REPORT

DATA COMPILATION PLAN TO SUPPORT NUMERICAL FLOW MODELLING STRATEGY

NICOLA RIVER PROJECT

Submitted to:

Fraser Basin Council

Submitted by:

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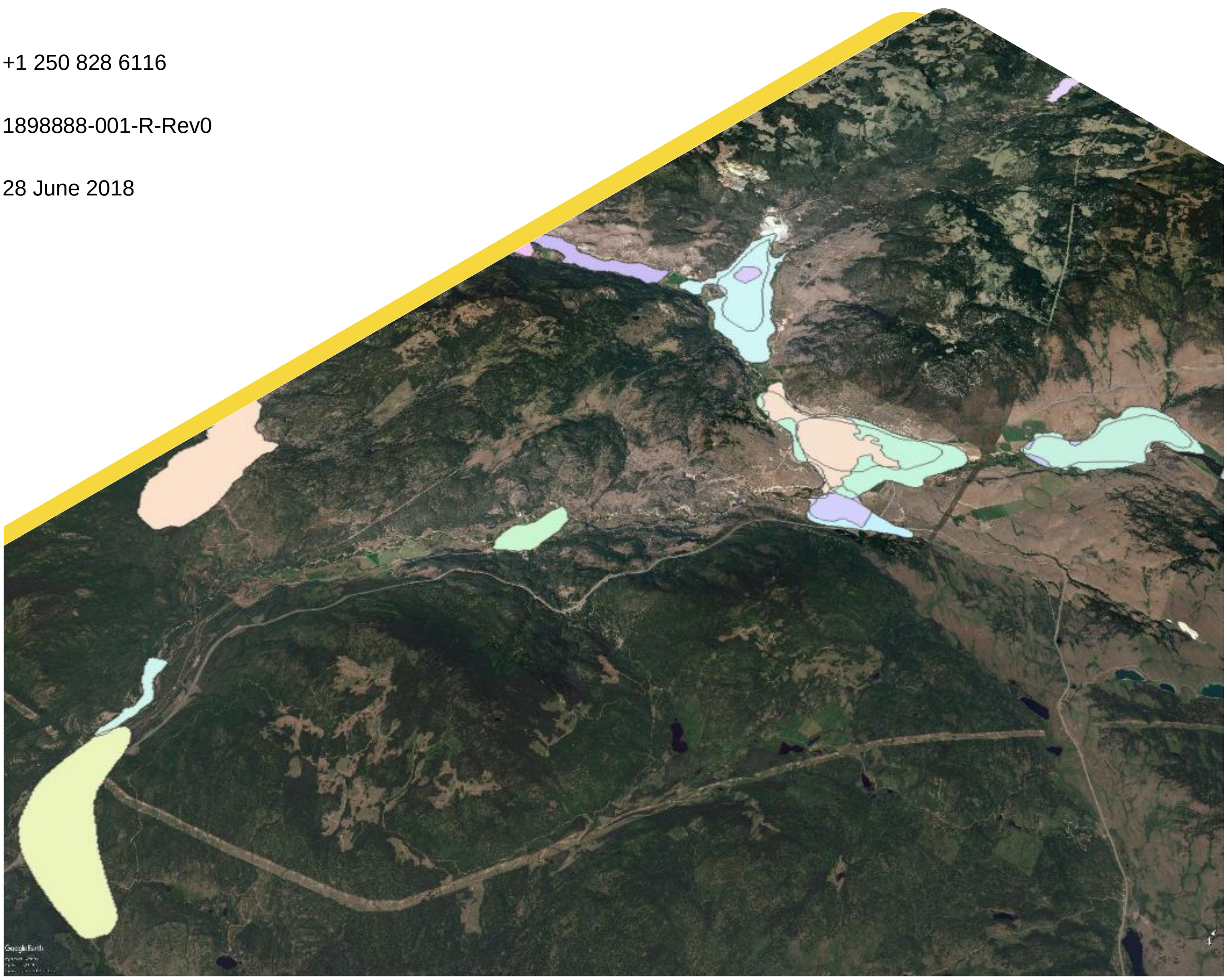

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Executive Summary

Golder Associates Ltd. (Golder) was retained by the Fraser Basin Council to compile and analyse existing data to develop a conceptual hydrogeological model for the Nicola watershed. The general study area includes the Nicola Valley from Nicola Lake downstream to Spences Bridge, the Coldwater River valley from the Coquihalla Highway crossing to the City of Merritt and the lower part of Guichon Creek encompassing the Nicola-Mameet Indian Reserve (NMIR) and the community of Lower Nicola. This study is the second phase of effort to ultimately develop a groundwater flow model for the unconsolidated valley bottom areas within the Nicola Watershed. The valley bottoms generally represent areas of the highest groundwater availability, greatest groundwater use and highest environmental flow needs.

The Nicola watershed contains broad, deep valleys and thick quaternary sediments resulting from at least two major periods of non-glacial sedimentation and two distinct periods of glaciation. Near-surface Quaternary valley bottom deposits primarily consist of modern alluvium and fan deposits near present-day elevations. The unconfined Upper Merritt Aquifer is thought to have formed by the Coldwater River eroding glacial lake sediments and backfilling sand and gravel. Post glacial alluvium at Merritt is mapped as continuous with alluvium extending up the Coldwater Valley, alongside the Nicola River from Merritt to Nicola Lake and downriver from Merritt towards Spences Bridge (Fulton 1975).

Post-glacial fan deposits consisting of poorly sorted gravel, sand and silt are present in the Coldwater Valley, beneath the NMIR and Lower Nicola community. The modern alluvium and fan deposits form “connected aquifers” alongside the Nicola and Coldwater Rivers, Guichon Creek and Spius Creek. To date, twenty-five aquifers have been mapped in the Nicola Watershed with seven of the aquifers considered likely to be connected to surface water. Deeper confined aquifers are present in the Merritt and Lower Nicola areas and are believed to have formed by depositional events between the formation and drainage of the three Nicola Valley glacial lakes.

Bedrock within the study area includes the Nicola Group (primary consisting of extrusive rock comprised of greenstone, andesite, basalt, agglomerate and tuff); Coast intrusions consisting of granite, granodiorite and gabbro; the Spences Bridge Group volcanic rock consisting of rhyolite, andesite, basalt, tuffs and breccias; the Coldwater Beds comprised of conglomerate, sandstone, shale and coal, and the Kamloops Formation of the Princeton Group consisting of volcanic rocks.

The model boundaries will be the valley bottom unconsolidated deposits within the Coldwater Valley extending form the Coquihalla Highway crossing to Merritt and the Nicola Valley from Merritt to Nicola Lake and from Merritt to Spences Bridge. The NMIR, Nooaitch Indian Reserve, Shackan Indian Reserve and Lower Nicola community are within the model boundaries

Inflow to the valley bottom unconsolidated deposits consists of precipitation recharge, freshet surface runoff outside of defined stream channels, inflow from bedrock along the valley bottom side, irrigation return in irrigated areas and river loses. A chloride mass balance method was used to estimate the percentage of precipitation infiltrating the subsurface by watershed elevation. Estimated precipitation recharge ranged from 3% of annual precipitation (10 mm) on the valley floor up to 25% of annual precipitation (190 mm) in the upland catchment areas at 1400 to 1800 masl. Freshet surface runoff was estimated to be a negligible source of valley floor recharge.

Outflow from valley bottom unconsolidated deposits consists of the groundwater pumping, outflow through valley bottom sediments at downstream model boundaries, groundwater flow into gaining river reaches and evapotranspiration. Outside of the City of Merritt, annual groundwater use is poorly understood. Estimations of annual groundwater use should be improved as more groundwater licence applications are received by the province and the uses of “unknown” and “other” wells are established. Licencing information provided by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNR) indicates that licenses for roughly 20% of the estimated annual irrigation use have been issued or applied for and licenses for only 1% of the estimated use by community water systems have been issued or applied for. Annual groundwater extraction for irrigation use in the study area has been estimated at 6,000,000 m^3/year. The City of Merritt is the next largest user, pumping 2,768,000 m^3 of groundwater in 2014. Estimated use by the First Nations water systems is 240,000 m^3/year and estimated use per domestic well is 1,830 L/day or 670 m^3/year. There are estimated to be roughly 400 domestic wells in the study area.

Sources of recharge to connected aquifers include losses from adjoining and overlying streams. Based on previous studies (Bennett and Caverly 2009, Golder 2016a) and current work it is assessed that:

- The Nicola River from the outlet of Nicola Lake to Merritt is essentially a net losing reach
- The Nicola River from Merritt to Spius Creek is essentially a net gaining reach
- The Nicola River from Spius Creek to Spences Bridge is essentially a net losing reach
- The Coldwater River upstream of Merritt is essentially a net gaining reach
- The Coldwater River through Merritt is essentially a net losing reach

Key data gaps and uncertainties in information required to support the development a numerical groundwater flow model include:

- Geodetic groundwater level elevation data within the key aquifers of interest
- Lidar mapping or a finer resolution digital elevation model; current topographic dataset is based on a 20 m contour interval
- Geodetic elevations of hydrometric stations
- Riverbed conductance
- The locations, completion depths and pumping rates of wells associated with all groundwater licences
- The total thickness of the valley bottom sediments is not known in most locations

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1.0 INTRODUCTION

This report outlines the compilation and analysis of existing data to support the development a numerical groundwater flow modelling strategy and to better inform the conceptual hydrogeological model for the project area. Methods for the analysis of the data to arrive at required study area extents, input parameters and boundary conditions are described. Data gaps and the proposed preliminary approach to address these data gaps have also been itemized.

This study is the second phase of ultimately developing a groundwater flow model for the unconsolidated valley bottom areas within the Nicola Watershed. The valley bottoms generally represent areas with the highest groundwater availability, greatest groundwater use and highest environmental flow needs.

The first phase of the Nicola Watershed study was to review maps and classify aquifers within the ultimate model area. The aquifer mapping and classification was completed in 2017 and early 2018 (Golder 2018) and resulted in the mapping of 13 new aquifers, the revision of 10 existing aquifers and 2 aquifers remaining unchanged.

2.0 PROJECT OBJECTIVES & SCOPE OF WORK

The project objectives were to:

- compile existing data that is required to develop a numerical groundwater flow model for the study area.
- where possible, develop a conceptual hydrogeological model(s) for the study area.
- identify information gaps limiting the ultimate development of a numerical groundwater flow model(s) for the study area.

The scope of work was to:

- Compile existing data and, where justified, link data to one or more of the twenty-five mapped aquifers in the study area:
- Develop mean monthly flows for the Water Survey of Canada (WSC) stations on the Coldwater River, Nicola River, Guichon Creek and Spius Creek.
- Develop a hydrologic model to generate mean monthly flows for the major ungauged tributaries in the study area.
- Prepare a technical report including:
  - a brief description of the work performed
  - a summary of the sources of the compiled data
  - the complied data primarily in spreadsheet format
  - a generalized description of the conceptual model(s) for the study area
  - a list of any additional data required to develop a numerical groundwater flow model of the study area
  - an overview of the proposed modeling strategy for the study area

3.0 MODEL STUDY AREA EXTENTS

As a preliminary step, the general areas of interest which will be considered in the numerical model need to be selected. At this stage, the study area is shown on an Area Plan provided as Figure 1.

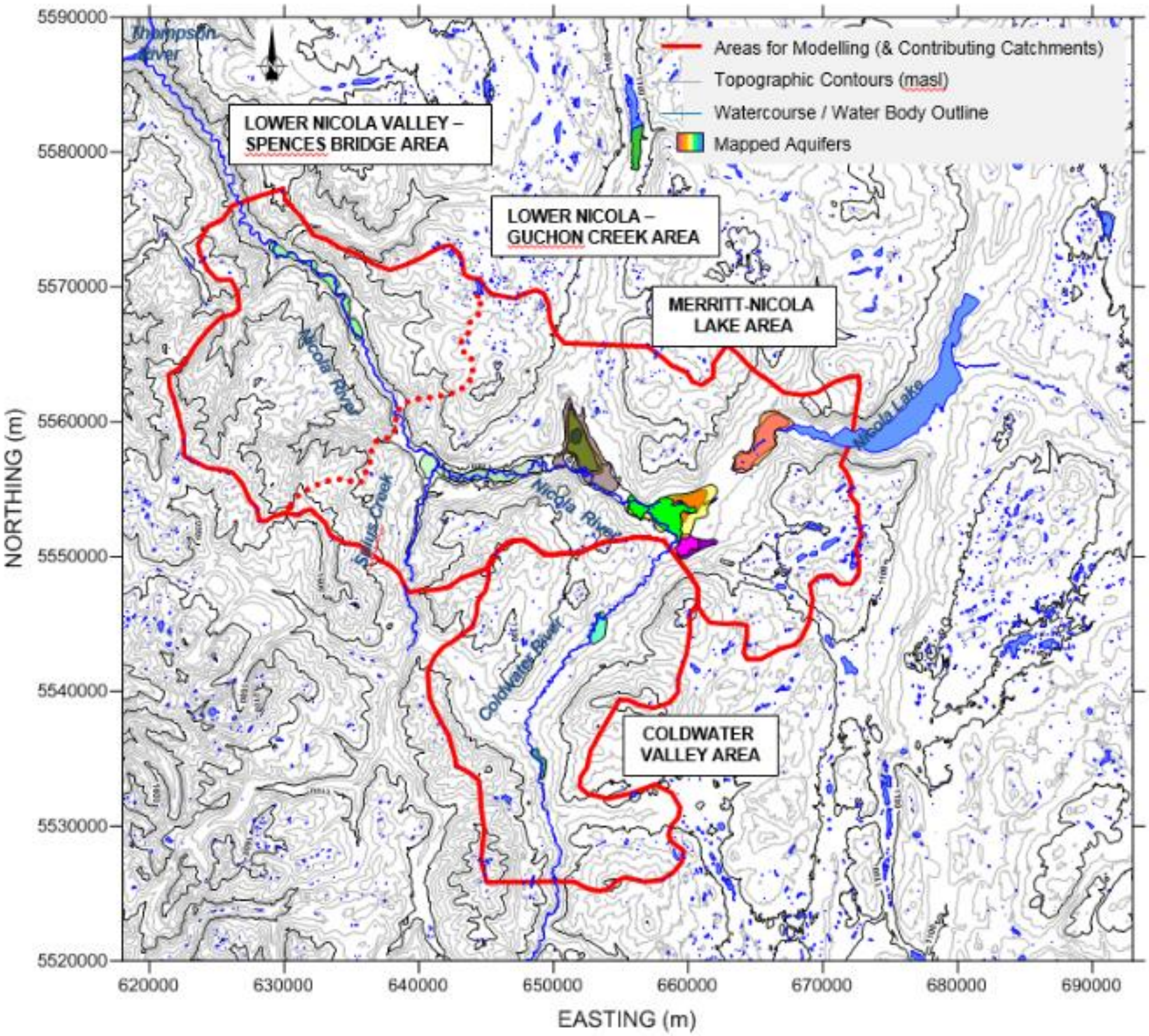

Figure 1: Area Plan illustrating model study areas and mapped aquifers (Golder 2018b)

Specific areas of interest within the overall study area include:

- Lower Nicola Valley Area:
  - Nicola River from its confluence with the Coldwater River downriver to Spences Bridge
  - Guichon Creek downstream of Mamit Lake to Nicola River confluence

  - Lower Spius Creek to Nicola River confluence
- Merritt-Nicola Lake Area
  - City of Merritt to Nicola Lake dam
  - Coldwater River within the City of Merritt
- Coldwater River Valley Area
  - Coldwater River from Highway 5 (Coquihalla) crossing downriver to the City of Merritt
  - Paul's Basin

4.0 DATA SOURCES

Data sources utilized to develop a conceptual model of the study area and to build the flow model data set included:

- British Columbia Ministry of Environment and Climate Change Strategy (ENV) Water Well Database (WELLS Database), including individual water well records and lithological records
- ENV surface water and groundwater licencing database
- British Columbia Ecological Reports Catalog (EcoCat)
- Natural Resources Canada's GEOSCAN Database
- British Columbia Geological Survey's public access databases
- hydrogeological, geological, and geotechnical reports from previous studies such as work completed to develop the Nicola Water Use Management Plan (WUMP).
- topographic data from Natural Resources Canada's Canadian Digital Elevation Model (CDEM)
- federal and provincial and hydrometric data
- Climate Data BC and climate models to predict precipitation versus elevation within the study area.
- aquifer parameters such as hydraulic conductivity, storativity and water levels provided in several published reports (see references in Section 16.0)
- ENV observation well data
- groundwater and surface water licencing information provided by FLNR
- agricultural water use reported in Summit (2007)
- municipal and community data regarding water consumption
- ground and surface water quality data from Golder (2008) and sampling completed by FLNR

5.0 CLIMATE

The closest Environment Canada climate station to the study area is the “Merritt STP” station located in Merritt at an elevation of 609 m above mean sea level (masl). Environment Canada 1981 to 2010 climate normals indicate that the mean annual temperature in Merritt is 4.2ºC, and daily average temperature ranges from -3.7ºC in December to 18.8ºC in July. The total annual precipitation is 321 mm, of which 50% falls between October and March. The wettest month is December and the driest month is April. Snowfall accounts for 20% of the annual precipitation.

This study utilized the ClimateBC database (Wang et al. 2012) to assess the potential spatial variability in meteorological variables such as precipitation and evapotranspiration. ClimateBC utilizes data from the PRISM model (Parameter-elevation Relationships on Independent Slopes Model, Daly et al., 2008) to generate distributed precipitation surfaces that incorporates weather station data, a digital elevation model, and expert knowledge such as rain shadows, coastal effects, orographic lift, and temperature inversions over topographically-delineated ”facets”. By incorporating the effects of a variable topography, results will more closely approximate the heterogeneous distribution of precipitation and meteorological variables in the mountainous regions. Maps of the average annual precipitation and evapotranspiration are provided in Figure 2 and Figure 3. Hydrometric catchment boundaries are shown on the figures as solid black lines and the proposed flow model boundaries are shown as dashed black lines.

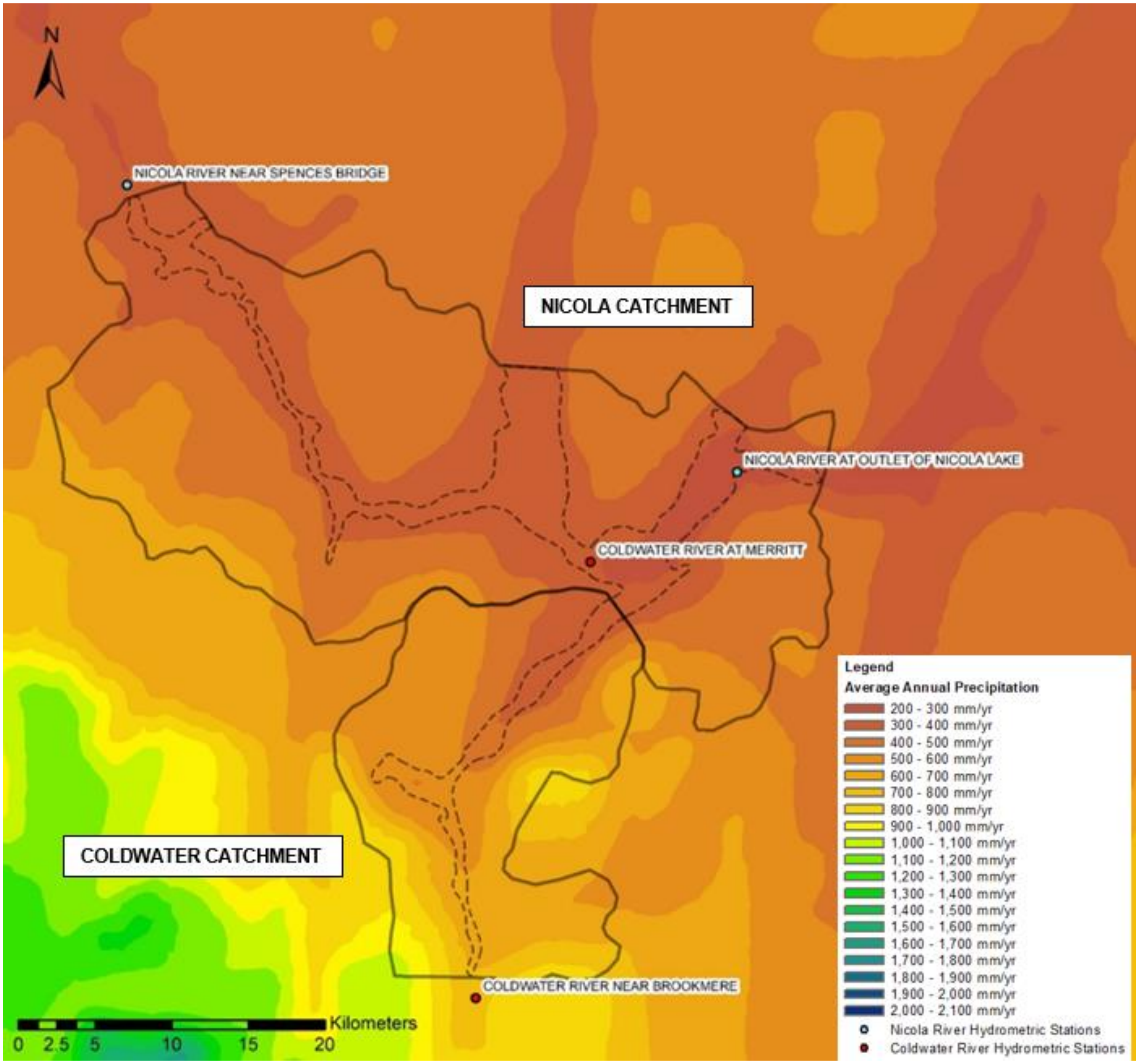

Figure 2: Map of annual average precipitation by elevation (mm/year)

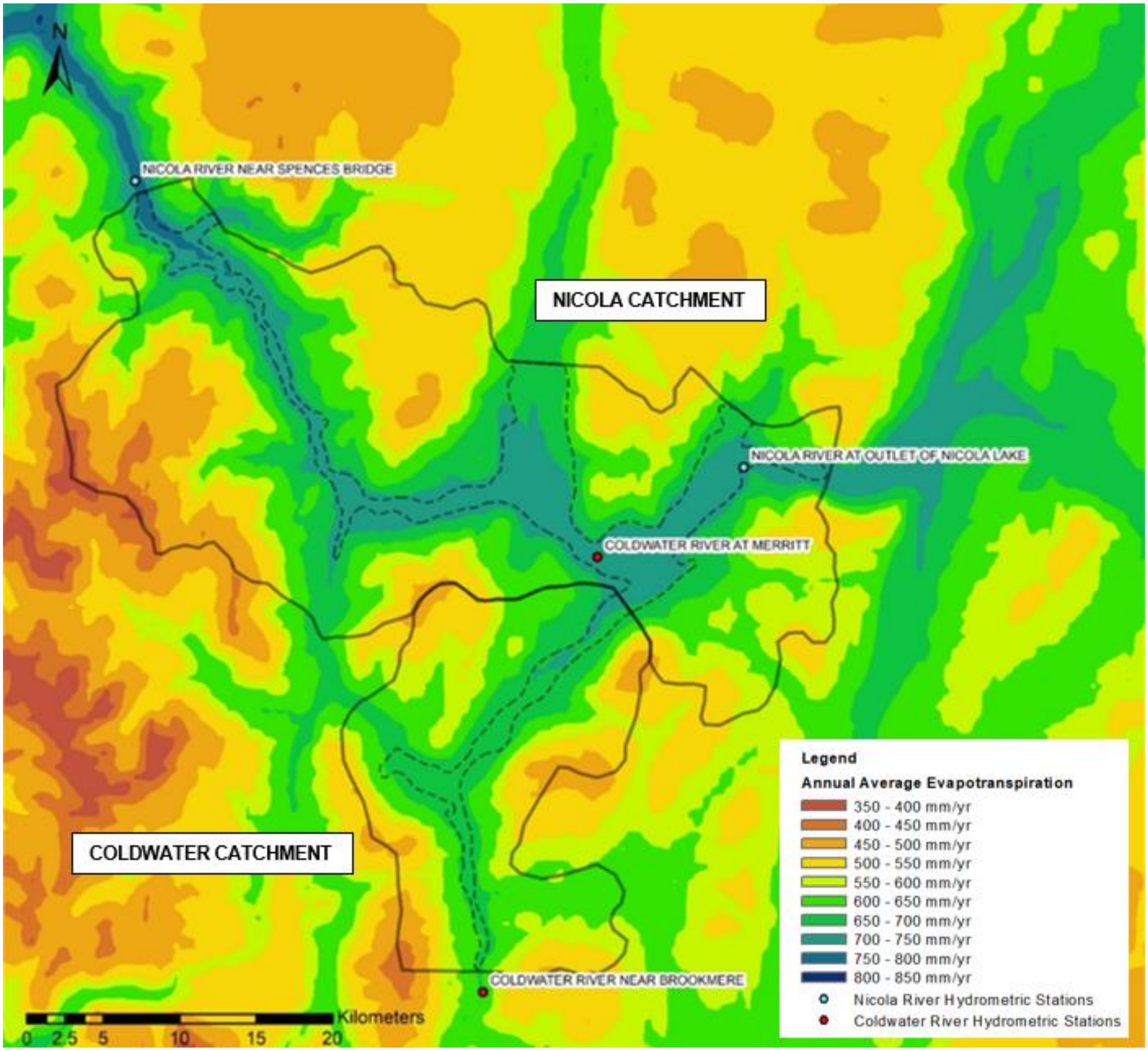

Figure 3: Map of annual average potential evapotranspiration by elevation (mm/year)

6.0 GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The primary reference that defines the framework for the geological setting and background of the Study Area is the Geological Survey of Canada Memoir 380 – Quaternary Geology and Geomorphology, Nicola-Vernon Area, British Columbia, written by Robert J. Fulton (1975). Fulton describes the area as “an area of rolling rocky uplands, only thinly-veneered with Quaternary deposits, and broad deep valleys containing lakes and thick quaternary sediments”. The extent of Quaternary valley bottom deposits shown in IMAP and mapped aquifers within these deposits are illustrated on Figure 4. The principal groups of Quaternary sediments are a result of at least two major periods of non-glacial sedimentation and two distinct periods of glaciation. The principal Quaternary sediment groups, associated age, and type-section subdivisions are described as follows:

- Okanagan Centre Drift (Okanagan Centre Glaciation, before 43,800 B.P)
- Bessette Sediments (sands, silts and gravels) deposited between the Okanagan and Fraser glaciations
- Kamloops Drift (Fraser Glaciation, approximately 19,000 – 10,500 B.P)
  - Lower stratified unit
  - Unstratified unit
  - Upper stratified unit
- Postglacial deposits (alluvium, lacustrine and colluvium (from 10,500 B.P to current)

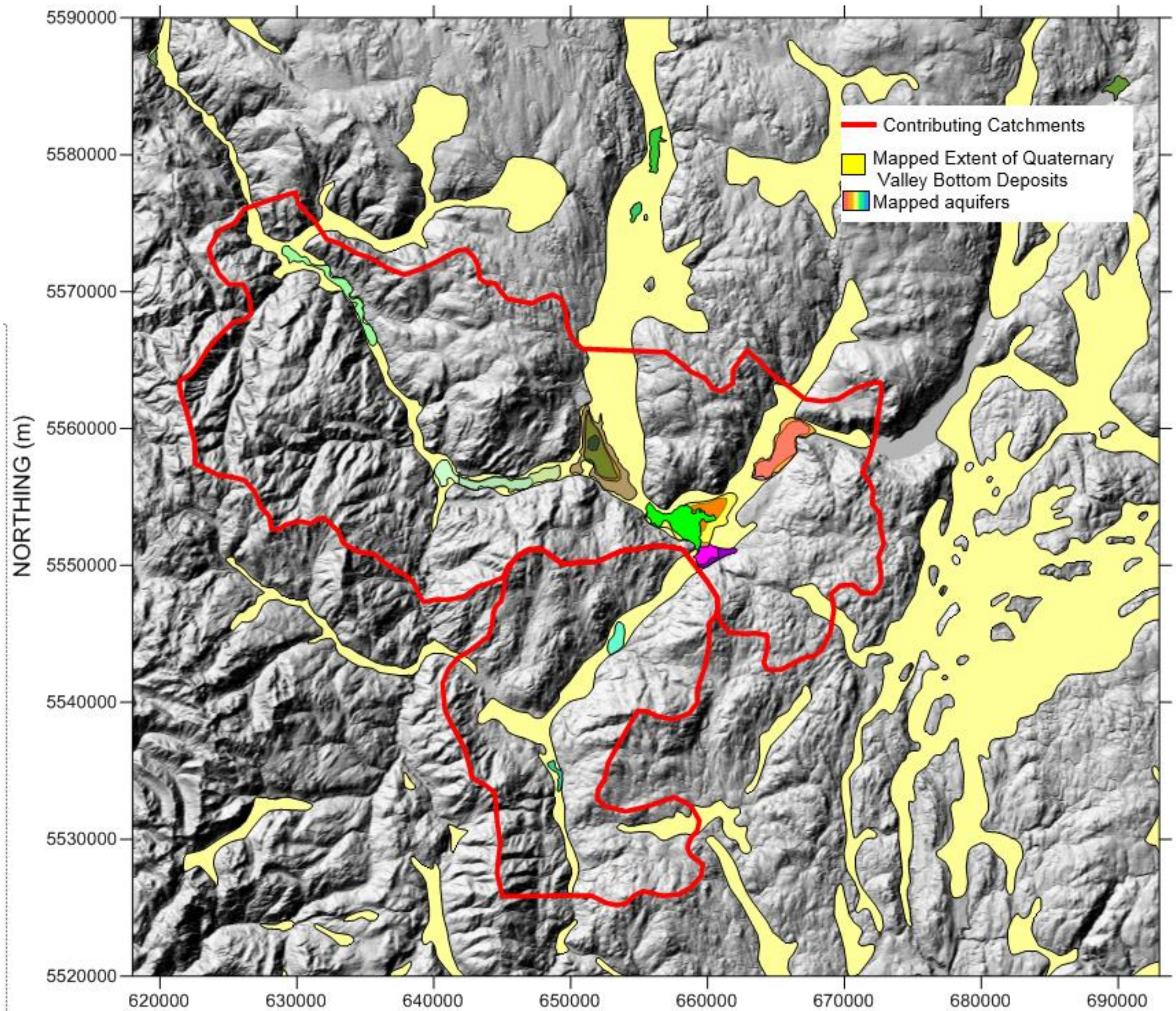

Figure 4: Map of Quaternary deposits and mapped aquifers

Most of the surficial geology in the study area is the product of the Fraser Glaciation with the primary deposits on the valley slopes and uplands being glacial drift or till. As the glaciers wasted at the end of the Fraser Glaciation, stagnant ice and meltwater formed most of the Quaternary geology and geomorphology of the valley bottoms. The Nicola Basin was occupied by three glacial lakes: glacial Lake Quilchena which drained south, followed by glacial Lake Hamilton which drained east, ending with glacial Lake Merritt which drained north (Fulton 1969).

Fulton (1969) concluded that lacustrine deposition associated with the glacial lakes was minor as the ice was thought to be relatively clean, but that large quantities of silt were carried into the Merritt area from wasting ice in the Guichon Creek valley which was a major meltwater channel.

Near-surface Quaternary valley bottom deposits primarily consist of modern alluvium and fan deposits near present-day elevations. The unconfined Merritt aquifer (Upper Merritt Aquifer No. 74) is thought to have formed by the Coldwater River eroding glacial lake sediments and backfilling sand and gravel. Post glacial alluvium at Merritt is mapped as continuous with alluvium extending up the Coldwater valley, alongside the Nicola River from Merritt to Nicola Lake and downriver from Merritt towards Spences Bridge (Fulton 1975).

Post glacial fan deposits consisting of poorly sorted gravel, sand and silt are present in the Coldwater Valley, beneath the Nicola-Mameet Indian Reserve and Lower Nicola community (Stumbles Creek Aquifer No. 76) and where Claperton Creek emerges onto the Nicola valley floor (Unicola Aquifer No. 79) at the west end of Nicola Lake. The Stumbles Creek Aquifer formed by meltwater eroding material in the upper Guichon valley and depositing the material as the meltwater entered post glacial lakes in the Nicola Valley. The modern alluvium and fan deposits form aquifers that are hydraulic connected to surface waters (“connected aquifers”) alongside the Nicola and Coldwater Rivers, Guichon Creek and Spius Creek.

Deeper confined aquifers are present in the Merritt and Lower Nicola areas and are believed to have formed by depositional events between the formation and drainage of the three Nicola Valley glacial lakes. High-yield irrigation and municipal wells have been constructed in the Lower Nicola Outwash Aquifer (No 1171) and the Lower Merritt Aquifer (No 1167).

Bedrock geology within the study area is illustrated on Figure 5 created from the IMAP bedrock geology layer. Major faults are shown in black and the model study areas are outlined in red. The principal rock groups are the:

- Nicola Group (green) of the Upper Triassic, primary consisting of extrusive rock comprised of greenstone, andesite, basalt, agglomerate and tuff. The Nicola Group forms a wide band extending north from Merritt to Kamloops. The Nicola Group is considered to be of low permeability and highly fractured with fracture-flow being the source of groundwater to wells drilled in bedrock. The Guichon Creek Fault separates the Nicola Group from the Coast Intrusion to the west of Guchion Creek.
- Coast intrusions - Guichon Creek Batholith (darker red) of the Jurassic consisting of granite, granodiorite and gabbro.
- Spences Bridge Group – Spius Creek Formation and Pimaninus Formations (lighter red) of the Lower Cretaceous lying alongside and south of the Nicola River and west of the Coldwater River (Coldwater Fault). These two formations are volcanic rock consisting of rhyolite, andesite, basalt, tuffs and breccias.
- Coldwater Beds of the Princeton Group (light blue) are present south and east of Merritt and consist of sedimentary rock comprised of conglomerate, sandstone, shale and coal.
- Kamloops Formation of the Princeton Group (dark blue) is volcanic rock lying west of the Coldwater River and extending roughly 10 km up Guichon Creek from the Nicola River. The Kamloops group is locally mafic and includes flow and volcaniclastic rocks.

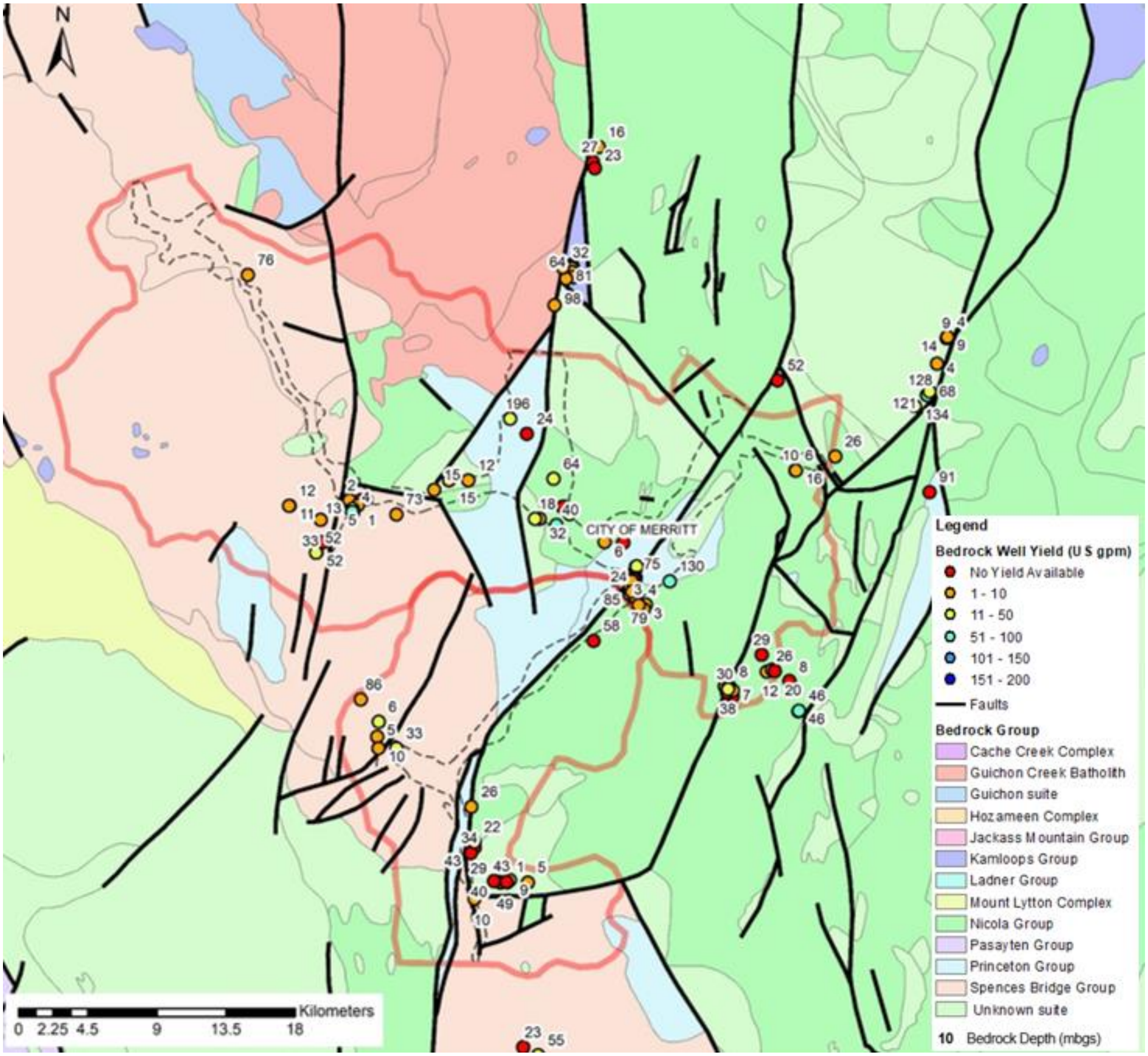

Figure 5: Map of bedrock geology, bedrock water well yields (US gpm) and depth to bedrock below surface (m)

7.0 MODELING STRATEGY AND EXTENT

The valley bottom sediments within the study area form the aquifer complex of interest. They contain both known (and defined) aquifers, as described previously in Section 6.0, as well as potentially unknown aquifers. The aquifer complex as a whole is inferred to be channel-shaped, on the order of 110 km long, 500 m to 1000 m wide and 20 to 170[1] m deep. The irregular shape of the aquifer complex combined with the very long extent of the channels in comparison to their relatively small width and depth can render the aquifer complex cumbersome for block-centered numerical models such as MODFLOW.

Accordingly, simplifications to the extent of the aquifer complex are required to facilitate numerical modelling. The proposed extent of the area to be modelled, (Figure 1:), the rationale for the delineation of that area, and methods to derive the top, base and lateral limits of the modelled area are summarized below.

- Only the unconsolidated deposits will be included in the modelling study, with the lateral extent of the model areas limited to the mapped extent of Quaternary deposits within these areas (see Figure 4). The exclusion of bedrock aquifers from the numerical groundwater flow model will allow for the simplification of the model and the reduction of the model mesh required. Exclusion of the bedrock aquifers is considered reasonable, given that the unconsolidated aquifers represent the areas of highest groundwater availability, greatest groundwater use and highest environmental flow needs.
- Some of the more distant parts of the study area have been excluded to limit the model extent. Specifically, the Nicola Valley below the WSC station near Spences Bridge has been excluded given the absence of significant aquifers in that area; the Stump Lake Area was excluded due to the absence of continuous, connected unconsolidated deposits connecting those aquifers to the rest of the aquifer complex; and an area of the Guichon Creek valley at the south end of Mamit Lake was excluded because the mapped extent of the Quaternary deposits was not considered to be reliable in this area.
- The model top will be determined by the ground surface elevation data from the DEM database (see Figure 1: for topographic mapping) and/or Lidar mapping as available at the time of the model construction.
- The bedrock surface elevation below the unconsolidated deposits will form the base of the model areas. This implies that the full vertical extent of the unconsolidated valley deposits within the study area will be included. As there is very little data on bedrock depth and bedrock topography within the valleys (an identified data gap in Section 12.0), the following approach will be used to determine this surface within the model areas:
  - The maximum depth to bedrock along the valley centrelines within the study area was estimated from the intersection of the opposing, extrapolated valley side slopes above the Quaternary deposits, as depicted in Figure 6. This extrapolation was conducted at regular intervals of approximately 5 kms along the valleys where bedrock data is absent. The extrapolation took into consideration the locations of known depth to the bedrock surface depicted on Figure 5.
  - Following the estimation of the maximum depth to bedrock along the centreline of the valleys, a map of the bedrock surface below the valley floor will be developed. A quasi U-shaped or trapezoidal-shaped bedrock surface (in cross-section) will be inferred between the maximum bedrock depth along the valley centerline and the ground surface elevation at the limits of the valley floor (i.e. limits of the Quaternary deposits). This work will be carried out during the numerical modeling phase of the project.

[1] Depth of deepest known well

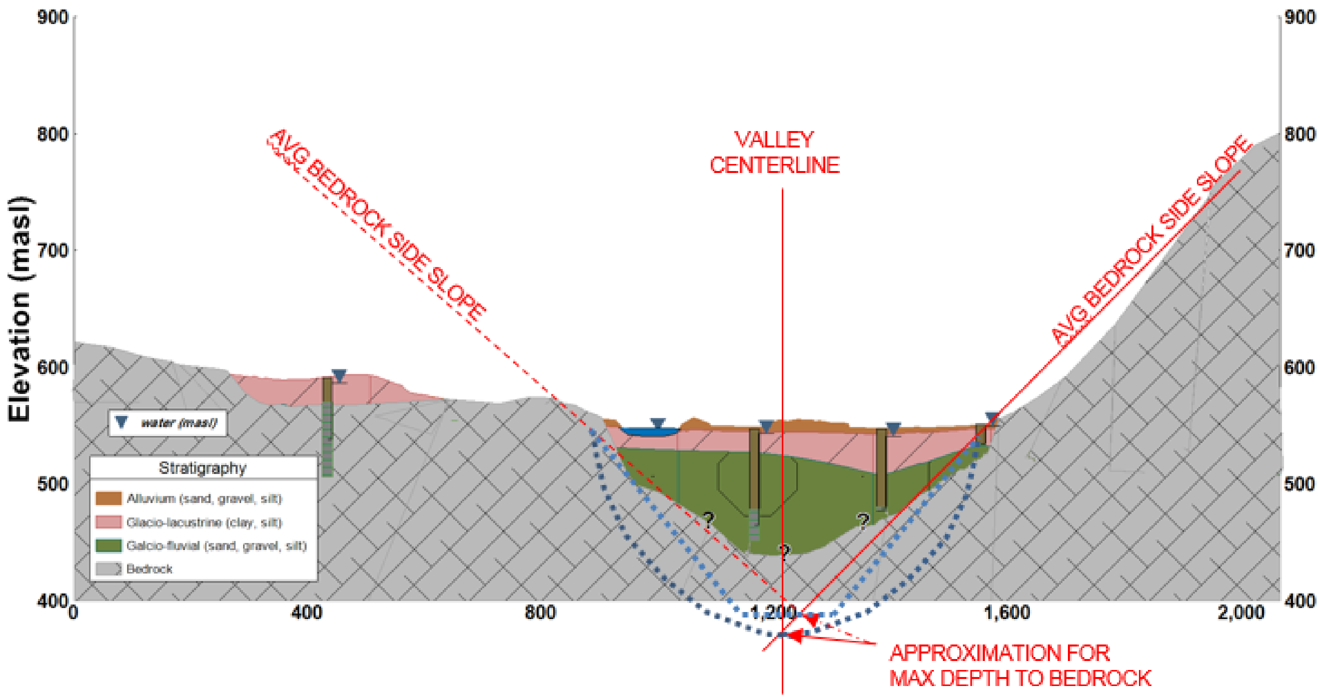

Figure 6: Geologic cross-section (Golder 2016) and method to extrapolate bedrock surface

8.0 STUDY AREA BOUNDARY CONDITIONS

8.1 Inflows

Flow inputs to the model study area are shown on the schematic cross-section in Figure 7. These include groundwater recharge (net of direct infiltration minus evapotranspiration), bedrock inflow, slide-slope runoff, and irrigation return. A description of the flow inputs and their estimation methods is provided below.

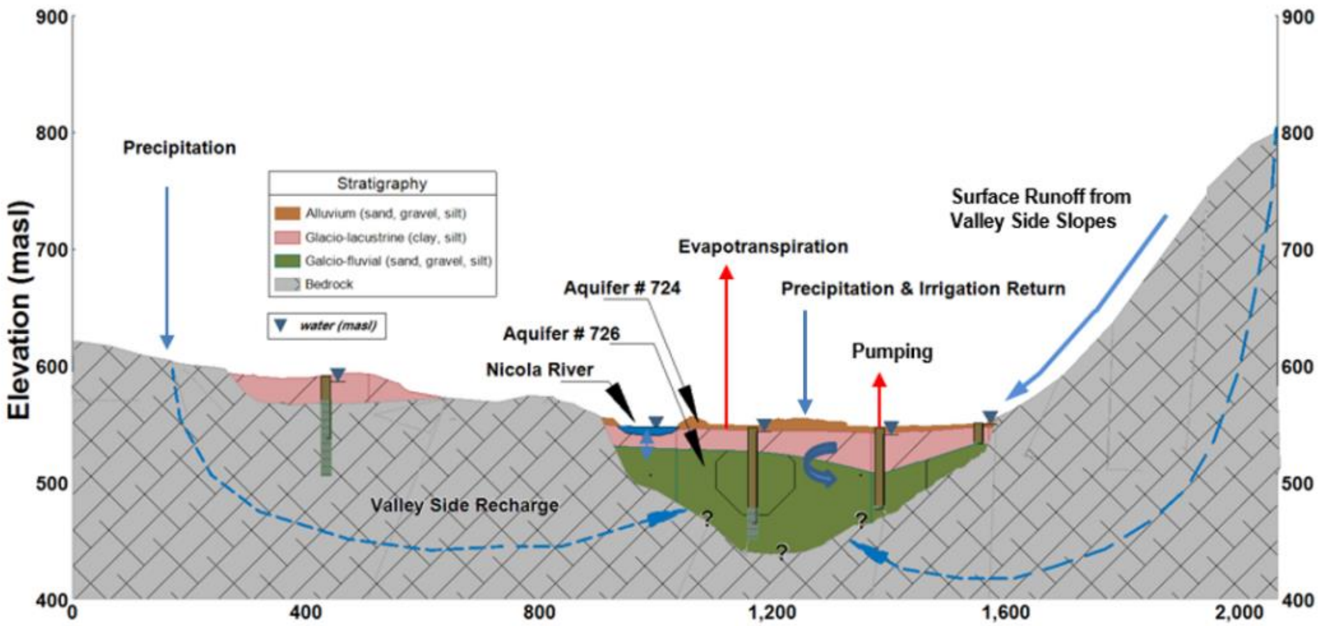

Figure 7: Conceptual cross-section illustration of recharge (blue arrows) to and discharge (red arrows) from valley sediments

8.1.1 Groundwater Recharge

Groundwater recharge due the infiltration of precipitation on the valley floor and in the mountain side-slopes was estimated for the model study area using the chloride mass balance method (Wood and Sanford, 1995). The basic equation applicable for this evaluation is:

$$q = (P)(Clwap)/Clgw,$$

where, q is the recharge flux (mm/yr), P is average annual precipitation (mm/yr), Clwap is precipitation-weighted mean chloride concentration in precipitation (mg/L), and Clgw is average chloride concentration in groundwater (mg/L). Subject to there being no overland run-off or other non-evaporative losses of precipitation falling on the area of interest, the method is based on the premise that the mass of chloride in precipitation falling on the area of Study is preserved in the recharge; therefore, the increased concentration of chloride in the groundwater system reflects the amount of water that has been evapotranspirated and therefore the amount of recharge. For instance, doubling of the chloride concentration between precipitation and the groundwater would indicate that 50% of the precipitation water had been evapotranspirated or that recharge is 50% of the precipitation (typically expressed as [L]/[T]).

A concentration of chloride in precipitation (Clwap) of 0.015 to 0.019 mg/L was used for the analysis. This was the average range for Kamloops measured over a two-year collection period as part of a hydrological study for the City of Kamloops (Golder 2003). The Kamloops precipitation data are considered to be appropriate for use in the Merritt watershed study considering the proximity of the two locals with similar climates and mean annual precipitation. Groundwater chloride concentrations used for the recharge assessment includes deep lake samples (assumed to represent groundwater recharge to lake) obtained as part of the Kamloops study (Golder 2003), published (Golder 2016) and unpublished groundwater data collected by FLNR. and provincial observation well data. The sampling locations and approximate chloride concentrations are shown in Figure 8 and a plot of the data as groundwater recharge versus elevation is provided as Figure 9.

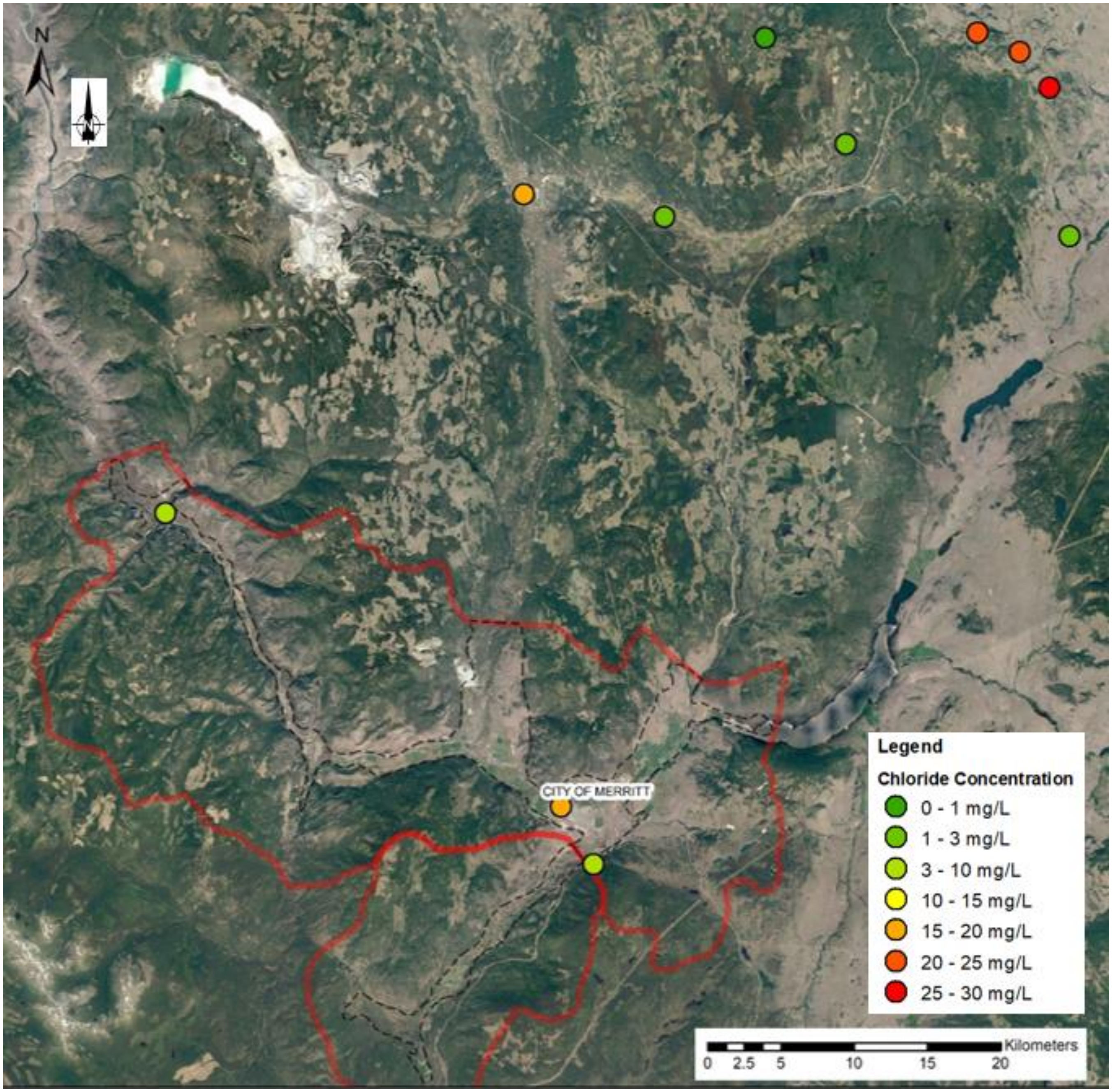

Figure 8: Groundwater chloride sampling locations in the Kamloops-Merritt area

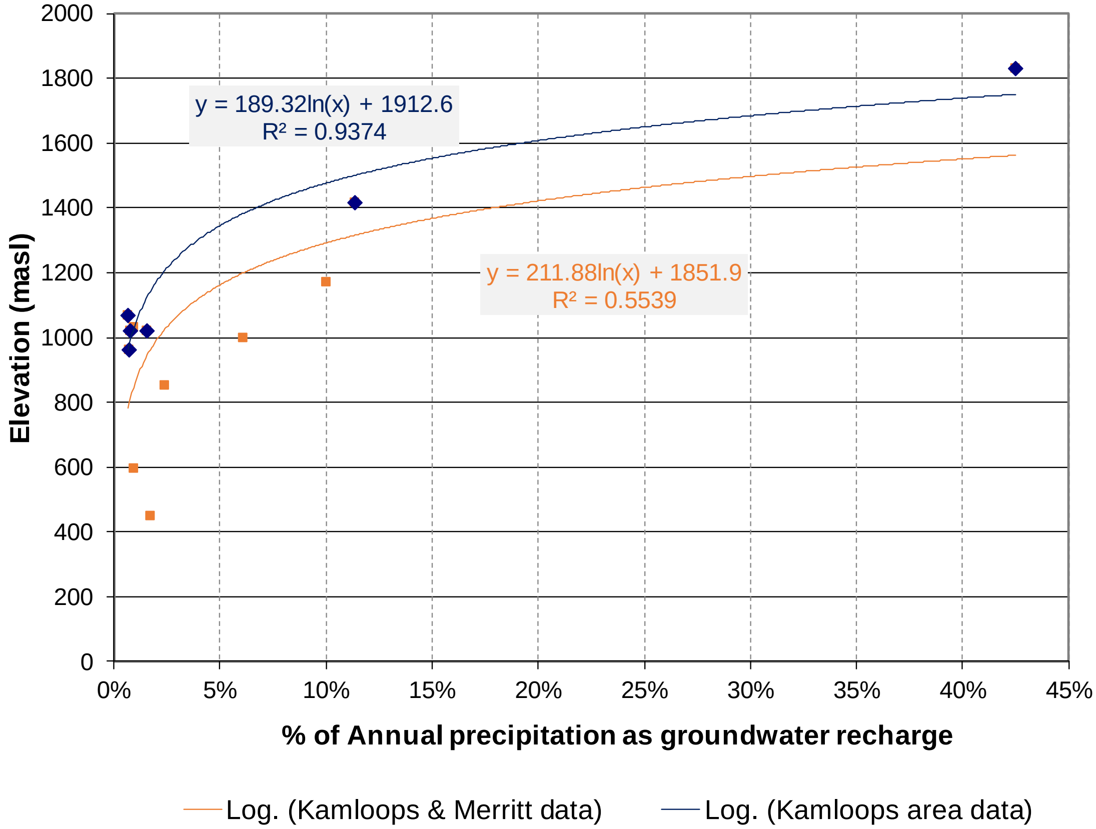

Figure 9: Percent of annual precipitation as groundwater recharge vs elevation

Based on the data plotted on Figure 9 and the distribution by elevation of mean annual precipitation (MAP), the percentage of MAP becoming groundwater recharge and the resulting groundwater recharge as mm per year by elevation zone are summarized in Table 1 and geospatially illustrated on Figure 10. These annual average values were cross-checked by values reported in the literature for typical semi-arid regions (Golder 2016b), which are summarized in Appendix A. The recharge estimates in the above table fall within the reported range for semi-arid regions of the United States and Saudi Arabia where annual precipitation recharge was estimated to range for 1% to 4% of MAP corresponding to 11 to 20 mm/year. The United States Geological Survey (USGS) completed a study of the Columbia Plateau in Washington and Oregon and estimated recharge to be 27% of MAP or 127 mm/year.

Table 1: Estimates of Recharge from Infiltration using Chloride Mass Balance Method

Elevation Zone		% of Annual precipitation as groundwater recharge	Mean annual precipitation (mm)	Predicted groundwater recharge (mm/year)
Valley bottom[1] up to 1,000 masl		3%	321	10
1,000 to 1,200 masl		5%	563	28
1,200 to 1,400 masl		10%	643	64
1,400 to 1,800[2] masl		25%	770	193
Contributing Catchment (excluding valley floor)		Nicola Catchment		Coldwater Catchment
Annual Precipitation Recharge	**(m^3/y)**	34,200,000		18,300,000
	(m^3/d)	94,000		50,000

[1] valley bottom elevations approximately 250 masl at Spences Bridge, 600 masl at Merritt, 700 to 800 masl in the Coldwater valley
[2] height of land above Coldwater and Nicola Valley sides approximately 1,700 and 1,800 masl respectively

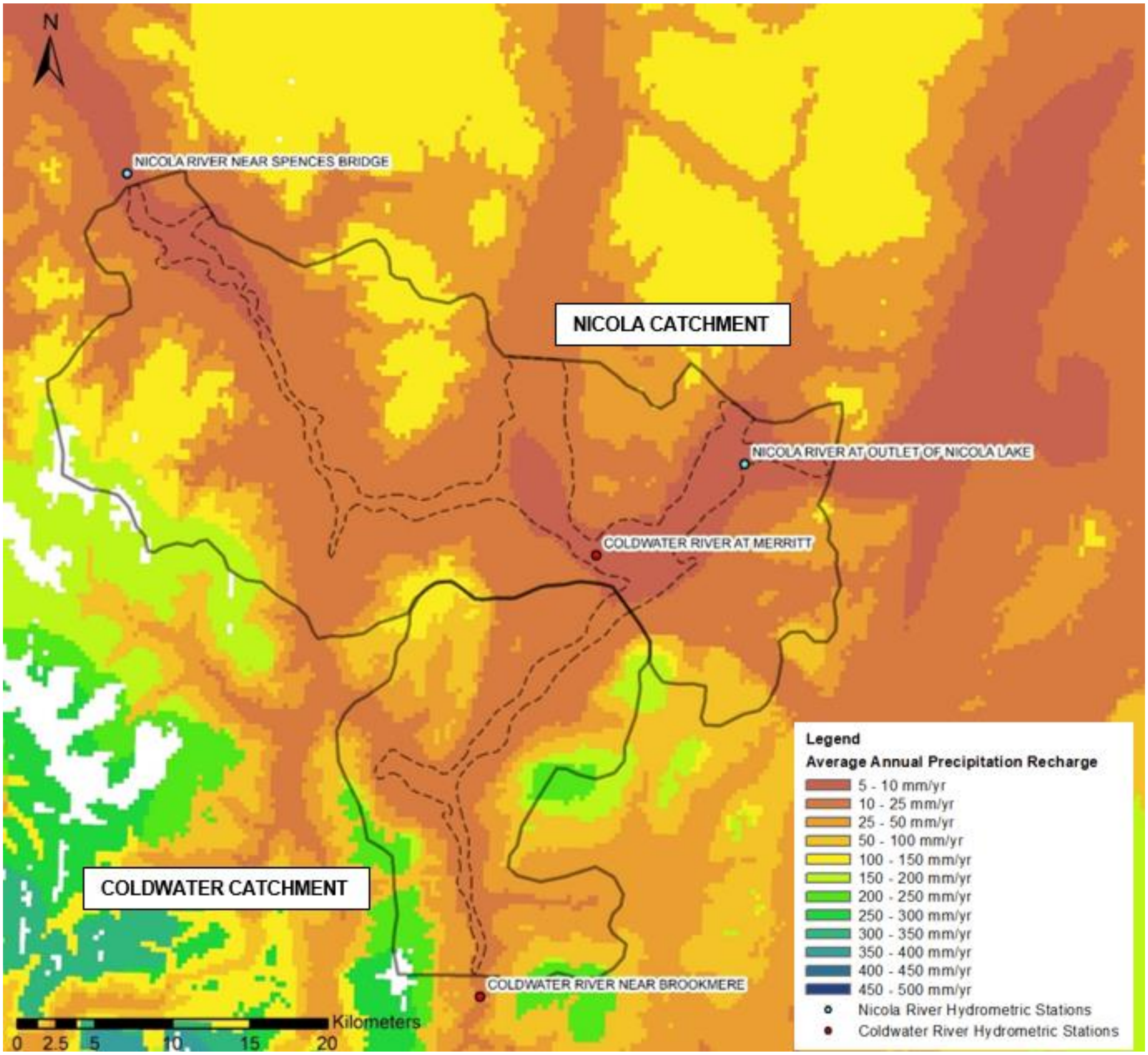

Figure 10: Estimated groundwater recharge from precipitation by elevation in the study area

8.1.2 Surface Runoff

Surface runoff (average annual and monthly averages) from the valley slide slopes often manifests as ephemeral streams during the freshet period that route water to the valley floor (see Figure 11). The quantity of side-slope surface runoff that contributes recharge to the aquifer complex during the freshet (RO) has been estimated from a water balance analysis using both the ClimateBC database (Wang et al. 2012) and stream flow data from the valley rivers within the aquifer complex. The Coldwater River valley was chosen to estimate surface runoff due to it relative geometric uniformity, minor tributary inflow, higher precipitation and greater snowpack (higher potential for runoff) as compared to the Nicola Valley. Surface runoff recharge calculated for the Coldwater River valley will be applied to the entire model surface.

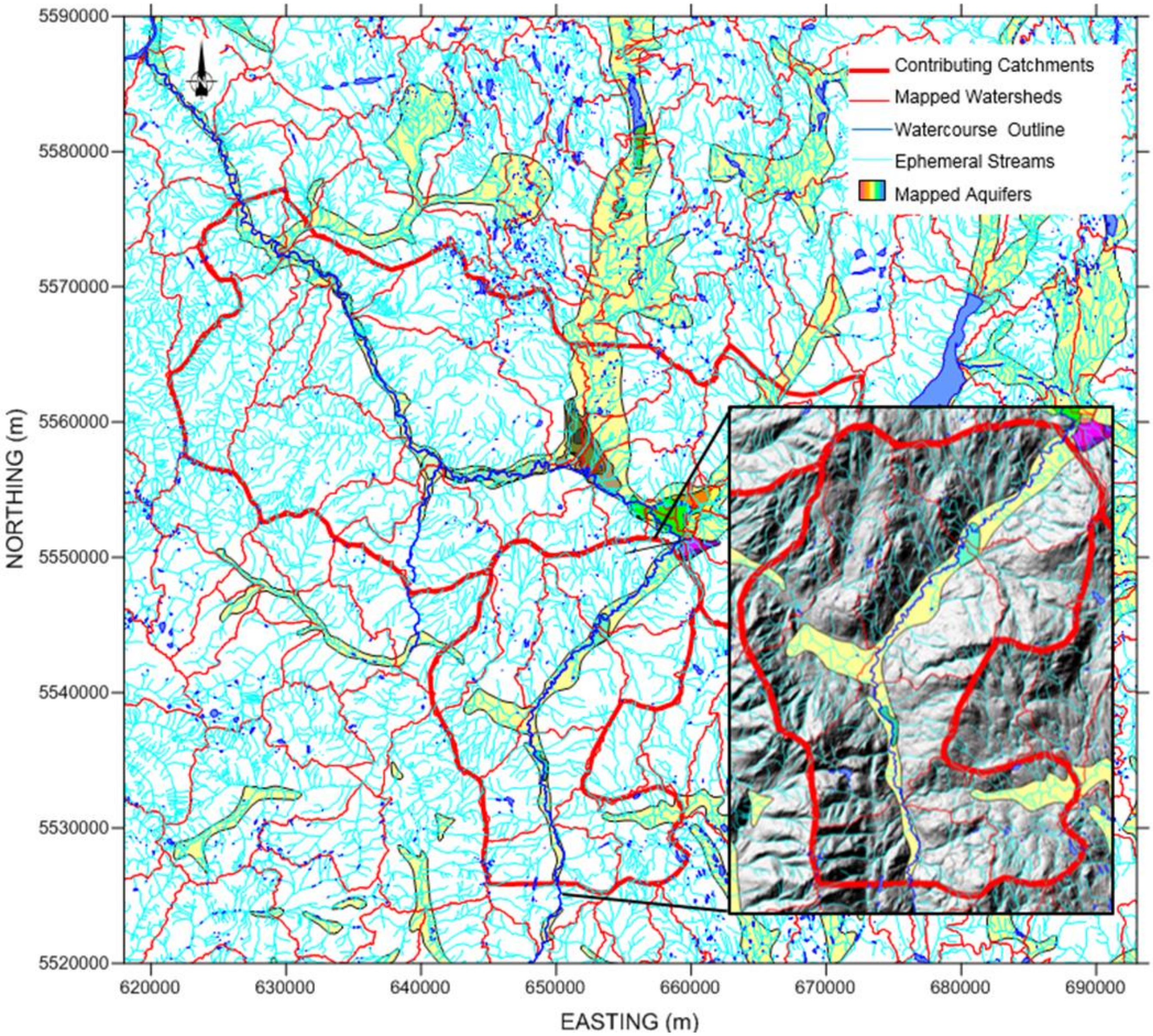

Figure 11: Watershed boundaries and ephemeral streams

For this water balance analysis, the following equation was applied:

$$\text{Equation 1:} \qquad RO = (P + S) - (ET + R_{sideslope} + RO_{river})$$

Where:

RO = runoff from valley side-slopes that does not reach the valley river system

P= precipitation (total for freshet months)

S = annual average snowpack in water equivalents

ET = evapotranspiration (total for freshet months)

RO_{river} = equivalent to measured change in freshet flow between upstream/downstream hydrometric stations in the valley river; represents side-slope runoff which entered valley river system instead of infiltrating into the aquifer complex. Tributary inflow and baseflow between hydrometric stations are negated.

$R_{sideslope}$ = groundwater recharge to bedrock through the valley side-slopes (total for freshet months only)

The climate variables in the above equation (P, S, ET) were determined using ClimateBC for the time spans specified above and were totaled, in terms of water volume, for the contributing catchment areas excluding the valley floor area. A map showing the annual average snowpack in water equivalents is provided in Figure 12. This map also shows the locations of the hydrometric stations that were used evaluate the freshet period and the freshet volume (RO_{river}). The freshet volume was assumed to be derived entirely from slide-slope runoff. The peak freshet period was determined to occur during the months of May and June, on average, as shown by the hydrographs for the Coldwater River (Figure 13). The hydrograph for the Nicola River is included as Figure 14 for comparison purposes.

The difference in flow between the corresponding upstream and downstream hydrometric stations during the freshet period, excluding both baseflow and tributary inflow, was calculated and the results are tabulated in Appendix B. Tributary flow shown for the Nicola River is a combination of gauged and ungauged tributaries. Tributary flow shown for the Coldwater River are ungauged tributaries. The method to estimate ungauged tributary flow is also provided in Appendix B. Groundwater recharge to the valley side-slopes ($R_{sideslope}$) was previously estimated in Section 8.1.1. The side-slope recharge was totaled, in terms of water volume, for the contributing catchment areas excluding the valley floor area.

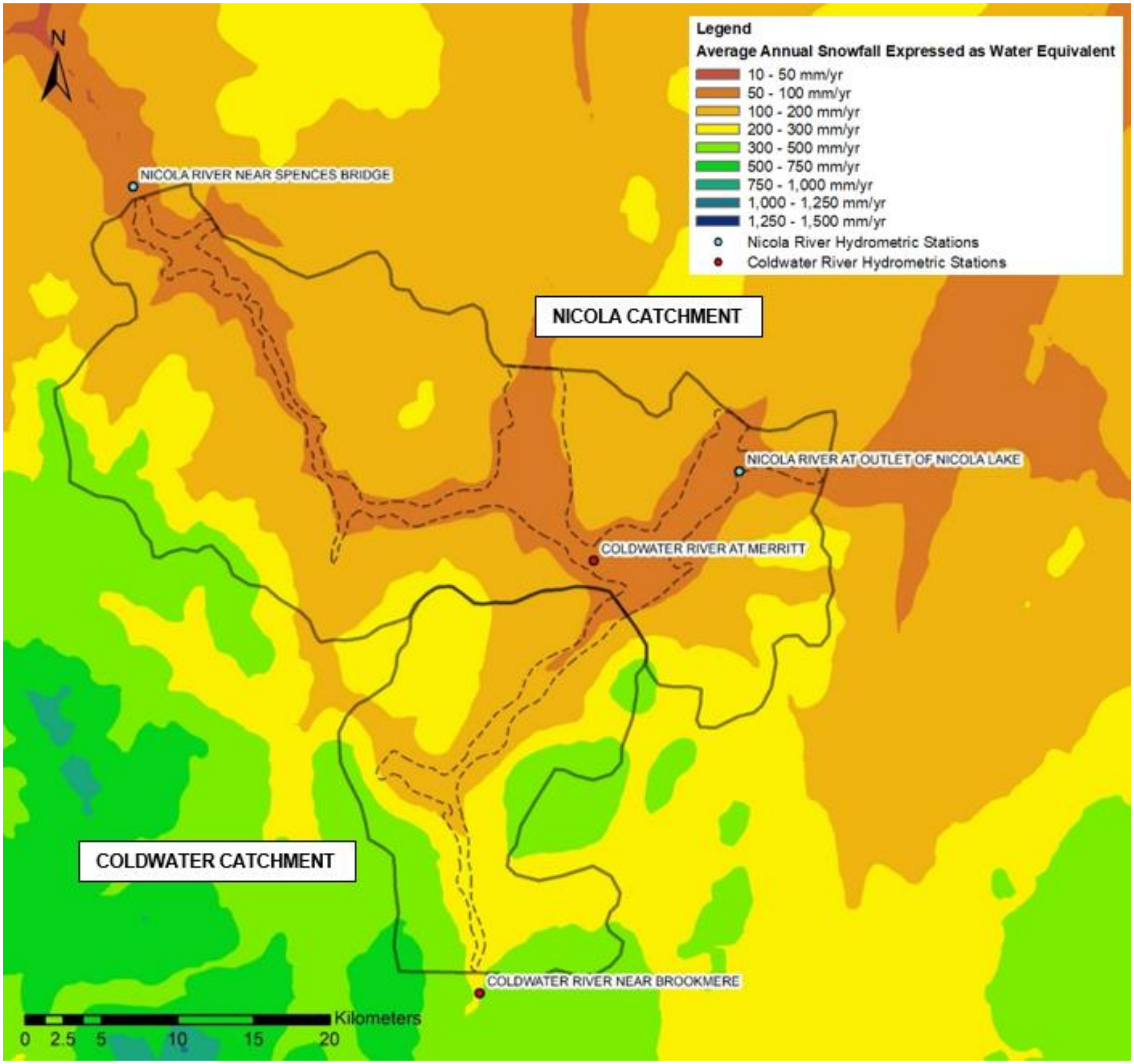

Figure 12: Annual average snowpack as water equivalent (mm/year)

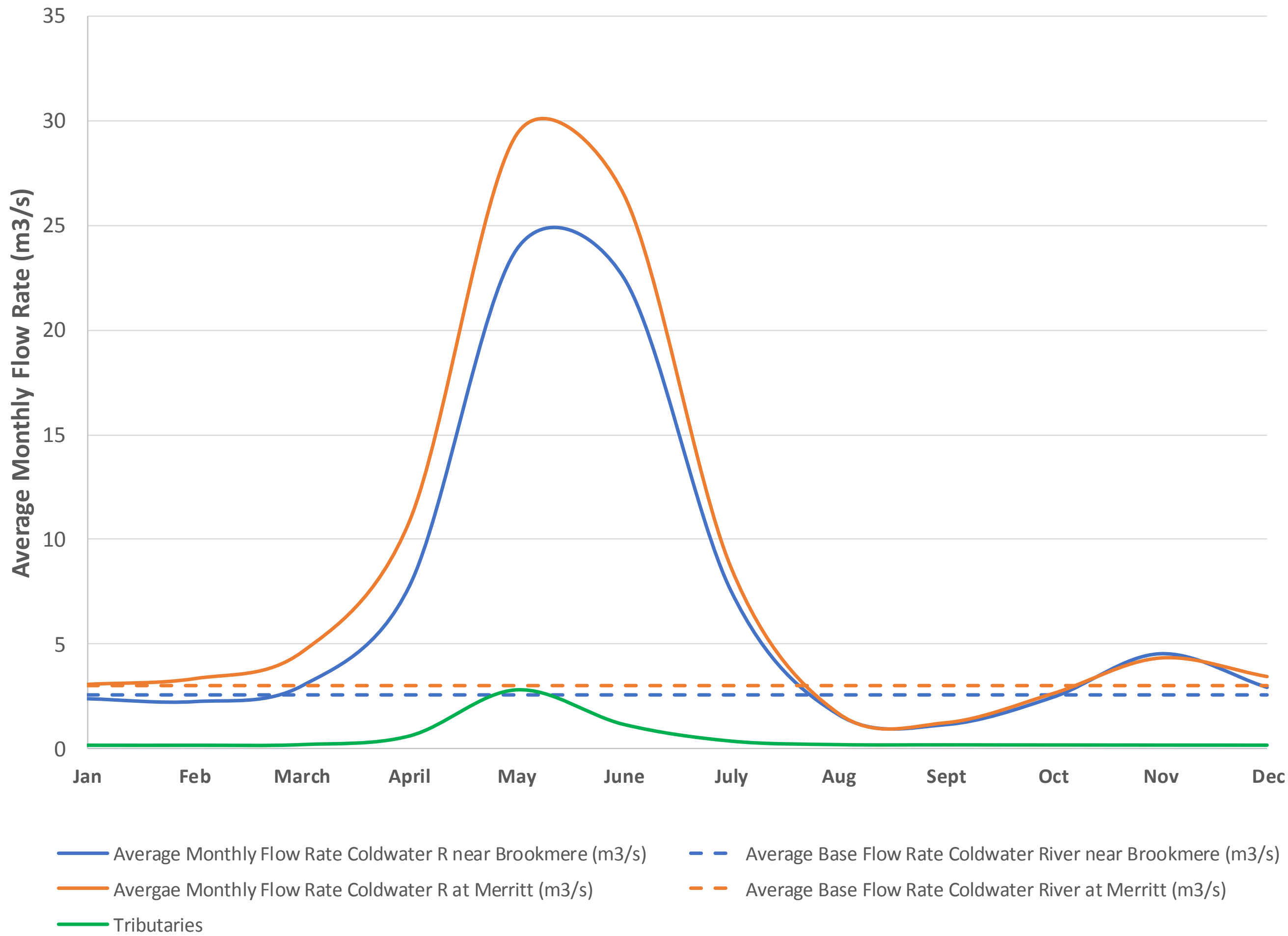

Figure 13: Mean monthly and annual average flow rates in Coldwater River

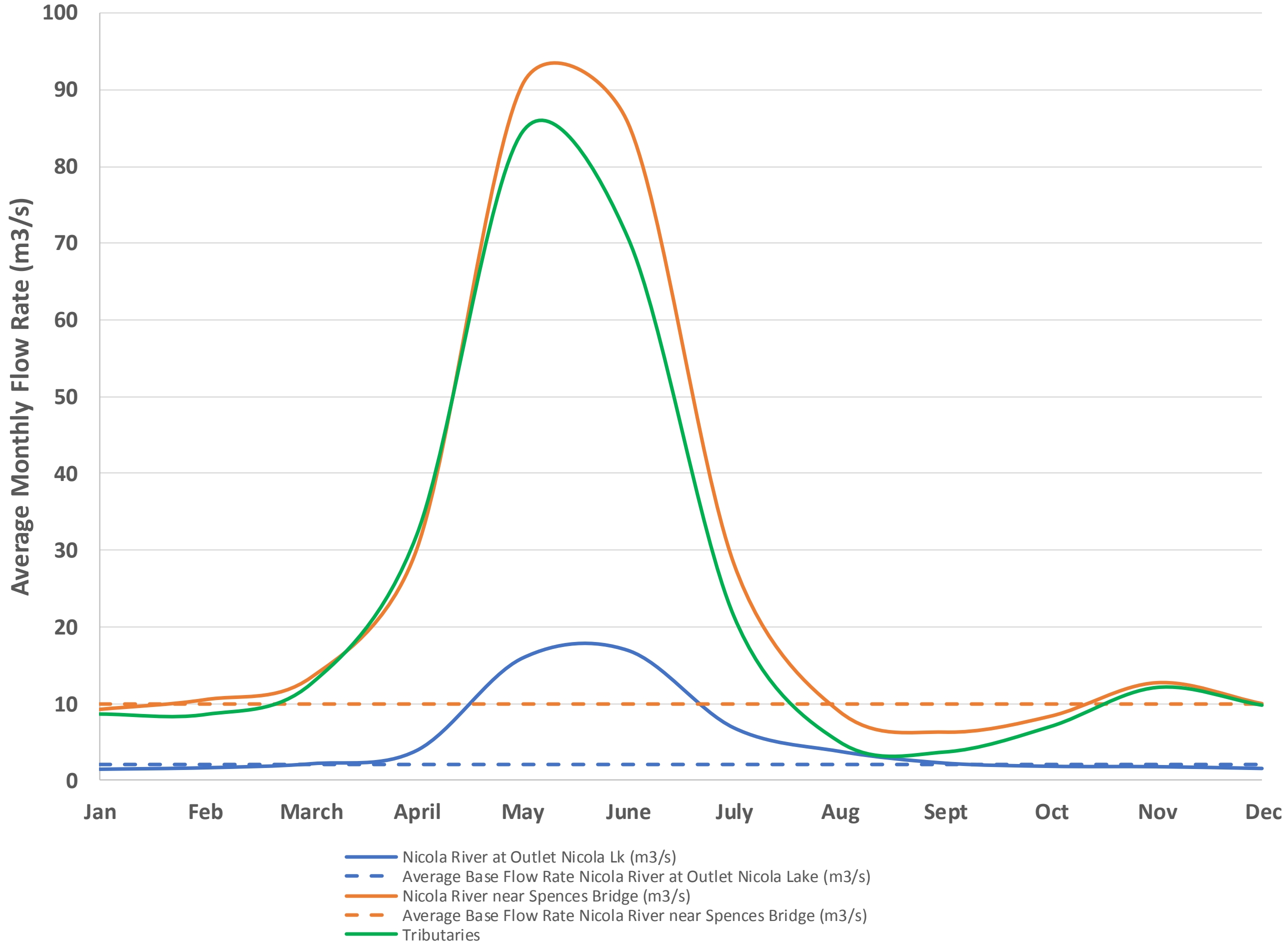

Figure 14: Mean monthly and annual average flow rates in Nicola River

The estimated volumes for all the variables in Equation 1, including the contributing areas from which these volumes were based, are summarized in Table 2 below. The contributing area is calculated as the valley side slopes directly connected to valley bottom and rather than the entire catchment area for the Coldwater River shown on Figure 1: and Figure 11. The contributing catchment area for the Coldwater river is estimated at 325 km^2 whereas the contributing area for side-slope runoff recharge to the valley bottom is estimated at 100 km^2. The results indicate that the side-slope runoff that does not enter the valley river system (RO), is negligible.

Table 2: Freshet Surface Runoff Estimates by Watershed Water Balance Analysis

Parameter	Coldwater Runoff
Contributing Area (km^2) excluding valley floor	100
Valley Floor Area (km^2)	34
(P) Precipitation (May and June) (m^3)	6,700,000
(S) Annual Average Snowfall as Water Equivalent (m^3)	21,500,000
(ET) Potential Evapotranspiration (May and June) (m^3)	20,200,000
(RO_{river}) Peak Freshet change in flow in River (May and June) (m^3)	12,800,000
($R_{sideslope}$) Bedrock Side-Slope Recharge (May and June) (m^3)	3,000,000
(RO) **Total Valley Side-Slope Runoff (May and June) (m^3)**	**-7,800,000**
(RO) **Valley Side-Slope Runoff (May and June) as mm of valley floor recharge**	**negligible**

8.1.3 Bedrock Inflow

Bedrock inflow (annual average value) to the unconsolidated deposits (model base) was estimated previously using the chloride mass balance method as described in Section 8.1.1. The annual groundwater recharge rate to the contributing catchment areas in Table 1 is considered to be nearly equivalent to bedrock inflow to the valley sediments plus tributary baseflow. Bedrock inflow was cross-checked using Darcy's Law (Q=KiA) and assigning the following parameters:

- Hydraulic conductivity of bedrock (K_B) based on, in order of preference: pumping test results, an empirical approach utilizing bedrock well yields to approximate K_B, or literature values associated with the known bedrock lithologies.
- Hydraulic gradient (i) based on the average slope of the valley sides next to the model study area.
- Cross-sectional flow area (A) equivalent to the bedrock surface area of the valley sides adjoining the valley Quaternary deposits.
- Assumed homogeneous and isotropic conditions in bedrock.

Well yields reported by the driller at the time of drilling are subject to inaccuracy and error due to, amongst other things, the short term and variable nature of yield testing and relatively poor documentation of test run times. Reported bedrock well yields were plotted spatially to assess the potential for correlation between high yields and lithologies (see Figure 5). Well yields (and water levels) were utilized to estimate hydraulic conductivity using the method of Kasenov (2006), assuming a drawdown equal to that of the water column in the well. Hydraulic conductivity values were assumed to be applicable over the entire depth of the well due to the tendency for deep, open-hole or long-screened completions for the domestic wells. Bedrock mapping, which provides the reported well yields in bedrock water wells, is provided in Figure 5. The geometric mean hydraulic conductivity estimated from the Kasenov method was 4×10^{-7} m/s which is a high conductivity value for bedrock.

Golder (2018a) developed a hydrogeological model for the New Afton Mine area near Kamloops. Bedrock in the New Afton Mine area includes the Nicola and Kamloops Groups which are also present in the study area. The geometric mean of all hydraulic conductivity testing of bedrock at the New Afton Mine was $1x10^{-8}$ m/s. Calibrated flow model bedrock hydraulic conductivities ranged from $3x10^{-7}$ m/s for the Cherry Creek Aquifer to $2x10^{-9}$ for the Iron Mask Batholith. Hydraulic conductivities for the Nicola and Kamloops Groups were modeled at $1x10^{-8}$ and $2x10^{-8}$ m/s respectively.

Golder also estimated the hydraulic conductivity of bedrock for the Coldwater catchment by estimating bedrock recharge to the valley sediments as represented by the change in base flow from Brookmere to Merritt (tributary inflow subtracted) plus the groundwater outflow through the valley sediments at the outflow boundary near Merritt. This estimated recharge flux was used to back-calculate an estimate for the hydraulic conductivity using Darcy's Equation (Q=KiA).

For this hydraulic conductivity estimation, the following equation was applied:

Equation 2: $$K_{Bedrock} = (RO_{River\text{-}TribFlow} + R_{ValleyOutflow}) / iA$$

Where:

$K_{Bedrock}$ = hydraulic conductivity of bedrock

$RO_{River\text{-}TribFlow}$ = measured change in base flow between hydrometric stations in the valley river minus the estimated tributary inflows

$R_{ValleyOutflow}$ = outflow through the valley sediments

i = hydraulic gradient estimated from the average valley side-slope

A = surface of bedrock inflow estimated from the side-slope distance from edge of the quaternary deposits to the estimated maximum depth of bedrock below the valley sediments

Applying the modified Darcy equation, the estimated the hydraulic conductivity of bedrock was calculated at $2x10^{-7}$ m/s which was similar to the value used to model the Cherry Creek Bedrock aquifer. (2018a). The bedrock hydraulic conductivity derived by this method also validates the precipitation recharge as a reasonable estimate. The estimated parameter values and the results from these calculations are summarized in Table 3.

Table 3: Estimated K back-calculated from bedrock inflows

Hydraulic Parameters	Coldwater River Valley Area
I (m/m)	0.2
A (m^2)	17,300,000
$RO_{River\text{-}TribFlow}$ (m^3/s)	0.6
$R_{ValleyOutflow}$ (m^3/s)	0.06
$K_{Bedrock}$ (m/s)	2×10^{-7}

The range in estimated bedrock hydraulic conductivity and the associated recharge through bedrock for the Nicola and Coldwater catchments are summarized in Table 4.

Table 4: Bedrock inflow estimates from Darcy's Equation

Basin	K (m/s)	i (m/m)	A (m^2)	Q (m3/d)
Nicola Catchment	1×10^{-8} to 1×10^{-7}	0.3	80,400,000	20,000 to 200,000
Coldwater Catchment	1×10^{-8} to 1×10^{-7}	0.2	17,300,000	3,000 to 30,000

8.1.4 Upgradient Inflow (through Valley Sediments)

Inflow to the model study area from the upgradient valley sediments can be estimated using Darcy's Law (Q=KiA) and assigning the following parameters:

- Hydraulic conductivity of the valley sediments (K) based on, in order of preference: flow test results or literature values associated with the known sediment type based on geological mapping. (Golder 2018b);
- Horizontal hydraulic gradient (i) based on, in order of preference, the water table slope or the topographic slope along the valley axis;
- Cross-sectional flow area (A) through the valley sediments based on the depth to the water table and the approximate depth to bedrock determined from the average valley side-slopes. The total cross-sectional flow area is divided by the thickness of each major lithological unit (i.e. sand and gravel, silty sand etc.)
- Assumed homogeneous and isotropic conditions and predominately horizontal flow.

The estimated parameter values and the results from these calculations are summarized in Table 5. At the upstream model boundary of the Coldwater River valley, there are no unconsolidated sediments for groundwater inflow (valley base is bedrock) and all flow into the model at this boundary is from the Coldwater River.

Table 5: Estimates of groundwater inflow through valley sediments at upgradient model boundaries

Hydraulic Parameters	Lower Nicola - Guichon Ck Area	Nicola Lake Area
I	2×10^{-2}	3×10^{-3}
$A_{\text{Sand and Gravel}}$ (m^2)	2×10^4	9×10^3
$A_{\text{Silty Sand}}$ (m^2)	2×10^4	-
$K_{\text{Sand and Gravel}}$ (m/s)	1×10^{-3} to 2×10^{-3}	
$K_{\text{Silty Sand}}$ (m/s)	2×10^{-5} to 6×10^{-4}	
Q (m^3/s)	2 to 4	0.03 to 0.07
Q (m^3/day)	175,000 to 350,000	2,600 to 6,000

8.1.5 Irrigation

During the development of the Nicola WUMP, Summit (2007) estimated that the average amount of irrigation was 670 mm/year applied during the irrigation period of April through September.

Summit (2007) and Golder (2016a) estimated the area under irrigation, the estimated crop demand and irrigation efficiency, i.e. how much water was lost in delivery; these estimates and a review of irrigated area visible in Google Earth, have been used to prepare an irrigation demand summary provided as Table 6.

Table 6: Estimated Irrigation demand

Basin	Irrigated area (ha)	Estimated crop demand (m^3/year)	Irrigation efficiency	Total use (m^3/year)	Sourced from groundwater (%, m^3/year)	Sourced from surface water (%, m^3/year)
Coldwater & Pauls Basin	440	2,948,000	68%	4,335,000	23% 997,000	77% 3,338,000
Merritt to Nicola Lk	735	4,925,000	74%	6,655,000	25% 1,664,000	75% 5,001,000
Guichon below Mamit Lk	225	1,508,000	74%	2,037,000	5% 101,900	95% 1,935,000
Lower Nicola	965	6,466,000	67%	9,650,000	33% 3,185,000	67% 6,465,000
Totals	**2365**	**15,847,000**		**22,677,000**	**5,947,900**	**16,729,100**
Annual Licenced Extractions for Irrigation (m^3/year)[1]						
Nicola River – Nicola Lake outlet to Spences Bridge						15,900,000
Coldwater River						2,250,700
Guichon Creek below Mamit Lake						9,397,000
Total						**27,547,700**

[1] 2018 Data obtained from FLNR Water Allocation

Hay is the primary crop grown in the Nicola basin and the theoretical water requirement for forage crops based on estimated evapotranspiration is 575 mm/year (Bennett 2012). Based on previous water budgets completed for hay land areas in Westwold and Lower Nicola (Bennett, 2012, Golder 2016a), recharge from irrigation return has been estimated at 5% of applied irrigation or 34 mm/year over irrigated land. Estimated annual irrigation return by area is summarized in Table 7. Locations of applied irrigation will be determined during the modeling phase.

Table 7: Estimated annual irrigation return

Area	Irrigated area (ha)	Annual return (m^3)
Coldwater & Pauls Basin	440	150,000
Merritt to Nicola Lk	735	250,000
Guichon below Mamit Lk	225	77,000
Lower Nicola	965	328,000
Total		**805,000**

8.2 Outflows

8.2.1 Active Water Wells

Groundwater extraction locations and pumping rates in the study area are not fully known; therefore, an accurate quantification of groundwater extraction has been identified as a data gap (see Section 12.0). Groundwater use that can be defined by location and pumping rate will be included in the model as specified flow (outflow) boundary conditions. The ENV WELLS database contains information for 413 water wells in the study area; however, Golder's experience and documentation from others (Summit 2007) indicates that the WELLS database may contain roughly 40% to 50% of the wells in a geographic area. The listed uses for the 413 wells are:

- commercial and industrial – 5 wells
- irrigation - 10 wells
- water supply system – 20 wells
- private domestic – 190 wells
- other – 6 wells
- unknown – 182 wells
  - 10 wells with reported yield exceeding 75 US gpm
  - 61 wells with reported yield from 1 to 75 US gpm
  - 111 wells with no reported yield

Reported (driller's estimate) yields for wells with unknown use range up to 1,000 US gpm and reported yields for wells for "other" uses range up to 600 US gpm.

The *Water Sustainability Act* (enacted 29 February 2016) requires water licences for all non-domestic groundwater use. FLNR[2] provided groundwater licencing information for the study area, listing both issued licences and current (up to June 2018) licence applications.

Water systems in the study area are the City of Merritt, Lower Nicola Waterworks, Miller's Sunshine Valley Estates, Lower Nicola Mobile Home Park, Spring Island Mobile Home Park and Nicola Ranch. Of the seven listed water systems, only Miller's Sunshine Valley Estates has obtained a groundwater licence for 36,500 m^3/year. None of the other six water systems have an active groundwater use application and their intended annual groundwater use is unknown.

First Nations water systems in the study area are operated by the Coldwater Indian Band, Shackan Indian Band, Nooaitch Indian Band and the Lower Nicola Indian Band; none of these bands have applied for a groundwater use licence.

Annual groundwater use by the City of Merritt in 2009 was estimated at 3,150,000 m^3/year (Bennett 2009). The City of Merritt implemented water conservation measures and the groundwater use reported by the City of Merritt[3] for 2014 was 2,767,618 m^3. Summit (2007) reviewed the City of Merritt's water use and determined that per capita water use in the City of Merritt was 770 L/person/day. Summit also assumed that there were 2.38 capita per

[2] Information obtained from FLNR water allocation
[3] http://www.merritt.ca/sites/default/files/the_complete_circle.pdf

household corresponding to 1,830 L/day per household. The City of Merritt 2016 population was 7,139[4] and assuming a similar population in 2014, Summit's analysis suggested that in 2014 roughly 70% (2,000,000 m^3) of the groundwater withdrawal was domestic use and 30% was non-domestic use.

ENV Water Science Series Report No. 2016-03 (Associated, 2016) referenced a domestic groundwater use review for three gulf islands in the Nanaimo Regional District. Estimated annual groundwater use was 192.7 m^3/year/domestic well (530 L/day) which is much lower than an extrapolated Merritt area value of 1,830 L/day/domestic well i.e. 770 L/day/person assuming 2.38 person per household or domestic well.

Electoral district information from Statistics Canada[5] was used to approximate the population in the study area outside the City of Merritt. The total First Nation reserve population was 830 although no information was available for the Shackan Reserve. Appling a reserve population of 850 using 770 L/day would be an annual groundwater use of about 240,000 m^3/year. It is also assumed that First Nation reserves are serviced by community water systems.

The non-reserve population outside the City of Merritt is listed at 762 with the lower Nicola Waterworks District servicing 320[6] residents in Lower Nicola. Applying a per capita use of 770 L/day/person, the Nicola Waterworks District's annual groundwater use is estimated to be 90,000 m^3/year.

Separating the Lower Nicola community from the non-reserve population outside of the City of Merritt would leave 442 residents, some of which would be on community water system and the remainder on private domestic wells. Annual use for 442 residents would project to 124,000 m^3/year. Summit (2007) estimated that there were 600 domestic wells in the entire Nicola Watershed which is a larger area than the current study area. In the study area the WELLS database lists 190 domestic wells, 61 unknown use wells with yields up to 75 US gpm and 111 unknown use wells with no reported yield. If it is assumed that records contained in the WELLS database only represent 50% of the wells that are present and there are 400 domestic wells in the study area pumping 1,830 l/day/well, this would project to an annual volume of 267,000 m^3/year which is about twice the value calculated by per capita consumption.

Estimated annual groundwater withdrawals for irrigation use for the study area is estimated at approximately 6,000,000 m^3/year (Table 6). Issued groundwater licences and active applications for irrigation use in the Merritt water management precinct total 1,128,249 m^3/year. The Merritt precinct incorporates the Coldwater valley, the City of Merritt and all wells south of the Nicola River from Nicola Lake to Spius Creek.

There is one irrigation use application for the Lower Nicola Precinct for 18,000 m^3/year. The Lower Nicola precinct includes all wells on the north side of the Nicola River from Nicola Lake to Spius Creek.

The Spences Bridge water management precinct extends either side of the Nicola River from Spius Creek to Spences Bridge. As of June 2018, FLNR has not issued any groundwater licences for this precinct or received any groundwater licence applications.

Approximated annual groundwater pumping in the study area is summarized in Table 8. Estimations of annual groundwater use will be improved as more groundwater licence applications are received by the province and the use of "unknown" and "other" wells is established. Licencing information proved by FLNR indicates that roughly 20% of the estimated annual irrigation use has been issued or applied for and only 1% of the estimated use by community water systems has been issued or applied for.

[4] Merritt Herald 9 February 2017.
[5] http://www12.statcan.gc.ca/census-recensement/2016/as-sa/fogs-spg/Facts-csd-eng.cfm?LANG=Eng&GK=CSD&GC=5933008&TOPIC=1
[6] Merritt Herald 11 May 2017

Table 8: Estimated annual groundwater extraction by use

Use	Volume (m^3/year)
Irrigation	6,000,000
City of Merritt	2,768,000
First Nation water systems	240,000
Lower Nicola Waterworks	90,000
Domestic wells and small water systems	125,000 to 250,000
Commercial/industrial	Unknown (no issued or pending licences)

8.2.2 Downgradient Outflow (through Valley Sediments)

Outflow from the model study area to the downgradient valley sediments can be estimated using Darcy's Law (Q=KiA) and assigning the following parameters:

- Hydraulic conductivity of the valley sediments (K) based on, in order of preference: well test results or literature values associated with the known sediment type based on geological mapping (Golder 2018b).
- Horizontal hydraulic gradient (i) based on, in order of preference, the water table slope or the topographic slope along the valley axis.
- Cross-sectional flow area (A) through the valley sediments based on the depth to the water table and the approximate depth to bedrock determined from the average valley side-slope. The total cross-sectional flow area is divided by the thickness of each major lithological unit (i.e. sand and gravel, silty sand etc.).
- Assumed homogeneous and isotropic conditions and predominately horizontal flow.

The estimated parameter values and the results from these calculations are summarized in Table 9.

Table 9: Estimates of Downgradient Outflow through Valley Sediments

Hydraulic Parameters	Lower Nicola Valley Area	Coldwater River Valley Area
I	9×10^{-3}	8×10^{-3}
$A_{\text{Sand and Gravel}}$ (m^2)	4×10^3	2×10^4
$A_{\text{Silty Sand}}$ (m^2)	2×10^4	-
$K_{\text{Sand and Gravel}}$ (m/s)	1×10^{-3} to 2×10^{-3}	
$K_{\text{Silty Sand}}$ (m/s)	2×10^{-5} to 6×10^{-4}	
Q (m^3/s)	0.01 to 0.07	0.04 to 0.08
Q (m^3/day)	900 to 6,000	3,500 to 7,000

8.3 Specified Heads (Water Level Elevations)

Although a fully-coupled groundwater-surface water flow model provides a better representation of the physical processes that are active in the valley bottom aquifer complex, there are significantly more data requirements for such a model with limited existing data to support such an approach. The river data required for such a fully coupled model includes detailed information on the depth and width of the rivers, river bed sediment type and thickness, stage/discharge/volume curves, surface water inflows (tributary flows) and surface water extraction rates (licenced and non-licenced) for each major river segment. Most of this information is currently not available for the Nicola River and Coldwater River but could be estimated or inferred. A staged approach with respect to the addition of increasingly greater complexity to the model design is warranted so that the uncertainties associated with the inferred or assumed model inputs are minimized. This approach will achieve the required model predictions with the lowest level of uncertainty associated with these predictions given the available data.

For the initial stages of model development (model designed with the lowest level of complexity), it is considered prudent for surface water bodies such as lakes and rivers within or next to the aquifer complexes within the model study areas to be represented as specified head boundary conditions. A description of the boundary conditions and the estimation method for the heads is provided below.

8.3.1 Lakes

Nicola Lake is the only lake in the vicinity of the study area. This lake influences or controls groundwater levels in the adjacent valley aquifer system on the west side of the lake (i.e., the Merritt-Nicola Lake Area). It is not necessary to include the entire lake within the model study area; instead, only the western portion of Nicola Lake which is in contact the valley aquifer system will be represented as a specified head boundary condition. This entails estimation of the average annual (or monthly average) surface water level elevation of the lake and the average or maximum depth of the lake.

A plot of the lake’s surface water elevation over time and the annual average surface water level elevation is provided in Figure 15. This data is based on lake stage records from the Nicola Lake near Quilchena Gauge Station (08LG046). Bathymetry data for the lake obtained from Data BC indicates that the lake depth is approximately 1.5 m at the location of the eastern model study area limits where the lake spans the full width of the valley floor.

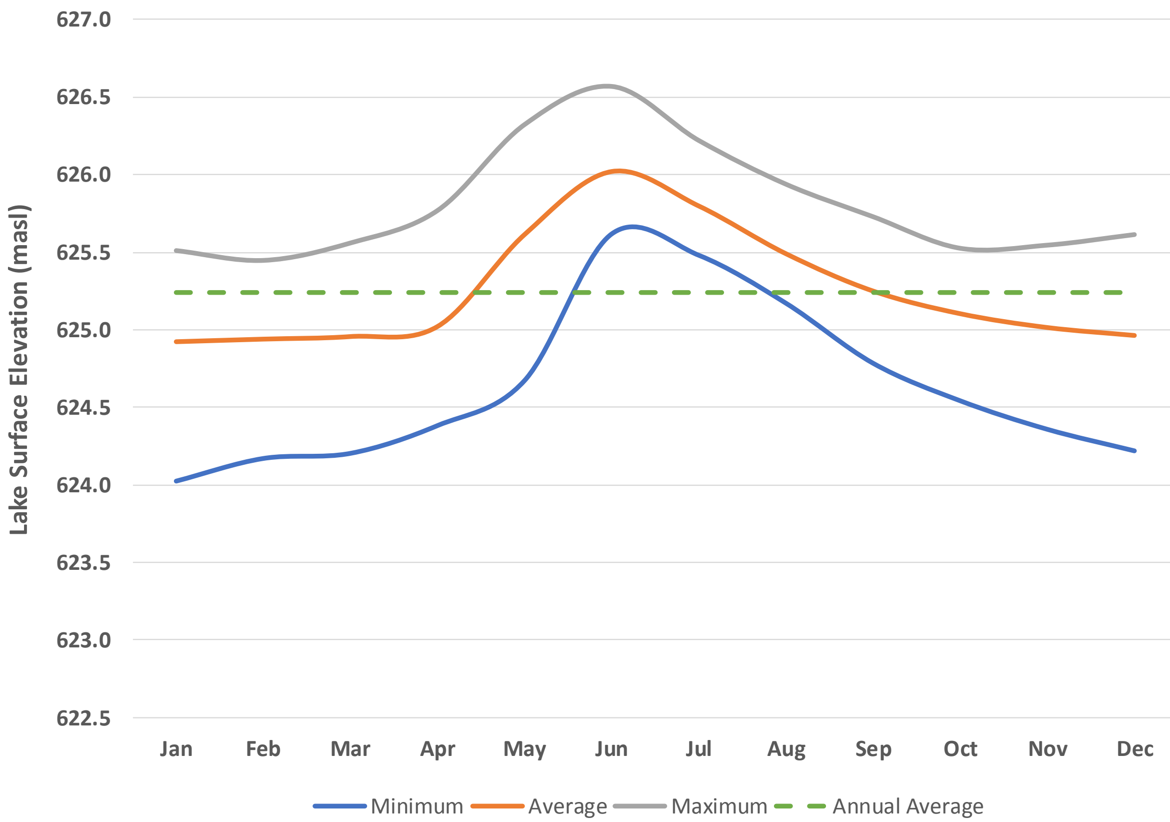

Figure 15: Average monthly surface elevation of Nicola Lake (1933 – 2015)

8.3.2 Rivers and Streams

Continuously flowing rivers or streams, including the Coldwater River, Nicola River and Spius Creek (see Figure 1) will be incorporated in the model either as specified head boundary conditions or as head-dependant boundary conditions (e.g., the river package in MODFLOW). This entails estimation of the average annual (or monthly average) surface water level elevation (or river stage and depth) at the hydrometric stations within or in close proximity to the model areas, and then interpolating the water level elevation along the river course between these stations (i.e., linear interpolation may be assumed). Where surface water level data are not available, then topographic data along the river will be used as a surrogate.

The estimated average annual water level elevations for the relevant hydrometric stations for Nicola River are provided in Table 10, and the station locations for both the Nicola River and Coldwater River are shown on Figure 2. It should be noted that the water level elevations are rough estimates. This is because geodetic elevations for the gauges were not available; therefore the gauge elevations were estimated from topographic data in Google Earth. The absence of accurate surface water level elevation data was identified as a data gap (see Section 12.0).

Table 10: Hydrometric station summary

WSC Station	WSC Sta No.	Est. Guage elev (masl)*	Avg Stage (m)	Est. Avg river elev (masl)	Est reach (km)	Est. gradient (m/km)
Nicola River @ outlet Nicola Lake	08LG065	626 ±10	1.06	627.06 ±10	n/a	n/a
Nicola River@ Coldwater River confluence	n/a	n/a	n/a	593.00 ±10	12	2.84
Nicola River d/s Merritt	08LG007	n/a	n/a	575.00 ±10	7	2.57
Nicola River near Spences Bridge	08LG006	341 ±10	1.70	342.70 ±10	38	6.11
Estimated total length					57	
Coldwater River near Brookmere	08LG048	873 ±10	1.06	874.06 ±10	n/a	n/a
Coldwater River at Merritt	08LG010	594 ±10	1.30	595.30 ±10	33	8.45
Estimated total length					33	
Guichon Ck @ outlet Mamit Lake	08LG041	n/a	n/a	956.00 ±10	n/a	n/a
Guichon Ck @ Lower Nicola	08LG004	n/a	n/a	580.00 ±10	25	15.04
Estimated total length					25	

Geodetic elevations of WSC stations have not been established; all geodetic elevations estimated from Google Earth
n/a – not applicable

Riverbed conductance (water transfer restriction between the river and the underlying aquifer because of lower permeability river bottom sediments) will need to be considered or assumed. This requires the input of the following parameters:

- River bottom elevation
- River bed thickness
- Width of river
- Vertical hydraulic conductivity (K_V) of riverbed sediments

The absence of information on the above parameters was identified as a data gap (see Section 12.0). Their estimation will be carried out during the numerical modeling phase of the project. These parameters will be assigned based on available data where possible or based on ancillary evidence or best-guess values, with consideration of google imagery, lidar mapping[7] and geological mapping.

[7] FLNR indicates that completion of LIDAR mapping of Nicola Valley is fall 2018

9.0 INPUT PARAMETERS AND HYDROSTRATIGRAPHIC LAYERS

9.1 Input Parameters

Based on aquifer mapping reported in Golder (2018b), there are five main hydrogeologic units within the study area. The five units and the aquifer types associated with the units are provided in Table 11. The locations where the type of valley bottom sediments are unknown were identified as a data gap (see Section 12.0).

The initial hydrogeological parameters (hydraulic conductivity) that will be assigned to the study area to represent the unconsolidated hydrostratigraphic units (i.e., the aquifer and aquitard units) are based on measured values from well test results or, where test results are not available, are based on literature values. Table 11 below summarizes these input parameters and provides the source information for these values.

Table 11: Hydraulic Conductivity of Hydrostratigraphic Units

Hydrogeologic Unit	Primary Aquifer Types (ENV 2016)	K (m/s)	Source
Sand and Gravel	1a, 1b, 1c, 2, 3, 4a	$1x\ 10^{-3}$ to $2x\ 10^{-3}$	Golder 2016a
Silty Sand	4b, 4c	2×10^{-5} to 6×10^{-4}	Golder, 2005
Silty Clays	not applicable	2×10^{-8} to 6×10^{-6}	Freeze and Cherry, 1979
Till	No applicable	3×10^{-8} to 3×10^{-7}	Golder 2018a
Bedrock	5a, 6a, 6b	1×10^{-8} to 1×10^{-7}	Section 8.1.3, Golder 2018a

A specific yield of 0.25 m/m and a storativity of 5E-4 (for a confined aquifer storativity typically ranges from 5E-5 to 5E-3 (Todd 1980); for an unconfined aquifer storativity is similar to specific yield and typically ranges from 0.1 to 0.3 (Lohman 1972)) are considered representative storage properties for the valley sediments as a whole. Therefore, these values will be assigned to all the units in the table above unless new data on these parameters becomes available.

9.2 Hydrostratigraphic Layers

Top and bottom surfaces as well as the lateral extent of the unconsolidated hydrostratigraphic units will be extracted from the aquifer mapping model completed previously (Golder 2018b). This extraction and the development of the stratigraphic layers or surfaces will be carried out during the numerical modeling phase of the project.

10.0 MODEL CALIBRATION APPROACH

The model will be calibrated using available average annual groundwater level elevations from existing monitored wells. At this time the only available groundwater hydrograph is from the Provincial Observation well No 296 completed in the Upper Merritt Aquifer. The absence of sufficient groundwater level elevation data within the key aquifers of interest was identified as a data gap (see Section 12.0).

The model will also be calibrated to the average annual base flow rate estimated between corresponding upstream and downstream hydrometric stations (excluding tributary flow) within or near to the model study area. The average annual base flow estimates between the most upstream and most downstream stations with respect to the study area are provided in Appendix B. Estimates of base flow between mid-river stations will be carried out during the numerical modelling phase of the project. Flow test information conducted on water wells (i.e. pumping tests) made available to Golder will also be used for model calibration if appropriate.

Mean monthly hydrometric flow, estimated tributary inflow and estimated irrigation extraction for the Nicola River from the outlet of Nicola Lake WSC to the WSC station near Spences Bridge are plotted in Figure 16. The methodology to estimate mean monthly flows for ungauged tributaries to the Nicola and Coldwater Rivers is provided in Appendix B.

Figure 16 is restricted to flows up to 35 m^3/s to better illustrate comparisons of flows outside of freshet. Mean monthly freshet flows in the Nicola River near Spences Bridge range up to roughly 90 m^3/s. Groundwater - surface water exchange ($GW\text{-}SW_{ex}$) shown as black bars is calculated as:

Equation 2: $$GW\text{-}SW_{ex} = Q_{upstream} - Q_{downstream} - Q_{tributaries} + Q_{irrigation}$$

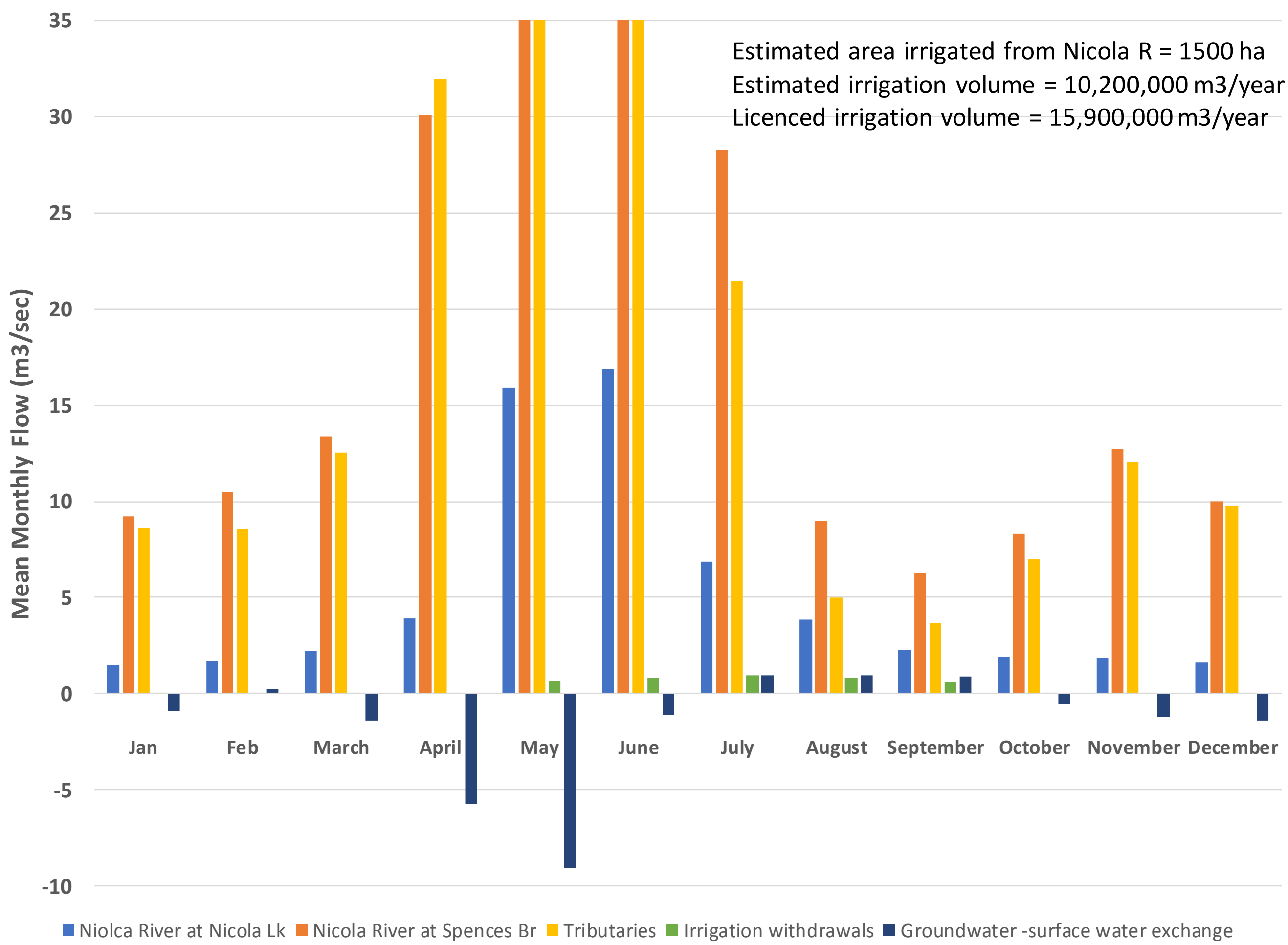

Figure 16: Nicola River Hydrograph

Figure 16 illustrates that based on mean monthly flows and estimated tributary inflows:

- The Nicola River reach from the outlet of Nicola Lake to the WSC station near Spence Bridge is losing from November through June with the exception of February, i.e. the river is losing water and recharging connected aquifers and the black bars are negative.
- The Nicola River is gaining in July, August, September, i.e. connected aquifers are recharging the river.

Golder prepared a surface water-groundwater budget for the Nicola River from Merritt to the Spius Creek confluence (Golder 2016a). The study concluded that this reach of the river was a gaining reach year round except for April. A comparison of the water budget results to this study suggests that:

- The Nicola River from the outlet of Nicola Lake to Merritt is essentially a losing reach
- The Nicola River from Merritt to Spius Creek is essentially a gaining reach
- The Nicola River from Spius Creek to Spences Bridge is essentially a losing reach

Table 12: Hydrometric station summary - Coldwater River

WSC Station	Sta No.	Est. Guage elev (masl)[1]	Average Stage (m)	Est. Average river elev (masl)	Est reach (km)	Est. gradient (m/km)
Coldwater R near Brookmere	08LG048	873	1.06	874.06	n/a	n/a
Coldwater R @ Merritt	08LG010	594	1.30	595.30	33	8.45

[1] Geodetic elevations of WSC stations have not been established; all geodetic elevations estimated from Google Earth
n/a – not applicable

Mean monthly hydrometric flow, estimated tributary inflow and estimated irrigation extraction for the Coldwater River from Brookmere WSC to Merritt WSC is plotted as Figure 17. The chart is restricted to flows up to 12 m^3/s to better illustrate comparisons of flows outside of freshet. Mean monthly freshet flows in May and June range from roughly 23 m^3/s at Brookmere WSC to 29 m^3/s at Merritt WSC.

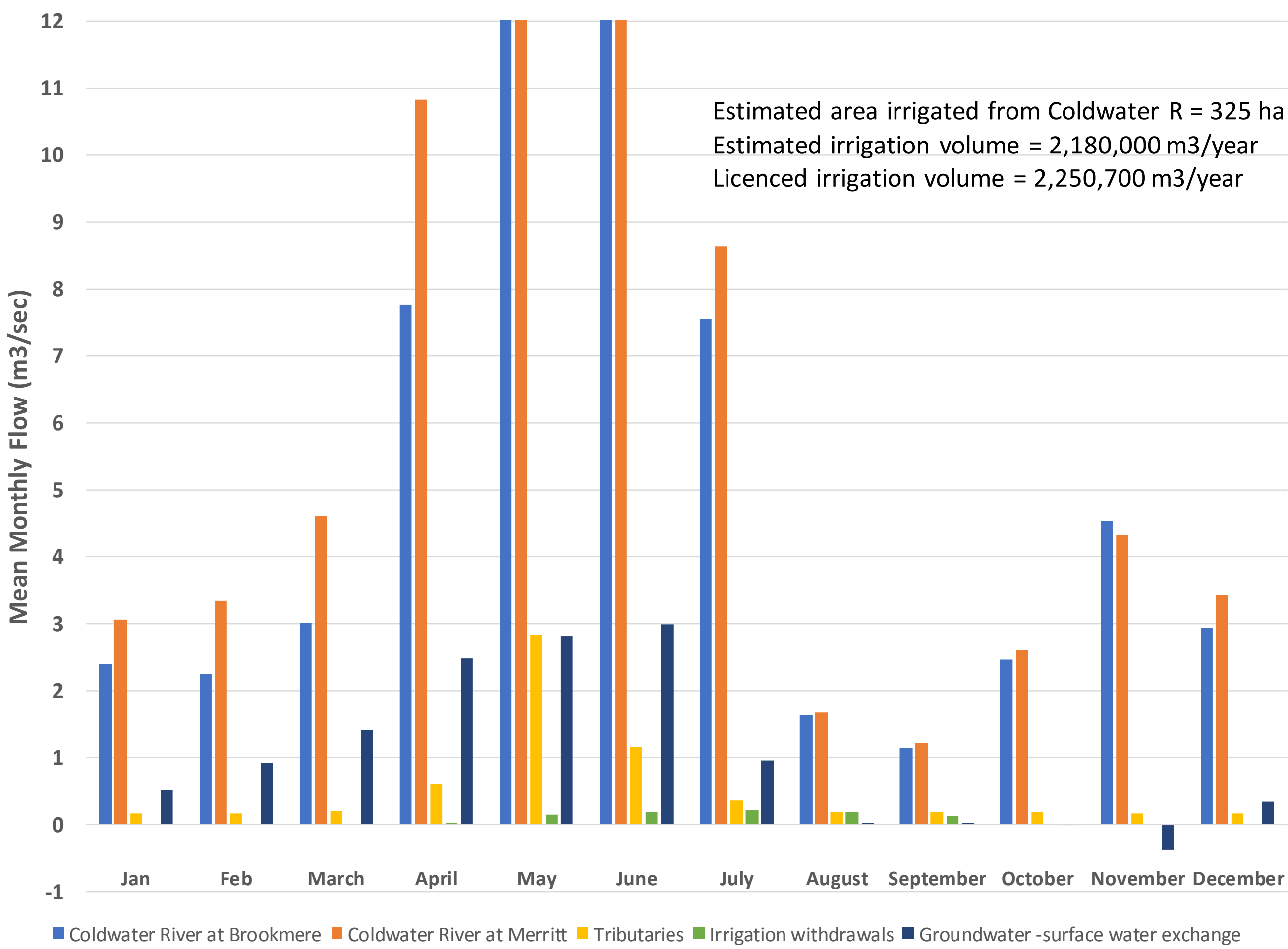

Figure 17: Coldwater River hydrograph

Figure 17 illustrates that based on mean monthly flows and estimated tributary inflows:

- The Coldwater River reach from Brookmere to Merritt is a net gaining reach from December through July, i.e. groundwater is recharging the river and the black bars are positive.
- Groundwater recharge to the river is much higher than tributary inflow from December to July with the exception of May when both inflows are estimated to be similar.
- Net groundwater recharge to the river from August through October is essentially zero. This also means that gaining reaches may be offset by losing reaches between Brookmere and Merritt. For example, ENV measured flow in the Coldwater River in August and September 2005 and concluded that the river lost up to 40% of its flow between the music festival site immediately upstream of Merritt to Claybanks Park in Merritt. Additional river losses were expected to occur from Claybanks Park to Voght Park where municipal wells are located (Bennett 2009).
- The Coldwater River is a net losing reach in November.

11.0 CONCEPTUAL MODEL

Based on the information reviewed in this project, the aquifer mapping (Golder 2018b) and the water budget developed for the Nicola River area from Merritt to Spius Creek (Golder 2016), a conceptual groundwater flow model has been developed for the study area.

The valley bottom unconsolidated materials consist of Quaternary fan deposits and modern alluvium that form unconfined aquifers. From available well records, the Quaternary fan deposits (Stumbles Creek Aquifer) are up to 42 m thick. Maximum reported well depths in the modern alluvium were 46 m for the Upper Merritt Aquifer and 33 m for the West of Merritt Aquifer located between Lower Nicola and Spius Creek.

Thick glacio-lacustrine sediments separate the Quaternary deposits from interglacial deposits that form confined aquifers at Lower Nicola and Merritt. The confined aquifers have been developed for water supply. Flowing municipal and irrigation wells have be completed in the “Lower Nicola Outwash Aquifer”. In 2007, the City of Merritt constructed a 140 m deep municipal supply well that intercepted two separate confined aquifers below the unconfined Merritt Aquifer; these two confined aquifers have been mapped as the “Middle Merritt Aquifer” and the “Lower Merritt Aquifer”. A nested observation well completed in the Middle and Lower Merritt Aquifers encountered flowing conditions indicating an upward hydraulic gradient into the overlying Upper Merritt Aquifer. A 120 m deep flowing well was drilled in the Coldwater River valley sediments at the “music festival” site roughly 1.5 km upriver of Merritt.

The total thickness of the valley bottom sediments in the study area is not document but has been proven to be at least 165 m thick at Merritt during the drilling of a municipal supply well. Bedrock side slopes have been extrapolated beneath the valley sediments to estimate the maximum thickness of the valley sediments every 5 km along the main valleys in the study area. Based on the extrapolation, the thicknesses of the unconsolidated valley bottom deposits are estimated to be roughly:

- Coldwater River valley - 30 (upriver) to 110 m thick (downriver)
- Merritt to Nicola Lake - 100 to 330 m thick
- Merritt to Spius Creek - 55 to 275 m thick
- Spius Creek to Spence Bridge - 30 to 180 m thick
- Guichon Valley below Mamit Lake 20 to 100 m thick

The primary direction of groundwater flow in the study area is inferred to be aligned with the axes of the valleys. Horizontal groundwater gradients through the unconsolidated aquifers are inferred to be the same as river gradients:

- Coldwater River from Brookmere WSC station to Merritt WSC station – average gradient of 8.5 m/km
- Nicola River from the Nicola Lake outlet Coldwater River confluence at Merritt – average gradient of 2.8 m/km
- Nicola River from Merritt to WSC station near Spences Bridge – average gradient of 6.1 m/km

11.1 Geological units

The primary geologic units in the study area are:

- Bedrock valley sides and uplands forming the catchment areas.
- Quaternary deposits consisting of alluvial fans and modern alluvium (unconfined aquifers)
- Valley bottom glacial lake sediments (confining units) deposited during the Fraser Glaciation
- Glaciofluvial sand and gravel (confined aquifers) deposited between glacial lake events
- Glacial till

11.2 Recharge and Discharge

A conceptual drawing illustrating the primary sources of recharge (inflow - blue arrows) to and discharge (outflow - red arrows) from the valley bottom unconsolidated deposits is provided as Figure 7. Groundwater flow within the valley sediments/aquifer is primarily parallel to the valley axis and therefore out of the page. Individual types of recharge and discharge are discussed in the following sections.

11.2.1 Recharge

In general terms, the groundwater flow system in the valley bottom unconsolidated deposits is recharged by:

- Bedrock inflow: Precipitation infiltrating in the valley sides and uplands surrounding the study area recharges the valley bottom sediments through contact along the bedrock valley sides. All of this recharge is assessed to report to the main valleys as demonstrated by Jameison and Freeze (1982) and many later works for mountain regions. Recharge from bedrock is assumed to be one-way flow from the valley side bedrock into the adjoining valley fill sediments. Aquifers positioned at increasing depth will have been recharged at increasing elevations as indicated by increasingly depleted isotopes of oxygen and hydrogen with increasing well depths (Golder 2016a). Based on topographic and watershed divides, Golder estimated that the upland contribution areas are*:*

  - Nicola Catchment (excluding valley floor area) - *665 km^2*
  - Coldwater Catchment (excluding valley floor area) - *290 km^2*

  A chloride mass balance and precipitation mapping were used to predict annual precipitation recharge by elevation zones. Annual precipitation recharge is estimated at:

  - Valley bottom up to 1,000 masl – 10 mm/year
  - 1,000 to 1,200 masl – 30 mm/year
  - 1,200 to 1,400 masl – 60 mm/year
  - 1,400 to 1,800 masl – 190 mm/year

- Surface runoff (overland flow) from the valley side-slopes (outside of the tributary stream channels) onto the valley floor during freshet is predicted to be a negligible source of recharge to valley floor sediments.
- Upward groundwater flow from deep confined aquifers recharging the overlying Quaternary aquifers (Stumbles Creek Aquifer, West of Merritt Aquifer and Upper Merritt Aquifer). Areas of connection between aquifers and recharge rates are not well understood.
- Groundwater flow into the study area from upgradient valley sediments such as the unconsolidated sediments beneath Nicola Lake.
- Irrigation return; Golder has estimated that 5% or 34 mm/year of applied irrigation recharges the unconfined valley aquifers based on the granular lithology reported in well logs for wells completed in the unconfined aquifers. The irrigation return rate corresponds to roughly 805,000 m^3/year for the irrigated area within the study boundaries.

ENV created a guidance document (ENV 2016) for assessing the likelihood of an aquifer being connected to a "proximal" stream and utilized an aquifer's sub-ranking type as a method of screening the likelihood of connection:

- Types 1a,1b, 1c, 2, 3 and 4a are unconfined and likely connected to an overlying or bordering stream.
- Types 4b and 4c (confined aquifers) are not likely to be connected.
- Types 5a, 6a and 6 b (bedrock aquifers) generally are not likely to be connected.

Based on the guidance document seven of the twenty-five mapped aquifers in the Nicola Watershed are likely to be connected to the Nicola River or Coldwater River: Spences Bridge Aquifer (1b); Upper Merritt Aquifer (1c); West of Merritt Aquifer (1c); Guichon Creek, South of Kamloops Aquifer (3); Stumbles Creek Aquifer (3); Unicola Aquifer (3/1c) and Joeyaska Shallow Aquifer (4a/4b).

Sources of recharge to connected aquifers include losses from adjoining and overlying streams. Based on previous studies (Bennett and Caverly 2009, Golder 2016a) and current work it was assessed that:

- The Nicola River from the outlet of Nicola Lake to Merritt is essentially a net losing reach and recharging connected aquifers.
- The Nicola River from Merritt to Spius Creek is essentially a net gaining reach and being recharged by connected aquifers.
- The Nicola River from Spius Creek to Spences Bridge is essentially a net losing reach.
- The Coldwater River upstream of Merritt is essentially a net gaining reach.
- The Coldwater River through Merritt is essentially a net losing reach.

11.2.2 Discharge

Flow out of the valley bottom sediments contributes to:

- Recharge to the Coldwater River. The Coldwater River from Brookmere to Merritt is primarily a gaining reach with groundwater recharge to the river (baseflow) much greater than tributary inflow. Based on a previous study (Bennett 2009) the gaining portion of the Coldwater River is considered to lie upstream of the City of Merritt and the river loses flow to the Upper Merritt Aquifer as the river flows over the aquifer though Merritt.
- The Nicola River from Merritt to Spius Creek is essentially a gaining reach receiving recharge from connected aquifers created from Quaternary alluvial fan and alluvial deposits. The connected aquifers have been mapped along this reach of the Nicola River.
- Groundwater flow out of valley bottom unconsolidated sediments occurs at the downstream end of the study area and is a function of the cross-sectional area of the valley sediments, the hydraulic gradient which is assumed to be similar to the topographic gradient and the hydraulic conductivity of the valley sediments. Ultimately, this flow will discharge to the Thompson River.
- Evapotranspiration is an aquifer discharge but assumed to only occur where the groundwater is within 2 m of the ground surface (Bennett 2012). Potential valley floor evapotranspiration is 2 to 3 times annual precipitation. It is also assumed that negligible ET occurs from November to March when the ground is frozen. The theoretical annual evapotranspiration for forage crops is 575 mm/year with, 5% of the annual evapotranspiration occurring in May, 10% in June, 20% in July, 25% in August, 25% in September and 15% in October.
- Groundwater extraction; irrigation use is estimated to be the largest groundwater withdrawal in the study area followed by the City of Merritt, First Nations water systems, private domestic wells and small water system and finally the Nicola Waterworks District. Annual groundwater withdrawals in the study area are estimated at approximately 9,300,000 m^3/year with roughly 65% of the groundwater pumped used for irrigation. Aside from groundwater use by the City of Merritt, there is a substantial lack of information on groundwater extraction points and rates.

12.0 DATA GAPS & UNCERTAINTY

Based on the results of this study, the primary data gaps and uncertainties with respect to information required to support the development a numerical groundwater flow modelling strategy are as follows.

- **Unknown Sediment Type**: There are several locations within the study area where the type of valley bottom sediments are unknown. Without drilling records, the sediment type will need to be assumed. The absence of this information will result in uncertainty in the total volume/capacity of the valley bottom aquifer system.
- **Thickness (Depth) of the Valley Bottom Sediments**: The thickness of the valley bottom sediments within the study area is not known in most locations. The absence of this information will result in uncertainty in the total volume/capacity of the valley bottom aquifer system. An estimation method has been proposed (see Section 7.0); however, confirmation would require drilling records at selected locations.
- **Groundwater Heads:** There is currently only one observation well within the study area with known water level elevation data (see Section 10.0). Without sufficient groundwater level elevation data within the key aquifers of interest, model calibration will be limited. A limited calibration of the model impacts the relative accuracy of the model predictions.
- **River Heads**: Geodectic elevations of hydrometric stations is currently unavailable. Geodetic data will enable conversion of river stage measurements at the stations into accurate river level elevations. These data will be incorporated as specified-head boundary conditions in the numerical groundwater flow model. Large errors in the river heads will impact the relative accuracy of the model predictions.
- **Topography**: Current topographic dataset is based on a 20 m contour interval. Lidar mapping or finer resolution DEM would be beneficial, particularly since the topographic dataset will be used to estimate the surface water level elevations in the rivers between hydrometric stations. Large errors in the river heads will impact the relative accuracy of the model predictions.
- **River Beds**: Riverbed conductance (i.e., the water transfer restriction between the river and the underlying aquifer because of lower permeability river bottom sediments) requires estimates of the river bed K and thickness. These measurements are currently not available. Assumed values may be required to limit transfer rates to within reasonable values. The values may be adjusted during model calibration.
- **Groundwater Extraction Locations and Rates**: The locations of pumping wells associated with all groundwater licences and the associated pumping rates and completion depths is currently not available. The absence of this information will result in uncertainty in estimates of the current capacity of the aquifer system.

The primary implications of the data gaps and uncertainties outlined above are: the under or over-estimation of the capacity of the aquifer system and, ultimately, the lower accuracy of the model predictions. Although alternative approaches have been proposed to provide best guess estimates for data gaps, the preferred approach is to obtain direct measurements where possible.

13.0 CONCLUSIONS

This report outlined the compilation and analysis of existing data to the support the future development of a numerical groundwater flow modelling strategy. In addition, a strategy for the development of the numerical model was broadly described. Through this process of data compilation and assessment and the development of the modelling strategy, the conceptual hydrogeological model for the project area was updated. Within the framework of this study, key data gaps and uncertainties were identified and the associated implications were briefly discussed.

14.0 LIMITATIONS

This report was prepared for the exclusive use of the Fraser Basin Council and may be shared with FLNR and ENV. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Golder Associates Ltd. (Golder) accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

The report is based on data and information collected during investigations conducted by Golder and is based solely on the condition of the Site at the time of the investigations as described in this report, supplemented by historical data provided to Golder as described in this report. Golder has relied in good faith on information provided by third parties. We accept no responsibility for any deficiency, misstatements, or inaccuracies contained in this report as a result of omissions, misinterpretations, or fraudulent or negligent acts of others.

Golder makes no warranty, expressed or implied, and assumes no liability with respect to the use of the information contained in this report at the subject Site, or any other site, for other than its intended purpose. If new information is discovered during future work, including excavations, borings or other studies, Golder should be requested to re-evaluate the conclusions of this report and provide amendments as required prior to any reliance upon the information presented herein.

The services performed as described in this report were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

15.0 CLOSURE

We trust that this report and the associated data sheets and maps summarize the available data which can support future numerical modelling studies for the study area. Should you have any questions, please do not hesitate to contact the undersigned.

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APPENDIX A

Recharge Estimates - Literature Review for Semi-Arid Regions

RECHARGE RATE ESTIMATION METHODS

Literature Review

The following journal articles were reviewed for published recharge rates in other semi-arid regions that could be applied to the Study Area. A summary of the literature review, including the recharge rates derived from other studies and the calculated equivalent recharge rates for the Study Area, are presented below.

REFERENCE

Wood, W.W., and Sanford, W.E. (1995). Chemical and Isotopic Methods for Quantifying Ground-Water Recharge in Regional, Semiarid Environment. Groundwater 33 (3), 458- 468.

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Table A1: Summary of Recharge Rates from Literature Review

Author	Journal; year	Investigative Area	Recharge Rate	Method	Comments	Equivalent Recharge Rate applied to Nicola Study Area*
Wood and Sanford	Groundwater; 1995	semi-arid Southern High Plains of Texas and New Mexico	11 mm/yr	Chloride mass balance; consistent with other physical measurements	Equivalent to about 2% of MAP of 450 mm/yr for this investigative area.	2% of MAP ≈ 6 mm/year.
Subyani	Environmental Geology; 2004	typically arid Wadi Tharad, western Saudi Arabia	11% of MAP	Chloride mass balance		11% of MAP ≈ 35 mm/year.
Green et al.	Nature; 2012	semi-arid Edwards Plateau Texas	5 mm/yr	River recharge	Recharge rate derived for MAP of 450 mm/yr for this investigative area.	1% of MAP ≈ 3 mm/year.
Sibanda et al.	Hydrogeology Journal; 2009	Nyamandhlovu Aquifer of Zimbabwe	15 - 20 mm/yr	Various: chloride mass balance, water table fluctuation method, flownet computations, ^{14}C age dating and groundwater modelling. Groundwater modelling provided best estimate (15-20 mm/yr). Chloride mass balance estimated up to 3x higher recharge (19-62 mm/yr).	Equivalent to about 3-4% of MAP of 555 mm/yr for this investigative area.	3-4% of MAP ≈ 10-13 mm/year.
			Sibanda et al. (2009) provided recharge rates from other similar studies in this region:			
			20 - 25 mm/yr	- Mid Zambezi basin		
			15 mm/yr	- northeast Botswana		
			15 - 25 mm/yr	- Botswana		
			14 - 28 mm/yr	- Nyamandhlovu area		
Bazuhair and Wood	Journal of Hydrology; 1996	Western Saudi Arabia	3 - 4% of MAP	Chloride mass balance	>200 mm/yr of MAP.	3-4% of MAP ≈ 10-13 mm/year.
			Bazuhair and Wood (1996) provided the following recharge rates from other hydrogeologically similar areas:			
			3 - 7% of MAP	- Great Basin in western US (average annual precipitation of 280 mm/yr)		
			1% of MAP	- Lower Colorado River Basin of western US (average annual precipitation of 355 mm/yr)		
			4% of MAP	- Rio Grande Basin in western US (average annual precipitation of 300 mm/yr)		
USGS	Scientific Investigations Report 2011-5124	Columbia Plateau - Washington, Oregon and Idaho	27% of MAP	Recharge modelling	MAP of 427 mm/yr for this investigative area.	27% of MAP ≈ 87mm/yr.

* The equivalent recharge rate estimated for the Study Area was based on a mean annual precipitation rate at Merritt, BC of 321 mm/yr.

APPENDIX B

Hydrological Analyses of Ungauged Tributaries to the Nicola & Coldwater

NICOLA RIVER

The Nicola River crosses through a variety of different landscapes. The study reach spans over 75 kms from Nicola Lake through the valley bottoms eventually discharging into the Thompson River. Tributary streams to the Nicola River are located in mountainous terrain and forest/range land. Their watershed characteristics vary in attributes such as contributing watershed area, aspect, and elevation.

Golder performed a regional assessment focused on the Nicola River and its contributing tributaries between available gauges near Nicola Lake and Clapperton. To estimate mean monthly flows for the main tributaries to the Nicola River, a regional hydrology approach was used to analyze the various watersheds based on the above characteristics. This study focussed on 3rd order or larger tributary systems. Smaller tributary streams are not included in this assessment.

Coulson and Obedkoff (1998) delineated British Columbia into different Hydrologic Zones that exhibit similar hydrologic characteristics. Based on their work, this study reach of the Nicola River is located in the *Northern Thompson Plateau* and the *Eastern South Coast Mountains* Hydrologic Zones. The majority of runoff in the Nicola River basin (approximately 80%) results from spring snowmelt. The remaining runoff is primarily generated by spring and fall rainstorms (Obedkoff, 1987).

Golder mapped the Nicola River and associated tributaries, and overlaid the *Northern Thompson Plateau* and *Eastern South Coast Mountains* Hydrologic Zone boundaries. Water Survey of Canada (WSC) hydrometric stations (active and discontinued) within a 55 km radius of the Nicola River were assessed. A radius of 55 km was used as the area remained largely within the two hydrologic zone boundaries.

A total of 84 stations were initially identified. These were screened and hydrometric stations were removed if they were located outside of the two hydrologic zone boundaries, had less than 10 years of data available, or had too large/small watershed area. A regional analysis was then conducted based on the remaining WSC hydrometric stations. The purpose was to identify gauged watersheds that could be used as an analogue for the ungauged tributary systems. Table B-1 shows a summary of the delineated watersheds contributing to the Nicola River as well as the hydrometric stations associated with each watershed used in the analysis.

Table B-1: Catchment Names, Areas, and associated Hydrometric Stations used in the Regional Analysis

Watershed Name of Tributary to Nicola River	Watershed Area (km^2)	WSC Hydrometric Stations Used in Analysis		
		Station ID	Name	Operation Status
Shackelly Creek	24.2	08LG066	Chataway Creek Near the Mouth	Discontinued
Skeikut Creek	25.8	08LG066	Chataway Creek Near the Mouth	Discontinued
Gordon Creek	29.7	08LG066	Chataway Creek Near the Mouth	Discontinued
Stumbles Creek	52.1	08LG019	Stumbles Creek	Discontinued
Shakan Creek	55.0	08LG019	Stumbles Creek	Discontinued
Hamilton Creek	57.8	08LG019	Stumbles Creek	Discontinued
Nuaitch Creek	83.6	08LG056	Guichon Creek	Discontinued
Skuhun Creek	108.5	08LG009	Witches Brook Near Merritt	Discontinued
Clapperton Creek	166.6	08LG068	Spius Creek below Silver Creek	Discontinued
Spius Creek	292.2	08LG008	Spius Creek Near Canford	Active
Guichon Creek	320.8	08LG067	Guichon Creek at the Mouth	Active
Coldwater River	473.4	08LG010	Coldwater River at Merritt	Active

The purpose of the regional analysis was to determine mean monthly flows of streams that contribute to the Nicola River. Based on available hydrometric data, as well as contributing drainage area, a summary of the results of estimated mean monthly flow for each drainage area is provided in Table B-2. Estimations of base flow and mean monthly flow during freshet are provided in Table B-3.

Table B-2: Estimates of mean monthly flows for Catchments of Nicola River

Watershed Name	Watershed Area (km^2)	Estimated Mean Monthly Flow (m^3/s)										
		Jan	Feb	Mar	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Shackelly Creek	24.2	0.009	0.009	0.015	0.079	0.25	0.11	0.043	0.014	0.0055	0.0052	0.0061
Skeikut Creek	25.8	0.010	0.010	0.016	0.084	0.27	0.12	0.046	0.014	0.0059	0.0055	0.0065
Gordon Creek	29.7	0.011	0.012	0.019	0.096	0.31	0.14	0.053	0.017	0.0068	0.0063	0.0075
Stumbles Creek	52.1	0.045	0.042	0.044	0.047	0.11	0.044	0.033	0.028	0.040	0.038	0.041
Shakan Creek	55.0	0.048	0.044	0.046	0.050	0.11	0.046	0.035	0.030	0.042	0.040	0.043
Hamilton Creek	57.8	0.050	0.047	0.049	0.052	0.12	0.049	0.037	0.031	0.044	0.042	0.045
Nuaitch Creek	83.6	0.032	0.034	0.047	0.16	0.61	0.43	0.164	0.067	0.060	0.058	0.046
Skuhun Creek	108.5	0.0061	0.0081	0.014	0.11	0.57	0.25	0.057	0.022	0.013	0.013	0.0092
Clapperton Creek	166.6	1.8	1.1	2.1	4.9	12.6	10.7	2.0	0.28	0.27	1.1	1.8
Spius Creek	292.2	3.4	3.7	5.3	14.8	37.7	30.2	9.4	2.3	1.6	2.8	5.5
Guichon Creek	320.8	0.20	0.27	0.31	0.68	2.49	2.12	0.98	0.48	0.33	0.29	0.25
Coldwater River	473.4	2.9	3.2	4.4	10.3	27.8	25.1	8.3	1.6	1.2	2.5	4.1

Table B-3: Mean Monthly Flows in the Nicola River

	Average Monthly Flow Rate (m^3/s)												Average May June Flow Rate (m^3/s)	Average Base Flow Rate (m^3/s)*	Freshet Flow Rate minus Base Flow (m^3/s)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec			
Nicola River at Outlet Nicola Lk	1.5	1.7	2.2	3.9	15.9	16.9	6.9	3.8	2.3	1.9	1.8	1.6	16.4	1.6	14.8
Nicola River near Spences Bridge	9.2	10.5	13.4	30.1	90.7	85.7	28.3	9.0	6.3	8.3	12.7	10.0	88.2	9.9	78.4
Estimated tributary inflow + Coldwater River	8.6	8.6	12.6	32.0	84.5	70.7	21.4	5.0	3.7	7.0	12.1	9.8	77.7	9.3	68.4
Change in Freshet Flow between Outlet at Nicola Lk and Spences Bridge minus Tributary Inflow															-4.9
Change in Freshet Flow between Outlet at Nicola Lk and Spences Bridge minus Tributary Inflow (m^3/day)															-420,578

*For base flow estimates (low flow), December, January and February months were used

COLDWATER RIVER

The Coldwater River watershed is located between Brookmere (upstream) and Merritt (downstream). Coldwater River drains approximately 917 km^2 upstream of the bridge crossing at Main Street in Merritt with a total of approximately 600 km2 of that area located downstream of Brookmere. The watershed is primarily forested and is located on the Thompson-Okanagan Plateau region (Pike et al. 2010). It is characterized by mountainous terrain with elevations up to approximately 1,800 m.

Highway 5 parallels Coldwater River for approximately 30 km downstream of the highway crossing near Brookmere. There are resource roads and resource activities within the upper watershed and agriculture occurring on the floodplain.

Golder performed a hydrological analysis focussed on the Coldwater River and its contributing tributaries between Water Survey of Canada (WSC) hydrometric stations near Brookmere and in Merritt. There are six main ungauged tributaries to the Coldwater River in this region as well as other minor streams and floodplain areas. Numbers for unmade watersheds are numbers assigned by IMPA to unnamed third order streams. A regional analysis was used to identify analogue stations for each of the main tributaries to the Coldwater River (Table B-4).

Table B-4: Main Coldwater River tributaries between Brookmere and Merritt.

Main Tributaries to Coldwater River		WSC Hydrometric Stations		
Watershed name or ID	**Area (km^2)**	**Station Name**	**Station ID**	**Area (km^2)**
Watershed ID 19322	12.4	Bethsaida Creek above Highland Valley Road	08LG055	15.5
Voght Creek & Howard Creek	263.2	Witches Brook near Merritt	08LG009	139
Gillis Creek	12.3	Bethsaida Creek above Highland Valley Road	08LG055	15.5
Midday Creek & Watershed ID 19260	89.4	Stumbles Creek near Lower Nicola	08LG019	52.3
Kwinshatin Creek	28.3	Axe Creek at Lot 781	08LG051	26.2
Godey Creek	47.1	Stumbles Creek near Lower Nicola	08LG019	52.3
Remaining minor streams and floodplain	142.9	Witches Brook Near Merritt	08LG009	139
Total	**595.6**			

Analogue stations were used to estimate mean monthly flows for each of the main tributaries and were chosen based on watershed and station characteristics such as: drainage area, proximity to Coldwater River watershed, length of record, upstream hydraulic influences, elevation, and measurement consistency. Based on the available hydrometric data, a summary of the results of estimated mean monthly flow for each main tributaries is provided in Table B-5. Estimations of base flow and mean monthly flow during freshet are provided in Table B-6.

Table B-5: Estimated mean monthly flows for the main tributaries to Coldwater River between Brookmere and Merritt

Tributary	Mean Monthly Flows (m^3/s)											
	January	February	March	April	May	June	July	August	September	October	November	December
ID 19322	0.010	0.009	0.012	0.035	0.219	0.076	0.029	0.018	0.014	0.014	0.014	0.013
Voght & Howard Creek	0.013	0.017	0.030	0.235	1.195	0.520	0.121	0.046	0.028	0.028	0.019	0.014
Gillis Creek	0.010	0.009	0.012	0.035	0.217	0.076	0.029	0.018	0.014	0.014	0.014	0.012
Midday Creek & ID 19260	0.069	0.064	0.066	0.072	0.162	0.068	0.050	0.043	0.062	0.058	0.063	0.067
Kwinshatin Creek	0.006	0.006	0.009	0.036	0.190	0.056	0.022	0.008	0.004	0.005	0.005	0.006
Godey Creek	0.042	0.039	0.040	0.043	0.098	0.041	0.030	0.026	0.037	0.035	0.038	0.040
Minor Streams and Floodplain	0.008	0.011	0.019	0.146	0.744	0.324	0.076	0.028	0.018	0.017	0.012	0.009
Total	**0.16**	**0.16**	**0.19**	**0.60**	**2.83**	**1.16**	**0.36**	**0.19**	**0.18**	**0.17**	**0.16**	**0.16**

Table B-6: Freshet Flows in the Coldwater River

	Average Monthly Flow Rate (m3/s)												Average May June Flow Rate (m^3/s)	Average Base Flow Rate (m^3/s)*	Freshet Flow Rate Above Base Flow (m^3/s)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec			
Coldwater R near Brookmere	2.4	2.3	3.0	7.8	23.9	22.5	7.5	1.6	1.1	2.5	4.5	2.9	23.2	2.5	20.7
Coldwater R at Merritt	3.1	3.3	4.6	10.8	29.3	26.5	8.6	1.7	1.2	2.6	4.3	3.4	27.9	3.3	24.7
Estimated tributary inflow	0.2	0.2	0.2	0.6	2.8	1.2	0.4	0.2	0.2	0.2	0.2	0.2	2.0	0.2	1.8
Change in Freshet Flow between Brookmere to Merritt minus Tributary Inflow													2.2		
Change in Freshet Flow between Brookmere to Merritt minus Tributary Inflow (m^3/d)													186,965		

*For base flow estimates (low flow), December, January and February months were used

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