment and calculated the distance of the well from this PoHC. Using the distance from the stream and hydraulic properties associated with each aquifer type, stream depletion factors were then estimated for each well. The points of hydraulic connection between where a well is located and the closest adjacent or downstream stream reach that is "open" could result in a focussing or enhancement of groundwater capture within specific areas, shown in Figure 15.

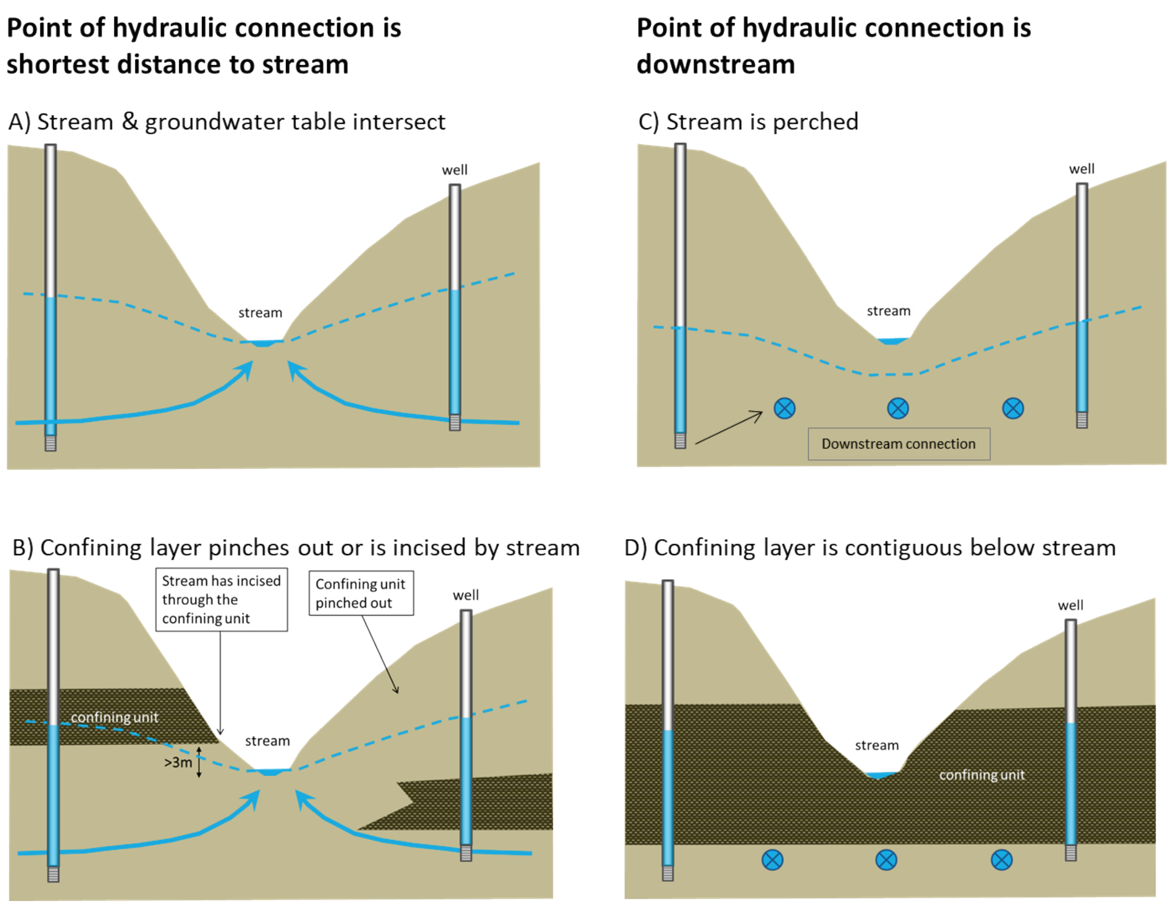


Figure 14: Conceptualization of where the points of hydraulic connection on the stream will occur depending on whether the stream is open, perched or blocked. Reproduced with permission from (Sivak & Wei, 2019).

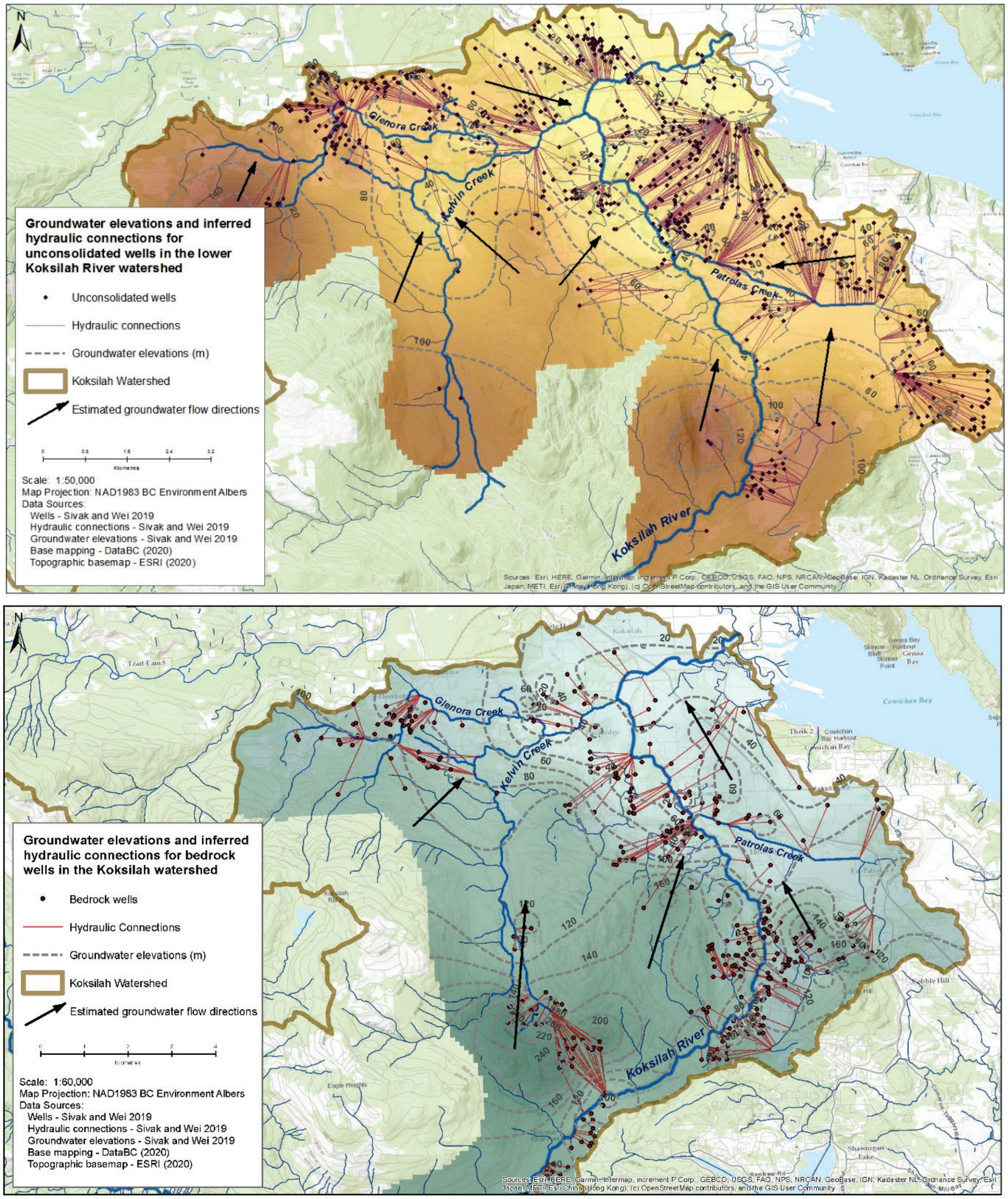


Figure 15: Groundwater elevations and estimated points of hydraulic connection in unconsolidated and bedrock aquifers, after (Sivak & Wei, 2019).

Most wells within the watershed were found to be hydraulically connected at some point along the streams. Significant "open" stream reaches with a high likelihood of hydraulic connection were identified along the Koksilah River mainstem, and lower reaches of Patrolas and Glenora Creeks; in these locations impacts of groundwater capture were considered more likely to influence stream discharge. Lower order tributaries in the uppermost part of the watershed were inferred to be perched and therefore less likely to be hydraulically connected to the groundwater system along those upstream locations, however additional field work to verify evidence of groundwater connection in upland streams was recommended.

The effect on the spatial distribution of groundwater demand and impacted reaches is discussed further in section 3. The effect of well distance and aquifer properties (transmissivity, storativity and specific yield) on the timing of stream depletion are discussed in section 5.2.2.

2.2.1 Groundwater and Environmental Flow Needs

Aquatic species such as anadromous salmon are dependent on specific water quality and quantity conditions in the stream during different life stages including rearing, migration, and spawning (Stalnaker, et al., 1995). Species such as steelhead, Coho, and Chinook salmon that spend extended rearing periods in freshwater environments may be more sensitive to changes in instream conditions in comparison to species such as Chum that migrate to the sea earlier (Mantua, et al., 2010). Environmental flow needs (EFN) assessments evaluate the instream conditions (water quality and quality) needed for fish survival, many of which are inherently dependent on or influenced by groundwater interactions (Douglas, 2006). Figure 16 illustrates how fish diversity and abundance are influenced by streamflow and related factors, many of which are linked to groundwater influences, for example:

a) Groundwater seepage from permeable aquifers may provide a more consistent source of flow in comparison to rapid rainfall dependent streamflow response, and is a primary source for maintenance of base flow during long summer dry periods (Winter, 2007);
b) Groundwater provides thermal regulation of instream temperatures. Groundwater temperatures typically reflect average (annual) air temperatures, therefore locations of groundwater seeps provide thermal refugia where fish preferentially congregate during summer periods when surface water temperatures increase to stressful or lethal levels. In cold regions, groundwater inflows maintain ice-free overwintering areas in the stream (Power, et al., 1999);
c) Groundwater influxes can contribute minerals and nutrients that increase growth of primary producers such as algae and periphyton, in turn increasing the availability of macroinvertebrate prey which are the source of food for fish (Mejia, et al., 2016). Alternately, excess nutrients within polluted groundwater can contribute to algae overgrowth and eutrophication of aquatic environments (Terziotti, et al., 2018);
d) Fish growth in rearing stages may be higher in gaining reaches due to warmer (winter-early spring) temperatures, nutrients and food availability (Mejia, et al., 2016);
e) Groundwater may be lower in dissolved oxygen (DO) in comparison to surface water, affecting survival and fitness (e.g. length, mass) of fish during early life stages in stream reaches with large groundwater influxes (Malcolm, et al., 2009; Bloomer, et al., 2016). Conversely, because oxygen saturation depends on water temperature, areas of colder groundwater influx may be higher in DO once equilibrated to atmospheric conditions (U.S. Geological Survey, 2013).

The critical role of groundwater inputs for maintenance of aquatic habitats reinforces the importance of understanding and managing groundwater withdrawals from hydraulically connected aquifers to reduce negative impacts on streamflow, particularly during low flow periods.

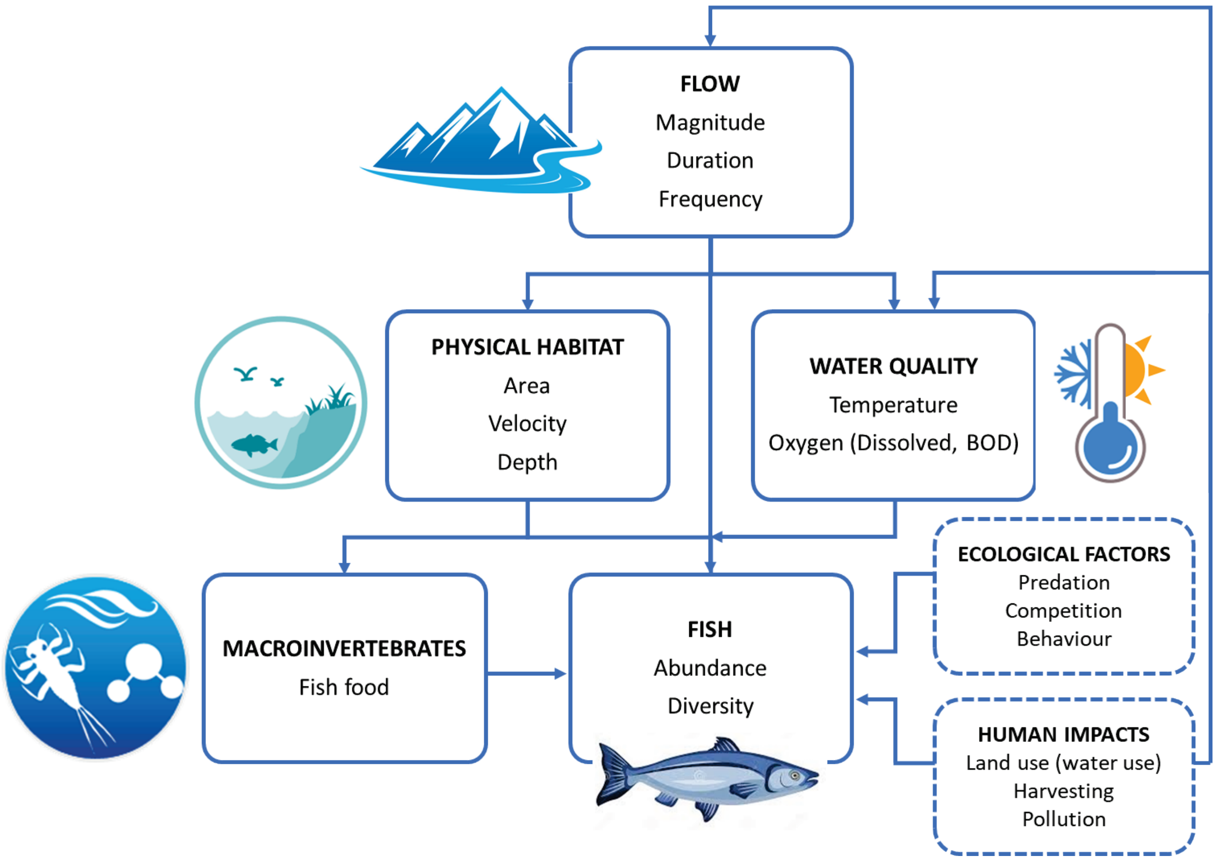


Figure 16: Influence diagram showing how fish diversity and abundance are a function of streamflow, which affects the availability and suitability of aquatic habitat. Groundwater interactions with surface water systems influence most of these factors by maintaining base flow during the dry season, providing thermal regulation, contributing nutrients for macroinvertebrate growth, and affecting fish behaviour such as redd site selection. In turn, human impacts from land use, water demand, and pollution influence groundwater quality and quantity. External factors outlined with dotted lines are not typically considered within instream flow assessments. BOD=Biochemical Oxygen Demand. Modified from Figure 6, Hatfield, et al (2003a).

2.3 Groundwater monitoring

Groundwater monitoring provides direct information on aquifer conditions that can vary seasonally, spatially and change over time within an area of interest. Evaluating the patterns of fluctuation of water levels in aquifers and streams can also provide clues regarding the relationships between different water sources. Information on groundwater levels, temperature, and quality in the study area is primarily obtained from wells in the Provincial Groundwater Observation Well Network (PGOWN) (Ministry of Environment and Climate Change Strategy, 2019). While numerous observation wells have operated historically in the South Cowichan/Cobble Hill area with records going back to as early as 1979 (OW233 Cowichan Bay Vee Road), the first PGOWN wells in the Koksilah River watershed were established more recently (Table 4). In 2017 two observation wells were installed in the Glenora area, and in 2019/2020 three wells were established in the Cowichan Station area. In 2019 and 2020 three Cowichan Station area wells were installed to improve understanding of annual fluctuations in groundwater levels and temperature in AQ197 (unconsolidated aquifer) and AQ198 (bedrock aquifer), and to provide insight into interactions between the aquifers and with the adjacent stream. Hydrographs for PGOWN wells in the watershed are shown in Figure 17 to Figure 22 and discussed below.

Table 4: Groundwater monitoring within the Koksilah River watershed.

Well	Name	Well depth (m)	Ground elevation (m asl)*	AQ	Aquifer material type	Closest stream	Distance from stream (m)
OW430	Cowichan (McLay Rd. Deep)	78.03	75[a]	198	Bedrock	Tattam Brook (Glenora Creek sub-tributary)	253
OW431	Cowichan (McLay Rd. Shallow)	28.04	75[a]	199	Sand and gravel	Tattam Brook	253
OW488	Cowichan Station (Koksilah Rd)	28.96	57.027[b]	197	Sand and gravel	Weeks Creek (Koksilah River sub-tributary)	128
OW489	Cowichan Station (Uphill Rd)	19.51	27.323[b]	197	Sand and gravel	Koksilah River	176
OW493	Cowichan Station (Jack Fleetwood Park)	62.48	19[a]	198	Bedrock	Koksilah River	49

*Elevation source and approximate accuracy: a= 2 m Digital Elevation Model (DEM) (±2 m) b= Survey (± 0.1 cm)

Figure 17 shows the combined hydrographs for the Glenora area observations wells (OW430 and OW431) for the period from 2013 to 2020. Groundwater fluctuations within the underlying bedrock aquifer (AQ198) follow the same seasonal pattern as observed in the overlying unconsolidated aquifer (AQ199). Groundwater is shallower in the overburden compared to bedrock, which leads to a vertical gradient which is consistently downward. Consequently, there appears to be little to no time lag in water level fluctuations between the two aquifers. In the bedrock well, rainfall events or recharge occurrences result in a greater amplitude in the immediate groundwater level fluctuation, consistent with a slug or piston-like response to recharge in a fractured rock system compared to a more dampened response in porous media.

Three observation wells (OW488, OW489 and OW493) are located along an approximately perpendicular transect that extends eastward from the Koksilah River in the Cowichan Station area shown in Figure 18. Observation wells 488 and 489 are completed in the overburden aquifer and OW493 is in the bedrock aquifer. Groundwater elevation fluctuation in OW488 and OW489 for the initial period of record are included in Figure 19, with the record for the two wells superimposed with separate vertical axes to allow comparison. OW489 has greater pumping interference and responds to recharge events more rapidly whereas OW488 is deeper, has less pumping interference, and has an approximate two-week time lag in response to recharge events in comparison to OW489. The groundwater levels decline more slowly in OW488, possibly because the aquifer is less influenced by adjacent pumping at that location. Based on the groundwater elevation for both traces, the flow gradient is downward and toward the Koksilah River valley to the west. Unfortunately, a gap in the record for OW489 occurred during summer 2019 due to failure of the sensor.

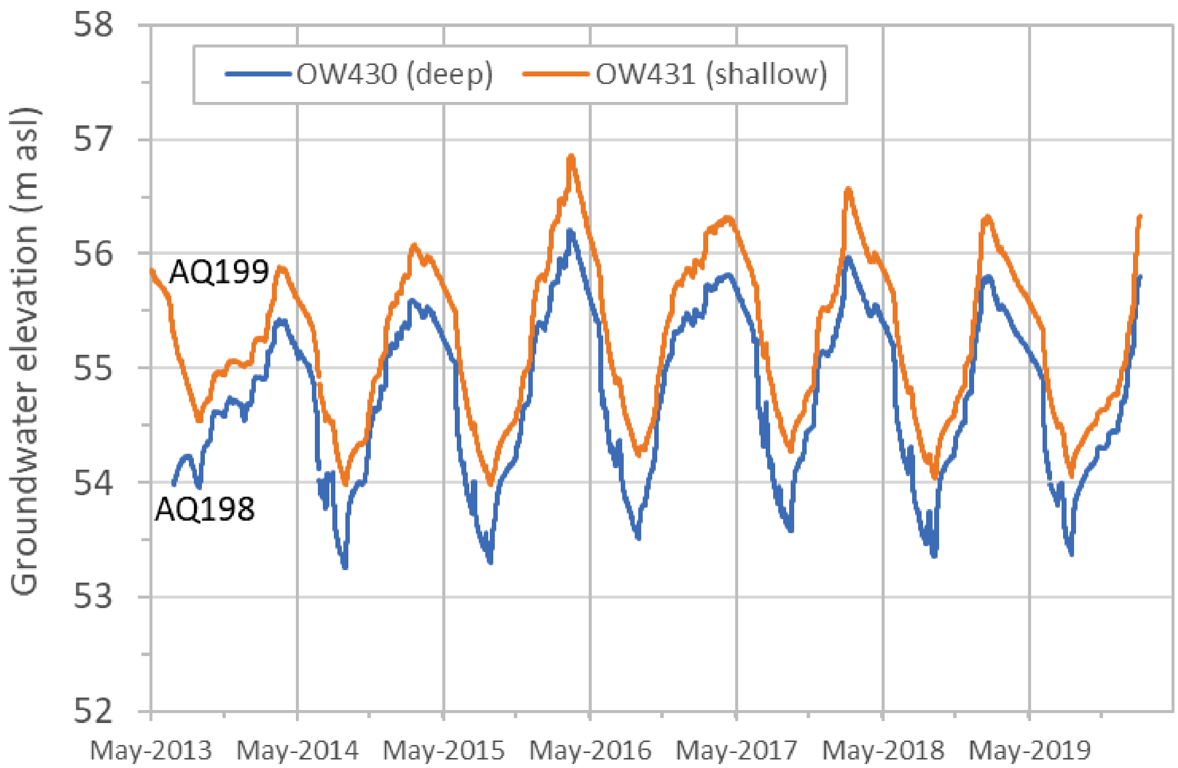


Figure 17: Groundwater level hydrograph OW430 Cowichan (McLay Rd. Deep), and OW431 Cowichan (McLay Rd. Shallow) 2013 - 2020.

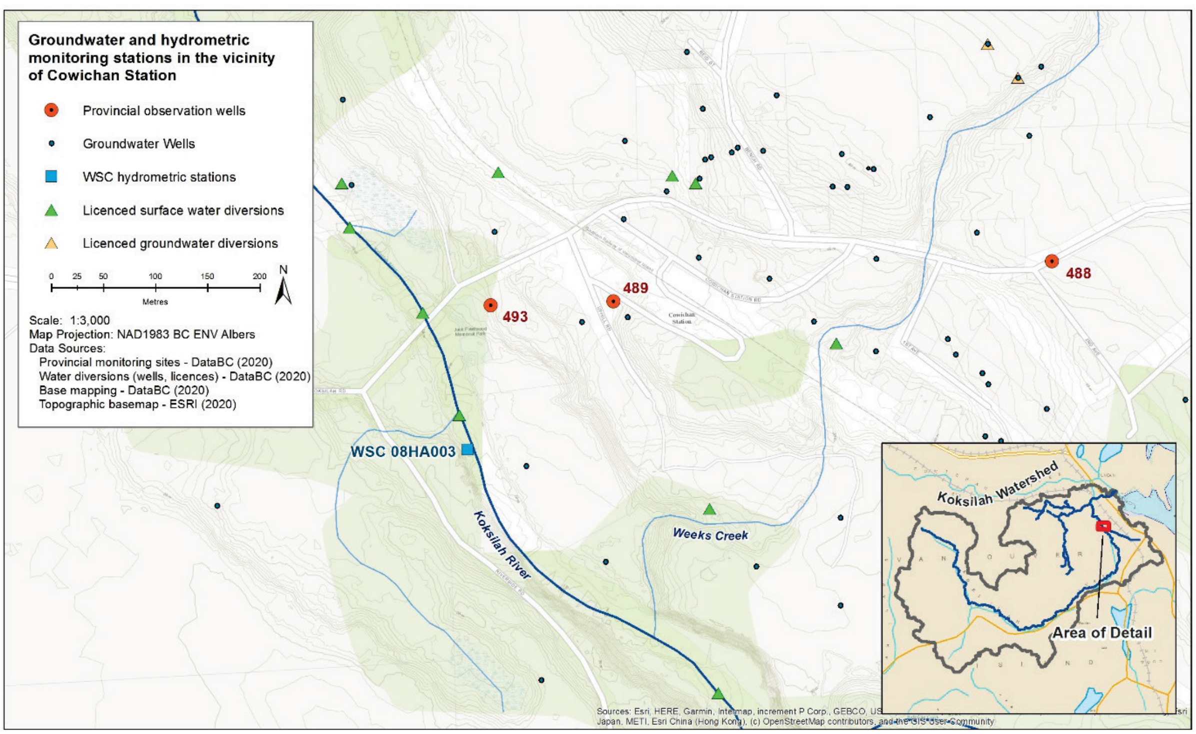


Figure 18: Observation well locations in the vicinity of Cowichan Station.

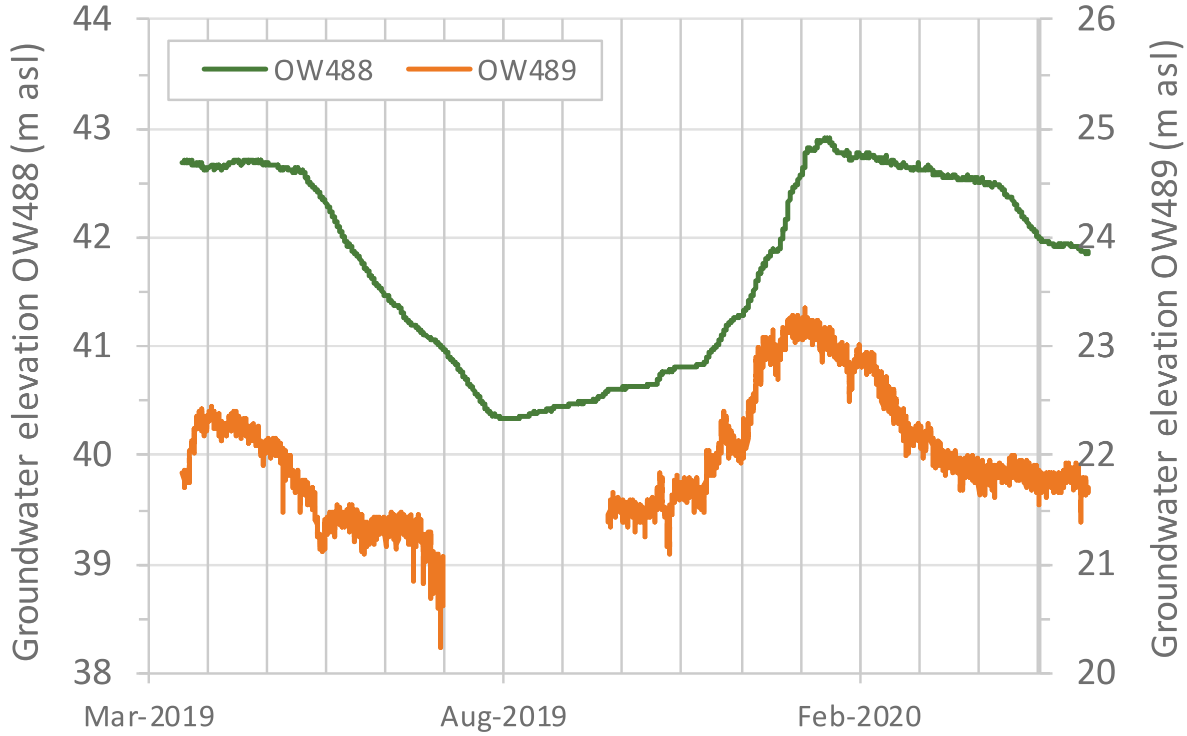


Figure 19: Groundwater level hydrographs in AQ197, OW488 Cowichan Station (Koksilah Road) and OW489 Cowichan Station (Uphill Road) 2019-2020.

Monitoring results from the newest OW493, constructed in fractured bedrock AQ198, are shown in Figure 20, superimposed with the record for OW489 in the overlying unconsolidated AQ197. The groundwater level fluctuations in the two wells follow a similar pattern, however there is less pumping interference observed in OW493. The groundwater gradient is downward from the unconsolidated aquifer toward the bedrock aquifer and the Koksilah River, which is 49 m to the west of OW493.

The lithological record from OW493 indicates that AQ197 pinches out upslope of the Koksilah River, and fractured bedrock AQ198 underlies the river at this location. Stage height at Koksilah River hydrometric station 08HA003 (located 136 m southwest of OW493) was converted to geodetic elevation using the approximate elevation of the river at the station location (elevation ~9.34 masl). As shown in Figure 21 there is < 3 m difference between elevation of the water table in AQ198 and in the river, and the fluctuation in river stage at station 08HA003 closely aligns with groundwater level fluctuation in OW493. This demonstrates the close hydraulic connection between the Koksilah River and the bedrock aquifer.

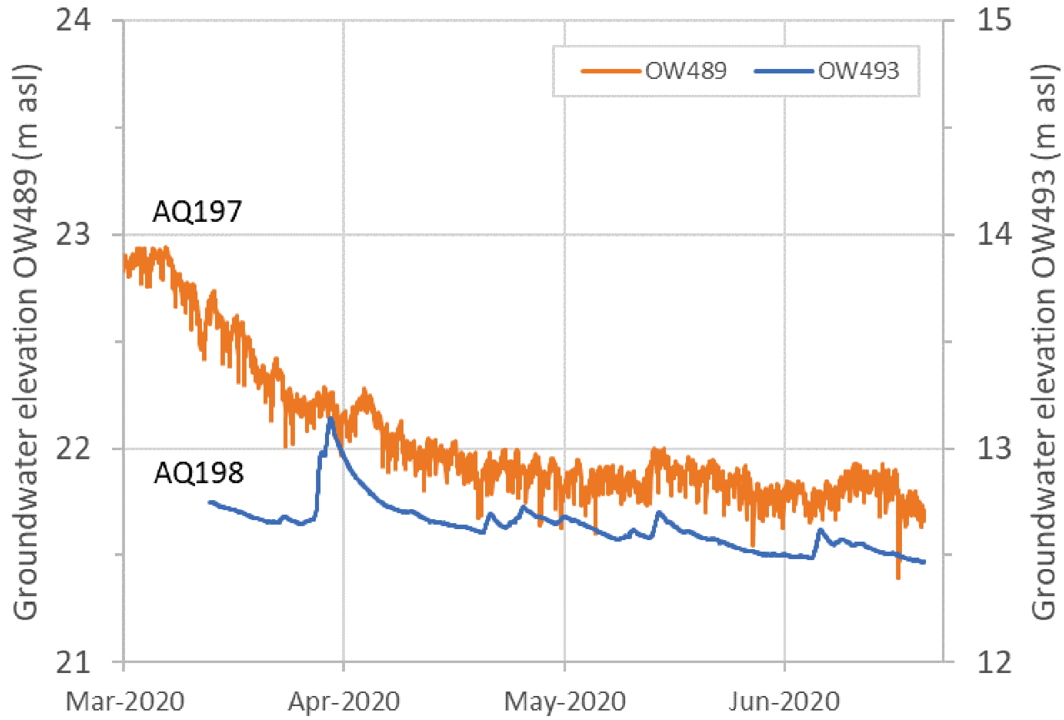


Figure 20: Groundwater level hydrograph OW489 and OW493 Cowichan Station (Jack Fleetwood Park) March-June 2020.

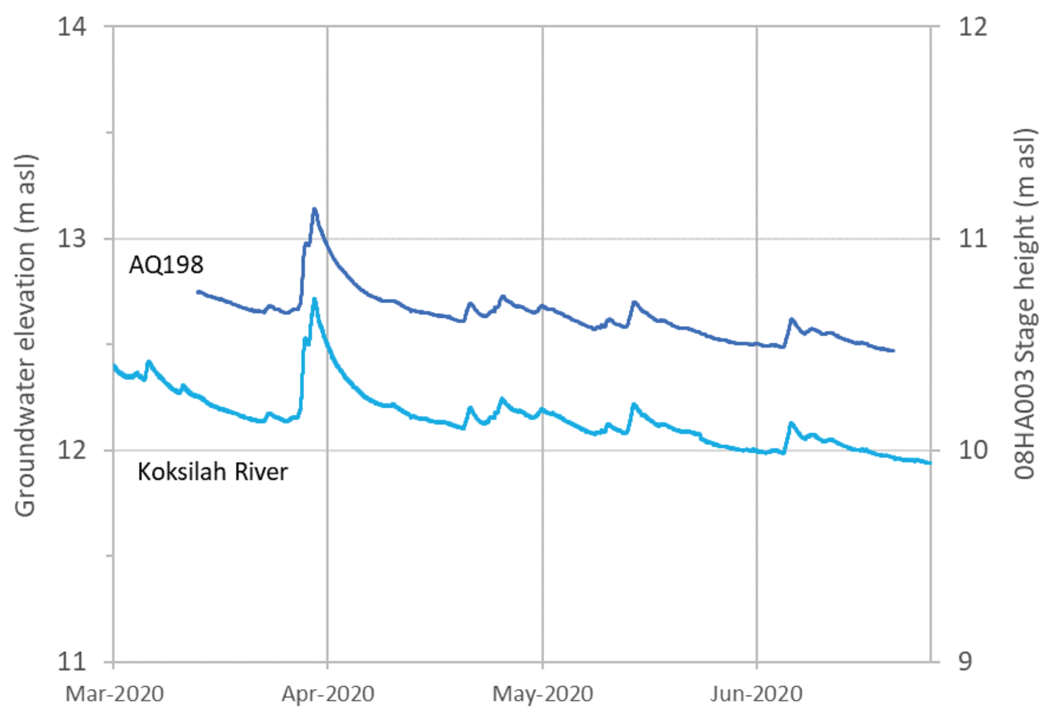


Figure 21: Groundwater level hydrograph OW493 Cowichan Station (Jack Fleetwood Park) compared to Koksilah River stage height at 08HA003, March to June 2020.

Figure 22 shows the relationship between groundwater levels in AQ197 (OW489), AQ198 (OW493), stage height in the Koksilah River at Cowichan Station (08HA003) and total precipitation at Shawnigan Lake (EC1017230). The pattern of water level decline (recession curve) within the river and aquifers follow a very similar pattern with minimal time lag (<1 day) between responses in the different sources. In Figure 22 the response in OW489 is evidently affected by pumping of adjacent well(s), but the general trend of the curve mimics levels in the underlying bedrock aquifer and in the stream.

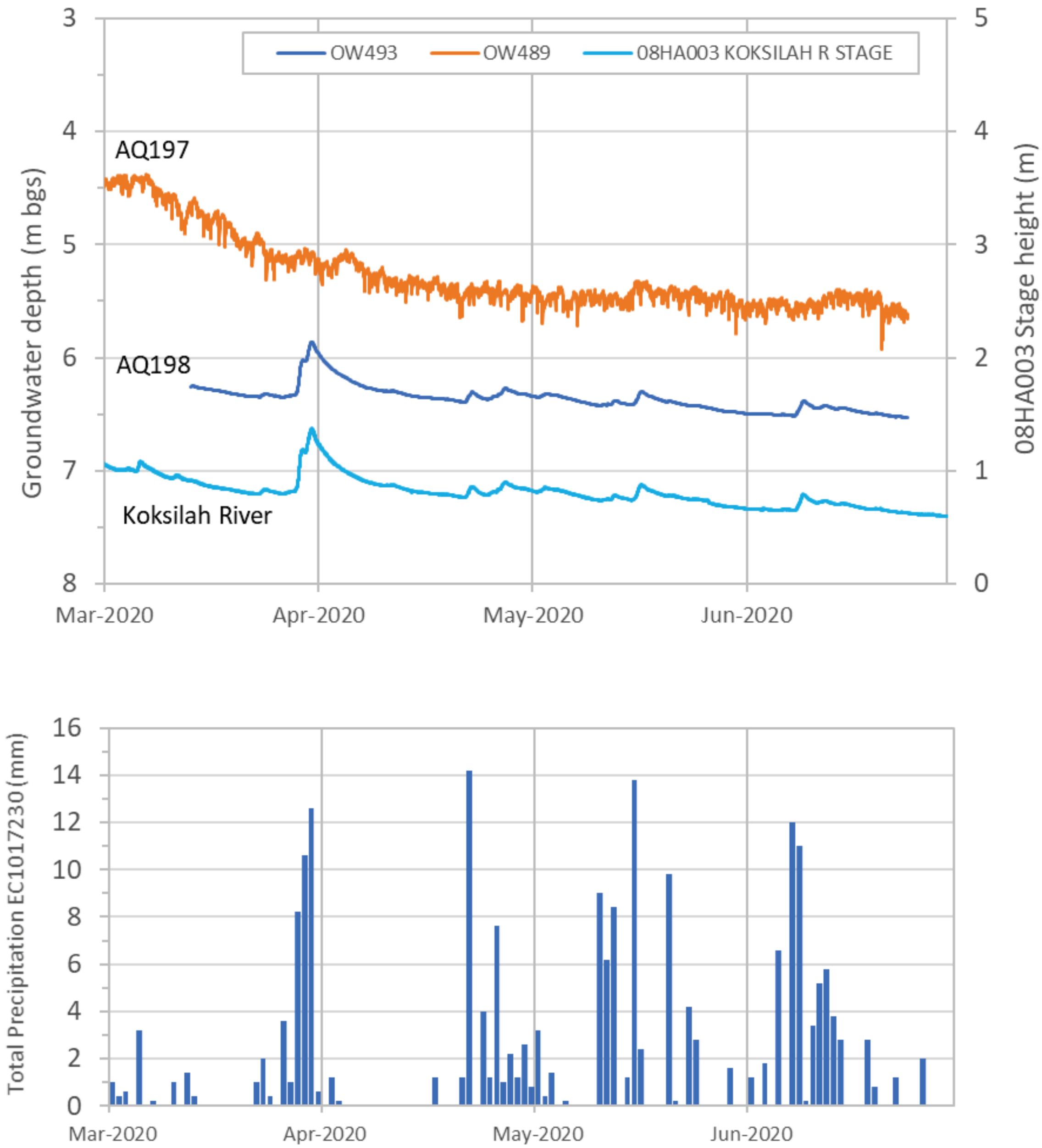


Figure 22: Relationship between groundwater levels in AQ197 (OW489), AQ198 (OW493), Koksilah River at Cowichan Station (08HA003) and precipitation (Shawnigan Lake EC1017230).

Groundwater levels and stage height respond to inputs of precipitation, however the amplitude of response with higher rates of precipitation is greater in the early spring. Precipitation events in April and May up to around 14 mm daily are noticeable on the hydrographs, however the vertical increase is less than observed in March. This is likely due to increasing rates of evapotranspiration, which reduces recharge and runoff during the later spring and summer. Similarly, from April onward, small daily increments of precipitation (≤ 2 mm) have minimal observed effect on stream or aquifer levels. There also is likely to be a variation in local precipitation levels in the area of the observation wells, compared to precipitation measured at the Shawnigan Lake station.

3. WATER DEMAND IN THE KOKSILAH RIVER WATERSHED

This section describes the present understanding of water use within the Koksilah watershed. The analysis focusses largely on water use in the summer period, because that is the time of year when streamflow is lowest and therefore more sensitive to water use impacts. Understanding the sources, volumes, and timing of water use within the watershed is vital in informing water management decisions aimed at reducing impacts on environmental flow needs (EFN) during the peak dry season (July-August annually). It should be emphasized that the water use estimates for both surface and groundwater (licensed, unlicensed, and inferred usage) summarized in this report may be considered *maximum potential water demand* associated with different land use types in the watershed and are subject to sources of error as identified in the following sub-sections.

3.1 Licensed water demand (surface water and groundwater)

Table 5 provides a summary of licenced water demand by water use purpose category (consumptive uses only) in the Koksilah watershed, compiled from the Water Rights Database (Province of B.C., 2020). The database can be accessed via the public Water Licence Search query. Irrigation licences typically specify that water may be used from April 1 to September 30, but average daily volumes were calculated assuming irrigation would begin May 1 and it is believed that most irrigators would usually start later than that. Licensed (non-domestic) groundwater use is also included in Table 5; however at this time, this represents a small fraction of total groundwater demand as discussed further in section 3.2.

Licensed demand is likely to vary from the volume of actual water use. Licences are typically issued based on a maximum potential demand, while actual water usage is likely to vary seasonally and inter-annually. Most licenses do not require metering or recording/reporting of water use volumes. In addition, some surface water licenses may no longer be in use, for example within smaller tributaries where the flow is significantly reduced, or the stream channel dries up in during summer. Usage may be lower than the allotted volume, particularly for the industrial users, based on interviews with licensees. Unreported or unauthorized surface water diversion may also be occurring, but the extent of this has not been fully investigated.

The greatest annual water demand by volume is associated with usage for irrigation, followed by industrial use. Licensed domestic use of surface water is estimated as only approximately 1.3% of total daily water demand (domestic use of groundwater does not require a licence under the WSA).

The licensing of existing non-domestic groundwater use (i.e., used prior to 2016), which has been underway in B.C. since the enactment of the WSA in 2016, is still within a transition period and most groundwater diversions in the watershed remain unlicensed (described in more detail in section 4.4). As of January 2020, approximately 110 applications for groundwater diversions in the Koksilah watershed have been received and eight existing-use licenses have been issued, representing approximately 5.4% by volume of estimated non-domestic groundwater use. Water use associated with applications where a licence has not yet been issued, are included in water use estimates in section 3.2 (inferred based on land use), because the volume applied for can differ from the final licensed volume. While complete applications for new groundwater use (i.e., use of groundwater commencing after the enactment of the WSA in 2016) must be considered as per the legislation, requirements for technical assessments and the associated costs required to inform decisions, as well as potential costs to new users for developing mitigation measures to prevent impacts to low flows, other users, and indigenous interests, are causing significant delays in the adjudication of applications. Water use for a domestic purpose by occupants of one or more homes on a single parcel does not require a license. Currently there are no restrictions on drilling of wells for domestic or non-domestic purpose in this area. These water management challenges could be addressed through development of regulations under the WSA.

Table 5: Licensed water use in the Koksilah River watershed.

Source / Water Use Type[1]	Number of Licences	Percentage of Licences	Average Daily Licenced Volume (m^3/day)[2]	Percentage of Licenced Volume (m^3/day)
Surface Water				
Irrigation[3]	72	52	13,139	71
Industrial	6	4	5,109	28
Domestic[4]	57	41	244	1.3
Stock watering	3	2	45.5	0.2
Waterworks	1	1	11.4	0.1
Total	**129**[5]	**100**	**18,549**	**100**
Groundwater[4,6]				
Irrigation[3]	3	38	551	53
Industrial	2	25	468	45
Stock watering	1	13	26	2.5
Recreational	1	13	2	0.2
Commercial	1	13	2	0.2
Total	**8**	**100**	**1,049**	**100**

[1] *Consumptive uses only (i.e. does not include storage or conservation licenses).*
[2] *Licenced volume may not represent actual use.*
[3] *Daily average usage during irrigation period May 1 - September 30 (annual volumes averaged over 153 days)*
[4] *Domestic groundwater use does not require a licence.*
[5] *Some licenses have multiple purposes and therefore appear under multiple categories.*
[6] *Does not include applications that have been submitted but not yet licenced.*

3.2 Groundwater demand

Although groundwater is estimated to constitute a significant portion of water demand in the Koksilah watershed, the location and volume of groundwater diversions is largely unknown. For this work, estimation of groundwater demand in the watershed involved compiling data from a variety of sources, including:

- Water licences that have been issued;
- Groundwater licence applications that have been received;
- Mapped locations of registered wells and accompanying well information;
- Parcel data (e.g., B.C. Assessment, agriculture use data, cadastral fabric); and,
- Water service area information.

The methods used to estimate groundwater use in the Koksilah watershed are described in more detail in Appendix A.

The number and percentage of parcels estimated to be using groundwater from registered wells (i.e., wells included in the provincial GWELLS database) are summarized by inferred water use type in Table 6. Estimated daily demand during the irrigation period (May 1 to September 30) is also provided. Irrigation estimates have been averaged equally over the irrigation period; however, irrigation is likely to increase during July and August and varies depending on factors such as precipitation inputs, and cycles of crop planting and harvesting. Around 79% of parcels in the watershed outside of water service areas are assumed to be using groundwater primarily for domestic purposes, but the usage is only about 8% by volume compared to other water use types. In comparison, most of the groundwater use by volume supports agriculture, representing an estimated 57% of daily groundwater demand during the growing season. An additional 53 parcels potentially supporting agricultural activities were also identified which could be using up to 3,754 m^3/day groundwater for irrigation (this would increase total agricultural use to around 65%), but these were not included in the demand total because they are not believed to be irrigating at this time. The second largest user of groundwater by parcel is for waterworks such as improvement districts and utilities, which supply residential needs in addition to some commercial and institutional use in serviced areas. Groundwater for industrial use is estimated as only 9% of daily groundwater demand by volume in summer.

Table 6: Summary of estimated groundwater use by parcel within the Koksilah watershed (includes licenced and inferred use).

Water Use Type[1]	Number of Parcels[2]	Percentage of Parcels	Estimated groundwater demand (m^3/day)	Percentage of Total Estimated Groundwater Demand
Agriculture[3]	93	14	7,866	57
Waterworks	7	1	2,147	16
Industrial	7	1	1,282	9
Civic/Institutional/Recreational[4]	13	2	670	5
Domestic	514	79	1,042	8
Commercial	18	3	721	5
Total	**652**		**13,728**	

[1] Consumptive uses only.
[2] Parcels assumed to be using groundwater primarily for purpose listed (only one purpose was estimated for each parcel, so volumes for other purposes may not be captured for some parcels).
[3] Irrigation demand during growing season (May 1 – September 30), and/or stock watering (year-round).
[4] Assumed water use for irrigation purposes (e.g., golf course) occurs May 1 – September 30.

3.3 Combined water demand by purpose

Average daily licenced and inferred water demand by purpose during the peak irrigation period for surface and groundwater sources are presented in Table 7 and Figure 23; annual demands are shown in Figure 23. It is estimated that water demand in the watershed totals 32,277 m^3/day during the summer, and roughly 7.2 million m^3 annually. During the summer period, licensed surface water use is roughly 57% of total demand. Although available information appears to suggest that surface water use exceeds estimated groundwater use, it is important to note that licenced quantities are not metered and actual surface water demand may be lower than indicated (see section 3.1).

Based on observations in recent years, the period during which surface and groundwater demands are likely to affect stream discharge and instream habitat quality for fish is from mid-July to early September when fall rains begin. As detailed in Table 7 and illustrated graphically in Figure 24, agricultural purposes use the most water from both surface and groundwater sources during the irrigation period, constituting approximately 65% of water diversions during the summer and roughly 45% of water demand on an annual basis (see Table 8). Agricultural land use represents approximately 30% of the land base in the lower watershed as shown in Figure 25 (which does not include vacant and privately managed forests lands), and about 66% of the land base in the watershed overall.

Occupying approximately 3% of the land base, the second highest water demand by volume is industrial uses, diverting 20% of overall summer demand and 32% of annual demand. The main industrial users include gravel extraction (washing), and pond and aquaculture. The largest land use by area in the lower watershed is residential (47%), but domestic use and waterworks (which includes residential and some commercial/institutional use in serviced areas) consume up to 11% of total water demand in summer and 17% annually, mostly from groundwater sources.

Table 7: Daily estimated water use by purpose in the Koksilah watershed (irrigation period).

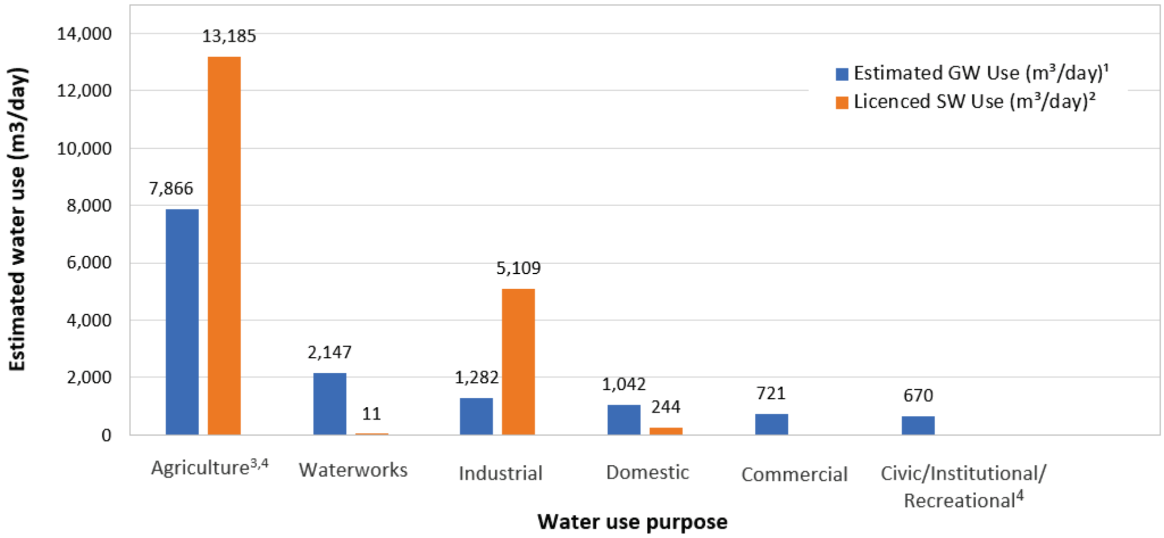
Water Use Type[1]	Licenced Surface Water [2]		Estimated Groundwater Use (licenced & inferred)		Total (surface & groundwater)	
	m^3/day	% of total	m^3/day	% of total	m^3/day	% of total
Agriculture[3,4]	13,185	71	7,866	57	21,051	65
Industrial	5,109	28	1,282	9	6,391	20
Waterworks	11	0.1	2,147	16	2,158	7
Domestic	244	1.3	1,042	8	1,286	4
Civic/Institutional/Recreational[4]	0	0	670	5	670	2
Commercial	0	0	721	5	721	2
Total	**18,549**		**13,728**		**32,277**	

[1] Consumptive uses only.

[2] Licenced volume may not represent actual use.

[3] Includes irrigation and stock watering.

[4] Assumed irrigation period May 1 - September 30 (annual estimates averaged over 153 days).



[1] Includes licensed and inferred groundwater use (consumptive uses only)
[2] Consumptive purposes only. May not represent acutal use.
[3] Includes irrigation and stock watering.
[4] Assumed irrigation period May 1 - September 30.

Figure 23: Daily average estimated water use (August) by purpose in the Koksilah watershed.

Table 8: Annual estimated water use by purpose in the Koksilah watershed.

Water use type[1]	**Licenced Surface Water [2]**		**Estimated Groundwater Use (licenced & inferred)**		**Total Annual Demand (surface & groundwater)**	
	m^3/year	**% of total**	**m^3/year**	**% of total**	**m^3/year**	**% of total**
Agriculture[3,4]	2,017,305	51	1,248,728	38	3,266,033	45
Industrial	1,864,785	47	468,048	14	2,332,833	32
Waterworks	4,161	0.1	783,550	24	787,711	11
Domestic	89,060	2	380,382	12	469,442	6
Civic/Institutional/Recreational[4]	0	0	114,706	4	114,706	2
Commercial	0	0	262,990	8	262,990	4
Total	**3,975,311**		**3,258,404**		**7,233,715**	

[1] Consumptive uses only.
[2] Licenced volume may not represent actual use.
[3] Includes irrigation and stock watering.
[4] Assumed irrigation period May 1 - September 30 (annual estimates averaged over 153 days).

An example of a typical central pivot sprinkler system used typically used for irrigation of forage crops is shown in Figure 26. A sub-tributary to Koksilah River, Glenora Creek, in August 2019 is shown in Figure 27. The spatial distribution of water demand in the watershed is shown in Figure 28 in which surface and groundwater demand are illustrated using points of different size, corresponding to categories of estimated water use. From this figure it is observed that water demands are concentrated in the lower watershed, around the Koksilah River mainstem and major tributaries including Patrolas, Kelvin and Glenora Creeks.

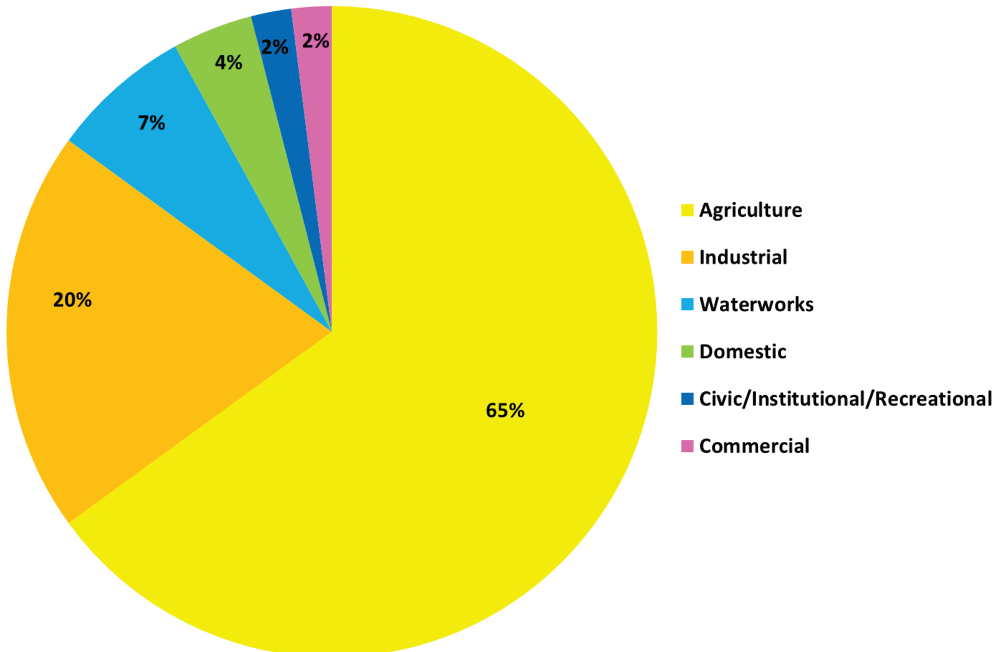


Figure 24: Percent of total water demand in the Koksilah watershed by purpose during the irrigation period. Includes licensed surface water diversions and licenced/inferred groundwater use. Excludes water for non-consumptive purposes such as conservation.

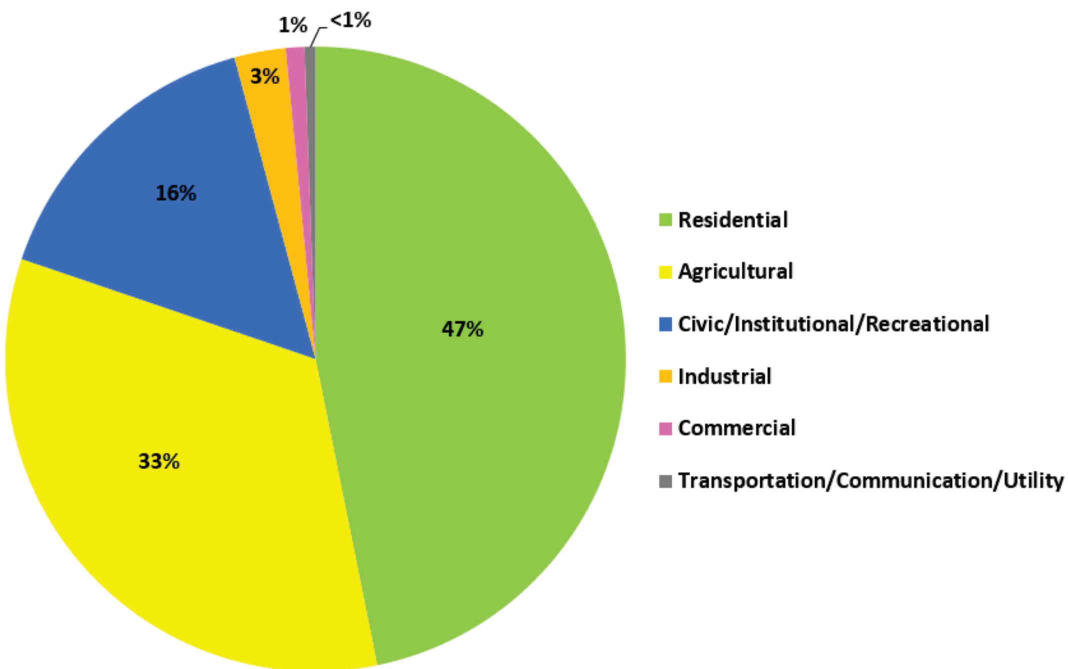


Figure 25: Land-use in the Koksilah watershed. Based on primary Actual Use Codes reported for each parcel from B.C. Assessment, and excludes vacant parcels and private managed forest lands (primarily in the upper watershed).

Figure 26: Diversion of surface and groundwater for irrigation is a major use of water in the lower Koksilah watershed. Central pivot sprinkler system shown above (Photo: Megan Wainwright).

Figure 27: Glenora Creek in August 2019. The stream was mainly dry, but salmonid fry were observed within remnant pools below undercut banks (Photo: Megan Wainwright).

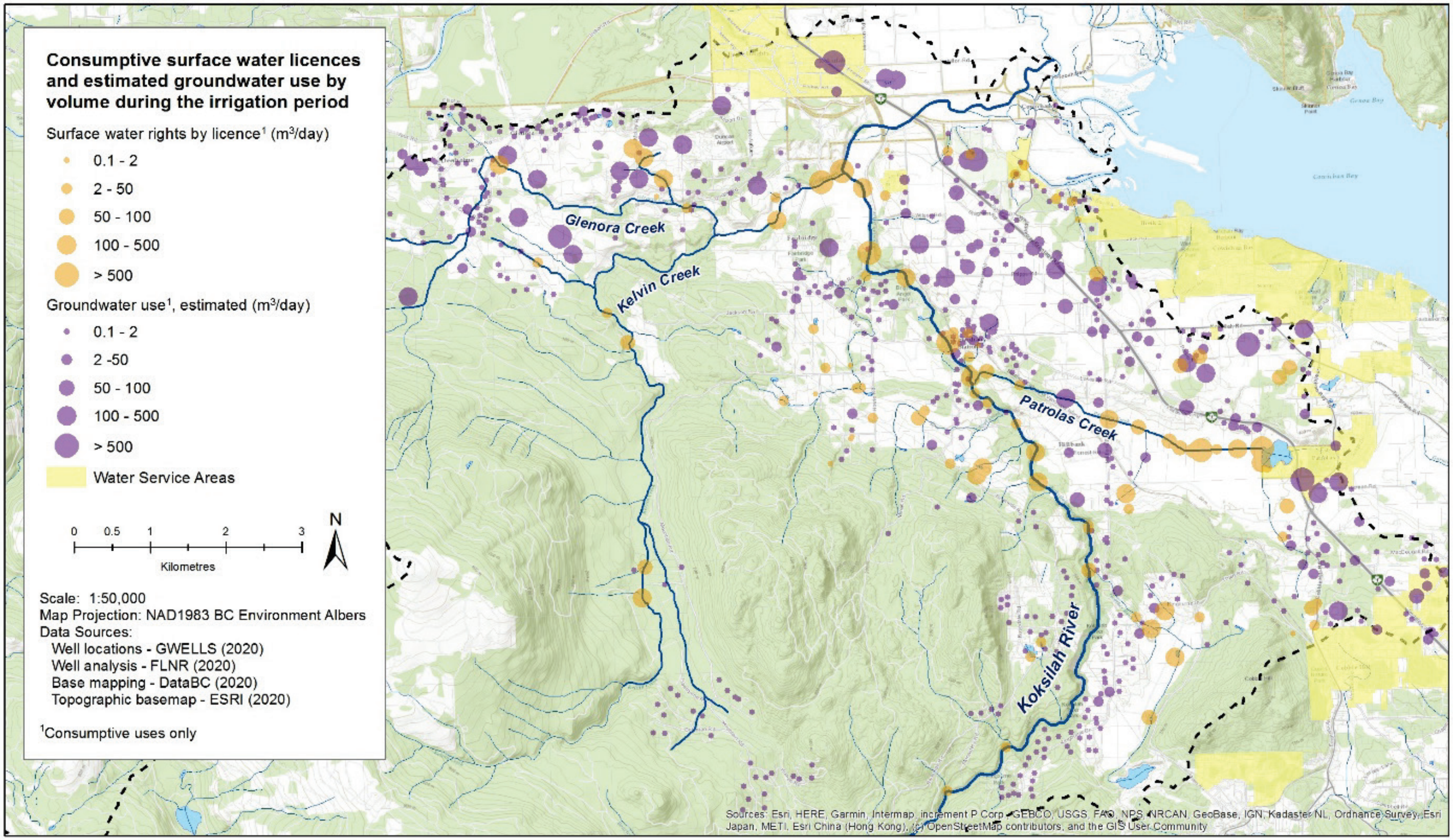


Figure 28: Spatial distribution of surface and groundwater demand in the Koksilah River watershed.

4. HISTORIC WATER DEVELOPMENT IN THE KOKSILAH WATERSHED AND REGULATORY APPROACHES TO IMPROVE STREAMFLOW FOR AQUATIC LIFE

This section describes the changes in water use over time in the Koksilah watershed and discusses some of the regulatory approaches available under the *Water Sustainability Act* (WSA) for the preservation of instream flows, protection of aquatic species and habitats, and management of water resources during times of scarcity.

4.1 Surface water licensing and early evidence of overuse

Since ancient times the *Quw'utsun'* people inhabited river-based villages, including at *Hwulqwselu* on the lower (present-day) Koksilah River (Marshall, 1999). Water sources for these settlements likely included water from streams and springs. Following European settlement and the establishment of British Columbia, the first *Water Act* was passed in 1909 (Wilson, 1989). Early surface water licensing in the Koksilah watershed dates back to 1904[†] for domestic use. Licensing for irrigation, which is the primary water use by volume in present day, did not occur until 1947; from this point forward irrigation, and associated storage purposes, made up the bulk of water licensing in the watershed through to the 1970s (Province of B.C., 2020). By the end of the 1970s licensing slowed significantly as seasonal supply issues became evident to provincial staff, leading to a fully recorded status being placed on the stream at the end of 1980 (Ministry of Environment and Parks, 1986). Subsequent licensing would be limited to domestic use or diversion from off stream storage (i.e., dugouts) captured during the high flow season.

4.2 Cowichan-Koksilah Water Management Plan and increasing groundwater development

Following Tutty's (1984) report, the province penned the Cowichan-Koksilah Water Management Plan (Ministry of Environment and Parks, 1986). Like the previous assessment, the water management plan identified that flows during the summer season were inadequate for fish and recommended a suspension of further licensing. In certain tributaries such as Glenora Creek, overallocation concerns were highlighted, as water availability in the creek during the low flow period was noted as being less than the existing licensed quantity. Groundwater development potential was regularly discussed throughout the plan as a mitigative option in terms of addressing water needs for further development of agricultural lands, of which a significant portion ("one-quarter of the good agricultural land") remained undeveloped at that time (Ministry of Environment and Parks, 1986).

Records in the provincial wells database show that from the early 1970s through to the mid-1990s, groundwater development in the Koksilah watershed increased exponentially as illustrated in Figure 29. It is reasonably presumed that this occurred for several reasons:

- Fewer land parcels with ready access to surface water were available with time, thereby increasing well development for more recently developed lots;
- Fewer surface water licenses, particularly those without a significant storage requirement, were being issued with time;
- As the diversion and use of groundwater was unregulated until 2016, groundwater development was a viable option (albeit relatively expensive one considering cost of drilling and operating a well) for those seeking water for irrigation;

[†] Date of first use indicated on the licence pre-dated the *Water Act*.

- Advancements in well drilling technology (e.g. air rotary rigs compared to cable tool drilling) made obtaining groundwater from deeper unconsolidated formations and bedrock aquifers easier.

The change in total estimated summertime water demand from surface water licenses and groundwater wells in the watershed over time is shown in Figure 30. These estimates are based on licensed surface water usage and inferred groundwater usage from registered wells, assuming historic usage volume was roughly equivalent to current use. The groundwater demand estimate in this case only includes known wells and does not include inferred usage on parcels with no registered well; however, it is noted that well record submission by drilling companies is generally good in this area and most wells are likely registered. Although there are potential errors introduced by the estimation methods, it is apparent that water demand in the watershed continued to increase in the watershed (by approximately 20%) after the point in time when cumulative impacts from groundwater capture and surface water allocation in the stream had already been observed.

Present understanding of the interaction between groundwater and surface water within the Koksilah watershed rests on the probable connection between nearly all wells and streams to varying degrees. While testing of this hypothesis remains, it suggests that even though surface water licensing ceased several decades previous, increased groundwater development over time has undoubtedly contributed to declining seasonal low flows in the river.

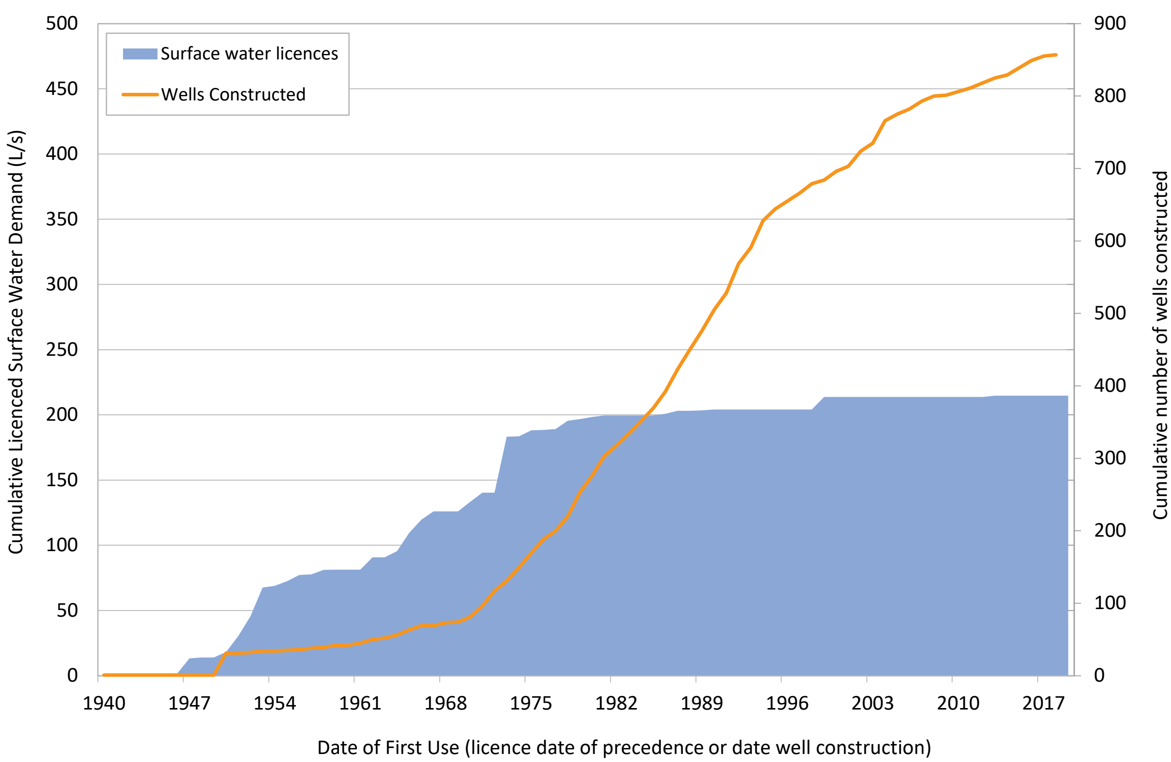


Figure 29: Cumulative licensed surface water demand during the irrigation period (L/s) compared to number of wells constructed over time. Only includes consumptive demands. GWELLS data includes historical dug wells, monitoring wells, and dry holes so there are likely fewer wells in use than are represented here.

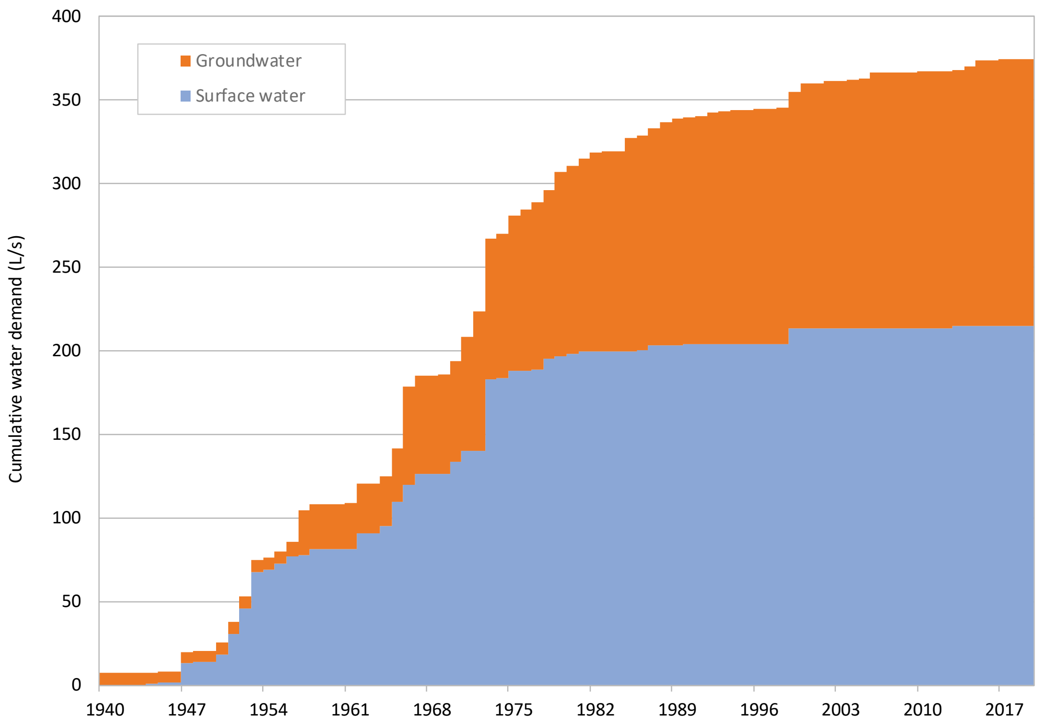


Figure 30: Cumulative total water demand (surface and groundwater, L/s) estimated over time for the irrigation period (peak usage).

4.3 Regulatory changes under the *Water Sustainability Act*

When it was developed as B.C.'s vision for water, the Living Water Smart Strategy, founded in science, was an ambitious plan that proposed to transform water management in the province (Province of B.C., 2008). The *Water Sustainability Act* (WSA), which came into force in February 2016, incorporates many of the principles included in the Living Water Smart Strategy such as licensing of non-domestic groundwater use, recognition of water needs for protection of aquatic ecosystems and species, and the ability to develop area-based regulations and water sustainability plans in response to specific issues (Province of B.C., 2018a). Aspects of the WSA with relevance to water management options in the Koksilah watershed are described further in the following sections.

4.4 Licensing of non-domestic groundwater

A distinct feature of the WSA is regulated diversion and use of groundwater in addition to surface water. Under the previous *Water Act* (Province of B.C., 2014)*,* groundwater development and use was essentially unregulated (Nolan, 2005) with the exception of a small number of projects involving larger groundwater demand exceeding 75 L/s that were subject to review under the *Environmental Assessment Act* (Province of B.C., 2002). Prior to the WSA coming into force in February 2016, B.C. was the last province of Canada without some form of groundwater licensing, and for many provinces groundwater allocation had been in place for 50 years or more (The Expert Panel on Groundwater, 2005; Nolan, 2005). The B.C. Auditor General reports on groundwater in 1999 (Office of the Auditor General of British Columbia, 1999), and again in 2010 highlighted the need to regulate groundwater use and modernize the *Water Act* in order "to protect groundwater from depletion and contamination and to ensure the viability of ecosystems it supports" (B.C. Office of the Auditor General, 2010).

Under the WSA, domestic groundwater use—water pumped from a well for a single household—has deemed rights, exempting this water use from licensing. Apart from this, the WSA generally requires authorization of non-domestic groundwater use under a licence or approval. Examples of non-domestic use include groundwater used for commercial, industrial, or irrigation purposes, or water supply systems providing water to a municipality, regional district, or private water service area. By regulation, certain groundwater uses are also exempt from the authorization requirement e.g. diversion of groundwater for perimeter drainage (all types of landowners) or land drainage by local governments. The *Act* could also enable licensing of domestic groundwater use in specific areas but would require a separate regulation to bring that authority into effect.

Under the previous *Water Act*, groundwater rights existed under common law. In recognition of these rights a transitioning period, defined by regulation, allows those using groundwater before the WSA came into effect to apply to licence their historic groundwater use. Various requirements and provisions of the legislation specifically apply to existing users, which reduces some of the burdens of the application process (such as application fees) and affords a level of fairness regarding common law rights that were in existence prior to implementation of the WSA (e.g., existing-use licences are given a priority date that is backdated to when the user first started consistently using the water being applied for). However, such benefits are only available to existing groundwater users until the end of the transitioning period (presently scheduled to end on March 1, 2022).

The transition of existing non-domestic groundwater users into a new licensing scheme has presented unique challenges for water management. The province has faced bringing groundwater users into an existing water licensing scheme at a time when pressures from overuse within a watershed or aquifer may already be happening, which may be exacerbated by cumulative impacts from other factors such as land use and climate changes. Awareness of the new legislation has initially been slow to occur, and existing-use applications are not being received in nearly the quantity expected. Existing users may be resistant to apply due to personal financial investment made in their wells and previous entitlement to use groundwater without government oversight. In order for the WSA to be an effective tool for water management, the majority of non-domestic groundwater use must have an authorization; to achieve this, targets for licensing must be established and pursued in the Koksilah watershed and elsewhere.

4.5 WSA, First Nations water rights and duty to consult on water allocation decisions

Water is central to the spiritual and cultural tenets of indigenous peoples as a life-sustaining element essential to the health and well being of all living things. Water is equally important for the exercising of Aboriginal rights and interests on the land, from provision of drinking water for communities to economic development, transportation, and supplying food and medicines (Assembly of First Nations, 2020). Colonization by non-native settlers in Canada deprived Indigenous Peoples of their traditional use and control of water resources, changing the quality and quantity of water in lakes and rivers, altering aquatic habitats and transportation routes, and causing flooding and forced relocation of villages from traditional lands (Nolan, 2005). The European human-centrist world view of natural resources such as water existing for our exploitation and control is fundamentally different from traditional Indigenous eco-centrist teachings, which considers the inherent rights of nature and humans’ responsibility as stewards and protectors of those resources (Native Counselling Services of Alberta, 2020).

Although beyond the scope of this report to discuss the complex history of water law and indigenous interests in Canada[‡], it is necessary to describe aspects of the WSA that pertain to Aboriginal rights under the *Constitution Act* (1982), and consideration of potential impacts of water allocation decisions in B.C. and in the Koksilah watershed on treaty rights and asserted Aboriginal rights and title.

The Province of B.C. has a legal duty to consult with First Nations on decisions that may adversely impact constitutionally protected Aboriginal rights, including decisions regarding allocation of surface and groundwater. Through the Crown consultation process, statutory decision makers must consider whether a decision may have an adverse impact on Aboriginal rights or title, or treaty rights, and to consider accommodation measures, as appropriate (Province of B.C., 2020).

Within the Koksilah watershed there is an awareness that diversion of water directly from the streams and streamflow depletion from existing groundwater users is likely a major influence contributing to streamflows declining below the environmental flow needs (EFN) and critical levels during drought periods. These seasonal water deficits are indicative of impacts to Indigenous interests, such as the ability to fish or use the river and riparian areas for social or cultural practices like hunting, spiritual bathing, or food gathering as was done historically.

In February 2020, the Chief of Cowichan Tribes and Minister of FLNR signed an Interim Letter of Agreement outlining how Cowichan Tribes and the Province will work together in Partnership to develop a common understanding and framework for ensuring water sustainability and protection of Indigenous interests in the watershed. Initial work includes scoping the need for a Water Sustainability Plan (WSP), an area-based regulation under the WSA, and to determine if a WSP would be effective and feasible. Progress and results of this collaborative partnership are likely to be of interest to groups in other areas of the province facing similar concerns related to water scarcity.

4.6 Key aspects of the WSA related to management in water-scarce regions

Issues with respect to seasonal streamflow declines are not unique to the Koksilah River. Seasonal restrictions on water usage have been instituted within many streams in the province, in particular in areas with the greatest current and growing populations (Gower & Barroso, 2019). The Coldwater River in B.C's arid interior has been impacted by similar pressures, as summer withdrawals for irrigation and municipal use have depleted streamflows and have affected aquatic ecosystems and fisheries (Nicola WUMP Multi-Stakeholder Committee, 2010). The need to respond to droughts and floods, which are exacerbated by climate change impacts, to ensure the integrity of water flows for aquatic species and habitats, and to build knowledge of water conditions through monitoring and research have been highlighted as three top priorities integral to B.C.'s future (Simms & Brandes, 2016).

The WSA authorizes government to take action to help prevent or reduce adverse impacts on water users by enforcing licence conditions or the priority of rights. Completion of an environmental flow study for a specific stream could be a prerequisite for issuance of a water license for a surface water source or hydraulically connected groundwater source. A water license may include conditions related to volume, timing and duration of surface or groundwater diversion related to seasonal impacts or stream conditions, including requirement to develop and use water from storage e.g. ponds, dugouts, dams etc. Monitoring and reporting of water usage, groundwater levels or other field or operational data may also be required. Where aquifers are at risk of overallocation, a

[‡] Readers interested in this topic may refer to (Bartlett, 1988), Nolan (2005), (Overduln, et al., 2019) and other sources.

requirement for pre-authorizations for well drilling or licensing of domestic groundwater use through regulation could be considered.

In specified circumstances, such as if a significant water shortage is declared, despite potential impacts to water users, government can take action to prevent or reduce adverse impacts on regionally significant aquatic ecosystems or fish populations whose survival is at risk. The WSA defines actions that may be taken by officials with different levels of statutory authority under the *Act*, while guidance has been developed regarding assessment requirements including detailed evaluation of water supply, usage, and storage, prior to voluntary or enforcement actions being initiated in a watershed (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019).

4.6.1 Voluntary reductions

If water availability concerns are identified in a watershed, a first step is to communicate these concerns to authorized water users and request that they voluntarily reduce usage or undertake other actions to mitigate impacts. Staff are expected to engage with water users on a source that is at risk as soon as a water scarcity is predicted to occur, and to give advance notice of actions being considered, to allow potentially impacted users to respond and prepare. In some cases, voluntary reductions may be sufficient to improve streamflow conditions so that Orders or other regulatory actions are not needed.

Part 3 of the WSA contains tools for regulating water use during times of water scarcity, or in areas where scarcity is ongoing, to protect instream flows for aquatic species. These tools fall under three main categories: Temporary Protection Orders, Water Objectives, and Water Sustainability Plans.

4.6.2 Temporary Protection Orders

If stream flows become very low, Temporary Protection Orders (TPO’s) are measures to take immediate action to protect aquatic habitats by temporarily reducing or stopping (curtailing) water use until streamflow recovers to a point where aquatic species are no longer imperilled. The curtailment under a TPO can apply to both surface water use, and groundwater extractions from hydraulically connected aquifers. There are two types of orders under this category: critical environmental flow protection orders and fish population protection orders.

Critical Environmental Flow Protection Orders

Critical Environmental Flow Protection Orders (issued under sections 86 and 87 of the WSA) are based on the first-in-time, first-in-right (FITFIR) water licensing principle central to past and current water legislation in B.C. Water rights are prioritized according to licence date, with the oldest licence on a stream or aquifer having highest priority and so forth, while the water use purpose is not considered. Specific to this type of TPO is the Critical Environmental Flow Threshold (CEFT), defined as an established streamflow that delimits an environmental red line superseding all other rights on the water source, other than essential household use. From a practical standpoint this means that if the CEFT is reached, water use can be reduced or curtailed. Unauthorized use has no FITFIR priority and would be the first to be cut off, through compliance enforcement. Other water use would continue to be cut off in order of priority of rights, until streamflow rises above the CEFT. Even if flows go below the CEFT, property owners retain the right to use a limited quantity for essential household needs, set at 250 litres per day per household. Refer to Figure 31 for a visual representation of the precedence of rights under this type of TPO.

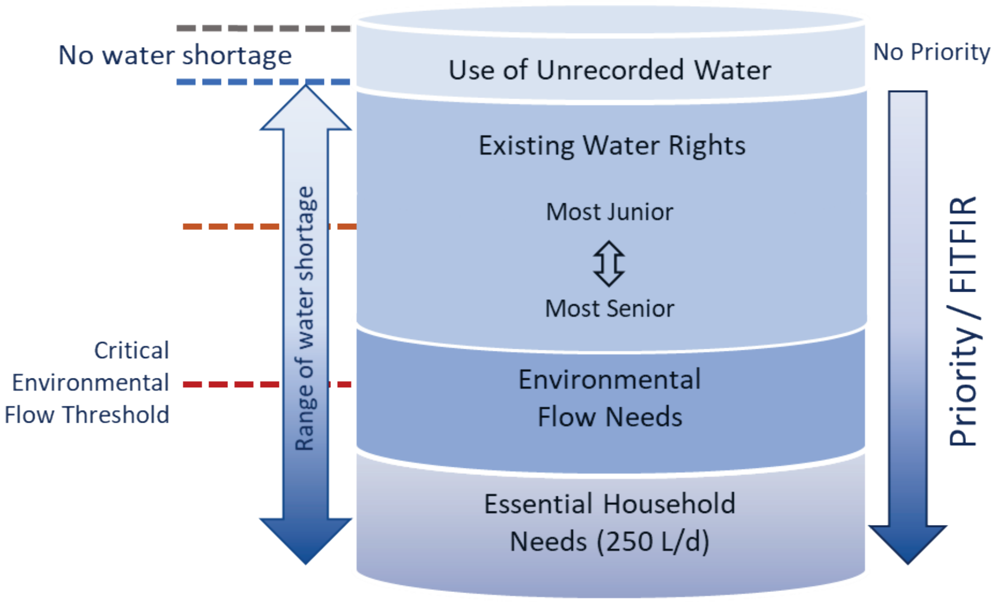


Figure 31: Precedence of water rights under an Environmental Flow Protection Order. Unauthorized use, such as use of unrecorded water would be cut off first while authorized use would be cut-off in order of priority date until streamflow returned to a level above the Critical Environmental Flow Threshold (CEFT). Even under a Temporary Protection Order domestic users would continue to be allowed a limited quantity (250 L/day per household) for essential household needs.

Fish Population Protection Orders

Fish population protection orders (issued under section 88 of the WSA) are used in cases where the survival of an entire population of fish is at risk (e.g. there is a risk of local extirpation or extinction). In this case, regulation of water use is carried out but does not have to adhere to the FITFIR principle. Rather, who is affected by an Order, how much water may be used, and when water use may occur is at the discretion of the Minister with the aim of achieving immediate benefits to the aquatic habitat. A potential benefit of a fish population protection order is the flexibility to reduce hardship resulting from curtailment of water use impacting a larger population of users, while focusing on reductions in water use most likely to rapidly improve in-stream flows.

In summary, Critical Environmental Flow Protection Orders (section 86 and 87) respect the rule of FITIFIR, systematically curtailing use according to precedence of water rights until streamflow recovers to the CEFT. Fish Population Protection Orders (section 88) are implemented on the basis that survival of a local fish population “may be or may become threatened,” therefore justifying a higher threshold of urgent and strategic response that disregards FITFIR. A curtailment model is a method used to determine potential groundwater users that could be asked to reduce or stop use under a temporary protection order. The development of a curtailment model for Koksilah watershed is described further in section 5.2, and detailed within Appendix B.

4.6.3 Water Objectives

Another potential tool to address water shortages are water objectives, enabled under section 43 of the WSA. Water objectives are an area-based planning tool used to establish a vision for water quantity, quality, and/or physical state (e.g., flow, temperature) of an aquatic ecosystem or aquifer. An example could be establishing specific limits that groundwater quality parameters should not exceed (e.g., a maximum chloride concentration within a coastal area at risk of saltwater intrusion).

Another example could be a minimum quantity of flow that is required to be maintained in a stream during different time periods of the year in order to maintain aquatic habitat or protect specific species during crucial life stages.

When water objectives are implemented by regulation, they can influence decisions made under other laws apart from the WSA by requiring public officials to consider the water objectives in their statutes or policies, in order to achieve common goals across jurisdictions of natural resource development and local government planning e.g. logging or farming in a watershed. For example, water objectives could be included within an official community plan or a regional growth strategy. Where possible, the objectives are intended to build on existing strategies implemented in an area. In cases where existing policies or initiatives are deemed sufficient, WSA water objectives have the potential to add authority to these approaches by making them enforceable under legislation. Where approaches are not meeting management goals within a watershed, water objectives present an opportunity to replace or add to what is already in place. The goal is to protect values for water that are collaboratively shared by the Province, Indigenous governments, local governments, and the people within a given area, concentrating on key stressors within a watershed rather than on every human activity.

4.6.4 Water Sustainability Plans

Water Sustainability Plans (WSP), like regulated use of groundwater, were introduced by the WSA and are fundamentally distinct from TPOs in their permanence, as they are intended to address perennial issues related to water scarcity. The intent and process for development of a WSP are described under Division 4 of the WSA. A WSP applies to a distinct geographic region (i.e., watershed), addressing a distinct set of issues through formal agreements on water and, potentially, land use. Plans may even go so far as to involve development of new area-based regulations, subject to approval by the Minister and Lieutenant Governor in Council. Plan development includes various levels of government (i.e., Provincial, Municipal, First Nations) and stakeholders (e.g., agricultural community), so is expectedly complex in terms of negotiation and process and consequently lengthy. For this reason, and due to the infancy of the WSA, no WSPs have been established in the province to date. Where aquatic habitat is continually degrading or where water scarcity and conflicts between users are a chronic problem, the benefits of investing in a WSP are numerous.

The key difference between WSA water objectives and WSPs is in that water objectives would apply to future statutory decisions, making them an inherently proactive tool. Water Sustainability Plans, however, have the ability to modify existing rights, meaning that they could curtail or prohibit existing permissions or authorizations within a watershed. Financial compensation for changes to water rights could be considered as part of a WSP but are not guaranteed.

Presently, Cowichan Tribes and FLNR are working together in partnership to explore and scope long-term strategies to address the problem of seasonal low flows in the Koksilah River, in order to prevent flows from continuously reaching levels at which aquatic habitat is severely degraded and threatening the survival of fish populations. Tools in the WSA, including a WSP will be explored to determine if they will be appropriate and adequate to address the issues in addition to ensuring protection of Cowichan Tribes’ rights and recognizing their water governance jurisdiction. This scoping work will also involve engaging with the local community, including agricultural users, municipalities, environmental and citizen groups, to ensure a more balanced approach to maintaining a healthy aquatic habitat while still supporting a vibrant agricultural community. Over the long-term, the development of a sustainable water management plan using tools under the WSA may provide a new framework to more effectively manage water and land use in the Koksilah watershed.

5. OUTREACH AND REGULATORY ACTIVITIES IN KOKSILAH WATERSHED IN RESPONSE TO LOW FLOWS

5.1 Monitoring, communications and promotion of voluntary reductions in water use

Although concerns related to low flows in the Koksilah River during the dry season had been identified since the 1980s or earlier, attention to instream conditions for fish in the river during the peak dry season was renewed following enactment and implementation of the WSA. Field work to measure and report on stream conditions during the low flow period was undertaken by FLNR in 2017, and additional surface water monitoring stations were installed in 2018 and 2019 to augment monitoring at long-term Water Survey of Canada stations. Field observations were used to verify instream conditions and to communicate ongoing concerns about possible water shortages to surface and groundwater users in the watershed.

Beginning in summer 2017, and continuing in 2018 and 2019, Water Authorizations staff also did extensive outreach to promote voluntary reductions in water use with the aim to improve streamflows and avoid regulatory action. Figure 32 shows the timing and types of outreach undertaken, including:

- Letters mailed to water licensees (surface and groundwater) and inferred groundwater users (thousands of individual letters each year);
- Community meetings with the general public and water users (scheduled earlier every year to give more lead time for water users to plan for the coming dry season);
- Emergency meetings with individuals and businesses potentially impacted by water shortages or Temporary Protection Orders, prior to implementation of actions;
- E-bulletins (email updates), and online status reporting of conservation levels on the BC Drought Information Portal;
- Field inspections to look for active pumping and to identify locations of unauthorized diversions (compliance enforcement);
- Direct phone calls and field visits to water licensees and inferred groundwater users to obtain information on water usage, promote conservation measures, and provide notice of potential actions to be taken (hundreds of individuals contacted each year);
- Continuing field monitoring programs and providing data and analyses publicly through Real Time Water Data website;
- Planning for potential regulatory action, including development of a groundwater curtailment model (described in section 5.2 and Appendix B); and,
- Consultation and communications with First Nations (Cowichan Tribes) throughout the low-flow response period.

A major focus group for many outreach activities in the Koksilah watershed were industrial and agricultural water users. In general, the agricultural sector has been very receptive and many individuals have indicated they have already implemented changes in response to water availability concerns, such as altering the timing and duration of the irrigation season (e.g., planting crops earlier and stopping irrigating sooner), investing in dugouts or other storage features, and reducing the size of livestock herds. Financial costs and other hurdles, including the high cost of building storage or improving irrigation efficiency, have been identified as barriers to implementing further changes.

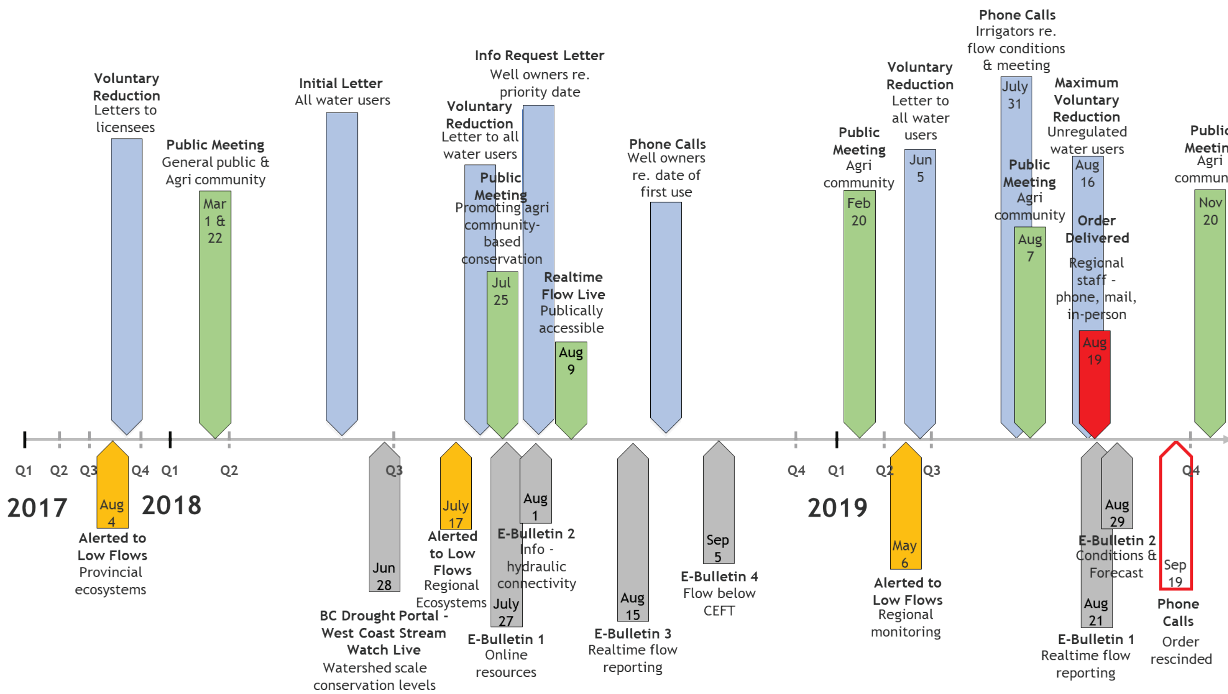


Figure 32: Outreach activities in the Koksilah watershed in 2017, 2018, and 2019. Yellow indicates date at which environmental data indicated critical low flow condition being reached, Grey indicates electronic communications via email or online, Blue indicates letter correspondence sent to water users, Green indicates public event in the community, and Red indicates issuance and rescinding of the Temporary Protection Order in 2019.

5.2 Groundwater curtailment model

As described above, during times of water scarcity affecting aquatic habitats one regulatory option under WSA is to require the reduction or cessation of water use (curtailment) through a Temporary Protection Order (TPO). A TPO can be applied to surface water users, and to users of groundwater from aquifers that are hydraulically connected to the impacted stream.

When water is extracted directly from a surface water source such as a stream, if a water shortage occurs, stopping the pump will result in an immediate change in flow within the stream. In comparison, if water is being pumped from an aquifer that is hydraulically connected to a stream, there is typically a time lag or delay between when changes are made to the pumping rate and when those impacts are observed in the stream (Barlow & Leake, 2012). This time lag depends on the properties of the aquifer (e.g. transmissivity, storativity) and on the distance that the well is from the stream—the farther the well is from the stream, the longer that delay or lag time will be. A groundwater curtailment model is a method to identify groundwater diversions that are hydraulically connected to the stream that, if curtailed, could improve streamflow. The methodology for developing the Koksilah watershed groundwater curtailment model closely follows the approach outlined within the Screening Tool for Guiding Short-Term Groundwater Curtailment during Water Scarcity (Province of B.C., 2016b). The curtailment screening tool is based on a simple but well recognized analytical solution (Glover & Balmer, 1954) to identify which wells, within a curtailment envelope or setback distance from the stream, that if they stopped pumping, would likely result in an increase in streamflow within a time period of interest. The model also gives an indication of which groundwater use e.g. from wells at further distance from the stream outside of the curtailment envelope, would likely not have a beneficial use on streamflow if they stopped pumping because the time lag would be too great.

A decision-maker's final determination of management steps to be taken considers several factors, including:

- Identified water users in the watershed;
- Potential increase in flows that could be expected as a result of curtailment actions;
- Potential impacts to aquatic ecosystems and species at different low-flow thresholds (assessed by a hydrologist or fisheries biologist); and,
- Estimated economic impacts that might result from regulatory action.

5.2.1 Methods

A groundwater curtailment model was developed to identify groundwater diversions that are hydraulically connected to the Koksilah River and if curtailed could result in an increase in streamflow. Methods for development of the model were based on the Screening Tool for Guiding Short-Term Groundwater Curtailment during Water Scarcity (Province of B.C., 2016b).

Information was gathered on aquifers and groundwater sources in the watershed (hydraulic connection, distance of the well from the point of hydraulic connection on the stream, estimated aquifer properties from statistical analysis of pumping tests and literature references), and groundwater demand (estimated volume, spatial distribution, water source and purpose of use). Four curtailment periods (7, 30, 60 and 90 days) were considered, based on theoretical time frames bracketing the period when streamflow approaches or fell below a CEFT, and when flows in the stream could be expected to increase naturally (e.g., following onset of fall precipitation). The methods and results from development of the groundwater curtailment model are described in greater detail in Appendix B. Key findings and observations from the model with relevance to the conceptualization of water user and impacts in the watershed are summarized below.

5.2.2 Results and discussion

A total of 624 wells representing parcels inferred to be using groundwater from registered wells likely hydraulically connected to the Koksilah River and its primary sub-tributaries (Glenora, Kelvin and Patrolas Creek) were considered in the groundwater curtailment model in 2019. Three main aquifer categories were considered hydraulically connected including wells in unconsolidated-confined (UC), unconsolidated-unconfined (UU), and fractured sedimentary or crystalline bedrock (BED) aquifers. Wells within increasing buffer distances from the point of hydraulic connection on the stream were captured as the duration of the curtailment increased, shown spatially in Figure 33 for example for wells in unconsolidated-unconfined aquifers.

Wells in unconsolidated-confined (UC) aquifers represent the greatest proportion of wells in the watershed. UC wells up to 1500 to 2500 m from the stream could be captured for a curtailment period lasting from 30 to 90 days. Wells in bedrock aquifers (BED) are the second largest category in the watershed, a curtailment duration of 30 to 90 days would include wells within an approximately 500 m to 800 m buffer distance from the stream. In unconsolidated-unconfined (UU) aquifers wells within 1000 m up to 1700 m from the stream would be captured for 30 to 90-day curtailment duration respectively.

To account for the lag time between cessation of groundwater pumping and streamflow response, a lag time calculation was used to estimate the return in streamflow as a proportion of groundwater demand (pumping rate). Wells were excluded from the final curtailment model when the proportion of groundwater flow to the stream was estimated to be relatively small (i.e. <20%), resulting in overall low net benefit of curtailment. The lag time calculation also enabled analysis of model sensitivity to different values of aquifer parameters (transmissivity and storativity). The curtailment model assumptions represent ideal conditions that may be violated due to spatial variation in aquifer confinement, thickness, and stream penetration. Excluding wells for which the expected benefit (streamflow return as a fraction of pumping) is low enables focus on wells within a smaller relative distance or spatial buffer from the stream where the expected benefit of curtailment is greatest, and where the model assumptions are more likely to be valid. Shorter curtailment periods (e.g. 7 days) are also a more likely scenario during which water use would be managed in order to obtain a rapid increase in streamflow in response to a critical streamflow threshold being observed; therefore it is important to identify optimum buffer distances from the stream where more immediate returns would be anticipated if groundwater pumping stopped.

For UU aquifers, the lag time sensitivity analysis suggests there would be the greatest streamflow return resulting from curtailment of wells within 400 m of the stream. The maximum recovery over a shorter period (less than 10 days from the start of curtailment) would be expected from wells located within 200 m from the stream based on a range of transmissivity estimates. From a management perspective, this reinforces the value of focussing curtailment efforts on wells located closest to the stream if a rapid improvement of flows is desired.

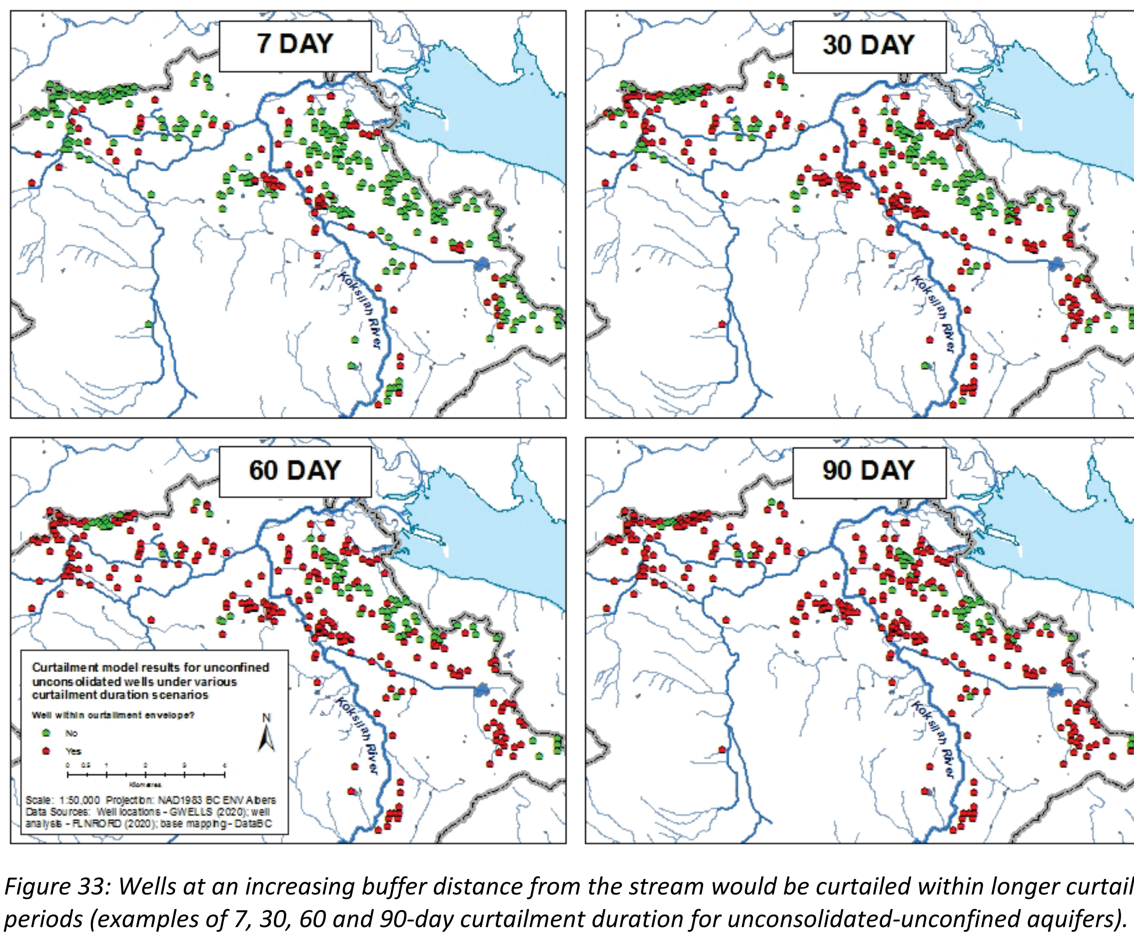


Figure 33: Wells at an increasing buffer distance from the stream would be curtailed within longer curtailment periods (examples of 7, 30, 60 and 90-day curtailment duration for unconsolidated-unconfined aquifers).

Within UC aquifers, because water in the aquifers is under confining pressure, the effect of pumping is anticipated to be felt more quickly and at further distance from the pumping well. Within the Koksilah watershed based on well lithology and subsurface mapping, the most realistic scenario was to assume aquifers are mostly partially confined, with a higher value of storativity in comparison to fully confined aquifers; the effect on the model is to focus on curtailment of wells within 600 m of the stream under longer curtailment periods, and within 300 m from the stream over shorter (≤10 day) curtailment periods.

In BED aquifers, excluding scenarios resulting in <20% recovery, would also tend to focus on wells within 600 m from the stream. In all lag time scenarios, curtailment of groundwater diversion from bedrock wells located within 100 to 200 m of the stream is likely to have the greatest beneficial impact on streamflow over a shorter curtailment period (≤10 days).

A commonly used method to estimate the degree of potential impact of a groundwater withdrawal on a nearby hydraulically connected stream is to calculate the stream depletion factor (SDF), essentially a streamflow-depletion response-time factor, defined as time period to reach the point at which 28% of the groundwater pumping is obtained from surface water capture (Barlow & Leake, 2012). The SDF depends on distance from the stream, and aquifer properties, and is calculated using the formula:

$$SDF = \frac{d^2}{D} = \frac{d^2}{\frac{T}{S}}$$

(Equation 1)

where

SDF=stream depletion factor (days)
d=distance between the pumping well and the hydraulically connected stream (m)
D=diffusivity (m^2/d)
T=transmissivity (m^2/d)
S=storativity (for a confined aquifer), or specific yield (for an unconfined aquifer)

Figure 34 illustrates the SDF for wells in different aquifer categories including bedrock (BED), unconsolidated-confined (UC), and unconsolidated-unconfined (UU), calculated using the distance of wells from point of hydraulic connection on the stream and aquifer properties used in the curtailment model. Within UC aquifers wells up to approximately 1200 m have a SDF <1 year (365 days), suggesting wells within this distance from the stream would contribute to stream depletion in an annual time frame. In comparison, wells in UU aquifers less than 750 m from the stream have SDF< 365 days, and for BED aquifers, wells within 320 m of the stream have SDF<365 days.

Importantly, from a water balance perspective, and considering water demands from various sources within the watershed, wells with larger pumping rates and at a narrower buffer distance from the stream are likely to influence streamflow capture at shorter time scales e.g. with more immediate impacts during the low flow season. In contrast, wells with lower pumping rates and at further distances from the stream are anticipated to influence streamflow capture (diversion of water that would naturally contribute to baseflow) over longer seasonal or annual time scales, resulting in a more diffuse or cumulative effect on streamflow depletion.

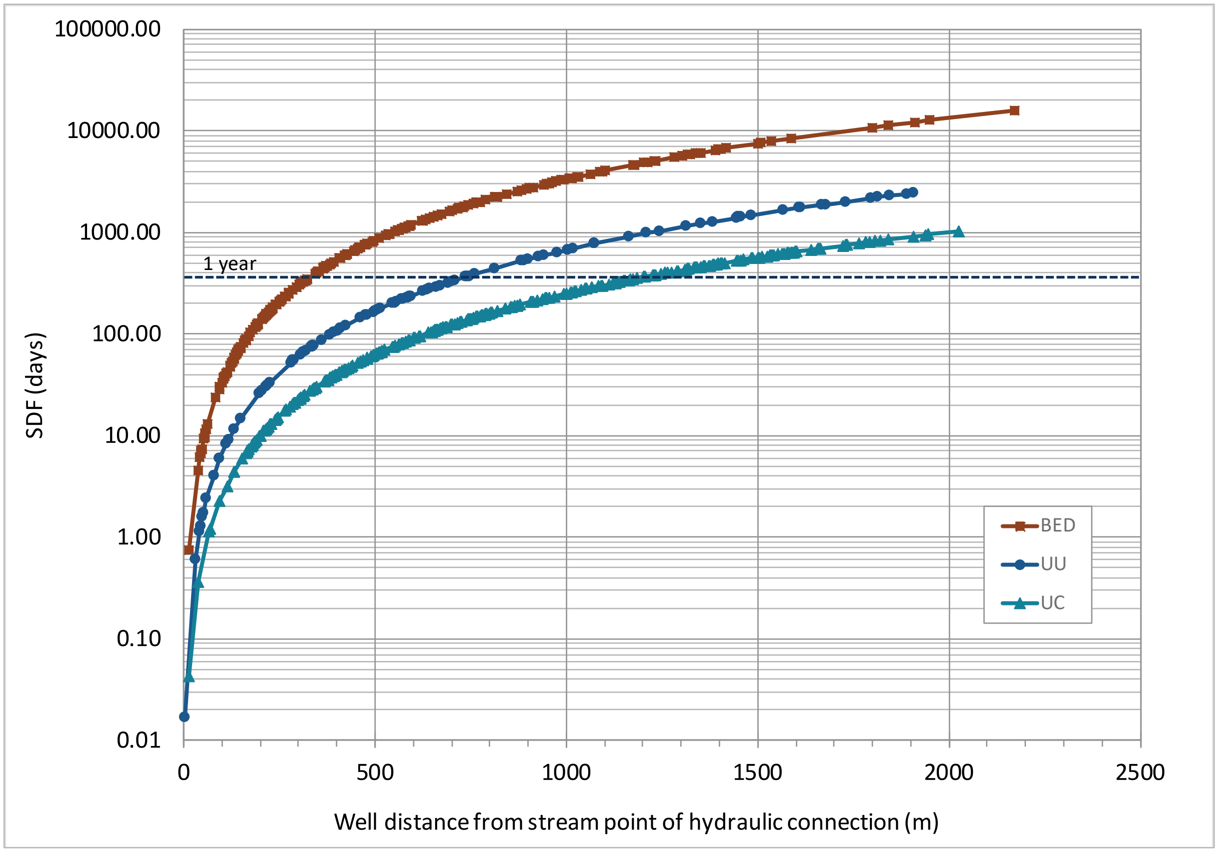


Figure 34: Stream depletion factor (SDF) of wells in different aquifer categories based on distance of wells from point of hydraulic connection on the stream and aquifer properties from curtailment model.

Figure 35 shows cumulative groundwater demand (%) from wells in different aquifer sub-types within the watershed compared to stream depletion factor(SDF). Coloured lines indicate stream depletion “time periods” of 30 days, 1 year and 10 years. Groundwater pumping from wells with a stream depletion factor <30 days is likely to have an immediate effect on improved stream flow if curtailed during times of water scarcity. Stream depletion <1 year represents withdrawals that occur within an annual period of the water cycle. Approximately 75% of cumulative demand is from confined-unconsolidated aquifers within a 1-year SDF (time) from the stream. In comparison groundwater from unconfined-unconsolidated aquifers, and from bedrock aquifers have higher SDF’s therefore are likely contribute to diffuse or cumulative impacts on water balance in the watershed but are likely to be challenging to manage during short-term streamflow mitigation efforts.

The curtailment model analysis indicates that surface water diversions directly from the stream and pumping of wells located at a shorter, <300 m from the point of hydraulic connection on the stream, are likely to have a more immediate impact—involving induced recharge or capture depending on the direction of groundwater flux—that could be regulated in a curtailment scenario to improve streamflows in response to a critical threshold being reached.

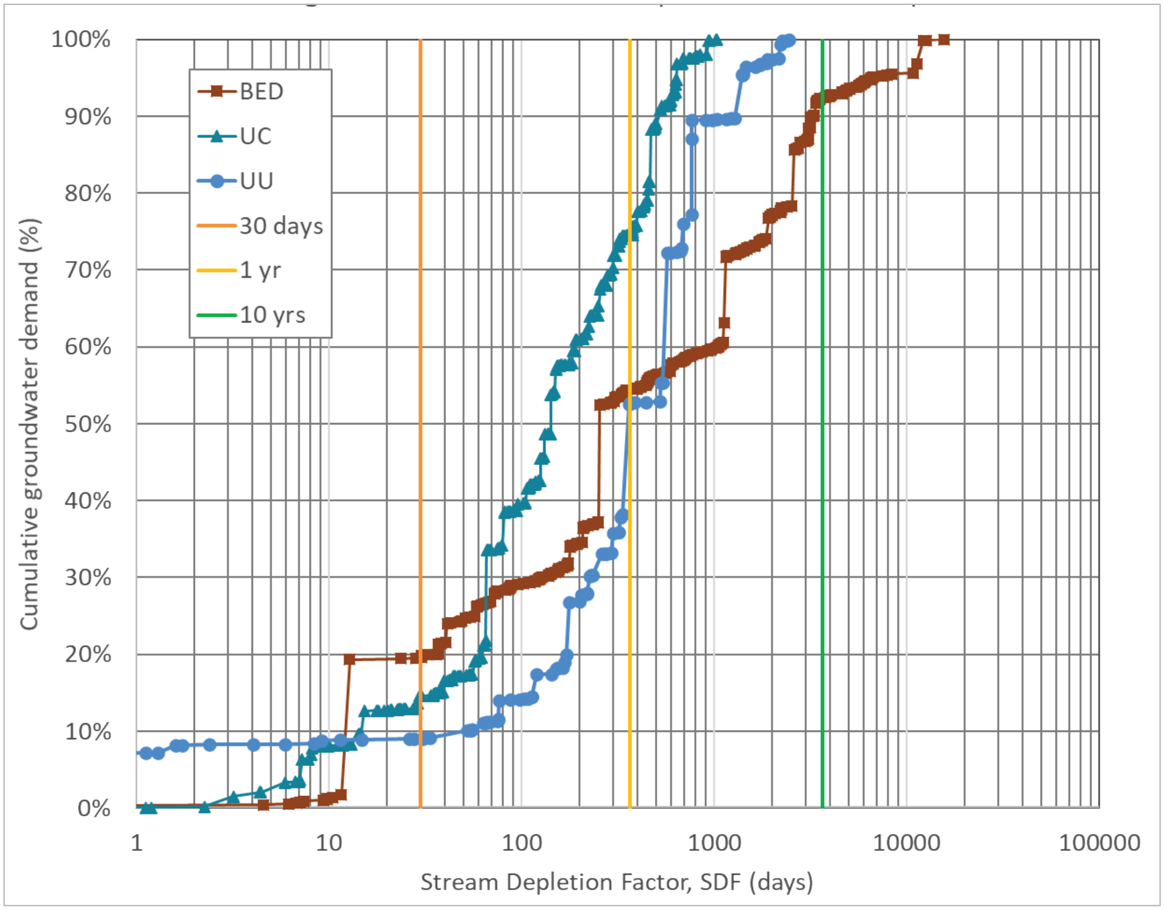


Figure 35: Cumulative groundwater demand by aquifer sub-type, versus Stream Depletion Factor (SDF). Cumulatively, more than 70% of groundwater use in Koksilah watershed is from wells with <1 year SDF, representing a predominantly annual cycle of groundwater recharge and flux to surface water. After Hatfield Consultants (2021).

5.3 Economic impacts of regulatory options

Agriculture is an important contributor to B.C.'s economy, generating $3.9 billion in farm cash receipts in 2019 (Statistics Canada, 2020). Maintenance of local agriculture is also essential for the preservation of local food security, provision of employment opportunities, and is a central part of the rural character of the South Cowichan area. While considering options to mitigate low streamflows in the Koksilah River during the summer 2018 and 2019, FLNR worked with the Ministry of Agriculture to develop estimates of the potential economic impacts of different regulatory options on irrigators and other farmers.

In 2019, the estimated total potential economic cost to the agricultural sector if a FITFIR-based TPO (Critical Environmental Flow Protection Order under sections 86 and 87 of the WSA) was to be put in place for a month was estimated at more than $5.4 million (Andrew Petersen, Ministry of Agriculture, Food and Fisheries, personal communication, August 13, 2019). For example, if irrigation were to be completely shut down, the cost could include up to $1.5 million for loss of 50% of corn, grass forage and market vegetables production, approximately 75% decline in fruit production, and potential loss of up to 100% of nursery plant stock. For farms with livestock, the cost was estimated as up to $3.9 million, which included costs for investments in equipment, charges for water delivery, and decline in poultry and milk production. Some long-term impacts from decline in herd or flock size would also be anticipated. Two waterworks, providing supplies for approximately 759 residential connections, could also have been impacted; for example, curtailment could have involved reduction in water use to a volume required to maintain water for only essential household needs (250 L/d/connection). Ultimately, the socio-economic impacts of a FITFIR-based TPO were considered too high on balance with the anticipated streamflow gains and, as such, were not recommended as a suitable regulatory option.

An alternative was to consider a Fish Population Protection Order (under section 88 of the WSA) that would give the Minister discretion over which water users are restricted, allowing for the consideration of water needs and impacts associated with the various water use sectors, regardless of FITFIR priority. By focussing primarily on surface water licensees and groundwater users in close proximity to flowing streams that used water to irrigate forage crops (grass and corn), the anticipated estimated cost of the shutdown on the agricultural sector was reduced to $465,000 (a 91% reduction in potential economic impacts). In addition, one industrial user projected losses from $75,000 to $100,000 for every month of shutdown. A section 88 TPO can only be utilized if there is sufficient evidence that flows in a specified stream are, or are likely to become, so low that the survival of a fish population in the stream may be (or may become) threatened. One benefit of a section 88 TPO is that this approach requires the Minister to consider the needs of agricultural water users, while enabling the regulator to adapt and focus on areas of water use likely to produce the greatest benefit in improved streamflow within a short time period while minimizing negative economic or other impacts.

The economic analysis of temporary protection orders under the WSA illustrates the fundamental value of water to economic sectors in Koksilah watershed. Water, in particular groundwater (as the primary source of base flow during the summer period), also has inherent value in situ providing ecosystem services. If it occurs, over-exploitation of groundwater may be associated with other costs and impacts, including reduced natural discharge impacting fisheries, expenses born by water users to increase the depth of their wells or expend more energy to pump from greater depths in an aquifer, and other adverse impacts that must be considered within management options (van der Gun & Lipponen, 2010).

5.4 Temporary Protection Order issuance (2019)

5.4.1 Assessment of aquatic impacts and target threshold return

A technical assessment of species and biological impacts associated with specific stream discharge thresholds was prepared based on a field assessment, historical data, and literature information (Szczot, 2020). While additional assessment is presently underway to verify an appropriate critical environmental flow threshold for the Koksilah River, two critical environmental flow thresholds have been proposed, a higher threshold of 490 L/s equivalent to ~5% MAD, and an interim lower threshold of 180 L/s based on preliminary assessment of instream habitat suitability for Coho and Steelhead species and other factors (Szczot, 2020). In 2019, a lower limit of 180 L/s at the Koksilah Trestle (08HA022) was established as the interim flow threshold and management focused on restoring minimum flows to this level through the TPO.

In mid-August 2019, flows at Koksilah Trestle (08HA022) were at 140 L/s and trending downwards (August 15, 2019, data from Real-Time Water Data Aquarius Portal (Province of B.C., 2019)). In reviewing available information, FLNR staff were concerned that streamflow was likely to become so low that the survival of coho and steelhead salmonid fry in the stream could become threatened. Therefore, the approach was to issue a Fish Population Protection Order (S.88 TPO), which does not rely primarily on FITFIR priority dates (compared to a S.86/87 TPO).

The final list of surface and groundwater users within the watershed that were considered for inclusion in the curtailment order was refined based on criteria including field verification of stream conditions, water use purpose, modelled lag time and expected return flows. The curtailment list was refined to produce an expected benefit (return flows of approximately 100 L/s) required to supplement the current and projected streamflow conditions to levels above the interim CEFT.

Tributaries in the lower-middle watershed were visited to determine if they were still flowing. Field parameters (temperature, specific conductivity, and pH) were measured using a hand-held YSI to determine if there was evidence of groundwater influence. Water temperatures measured in pools ranged from 11 to 15 °C, based on the amount or rate of groundwater input, shade covering and aspect. (Water temperature lethal to fish is in the range of 25 °C, but negative affects on physiology and behaviour may occur at temperatures >12 to 15 °C (U.S. Environmental Protection Agency, 2001).) Fish fry were observed in most pools, including isolated remnant pools in sections of the stream that were mainly dewatered. From the field assessment, surface water users with a point of diversion in a section of the stream where there was no flow were generally excluded from the curtailment list, as it was inferred that they were not using water (the stream was dry).

The model examined theoretical lag times of 30, 60 and 90 days. A lag time of 7 days was chosen for the final iteration as the curtailment was implemented later in the dry season, when fall rains were expected within a period of a few weeks. The curtailment model showed that, even in an ideally connected system, for groundwater users at further distance from the stream, the percent of pumping volume that would theoretically be returned to the stream would be relatively low. Considering aquifer heterogeneity and other potential sources of error, it was decided to exclude wells for which the expected benefit (percent of groundwater pumping) anticipated to return to the stream was less than 20%. To minimize economic impacts, stock watering and irrigation of non-forage crops were excluded, as was use of water for domestic purposes.

5.4.2 Notification of potentially affected users and issuance of TPO

To ensure procedural fairness, prior to issuance of the TPO water authorizations and water protection staff attempted to contact all water users that would potentially be impacted by the TPO by phone, letter, and/or in person. Irrigators were invited to a community meeting to discuss their concerns and the proposed approach to improve streamflow, along with representatives of FLNR, Ministry of Agriculture (AGRI) and the Cowichan Watershed Board.

A Fish Population Protection Order (section 88 of the WSA) was issued in the Koksilah watershed on August 16, 2019. Written letters were delivered by hand to affected parties, where possible, on August 19. As a result of the considerations and exclusions noted above, curtailed water uses included irrigation of forage crops (such as hay and corn) and industrial purposes. The Order listed 44 surface water and groundwater licences (42 irrigation purpose and 2 industrial purpose) and wells on 21 parcels inferred to be using unlicensed groundwater. The Order was rescinded on September 19, 2019, following the onset of fall rains.

Field monitoring in the watershed, including measurement of streamflow (and temperature in continuous sensors) at established year-round and seasonal stations (see Figure 8), continued during the curtailment period. Observation wells were monitored continually (hourly readings of groundwater level and temperature) as per network standards. The resultant data were used to evaluate the effectiveness of the TPO on increasing flows in the lower watershed. Staff conducted field visits to verify compliance and identify if, and where, irrigation was continuing. This work concluded that there was an overall high level of compliance and cooperation with the Order across the affected areas.

5.5 Evaluation of TPO impacts on streamflows and water users

Following the 2019 TPO, an analysis was commissioned to examine the response in flows or hydraulic conditions in the stream. NHC (Northwest Hydraulic Consultants Ltd., 2020) completed a review of data collected in the Koksilah River within the period prior to, during, and after the TPO was issued. The primary question was whether issuance of the TPO caused, or contributed to, an increase in streamflow. Flows in Chemainus River watershed, north of Koksilah, were used as a representative watershed with similar land use and watershed characteristics for comparison. Because water use was not curtailed in the Chemainus River watershed, flow recession curves compared to historical conditions were considered representative of, or proportional to, conditions that might have occurred in the Koksilah River in absence of a TPO.

Hydrographs for August 2017, 2018 and 2019 at WSC08HA003 (Cowichan Station) are shown in Figure 36 illustrating streamflow in comparison to 5% of the mean annual discharge (MAD) (490 L/s) and a lower interim flow threshold (180 L/s) established as an interim guideline in consideration of agricultural water needs.

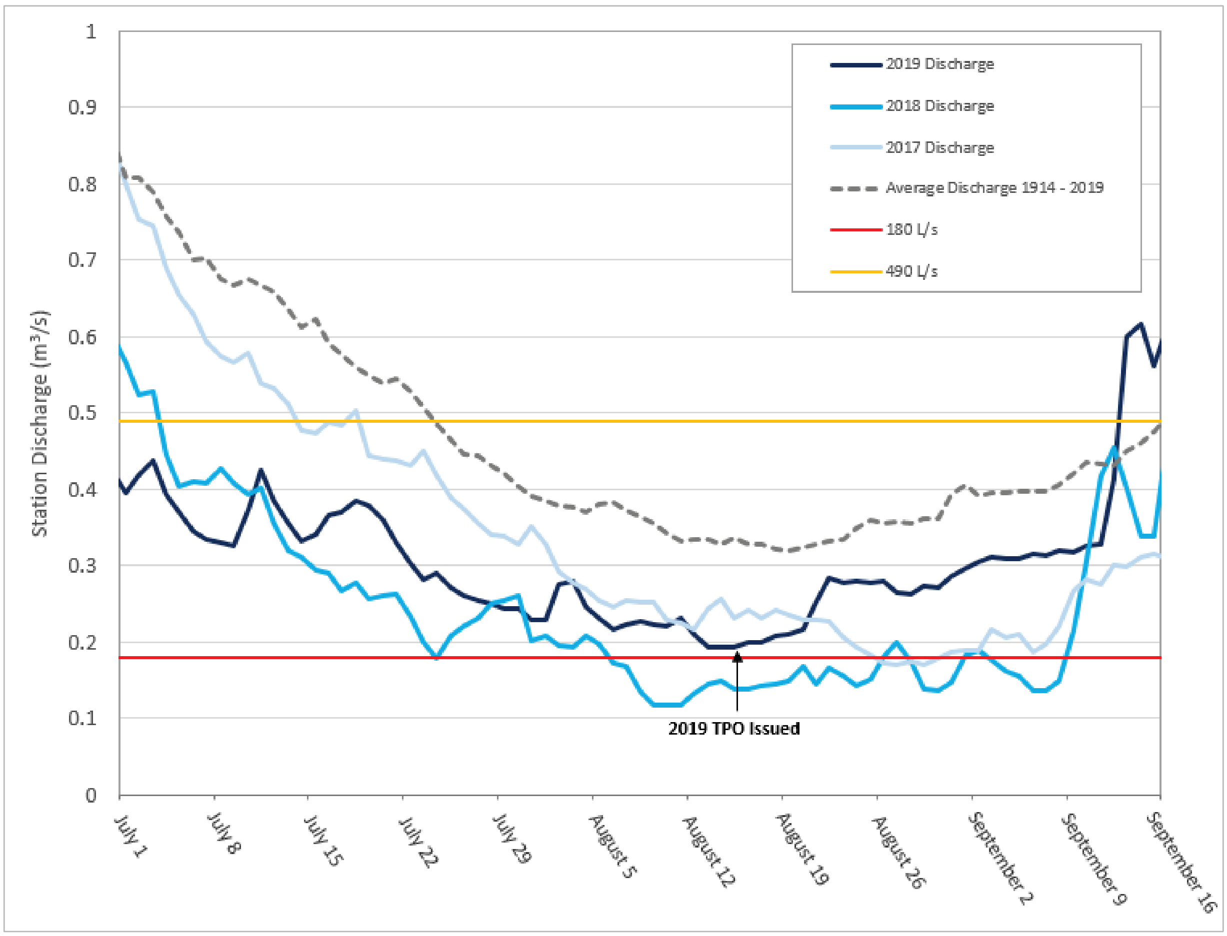


Figure 36: Koksilah River discharge August 2017, 2018 and 2019 at WSC08HA003 (Cowichan Station) in comparison to the interim environmental flow threshold (180 L/s) and 5% MAD (490 L/s).

For the 2019 period, the TPO was issued on August 16 and delivered to water users on August 19, 2019. By August 24, flows in the Koksilah River began to stabilize and increase in comparison to previous years. In comparison, during the same time frame in late August 2019, discharge in Chemainus River (not shown) continued to decline.

Other potential indicators reductions in surface and groundwater diversion in response to the TPO included water temperature, and groundwater levels. Surface water temperature measured at instream monitoring stations in the Koksilah River exhibit a diurnal fluctuation based on air temperatures and insolation (sun) on the water surface. Beginning approximately two days following the curtailment order water temperature in Koksilah River at both the Cowichan Station site (08HA003) and downstream trestle (08HA022) began to show a declining trend, which was interpreted as indicating an increase in groundwater inputs affecting stream temperatures.

Groundwater levels in OW430 and OW431 in Glenora, and OW488 at Cowichan Station, began to increase approximately two days following issuance of the TPO despite minimal to no precipitation inputs during this period. This review concluded that the TPO issued in 2019 did produce a change in groundwater and streamflow conditions, likely as a result of decreased water use (Northwest Hydraulic Consultants Ltd., 2020). Voluntary reductions in water use within the watershed were promoted via communications with water users in 2017 and 2018, and streamflow during these periods declined below the 180 L/s interim threshold. During August 2019, flows increased following the TPO and were higher than during the similar period in 2017 and 2018 validating potential effectiveness of the Order.

The degree of actual impacts to agricultural producers and industrial users issued a TPO in 2019 is uncertain. In general, impacts to agricultural water users would depend on the timing and duration of the curtailment period (at what point during the irrigation season users are asked to discontinue or reduce use), the farm and crop type, and availability and cost of alternative water source if water is still needed. In 2019, the impacts of the TPO were thought to be lower than projected as many fields had already been cut, and the irrigation season was already close to finished by the time the Order was issued.

One of the benefits of the TPO in 2019 was that it brought renewed attention to the problem of low streamflows during the dry season and the influence of surface and groundwater use on conditions in the Koksilah watershed. However, this type of management approach is reactive, requires significant time and resources to implement, and imposes external solutions on user groups. As a long-term solution, other proactive management options such as monitoring and reporting of water use, establishing and enforcing licence conditions affecting timing, frequency and volume of water demand, further promoting voluntary water use reductions, and subsidizing improvements to infrastructure for key sectors (e.g., early detection and reparation of leaks, improved usage efficiency, development of storage). Water users could establish cooperative water supply solutions including storage, shared works, and working together to manage timing and volumes of water demand; these strategies are likely to have a more beneficial impact in comparison to a curtailment approach.

6. CLOSURE

As part of ongoing work to characterize and improve hydrological conditions within the Koksilah River watershed, water demand from surface and groundwater sources was evaluated, summarized, and considered in the context of water management options available under the *Water Sustainability Act*. The Koksilah watershed has been identified as a watershed of concern for a number of years; and although restrictions imposed on surface water licensing have been in place since 1980, it is estimated that groundwater development has doubled the total water demand in the watershed since that time.

Total annual water demand in the Koksilah watershed is estimated to be approximately 7.2 Mm^3 annually. The greatest use of water by volume is for agriculture, representing approximately 65% of water usage from surface water and groundwater sources during the dry season, and 45% of total annual demand. Residential use from domestic wells and within serviced areas are largely supplied by groundwater and constitute approximately 17% of water demand annually. Additional work is needed to verify water demand, including reviewing existing licences for beneficial use, metering usage, and continuing communication with water users. Transitioning of existing non-domestic groundwater users into the water licensing scheme is an essential step which will improve the accuracy of water balance estimates.

Aquifers and wells in the watershed are interpreted to be hydraulically connected to the Koksilah River and tributaries, contributing to streamflow depletion via capture of discharge that would flow naturally toward the stream under non-pumping conditions. Induced recharge from higher volumes of groundwater pumping close to the stream is also probable, but likely limited to a narrower buffer zone surrounding the stream due to aquifer heterogeneity. Cumulative impacts from both surface and groundwater diversions are anticipated to be concentrated within the lower part of the watershed, which has historically been associated with preferred aquatic habitat for salmonid species. Significant adverse impacts to fisheries are likely to be greater for species such as Coho, Chinook and steelhead that inhabit the stream during early development stages for a larger period of time period during the dry season when flows are at their lowest, compared to species such as Chum that migrate to a marine environment earlier in the spring.

The *WSA* provides mechanisms to address seasonal shortages within streams and aquifers, including Temporary Protection Orders to curtail surface water withdrawals and groundwater use in hydraulically connected aquifers. Over the long-term other strategies, including Water Objectives or Water Sustainability Plans under the WSA, could help ensure equitable distribution and use of water resources in the watershed and mitigate adverse impacts to aquatic species. Measures to ensure Indigenous water rights and title are considered and retained are a critical component of ongoing and future planning work that is focused on a partnership and collaborative relationships between the provincial government and local First Nations, including Cowichan Tribes.

An analysis of data on wells, aquifers, land use, and water rights supported the development of a groundwater curtailment model that identified the distance from the river that wells, if curtailed, would reduce the effects of streamflow depletion caused by groundwater pumping. The model was developed for wells constructed in unconsolidated (unconfined and confined) and bedrock aquifers that are potentially hydraulically connected to the Koksilah River and its tributaries. Variable time frames for curtailment, from 7 days, to 30, 60 and 90 days were considered. At each time step, a larger number of wells were included within the curtailment envelope. Due to the potential lag time of streamflow response after groundwater pumping stops, for shorter curtailment periods (<30 days), regulating groundwater users within 200 m of the stream is likely to have a more rapid beneficial impact. Curtailment of groundwater users at greater distance (>600 m) from the stream is less likely to improve streamflow over shorter curtailment periods.

The model presents information that can be used to guide regulatory or voluntary actions in the Koksilah watershed, while considering potential sources of error and uncertainty. Curtailment of water use is only one of many regulatory and management approaches that could be used to reduce seasonal shortages and stress on aquatic ecosystems in streams that are hydraulically connected to aquifers. Other management options such as establishment and enforcement of licence conditions affecting timing, frequency and volume of water use, promotion of voluntary water use reductions, promoting or subsidizing improvements to infrastructure (e.g., early detection and reparation of leaks, improved usage efficiency, utilization of storage) are likely to have a more beneficial impact in comparison to groundwater curtailment.

The Province is committed to working cooperatively with agencies and water users in the watershed to help ensure that the ecological values of the stream and First Nations water rights are protected, while maintaining equitable use and sustainability of water resources for economic benefit and human needs. While significant work has been done over the last decade or more to characterize aquifers and complete groundwater balance and groundwater surface water interaction studies, many uncertainties remain. Continued investment in characterization and monitoring studies will further support improved knowledge and resource management in the watershed.

Responding to low flows in the Koksilah River in summer 2017-2018, FLNR primarily focused on monitoring, outreach and communications to promote voluntary reductions in water use. The results in terms of observed changes or improvements in streamflow compared to the timing of communications were inconclusive. Combining promotion of voluntary reductions with issuance of a S.88 TPO in 2019 enabled FLNR to limit the total number of potential water users impacted, while minimizing potential long-term impacts (e.g. damage to crops that can't recover from drought, such as fruits and trees, or impacts on livestock). Based on analysis of flow data, the curtailment of surface and groundwater use resulted in an increase in streamflow and reduced water temperatures. The TPO also brought increased public attention to the ongoing concerns and challenges faced in the watershed.

As one of the largest water use sectors, the agricultural community have been engaged over three summers of active monitoring and communications. The Ministry of Agriculture has been an advocate for the farming community and will likely continue to be a key partner for implementing long-term water strategies. Collaborative management involving water user communities or irrigation districts, where industry self-regulates withdrawals in response to identified water shortages could be a successful approach, that minimizes government intervention and adverse economic impacts, while responding to and mitigating low flow concerns.

7. DATA GAPS AND RECOMMENDATIONS FOR FURTHER WORK

Over the past decades, recognition of the complex interactions between surface and groundwater has benefited from field-based research and development of models to examine these interrelationships. In B.C., new tools under the *WSA* have enabled water managers to consider the cumulative impacts of surface water use and groundwater pumping on streamflow during times of scarcity. In the Koksilah watershed, our understanding of factors influencing hydrologic processes, including where and how much water is being used and the linkage to streamflow and survival of aquatic species, has improved but is still being developed.

Below are recommendations that would improve this understanding over time:

a) Well inventory: The spatial location of wells in the GWELLS database is known to vary from actual well location, presenting a source of uncertainty. Specific errors and omissions in the database identified during the analysis should be corrected, in cooperation with GWELLS database administrators in the Ministry of Environment and Climate Change Strategy. This could include documenting the status of abandoned or decommissioned wells and relocating wells with significantly incorrect spatial coordinates. Communication with owners of parcels identified as potentially utilizing a groundwater source (see 3.2) could provide additional records to improve inventory and knowledge of active wells in the subject area.

b) Continue work to identify and reduce unauthorized water use. Field reconnaissance and compliance enforcement in 2017 and 2018 identified some unauthorized users drawing water from the river. Identifying and regulating unauthorized water use, during drought periods and other times during the year, is likely to result in direct improvements to river flow and ensures a fairness for water users following the regulations.

c) Improve water use estimates for the various water use sectors: This could include desktop assessments of water use in the related water sectors, or compilation of metering data for the region. A pilot study to improve water use monitoring and reporting (voluntary or required as a condition of water license) could involve subsidies or incentive programs for key water users, such as large-scale irrigators. Historic water licences in the watershed could be audited and compared to current/actual use, and allocations adjusted accordingly using Beneficial Use Declarations or under a Water Sustainability Plan.

d) Conduct a survey of streambed materials (qualitative) and properties (quantitative) to enhance understanding of hydraulic connections between streams and aquifers.

e) Increase number and spatial distribution of surface water monitoring sites: Presently there is only one permanent, year-round monitoring station in the middle to lower watershed (WSA 08HA003), while FLNR staff conduct seasonal monitoring at a small number of additional sites depending on availability of staff resources. Enhanced monitoring, especially during the low flow period is needed to improve understanding of conditions in the watershed. Quantifying contributions from the primary sub-tributaries (Kelvin, Glenora and Patrolas Creeks), and comparing this to modelled flows and estimated water use within the sub-basins would assist with understanding the effect of water use on stream conditions. Field verification of seasonal flow conditions within first and second order tributaries in the upper watershed would assist with verification of the groundwater conceptual model, e.g. perennial flowing streams are more likely to be reliant on and indicative of groundwater contributions to baseflow.

f) Expand the groundwater monitoring network: Monitoring of groundwater levels and temperature at more sites would help develop a better understanding of annual and seasonal groundwater variability and interactions among aquifers (e.g., between unconsolidated and bedrock) and with surface waterbodies. It is noted that groundwater monitoring was increased with the construction of two wells in March 2019 and another in March 2020 in the Cowichan Station area. Additional monitoring sites are recommended, including sites that would provide information on bedrock aquifers in the upper and middle part of the watershed, in the lower watershed on the west side of the Koksilah River and near Kelvin Creek. Pairing of groundwater monitoring stations with surface water monitoring is useful to verify hydraulic connection aspects.

g) Expand and restore climate and meteorological data collection within the watershed. With closure of the Kelvin Creek climate station (EC1012573) in 2016, there are currently no active public meteorological stations in the watershed. Restoration of this monitoring location or establishing new site(s) to gather climate data for comparison to surface and groundwater monitoring data is recommended. For example, a climate station, coupled with a groundwater observation well and surface flow monitoring at the same location in the upper basin would improve understanding of inputs contributing to runoff and groundwater recharge.

h) Determine changes in water use and effects on streamflow as a result of voluntary and regulatory actions. Ongoing monitoring within the Koksilah River watershed is needed to understand how conditions of streamflow and water temperature change due to changes in surface or groundwater use. A survey of water users could document if water usage patterns (self-reported) have changed in response to communications from FLNR staff during the dry season, or on a long-term basis.

i) Develop a coupled groundwater-surface water numerical model for the watershed, calibrated to field observations. Such a model could serve as a support tool for evaluating the effects of precipitation and water usage on streamflow.

j) Investigate whether factors such as land use change (including forestry, rural development), climate change, and geomorphological change have contributed to declining summer low flows. This is the focus of work completed in 2020-21 (Hatfield Consultants LLP, 2021).

k) Research alternative options for mitigating seasonal low flows such as development of storage, which could potentially include options for surface storage or aquifer storage through artificial recharge.

l) Continue to communicate and collaborate with water users in the watershed to identify solutions, including work to scope and consider other regulatory tools and options under the WSA e.g. water objectives, groundwater allocation restrictions, or a water sustainability plan.

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APPENDIX A. METHODS TO ESTIMATE GROUNDWATER USAGE

A1. Identify locations and purpose of groundwater use

The analysis to identify specific parcels and wells to consider for inclusion in the groundwater curtailment model involved bringing several datasets together using ArcGIS and database tools (i.e., MS Access). This process is shown schematically in Figure A1.

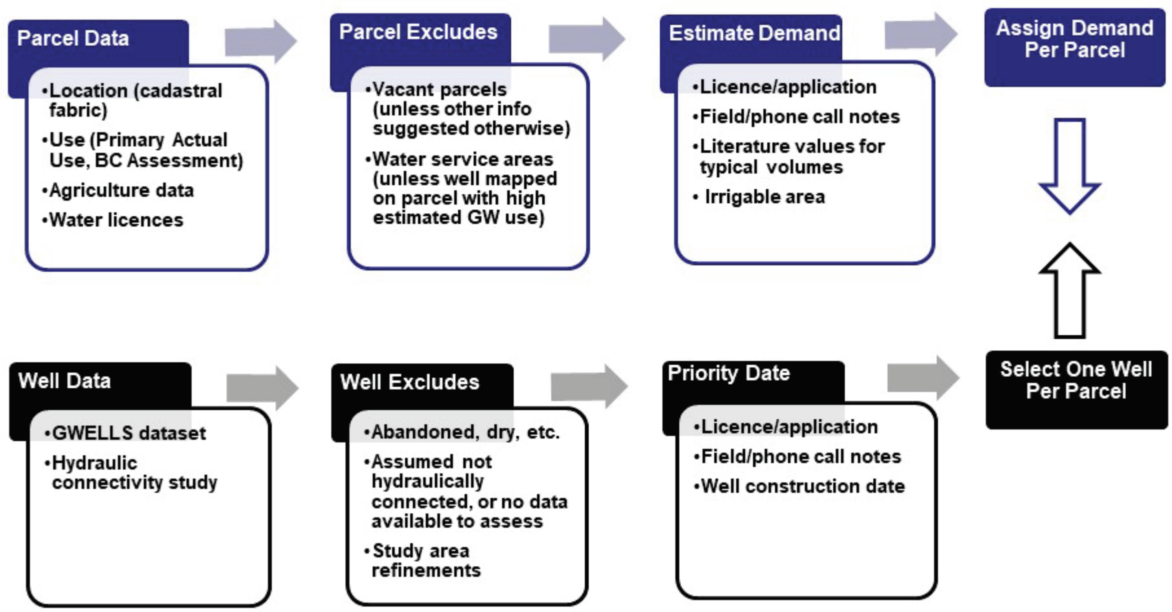


Figure A1: Process for determination of locations and volume of groundwater use

The following information was used to estimate where groundwater is being used in the Koksilah River watershed:

a) **Identify area of interest:** The entire Koksilah River watershed was initially identified as the area of interest (shown in Figure 1). In the previous groundwater curtailment analysis (Barroso & Wainwright, 2018) a sub-selection was made of wells within a buffer zone of 1 km from the Koksilah River mainstem and main sub-tributaries (i.e., Patrolas, Kelvin, and Glenora Creeks). For the 2019 analysis the whole watershed area was included because results from a study of hydraulic connectivity of wells to streams in the watershed (Sivak & Wei, 2019) suggested that the majority of wells in the watershed have a point of hydraulic connection to the Koksilah River or its tributaries. The reach of the Koksilah River downstream of Highway 1 in Duncan is believed to be tidally influenced and therefore was not identified as a concern with respect to low flows affecting instream habitat of identified species with fresh water developmental stages (Jaro Szczot, FLNR Aquatic Ecologist, personal communication, July 2018). Therefore, wells having points of hydraulic connection downstream of the highway were excluded from further analysis.

b) **Identify land use on the parcel:** Parcel (lot) information was obtained by joining cadastral data (ParcelMap BC, ArcGIS layer from DataBC) to tabular data from BC Assessment (BCAA; roll year 2018) based on parcel identifier (PID) numbers. Using the Primary Actual Use (PAU) code assigned to each parcel, the study area was further refined by focusing on the lots where water use is expected to be occurring. Several PAU codes were excluded from further analysis, based on the assumption that no water is currently being used. These included most codes indicating "vacant" parcels, and the following PAU codes:

- Parking, outbuilding only (Residential use category);
- Parking, storage, billboard only (Commercial use category);
- Railway, telephone, fiberoptic, telecommunications, gas, and electrical distribution systems (Transportation/Communication/Utility category);
- Logging, water lots, parking lots, roads, bridges, pipelines (Industrial use category); and,
- Government reserves (Civic, Institutional, and Recreational use category).

It is noted that PAU data is not available for all lots in the study area due to PID mismatches (e.g., due to recent subdivisions, strata properties, etc.), unreported PAUs, and certain types of land (e.g., Reserve lands). In addition, the PAU code represents only the principal use of the parcel (whereas there may be multiple uses) and is not necessarily correct, up to date, or reflective of the land use of interest for the consideration of non-domestic groundwater rights. For example, a parcel's PAU may indicate single family residential, but there could be farming or commercial use of groundwater for a non-domestic purpose.

c) **Identify where water is being provided within a water service area:** An internal spatial dataset on local water service areas (LWSAs) was reviewed and, where possible, updated. This dataset includes known and inferred boundaries of municipal supply systems and smaller-scale water purveyors believed to be using groundwater. Parcels falling within the boundaries of a LWSA were excluded from further analysis if the parcel use did not indicate a non-domestic water use and no well was plotted on the parcel (i.e., the parcel was assumed to be using water from the water purveyor). For this analysis, it was assumed that parcels that fall within a LWSA but have a well plotted on the parcel and a PAU code indicating a large volume water user (e.g., agriculture, and some types of industrial use) would preferentially draw water from the well rather than pay for purveyed water.

d) **Identify wells to be exclude from analysis:** Well data were obtained from the GWELLS database (accessed as an ArcGIS layer from DataBC). Wells were excluded from the curtailment analysis if:

- Well record indicated the well had been decommissioned or abandoned, or is a dry well;
- Well use information indicated no active pumping (e.g., observation well, monitoring well);
- Well location plotted outside the cadastral fabric, and it wasn't clear which parcel the well may be servicing;
- The point of hydraulic connection on the Koksilah River was downstream of Hwy 1 (based on (Sivak & Wei, 2019));
- The well construction date was unknown and it was not possible to determine a priority date (these were mainly historical shallow dug wells about which little information was known and not considered likely to impact the analysis significantly); or,
- There was information indicating the well was not likely hydraulically connected to surface water.

e) **Compile groundwater licence data:** Data on water licences and groundwater licence applications (new and existing use) was used to help inform parcel use and groundwater demand. For example, licence and application water use purposes were used to override parcel use designations based on PAU codes (e.g., a residential use category could be overridden to agriculture use if an irrigation licence was appurtenant to the parcel) and bring excluded parcels back into the analysis (e.g., due to “vacant” PAU codes). In cases where a surface water licence is appurtenant to a parcel with a documented well, it was assumed that the parcel is using water from both sources. Licenced and application water volumes were incorporated into the groundwater demand estimation.

f) **Verify parcels of agricultural use:** Data on land use in the watershed obtained from Ministry of Agriculture were used to confirm which parcels support agricultural activities. Although the land use survey data is from 2012, it was assumed that this information is more accurate than the PAU code assigned to the parcel. The agriculture data was used to flag parcels that were reported as actively irrigating or raising livestock (especially cattle), which was used to override PAU-designated land uses (described in “e” above) and assign water demand.

g) **Identify locations of potential unregistered wells:** Some land parcels were identified as potentially using groundwater from unregistered wells. These potential groundwater users were identified using specific PAU codes and other considerations as noted above, such as location outside of a local water service area, with no surface water licence, not located adjacent to a stream, and with no registered well on the parcel.

A2. Estimated Groundwater Demand by Purpose of Use

Groundwater demand was initially assigned on a parcel basis; water demand was then assigned to representative wells. If there was a groundwater licence or application associated with the parcel, demand was assigned based on the licence or application volume. If these were not available, water demand was estimated by coupling literature values for typical water use volumes with inferred land parcel use. Typical water use volumes use were compiled from literature sources (Miles, 2009; Morales, et al., 2011; Sunderland, 2018; Bennett, et al., 2021), a water budget study for aquifers in the area (Harris & Usher, 2017; Lapcevic, et al., 2020), historical water allocation and management plans (Ministry of Environment and Parks, 1986), and effluent data from *Environmental Management Act* discharge permits. Irrigation demand for agriculture parcels was generally calculated using a standard irrigation duty and estimation of irrigated area. Examples of methods used to estimate water demand based on inferred land use are provided in Table B1 (not an exhaustive list).

Table A1: Examples of methods used to estimate water demand in the absence of licence or application groundwater volumes

Water use category	Example	Method for estimation of water demand based on land use
Domestic	Residential lot	1.75 m^3/d (385 Igpd)
Agriculture (irrigation and/or stock watering)	Various crop types (e.g., grain & forage, vegetable, tree fruits), various animal types (e.g., beef, dairy, poultry)	Irrigable area (if available), multiplied by a standard irrigation duty (1 acre-foot per acre); if irrigable area was not available, assumed 50% of total lot area. Stock watering based on type of animal (literature values).
Commercial	Retail, bed and breakfast, seasonal resort, manufactured home park	Based type of activity (literature values) or proportion relative to domestic use

Water use category	Example	Method for estimation of water demand based on land use
Industrial	Brewery, winery, metal fabrication, processing/manufacturing	Based on type of activity (literature values)
Institutional	Government buildings, churches, schools	Equivalent to domestic demand if small scale, or based on building size/floor-space, or based on type of activity (literature values), or site-specific information (if available)
Recreational	Parks and playing field, recreational camps	Based on type of activity, irrigation duty, or other available information
Waterworks	Municipal water provider, improvement district, utility, or small water system not included in other categories	Estimated based on population/lots served, or metering or operational data if available

Estimating the groundwater pumping rate associated with wells in the area of interest was one of the more challenging aspects in developing the curtailment model. An MS Access database was created to manage parcel and well attributes, track selection and exclusion criteria, and to generate a master list of wells with associated water demand to input to the curtailment model spreadsheets developed in previous work (Province of B.C., 2016b). Information and data from the following sources assisted with the development of groundwater demand estimates:

a) **Licenced quantity:** For parcels with appurtenant water licences, information from groundwater and surface water licenses was useful for understanding the purpose and volume of water use. On a given property water may be provided from a well, a licenced or unlicensed surface water intake, or both. If the parcel had an appurtenant surface water licence, the estimated demand was distributed between the groundwater and surface water source depending on the details in the licence. If there was a groundwater licence appurtenant to the parcel, the licence volume was used for the demand (there are currently eight groundwater licences issued in the watershed, during this transition period for licensing existing groundwater use, discussed in b) below). If there was a surface water licence appurtenant to the parcel, half of the licenced volume was attributed to registered wells, based on the assumption that groundwater was likely to be a secondary, rather than the primary, source of water supply for these sites.

b) **Existing-use groundwater applications:** During the transition period to bring existing non-domestic groundwater users into the water licensing scheme under the *Water Sustainability Act*, groundwater users who have been extracting groundwater prior to February 29, 2016, have until March 1, 2022 to apply for a licence. The data from existing-use groundwater applications received by West Coast Water Authorizations were used to estimate water demand for subject parcels where available. Other types of water licence applications (i.e., new-use surface water and groundwater applications) were not considered, as the applicants would not be permitted to extract water prior to receiving a water licence.

c) **Domestic water use:** Domestic water use was generally estimated as 1.75 m^3/d (385 Imperial gallons per day), slightly under standard volume of 2 m^3/d allocated for a domestic purpose surface water licence in the West Coast region. This value is likely much higher than a typical household would actually use. Residential water use statistics estimate that household use in B.C. is the third highest within Canadian provinces, on average 0.300 m^3 (300 litres) per person per day in 2013, including outdoor use (Statistics Canada, 2017). Local estimates of residential water use within the Koksilah watershed have not been published. Estimates from the Town of Ladysmith, for comparison, showed water use in the range of 300 m^3/person/year (860 litres/person/day) in 2009, while other municipalities in this region such as Duncan and North Cowichan have implemented water metering, which is expected to reduce usage volumes, and provide better estimates of water usage over time (Cowichan Valley Regional District, 2010). Under Section 6 (4) of the *Water Sustainability Act*, domestic groundwater use—water for household needs, including irrigation of a garden no more than 1,000 m^2—is excluded from water licensing requirements (Province of B.C., 2018a). Wells assumed to be used for domestic purposes (based on their location on a non-vacant residential parcel) were included in the curtailment model even though the total volume is assumed to be small in comparison to other water uses. S.22 (9) of the WSA requires that domestic water use be eligible for curtailment if a significant water shortage is declared. Under a WSA S. 86, 87 or 88 curtailment scenario, surface and groundwater users would be allowed continued usage of up to 250 litres per day per household for essential household needs.

d) **Agriculture water use:** Irrigation demand was estimated by multiplying the inferred irrigable area on a parcel by an irrigation duty of 1 acre-foot per acre, which is a standard estimate for irrigation of crops in the Vancouver Island Region (Ministry of Environment, 2006). The actual irrigation demand may be lower or higher, depending on the crop type, irrigation method, and the actual portion of the parcel being irrigated in the time period of interest. To provide a more refined estimate, the BC Agriculture Water Calculator (Province of British Columbia, Government of Canada, Okanagan Basin Water Board, Investment Agriculture Foundation of BC, Partnership for Water Sustainability in BC, 2018) could be used to estimate demand based on crop type, soil type and climatic characteristics and spatial area of lot or irrigated portion of lot, as per the methods in the Cowichan Agricultural Water Demand Model (van der Gulik, et al., 2013). However, due to the size of the study area and number of parcels assumed to be irrigating, it was not feasible to estimate irrigation demand on a parcel by parcel basis. Instead, air photo imagery was used to estimate irrigable area for a subset of representative parcels using ArcGIS tools, and the water demand estimated using inferred crop type provided within a BC Assessment primary actual use dataset. The sensitivity analysis found there was generally good agreement between the water use estimate from the Agricultural Land Use calculator and the standard irrigation duty applied to 50% of the parcel area (typical area of parcel being irrigated). Data from the Agricultural Land Use Model (van der Gulik, et al., 2013) were also used to identify which parcels likely supported livestock, which would escalate economic impacts in the event of temporary protection orders.

e) **Interviews with water users:** Over the course of the drought response in 2017 to 2019, hundreds of groundwater and surface water users in the watershed were contacted with letters, phone calls, and site visits to convey water scarcity concerns, ask for voluntary reductions in water use, gain information on current water use, and deliver information on temporary protection orders. Information on water use purposes, sources, and volumes gained in conversations and observed during site visits were incorporated into the curtailment model and water demand database.

APPENDIX B. KOKSILAH GROUNDWATER CURTAILMENT MODEL

During times of water scarcity affecting aquatic habitats one regulatory option under the *Water Sustainability Act* is to require the reduction or cessation of water use (curtailment) through a Temporary Protection Order (TPO). A TPO can be applied to surface water users, and to users of groundwater from aquifers that are hydraulically connected to the impacted stream.

When water is extracted directly from a surface water source such as a stream, if a water shortage occurs, stopping the pump will result in an immediate change in flow within the stream. In comparison, if water is being pumped from an aquifer that is hydraulically connected to a stream, there is typically a time lag or delay between when changes are made to the pumping rate and when those impacts are observed in the stream. This time lag depends on the properties of the aquifer (e.g. transmissivity, storativity) and on the distance that the well is from the stream—the farther the well is from the stream, the longer that delay or lag time will be. A groundwater curtailment model is a method to identify groundwater diversions that are hydraulically connected to the stream that, if curtailed, could improve streamflow. The methodology for developing the Koksilah watershed groundwater curtailment model closely follows the approach outlined within the Screening Tool for Guiding Short-Term Groundwater Curtailment during Water Scarcity (Province of B.C., 2016b). The curtailment screening tool is based on a simple but well recognized analytical solution (Glover & Balmer, 1954) to identify which wells, within a curtailment envelope or setback distance from the stream, that if they stopped pumping, would likely result in an increase in streamflow within a time period of interest. The model also gives an indication of which groundwater use e.g. from wells at further distance from the stream outside of the curtailment envelope, would likely not have a beneficial use on streamflow if they stopped pumping because the time lag would be too great.

The process for considering groundwater curtailment under a TPO involves gathering information on the study area, the aquifers and groundwater sources, and the groundwater demand (i.e., who is using groundwater, how much is being used, and from which source it is being drawn from). Methods used to estimate groundwater demand during the initial phase of WSA implementation are described in Appendix A.

Development of the groundwater curtailment model also required assessment of the degree and nature of hydraulic connection of wells and aquifers to surface water bodies, which included considering whether the well is drawing from a hydraulically connected aquifer, estimating the hydraulic properties of any connected aquifers, and using subsurface lithological data and geologic mapping to predict where on the stream the impacts of groundwater pumping might occur (the point of hydraulic connection (PoHC)).

The groundwater curtailment model produces a list of wells that would be targeted to stop or reduce pumping in order to increase streamflow within a specified curtailment period. The curtailment period is the time frame between when curtailment would begin, for example when flows in the stream approach or go below the Critical Environmental Flow Threshold (CEFT), and when flows in the stream are expected to increase naturally (e.g., following onset of fall precipitation). The list of groundwater users to be curtailed is then combined with the list surface water users (i.e., licensees with pumps or intakes on the stream of interest or other connected waterbodies) to create one list of water users that could be considered for curtailment orders under TPO measures.

The key steps taken to develop the groundwater curtailment model are described in greater detail below.

B1. Curtailment model data inputs

The general steps taken to develop a groundwater curtailment model for the Koksilah watershed were to:

a) Compile information on groundwater users (known and inferred);
b) Estimate groundwater demand (pumping rate);
c) Compile data on aquifer properties (transmissivity, storativity, specific yield);
d) Determine hydraulic connectivity of groundwater sources and wells;
e) Estimate the distance of wells to the point of hydraulic connection (PoHC) on the stream;
f) Determine remaining curtailment model parameters (e.g., curtailment period duration, target streamflow recovery, representative values of aquifer properties); and,
g) Enter data into model spreadsheet and evaluate and refine results.

The process is shown in Figure B1 and the steps are described in the sub-sections below.

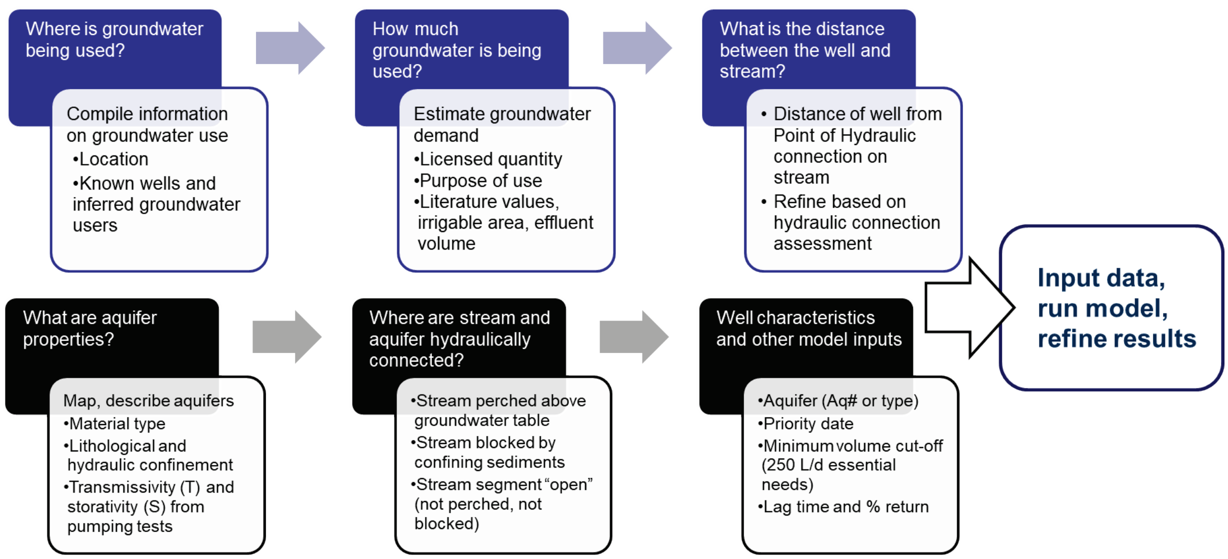


Figure B1: Process for development of a groundwater curtailment model.

B1.1 Compile information on groundwater users

The analysis to identify specific parcels and wells to consider for inclusion in the groundwater curtailment model involved bringing several datasets together using ArcGIS and database tools (i.e., MS Access). The principle step was to identify where and how much groundwater was in use in the watershed, which was modelled for each parcel. The process involved compiling data on the locations of registered wells, estimating water needs depending on the land use indicators, and accounting for water availability from alternate sources including surface water licences or local water service providers. Due to the large number of parcels and wells, groundwater use estimates were initially modelled collectively, rather than on a parcel-by-parcel basis.

Of 1396 registered wells in the Koksilah River watershed, 1297 were initially identified for inclusion in the groundwater curtailment model (excluding dry holes, duplicate records, and decommissioned wells). An additional 185 wells were excluded due to lack of sufficient information (e.g. lithology) to assess the likelihood of hydraulic connectivity, bringing the total number of wells available for inclusion in the analysis to 1112. Although there are an estimated 2810 parcels in the watershed that were inferred to be using water from a non-purveyed source (i.e., are outside of a known water service area), only parcels that contained at least one documented well could be included in the analysis due to the required model inputs (e.g., source aquifer, proximity of well to any hydraulically connected sources). Because many parcels have multiple wells, the number of parcels (used as a proxy for inferred groundwater users) included in the model was reduced to 624 in the 2019 analysis.

B1.2 Estimate Groundwater Demand

Groundwater demand was estimated on a parcel basis, then assigned to representative wells. If there was a groundwater licence or application associated with the parcel, demand was assigned based on the licence or application volume. If these were not available, water demand was estimated using literature values for typical water needs associated with the type of land use on the parcel. Typical water use volumes use were compiled from literature sources (Miles, 2009; Morales, et al., 2011; Sunderland, 2018; Bennett, et al., 2021), water budget studies for aquifers in the area (Harris & Usher, 2017; Lapcevic, et al., 2020), historical water allocation and management plans (Ministry of Environment and Parks, 1986), and effluent data from *Environmental Management Act* discharge permits. Irrigation demand for agriculture parcels was calculated using a standard irrigation duty and an irrigation area estimated for each parcel. Where possible, groundwater use estimates were updated with actual demand if the information became available during field visits or discussions with water users. Refer to Appendix A for detailed description of methods to estimate groundwater demand.

B1.3 Assign representative wells per parcel and priority dates

Where there was a single well on a parcel, the water demand for the land use was assigned to that well. The approach of how to address multiple wells on a parcel can influence whether a well is included or excluded from the curtailment list and therefore requires careful consideration. Different approaches that were considered included:

a) Divide the parcel demand between all wells on the parcel. A disadvantage to this approach is that some parcels or wells might be excluded from the initial curtailment list based on the lower inferred water demand per well;
b) Assign the parcel demand to the well that is deemed most likely to be in use (based on well depth, date of construction, driller's yield estimate, and lithology); for example, if there are multiple wells, one could assume that the newest well, or the most productive well is the one that is most likely to be in use.
c) Assign the parcel demand to all wells on the parcel while developing the initial curtailment list. Since this method models one large drawdown cone for each well rather than several smaller ones, there is a greater chance that the groundwater demand associated with the parcel would result in the parcel being included in the curtailment envelope.

Because the modelled stream depletion depends on the water demand and aquifer properties, approaches (a) and (b) were discarded, as they could result in a parcel being prematurely excluded from the curtailment list; this idea is shown graphically in Figure B2. Approach (c) is considered a fairer approach, as it uses the greatest potential drawdown associated with each parcel (i.e., parcels with multiple documented wells are treated the same as parcels with just one registered well). If a parcel is included in the curtailment list based on water use from one or more wells, the final curtailment list was then refined to include that parcel. Although it is possible (and often likely) that when multiple wells exist on a parcel they are being used for different purposes, water use type was modelled on a parcel basis so only the type associated with the greatest water demand would be captured (e.g., for a parcel believed to be irrigating, domestic use would not be included).

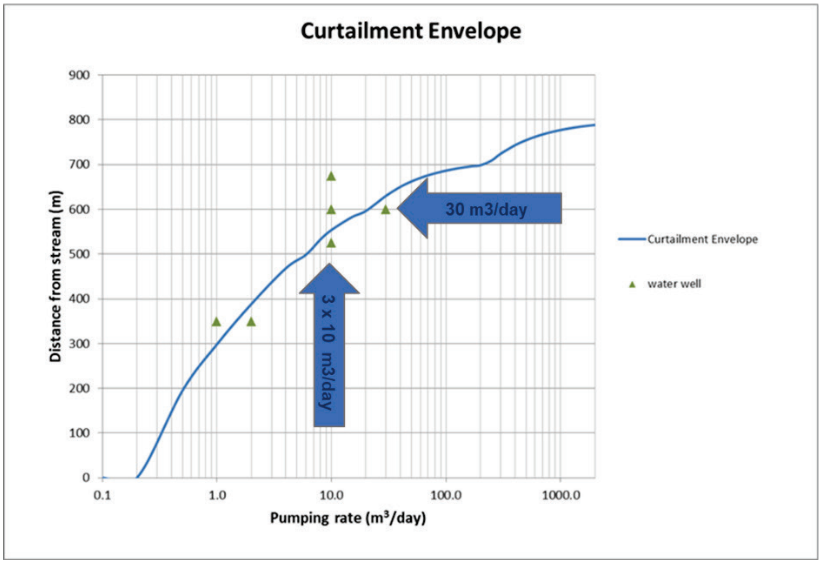


Figure B2: Curtailment model approaches for properties with multiple wells on the same parcel. If the total estimated demand is divided between multiple wells on the parcel (e.g. 3 x 10m^3/d), they could be excluded from curtailment if one or more of the well falls above (outside) the curtailment envelope. Applying the combined (total) demand to all wells on the parcel during the initial run of the curtailment model avoids this potential source of error.

To maintain fairness of precedence for senior users, the priority date (generally inferred from the well construction date) of the oldest well on the property was used in the curtailment model (excluding wells with a construction date of 1950-01-01, a placeholder within the GWELLS database when the construction date of a historic well is unknown).

Conversations with property owners assisted with verification of the well inventory and identification of the primary water supply well in some cases, but availability of this type of information was limited. Knowledge of the inventory and status of wells on each parcel is expected to improve in future with licensing of non-domestic groundwater use.

B1.4 Determine hydraulic connectivity of groundwater sources and wells

As described in section 2.1, there are five unconsolidated and two bedrock aquifers that have been mapped in the Koksilah watershed. Rather than considering only wells associated with mapped and classified aquifers for inclusion in the curtailment model, all wells within the subject area were categorized based on the type of aquifer material, and aquifer confinement at the well location, both determined from the well construction record. Using the determination of aquifer type for each well from Sivak and Wei (2019), wells were separated into three main categories – unconsolidated-confined, unconsolidated-unconfined, and bedrock (combining crystalline and sedimentary rock types).

B1.5 Compile data on aquifer properties

Hydraulic properties of the aquifers in the Koksilah River watershed and adjacent Cowichan River watershed have been compiled in Foster (2014), Carmichael (2014) and Sivak and Wei (2019). The curtailment model was run separately for unconsolidated-confined, unconsolidated-unconfined, and bedrock wells using representative values of transmissivity (T) and storativity (S) or specific yield (Sy, for unconfined aquifers) for each aquifer type based on those studies, which are consistent with values for these aquifer types in BC (Province of B.C., 2016b). Multiple iterations of the model were run to evaluate sensitivity and to select an appropriate representative value for properties of the different aquifer types.

B1.6 Calculate distance of groundwater sources to the stream

The Glover model assumes that the stream and aquifer are connected along the entire length of the stream. Related work in this study area showed that Koksilah River and tributaries have sections that are likely hydraulically connected, while other stream sections are perched or disconnected from the groundwater system due to the presence of confining sediments below the stream (Sivak & Wei, 2019). Rather than calculating the shortest distance of a well from the stream, the distance of registered wells to a point of hydraulic connection (the closest “open” stream segment) on the Koksilah River or connected tributary creeks was determined from the hydraulic connectivity study (Sivak & Wei, 2019). These determinations were reviewed, and modifications were made if needed (e.g., determination of nearest flowing stream based on field visits, or recalculation of distance to the nearest PoHC).

An example of hydraulic connections between wells and streams is presented in Figure B3. Further field assessments aimed at documenting streambed materials and evaluating evidence of groundwater inputs would be useful additional work to verify the map inferences.

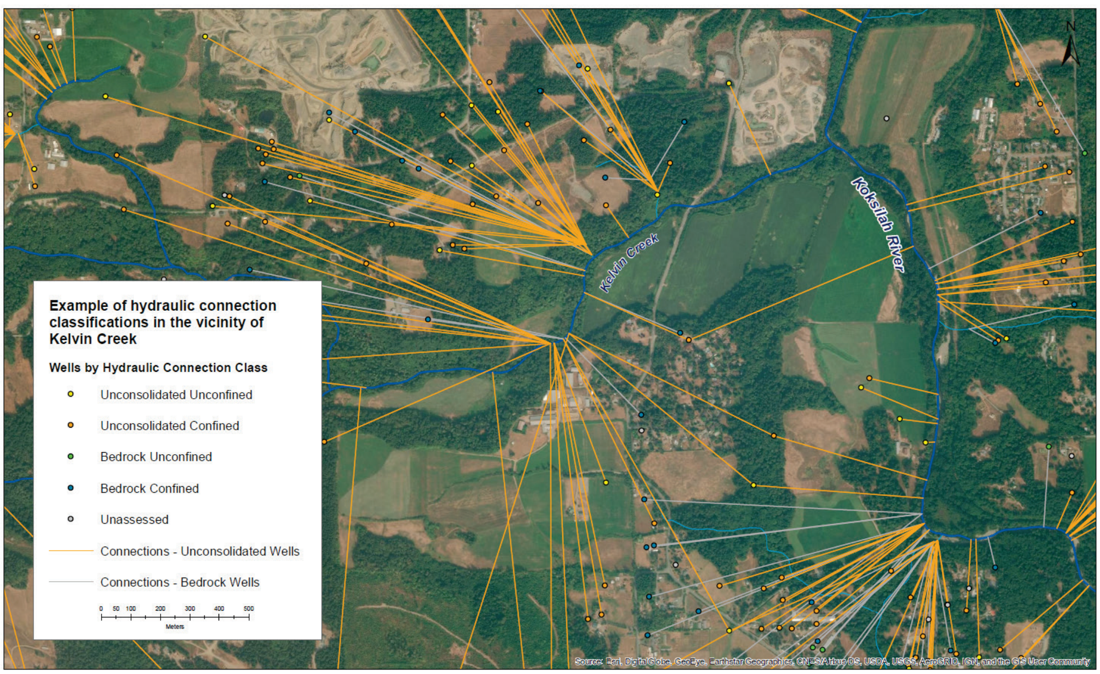


Figure B3: Points of hydraulic connection along Kelvin Creek and Koksilah mainstem.

B1.7 Estimate aquifer parameters and specify curtailment inputs

The input parameters for the groundwater curtailment model are summarized in Table B1. The aquifer properties were based primarily on compiled aquifer properties from Carmichael (2014) for a simplified grouping of three aquifer types, which were modified using sensitivity analysis and review of model results. Due to inferred tidal influence in the lower river, none of the wells adjacent to, or with points of hydraulic connection to, Koksilah River east of the Highway 1 Bridge were included, so it was not appropriate to use a higher T (for unconfined fluvial subtype 1b aquifers nearest the estuary). A moderate T (300 m^2/d) was considered appropriate for other unconsolidated-unconfined aquifers adjacent to Koksilah River (subtypes 1b and 4a) further upstream of the highway bridge. For the unconsolidated-confined aquifers we utilized the same T value as in Sivak and Wei (2019) but with a lower S more consistent with literature values for confined aquifers (e.g. (Freeze & Cherry, 1979). A median T and S value between values for sedimentary and crystalline bedrock wells was chosen for bedrock wells in the model for simplification purposes and based on sensitivity of the model. In both UC and BED aquifers the sensitivity was calibrated to include wells within a smaller distance from the stream as being more realistically hydraulically connected such that curtailment would improve flows within a reasonable time frame, and considering that closer to the stream, the model assumptions are more likely to be valid.

Table B1: Curtailment model input parameters

Input Parameter	**Value assigned**	**Notes**
Curtailment duration (days)	30 to 90 days	Multiple periods (30, 60 and 90 days) were considered, representing time frame from the start of July to late September (predicted time when fall rain would improve streamflow)
Threshold recovery discharge (m^3/d)	0.2	Minimum amount of streamflow recovery produced by a curtailment action on an individual well; approximate based on essential household use of 250 litres per day (0.250 m^3/d) under *Water Sustainability Act*, S. 22(11) (Province of B.C., 2018a)

Aquifer type	Transmissivity, T (m^2/d)	Storativity or Specific yield (unconfined aquifers) (unitless)
Unconsolidated-unconfined	300	0.2
Unconsolidated-confined	200	0.05
Bedrock (sedimentary, crystalline)	1.5	0.005

The curtailment model is based on the formula (Glover & Balmer, 1954; Rathfelder, 2016):

$$\frac{\Delta Q_s}{Q_w} = \mathrm{erfc}\left(\sqrt{\frac{Sd^2}{4Tt}}\right) \quad \text{(Equation 2)}$$

where:

ΔQ_s = change in streamflow caused by groundwater pumping
Q_w = constant pumping rate of the well
$\Delta Q_s/\Delta Q_s$= streamflow depletion expressed as a fraction of pumping
Erfc = complementary error function
S = aquifer storativity for confined aquifers or aquifer specific (S_y) yield for unconfined aquifers (no units)
d = distance from the hydraulically connected stream
T = aquifer transmissivity (m^2/d)
t = lag time (days)

D = distance of well from the point of hydraulic connection on the stream (m)

Assumptions of the curtailment model include the following:

a) The stream is infinitely long and straight and the stage (water height) of the stream is constant;
b) The stream bed penetrates the entire aquifer thickness;
c) Water in the aquifer and the stream are perfectly connected and the streambed materials do not impede flow between the aquifer and stream;
d) Aquifer materials are homogeneous and have a consistent transmissivity and storativity throughout;
e) The aquifer extends infinitely from the stream boundary, and the lateral boundaries of the aquifer do not influence the aquifer response to pumping;
f) Thickness of the aquifer is constant, and it has an impervious base below;
g) If the aquifer is unconfined, there is a small/negligible drawdown of the water table in response to pumping;
h) The identified stream is the only possible source of recharge to the aquifer; and,
i) Pumping occurs from an individual well that is screened across the entire thickness of the aquifer and the pumping rate is constant and continuous (Glover & Balmer, 1954; Province of B.C., 2016b).

The assumptions of the Glover model are meant to reduce the flow geometry and geology of the system to their simplest form, so that the stream depletion can be solved mathematically. While it is recognized that the complexities within an actual system such as the Koksilah watershed can violate many of these assumptions, the model is still useful to understand how differences in aquifer and well properties affect surface and groundwater interaction. The model is conservative and will likely overestimate potential impacts of the well pumping on streamflow where the assumptions are violated.

B1.8 Estimate lag time and predicted streamflow recovery

If water being pumped directly from a stream suddenly stops or decreases, one would expect to see a nearly immediate increase of flow in the stream equivalent to how much the pumping rate was reduced. Within an aquifer, however, there is usually a lag time between when pumping of a well stops and a when response in a hydraulically connected stream occurs (Barlow & Leake, 2012). The lag time depends on the distance of the well from the stream and the aquifer characteristics (transmissivity and storativity). Over shorter time scales, the predicted increase in streamflow when groundwater pumping stops is not 100% but is a smaller proportion of the groundwater pumping volume. In that sense, although a well located at further distance from a stream may influence streamflow, the lag time between when the pumping stops and when an observed streamflow response would be felt (if ever), would be too long for curtailment of the groundwater user to be effective.

Using the Glover model (Equation 1), a lag time calculation was added to the curtailment model spreadsheet to estimate the streamflow recovery volume as a percent (fraction) of pumping. The inclusion of lag time in the model was useful in order to consider the relative benefit that curtailment of a user might have on streamflow, which could help inform the management approach. For example, one option could be to exclude wells where the proportion of streamflow recovery is estimated to be relatively small (i.e. <10% to <20% or groundwater pumping rate), resulting in overall low net benefit of curtailment.

Wells were excluded from the curtailment list where the proportion of expected return was estimated as less than 20%. This approach functions as a safety factor, so that curtailment focused on locations where there was likely to be more significant benefit from the reduction in groundwater use, and to account for factors such as aquifer heterogeneity that would likely violate the model assumptions for wells at further distance from the stream.

B1.9 Run model, evaluate and refine results

Three iterations of the model were run for wells in the different aquifer categories (unconsolidated-unconfined aquifers, unconsolidated-confined, and bedrock). The model produces a list of wells that would theoretically cause a benefit to flows in hydraulically connected streams if pumping stopped within a specified curtailment duration. The curtailment curves and wells are also shown graphically and discussed in section B2 below.

For the purposes of exploring a Critical Environmental Flow Protection Order (section 86/87 TPO), which relies on the FITFIR principle, the curtailment model output was ranked by priority date. This list of wells was used to identify parcels (proxy for water users) that, combined with water licences, could potentially be used to issue a curtailment order. A Fish Population Protection Order (section 88 TPO) does not rely primarily on FITFIR; in that case the process for determining the final curtailment list depends on inclusion of additional criteria, such as type of water use. When a curtailment Order was issued in 2019 in the Koksilah watershed, the final list of licensees and inferred groundwater users to be curtailed was developed based on the amount of streamflow recovery deemed necessary to prevent detrimental impacts to the aquatic ecosystem, on field verification of stream conditions, and on other factors discussed in section 5.4 (above).

B2. Results

A total of 624 wells representing parcels inferred to be using groundwater from wells likely hydraulically connected to the Koksilah River and tributaries were included in the groundwater curtailment model in 2019. The number of wells constructed within each aquifer type are presented in Table B2.

Figure B4, B5 and B6 show the curtailment model results. The area under each curve represents the curtailment envelope for the time periods of interest (30, 60 and 90 days). Points plotted below the curve represent wells that fall within the curtailment envelope, depending on their pumping rate (x-axis) and distance from the stream (y-axis). Stopping groundwater extraction from wells within the curtailment envelope would be expected to result in proportional increase in flow within hydraulically connected streams during the specified time period. The number of wells that were included in the resultant curtailment envelope for each time period considered are summarized in Table B2.

Table B2: Wells included in the curtailment model and curtailment envelope outputs for each time period of interest

Aquifer type	Number of wells within each aquifer type (N = 624)	Wells included within curtailment envelope Curtailment period (days)			
		7	**30**	**60**	**90**
Unconsolidated-unconfined (UU)	98	36	50	66	74
Unconsolidated-confined (UC)	295	80	175	222	251
Bedrock (BED)	231	21	61	91	106

Within Figures B4, B5 and B6, there is a concentration of points (wells) plotted at a pumping rate of 2 m^3/d. These wells represent domestic groundwater users who are exempted from licensing requirements. As discussed in section 4.6.2, if a TPO is issued under a Critical Environmental Flow Protection Order (s.86/87) all water users would be required to stop or reduce use based on their priority date. For example, groundwater users falling within the model curtailment envelope, including domestic users, would be included in the curtailment list, along with users of surface water pumping water directly from the stream within stream reaches of interest. However, even if included in the curtailment envelope, domestic users are always allowed to continue use of water for essential household needs (up to 250 L/d). In contrast, under a Fish Population Protection Order (s.88 TPO), the water manager could choose to further exempt domestic users from curtailment, considering their actual water use is likely to be very low.

Overall, there are fewer wells constructed in unconfined-unconsolidated (UU) aquifers in the Koksilah watershed. For this aquifer type (Figure B4) at the longest time step (90 days), wells within approximately 1500 m of the closest hydraulically connected stream would be included in the curtailment envelope. This includes domestic groundwater users within approximately 800 m of the stream. For a shorter curtailment period of 30 days, wells within 500 m to 1000 m of the stream are included in the curtailment envelope.

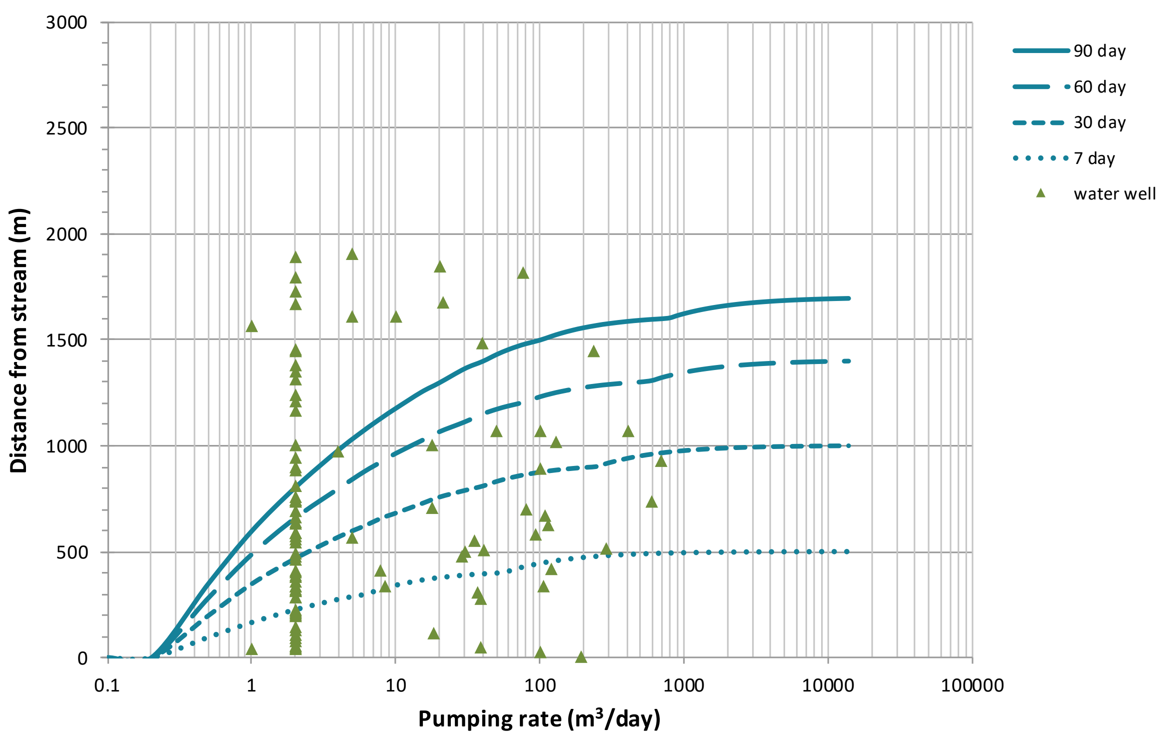


Figure B4: Curtailment model output for wells constructed in unconsolidated-unconfined (UU) aquifers of the Koksilah watershed (7, 30, 60, and 90-day periods)

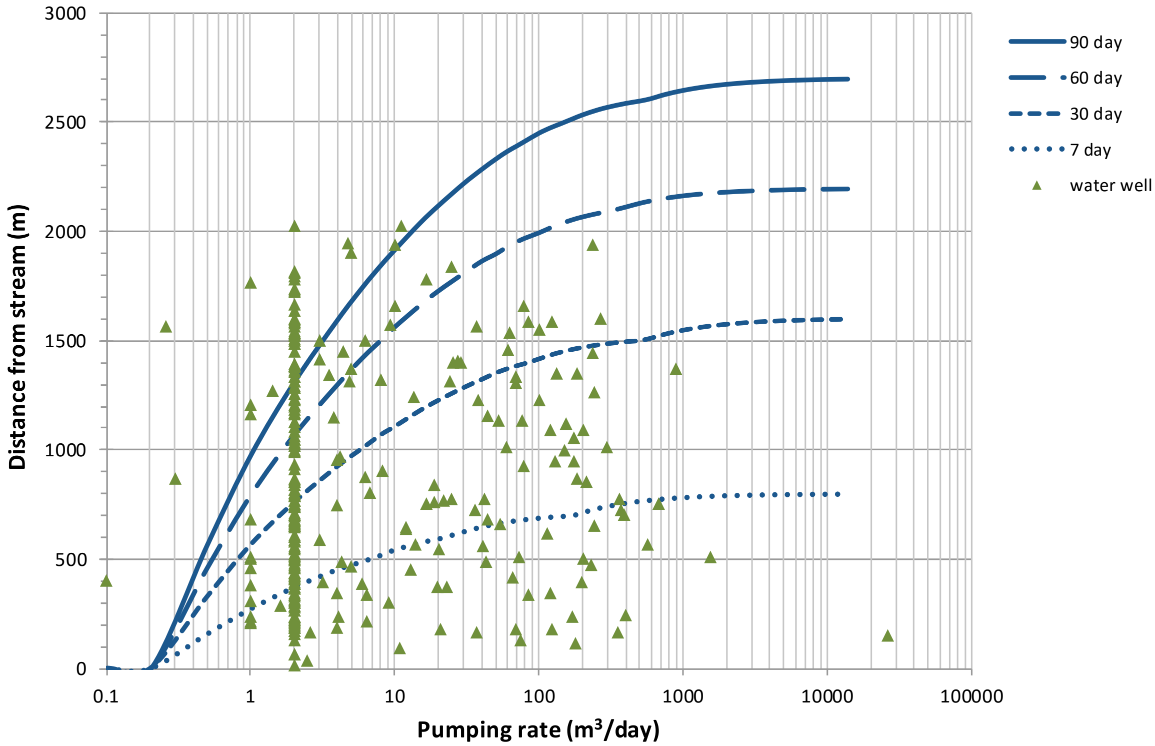


Figure B5: Curtailment model output for wells constructed in unconsolidated-confined (UC) aquifers of the Koksilah watershed (7, 30, 60, and 90-day periods)

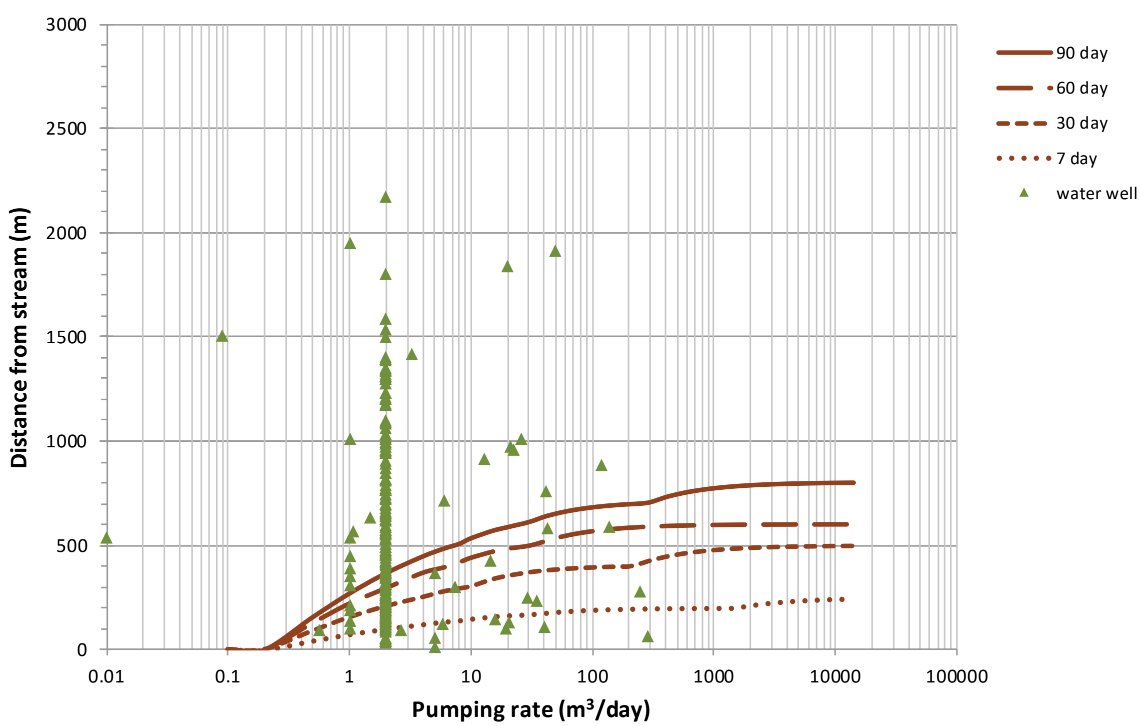


Figure B6: Curtailment model output for wells constructed in fractured bedrock (BED) aquifers of the Koksilah watershed (7, 30, 60, and 90-day periods)

More wells within the watershed are inferred to be constructed within a lithologically confined aquifer. For unconsolidated-confined (UC) aquifers (Figure B5), the curtailment envelope at the longest (90-day) time step captures wells within 2500 m from a hydraulically connected stream, including domestic wells up to 1300 m away. Within confined aquifers groundwater is under confining pressure; during well pumping water is initially released from storage and the resulting change in pressure is expected to propagate rapidly within the aquifer at a larger distance from the pumping well.

For bedrock (BED) aquifers during a 90-day curtailment period, wells within 800 m from the stream would be captured in the curtailment envelope (Figure B6); this would include domestic groundwater users closer than 350 m from the stream (if included in the TPO). The number of bedrock wells in the watershed is close to the number of UC wells, but in comparison fewer are included within the curtailment envelopes, especially within the shorter time frame of 30 or 60 days. While the model treats flow in bedrock aquifers as approximately equivalent to flow in unconsolidated materials with lower values of hydraulic properties (transmissivity and storativity), bedrock wells may be connected to the stream to a greater or lesser extent, depending on the orientation, density, width and connectivity of bedrock fractures. Thus, due to aquifer heterogeneity, there is a greater level of uncertainty related to model results for bedrock aquifers.

B2.1.1 Sensitivity analysis

The lag time curves show in Figure B7, B8 and B9 illustrate the effect of using different values for aquifer properties on sensitivity of the Glover model (Glover & Balmer, 1954; Rathfelder, 2016).

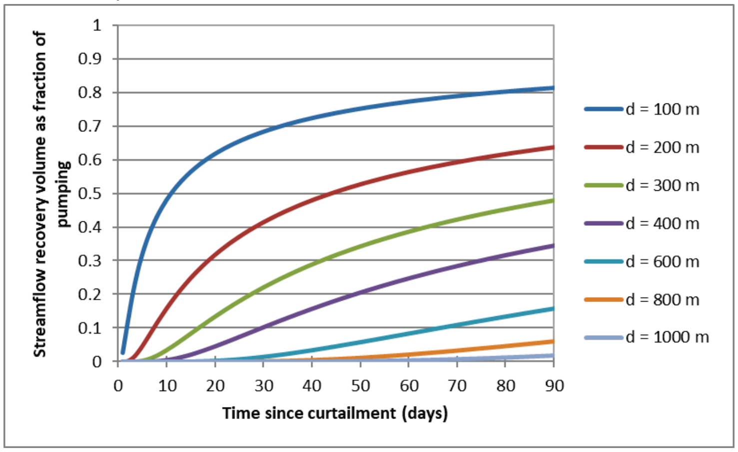
For unconsolidated-unconfined aquifers (Figure B7), increasing transmissivity increases the relative proportion of streamflow recovery (as a percentage of groundwater pumping) predicted within a shorter time frame i.e., the more transmissive the aquifer, the greater and faster the predicted return of groundwater to the system after pumping stops. Recovery of groundwater diversion of thirty percent or less would be expected from wells at a distance greater than 600 m from the stream after a curtailment period of 90 days. Within the range of all transmissivity estimates, the maximum recovery over a shorter period (less than 10 days from the start of curtailment) would be expected from wells located within 200 m of the stream; from a management perspective, this reinforces the value of focussing curtailment efforts on wells located closest to the stream if a rapid improvement of flows is desired.

For unconsolidated-confined aquifers (Figure B8) the storativity (S) value selected for the model has a strong influence on the predicted response; at very low S values, streamflow recovery as a fraction of pumping is relatively high and the system responds quickly, even for wells at a further distance from the stream. Based on lithologic records of wells within the Koksilah watershed the confining layers, if present, have a variable thickness and occurrence so that many aquifers are only partially confined, and therefore a relatively high S value (S=0.05) was selected for the final model. Under this scenario, curtailment of wells within 400 m or less of the stream would be expected to provide the greatest net benefit within short and moderate time periods (from 10 days up to 90 days).

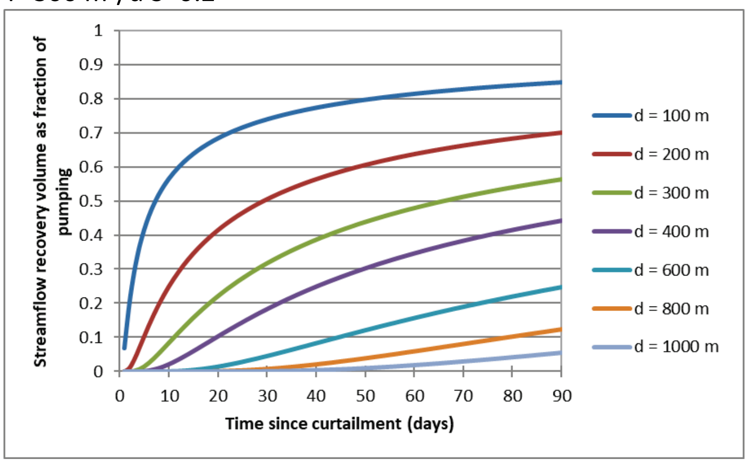
For bedrock aquifers (Figure B9), the predicted lag time response is sensitive to the values of aquifer transmissivity and storativity. Increasing the transmissivity value predicts a more rapid improvement to streamflow. In all lag time scenarios curtailment of groundwater diversion from bedrock wells located within 100 to 200 m of the stream is likely to have the greatest beneficial impact on streamflow over a shorter curtailment period (≤10 days).

The results of the curtailment model were used to inform management actions when streamflow in the Koksilah watershed declined below a critical environmental threshold (CEFT). Details on the final curtailment list determination and issuance of a TPO Order in 2019 are provided in section 5.4.

T=200 m^2/d S=0.2



T=300 m^2/d S=0.2



T=400 m^2/d S=0.2

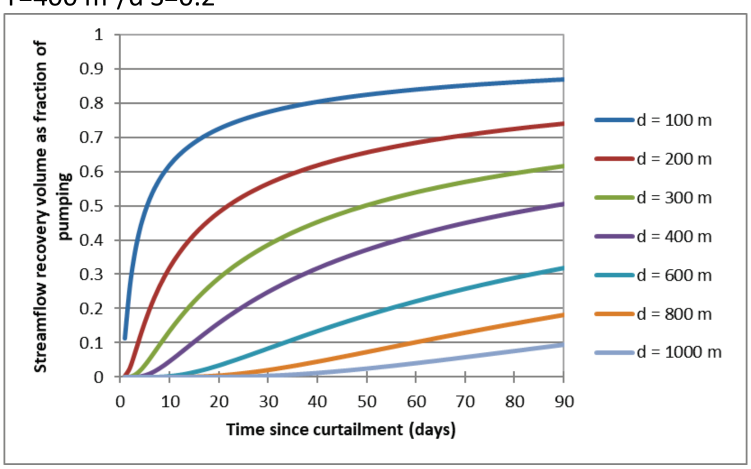
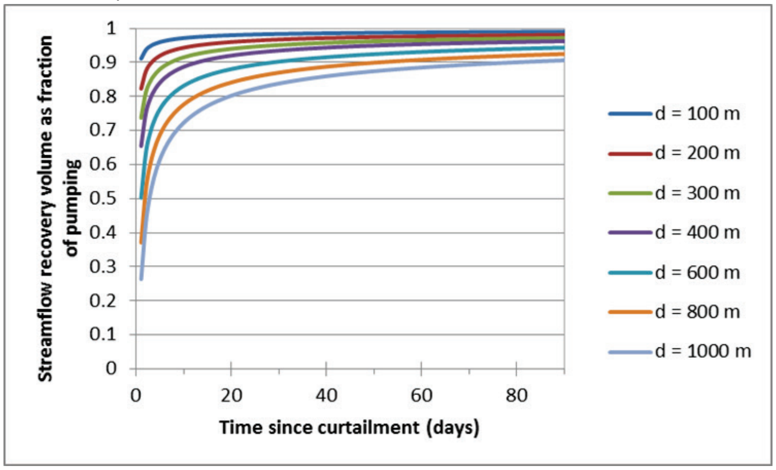
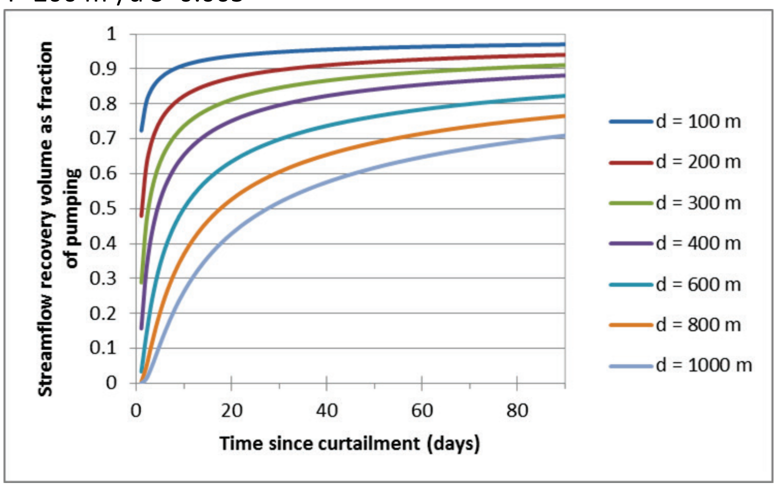


Figure B7: Example lag time for unconsolidated-unconfined aquifers using different transmissivity (T) values

T=200 m^2/d S=0.0005



T=200 m^2/d S=0.005



T=200 m^2/d S=0.05

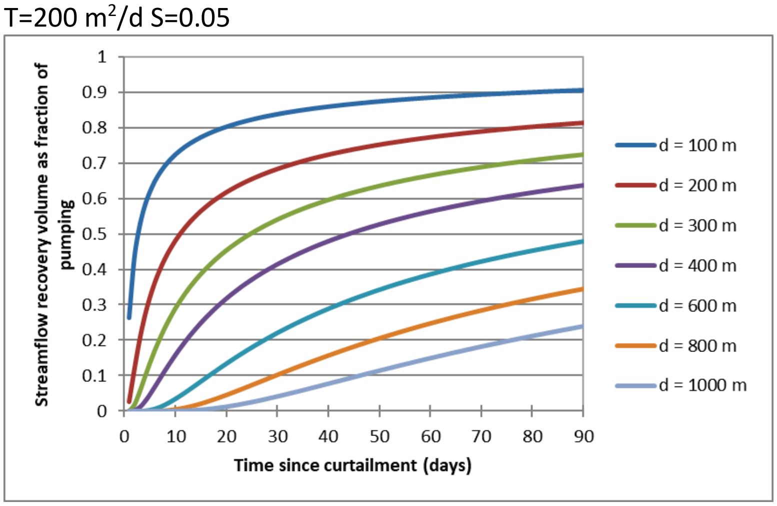
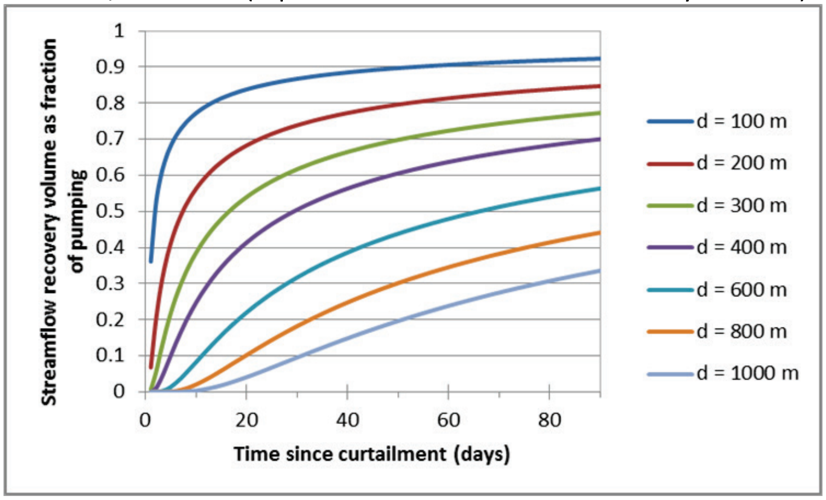
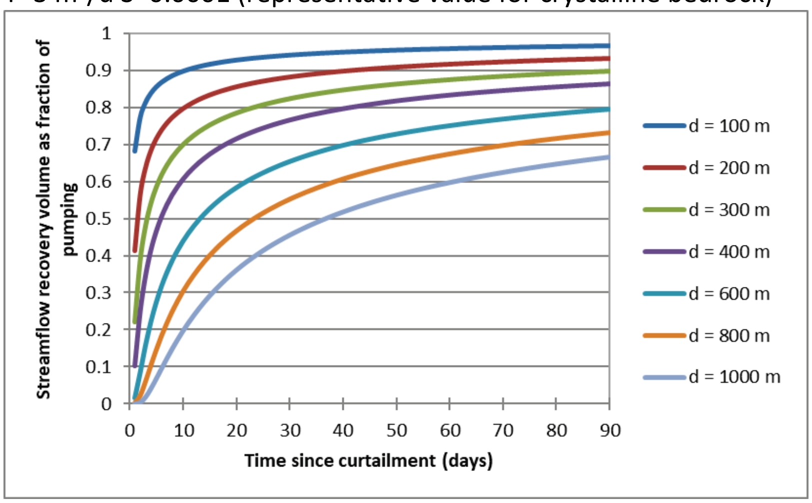


Figure B8: Example lag time for unconsolidated-confined aquifers using different storativity (S) values

T=0.3 m²/d S=0.001 (representative value for sedimentary bedrock)



T=3 m²/d S=0.0001 (representative value for crystalline bedrock)



T=1.5 m²/d S=0.0005 (median value for both fractured bedrock types)

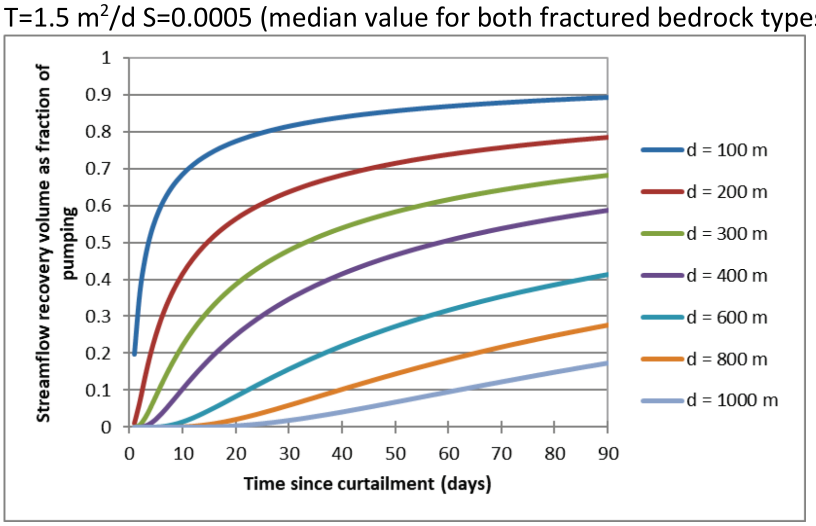


Figure B9: Example lag time for bedrock aquifers using different transmissivity (T) and storativity (S) values