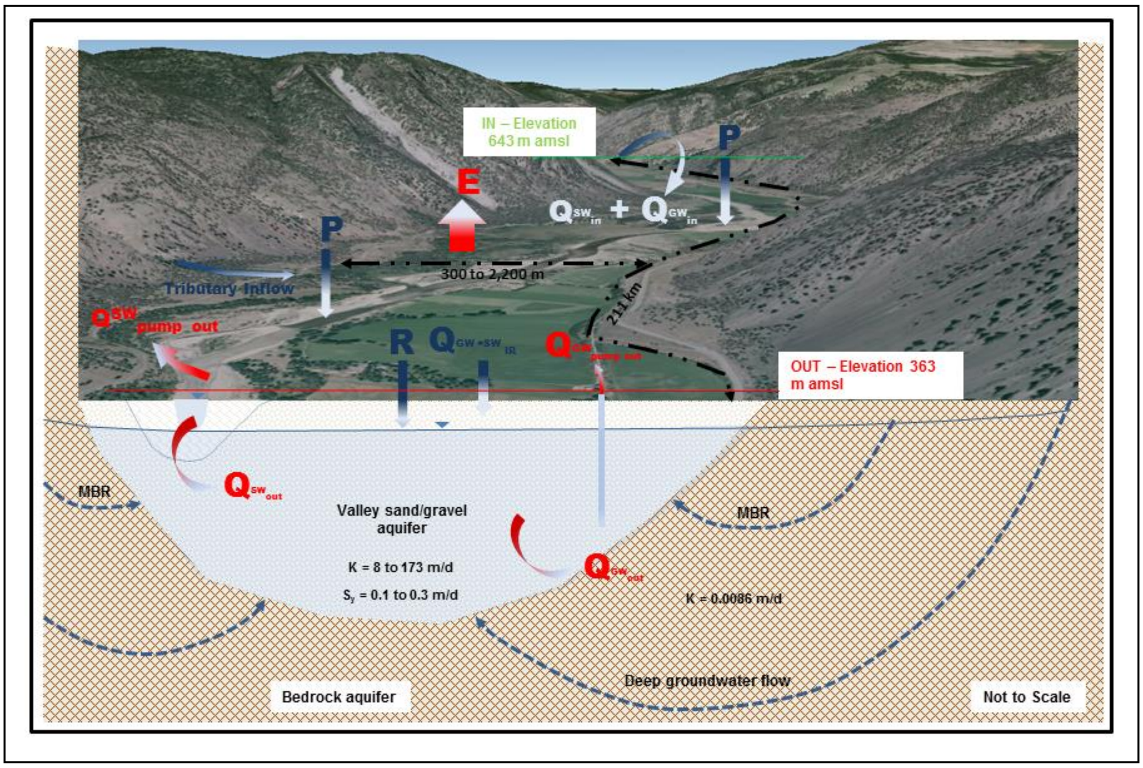
WATER SCIENCE SERIES

Monthly Water Budget for the Similkameen Valley Aquifer, British Columbia

Associated Environmental Consultants Inc.



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Executive Summary

Background

Water supply within the Similkameen River watershed is determined by rainfall and snowmelt and the storage capacity of reservoirs and aquifers. During dry years, water purveyors impose conservation measures to attempt to meet both human and environmental flow needs. However, with increased water demand in future, purveyors and private users will likely need to augment this demand through additional surface and groundwater withdrawals, reservoir storage, and management. Increasing water withdrawals and storage could impact environmental flows, aquifer levels, downstream water licences, and inflows into the Similkameen River.

Associated Environmental Consultants Inc. (Associated) have developed a water budget model for the Similkameen Valley Aquifer (Aquifer #259) to support groundwater allocation decisions and to promote water sustainability within the Similkameen River watershed.

Aquifer #259 is defined as a Type IB aquifer by MOE. As outlined by the B.C. guidebook for developing aquifer conceptual models authored by Hy-Geo Consulting (2014), Type IB water budgets are to include both the groundwater and surface water systems in the overall conceptual model. As such, the water budget model developed by Associated is an integrated groundwater and surface water model.

Following this, the conceptual water budget equation for Aquifer #259 is as follows:

$$P + Q^{SW}_{in} + Q^{SWtrib}_{in} + Q^{GW}_{in} + Q^{IRRreturn}_{in} + R = E + \Delta S + Q^{SW}_{out} + Q^{GW}_{pumpout} + Q^{SW}_{pumpout} + Q^{GW}_{out}$$

Terms are defined in the text of the report.

Overview of Water Budget Model

Based on the conceptual model for Aquifer #259, a Microsoft Excel spreadsheet model was developed that allows decision makers to assess the influence of future water demand and climate variability on groundwater levels within Aquifer #259, as well as the Similkameen River streamflows at the downstream extent of Aquifer #259.

The water budget model operates on a monthly time-step and requires the input of monthly data for estimated water demand, streamflows, groundwater geometry and levels, and climatic conditions. In the absence of reliable streamflow information for Aquifer #259, Associated developed estimates of Similkameen River streamflow at the upstream and downstream boundaries of Aquifer #259, as well as estimates of tributary inflows at the aquifer boundary. Water use estimates were obtained from the Agriculture Water Demand Model developed by the Ministry of Agriculture. Estimates of domestic water demand from groundwater were developed from pumping records and surface water extraction licences. Associated also obtained and made use of spatially modelled estimates of precipitation and evapotranspiration across Aquifer #259.

Climate variability is an important factor which affects water availability within the Similkameen River watershed. Accordingly, Associated has integrated the ability to assess the water budget for Aquifer #259 under three different climate scenarios (i.e. average, dry, and wet).

Groundwater level data from Observation Well 75 (Keremeos), situated inside the Aquifer #259 boundary, was used to calibrate the water budget model under all three climate scenarios. During the calibration process, a number of model components were adjusted to provide the best estimates of each parameter within the calibrated water budget model.

A summary of model sensitivities and calibration adjustments is provided within the report. A key limitation of model calibration is the scarcity of groundwater observation wells in Aquifer #259.

Water Budget Results

The water budget model generates estimates of monthly surplus/deficit within the system, along with estimated changes in groundwater level. Understanding that there is uncertainty associated with the input data, it was qualitatively determined that the error associated with the water budget results is approximately 10-25%.

Understanding that the Similkameen River has high value fish and aquatic habitat, environmental flow needs (EFNs) are an important consideration for future water allocation. EFNs have not been defined for the Similkameen River at this time; therefore, the water budget model provides a comparison of future estimated Similkameen River streamflow conditions and to previously defined critical flow thresholds determined for the Similkameen River by Associated (2016).

To account for uncertainty within the water budget, a safety factor was established and applied to estimated Similkameen River outflows and changes in groundwater level throughout the year. Safety factors are included predominantly to provide a visual comparison of estimated streamflows and critical flow thresholds within the Similkameen River.

The calibrated water budget model indicates that there are annual and monthly surpluses/deficits within Aquifer #259 and the Similkameen River depending on climate conditions. In addition, a function was added to the water budget model to calculate the potential available groundwater volume for water allocation after defining a groundwater level allocation threshold.

Recommendations

A number of recommendations were made to further refine the input data to, and the calibration of, the water budget model. The key recommendations are as follows:

- Attempt to establish additional hydrometric stations within the limits of Aquifer #259 on the Similkameen River at the U.S. border, as well as on tributaries contributing to Aquifer #259.
- Obtain water demand information for the Similkameen River south of the U.S. border to reduce uncertainty in Similkameen River outflows within the water budget model.
- Complete an EFN assessment for the Similkameen River to better constrain the critical flow threshold values used within the model.
- Refine spatial mapping of Aquifer #259 to allow consideration of hydrogeological sub-units during future water allocation.
- Increase the observation well network density within Aquifer #259 to allow improved model calibration by capturing changes in groundwater level across the aquifer.
- Complete a detailed surface water-groundwater interaction assessment within Aquifer #259 to improve estimates of mountain block recharge and the effects of groundwater pumping on groundwater levels and streamflows.
- Complete a field study to investigate aquifer recharge in Aquifer #259 to further refine estimates of aquifer recharge currently used within the water budget model.

Contents

1. INTRODUCTION

1.1 Project Overview

Within the Similkameen River watershed, water supply is determined by rainfall and snowmelt and the storage capacity of reservoirs and aquifers. During dry years, water purveyors impose conservation measures to ensure both human and environmental flow needs are met. However, with increased water demand, water purveyors and private users will likely need to augment this increased demand through additional surface and groundwater withdrawals, reservoir storage, and management. Increasing water withdrawals and storage could impact environmental flow needs, aquifer levels, downstream water licences, and inflows into the Similkameen River.

There are 16 known water suppliers and 831 active surface water licences issued by the B.C. Ministry of Forest, Lands, and Natural Resource Operations (MFLNRO) to store or use surface water within the watershed. This translates to approximately 116,000 megalitres (ML) of surface water licensed for off-stream use and approximately 38,000 ML licensed for in-stream (conservation) and other non-consumptive uses (Summit 2015) (Summit Environmental Consultants Inc. rebranded to Associated Environmental Consultants Inc. [Associated] in November 2015). In addition, groundwater has quickly become the primary or secondary source of water for many of the water suppliers and private individuals. A total of 1,873 wells are on record within the watershed with the majority of them heavily concentrated near the Similkameen River (Summit 2015).

Following this, with the implementation of the new *Water Sustainability Act* (WSA), existing and new non-domestic groundwater users will require a water licence. Therefore, to support groundwater allocation decisions and to ensure future water sustainability within the Similkameen River watershed, the B.C. Ministry of Environment (ENV) issued a Request for Proposal (RFP) for the development of a preliminary groundwater budget model for the Similkameen Valley Aquifer #259. This aquifer is situated between the Town of Princeton and the United States (U.S.) border and is an integrated part of the Similkameen River. There is a high reliance on groundwater supply from the aquifer for irrigation and domestic water use purposes; as well, the Similkameen River across the aquifer supports high value aquatic life.

The RFP challenged firms to design a water budget model that would provide government hydrogeologists a preliminary understanding of the surface and groundwater budgets of Aquifer #259 to support water allocation decisions under various climate conditions. Associated was awarded the contract to develop the groundwater budget model. This report details the model development and results of the preliminary groundwater budget for Aquifer #259.

Aquifer #259 is defined as a Type 1b aquifer by ENV. As outlined by the B.C. guidebook for developing aquifer conceptual models authored by Hy-Geo Consulting (2014), Type IB water budgets are to include both the groundwater and surface water systems in the overall conceptual model. As such, the water budget model developed by Associated herein is an integrated groundwater and surface water model and not solely a groundwater budget model.

1.2 Project Objectives

The objectives for the development of the water budget model for Aquifer #259 were as follows:

1. Develop a conceptual water budget for Aquifer #259 that details the water budget inputs and outputs relevant to the aquifer for both surface and groundwater.
2. Using the conceptual water budget, develop a water budget model on a monthly time-step under three climate scenarios (dry, wet, and average) that allows a user to assess potential

impacts of applications for new groundwater use on aquifer storage and environmental flow needs and considers a factor of safety to support water allocation.

3. Complete a qualitative assessment of data limitations and uncertainties of the water budget parameters used within the model. The assessment is also to address uncertainties within the model results.
4. Provide an estimate of available groundwater for future water allocation decisions based on consideration of existing groundwater use, maintaining current groundwater levels, and a recommended safety factor.
5. Identify data gaps and recommend monitoring activities to improve the characterization of Aquifer #259 and its groundwater fluxes and availability.

2. BACKGROUND

The following provides a brief overview of Aquifer #259 and the Similkameen River watershed. Portions of this section were drawn from reports recently prepared for Regional District of Okanagan-Similkameen for the development of the Similkameen Watershed Plan by Associated (i.e. Summit [2014; 2015]).

2.1 Aquifer #259

Aquifer #259 (also known as the Similkameen River Aquifer or Similkameen Valley Aquifer) is situated between the Town of Princeton and the U.S. border along the main reach of the Similkameen River (Figure 1). The aquifer is categorized by ENV as a Type IB unconfined fluvial/glaciofluvial sand & gravel aquifer along a moderate order river. The aquifer length is approximately 94 km with a spatial extent of 121 km^2. The aquifer is bounded on the edges by fractured bedrock aquifers with steep gradients.

Aquifer #259 is a linear feature along the Similkameen River with widths that vary between 300 and 4,000 m. Aquifer depth varies between 20 and 100 m and the depth to groundwater level also varies, but is expected to be between 1 and 30 m below ground surface (mbgs) (Province of B.C. 2016). In addition, the average aquifer gradient is approximately 0.0039 (measured between the two MOE observation wells [Princeton 220 and Keremeos 75]) (Figure 1).

The average reported well yields in the aquifer range from 1.3 to 34.0 L/s from a total of 919 groundwater wells recorded in Aquifer #259 (Province of B.C. 2016).

2.2 Topography and Soils

The Similkameen River watershed (and Aquifer #259) is included in the Thompson Plateau physiographic area (Holland 1976). The Thompson Plateau is a gently undulating upland of low relief, with some hills of more resistant bedrock. The Similkameen River headwaters are located in the Hozameen Range of the Cascade Mountains, in Manning Provincial Park, southwest of the Town of Princeton. In addition, the Okanagan Range of the Cascade Mountains is located along the U.S. border. The landscape consists of wide, flat-floored valley, rugged mountain ranges, and plateau areas with dry land vegetation and forest.

The watershed was glaciated with later ice stagnation and melting about 10,000 years before present, leaving glacially-shaped bedrock features, glacial till, and meltwater channels and deposits (Holland 1976). The modern agricultural and forest soils have been formed in these glacial till deposits overlying bedrock, in colluvial deposits below steep slopes, in glaciofluvial sands and gravels deposited by the meltwater streams (i.e. Aquifer #259), and in modern fluvial deposits beside rivers (Wittneben 1986). Most soils developed under a grassland-forest vegetation type and dry climatic conditions.

Figure 1 Aquifer #259 and selected Similkameen River watershed characteristics.

2.3 Geology

The following provides a summary of the surficial and bedrock geology applicable to Aquifer #259.

2.3.1 Surficial Geology

The surficial geology of Aquifer #259 is Quaternary-aged (i.e., 2.6 Million years ago to present) material comprising primarily of sand and gravel (Province of B.C. 2016). Borehole logs available through the Province of B.C. (2016) indicate that the surficial geology ranges from 150 m to 4 km in width and 20 to over 100 m in thickness. The depositional environment for these sediments is considered primarily recent alluvium, as well as older glacial drift deposits (Bostock 1930).

2.3.2 Bedrock Geology

The bedrock geology that borders Aquifer #259 varies in age from 35.4 to 510 Million years ago and includes sedimentary, igneous, and metamorphic rocks associated with the Quesnel, Post Accretionary, and Overlap Terranes (Schiarizza and Church 1996; Hoy et al. 1994). Numerous faults are associated with the accretionary formation of the bedrock within the Similkameen River watershed and the trend is generally north to south. Notable faults include the following:

- Boundary fault located near the Town of Princeton, which separates Eocene-aged sedimentary rocks of the Princeton Group (Overlap Terrane) from the Upper Triassic-aged basaltic volcanic rocks of the Nicola Group (Quesnel Terrane);
- Thrust fault west of the Village of Keremeos, separating sedimentary rocks of the Shoemaker Formation (Quesnel Terrane) from the metamorphic rocks of the Apex Mountain Volcanics (Quesnel Terrane); and
- Normal fault running from the community of Cawston to Chopaka, which represents a contact between a variety of sedimentary, extrusive and intrusive volcanics, and metamorphic rocks.

2.4 Climate and Vegetation

The Similkameen River watershed is located in the rain shadow from the Coast and Cascade Mountains, and the western section is cooler and moister while the southeastern section is warmer and drier. The climate across the entire watershed varies, but it is generally characterized by warm summers and cooler winters with a relatively even distribution of precipitation throughout the year. Based on Environment Canada climate station 1971-2000 averages (i.e., climate “normals”), mean air temperatures at Keremeos 2 (Station No. 1124112; Elevation = 435 m) range from -2.5°C in January to 20.9°C in July, while at Princeton A (Station No. 1126510; Elevation = 702 m) temperatures range from -6.2°C in January to 17.7°C in July (Environment Canada 2016). Air temperatures within the watershed are on average below freezing from December to February and have been recorded as low as -43°C. Approximately 20-40% of the total annual precipitation of 340 mm falls as snow.

The Similkameen River watershed is included in the Southern Interior Ecoprovince, with these biogeoclimatic zones present: Bunchgrass (BG), Ponderosa Pine (PP), Interior Douglas-fir (IDF) on the valley floors; Montane Spruce (MS) and Engelmann Spruce-Subalpine Fir (ESSF) at the higher elevations; and Alpine Tundra (AT) at the mountain peaks (Ministry of Forests and Range 2008). For Aquifer #259, the biogeoclimatic zones within the aquifer limits include BG, IDF, and PP.

2.5 Hydrologic Regime

The Similkameen River is about 196 km long, with headwaters in Manning Park. The watershed is located mainly in the Southern Thompson Plateau hydrologic zone, with the western headwaters in the Eastern South Coast Mountains hydrologic zone (Obedkoff 1998). Normal annual runoff is in the order of 200 to 1,000 mm per year in the wetter western parts of the watershed, with runoff of roughly 100 to 200 mm (or less) in the drier eastern section.

For Aquifer #259, the Similkameen River meanders across the entire length of the aquifer (Figure 1). In addition, numerous tributaries contribute streamflows to the Similkameen along the length of Aquifer #259. These tributaries include the Tulameen and Ashnola Rivers, and Allison, Hayes, Hedley, Keremeos, Wolfe, Soukup, and Smith Creeks, as well as many small ephemeral creeks (Figure 1).

The Similkameen River and tributaries are supplied mainly by rainfall and snowmelt. Annual peak flows commonly occur from May to July during snowmelt, with discharge at Similkameen River at Hedley, B.C., (Water Survey of Canada [WSC] hydrometric station 08NL038) (Figure 1) ranging from typically less than 15 m^3/s during winter to more than 275 m^3/s during the spring snowmelt period. The Similkameen River has an average baseflow (i.e., flow from groundwater discharge) that ranges from 2.0 m^3/s near the east boundary of Manning Park, to 6.0 m^3/s above the Tulameen River confluence, to 10.5 m^3/s near Hedley, and 11.0 m^3/s at Cawston, just north of the border. From July through April, after the high snowmelt-generated flows have subsided, water flow is generally low on average—this period includes the peak irrigation months, and the peak fish spawning periods (Glorioso et al*.* 2010).

3. CONCEPTUAL WATER BUDGET FOR AQUIFER #259 AND THE SIMILKAMEEN RIVER

3.1 Hydrogeologic Cross Sections

To understand the lithology of Aquifer #259, inferred hydrogeologic cross sections were developed for three locations along the length of Aquifer #259 using well lithological logs available through the Province of B.C. (2016). The location of each cross section is provided in Figure 1 and a summary of each cross section is as follows:

- Cross section A-A' – a schematic representation of the lithology at the boundary of Aquifer #1024 IIB (i.e., bedrock aquifer) and Aquifer #259 that represents down-valley groundwater flow through Aquifer #259 (Figure 2).
- Cross section B-B' – a schematic representation of the lithology of an area where Aquifer #259 is narrow (Figure 3).
- Cross section C-C' – a schematic representation of the lithology of Aquifer #259 at the U.S. border that represents the down-valley groundwater outflow through Aquifer #259 (Figure 4).

The lithology of each cross section indicates the presence of mainly unconsolidated sand and gravel material between the river valley and the bedrock below and along each side of the mapped aquifer. No confined aquifers were identified within the unconsolidated material, and bedrock is considered the only major confined to semi-confined system that is directly linked to the valley (i.e., Aquifer #259). The lithological findings from cross sections A-A', B-B', and C-C', are consistent with cross sections developed by Golder (2005; 2008) for selected locations around Princeton and Keremeos, and by Summit (2015) for a location around Keremeos/Cawston. Summit (2015) furthermore indicated the river and the valley aquifer are hydraulically interconnected by explanation of groundwater levels mimicking and slightly lagging Similkameen River hydrographs in the Keremeos area.

Using cross sections A-A', B-B', and C-C' and information available from the Province of B.C. (2016), the estimated average width of Aquifer #259 is approximately 1,100 m and the average depth is 30 m. This is consistent with Golder (2005) who reported an average width of 1,300 m and an average depth of 35 m for the aquifer.

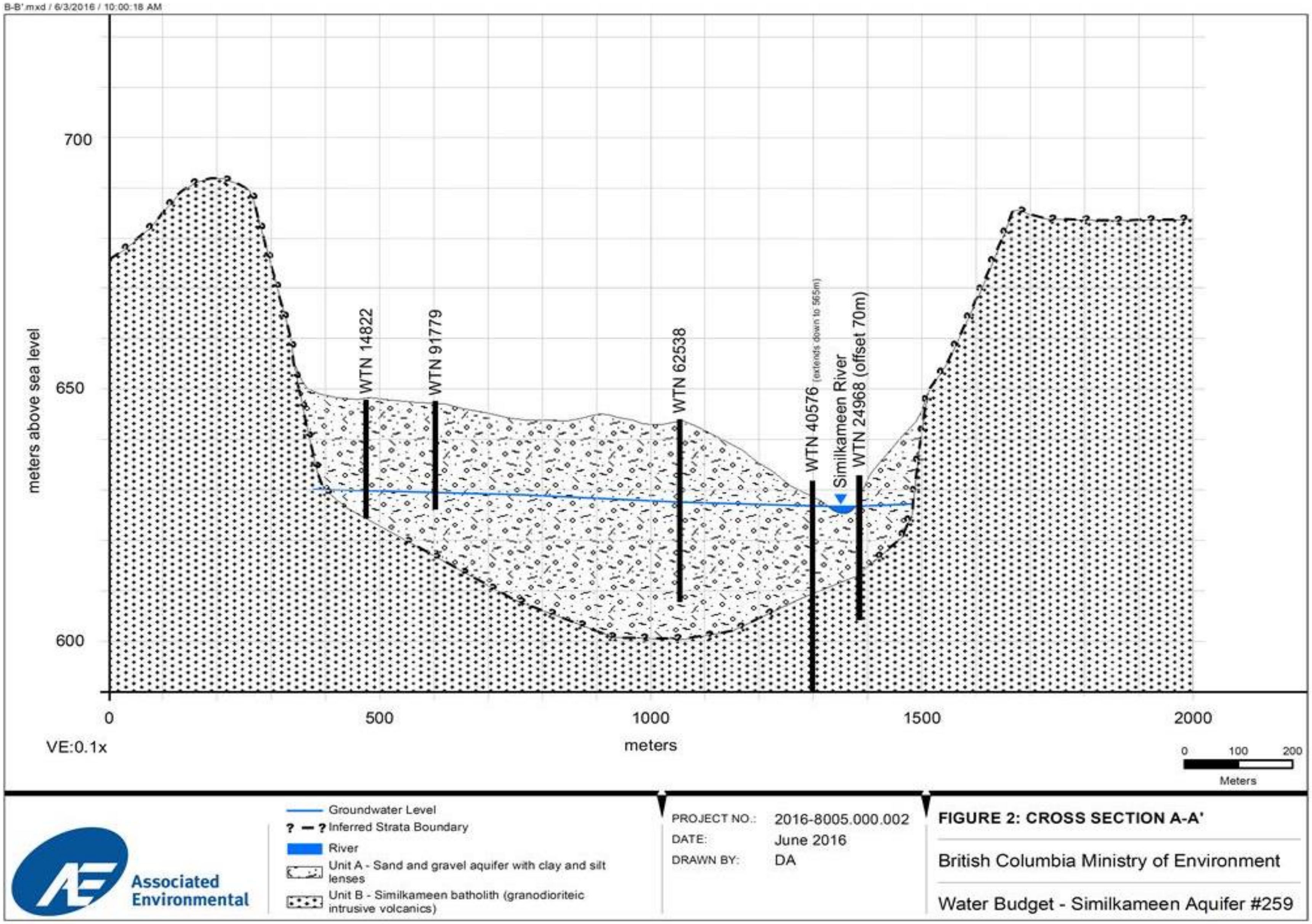


Figure 2 Cross section A-A'

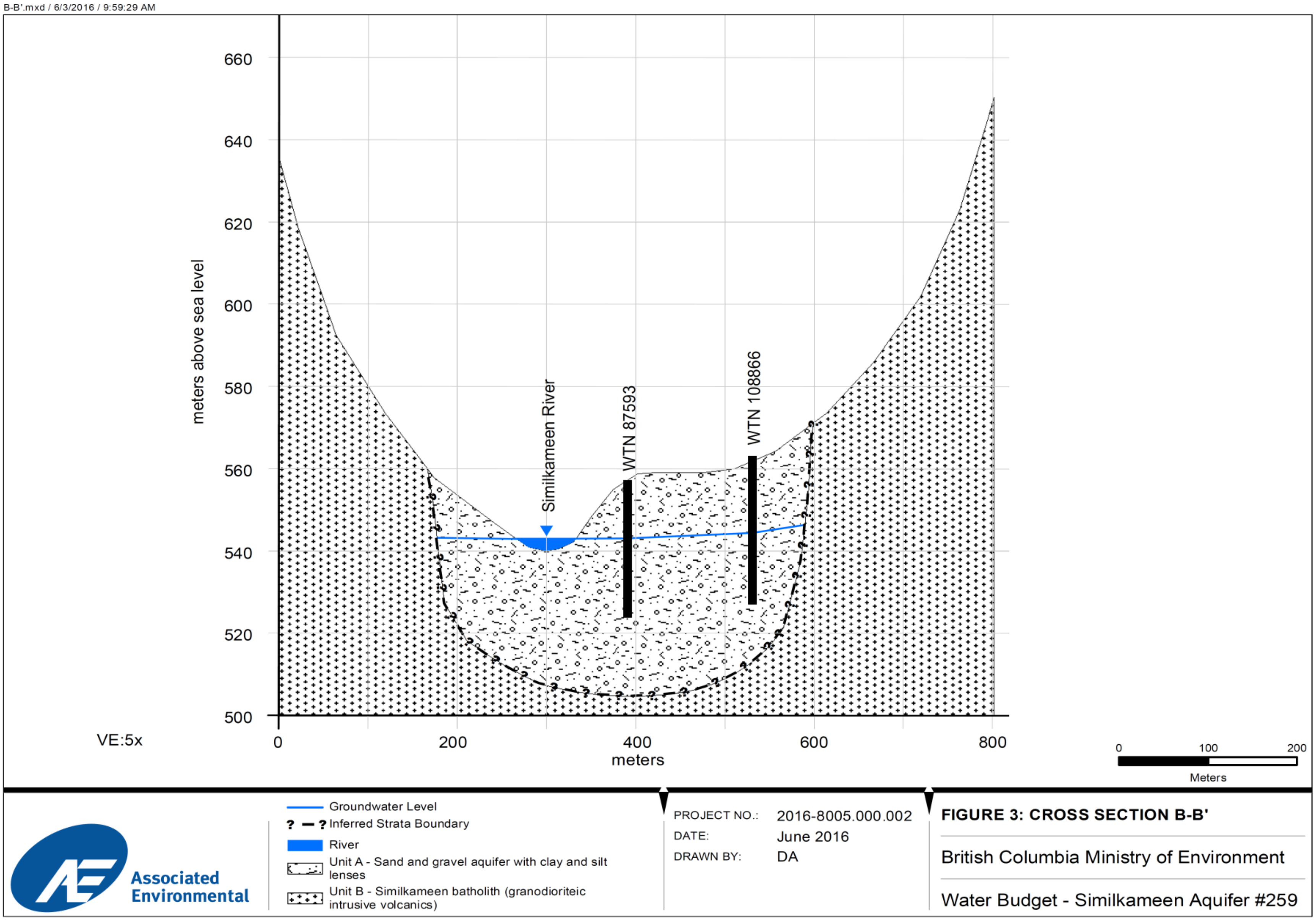


Figure 3 Cross section B-B'

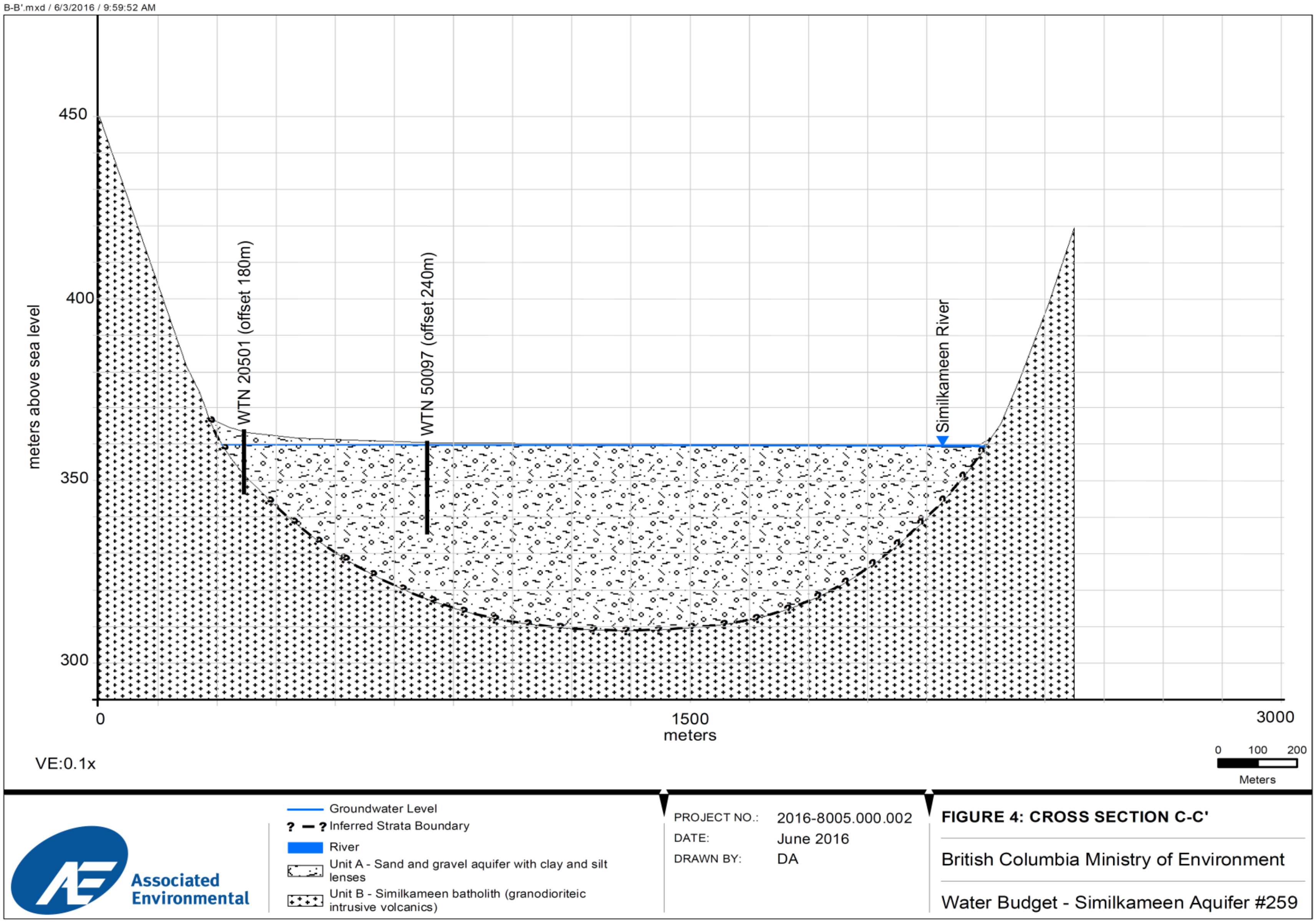


Figure 4 Cross section C-C'

3.2 Conceptual Model

As noted earlier, Aquifer #259 mainly comprises unconsolidated material underlain by bedrock that rises steeply on both sides of the river valley. No studies were identified that specifically investigated the Similkameen River bed geology and the direct communication between the river and the underlying aquifer. However, based on cross sections A-A', B-B', and C-C', the cross sections developed by Golder (2005; 2008) and Summit (2015), and through a review of selected well logs in close proximity to the Similkameen River, there are no impeding conditions to flow between the river bed and the underlying aquifer. As such, groundwater will interact with surface water regularly with gaining and losing conditions changing seasonally.

In addition, hydraulic conductivities of clean sands and gravel in Aquifer #259 are estimated to range between 0.8 and 173 m/day (Golder 2005, 2008; Summit 2015). This also indicates a conductive aquifer that responds quickly to a change in surface water flow conditions with minimum lag times between the groundwater and surface water (i.e., order of days instead of months). This suggests that Aquifer #259 and the Similkameen River are directly linked (Summit 2015) which is consistent with a Type IB aquifer classification. Accordingly, the conceptual model and associated equation (see below) are referred to herein as a 'water budget' in place of groundwater and surface water budgets separately.

The recommended water budget for Type IB aquifers presented in the B.C. guidebook for developing aquifer conceptual models authored by Hy-Geo Consulting (2014) was reviewed. The recommended equation for Type IB aquifers was redefined for this study to better conceptualize Aquifer #259 and to meet the objectives of this assignment, as follows:

$$P + Q^{SW}_{in} + Q^{SWtrib}_{in} + Q^{GW}_{in} + Q^{IRRreturn}_{in} + R = E + \Delta S + Q^{SW}_{out} + Q^{GW}_{pumpout} + Q^{SW}_{pumpout} + Q^{GW}_{out} \quad \text{(Eq. 1)}$$

where:

P = precipitation falling directly on the Similkameen River within the boundary of Aquifer #259

Q^{SW}_{in} = streamflow of the Similkameen River at the upstream end of Aquifer #259

Q^{SWtrib}_{in} = streamflow to the Similkameen River from tributaries within the limits of Aquifer #259

Q^{GW}_{in} = groundwater inflow to the aquifer at the upstream end of Aquifer #259 plus Mountain Block Recharge (MBR) to Aquifer #259 along its entire spatial extent

$Q^{IRReturn}_{in}$ = Irrigation return to Aquifer #259 from total seasonal water use

R = recharge to Aquifer #259 by precipitation directly on the aquifer surface (considering losses to evapotranspiration, unsaturated zone soil storage, and surface runoff)

E = evaporation from the Similkameen River

ΔS = change in the overall volumetric storage of the surface water and groundwater systems

Q^{SW}_{out} = streamflow at the downstream end of Aquifer #259

$Q^{GW}_{pumpout}$ = groundwater extracted from Aquifer #259 for annual (i.e., domestic – January to December) and seasonal (i.e., irrigation – April to September) demand

$Q^{SW}_{pumpout}$ = surface water extracted from the Similkameen River across Aquifer #259 for annual and seasonal demand

Q^{GW}_{out} = groundwater outflow at the downstream end of Aquifer #259

Equation 1 (and Aquifer #259) can be visualized through Figure 5. The conceptual model outlined in Equation 1 is used henceforth as the fundamental building block in the development of the water budget model (Section 4.0).

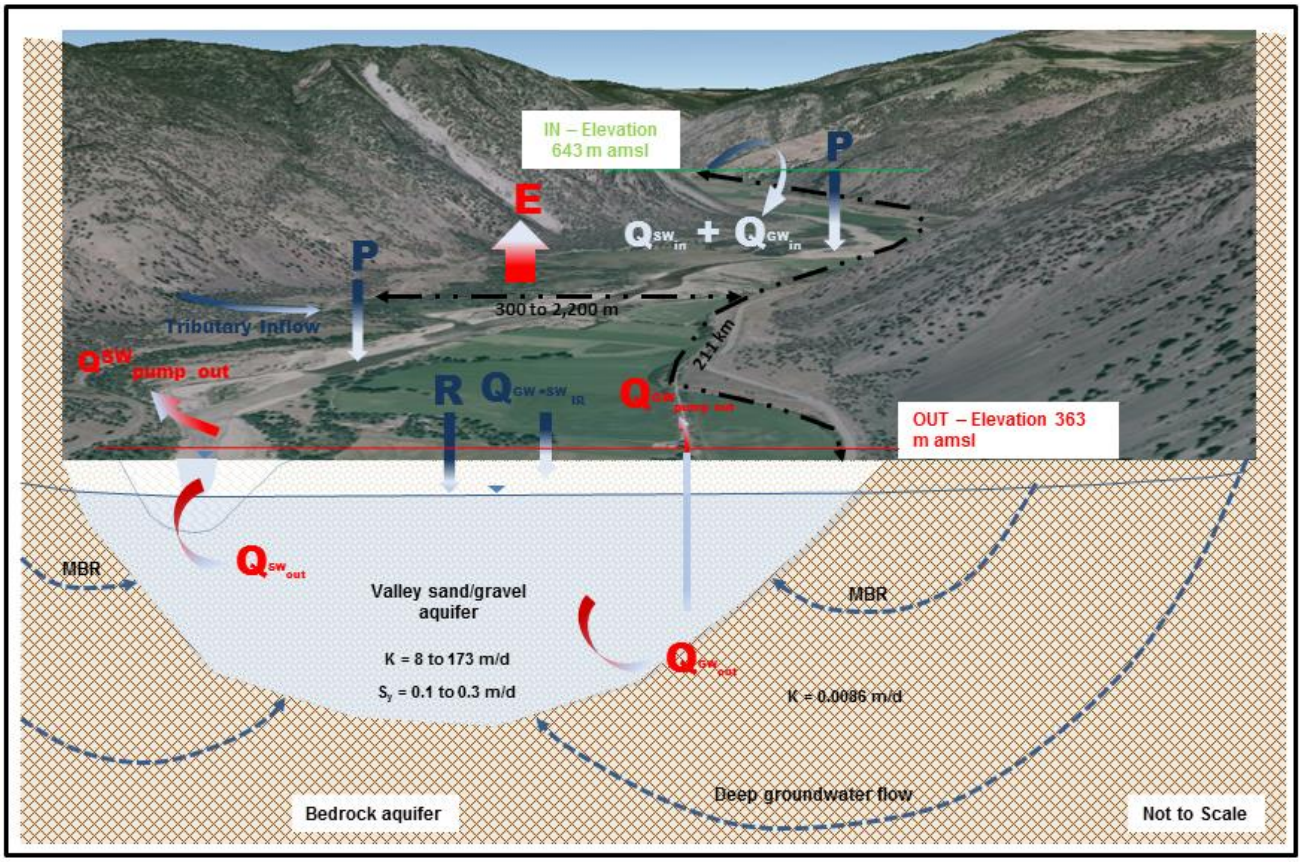


Figure 5 Conceptual water budget for Aquifer #259.

4. WATER BUDGET MODEL DEVELOPMENT

The development of the water budget model is outlined in this section. For model development in subsequent sections, the upstream extent of Aquifer #259 is considered to be just northeast of Princeton between the boundaries of Aquifer #259 and #1024, and the downstream extent is the U.S. border. The actual model is provided as Attachment 1 and a User Manual is included in Appendix A.

4.1 Overview of the Water Budget Model

A customized user-friendly Microsoft Excel spreadsheet model, representing Equation 1, was developed to allow assessment of the influence that future water use and/or climate variability will have on the Similkameen River, groundwater levels, and aquatic resources. The format of the model was initially developed following the format used by Bennett (2012), but was subsequently modified to meet the modelling requirements for Aquifer #259.

The water budget model was developed on a monthly time-step and considers three kinds of climate conditions (dry, wet, and average) within the Similkameen River watershed. The model also includes the following:

- Aquifer #259 characteristics (e.g., aquifer dimensions, hydraulic conductivity, storativity).

- Monthly time-step water budget parameters under various climate conditions.
- Consideration of connectivity between the Similkameen River and Aquifer #259, and adjacent aquifers, by the integration of surface water and groundwater parameters within the overall water budget.
- Flexibility to vary input parameters to assess the influence that a specific parameter has on the output values (i.e., the ability to conduct a sensitivity analysis).
- Calibration of model inputs and outputs using available streamflow and observation well information.
- Uncertainty associated with the input parameters and a recommended safety factor to consider when reviewing/assessing the output.
- Assessment of potential impacts to the Similkameen River and Aquifer #259 by current water licensing, future water licences (surface or groundwater), and consideration of Environmental Flow Needs.
- Flexibility to add different input parameters.

Subsequent sections provide detail on the model and its development.

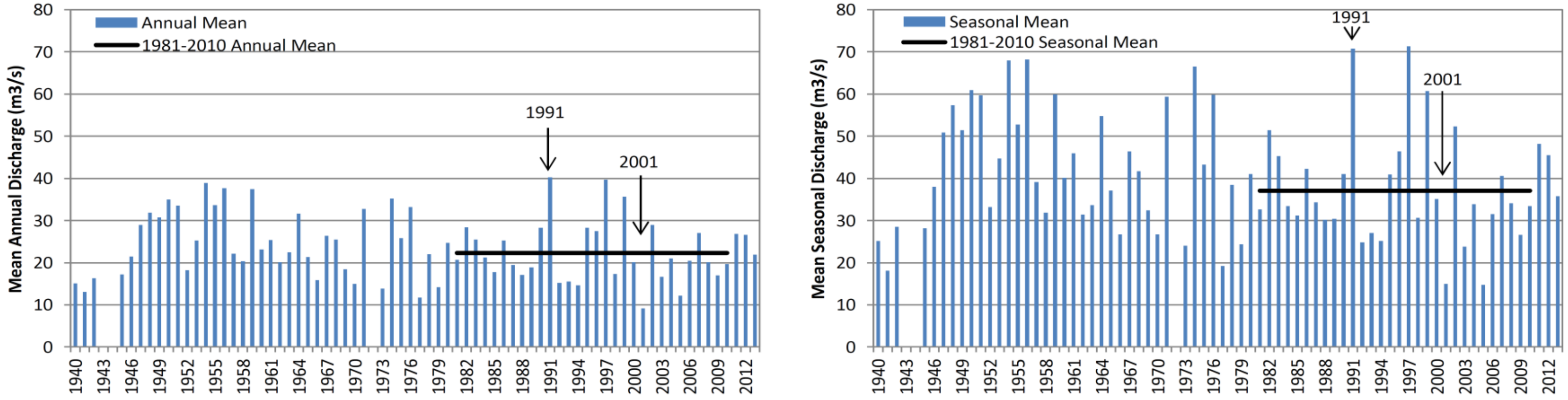
4.2 Model Climate Scenarios

To evaluate water budget variability within the Similkameen River watershed and Aquifer #259, three separate climate scenarios were identified. The climate scenarios represent dry, wet, and average conditions included within the most recent climate normal period (1981-2010) based on available climate, streamflow, and groundwater information.

Summaries of the selected climate scenarios within the water budget model are as follows:

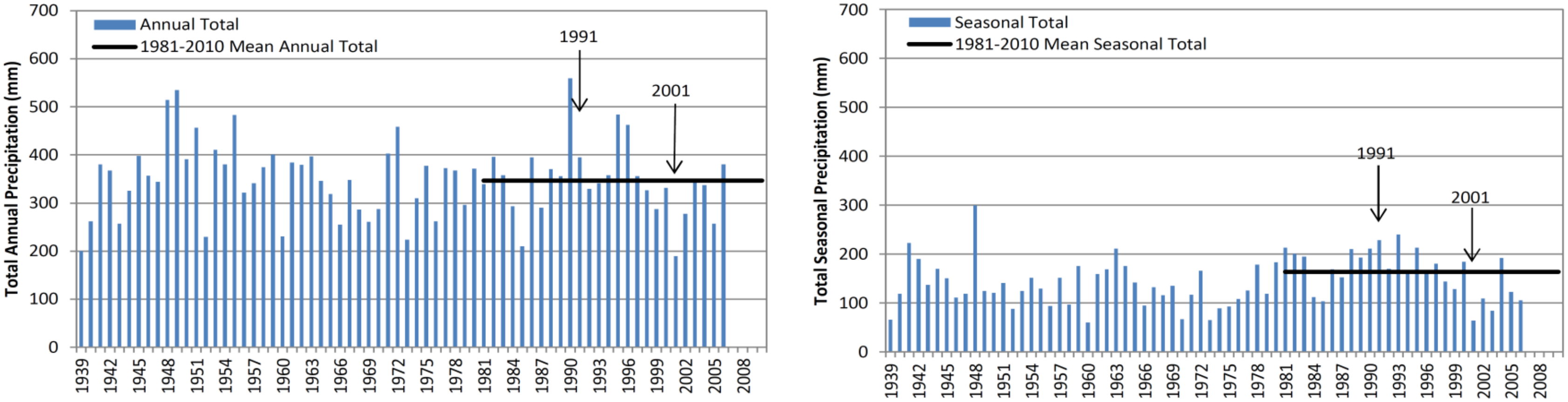
- **Dry Year** – represented by the climate, streamflow, and groundwater conditions observed within the watershed in 2001. During 2001, mean annual and mean seasonal (April to September) discharge within the Similkameen River (at WSC Stations 08NL007, 08NL038, and 08NL022 [Figure 1]) was the lowest on record or very close to the lowest (Figure 6a/b). In addition, total annual and total seasonal (April to September) precipitation measured at Princeton A (Station No. 1126510; Figure 1) was also the lowest on record or very close to the lowest (Figure 6c/d). Similarly, groundwater levels within the observation well at Cawston (Well 203) had summer levels close to the lowest on record.
- **Wet Year** – represented by the climate, streamflow, and groundwater conditions observed within the watershed in 1991. During 1991, mean annual and mean seasonal (April to September) discharge within the Similkameen River (at WSC Stations 08NL007, 08NL038, and 08NL022) was the highest on record or very close to the highest (Figure 6a/b). In addition, the total seasonal (April to September) precipitation measured at Princeton A (Station No. 1126510) was close to the highest on record (Figure 6c/d). Similarly, groundwater levels within the observation well at Cawston (Well 203) had spring levels close to the highest on record.
- **Average or Normal Year** – represented by the average climate, streamflow, and groundwater conditions from 1981 to 2010. This time period is drier than other climate normal periods within the Similkameen River watershed (Summit 2015); however, land use and surface and groundwater withdrawals during this period likely reflect current conditions and therefore are considered most appropriate for water allocation purposes.

In addition to these three scenarios, the water budget model allows users to input other climate information to create their own scenario.



A) *Mean annual discharge at Similkameen River near Princeton (WSC 08NL007), 1940-2013.*

B) *Mean seasonal discharge (April to September) at Similkameen River near Princeton (WSC 08NL007), 1940-2013.*



C) *Total annual precipitation at Princeton A (Climate ID: 1126510), 1939-2010.*

D) *Total seasonal precipitation (April to September) at Princeton A (Climate ID: 1126510), 1939-2010.*

Associated Environmental	DATE: **JUNE 2016**	*Figure 6 – Annual and seasonal trends in Similkameen River discharge and precipitation*
	DRAWN BY: **LB**	Prepared for: **B.C. Ministry of Environment (MOE)**

Figure 6 Long-term streamflow and precipitation monitoring at selected stations within the Similkameen River watershed.

4.3 Model Development

The water budget model required information for each of the components of the conceptual water budget outlined in Equation 1 (Section 3.2), as well as for each climate scenario. The following sections summarize the information used for each component.

4.3.1 Aquifer Schematization

For the water budget model, the upstream extent of Aquifer #259 was considered to be just northeast of Princeton between the boundaries of Aquifers #259 and #1024 (i.e., at cross section A-A') as this was deemed the most representative location of groundwater inflows to Aquifer #259 (Figure 1). The downstream extent is the U.S. border (i.e., at cross section C-C') (Figure 1).

The length of the mapped aquifer (i.e., 94.3 km) was included within the model and was calculated using the centerline length of the aquifer from the start of the aquifer (south-west of Princeton) to the end at the U.S. border.

4.3.2 Surface Water Inflows

Similkameen River Inflows

Based on the schematization of Aquifer #259 identified in Section 4.3.1, the Similkameen River inflows at the upstream extent of Aquifer #259 are considered the sum of streamflows recorded at the WSC hydrometric stations Similkameen River at Princeton (WSC Station 08NL007) and Tulameen River at Princeton (WSC Station 08NL024) (Figure 1). Accordingly, the mean monthly streamflows recorded at both WSC hydrometric stations were combined and used for each climate scenario.

Tributary Inflows

Along the extent of Aquifer #259, tributary streamflow monitoring has occurred at some point for a large number of the tributaries. However, only two tributaries (Hedley Creek and Ashnola River) currently have active WSC hydrometric monitoring near their mouth, while other studies (e.g. Summit [2015]) have estimated net and naturalized streamflows for other tributaries.

The specific tributaries considered within the water budget model are Allison, Hayes, Hedley, Keremeos, Wolfe, Smith, and Soukup Creeks, and Ashnola River, as well as the large number of small to medium sized ephemeral creeks (Figure 1). All tributary streamflow estimates were combined for the purpose of this study.

The following provides a summary of the tributary inflows included within the water budget model for each climate scenario:

- Hedley Creek and Ashnola River
    - Measured mean monthly net streamflows recorded at WSC hydrometric stations Hedley Creek near the Mouth (WSC Station 08NL050) and Ashnola River near Keremeos (WSC Station 08NL004) scaled by drainage area to the mouth of each watershed for each respective climate scenario.
- Allison, Hayes, and Keremeos Creeks
    - Estimated mean monthly net streamflows estimated by Summit (2015) for each respective climate scenario. The net flows for these creeks were estimated using discontinued WSC hydrometric stations on each respective creek and scaling through regional analysis (Summit 2015).
- Wolfe, Smith, and Soukup Creeks
    - Estimated mean monthly net streamflows for each climate scenario using discontinued WSC hydrometric station records (WSC Stations 08NL041, 08NL034, and 08NL035

    - [Figure 1]) scaled through regional comparisons with other WSC stations (e.g. WSC Station 08NL007).
- All other tributaries combined
    - Estimated mean monthly net streamflows for each climate scenario were scaled using average mean monthly unit discharge estimated for Wolfe, Smith, and Soukup Creeks. The estimated drainage area for 'all other tributaries combined' is 1,079 km^2, which represents the remaining drainage area contributing to Aquifer #259 not included in the above-noted tributaries.

The uncertainty and sensitivity of the tributary inflows within the water budget model are discussed in Section 4.6. The tributary inflow estimates for each climate scenario were used as calibration parameters to improve the representation of the model (Section 4.4). Therefore, the approach outlined above helped to approximate an initial magnitude of tributary inflows, but the final values included within the model are likely a better representation of the inflow volumes.

4.3.3 Surface Water Outflows

The Similkameen River outflows at the downstream extent of Aquifer #259 are represented by streamflows that cross the U.S. border. A WSC hydrometric station (discontinued or active) is not present at this location; however, the WSC station on Similkameen River near Nighthawk (WSC Station 08NL022) is located approximately 25 km downstream.

Summit (2015) identified that this hydrometric station does not accurately reflect streamflow conditions at the U.S. border due to natural regulation of streamflows by Palmer Lake during high flow periods. In addition, water demand information could not be obtained from the Washington State Department of Ecology to consider the influence of water demand between the U.S. border and the location of WSC Station 08NL022 (Summit 2015). As a result, Summit (2015) estimated streamflows at the border by extrapolating from estimated Similkameen River and tributary inflows upstream.

Understanding that Summit (2015) identified limitations in scaling streamflows measured at WSC Station 08NL022 to the U.S. border, in order to give ENV the flexibility of easily adding new outflow information to the water budget model at a future date, the WSC Station 08NL022 records for each climate scenario were scaled to the U.S. border (using a drainage area of 8,117 km^2). A recommendation to improve the accuracy of the outflow information is provided in Section 5.

Following the approach outlined above, groundwater contribution to the Similkameen River is integrated into the water budget model, since baseflows are captured within the hydrometric records.

4.3.4 Surface Water and Groundwater Demand

Surface and groundwater withdrawals for the Similkameen River and Aquifer #259 were estimated for inclusion within the water budget model. The term 'water demand' is used herein to represent water withdrawals, as requested by ENV. Water demands were estimated by source, as well as by withdrawal timing—annual or seasonal. Annual demand was defined as withdrawals that occur over the entire year (i.e. Domestic – January to December), while seasonal demand occurs for a portion of the year (i.e. Irrigation – April to September). The timing for seasonal demand (i.e., April to September) was determined based on a review of select water licences issued for irrigation purposes within the extent of Aquifer #259; the general licence period ranged between April and September and was therefore adopted herein.

The following sections provide a summary of the surface and groundwater demands included within the water budget model.

Ministry of Agriculture – Agriculture Water Demand Model

The B.C. Ministry of Agriculture (MOA) and Agriculture and Agri-Foods Canada developed an Agriculture Water Demand Model (AWDM) for the Canadian portion of the Similkameen River watershed (van der Gulik et al. 2013). The model was created to estimate current and future agriculture water demand (including both crop irrigation and livestock watering) on a property-by-property basis.

The AWDM is based on a Geographic Information System (GIS) database that contains cadastre information (showing the boundaries of land ownership), crop type, irrigation system type, soil texture, and climatic data (van der Gulik et al. 2013). This information was assembled from background information, high-resolution orthophotos, and GIS, and was confirmed by ground surveys in 2008 by MOA. Land uses (including crop type and method of irrigation) were identified and water demands were estimated at the scale of the individual land parcel and finer.

The AWDM calculates the daily evapotranspiration demand for each parcel using a form of the Penman-Monteith equation (van der Gulik et al. 2013). It also computes the existing soil moisture and the daily precipitation. The irrigation requirement is the residual demand that cannot be met from these two sources. The climate (dataset) is the key driver of the evaporation calculations. In the Similkameen River watershed, a 1950-2010 gridded dataset consisting of cells measuring 500 m by 500 m is available, and temperature (minimum, maximum, and mean) and total precipitation for each day of the year have been estimated for each cell. A detailed description of how the model calculates agricultural water demands is provided by van der Gulik et al. (2013).

For the water budget model, agriculture demand information was obtained from MOA for 1981-2010. For each parcel of land included within the AWDM, a water source type is defined (surface or groundwater), but a source name (e.g., Aquifer #259, Similkameen River) is not. Therefore, to ensure that all lands within the spatial extent of Aquifer #259 (and adjacent to the aquifer) that use the Similkameen River or Aquifer #259 as a water source are considered, a 100 m buffer was added to the edge of Aquifer #259. All land parcels that bisected, fell within, or were adjacent to the 100 m buffer were considered to be supplied by either the Similkameen River or Aquifer #259.

Following this, the total agricultural water demands were summarized by surface water and groundwater sources. A summary of the AWDM data included within the water budget model is as follows:

- Total monthly irrigation water demand for groundwater supplied lands was included as a 'Seasonal' groundwater demand. Note that irrigation water demand from the AWDM for the Fairview Heights Irrigation District (FHID) was not included, as Summit (2015) identified that actual water demand records for FHID better reflect the magnitude of water demands. The FHID values are discussed further in subsequent sections.
- Total monthly stockwatering water demand by groundwater sources was included as an 'Annual' groundwater demand. Also, stockwatering water demands identified by the AWDM to be sourced from unknown sources were also assumed to be extracted from groundwater sources.
- Total monthly irrigation water demand for surface water supplied lands was included as a 'Seasonal' surface water demand.
- Total monthly stockwatering water demands from surface water sources were not included, as there are no current water licences for stockwatering purposes issued for the Similkameen River within the spatial extent of Aquifer #259.

For each of the climate scenarios, agricultural water demand information for the wet (1991) and dry (2001) years from the AWDM were used, while the average water demand for the 1981-2010 period was used for the average/normal year scenario.

Note that the AWDM estimates agricultural water demands based on climate, soil, and crop type information, but does not consider a water licence's period of use (e.g., water withdrawals approved for April to September for irrigation purposes). As a result, the AWDM provides estimates of water demands outside of the licensed windows for irrigation (generally April-September). Therefore, for modelling purposes herein, the AWDM irrigation water demands for the months October-March were not considered. It was assumed that all farmers irrigate within the designated water licensing windows of their respective licence (assumed to be April-September within the water budget model).

Surface Water Demands

In addition to the irrigation water demands summarized above, licensed surface water demands were estimated following a similar approach as outlined by Summit (2015). This included the following:

- All current points-of-diversion within the spatial extent of Aquifer #259 that were licensed to Similkameen River were obtained from MFLNRO (2016a). Note that water licences associated with other watercourses within the spatial extent of Aquifer #259 were not considered, as they are inherently captured within the Tributary inflow estimates (Section 4.3.2).
- Current water licences for the Similkameen River within the spatial extent of Aquifer #259 included licensing for domestic, irrigation, irrigation local authority, waterworks local authority, processing, and mining—hydraulic water use purposes. Given that the monthly distribution of water demands is typically not indicated in water licence data, several assumptions were necessary to distribute the total licensed quantities throughout the year. These assumptions were as follows:
    - The total licensed volume is evenly distributed throughout the year for 'processing' and 'mining – hydraulic' purposes. This was included as an 'Annual' water demand.
    - For 'domestic' purposes, total annual licensed quantities were distributed based on the 1991-2010 mean distribution of actual domestic (indoor and outdoor) water demand reported by Summit (2015) for the Hedley Improvement District (Table 4-1). This was included as an 'Annual' water demand.

Table 1 Domestic (indoor and outdoor) monthly water demand distribution for the Similkameen River watershed based on records from the Hedley Improvement District, 1991-2010 (adapted from Summit [2015]).

Month	Demand (% of annual)	Month	Demand (% of annual)
January	5.6	**July**	16.3
February	4.8	**August**	14.9
March	5.3	**September**	9.2
April	6.7	**October**	6.1
May	10.5	**November**	4.6
June	11.0	**December**	5.0

  - For ‘waterworks local authority’ purposes, total annual licensed quantities were not included as a surface water demand, as Summit (2015) reported that FHID currently uses groundwater only for water supply and the Similkameen Improvement District does not currently operate an intake on the Similkameen River.
  - For ‘irrigation’ and ‘irrigation local authority’ purposes, all licensed use was assumed equal to the estimates provided by the AWDM.

In total, the Similkameen River within the spatial extent of Aquifer #259 is licensed for a total demand of approximately 58,166,000 m^3/yr.

This total demand is summarized per water use purpose as follows:

- domestic – 31,000 m^3/yr;
- irrigation – 7,589,000 m^3/yr;
- irrigation local authority -21,923,000 m^3/yr;
- mining – hydraulic – 883,000 m^3/yr;
- processing – 20,000 m^3/yr; and
- waterworks local authority – 27,720,000 m^3/yr.

Within the water budget model, there is the option to select actual or total licensed surface water demand. The total licensed option includes all the licensed demands identified above and distributed annually and seasonally using Table 1 (domestic, waterworks), evenly distributing them throughout the year (processing, mining – hydraulic), and using the average seasonal demand distribution for 1981-2010 from the AWDM (irrigation, irrigation local authority). The water demand option within the model allows a user to assess the influence of actual use or existing total allocation on the Similkameen River within Aquifer #259. Due to the uncertainty of the tributary inflow estimates, the total licensed allocation within all the tributaries could not be accounted for. Accordingly, the total licenced surface water demand option includes licensed extractions from the Similkameen River within the extent of Aquifer #259 and actual water use within the tributaries and the Similkameen River inflows (i.e., Similkameen and Tulameen Rivers).

Groundwater Demands

In addition to the irrigation groundwater demands estimated by the AWDM, groundwater demands within the extent of Aquifer #259 were estimated as follows:

- Total monthly groundwater demands for the Town of Princeton, Keremeos Irrigation District, and FHID (who all use groundwater as their main supply source) reported by Summit (2015) were used for each climate scenario. This was included as ‘Annual’ water demand.
- There are a total of 318 private domestic wells documented within the extent of Aquifer #259 (MFLNRO 2016b). No water demand information was available for these wells; therefore, domestic water demands were estimated following SRK (2013) who completed a similar assessment for the Regional District of Nanaimo. Understanding that climate and land use differences exist between the Similkameen River watershed and Nanaimo, in the absence of site-specific information, the approach and results outlined by SRK (2013) were adopted herein to estimate the approximate magnitude of private domestic groundwater use. SRK (2013) reported that the average annual domestic water demand from private wells was equivalent to 192.7 m^3/yr/well and that 30% of the demand occurred during summer (June-August). This annual value was adopted for water demands from Aquifer #259 and based on the number of reported wells, the estimated domestic groundwater demand for summer (June – August) was

6,137 m^3/month and for all other months was 4,762 m^3/month (for a total annual water demand of 61,269 m^3/yr).

- There are a total of 378 private wells documented with a water use purpose of ‘unknown’. These wells were not considered within the water budget model since their water use purpose could not be determined. Similarly, all private irrigation wells were not included, since irrigation well use was assumed equal to the estimates provided by the AWDM.

4.3.5 Precipitation

Total annual and monthly precipitation on to Aquifer #259 for each climate scenario was calculated using the total monthly precipitation records for the Princeton A climate station (Station No. 1126510). This climate station is the only station within the Similkameen River watershed with records that cover the current climate normal period (1981-2010). It was assumed that the records collected at Princeton A (Station No. 1126510) were representative of the entire aquifer area. The precipitation values were used to estimate precipitation on to the Similkameen River and aquifer recharge by direct precipitation. The latter is further described in Section 4.3.8.

4.3.6 Evaporation from the Similkameen River

The gridded climate dataset (500 m by 500 m cells) identified in Section 4.3.4 also includes calculated evapotranspiration for the Similkameen River watershed. Evapotranspiration is calculated using a form of the Penman-Monteith equation based on gridded air temperature information.

The evaporation term (E) is considered to represent evaporation from the Similkameen River across Aquifer #259. To estimate the total monthly evaporation from the river surface, the gridded climate dataset was clipped to the extent of the aquifer and the monthly weighted average was calculated for each scenario.

4.3.7 Irrigation Return Flows

Irrigation return flows recharge the aquifer. The amount of irrigation return flow is dependent on the types of irrigation systems used, as well as general watering practices (i.e., over or under watering). Within the AWDM, there is a component of the total water demand calculated that represents water lost to deep percolation due to overwatering (Fretwell, pers. comm., 2016). The value is dependent on the crop rooting depth and availability coefficient, the soil texture, the irrigation system used, and the irrigation management practices (good, average, poor) (Fretwell, pers. comm., 2016). The percolation factors for average irrigation management can range from 7.5% for drip irrigation on heavier soils to 42.5% for a gun irrigation system on sandy soils (Fretwell, pers. comm., 2016).

The deep percolation values were not obtained from the AWDM dataset for Aquifer #259 (Section 4.3.4). As a result, irrigation return flows were estimated to be 15% of the total irrigation (seasonal) water demands within the water budget model. A factor of 5% was used to account for losses within the Okanagan Basin (Summit 2010), but due to the sand and gravel nature of Aquifer #259, a 15% factor was assumed to better reflect the aquifer conditions.

The irrigation return flow factor (15%) was applied to all months with an irrigation (seasonal) water demand. However, understanding that percolation factors can range from 7.5% to 42.5%, a range of 0% to 50% has been built into the model sensitivity (Section 4.6.2).

Irrigation return flows are an estimated input into the water budget model; however, the model includes the option to allow a user to specify their own factor for seasonal or specific month applications if more detailed information is available. The uncertainty and sensitivity of this parameter is discussed in Section 4.6. However, adjusting the irrigation return factor between 0% and 50% resulted in a minimal change to the overall water budget.

4.3.8 Aquifer Recharge from Precipitation

Aquifer recharge can be estimated in a number of ways (e.g., numerical modelling, base flow separation); however, data for or from direct measurements is rarely available. This is the case for Aquifer #259.

In the absence of aquifer specific recharge information, a generally accepted method is to use published estimates of recharge from similar aquifers or from aquifers within the same geographic area as an estimate (SRK 2013; Golder and Summit 2009). This approach uses the following equation to estimate annual aquifer recharge (*R*) from precipitation only (and does not include recharge from river losses or groundwater inflows/MBR):

$$R = P \times A_{aquifer} \times \%\ recharge \qquad \text{(Eq.2)}$$

where:

P = total annual precipitation on the aquifer surface area

$A_{aquifer}$ = aquifer surface area receiving direct precipitation

% recharge = coefficient to account for the loss of total annual precipitation due to evapotranspiration, unsaturated zone soil storage, and direct runoff from the aquifer surface

Golder and Summit (2009) reported a % recharge of between 5% and 20% for the Okanagan Basin, based on centroids of static water level above mean datum, i.e., divided grid with groundwater levels above datum. In addition, SRK (2013) noted that based on their study on Vancouver Island, % recharge can range between 10% and 66% for soils overlying bedrock, while Golder (2005) reported % recharge values between 2 to 24% for arid to semi-arid areas.

For the water budget model, a % recharge value of 20% was adopted. This value is a calibrated value (Section 4.4) and is consistent with the value used by Golder and Summit (2009) for a similar elevation centroid and aquifer material.

The % recharge is applied to the valley aquifer area, which does not include the surface of the Similkameen River itself. For some investigations, recharge is estimated annually and distributed equally throughout the year; however, a monthly distribution of recharge was developed qualitatively for inclusion within the water budget model based on air temperature, precipitation, and observed groundwater level information. This was done to consider recharge to the aquifer on a monthly time-step. The monthly distribution considers months with freezing temperatures and snow cover as having lower recharge than months with warm temperatures, rainfall, and snow melt.

Within the water budget model, the % recharge value is applied to the total annual precipitation and the resultant value is distributed into monthly volumes through the monthly recharge distribution. The monthly recharge distribution was assumed constant for all climate scenarios, but the water budget model includes the flexibility of a user to include different monthly recharge distributions (and % recharge values).

4.3.9 Groundwater Inflows

Upstream Groundwater Inflows into Aquifer #259

Groundwater inflow through the upstream end of Aquifer #259 was considered to be represented by the aquifer geometry summarized at cross section A-A’ (Figures 1 and 2). Using this geometry, groundwater inflows were estimated using Darcy’s Law:

$$Q = K\, i\, A \qquad \text{(Eq.3)}$$

where:

Q = inflow through the upstream end of Aquifer #259 (m^3/day)

K = hydraulic conductivity for the aquifer material (m/day)

i = the hydraulic gradient (m/m)

A = aquifer area (width times thickness of the saturated aquifer material) (m^2)

Golder (2005) reported *K* values for Aquifer #259 that ranged between 0.5 and 86 m/day for aquifer materials in the Princeton area. Golder (2005) also reported that hydraulic gradients in the same area ranged from 0.003 to 0.008 between different wells sets in the aquifer. These ranges were used to constrain the groundwater inflows. Note that the groundwater inflows estimated using this approach represent groundwater inflows from the upstream end of Aquifer #259 only. Groundwater inflows from adjacent bedrock aquifers are estimated through Mountain Block Recharge (upcoming section).

The aquifer geometry through the upstream end of Aquifer #259 was estimated to be 1,150 m wide and 20 m deep (in saturated aquifer material). The average hydraulic gradient was also estimated to be 0.005.

Upon refinement of the water budget model through calibration (Section 4.4.2), groundwater inflows through the upstream end of Aquifer #259 were estimated to be 10,235 m^3/day using a K value of 89 m/day. The groundwater inflows are assumed constant over the course of the year and under each climate scenario.

Mountain Block Recharge

Mountain Block Recharge (MBR) is the collective name for the fractured bedrock aquifer located on both sides and below the unconsolidated aquifer interacting with groundwater flow into Aquifer #259.

Within the water budget model, MBR is calculated using two different methods as follows:

- The first method has been adopted by a number of authors (e.g., Bennett [2012], Golder and Summit [2009], Hy-Geo Consulting [2015]) and is referred to herein as the Nielson-Welch and Allen (2007) MBR method. Nielson-Welsh and Allen (2007) estimated that 35 to 50 mm/year of available precipitation could migrate as deep groundwater flow through the mountain bedrock to a valley bottom aquifer. Following this, Bennett (2012) applied this 35-50 mm/year range as a flux rate, in a similar manner to Darcy's Law (Eq. 3), but replaced the K value with the flux rate (i.e. 50 mm) to estimate MBR for the Westwold Valley Aquifer and doubling the value to represent inflows from two sides of the aquifer.
- The second method is the Darcy's Law equation method. This method applies Darcy's Law (Eq. 3) with estimated values for K, i, and A from aquifer cross section data for both Aquifer #259 and the estimated saturated thickness in contact with the fractured aquifer system. Estimated hydraulic conductivity values for a fractured aquifer in the BC Southern Interior was suggested by both Bennett (pers. comm., 2016) and Welch (pers. comm., 2016) to be in the order of 1E-07 m/s or 0.0086 m/day.

The water budget model includes the option to use either method. The Nielson-Welch and Allen (2007) MBR method within the model includes the option to vary the flux rate between 35 to 50 mm/year, and a user can define the specific input parameters for Darcy's Law equation method. Both methods provide values in the same order of magnitude; specifically, the Nielson-Welch and Allen (2007) MBR method provides an estimate of 1,550 m^3/day (assuming a 50 mm flux rate), compared to an initial estimate of

978 m^3/day using the Darcy's Law equation method with gradient of 0.01 (assuming a K of 0.0086 m/day). The Darcy's Law equation method was used within the model calibration.

Upon refinement of the water budget model through calibration (Section 4.4.2), the MBR contribution to Aquifer #259 (using the Darcy's Law equation method) was estimated to be 4,889 m^3/day using an estimated gradient of 0.05. The contribution from adjacent steep bedrock areas could be higher than average Aquifer #259 groundwater flows. Following this, the MBR inflows to Aquifer #259 are assumed constant over the course of the year and under each climate scenario.

Note that recharge into mountain block aquifers could have a lag time in the order of months and hydraulic gradients may increase during certain times of the year. As a result, MBR inflows may not be constant over the course of the year; however, without available information on MBR inflows within the Similkameen River watershed and surrounding areas, a constant inflow value is considered reasonable for modeling purposes. This assumption may influence model calibration during baseflow periods (Section 4.4.2).

4.3.10 Groundwater Outflow

Groundwater outflow through the downstream end of Aquifer #259 was considered to be represented by the aquifer geometry summarized at Cross section C-C' (Figures 1 and 4). The groundwater outflows were estimated using Darcy's Law as described in Section 4.3.9.

The hydraulic conductivity (*K*) for Aquifer #259 at this location likely varies due to the presence of heterogeneous lithologies. Summit (2015) reported *K* values for Aquifer #259 that ranged between 0.86 and 173 m/day (median of 138 m/day) for aquifer materials in the Keremeos area based on actual aquifer tests. Summit (2015) also reported that hydraulic gradients in the same area ranged from 0.004 and 0.005 between different wells sets in the aquifer. These ranges were used to calculate the groundwater outflows.

The aquifer geometry through the downstream end of Aquifer #259 was estimated to be 1250 m wide and 60 m deep (in saturated aquifer material). The average hydraulic gradient was estimated to be 0.004.

Upon refinement of the water budget model through calibration (Section 4.4.2), groundwater outflows through the downstream end of Aquifer #259 were estimated to be 20,000 m^3/day using a K value of 100 m/day. The outflows from Aquifer #259 are assumed constant over the course of the year and under each climate scenario.

The range of *K* values used for the groundwater outflow estimates was measured from aquifer tests in different wells near the U.S. border. Accordingly, moderate uncertainty is associated with groundwater outflow estimates due to uncertainty in the homogeneity of the aquifer. Further discussion of uncertainty and parameter sensitivities is provided in Section 4.6.

4.3.11 Change in Storage

Within the water budget model, the net result from the accounting of the inflow and outflow components is a surplus or deficit of the system. This surplus or deficit is considered the change in storage (ΔS) of the surface and groundwater systems and is provided for each climate scenario on an annual and monthly time-step.

Since the ΔS considers both the surface and groundwater systems together and the conceptual model does not include a specific surface water loss to groundwater term within Eq.1, the ΔS is assumed to represent a change in aquifer storage (volume) only (identified as ΔS^{GW}). This is a simplified assumption and likely overestimates the ΔS^{GW}, since some surface water storage within the Similkameen River channel occurs during the freshet period.

Under average climate conditions, it was estimated that channel storage accounts for 10-15% of the monthly ΔS during the freshet period. This was estimated assuming a trapezoidal channel for the Similkameen River with a top width of 60 m for the portion of the channel across Aquifer #259 (approximately 94 km). This estimated change in storage is equivalent to a change in groundwater level of approximately 0.15 m. Comparing this value to Figures 7, 8, and 9 (Section 4.2.2), this value does not significantly improve model calibrations during the freshet period. Channel storage considerations should be considered; however, due to the uncertainty of the channel dimensions and varying river flows across the aquifer, the approach of assigning the total storage change to groundwater alone was still considered reasonable at this time due to the lack of available information. A recommendation to consider channel storage within a future version of the model is provided in Section 5.2.

Following this, for model calibration and visual display purposes the change in aquifer volume storage (ΔS^{GW}) was converted to a change in aquifer groundwater levels as follows:

$$\Delta h^{GW} = \Delta S^{GW} / (S_y \times A) \qquad \text{(Eq.4)}$$

where:

Δh^{GW} = change in groundwater levels (saturated levels) in the aquifer (m)

ΔS^{GW} = change in groundwater storage; assumed equivalent to the change in storage of the surface and groundwater systems (ΔS) (m^3)

S_y = specific yield or storativity of the unconfined aquifer (dimensionless). Specific yield is the level of saturation in an unconfined unit that varies with changes in the amount of storage in the aquifer. Specific yield is calculated following $S_y = S - hS_s$, where S is storativity for an unconfined aquifer and hS_s is storativity for a confined aquifer. Specific yield is dimensionless with a typical range between 0.02 and 0.3 for fine to clean sands and coarse gravel (Fetter 1994). The model was calibrated using specific yield of 0.26 (Section 4.4.2).

A = Aquifer #259 area (m^2)

Using Equation 4, it was estimated that a 1 m change in groundwater level within Aquifer #259 with a specific yield of 0.26 represents an aquifer storage volume of approximately 31,460,000 m^3.

The modelled change in aquifer storage (changed to groundwater levels) was compared and calibrated to observed changes based on the change in groundwater levels recorded in ENV observation wells within Aquifer #259 (Section 4.4).

4.4 Model Calibration

The net results of the water budget model are represented by the surplus and deficits of the system on an annual and monthly basis. The surplus and deficits indicate the differences between the inflows and outflows of the surface and groundwater systems and these differences were related to a change in aquifer storage in the water budget model.

Following this, a model sensitivity tab was added to the water budget model to allow for the refinement of selected input and output parameters, as well as to assess their sensitivity to the overall results (Section 4.6.2; Appendix A).

The following sections summarize the ENV observation well used for calibration, as well as the results of the model calibration. A discussion on model sensitivities is provided in Section 4.6.

4.4.1 Observation Wells for Aquifer #259

In the Similkameen River watershed, there are three active and three inactive observation wells for which groundwater level data were available (Figure 1). The observation wells are the responsibility of ENV. The three active observation wells are as follows:

- Well 75 (Keremeos) – installed within Aquifer #259;
- Well 203 (Cawston) – installed within Aquifer #259; and
- Well 264 (Mt. Kobau) – installed within bedrock above the Similkameen River valley. This well was not considered further since it is not located within Aquifer #259.

Table 2 summarizes the data and period available for the six monitoring wells.

Table 2 Observation wells (inactive and active) within the Similkameen River watershed.

Location	Well No.	Status	Years of Available Data
Keremeos	75	Active	1963 - 2013
	76	Inactive	1969 - 2002
	77	Inactive	1969 - 2002
Cawston	203	Active	1977 - 2011
	264	Active	1980 - 2000
Princeton	220	Inactive	1977 - 1999 (plus sporadic data in 2000)

A decline in groundwater levels from May to July/August when river levels are high was identified in Well 203 (Cawston), but was not in Well 75 (Keremeos). This could be a result of pumping in the area of Well 203 (Cawston), as the decline is consistent with the timing of the irrigation season. Due to the uncertainty of the groundwater level trends observed in Well 203 (Cawston), only Well 75 (Keremeos) was used for calibration purposes.

This creates a calibration limitation for the water budget model, as the groundwater levels from one observation well with Aquifer #259 are unlikely to be representative of the entire aquifer area (i.e. 121 km^2). However, without other observation well information available for Aquifer #259, the groundwater levels (and associated change in aquifer storage) for Well 75 (Keremeos) are the best dataset available at this time.

The following provides an overview of the Well 75 (Keremeos) and the corresponding groundwater levels (and change in aquifer storage) used for calibration purposes.

Well 75 (Keremeos)

Well 75 (Keremeos) was drilled and constructed in 1967 to a depth of 28 m. The well was drilled mainly into sand, coarse gravel, and fine to silty/fine sands. This indicates that it is completely within the unconsolidated primary unconfined aquifer of Aquifer #259. Although not much information is supplied in the well log on well construction and screening, it is mentioned that the well is drilled as a 152 mm (6 inch) well. The well is situated approximately 789 m away from the Similkameen River in Keremeos.

Mean monthly groundwater levels from 1991 (wet scenario), 2001 (dry scenario), and 1981-2010 (average scenario) were used as input to the model. All available records (i.e., 1981-2010) were used to calculate mean monthly groundwater levels for the average scenario. For both the dry and wet scenarios (i.e., 1991 and 2001), there were data missing for some months. Accordingly, groundwater levels were estimated for months with missing data by calculating the average groundwater level of the preceding and following months. The resultant average total annual groundwater level fluctuation for the wet, dry, and average climate scenarios is 1.5, 0.9, and 1.1 m, respectively.

The measured groundwater levels from Well 75 (Keremeos) were used for comparison with the simulated change in groundwater storage from the model (in mbgs) under the model sensitivity tab. Initial January measured groundwater levels from Well 75 (Keremeos) under each respective climate scenario were used as the starting point for both the measured and simulated results.

The measured change in aquifer storage and groundwater levels were used as part of the calibration method. Following Bennett (2012), the change in storage for each month was normalized by starting the January levels at 0 m, with values for subsequent months added cumulatively. As such, this method applies a one month advance to modelled changes in aquifer storage and groundwater levels. On the model sensitivity tab, graphs of change in aquifer storage and groundwater levels were included to visually aid in the calibrations.

4.4.2 Calibration Results

The water budget model was calibrated for the three climate scenarios. Further refinement to the finalized calibrated inflow and outflow values can be performed using the model sensitivity tab within the model or using new data as it becomes available.

The calibration results compared favourably with the measured groundwater levels of Well 75 (Keremeos), but some inflow and outflow values (with high uncertainties) were changed to improve the modelled results. Through visual inspection and comparing the coefficient of determination (R^2) and Root Mean Square Error (RMSE) values between the estimated and observed change in groundwater level for each month, the following parameter adjustments were made:

- Estimated tributary inflows were reduced by approximately 30% for all climate scenarios.
- Specific yield was selected to be 0.26.
- Groundwater inflow hydraulic conductivity was selected to be 89 m/day.
- Groundwater outflow hydraulic conductivity was selected to be 100 m/day.
- % recharge by direct precipitation was reduced to 20% (distributed on a monthly basis; Section 4.3.8).

These five parameters were adjusted independently from the other inflow/outflow values within the water budget. The most sensitive calibration parameters were the estimated tributary inflows and the aquifer specific yield.

The water budget model was reset with the calibrated values for each climate scenario and the inflow and outflow values included within the model are considered the most appropriate values for each climate scenario at this time. However, if desirable, further calibration can be performed using the model sensitivity tab. Figures 7, 8, and 9 present the calibrated model output for each climate scenario.

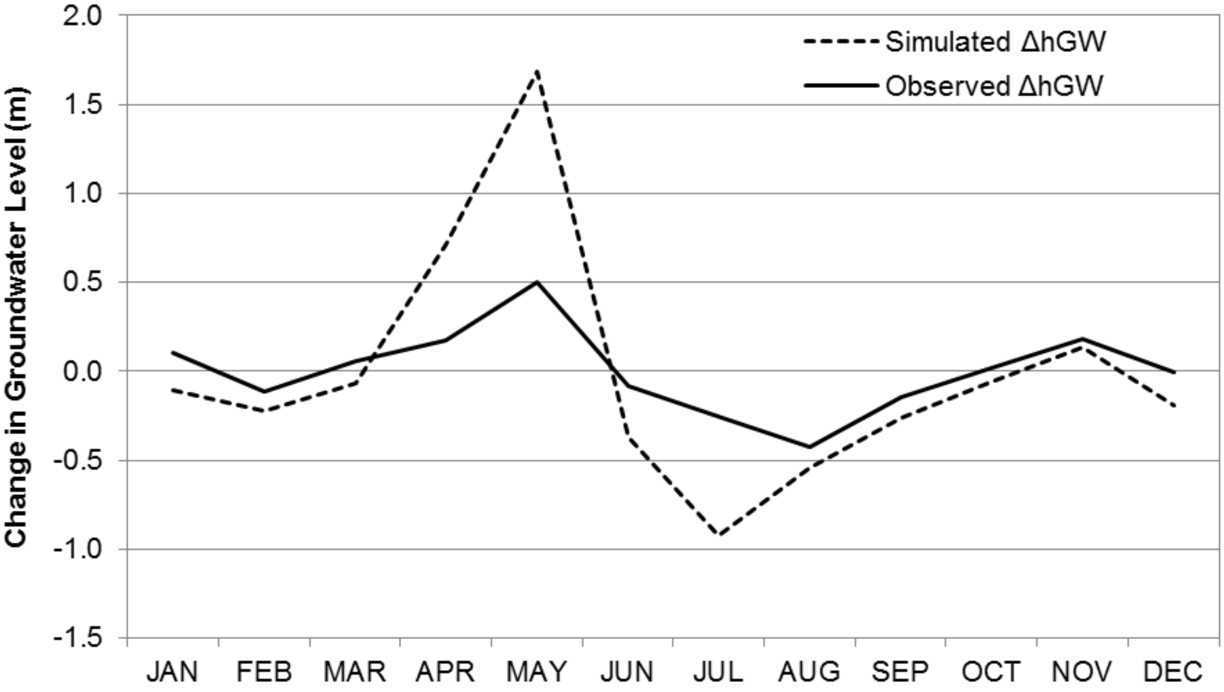


Figure 7 Estimated change in aquifer storage compared to Well 75 (Keremeos) – average climate scenario.

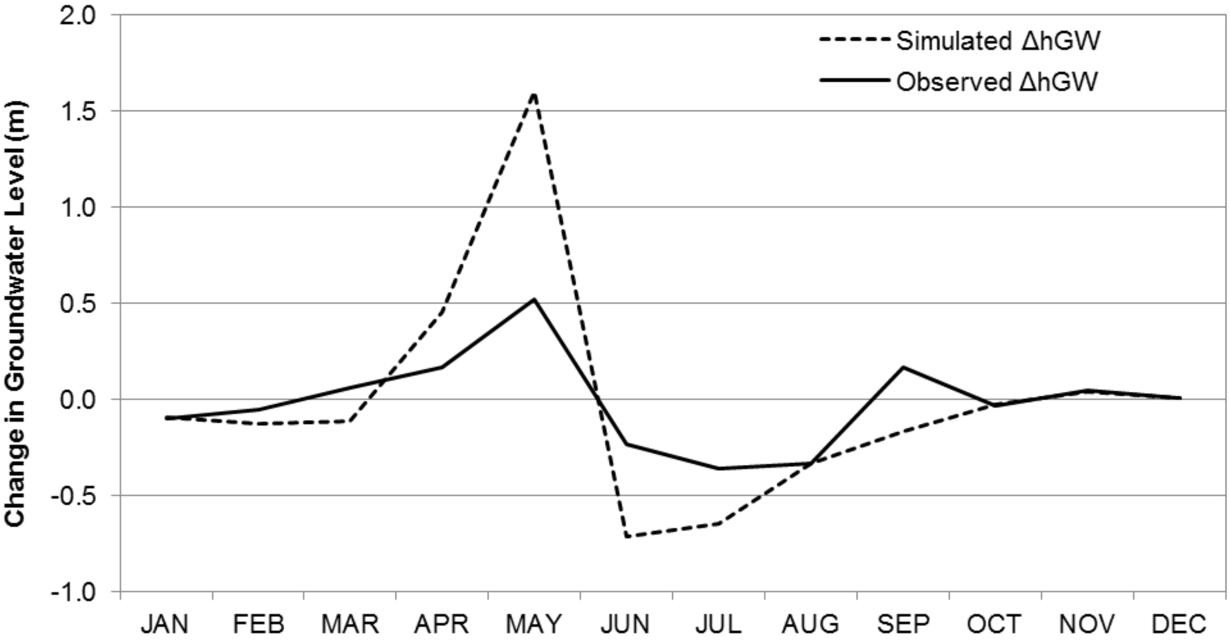


Figure 8 Estimated change in aquifer storage compared to Well 75 (Keremeos) – dry climate scenario.

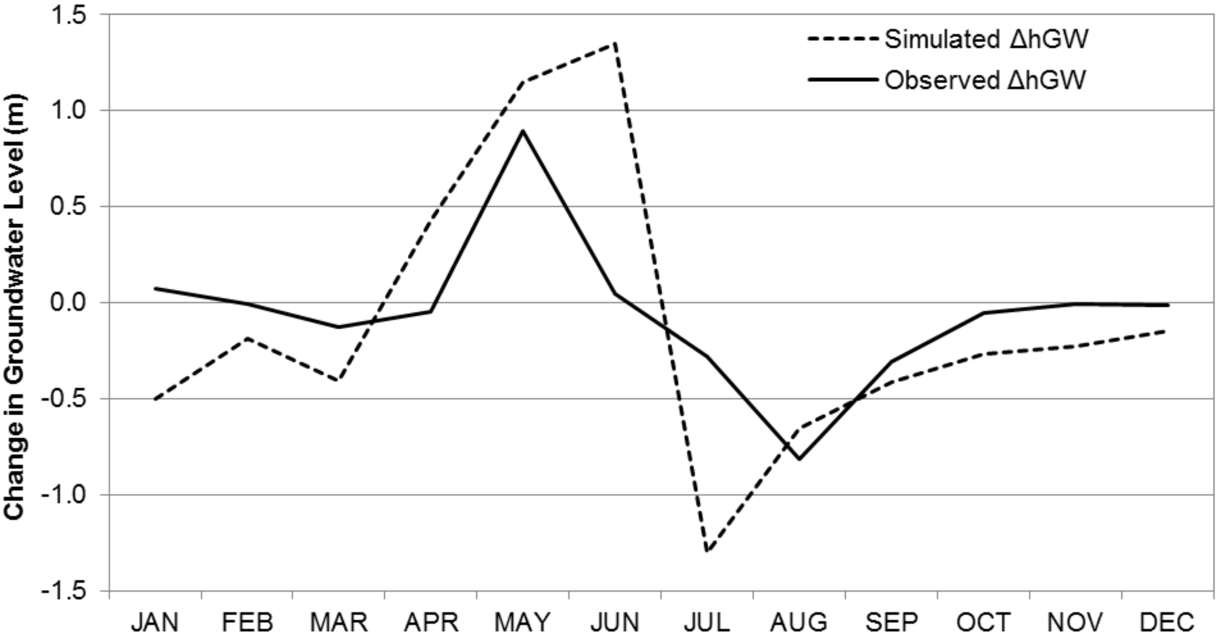


Figure 9 Estimated change in aquifer storage compared to Well 75 (Keremeos) – wet climate scenario.

The water budget was reasonably calibrated to the measured groundwater levels measured at Well 75 (Keremeos) for each climate scenario. However, since data from only one observation well was available for Aquifer #259, the high Similkameen River and tributary inflows during the freshet period resulted in an overestimate of the changes in aquifer storage and groundwater levels (as discussed in Section 4.3.11). The calibration of groundwater levels to be within approximately 0.2-1.0 m for the freshet period under all climate scenarios was the best fit achieved without negatively affecting the results for the lower flow periods.

The freshet period calibration results are important as there are no other avenues for the high surface water inflows to report to apart from outflow in the river or inflow to the aquifer. The variability in the measured and simulated groundwater levels is considered to be a result of the following:

- The estimated Similkameen River outflows are potentially too low.
- The tributary inflows during the high flow months are overestimated.
- The measured changes in groundwater levels from Well 75 (Keremeos) do not reflect average aquifer conditions across the entire 94 km long aquifer.

The above noted factors could refine calibration to a higher degree of accuracy in the future and recommendations to improve the results are provided in Section 5.2.

4.5 Model Results

The results for the water budget model include the following:

- water budget summary table of all inflow and outflow values and ratio of surface inflow minus recharge to surface outflow;
- Similkameen River outflow hydrograph and EFNs related to rearing and spawning of key fish species;
- estimated change in aquifer storage in comparison to measured aquifer changes; and

- estimated changes in surface water and groundwater storages (basically separating the surplus/deficit into separate surface water and groundwater components) so that the different components can be evaluated.

Within the model, the water budget tab provides a numerical summary of the calibrated water budget, while the model output tab provides a graphical representation of the results (Appendix A). The model output tab also allows a user to add a new water licence (surface water or groundwater) and to assess the potential impacts of the licensed volume on the Similkameen River streamflows at the U.S. border, on EFNs, and on Aquifer #259.

The model output tab also includes a graphical summary of the estimated changes in surface water and groundwater storage. This graphical summary is only used for display purposes to show model users the differences between surface water and groundwater storage magnitudes based on the separate surface water and groundwater variables within the conceptual model (Equation 1). The total storage values from the two components are equal to the ΔS for the system, which assumes that the change in surface water storage is attributed to a loss or gain in aquifer storage (Section 4.3.11).

The following sections provide a summary of the water budget results for each climate scenario, as well as how the model can be used to add a new licence and assess how the licensed volume could influence the Similkameen River and EFNs.

4.5.1 Water Budget Results

The water budget results included system surpluses or deficits on a monthly basis under the three different climate scenarios, while on an annual standpoint, a surplus occurred under the dry scenario and deficits occurred under the average and wet scenarios. The water budget monthly surplus/deficit results are presented in Table 3 for the three climate scenarios (average, dry and wet). A detailed breakdown of each water budget (inflows and outflows) is provided within the water budget tab within the model.

Table 3 Water budget results for the three different climate scenarios.

Month	Average Scenario		Dry Scenario		Wet Scenario	
	Surplus/Deficit (m^3)	Δh^{GW} (m)	Surplus/Deficit (m^3)	Δh^{GW} (m)	Surplus/Deficit (m^3)	Δh^{GW} (m)
January	-3,400,912	-0.108	-3,002,553	-0.096	-15,785,177	-0.503
February	-7,199,699	-0.23	-4,014,638	-0.128	-6,047,587	-0.193
March	-2,353,286	-0.075	-3,611,433	-0.115	-12,798,736	-0.408
April	22,050,220	0.703	14,187,730	0.452	13,202,483	0.421
May	52,615,784	1.678	50,088,257	1.597	35,811,998	1.142
June	-11,901,190	-0.379	-22,581,738	-0.72	42,219,934	1.346
July	-29,017,399	-0.925	-20,330,344	-0.648	-40,869,567	-1.303
August	-17,055,833	-0.544	-10,593,319	-0.338	-20,703,448	-0.66
September	-8,343,743	-0.266	-5,311,719	-0.169	-13,139,312	-0.419
October	-1,921,513	-0.061	-949,337	-0.03	-8,579,342	-0.274
November	3,974,931	0.127	1,223,238	0.039	-7,281,583	-0.232
December	-6,125,767	-0.195	49,100	0.002	-4,752,232	-0.152
Annual Total (m^3/year)	-8,678,406	-0.277	-4,846,756	-0.155	-38,722,569	-1.235

Table 4 provides a comparison of the estimated groundwater and surface water demand as a percentage of estimated annual inflows to Aquifer #259. Based on actual water demands, groundwater demands are estimated to represent 0.4 to 1.5% of total annual inflows, while surface water demands represent 0.3 to 1.2% of the inflows.

Table 4 Total actual groundwater and surface water demand compared to estimated annual inflows to Aquifer #259 for the 3 different climate scenarios.

Climate Scenario	Estimated Groundwater Demand (m^3/year)	Groundwater Demand as a % of total annual inflow	Estimated Surface Water Demand (m^3/year)	Surface Water Demand as a % of total annual inflow	Total Annual Water Budget Inflow (m^3/year)
Average	12,296,102	0.7%	9,116,410	0.5%	1,753,415,111
Dry	12,968,726	1.5%	9,852,451	1.2%	850,628,688
Wet	10,962,950	0.4%	8,384,947	0.3%	3,115,110,802

Also, as part of the water budget results, the ratio of surface inflow (Q^{sw}_{in}) minus aquifer recharge (*R*) to surface outflow (Q^{sw}_{out}) is provided (on the model output tab). A ratio higher than 1.04 indicate months when the surface water component is the dominant input into the system, while values closer to 1.00 indicate times when the inflow and outflow are at or close to equilibrium (Hy-Geo Consulting 2014). Following this, the model results for the average climate scenario indicate that during the months April to May (and June under the wet scenario), the Similkameen River is the major source of aquifer recharge while the other months are likely to be baseflow contribution from groundwater to the river.

4.5.2 Environmental Flow Needs

This section provides a brief overview of the consideration of environmental flows needs (EFNs) within the water budget model. The development of specific EFNs for the Similkameen River watershed is a very involved task and was outside of the scope of this study. However, the inclusion of an EFN was still considered within the functionality of the water budget model through the use of critical flow thresholds for the Similkameen River reported by Associated (2016). Portions of this section were drawn from the report prepared by Associated (2016) for the B.C. Ministry of Forests, Lands, and Natural Resource Operations (MFLNRO) in support of drought investigations within the Similkameen River watershed.

A total of 23 species of fish have been observed in the Similkameen River. Rainbow trout (*Oncorhynchus mykiss*), mountain whitefish (*Prosopium williamsoni*), longnose dace (*Rhinichthys cataractae*), and various sculpin species (*Cottoidea* spp.*)* are the dominant fish species resident in the watershed. The Similkameen River also provides the largest unaltered habitat for umatilla dace in Canada (Associated 2016). In addition, the Similkameen River provides one of only two habitats where recruitment of umatilla dace is known to occur (the Columbia River provides the other) (Associated 2016). There are no anadromous fish in the Canadian portion of the Similkameen River, due to fish barriers at Enloe Dam and Coyote Falls (in Washington State) near the mouth of the river (Figure 1).

The Similkameen River has high value side channel habitat suitable for fish spawning, rearing, and incubation; however, the naturally low water levels may contribute to low fish productivity by limiting habitat availability and reducing fish survival (Associated 2016). Adults have also been documented to migrate downstream of Princeton to overwinter due to the presence of deeper and more frequent pool habitat (Associated 2016).

No legislated environmental flow needs have been defined for the Similkameen River. However, Associated (2016) completed an overview of fish populations at risk within the Similkameen River. This assessment provided estimates of critical flow thresholds at various locations along the Similkameen River. The critical flow thresholds were defined as the minimum streamflows at which aquatic habitat was available for fish species to thrive (Associated 2016). The critical flow thresholds were provided by MFLNRO for rearing and spawning/migrating fish species at risk and were defined as follows:

- Rearing of rainbow trout and mountain whitefish – greater of 5% of mean annual discharge (MAD) or the lowest recorded mean monthly discharge; and
- Spawning/migration threshold for umatilla dace and northern mountain sucker (spawning) and mountain whitefish (migration) – considered double the rearing threshold.

Note that the critical flow thresholds were defined for the irrigation season only by Associated (2016), as this is the period where water conflicts largely occur due to seasonal water demands and low streamflows.

Following the above, the critical flow thresholds defined by Associated (2016) are included within the water budget model. Associated (2016) estimated critical flow thresholds at the WSC hydrometric station on Similkameen River near Nighthawk (WSC Station 08NL022) (Figure 1) and these values were scaled to the U.S. border (following Section 4.3.3). The EFN values included within the model are as follows:

- Rearing: 4.78 m^3/s (May to October); and
- Spawning/migration: 9.53 m^3/s (May to September).

Within the water budget model, a graph of the Similkameen River outflows at the U.S. border is provided as model output. Included within the graph are the critical flow threshold values (identified as

EFN values) for the respective months that they apply to and the actual and estimated net streamflows (i.e. after the addition of a new licence [Section 4.5.3]) can be compared to support allocation decisions.

4.5.3 New Water Licence(s)

The water budget model also includes an application to allow a user to add a new water use licence for either surface water or groundwater demand. This application is included within the model output tab (Appendix A).

Once on the model output tab, a user specifies the annual licensed volume for a new licence and selects the period of use: annual, seasonal, or other. Annual licensed volumes are distributed into monthly values using Table 1 for annual licences (Section 4.3.4), seasonal licensed volumes use the average AWDM irrigation water demand distribution for 1981-2010 (Section 4.3.4), while other is a user specified water demand distribution. A new licence can be entered as a combined bulk volume (to consider multiple licences) or as just one licence.

Although the water budget model reacts as a black box with both surface water and groundwater systems acting in an integrated manner, the influence of a new licence on Similkameen River outflows and Aquifer #259 are included individually as an output. The exact influence of a single licence on Similkameen River outflows or on Aquifer #259 is not specifically known; therefore, the licensed volume is removed from the Similkameen River outflows and the change in aquifer storage independently of one another. This is considered a conservative approach to support water allocation decisions.

The results from the addition of a new licence(s) are displayed graphically on the model output tab and EFN considerations are specifically included within the Similkameen River outflow hydrograph.

4.6 Uncertainty, Sensitivity, and Safety Factor

The following section provides a summary of uncertainties within the model inflows and outflows, a review of the sensitivity of each inflow and outflow, and a recommended safety factor to consider when assessing potential impacts by a new licence (Section 4.5.3).

4.6.1 Model Uncertainty

The water budget model has numerous uncertainties related to the accuracy of the inflow and outflow values. The largest uncertainty in the model is associated with the calibration of the results to only one well (i.e. Well 75 [Keremeos]) for the entire aquifer area (121 km^2). This suggests that there is potentially a 50% or higher uncertainty within the model results.

For all the inflow and outflow parameters included within the water budget model, a qualitative assessment of their uncertainty was completed by assigning a rank of low, moderate, or high uncertainty (Table 5). A low uncertainty was defined as parameter with 0-10% uncertainty, moderate represents 10-25% uncertainty, and high is >25% uncertainty.

The highest uncertainties were identified to be related to the estimates for tributary inflows (Section 4.3.2) and MBR inflows (Section 4.3.9) (Table 5).

The overall uncertainty for the model output is therefore a result of the uncertainties associated with the model inflow and outflow components from Table 5. Following this, it is judged that the model results have a moderate uncertainty (10 to 25%).

Table 5 Qualitative assessment of uncertainty for inflow and outflow parameters within the water budget model.

Model Components	**Input Value Uncertainty**	**Model Sensitivity**
INFLOWS		
Direct Precipitation on to the Similkameen River	Low	Low
Similkameen River Inflow	Moderate	High
Tributary Inflows	High	High
Direct Aquifer Recharge	Moderate	Low
Irrigation Return Flows	Low	Low
Groundwater Inflow at Upstream Aquifer Boundary	Moderate	Moderate
Mountain Block Recharge (Bedrock Aquifer) to Aquifer #259	High	Low to Moderate
OUTFLOWS		
Direct Evaporation from Similkameen River	Moderate	Low
Similkameen River Outflow	Moderate	High
Groundwater Outflow at Downstream Aquifer Boundary	Moderate	Moderate
Existing Annual Surface Water Demand From Similkameen River	Low	Low
Existing Seasonal Surface Water Demand From Similkameen River	Low	Low
Existing Annual Groundwater Demand	Low	Low
Existing Seasonal Groundwater Demand	Moderate	Low
Total Licensed Water Demand	Low	Low

4.6.2 Model Sensitivity

A model sensitivity tab is included within the water budget model to allow a user to assess the sensitivity of selected inflow and outflow parameters (Appendix A). The parameters included within the model sensitivity tab are as follows:

- specific yield;
- aquifer recharge (as a percentage of annual precipitation);
- irrigation return flows;
- tributary inflows;
- hydraulic conductivity (groundwater inflows and outflows);
- mountain block recharge; and
- actual and total licensed surface and groundwater demands.

Specified ranges of parameter values (or the option to increase/decrease values by a percentage value) are included to allow a user to assess the sensitivity of each parameter within the model.

Table 5 provides the qualitative model sensitivities for the selected inflow and outflow parameters based on using the model sensitivity tab and through the calibration of the model for the three climate scenarios. The parameters with the highest sensitivities to model were the Similkameen River inflows, Tributary inflows, and Similkameen River outflows. This is consistent with Type IB aquifers, which are highly influenced by surface water inputs, similar to that observed in Figures 7 to 9.

Specific yield is also considered to have a moderate to high sensitivity within the model. Specific yield increases or decreases storage within an aquifer; therefore, varying this value can significantly change model results. For example, a specific yield change of 0.01 for Aquifer #259 with a change of storage of 1 m represents an additional storage of 1,206,294 m^3.

4.6.3 Safety Factor

Based on the uncertainty of the model results (Section 4.6.1), a safety factor should be taken into consideration when assessing a new water licence from Aquifer #259 or from the Similkameen River. The following summarizes the safety factors implemented within the model output tab:

Similkameen River Outflows Safety Factor

Within the model, the Similkameen River outflows are scaled to the U.S. border from streamflow records collected at WSC Station 08NL022. Using this approach, the approximate magnitude of streamflows at the U.S. border is correct, but the streamflows are likely underestimated. The underestimation is due to the unknown amount of water demand between the U.S. border and WSC Station 08NL022.

Understanding this, water allocation staff require an understanding of naturalized and net streamflow conditions in order advise the decision maker with respect to an application for diversion of water. Therefore, the safety factor included within the water budget model for the Similkameen River outflows is the estimated range of naturalized flows (i.e. no licensed use) to maximum licensed water demand (under all existing licences). Summit (2015) reported that surface and groundwater users within the Similkameen River watershed currently use approximately 40% of their licensed volumes under average (1981-2010) conditions, so it was assumed that the Similkameen River outflows reflect 40% upstream water demand.

Following this, the Similkameen River outflow safety factor was implemented as follows:

- All water licences upstream of the U.S. border were summarized by Summit (2015) and grouped into offstream, instream, and storage purposes. Only offstream licences were considered herein, as instream licences do not significantly alter streamflows since they are in place to maintain streamflows and storage licensed volumes were comparably small.
- The offstream licensed volumes reported by Summit (2015) were used to naturalize the streamflows by adding the estimated 40% of licensed demand to the streamflows. To estimate streamflows under maximum licensed demand, 60% of the licensed demand was removed from the streamflows.

This safety factor provides the estimated range of streamflows under naturalized and maximum licensed water demand conditions based on water demand within the Canadian portion of the Similkameen River watershed only. The estimated ranges were assumed the same for each climate scenario, as the total water demand within the Similkameen River watershed under dry and wet conditions are unknown at this time.

Note that when a new licence application is investigated through the model output tab, only the net and maximum licensed streamflows change, as a new licence does not affect naturalized flows.

Aquifer #259 Change in Storage Safety Factor

A moderate uncertainty rating (i.e. 10 to 25%) was reported for the water budget model results (Section 4.6.1). Understanding that the uncertainty associated within the water budget is largely related to errors with the inflow and outflow parameters (Table 5), an uncertainty of ±25% for the model results was assumed. Accordingly, a safety factor of ±25% of ΔS^{GW} (Simulated) was added to the output graph to visualise model uncertainty. However, applying ±25% to individual monthly results (i.e., January – December) resulted in unrealistic error estimates under high flow conditions. Therefore, ±25% of the absolute mean monthly ΔS^{GW} (Simulated) was calculated and assumed constant throughout the year. The safety factor was applied to 'Simulated Groundwater Level – Total Future Licensed Demand' since model uncertainties are inherent within estimated future groundwater levels.

Safety Factor Example

Figures 10 and 11 provide an example of the output graphs on the model output tab that include the safety factor highlighted zones, assuming the following conditions:

- Average climate scenario;
- New annual surface water licence of 100,000,000 m^3/year;
- Estimated actual water demand; and
- No parameter adjustments (i.e., calibrated values are used for all parameters).

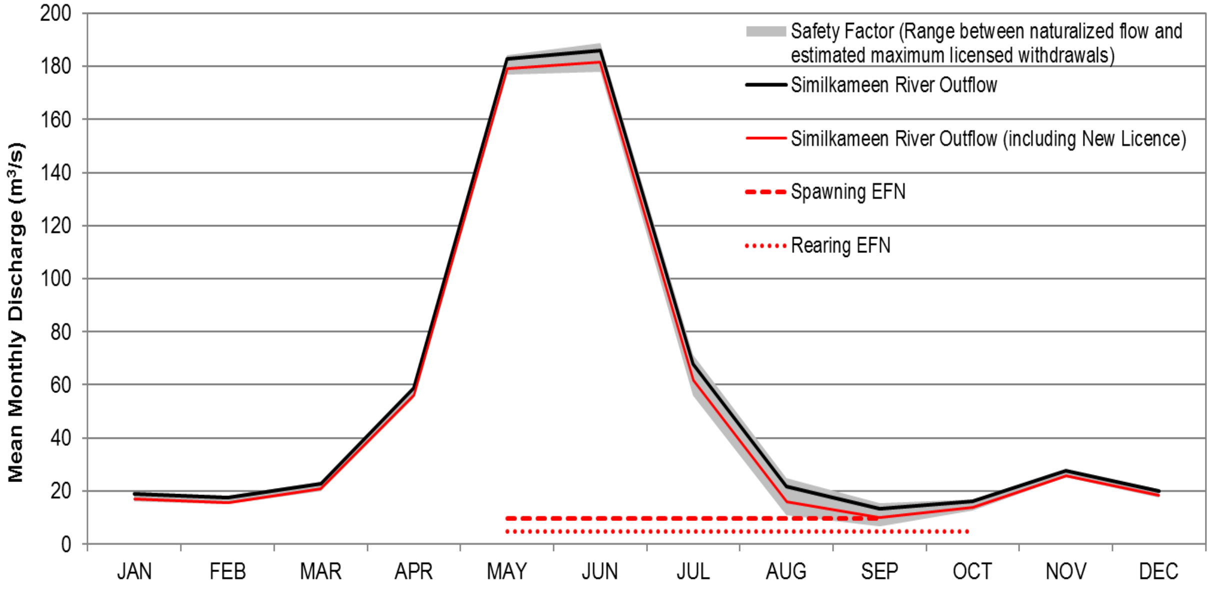


Figure 10 Example of Similkameen River outflow by adding a new water licence.

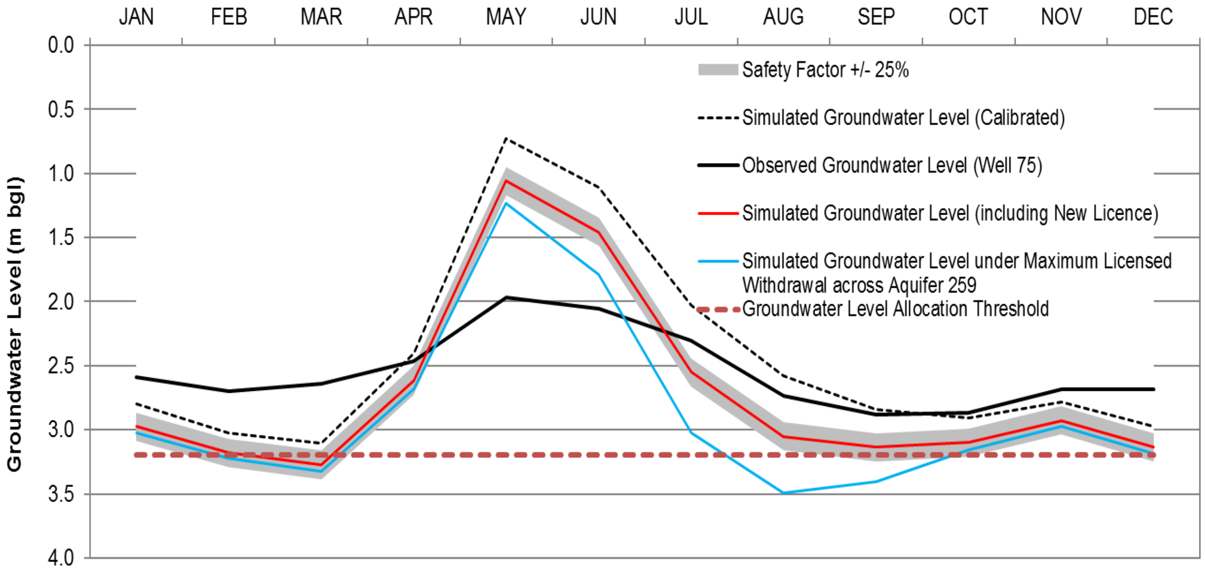


Figure 11 Example of change in groundwater level by adding a new water licence and including a 25% safety factor.

Note that the ±25% safety factor for the resultant change in aquifer storage was adopted in this report based on model parameter uncertainties. It is recommended that a safety factor calculated by stochastic modelling using Bayesian statistics and Metropolis-Hastings algorithm (Engeland 2005; Xu 2001), as well as Monte Carlo simulations be investigated at a later date to constrain the model output results.

4.6.4 Groundwater Allocation

Based on the model calibration results and by taking into account the safety factors and critical flow thresholds, a function was added to the water budget model to calculate the potential groundwater volume available for water allocation. This functionality is provided within the model output tab, which includes a manual input line where a groundwater level allocation threshold can be entered for individual months throughout the year. Currently, the groundwater level allocation threshold is set at 3.195 mbgs (Figure 11), which is the lowest groundwater level recorded by Well 75 (Keremeos) over the available period of record, but is considered above the estimated critical flow threshold values for the Similkameen River outflows. It is estimated that this groundwater level represents the maximum saturated storage level of the aquifer that can be used for withdrawal; if this level is reduced further, water would likely be withdrawn from the essential storage of the aquifer, which is not a sustainable solution. Within the water budget model, the groundwater level allocation threshold considers annual recharge, a portion of storage approximately to the critical flow threshold level, and surface and groundwater withdrawals.

The groundwater level allocation threshold included herein is merely a maximum suggested threshold and can be adjusted to accommodate any value that ENV deems appropriate for allocation. Using the allocation threshold level of 3.195 mbgs at Well 75 (Keremeos), the estimated volume available for groundwater allocation is provided in Table 6 on a monthly basis for the 3 different climate scenarios. Note that within the model the resultant groundwater allocation volumes consider maximum surface water licensed withdrawals and estimated actual groundwater use across Aquifer #259, since the water budget model considers both the surface water and groundwater systems directly connected. As described in Section 4.3.11, the water budget model considers the calculated change in storage for the entire system to represent a change in aquifer storage (volume) only; therefore, maximum surface water licensed withdrawals should be considered for allocation purposes. As a result, the volumes of water available for allocation reported in Table 6 should be used as a starting point at this time until the water budget model can be further refined or a specific groundwater level allocation threshold is defined by ENV for the aquifer.

Table 6 Estimated groundwater volumes available for groundwater allocation under the three climate scenarios.

	Estimated Total Monthly Volume of Groundwater Available for Water Allocation[1,2] (m^3)												
Climate Scenario	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Normal	10,841,683	3,859,294	1,338,150	22,786,034	72,130,472	55,154,364	21,558,215	5,556,825	2,721,041	7,279,373	11,643,235	5,417,089	220,285,776
Dry	5,375,039	1,577,710	-2,201,580	11,383,814	58,200,725	30,544,068	5,634,974	-3,903,902	-3,707,662	1,822,846	3,435,015	3,383,736	111,544,783
Wet	19,565,155	13,734,877	768,284	13,368,432	45,909,085	83,054,100	37,605,783	17,956,778	10,325,424	8,225,927	1,333,275	-3,519,336	248,327,784

Note:

1. Estimated total volume of groundwater available for allocation estimated using a groundwater level allocation threshold of 3.195 mbgs at Well 75 (Keremeos). The volume of groundwater available represents the estimated volume available between the groundwater level allocation threshold and the estimated groundwater level under a scenario of maximum licensed surface water use and actual groundwater use across Aquifer #259.

2. Negative values indicate groundwater levels are below the groundwater level allocation threshold. Additional groundwater allocation is not recommended.

5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

The main findings of the aquifer water budget study are as follows:

- Aquifer #259 is made up of mountainous terrain with steep valley walls and a narrow U-shaped valley bottom. The valley bottom is made up of high permeability sand and gravel. Aquifer #259 has been identified to be hydraulically connected to the Similkameen River and tributaries.
- Groundwater levels within Aquifer #259 follow an annual cycle, rising during the freshet season, declining thereafter, and then rising slightly during the early winter months.
- Aquifer #259 is approximately 94 km long and has very limited monitoring wells that are actively being monitored over time.
- The ENV Observation Well 75 (Keremeos) was the only active monitoring well used within this investigation that indicated minimal well interference from other wells in the area. Observation Well 75 (Keremeos) groundwater levels, when compared to hydrographs of the Similkameen River, indicated a similar cyclical pattern with a slight lag between the two in the order of days to perhaps a month. This indicated that they are both physically and hydraulically interconnected.
- There are a limited number of hydrometric stations actively monitoring the tributaries flowing into the Similkameen River along Aquifer #259 and there is no hydrometric station at the U.S. border (downstream extent of Aquifer #259).
- The water budget model was compiled using information from different sources with an estimated qualitative moderate uncertainty rating of 10–25%. The water budget was based on the best available information and new data was not collected to develop the model.
- The water budget was reasonably calibrated to the measured groundwater levels measured at Well 75 (Keremeos) for each climate scenario. However, since data from only one observation well was available for Aquifer #259, the high Similkameen River and tributary inflows during the freshet period resulted in an overestimate of the changes in aquifer storage and groundwater levels. The calibration of groundwater levels to be within 0.6 m for the freshet period (under all climate scenarios) was the best fit achieved without negatively affecting the results for the lower flow periods.
- The freshet period calibration results are important as there are no other avenues for the high surface water inflows to report to apart from outflow in the river or inflow to the aquifer. The variability in the measured and simulated groundwater levels is considered to be a result of the following:
    - The estimated Similkameen River outflows are potentially too low.
    - The tributary inflows during the high flow months are overestimated.
    - The measured changes in groundwater levels from Well 75 (Keremeos) do not reflect average aquifer conditions across the entire 94 km long aquifer.
    - The assumption that all change in system storage for Aquifer #259 is attributed to groundwater, neglecting the change in surface water storage.
- On average, actual groundwater use represents 0.7% of the annual water budget inflow.
- On average, the actual surface and groundwater demands (combined) represent 1.2% of the annual water budget inflow.
- The water budget results indicated that for all three climate scenarios the monthly budget varied between deficits during the low flow period to surplus during high flow river events. Overall, on an annual basis, the aquifer budget indicated a surplus during the dry scenario and a

deficit during the average and wet scenarios. Note that the wet scenario's observed groundwater levels (from Well 75 [Keremeos]) indicated a high groundwater level at the beginning of the year, but tapering off severely towards the end of that year, which caused a deficit and a much deeper groundwater level by the end of the year. The modeled groundwater levels during the wet scenario were also much lower and resulted in the deficit on an annual basis.

- Preliminary estimates of the volume of groundwater available for allocation were provided under each climate scenario.

5.2 Recommendations

There is a reasonable degree of confidence in the results of the water budget model, although due to the size of the aquifer, certain estimates and a number of assumptions were required. All the information provided in this report is valuable to support initial water allocations decisions; however, to further improve the water budget model of Aquifer #259, the following recommendations outlined below could be considered. Note that some of these recommendations were drawn from a report recently prepared for Regional District of Okanagan-Similkameen for the development of the Similkameen Watershed Plan by Associated (i.e. Summit [2015]).

- **Increase ENV observation well coverage within Aquifer #259**. The current ENV observation well program includes two active monitoring wells within Aquifer #259. To provide additional groundwater monitoring support and to provide additional water budget information, consider augmenting the ENV observation well network. With the two existing wells, plus the additional wells outlined below, this should be considered the minimum number of wells required to enable a basic program of monitoring of groundwater levels within the aquifer. The additional wells are as follows:
    - Reactivate the discontinued observation well in Princeton (Well 220). This well would be used to support water budget investigations within the upstream reaches of Aquifer #259, as well as to review potential impacts of aquifer drawdown by the Town of Princeton.
    - Install an observation well near the U.S. border. This well would be used to support water budget investigations within the downstream reaches of Aquifer #259.
- **Install a hydrometric station at the U.S. border**. A new hydrometric station at the U.S. border would help improve the understanding of the water budget of Aquifer #259 by providing a direct measurement of Similkameen River outflows.
- **Install a hydrometric station(s) on selected tributaries**. The tributary inflow volumes into the Similkameen River along Aquifer #259 was identified as a sensitive parameter to the overall water budget. As such, additional hydrometric stations on tributaries contributing to the Similkameen River along Aquifer #259 (e.g., Allison Creek, Hayes Creek, Wolfe Creek) would help improve the estimate of tributary inflows.
- **Obtain water demand information for the Similkameen River watershed below the U.S. border**. Water demand information between the U.S. border and the WSC hydrometric station Similkameen River near Nighthawk (WSC Station 08NL022) was not available from the Washington State Department of Ecology (WSDE) at the time of this report. This is currently a data gap, since streamflow records at WSC Station 08NL002 were scale to the U.S. border and considered representative of Similkameen River outflows. Consequently, Similkameen River outflows are likely underestimated within the water budget model. Therefore, water demand information should be obtained from the Washington State Department of Ecology and the WSC Station 08NL022 streamflow records should be naturalized to consider the water demands between the U.S. border and location of the hydrometric monitoring station. This would reduce

the uncertainty in Similkameen River outflows within the water budget model and help to improve the estimated range of streamflows under maximum licensed and naturalized conditions (i.e. Similkameen River outflow safety factor).

- **Complete an environmental flow needs assessment**. Summit (2015) identified that no specific EFN studies have been done for the Similkameen River. To provide FLNRO water allocation staff a complete assessment of water availability and risk of the Similkameen River due to existing and new water licences, EFNs must be determined. Consequently, a detailed investigation of EFNs is necessary for future allocation. This investigation should identify EFNs for the Similkameen River at selected locations, as well as corresponding groundwater levels to support the understanding of the volume of water available for allocation. This recommendation is consistent with Summit (2015).
- **Refinement of Aquifer #259 mapping**. Aquifer #259 is a mapped aquifer in the main Similkameen River valley bottom extending from Princeton to the U.S. border. It is mapped as one single unit of sands and gravels, but it is unlikely homogeneous for the entire mapped spatial extent. As a result, updated mapping and creation of a unique numbered system of sub-aquifer units is recommended to support management decisions. This will enable groundwater allocations to be tailored specifically to aquifer characteristics and the demand on that aquifer sub-unit. This mapping will also help to consider the amount of channel storage that occurs within the Similkameen River during the freshet periods, which will help to improve model calibrations. This recommendation is consistent with Summit (2015).
- **Complete a detailed surface-groundwater interaction assessment within Aquifer #259 near Keremeos and Cawston.** Complete a detailed investigation of the alluvial aquifers in the Keremeos-Cawston area to obtain a better understanding of aquifer recharge processes and the effects of groundwater pumping on flows in tributary streams and the Similkameen River. This would involve a combination of field studies (i.e., additional streamflow monitoring, pumping tests, and possibly well installation) and numerical groundwater/surface water modelling.
- **Complete an investigation to confirm aquifer recharge in Aquifer #259**. Since Aquifer #259 is in a semi-arid area, it is likely that chloride mass balance methods will work well to ascertain recharge to both the bedrock and unconsolidated aquifer areas.
- **Complete an investigation to confirm Mountain Block Recharge within the Similkameen River watershed.** A new deep well should be drilled in the fractured bedrock aquifer and packer testing completed in increments to confirm fracture density with depth as well as to confirm hydraulic conductivity for MBR inflows to Aquifer #259.

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APPENDIX A: MODEL USER GUIDE

A1. OVERVIEW

Associated Environmental Consultants Inc. (Associated) has developed a water budget model (WBM) for the Similkameen Valley Aquifer (#259) to aid in future water allocation within the aquifer boundary. The purpose of this Model User Guide is to provide users with details regarding the use of the WBM.

A1.1 Structure

The WBM developed for Aquifer #259 comprises two 'information' tabs, and five 'functional' tabs, as follows:

- Information tabs:
  - Main
  - Definitions
- Functional tabs:
  - Model Parameters
  - Input Data
  - Water Budget
  - Model Sensitivity
  - Model Output

Information tabs are intended to provide information and prompts to the user, and functional tabs provide the user with functionality to amend and execute the water budget for Aquifer #259.

A1.2 Navigation

This section provides an overview of key navigational features within the WBM, intended to improve usability.

A1.2.1 Main Tab

The 'Main' tab features a navigation ribbon on the right-hand side with quick-links to all functional tabs within the WBM.

A1.2.2 Functional Tabs

Each functional tab features a navigation ribbon with quick-links to all other functional tabs, as well as the 'Main' tab (Figure A1). In addition, a screen optimization button allows the user to automatically optimize each tab to fit on any given screen size (Figure A1). The user may still have to scroll up/down since the screen optimization function only adjusts the horizontal fit of the current tab for increased usability.

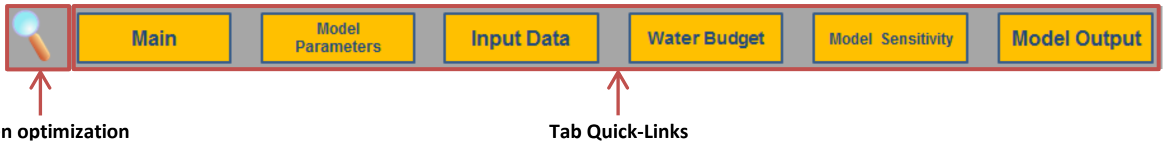
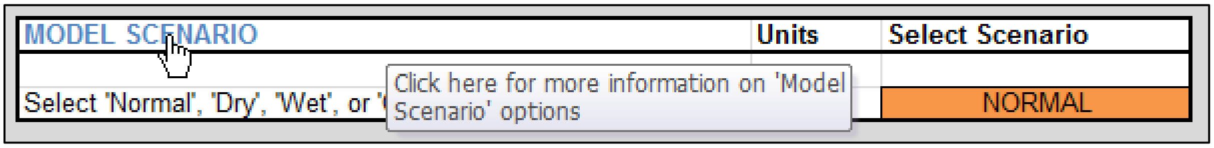


Figure A1 Navigation ribbon found on all functional tabs.

A1.2.3 Definition Links

The ‘Model Parameters’ tab and ‘Input Data’ tab allows the user to access more information on select model parameters and data by clicking on blue lettering (Figure A2). Definition links automatically navigate the user to a ‘Definitions’ tab, which provides information on model parameters and components, as well as data used within the model. The select definition is displayed in the top left corner of the ‘Definitions’ tab. Definition links provide the only method to access the ‘Definitions’ tab (i.e., no quick-link is provided for the ‘Definitions’ tab within the navigation ribbon).



Select 'Normal', 'Dry', 'Wet', or '

Click here for more information on 'Model Scenario' options

Figure A2 Example of definition links found on ‘Model Parameters’ tab.

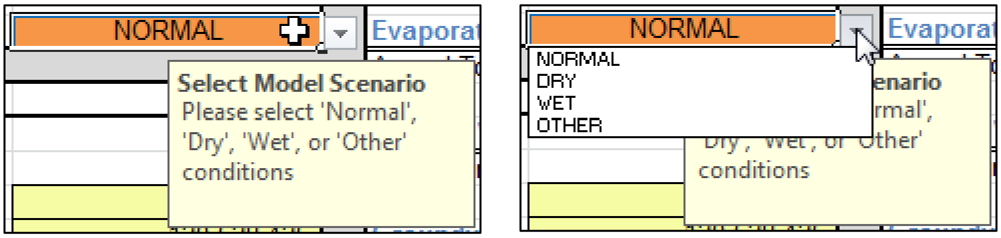
A1.3 Navigation

Throughout the model, cells are colour-coded dependent on their function. Table A1 provides a summary of cell colours and associated meanings throughout the model.

Table A1 – Summary of cell colours.

Cell Colour	Definition
User Input Cells	User Input Cells are editable by the user and contain data specific to Similkameen Aquifer #259.
Calculated Cells	Calculated Cells contain values calculated within the workbook based on data entered by the user.
Scenario/Option Cells	Scenario/Option Cells specify model conditions selected by the user. Available options are provided in a drop-down list.
Unused Cells	Unused Cells indicate values that are not used within the workbook based on the current Scenario/Options selected by the user.

An example of a *Scenario/Option Cell* is provided in Figure A3.



Select Model Scenario
Please select 'Normal', 'Dry', 'Wet', or 'Other' conditions

Figure A3 Example of a Scenario/Option Cell.

In addition, results provided on the ‘Water Budget’ tab are highlighted as shown in Table A2.

Table A2 – Summary of water budget result cell colours.

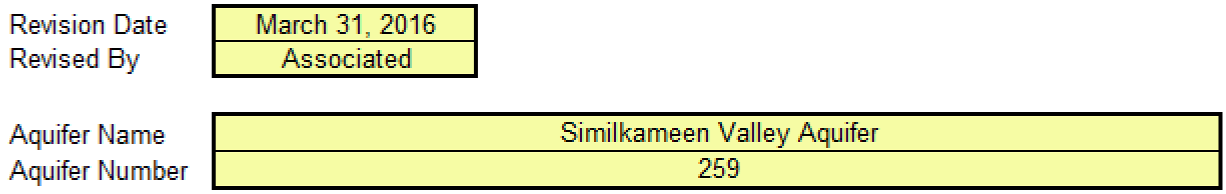
Cell Colour	Definition
Negative Result	Negative result (i.e., Monthly deficit or negative ΔS^{GW} [Simulated]).
Positive Result	Positive result (i.e., Monthly surplus or positive ΔS^{GW} [Simulated]).

A2. INFORMATION TABS

This section provides an overview of information tabs (i.e., ‘Main’ tab and ‘Definitions’ tab) included within the WBM.

A2.1 Main Tab

‘Main’ tab presents an overview of the conceptual model used within the WBM. Within the ‘Main’ tab, the user may enter information pertaining to model revisions (i.e., Revision Date and Revised By), along with aquifer information (i.e., Aquifer Name and Aquifer Number), as shown in Figure A4.



Revision Date	March 31, 2016
Revised By	Associated
Aquifer Name	Similkameen Valley Aquifer
Aquifer Number	259

Figure A4 User defined information presented on the ‘Main’ tab.

A2.2 Definitions Tab

The ‘Definitions’ tab provides information relevant to select model parameters and datasets used within the model. The intention of the definitions provided on this tab is as follows:

- Prompt the user on the different scenario/option selections.
- Provide information on how *Calculated Cells* within the ‘Model Parameters’ tab are determined.
- Provide recommended ranges for select model parameters and references to all data sources.

Additional information related to input data is provided within the main report which accompanies this appendix.

A3. FUNCTIONAL TABS

This section provides an overview of each functional tab included within the WBM. Each subsection provides a step-by-step explanation of each component within individual functional tabs.

A3.1 Model Parameters

The ‘Model Parameters’ tab allows the user to setup the water budget for select conditions. In addition, a summary of data used within the water budget under the select conditions is provided (i.e., all information provided in *Calculated Cells*). The 'Model Parameters' tab includes a selection of *User Input Cells, Calculated Cells,* and *Scenario/Option Cells*. Depending on the select conditions, some cells will be converted to *Unused Cells*.

A3.1.1 Model Scenario

The model scenario section allows the user to select the conditions for the water budget. The following options are provided by the *Scenario/Option Cell*:

- NORMAL = Average conditions, represented by mean monthly data for the latest climate normal period (i.e., 1981-2010).
- DRY = Dry conditions, represented by mean monthly data for 2001.
- WET = Wet conditions, represented by mean monthly data for 1991.
- OTHER = User-defined conditions, represented by 'Other' data on the 'Input Data' tab (see Section A3.3).

Calculated Cells within the 'Model Parameters' tab will be updated based on the model scenario selected by the user.

A3.1.2 System Characteristics

The system characteristics section allows the user to define Aquifer Characteristics and Similkameen River Characteristics. All parameters within this section are *User Input Cells* and should be defined by the user.

A3.1.3 Water Budget Inputs

The water budget inputs section allows the user to define, or select, a number of parameters, as follows:

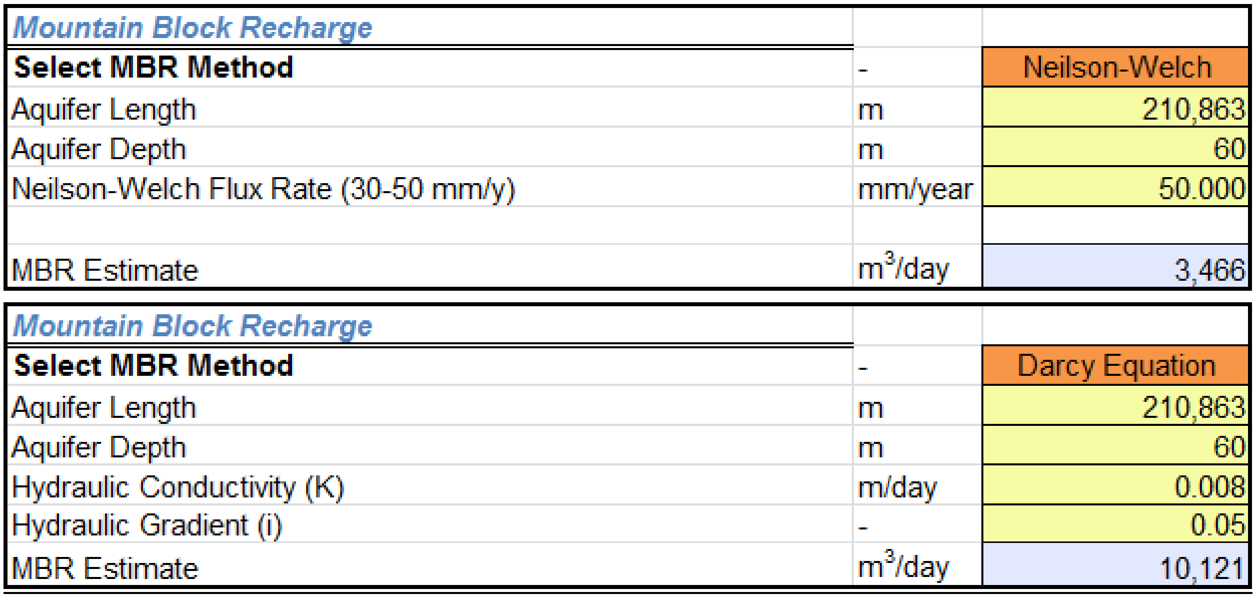
- **Precipitation:** The *Calculated Cell* provides the annual total precipitation based on the selected model scenario. The displayed value is calculated using precipitation data entered on the 'Input Data' tab.
- **Surface Water Inflow:** The *Calculated Cells* provide the mean annual Similkameen River and Tributary inflow estimates based on the selected model scenario. The displayed values are calculated using surface water inflow data entered on the 'Input Data' tab.
- **Aquifer Recharge:** The *Scenario/Option Cell* allows the user to select a monthly distribution for total annual precipitation (i.e., 'Fixed Percentage' or 'Monthly Distribution'). The *User Input Cell* should be used to define the percentage of monthly precipitation that provides recharge to Aquifer #259.
- **Water Demand:** The *Scenario/Option Cell* allows the user to select a distribution option for irrigation return to Aquifer #259 (i.e., 'Fixed Percentage' or 'Monthly Distribution'). The selection initiates the following responses:
  - <u>Fixed Percentage:</u> the *User Input Cell* should be used to enter the percentage of monthly total seasonal water use (i.e., seasonal water demand from both surface water and groundwater sources) that returns to Aquifer #259 (Figure A5).
  - <u>Monthly Distribution:</u> the *User Input Cell* is converted to an *Unused Cell* (Figure A5). Monthly irrigation return percentages are now taken from the monthly distribution provided by the user on the 'Input Data' tab.

Water Demand		
Select Irrigation Return Option	-	Fixed Percentage
Irrigation Return to Aquifer	%	15

Water Demand		
Select Irrigation Return Option	-	Monthly Distribution
Irrigation Return to Aquifer	%	15

Figure A5 Example of different Scenario/Option Cell selections for Irrigation Return. User Input Cell is converted to an Unused Cell if 'Monthly Distribution' is selected.

- **Groundwater Inflow:** The *Calculated Cell* provides an estimate of the groundwater inflow at the upstream boundary of Aquifer #259. All *User Input Cells* should be defined by the user based on aquifer characteristics and suggested Hydraulic Conductivity and Hydraulic Gradient values for Aquifer #259.
- **Mountain Block Recharge:** The *Scenario/Option Cell* allows the user to select a method for estimating Mountain Block Recharge (MBR) for Aquifer #259. The selection initiates the following responses:
  - Neilson-Welch: Three *User Input Cells* will become available (Figure A6). All *User Input Cells* should be defined by the user based on aquifer characteristics and the suggested Neilson-Welch Flux Rate value for Aquifer #259 (50 mm/y).
  - Darcy Equation: Four *User Input Cells* will become available (Figure A6). All *User Input Cells* should be defined by the user based on aquifer characteristics and suggested Hydraulic Conductivity and Hydraulic Gradient values for Aquifer #259.



Mountain Block Recharge		
Select MBR Method	-	Neilson-Welch
Aquifer Length	m	210,863
Aquifer Depth	m	60
Neilson-Welch Flux Rate (30-50 mm/y)	mm/year	50.000
MBR Estimate	m^3/day	3,466

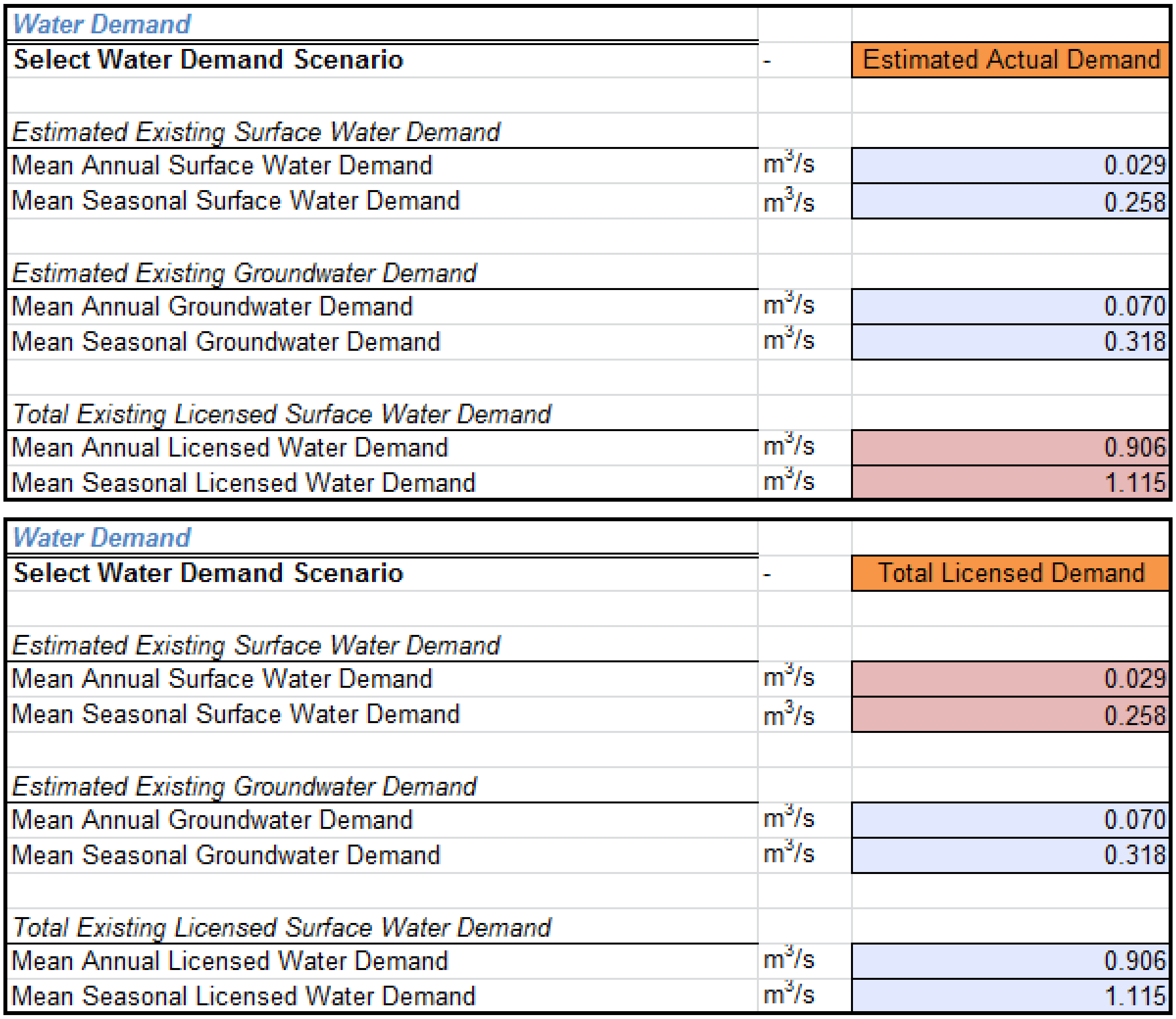
Mountain Block Recharge		
Select MBR Method	-	Darcy Equation
Aquifer Length	m	210,863
Aquifer Depth	m	60
Hydraulic Conductivity (K)	m/day	0.008
Hydraulic Gradient (i)	-	0.05
MBR Estimate	m^3/day	10,121

Figure A6 Example of different Scenario/Option Cell selections for Mountain Block Recharge.

A3.1.4 Water Budget Outputs

The water budget outputs section allows the user to define, or select, a number of parameters, as follows:

- **Evaporation:** The *Calculated Cell* provides the total annual evaporation estimate based on the selected model scenario. The displayed value is calculated using evaporation data entered on the 'Input Data' tab.
- **Surface Water Outflow:** The *Calculated Cell* provides the mean annual Similkameen River outflow estimate based on the selected model scenario. The displayed value is calculated using surface water outflow data entered on the 'Input Data' tab.
- **Groundwater Outflow:** The *Calculated Cell* provides an estimate of the groundwater outflow at the downstream boundary of Aquifer #259. All *User Input Cells* should be defined by the user based on aquifer characteristics and suggested Hydraulic Conductivity and Hydraulic Gradient values for Aquifer #259.
- **Water Demand:** The *Scenario/Option Cell* allows the user to select a water demand scenario (i.e., 'Estimated Actual Demand' or 'Total Licensed Demand'). The selection initiates the following responses:
    - <u>Estimated Actual Demand:</u> The *Calculated Cells* provide the mean annual and mean seasonal water demand from surface water and groundwater sources. The displayed values are calculated using existing water demand data entered on the 'Input Data' tab. The 'Total Existing Licensed Water Demand' cells are converted to *Unused Cells* (Figure A7).
    - <u>Total Licensed Demand:</u> The *Calculated Cells* provide the mean annual and seasonal total licensed water demand. The displayed value is calculated using total licensed water demand data entered on the 'Input Data' tab. This value represents water demand from surface water sources only since no licences currently exist for groundwater sources. In addition, total licensed water demand values do not consider the current scenario (i.e., 'Normal', 'Dry', 'Wet', or 'Other') since water licences are not conditional on climate conditions. The 'Estimated Existing Surface Water' cells are converted to *Unused Cells* (Figure A7).



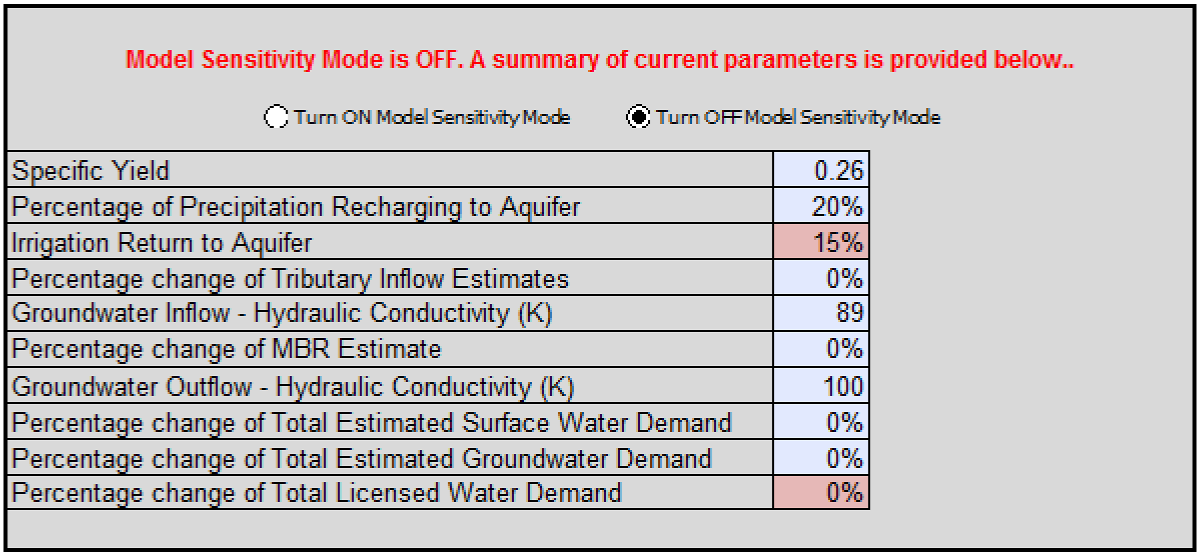
Water Demand		
Select Water Demand Scenario	-	Estimated Actual Demand
Estimated Existing Surface Water Demand		
Mean Annual Surface Water Demand	m^3/s	0.029
Mean Seasonal Surface Water Demand	m^3/s	0.258
Estimated Existing Groundwater Demand		
Mean Annual Groundwater Demand	m^3/s	0.070
Mean Seasonal Groundwater Demand	m^3/s	0.318
Total Existing Licensed Surface Water Demand		
Mean Annual Licensed Water Demand	m^3/s	0.906
Mean Seasonal Licensed Water Demand	m^3/s	1.115

Water Demand		
Select Water Demand Scenario	-	Total Licensed Demand
Estimated Existing Surface Water Demand		
Mean Annual Surface Water Demand	m^3/s	0.029
Mean Seasonal Surface Water Demand	m^3/s	0.258
Estimated Existing Groundwater Demand		
Mean Annual Groundwater Demand	m^3/s	0.070
Mean Seasonal Groundwater Demand	m^3/s	0.318
Total Existing Licensed Surface Water Demand		
Mean Annual Licensed Water Demand	m^3/s	0.906
Mean Seasonal Licensed Water Demand	m^3/s	1.115

Figure A7 Example of different Scenario/Option Cell selections for Water Demand.

A3.1.5 Model Sensitivity/Summary

The model sensitivity/summary section provides a summary of current parameter values used within the WBM (Figure A8). If model sensitivity mode is ON (see Section A3.4), a number of *Calculated Cells* and *User Input Cells* within the 'Model Parameters' tab are converted to *Unused Cells* as calculations are updated using values determined on the 'Model Sensitivity' tab (see Section A3.4). If model sensitivity mode is OFF, parameter values specified within the 'Model Parameters' tab are used within the WBS calculation and no percentage adjustments are applied.



Model Sensitivity Mode is OFF. A summary of current parameters is provided below..

○ Turn ON Model Sensitivity Mode ● Turn OFF Model Sensitivity Mode

Specific Yield	0.26
Percentage of Precipitation Recharging to Aquifer	20%
Irrigation Return to Aquifer	15%
Percentage change of Tributary Inflow Estimates	0%
Groundwater Inflow - Hydraulic Conductivity (K)	89
Percentage change of MBR Estimate	0%
Groundwater Outflow - Hydraulic Conductivity (K)	100
Percentage change of Total Estimated Surface Water Demand	0%
Percentage change of Total Estimated Groundwater Demand	0%
Percentage change of Total Licensed Water Demand	0%

Figure A8 Model Sensitivity/Summary section.

A3.2 Input Data

The 'Input Data' tab allows the user to enter data for many components of the water budget. The 'Input Data' tab consists of *User Input Cells* and *Calculated Cells*. Depending on the conditions selected on the 'Model Parameters' tab, some cells will be converted to *Unused Cells*.

A3.2.1 Water Budget Inputs and Water Budget Outputs

All data for 'Normal', 'Dry', and 'Wet' scenarios have been entered by Associated. Information on data origins and calculations is provided within the main report which accompanies this appendix.

Many data components provide *User Input Cells* for an 'Other' scenario, enabling the user to enter data for a specific condition/scenario. The 'Other' model scenario (see Section A3.1.1) should be selected to compute the water budget using these data. This option could be used to compute the water budget for a particular year (i.e., by entering data for a particular year).

A3.2.2 Model Calibration Data – Observation Well Data

Currently, the water budget is calibrated using groundwater level data from the Keremeos Observation Well (Observation Well 75). All data for 'Normal', 'Dry', and 'Wet' scenarios have been entered by Associated. A series of *User Input Cells* are provided to allow the user to enter groundwater level data from a second observation well to alter the calibration.

The 'Mean Groundwater Level' is currently calculated using only data provided by Associated (i.e., for Keremeos [Observation Well 75]). However, the *Calculated Cells* are formatted to update if groundwater data from a second observation well are entered into the blank *User Input Cells*.

A3.3 Water Budget

The 'Water Budget' tab provides the results of the monthly water budget for the scenario and conditions selected on the 'Model Parameters' tab. Results are calculated following procedures outlined within the main report which accompanies this appendix. This tab features no *User Input Cells*. Water demand cells are converted to *Unused Cells* based on the water demand scenario selected on the 'Model Parameters' tab (i.e., 'Estimated Actual Demand' or 'Total Licensed Demand').

If model sensitivity mode is ON, results are updated using parameters/adjustments specified on the ‘Model Sensitivity’ tab (see Section A3.4). If model sensitivity mode is OFF, parameters specified on the ‘Model Parameters’ page are used within calculations, and no adjustments are made to data entered on the ‘Input Data’ tab.

The ‘Result’ cells are coloured as described in Table A2.

A3.4 Model Sensitivity

The ‘Model Sensitivity’ tab allows the user to adjust select parameters and alter tributary inflow, water demand, and MBR estimates by a select percentage. A series of scroll bar controls are provided to allow the user to alter select parameters within a pre-determined range. To observe the influence of each modification on ΔS^{GW} (Simulated), the user must turn model sensitivity mode ON—this can be completed on either the ‘Model Sensitivity’ tab or the ‘Model Parameters’ tab (Figure A9).

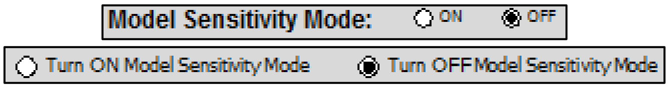
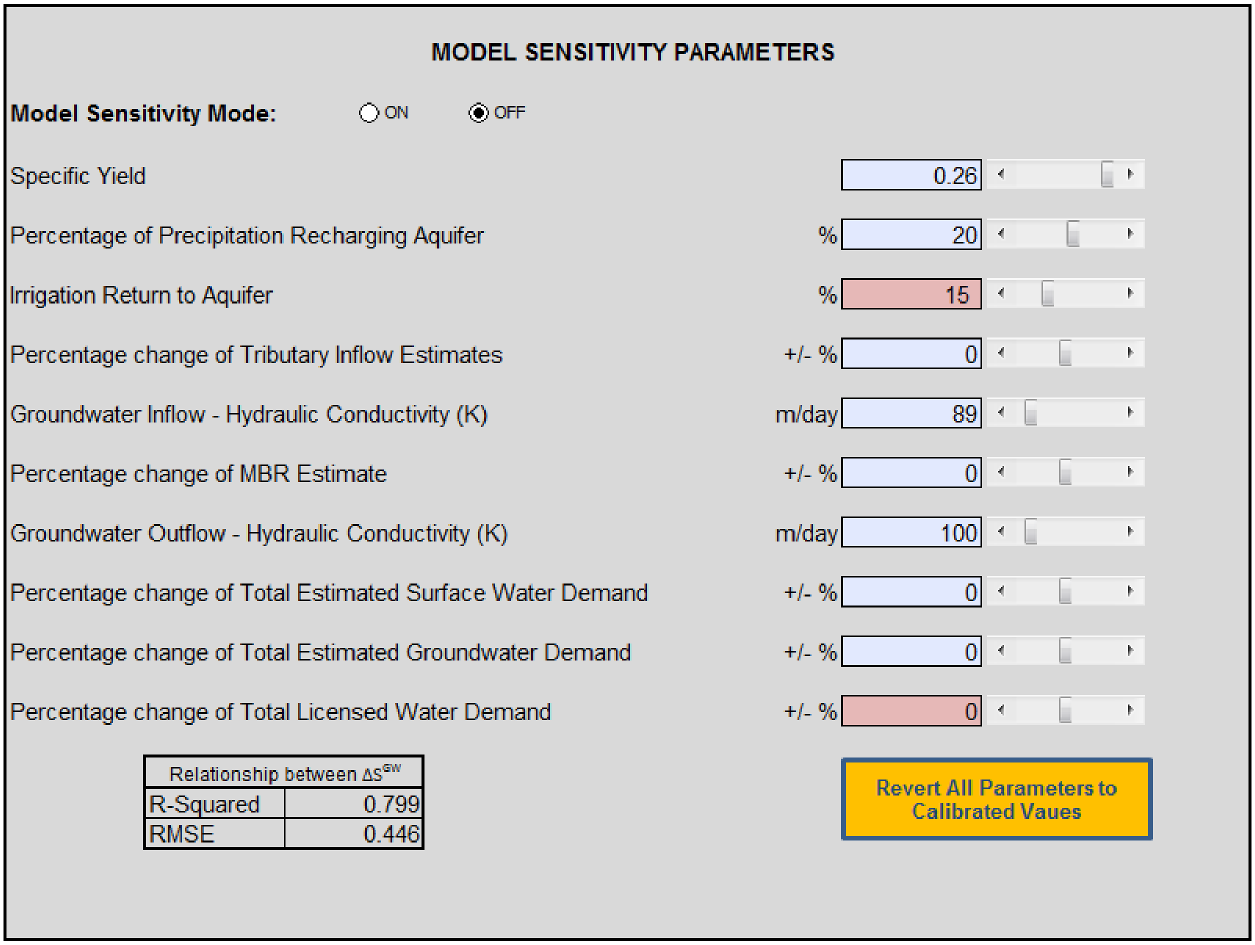


Figure A9 Model sensitivity mode controls

Plots of change in aquifer storage and groundwater levels are included within the ‘Model Sensitivity’ tab to allow the user to visualise the effect of varying parameters. Parameters modified on the ‘Model Sensitivity’ tab become superior to those on the ‘Model Parameters’ page when model sensitivity mode is ON. Accordingly, a number of *Calculated Cells* and *User Input Cells* within the ‘Model Parameters’ tab are converted to *Unused Cells* when model sensitivity is ON. A summary of values currently used for each parameter is provided on the ‘Model Parameters’ page – these values are updated depending on whether model sensitivity mode if ON or OFF.

The ‘Model Sensitivity’ tab provides a button to revert all parameters to calibrated values (Figure A10). By selecting this button, all parameters on the ‘Model Parameters’ tab are reset to calibrated values, and sensitivity adjustments are reset to zero or the calibrated values.


MODEL SENSITIVITY PARAMETERS

Model Sensitivity Mode: ○ ON ● OFF

Specific Yield		0.26
Percentage of Precipitation Recharging Aquifer	%	20
Irrigation Return to Aquifer	%	15
Percentage change of Tributary Inflow Estimates	+/- %	0
Groundwater Inflow - Hydraulic Conductivity (K)	m/day	89
Percentage change of MBR Estimate	+/- %	0
Groundwater Outflow - Hydraulic Conductivity (K)	m/day	100
Percentage change of Total Estimated Surface Water Demand	+/- %	0
Percentage change of Total Estimated Groundwater Demand	+/- %	0
Percentage change of Total Licensed Water Demand	+/- %	0

Relationship between Δs^{GW}	
R-Squared	0.799
RMSE	0.446

Figure A10 Overview of model sensitivity control and parameter reset button.

A3.5 Model Output

The **‘**Model Output’ tab provides a summary of model results and allows the user to explore the influence of future surface water and groundwater extraction licences on streamflows within the Similkameen River and groundwater levels within Aquifer #259. In addition, the ‘Model Output’ tab is formatted to print onto one sheet of paper if scaling is selected when printing. The ‘Model Output’ tab is separated into four main sections, as explained in this section.

A3.5.1 System Net

The system net section provides the net results of the water budget for the scenario and conditions selected on the ‘Model Parameters’ tab, and any adjustments performed within the ‘Model Sensitivity’ tab if model sensitivity mode is ON (see Section A3.4). In addition, the following *Calculated Cells* and *User Input Cells* are provided:

- **Estimated Similkameen River Outflow:** These *Calculated Cells* return the mean monthly Similkameen River outflow estimates for the scenario and conditions selected on the ‘Model Parameters’ tab. Similkameen River outflow estimates are altered depending on the water demand option selected on the ‘Model Parameters’ tab (see Section A3.1.4). The selection initiates the following response:
    - Estimated Actual Demand: Monthly Similkameen River streamflow values entered on the ‘Input Data’ tab are used to represent existing streamflow conditions at the downstream boundary of Aquifer #259.

    - Total Licensed Demand: Monthly streamflow values entered on the ‘Input Data’ tab are naturalized (i.e., estimated actual surface water demand is added back onto Similkameen River outflow estimates) and the total licensed water demand is then removed from naturalized streamflow estimates at the downstream boundary of Aquifer #259.

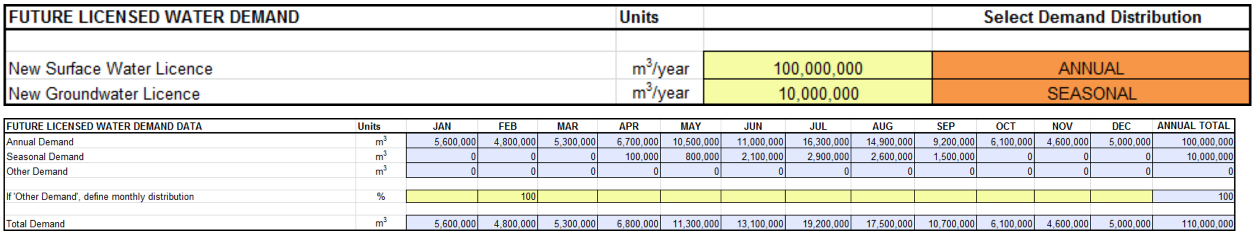
  Streamflow estimates do not account for adjustments to estimated actual or total licensed water demand performed within the ‘Model Sensitivity’ tab. In addition, adjustments to tributary inflow estimates do not affect streamflow estimates presented on the ‘Model Output’ tab.

- **Environmental Flow Needs (Spawning and Rearing):** These *User Input Cells* should be used to enter environmental flow needs determined for the Similkameen River. Two different thresholds (i.e., spawning and rearing) can be specified for different time periods. The environmental flow needs entered here are plotted on the estimated Similkameen River outflow graph to provide a visual comparison of estimated future streamflows and the required environmental flow needs.
- **Effect of Future Water Demand:** These *Calculated* Cells display the effect of future water demand (see Section A3.5.2) on the following:
    - Surplus/Deficit: Monthly future surface water and groundwater extraction licences are removed from the net surplus/deficit result.
    - ΔS^{GW} (Simulated): ΔS^{GW} (Simulated) values are adjusted to demonstrate the influence of future water demand on groundwater levels within Aquifer #259.
    - Estimated Similkameen River Outflow Values: Estimated Similkameen River streamflow estimates at the downstream boundary of Aquifer #259 are adjusted to demonstrate the effect of new licensed water demands (i.e., surface water and groundwater sources) on Similkameen River outflows.

A3.5.2 Future Licensed Water Demand

The future licensed water demand section allows the user to enter new surface water or groundwater source licence amounts into the *User Input Cells* and select a distribution for each using the *Scenario/Option Cells* (Figure A11).

If ‘annual’ or ‘seasonal’ demand is selected, the defined annual volume is automatically distributed monthly based on the distribution selected by the user (Figure A11). The user can select ‘other’ demand and define a monthly percentage distribution manually within the *User Input Cells* provided. The defined annual volume is then automatically distributed based on the user defined monthly distribution. The total future demand (i.e., future surface water demand and future groundwater demand) is used to adjust results in the system net section (see Section A3.5.1) to display the effect of future water demand.



FUTURE LICENSED WATER DEMAND	Units		Select Demand Distribution
New Surface Water Licence	m^3/year	100,000,000	ANNUAL
New Groundwater Licence	m^3/year	10,000,000	SEASONAL

FUTURE LICENSED WATER DEMAND DATA	Units	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
Annual Demand	m^3	5,600,000	4,800,000	5,300,000	6,700,000	10,500,000	11,000,000	16,300,000	14,900,000	9,200,000	6,100,000	4,600,000	5,000,000	100,000,000
Seasonal Demand	m^3	0	0	0	100,000	800,000	2,100,000	2,900,000	2,600,000	1,500,000	0	0	0	10,000,000
Other Demand	m^3	0	0	0	0	0	0	0	0	0	0	0	0	0
If 'Other Demand', define monthly distribution	%		100											100
Total Demand	m^3	5,600,000	4,800,000	5,300,000	6,800,000	11,300,000	13,100,000	19,200,000	17,500,000	10,700,000	6,100,000	4,600,000	5,000,000	110,000,000

Figure A11 Example of user defined future licensed water demand volumes and distributions.

A3.5.3 Output Graphs

Two main output graphs are provided on the 'Model Output' tab:

- Estimated Similkameen River Outflow: The streamflow graph displays the following for each climate scenario:
  - Estimated Similkameen River streamflow at the downstream boundary of Aquifer #259 (see Section A3.5.1);
  - Estimated future streamflows assuming that a new licence (i.e., surface water or groundwater) is removed from the Similkameen River;
  - A safety factor displaying the range between naturalized Similkameen River streamflows and streamflows under maximum licensed conditions across Aquifer #259.
  - Environmental flow needs for rearing and spawning.
- Δh^{GW} (Simulated): The Δh^{GW} (Simulated) graph displays the following for each climate scenario:
  - Calibrated change in groundwater level (Δh^{GW} [Simulated]) ;
  - Estimated future change in groundwater level following the removal of a new water licence under actual surface and groundwater use conditions;
  - A safety factor of ±25% of the absolute mean monthly Δh^{GW} (Simulated) was calculated and assumed constant throughout the year;
  - Estimated future change in groundwater level following the removal of a new water licence under maximum licensed water use and actual groundwater use conditions;
  - Observed change in groundwater level (i.e., recorded by Well 75 [Keremeos]) included for comparison purposes; and
  - Groundwater level allocation threshold.

A3.5.4 Surface Water and Groundwater Component Summary

The final section within the 'Model Output' tab provides estimates of the following for each of surface water and groundwater:

- Monthly surplus/deficit for the select scenario and conditions;
- Δh Surface water and Groundwater components; and
- Δh Surface water and Groundwater components including any new licensed volume.

Estimates provided in this section are based on the assumption that new surface water licences influence only surface water components, and new groundwater licences influence only groundwater components.