Appendix B – Groundwater - Surface Water Interaction (GW-2)

FINAL REPORT

Regional District of Okanagan-Similkameen

Similkameen River Watershed: Groundwater - Surface Water Interaction (GW-2)

June 2015

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1 Introduction

1.1 PROJECT BACKGROUND

The Similkameen Valley Planning Society (SVPS) and the Regional District of Okanagan Similkameen (RDOS) are currently developing the Similkameen Watershed Plan (SWP). To support the planning process, RDOS retained Summit Environmental Consultants Inc. (Summit) to complete a number of technical studies to advance the understanding of water resources in the Similkameen watershed. This report presents the results of the groundwater-surface water interaction assessment. It was completed as a component of Phase 2 of the SWP. It was preceded by the Phase 1 study, which was completed in 2014 (Summit 2014).

1.2 PROJECT OBJECTIVES AND TASKS

One of the high priority information gaps identified during the Phase 1 study was to analyse existing hydrometric, water use, and groundwater data for evidence of groundwater-surface water (GW-SW) interaction; specifically, groundwater withdrawal effects on streamflows (Summit 2014). Therefore, building upon previous assessments and the information collected during Phase 1, the ultimate objective of the Phase 2 GW-SW interaction study was to identify one or more site-specific locations where data suggests that GW-SW interaction could be reducing surface flows and to recommend a follow up study design for detailed assessment. To meet this objective, the specific tasks that were completed were as follows:

1. Identify several key locations along the Similkameen River where GW-SW interactions are or could be a management issue;
    a. Compile hydrometric data for these key locations and standardize the data to a common time period to eliminate climatic variability (if necessary);
    b. Compute the runoff at each of the key locations on a monthly basis, both for specific years of interest and for an average year;
    c. Analyze downstream changes in runoff along the river to identify any anomalies and compare to the locations of known wells; and
    d. Investigate the possible use of shallow groundwater in any areas where runoff results seem anomalous and confirm the potential for a groundwater withdrawal effect on surface water.
2. Plot the existing B.C. Ministry of Forests, Lands, and Natural Resource Operations observation well groundwater level data against Water Survey of Canada level data from the nearest hydrometric stations to determine if there are any linkages and the nature of such linkages;
3. Review the available water quality data from the Similkameen River and shallow groundwater wells to confirm the potential for a GW-SW linkage; and
4. Recommend one or more site-specific study locations for where the data suggests the potential for a GW-SW interaction could be occurring and reducing surface water flows.

2 Methods

2.1 PREVIOUS STUDIES

The Phase 1 study for the SWP identified only one investigation of GW-SW interaction in the Similkameen River watershed. That study was completed by Golder Associates Ltd. (2012) and included a groundwater under the direct influence of surface water (GUDI) assessment for review of the hydraulic connection of the Keremeos Irrigation District (KID) water supply wells to the Similkameen River. That study was not publically available at this time of this report, so a summary of results cannot be provided.

However, in support of groundwater protection planning for KID, Golder Associates Ltd. (2008) developed a numerical model to estimate 100-day and one-year travel time capture zones[1] from three well fields located 200 m, 850 m, and 1,000 m from the Similkameen River. The results indicated that the 100-day capture zone for the well field located 200 m away reached the river, while the one-year capture zone for the well field located 800 m away also reached the river. Note that the results were modelled only and were not field verified by monitoring groundwater levels closer to the Similkameen River. Still, the results suggested that large water supply wells (or well fields) located a fair distance from the Similkameen River can draw water from the river into the corresponding aquifer (Golder 2008).

Based on the results from Golder (2008), there is evidence to indicate a strong hydraulic connection between groundwater and surface water in the Similkameen River watershed near the Village of Keremeos. Therefore, given that a large number of wells are located close to the river throughout the watershed and that there is similar surficial geology throughout the river valley, there is potential for similar hydraulic connections elsewhere.

As a result, the following sections describe the methods used to identify key locations within the Similkameen River watershed where GW-SW interaction may be occurring and to attempt to quantify the amount of interaction.

2.2 IDENTIFICATION OF KEY GW-SW INTERACTION LOCATIONS

2.2.1 Initial Screening

Given the large number of registered water wells (i.e. more than 1,800 wells) within the watershed and the limited amount of previous GW-SW interaction investigations, an initial screening exercise was completed to identify key locations where surface water could be influenced by groundwater withdrawals. The screening assessment involved two tasks:

1. **Mapping all registered wells within the watershed boundaries and screening by GW-SW interaction potential.** After mapping the location of all registered wells included in the provincial database, all wells that were ≤6-inch diameter and located more than 100 m from a stream, and all

[1] A capture zone is defined as the spatial region surrounding a water supply well, in which water will flow into a well within a period of time (Toews and Allen 2007).

wells >6-inch diameter and located more than 300 m from a stream were eliminated from further study. The remaining wells were judged to be those with the greater potential to interact with surface water. Note that the 100 m setback is consistent with the procedures for identifying GUDI in B.C. (B.C. Ministry of Health 2012), while the 300 m setback is consistent with the arbitrary fixed radius method for defining capture zones (B.C. MOE 2006). For the latter, the 300 m setback distance is more appropriate for larger-diameter wells because these wells tend to pump at higher rates, which means that their capture zones tend to be larger.

2. **Identifying areas with potentially high groundwater extraction rates and surface water influence.** After the screening exercise was completed, the number of wells that met both criteria were sorted by sub-basin (as identified in the Phase 1 study) (Figure 2-1). Within each sub-basin, key locations where potential GW-SW interaction was occurring were identified through review of locations of high well density (particularly with wells >6-inch diameter) and potentially high cumulative extraction rates.

In addition to the screening assessment, discussions with the B.C. Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) were completed to ascertain whether known or assumed areas of GW-SW interaction within the Similkameen River watershed had previously been identified. The representative from FLNRO indicated that no areas were known outside of those identified in the public record (i.e. through review of the B.C. Ministry of Environment Ecological Reports Catalogue) (Pyett, pers. comm., 2014). A review of the public record was completed in the Phase 1 study and upon further review herein, no new information was gained.

2.2.2 Streamflow Compilation Review – Losing and Gaining Streamflows

2.2.2.1 Key SW-GW Interaction Locations

Following the methods in 2.2.1, numerous locations were identified for potential GW-SW interaction with the Similkameen River and tributaries. However, due to the high density of wells and population base, two key GW-SW interaction locations were identified as the locations with the highest probability of GW-SW interaction occurring. The two locations are as follows:

- **Key GW-SW Interaction Location 1 –** Similkameen River near Keremeos and Cawston
    - This location includes the area of Aquifer 259[2] from 4 km east of the mouth of the Ashnola River to Bearcroft River Road south of the Village of Keremeos (located in Sub-basin #9; Figure 2-1 and upcoming Figure 3-1).

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[2] Aquifer 259 is a mapped aquifer that represents the deposit of sands and gravels in the main Similkameen River valley bottom extending from the U.S. border to Princeton (Summit 2011). It is rated as a Class IIA aquifer by FLNRO meaning that aquifer demand is moderate relative to productivity, but that is highly vulnerable to surface contamination (Summit 2011). The spatial extent of Aquifer 259 is provided in Map 2 of Summit (2014) and in upcoming Figure 3-1.

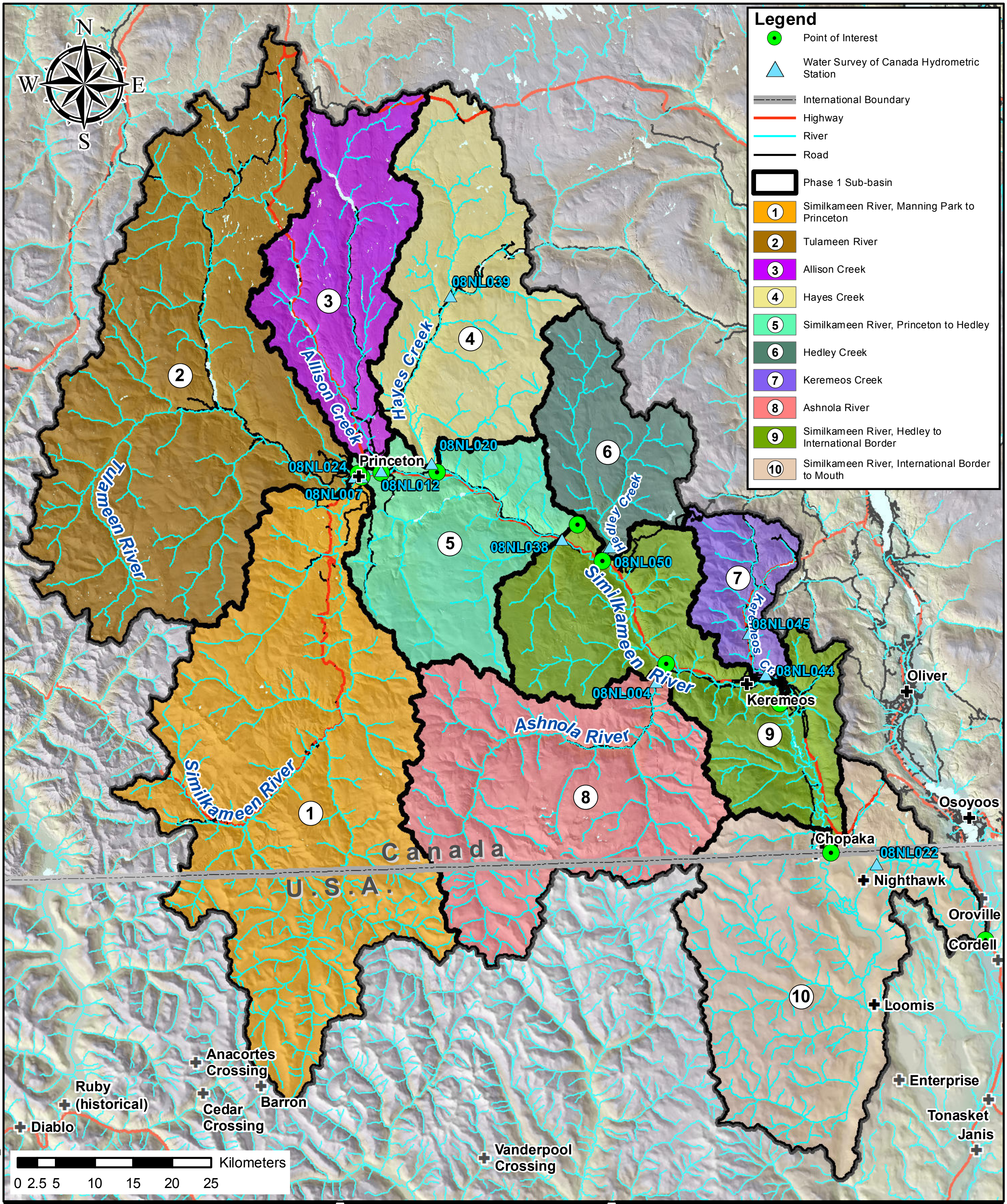

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FIGURE 2-1: SUB-BASINS AND POINTS OF INTEREST IN THE SIMILKAMEEN WATERSHED

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Similkameen Watershed Plan - Phase 2

- **Key GW-SW Interaction Location 2 –** Keremeos Creek Valley
  - This location includes the area of Aquifer 935[3] from the settlement of Olalla south to the Village of Keremeos (located in Sub-basin #7, Figure 2-1 and upcoming Figure 3-1).

Following this, to assess whether groundwater withdrawals are affecting streamflows at or near the key locations, hydrometric information from the Water Survey of Canada and net[4] and naturalized[5] streamflow estimates at selected points-of-interest within the Similkameen River watershed (Figure 2-1) (developed by Summit [2015a]) were compiled where available. The goal of the compilation was to identify relevant datasets and to review associated streamflow records at upstream and downstream locations of the two key locations for evidence of GW-SW interaction.

Generally, evidence of GW-SW interaction includes the identification of losing or gaining streamflows in available streamflow records. **Gaining streams** are those where downstream streamflow is greater than upstream streamflow because of surface and groundwater inflows, while **losing streams** are those that lose water as they flows downstream. Note that the reasons for a stream to be "losing" can be natural or human-caused, as follows:

- Under natural conditions, a stream on an alluvial fan that is raised and the water table beneath the stream is separated by an unsaturated, or dry, permeable (coarse) zone, can "lose" flow to the unsaturated zone as it migrates downstream. Additionally, losing conditions can also occur due to local topographic changes, when the water table becomes lower than the invert (or bottom) of the river/stream. In either situation, aquifers are getting recharged by "losing" streams, and streamflows are being reduced downstream.
- Losing stream conditions can be human-caused, created by the pumping of nearby groundwater supply wells with capture zones that include a stream/river. In locations where there is a high hydraulic connectivity between the aquifer and a stream/river, groundwater pumping can draw water from the stream/river and cause a reduction in surface streamflows.

With this in mind, a summary of the streamflow compilation and review completed at the two key GW-SW interaction locations is as follows:

Key GW-SW Interaction Location 1 – Similkameen River near Keremeos and Cawston
For this location, the nearest upstream hydrometric station on the Similkameen River (i.e. WSC Station No. 08NL038) is located about 30 km upstream of the Village of Keremeos, while the nearest downstream hydrometric station is over 50 km downstream (i.e. WSC Station No. 08NL022) (Figure 2-1). As a result, there was not sufficient local data to complete a direct upstream/downstream streamflow comparison or

[3] Aquifer 935 is a mapped aquifer that represents the deposit of sands and gravels in the Keremeos Creek valley (Summit 2014). It is rated as a Class IIB aquifer by FLNRO meaning that aquifer demand is moderate relative to productivity, with a moderate vulnerability to surface contamination (Summit 2014). The spatial extent of Aquifer 259 is provided in Map 2 of Summit (2014) and in upcoming Figure 3-1.

[4] Net streamflows are streamflows that include water extractions and storage effects upstream.

[5] Naturalized streamflows are streamflows that are estimates of natural flows adjusting net flows for the effects of water withdrawals and storage.

general review of streamflow water levels during periods of high groundwater pumping (i.e. irrigation season).

Key GW-SW Interaction Location 2 – Keremeos Creek Valley

For this location, two WSC hydrometric stations have been historically located on Keremeos Creek (Figure 2-1):

- Keremeos Creek below Willis Intake (WSC Station No. 08NL045; Drainage Area = 181 km^2; Period of Record = 1971-2013); and
- Keremeos Creek at Middle Bench Road (WSC Station No. 08NL044; Drainage Area = 221 km^2; Period of Record = 1971-1977)

The hydrometric stations are located within the identified key GW-SW interaction location at upstream (WSC Station No. 08NL045) and downstream (WSC Station No. 08NL044) points. Accordingly, periods of overlapping data (i.e. mean monthly seasonal [April to October] records from 1971-1977) were compiled and the upstream and downstream streamflows were compared. Note that both hydrometric stations are identified by the WSC to be measuring regulated or net streamflows. No water use information was available for the overlapping period of record (Summit 2014); therefore, the net streamflows were used as the best surrogate to assess losing or gaining streamflows and potential groundwater withdrawal effects.

2.2.2.2 Similkameen River – Headwaters to Mouth

As part of the companion Phase 2 water availability and risk study (Summit 2015a), median monthly net and naturalized streamflows and the 1 in 10-year and 1 in 50-year return period mean monthly low net streamflows were calculated at 10 points of interest (POI) within the Similkameen River watershed (Figure 2-1). The median values were for a 1981-2010 standard period, which represents the most current 30-year “normal” period. Included in the 10 POIs identified by Summit (2015a), four POIs are located on the Similkameen River (Figure 2-1), as follows:

- POI #1 – Similkameen River above the Tulameen River Confluence;
- POI #5 – Similkameen River near Hedley (at WSC Station No. 08NL038);
- POI #9 – Similkameen River at the International Border; and
- POI #10 – Similkameen River at the Mouth.

Following this, an additional assessment was completed to review whether the Similkameen River was losing or gaining streamflows from the headwaters to the mouth. This assessment was completed to help identify other areas within the watershed where losing streamflow conditions may be occurring, which could help identify additional areas where groundwater extraction may be reducing streamflows.

For this assessment, the mean monthly streamflows for September were compared for each POI (i.e. #1, #5, #9, and #10) from the most upstream to the most downstream. The September mean monthly streamflows were selected, as they represent the month during the irrigation season with the lowest streamflows and generally high groundwater withdrawals.

2.2.3 Assessing Groundwater Withdrawal Effects on Streamflows

Because natural losing streamflow conditions are not uncommon for streams flowing across alluvial deposits in certain hydrogeological settings, an alternative approach was used to assess whether groundwater withdrawals have the potential to affect streamflows at the key GW-SW interaction locations. This alternative approach was used to support the results of the streamflow compilation assessment described above (Section 2.2.2).

Under normal gaining streamflow conditions, groundwater flow contributes to streamflows downstream, and the component of groundwater flow into surface water, is referred to as baseflow. The amount of baseflow generally varies throughout the year and can vary between watersheds based on hydrogeologic conditions. In addition, the amount of baseflow contribution to surface water can be reduced due to groundwater withdrawals from wells. Accordingly, it is theoretically possible that if groundwater withdrawal through wells is sufficiently large, baseflows could be drastically reduced to the point where surface flows could infiltrate into the corresponding aquifer to make up for the deficit and thus losing stream conditions are artificially created.

Following this, an assessment of the net groundwater flow contribution to surface water at each of the key GW-SW interaction locations was completed to review groundwater withdrawals in comparison to groundwater recharge. For this assessment, all groundwater recharge by upgradient aquifer contribution and direct precipitation was assumed to naturally discharge to a stream/river and is equal to natural baseflow. The entire aquifer recharge areas in which the key locations are situated were considered to be the following:

- Aquifer 259 (Similkameen River valley) – portion of aquifer within Sub-basin #9 only; and
- Aquifer 935 (Keremeos Creek valley) – entire aquifer within Sub-basin #7.

As noted above, the amount of baseflow can be reduced by groundwater withdrawal from wells. Therefore, the resulting amount of groundwater discharge making it to a stream/river can be referred to as net groundwater discharge (or net baseflow) and can be calculated as follows:

$$Q_{\text{Net Discharge}} = Q_{\text{Recharge}} - Q_{\text{Withdrawals}} \qquad \textbf{Eq. 2-1}$$

where:

$Q_{\textit{Net Discharge}}$ = net groundwater discharge to a stream/river, also known as net baseflow (m^3/s)
$Q_{\textit{Recharge}}$ = groundwater flow and precipitation that is reaching the aquifer, also known as natural baseflow (m^3/s)
$Q_{\textit{Extraction}}$ = groundwater withdrawals from an aquifer (m^3/s)

Using Eq. 2-1, net baseflows were estimated for each key GW-SW interaction location. The following describes the methods to estimate each term.

Groundwater Recharge ($Q_{Recharge}$)

Recharge to an aquifer has five potential sources as identified by Golder and Summit (2009) and Alley et al. (1999). The five sources (and corresponding estimation procedure or values) are as follows:

1. Recharge from precipitation that infiltrates through the unsaturated zone to the water table.
   - Recharge from precipitation was considered for the alluvial aquifer only and for three separate recharge values: 5% (low), 8% (intermediate), and 30% (high). The 5% and 30% recharge values were assumed possible low and high ranges of recharge from precipitation, while the 8% recharge value was consistent with that used by Golder (2004; 2008) for groundwater protection planning purposes for the KID.

2. Losses from streams and other bodies of surface water such as lakes and wetlands.
   - River losses from the Similkameen River (near Keremeos) and Keremeos Creek were estimated based on numerical groundwater modelling completed by Golder (2008). For the Similkameen River, Golder (2008) estimated that river losses were 14,940 m^3/day; while for Keremeos Creek the losses were estimated to be 16,200 m^3/day. Golder (2008) applied both of these losses to Aquifer 259.
   - For estimation purposes, it was assumed that the only river losses occurring in Sub-basin #9 are in the area at Keremeos. Accordingly, the Golder (2008) river loss values were only applied to Aquifer 259 at Keremeos. This is a conservative assumption and is based on no other estimates for streamflow losses being available for other sections of Aquifer 259. It is also assumed that the Golder (2008) river loss estimates are consistent on a daily basis. These assumptions are supported by the results from Section 3.1.2 that indicates Similkameen River is gaining as it moves downstream.
   - For Aquifer 935, it was assumed that creek losses were equivalent to those estimated by Golder (2008) for Keremeos Creek and consistent on a daily basis. This assumption is generally consistent with the losing stream information identified for Keremeos Creek (Section 3.2.2).

3. Irrigation return flows.
   - Return flows were not considered to recharge groundwater because groundwater withdrawals were largely based on estimates provided by the B.C. Ministry of Agriculture's Agricultural Water Demand Model (AWDM) (van der Gulik et al. 2013), which includes irrigation estimates under optimal conditions (i.e. no overwatering by farmers – the crops receive only the necessary amount of water for growing optimal growth).

4. Upgradient bedrock aquifers.
   - There is a component of flow to the aquifers from bedrock and shallow thin alluvial aquifers along the sides of the aquifer; however, give the relatively large streamflows and alluvial aquifers that exist at the key GW-SW interaction locations, it has been assumed that this component is negligible. This assumption is consistent with approaches used by Golder (2008) and Golder and Summit (2009).

5. Upgradient alluvial aquifers.
    - For key GW-SW Interaction Location 1 (Similkameen River near Keremeos and Cawston), Aquifer 259 extends both upgradient and downgradient. As such, there is a component of groundwater inflows and outflows through the aquifer. Based on the geometry of the Similkameen River valley, it is assumed that Aquifer 259 is relatively consistent (i.e. transmissivity) through the key GW-SW interaction area. Therefore, it is assumed that the groundwater inflows are roughly equal to the outflows and therefore no net change. Note that for key GW-SW Interaction Location 2 (Keremeos Creek Valley), the same assumptions were used given that the mapped aquifer and withdrawal areas closely coincide.

Groundwater Withdrawals ($Q_{Withdrawals}$)

For each key GW-SW interaction location, water use information summarized by Summit (2015a) for the standard period (1981-2010) for sub-basins #7 (Keremeos Creek) and #9 (Similkameen River, Hedley to International Border) was used to represent groundwater withdrawals. This information included actual water use records (from the Phase 1 study) and irrigation water demands from the AWDM. Note that the AWDM was developed to provide current and future agriculture water demand (including both crop irrigation and livestock watering) on a property by property and total basin basis. More information about the AWDM is presented in Summit (2015a).

Note that the groundwater withdrawals summarized by Summit (2015a) were assumed representative of water use within each key GW-SW interaction location. This is likely an overestimate since the key locations only represent a small portion of each sub-basin. However, due to the lack of withdrawal information at smaller geographic scales and that the identified key locations have the highest concentrations of registered wells within each sub-basin; these estimates were felt to conservatively represent groundwater withdrawals.

2.3 OBSERVATION WELL ASSESSMENT

2.3.1 Comparison of Observation Well Data to Surface Water Data

Another way to investigate the linkages between groundwater and surface water is to compare either groundwater levels or quality data to nearby streamflow levels or quality data, respectively, to evaluate for apparent relationships. In the Similkameen River watershed, there are three active and three inactive FLNRO observation wells for which groundwater level data are available (Table 2-1 and upcoming Figure 3-1). In addition to the groundwater level data collection, the observation wells have been periodically sampled for water quality analysis.

Table 2-1 Observation wells within the Similkameen River watershed

Location	Well No.	Status	Years of Available Data	Number of Water Quality Samples Collected[1]
Keremeos	75	Active	1963 - 2013	6
	76	Inactive	1969 - 2002	4
	77	Inactive	1969 - 2002	1
Cawston	203	Active	1977 - 2011	3
	264	Active	1980 - 2000	3
Princeton	220	Inactive	1977 - 1999 (plus sporadic data in 2000)	3

Notes:
1. According to the B.C. Environmental Monitoring System Web Reporting (http://www.env.gov.bc.ca/emswr/).

The locations of the observation wells were assessed relative to the locations of nearby WSC hydrometric stations to determine whether any wells and hydrometric stations were within close proximity of each other and had overlapping datasets. A summary of the location assessment concluded the following:

- Active observation Wells 75 (Keremeos) and 203 (Cawston) are of particular interest because they are installed within the mapped sand and gravel aquifer along the river valley (i.e. Aquifer 259) and are generally located in key GW-SW Interaction Location 1. No WSC hydrometric station(s) on the Similkameen River were located in close proximity for comparison purposes; however, a discontinued station on Keremeos Creek (WSC Station No. 08NL044) included a period of overlapping record with Well 75 (Keremeos);
- Inactive observation Well 220 has been inactive since 1999; however, two WSC hydrometric stations (WSC Station No. 08NL007 and 08NL024) were located in close proximity to the well location (but both upstream of the Tulameen River and Similkameen River confluence); and
- Active observation Well 264 was not included because it is installed in bedrock above the Similkameen River valley.

Note that FLNRO observation well water level data are recorded as metres below ground level; however, for assessment purposes, the water levels were converted to metres above sea level (masl) by subtracting the recorded depth to water measurement from the approximate ground level of each well (as determined using Google Earth™).

2.3.2 Changes in Groundwater Levels over Time

Trend analysis was completed for all available groundwater level datasets for the observation wells in Keremeos (Well 75), Cawston (Well 203), and Princeton (Well 220). The purpose of trend analysis was to determine whether there was a statistically significant change (i.e. increase or decrease) in the groundwater level over time. Trend analysis is typically used when changes are expected to be subtle or where natural variation makes simple “before and after” comparisons challenging. In these cases, trends cannot necessarily be inferred graphically or by basic linear regression. For this study, the objective was to determine whether groundwater levels were changing over time, which could be related to some combination of changes in river flow (because of a hydraulic connection), changes in precipitation/recharge, and/or changes in groundwater use.

To assess whether the water levels in the selected observation wells have changed significantly over time, the Mann-Kendall trend test was applied using SYSTAT 13. This test is a non-parametric, rank-based test for assessing the significance of a trend in a time series. The user specifies either an upward, downward, or two-sided hypothesis.

One of the major underlying assumptions of the Mann-Kendall trend test is that consecutive samples are independent of one another. This assumption does not hold where automated sampling systems are used and water level data are collected frequently (e.g. hourly), which is the case for more recent data for Well 75 (Keremeos) and Well 203 (Cawston). Therefore, mean monthly groundwater levels were calculated for each well and the trend analysis was completed on the means. Note that for Well 220 (Princeton), groundwater levels were collected either weekly or monthly; therefore, all data was used.

Another underlying assumption of the Mann-Kendall trend test is that the sampling interval is consistent. For all wells, the sampling interval varied; however, the intervals were considered acceptable for this analysis to provide an idea of whether a trend is occurring (note: the software will not run the test of the sampling interval is unacceptable).

2.4 GROUNDWATER – SURFACE WATER QUALITY COMPARISON

As part of Phase 2, a companion study assessed the water quality of provincial and federal surface water quality monitoring sites located in Princeton, Keremeos, and Hedley (Summit 2015b). As a result, much information is already known about the surface water quality in these locations. Therefore for the study herein, a search of the provincial Environmental Monitoring System (EMS) Web Reporting database was completed to search for opportunities to compare the known water chemistry of the surface water quality sites to the water chemistry found at nearby groundwater sites (observation wells or other). The objective was to determine whether there was sufficient data available to complete tri-linear diagrams (i.e. piper plots and stiff diagrams) – graphical tools used to distinguish source water based on chemical characteristics. These diagrams can yield information about residence times, source water type, and whether groundwater is under the influence of surface water.

The results of the EMS database search indicated that in most cases, there are no wells with water quality data located in close proximity to surface water quality sites. The only two locations with groundwater and surface water quality information identified were as follows:

- **Hedley –** Groundwater samples were previously collected in 1998, 2001, and 2002 from a well registered under Candorado Mines Ltd. (EMS Site #E212954). The well is located approximately 500 m downstream of the Similkameen River at 20 Mile Creek surface water quality site (B.C.-Canada Site No. 08BCNL0008) (Summit 2015b). However, the groundwater samples were collected in 1998, after monitoring of the surface site ceased.

- **Princeton –** Groundwater samples were collected in 1987, 1997, and 2001 from Princeton Observation Well 220 (EMS Site #1401423), which is located approximately 700 m downstream of the Similkameen River at Princeton surface water monitoring site (B.C.-Canada Site No. 08BCNL0001) (Summit 2015b). There is overlapping data for the two sites; however, some crucial parameters for tri-linear diagrams (such as alkalinity) were tested only periodically at the surface water site and those periods do not align with the groundwater data.

Due to the limited amount of data described above, detailed analyses (e.g. tri-linear diagrams) were not feasible. However, descriptive statistics (i.e. mean, minimum, and maximum) were calculated from the three sets of groundwater data available for Hedley and Princeton, and the results were compared with concentrations found in surface water.

2.5 CONCEPTUAL MODEL OF GROUNDWATER FLOW

To help support the understanding of GW-SW interactions at the two key locations and the broader watershed, a conceptual model of groundwater flow developed by Golder (2004) (and used in numerical modeling [i.e. Golder 2008]) for the Keremeos area was reviewed. The conceptual model by Golder (2004) is summarized as follows:

- The horizontal extent of Aquifer 259 in the Keremeos area ranges between 1,800 m to 3,000 m and assumes the contact is where surficial soils meet bedrock. The contacts are no flow boundaries due to low bedrock hydraulic conductivities in comparison to alluvial hydraulic conductivities;
- Thicknesses of Aquifer 259 were estimated to range between 36 m and 40 m and the water table is located within sands and gravels;
- Aquifer recharge in the Keremeos area is primarily recharged by direct precipitation and runoff from the west, with groundwater flow towards the south and southeast and discharging into the Similkameen River.

No conceptual model of groundwater flow was outlined by Golder (2004; 2005) for Aquifer 935 (Keremeos Creek Valley). However, based on groundwater flow mapping for the lower Keremeos Creek valley by Golder (2006), it is assumed that the aquifer has no flow boundaries along the valley sides at the bedrock contacts, aquifer recharge is primarily through direct precipitation, and groundwater flow direction is down valley parallel to streamflows (Golder 2005).

Based on the conceptual model information summarized above, two additional tasks were completed for at the key GW-SW interaction locations to better understand aquifer shape, groundwater flow, and relationships to surface water. These additional tasks were as follows:

1. Preparation of cross-sections; and
2. Calculation of total groundwater and streamflow flux.

2.5.1 Cross-Sections

For each key GW-SW interaction location, a topographic and hydrogeologic cross-section was drawn. The cross-sectional surfaces were developed using 1:50,000 contours from digital elevation models obtained from National Resources Canada, while information from registered well logs was used to fill in surficial and bedrock geology information. Note that for the size (widths and depths), shape, and permeability of each respective aquifer, assumptions were also required and used well logs and available hydrogeologic reports (e.g. Golder [2004]).

The locations of the selected cross-sections are provided in Appendix A (Figure A-1).

2.5.2 Total Groundwater and Streamflow Flux

For a respective cross-section, the total flux of water through the section is equal to the total amount of groundwater flowing through the aquifer plus the streamflow within the river channel. Therefore to help provide a more detailed understanding of water movement through each of the key GW-SW interaction locations, the total groundwater and streamflow fluxes were calculated for each cross-section developed in Section 2.5.1. The calculation of each component of the total flux is described below.

Groundwater flow

The total amount of groundwater flow through a cross-section (assumed flow direction is parallel to streamflow) was calculated using the Darcy equation, as follows:

$$Q_{gw} = KiA \qquad \textbf{Eq. 2-2}$$

where:

Q_{gw} = groundwater flow through the aquifer (m^3/s)
K = aquifer hydraulic conductivity (m/s)
i = hydraulic gradient (unitless)
A = aquifer cross-sectional area (m^2)

Note that for each location, the *K* values were assumed equal to the values included in Figure 4 of Golder (2008) and within Golder (2005). Aquifer cross-sectional area (*A*) was calculated using mapped extents of both aquifers and estimated aquifer depths from registered wells and available hydrogeologic reports (e.g. Golder [2005]), while the hydraulic gradient (*i*) was estimated using digital elevation model information.

Streamflow

The total amount of streamflow through a cross-section was calculated using the net and naturalized streamflows compiled for the 10 points-of-interest included in Figure 2-1 and summarized Section 2.2.2.1. This information was completed as part of a companion Phase 2 project by Summit (2015a). Median monthly net and the 50-year return period low flows were used for the month of September. September is the lowest flow month during the irrigation season and would be the critical period for assessment of environmental flow needs in streams.

3 Results

The following sections provide the results of the GW-SW interaction assessment.

3.1 KEY GW-SW INTERACTION LOCATION ASSESSMENTS

3.1.1 Initial Screening

Table 3-1 summarizes information about the number of registered wells within each sub-basin (Figure 2-1) that met the GW-SW interaction screening criteria (i.e. wells >6-inch diameter within 300 m of a stream and wells ≤6-inch diameter within 100 m of a stream), while Figure 3-1 shows the density of wells per sub-basin. Sub-basins #7 (Keremeos Creek) and #9 (Similkameen River, Hedley to International Border) had the highest number of registered wells that met the screening criteria per area.

Table 3-1 Number of registered wells that met the screening criteria for potential GW-SW interaction within the Similkameen River watershed

Sub-basin	Sub-basin drainage area (km^2)	Total number of registered wells	Number of wells >6-inch diameter within 300 m of a stream	Number of wells ≤6-inch diameter within 100 m of a stream	Number of wells that meet both screening criteria	Number of wells meeting screening criteria per drainage area (wells/km^2)
1 - Similkameen River, Manning Park to Princeton	1,811	82	4	28	32	0.02
2 - Tulameen River	1,778	236	15	54	69	0.04
3 - Allison Creek	600	212	18	100	118	0.20
4 - Hayes Creek	779	221	2	100	102	0.13
5 - Similkameen River, Princeton to Hedley	601	220	29	77	106	0.18
6 - Hedley Creek	395	9	1	0	1	0.003
7 - Keremeos Creek	224	259	45	94	139	0.62
8 - Ashnola River	1,060	6	1	3	4	0.004
9 - Similkameen River, Hedley to International Border	869	643	101	182	283	0.33
10 – Similkameen River, International Border to Mouth[1]	168	28	4	14	18	0.11

Note:
1. Canadian registered well information only, as United States information was not available.

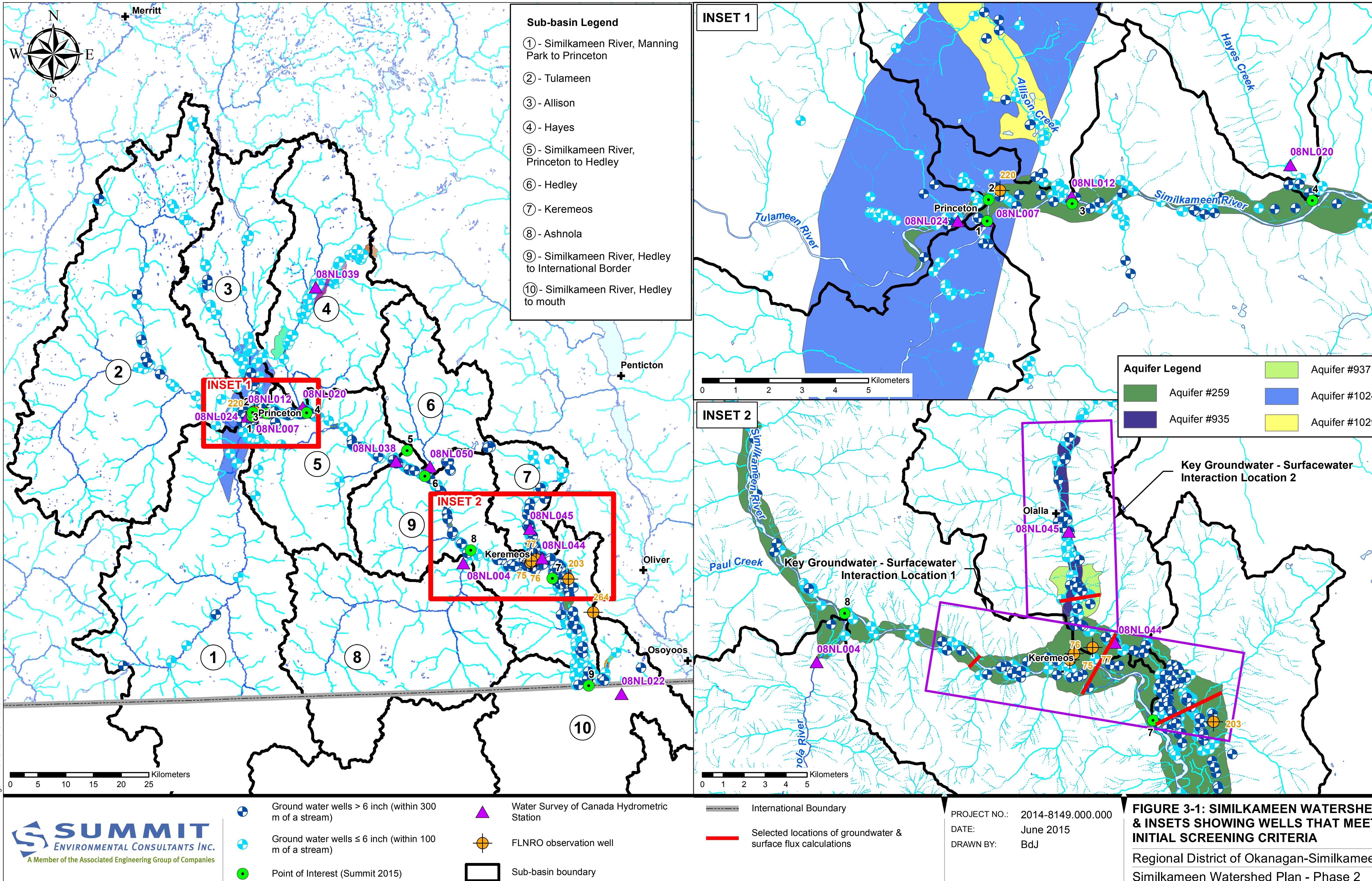

FIGURE 3-1: SIMILKAMEEN WATERSHED & INSETS SHOWING WELLS THAT MEET INITIAL SCREENING CRITERIA

Regional District of Okanagan-Similkameen

Similkameen Watershed Plan - Phase 2

As noted in Section 2.2.2.1, two key GW-SW interaction locations were selected based on the initial well screening review included in Table 3-1, as follows:

- **Key GW-SW Interaction Location 1 –** Similkameen River near Keremeos and Cawston
    - o The area of Aquifer 259 from 4 km east of the mouth of the Ashnola River to Bearcroft River Road south of the Village of Keremeos (located in Sub-basin #9) (Figure 3-1).
- **Key GW-SW Interaction Location 2 –** Keremeos Creek Valley
    - o The area of Aquifer 935 from the settlement of Olalla south to the Village of Keremeos (located in Sub-basin #7) (Figure 3-1).

Note that both locations were selected due to the high density of wells meeting the screening criteria, clustering of wells around the specific areas of interest, and previous GW-SW interaction assessments.

3.1.2 Streamflow Review – Losing and Gaining Streamflows

As described in Section 2.2.2, a review of streamflows was completed to investigate whether losing or gaining streams were present. Based on available data, the streamflow review was completed for:

- Key GW-SW Interaction Location 2 – Keremeos Creek Valley; and
- Similkameen River – Headwaters to Mouth (i.e. POIs #1, #5, #9, and #10 from Summit [2015a]).

Key GW-SW Interaction Location 2 – Keremeos Creek Valley

Table 3-2 summarizes the mean monthly streamflows recorded at the upstream (WSC Station No. 08NL045) and downstream (WSC Station No. 08NL044) hydrometric monitoring locations on Keremeos Creek for the periods of overlapping data (1971-1977). Note that both hydrometric stations are identified by the WSC to be measuring regulated or net streamflows. No water use information was available for the overlapping period of record (Summit 2014); therefore, the net streamflows were used as the best surrogate to assess losing or gaining streamflows and potential groundwater withdrawal effects.

The comparison indicates that for a large portion of the available record, Keremeos Creek loses streamflow down the valley (identified by the green shading in Table 3-2). In addition, Keremeos Creek has documented occurrences of zero flows and fish kills near the mouth of the sub-basin (B.C. MOE 2001), while creek flows have been recorded in the upper and intermediate portions of the sub-basin at the same time. The results suggest that Keremeos Creek is a losing stream; however, due to the lack of available water use information, it is unknown whether the creek is a naturally losing stream or whether it is related to water use (surface and groundwater).

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Table 3-2 Mean monthly discharge comparison between upstream and downstream locations on Keremeos Creek, 1971-1977

Upstream Location - Keremeos Creek below Willis Intake (08NL045) - Mean Monthly Discharge (m^3/s)							
Month[1]	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**
Apr	n/a[2]	0.949	0.169	0.564	0.210	0.272	0.213
May	3.00	4.56	1.07	2.86	1.77	2.05	0.805
Jun	3.17	7.25	0.710	8.27	3.96	2.74	0.866
Jul	0.761	1.92	0.286	2.05	0.828	1.10	0.295
Aug	0.251	0.542	0.131	0.583	0.347	0.568	0.126
Sep	0.209	0.342	0.107	0.297	0.233	0.369	0.130
Downstream Location - Keremeos Creek at Middle Bench Road (08NL044) - Mean Monthly Discharge (m^3/s)							
Month[1]	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**
Apr	n/a[2]	0.788	0.119	0.37	0.13	0.193	0.116
May	2.27	4.76	0.709	2.25	1.66	2.33	0.770
Jun	2.55	6.97	0.723	8.12	4.15	3.13	0.927
Jul	0.688	1.54	0.201	1.71	0.706	1.16	0.217
Aug	0.124	0.519	0.017	0.402	0.251	0.653	0.022
Sep	0.080	0.225	0.000	0.181	0.142	0.342	0.008
Difference between Downstream (08NL044) and Upstream (08NL045) Hydrometric Stations (m^3/s)							
Month[1]	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**
Apr	n/a[2]	-0.161	-0.050	-0.190	-0.080	-0.079	-0.097
May	-0.730	0.200	-0.361	-0.610	-0.110	0.280	-0.035
Jun	-0.620	-0.280	0.013	-0.150	0.190	0.390	0.061
Jul	-0.073	-0.380	-0.085	-0.340	-0.122	0.060	-0.078
Aug	-0.127	-0.023	-0.114	-0.181	-0.096	0.085	-0.104
Sep	-0.129	-0.117	-0.107	-0.116	-0.091	-0.027	-0.122

Notes:
1. WSC Station No. 08NL044 operated seasonally (April to September), so the upstream/downstream comparison is only limited to those respective months.
2. "n/a" – data is not available.

Similkameen River – Headwaters to Mouth

Table 3-3 summarizes the median September monthly net and naturalized discharge and selected low flow statistics for the Similkameen River from the headwaters (i.e. POI #1) to the mouth (i.e. POI #10) (Figure 2-1). The results indicate that the Similkameen River is a gaining river from the headwaters to the International Border (i.e. POI #9) and appears to be a losing river from the International Border to the mouth.

Table 3-3 Streamflow comparison for each Point-of-Interest on the Similkameen River

Point-of-Interest (POI)	Median Net Flow (m^3/s)	Median Naturalized Flow	10-year Return Period Monthly Net Low Flow	50-year Return Period Monthly Net Low Flow
	September[1]			
POI #1 – Similkameen River above the Tulameen River Confluence	4.53	4.99	2.64	1.84
POI #5 – Similkameen River near Hedley	9.39	10.4	5.21	3.23
POI #9 – Similkameen River at International Border	14.2	16.0	7.87	4.88
POI #10 – Similkameen River at the Mouth	13.8	15.4	7.51	4.27

Note:
1. Similkameen River discharge information for September from Summit (2015a).

Note that the discharges estimated for POI #10 do not include water use information for the United States; therefore, the Similkameen River naturalized flow estimates at the mouth have been identified to be underestimated (Summit 2015a). In addition, for estimating Similkameen River discharges at the International Border (POI #9), all POIs above the border were combined and the results were scaled to the border (Summit 2015a). As a result, there is also some uncertainty associated with the Similkameen River estimates at POI #9 and it is likely resulting in overestimated river flows (Summit 2015a).

Based on the results completed herein and understanding the limitations of the Similkameen River net and naturalized flows identified by Summit (2015a) for POIs #9 and #10, the Similkameen River would be considered a gaining river from its headwaters to mouth. The losing river condition is most likely a result of estimation methods and the lack of available United States water use information below the International Border.

3.1.3 Groundwater Withdrawal Effects on Surface Water

Following Section 2.2.3, an assessment of the net groundwater flow contribution to surface water at each of the key GW-SW interaction locations was completed to review groundwater withdrawals in comparison to groundwater recharge. This section presents the results at each key location.

Net Groundwater Discharge for Aquifer 259 (Similkameen River valley)

Table 3-4 presents annual groundwater recharge estimates for Aquifer 259 (portion in Sub-basin #9 only; Figure 2-1) under low, moderate, and high groundwater recharge conditions from direct precipitation and river losses.

Table 3-4 Annual groundwater recharge estimates for the portion of Aquifer 259 located in Sub-basin #9

Variable	Units	Groundwater Recharge from Precipitation Only			Groundwater Recharge – Precipitation and River Losses
		Low	Moderate	High	
Estimated surface area of Aquifer 259 within Sub-basin #9[1]	m^2	87,800,000			87,800,000
Mean annual precipitation[2]	mm	325			325
Estimated fraction of mean annual precipitation recharging aquifer[3]	%	5	8	30	8
Mean annual precipitation contribution to recharge	mm	16	26	98	26
	m	0.016	0.026	0.098	0.026
Annual recharge volume from direct precipitation	m^3/year	1,426,750	2,282,800	8,560,500	2,282,800
Annual recharge volume from Similkameen River losses[4]	m^3/year	n/a			11,366,100
Annual groundwater recharge of Aquifer 259 within Sub-basin #9	m^3/year	1,426,750	2,282,800	8,560,500	13,648,900
	m^3/s	0.045	0.072	0.271	0.433

Notes:
1. Surface area of Aquifer 259 located in Sub-basin #9 estimated from available mapping.
2. Mean annual precipitation (1981-2010) measured at the Keremeos 2 climate station (Meteorological Service of Canada Station No. 1124112).
3. Assumed low and high recharge estimates and intermediate recharge estimate from Golder (2008).
4. Assumed river losses from Similkameen River based on estimates from numerical modeling results from Golder (2008). Note that loses from the Similkameen River and Keremeos Creek were both included and it is assumed that the area around Keremeos is the only location recharging Aquifer 259 through stream losses.

Table 3-5 compares the annual net groundwater discharge results to groundwater withdrawals based on the Eq. 2-1 identified in Section 2.2.3. The results indicate that the low, intermediate, and high recharge estimates; which rely solely on recharge from the precipitation falling on and infiltrating into Aquifer 259 are not enough to support the estimated groundwater withdrawals. However, if recharge from river losses is included there is enough water to support the groundwater withdrawals. This suggests that recharge to the aquifer must include sources other than direct precipitation to meet groundwater withdrawal needs.

Mean monthly July groundwater withdrawals were also compared to median monthly September Similkameen River flows at POI #9 in Table 3-5. Different months were selected because the timing of groundwater extraction and its effect on streamflow depends on how far away from the river wells are located. For example, KID has wells with capture zones that intercept the Similkameen River with travel times ranging from within 100 days to greater than one year (Golder 2008). Therefore, the month with the highest groundwater withdrawal rate was selected (i.e. July) and compared to the month with the lowest flows in the Similkameen River during the irrigation season (i.e. September), regardless if those occurred in the same month or not. From this comparison, it was determined that even though surface water and groundwater are closely linked, the groundwater withdrawal is a small fraction of the Similkameen River flow. For example, the groundwater withdrawals during the month when the highest groundwater withdrawals are taking place (i.e. July) is equal to 6% of the Similkameen River flow when the river flow is at its lowest during the irrigation season (i.e. September) under median conditions. Note that only during the 50-year return period low flow conditions, does the largest groundwater withdrawal rates approach 20% of the Similkameen River flows for the month of September.

Table 3-5 Estimates of net groundwater discharge from the portion of Aquifer 259 located in Sub-basin #9 compared to Similkameen River flows at POI #9

Variable	Units	Groundwater Recharge from Precipitation Only			Groundwater Recharge – Precipitation and River Losses
		Low	Moderate	High	
Annual groundwater recharge of Aquifer 259 within Sub-basin #9	m^3/year	1,426,750	2,282,800	8,560,500	13,648,900
	m^3/s	0.045	0.072	0.271	0.433
Groundwater Withdrawals[1]	m^3/year	9,713,088	9,713,088	9,713,088	9,713,088
Net groundwater discharge	m^3/year	-8,286,338	-7,430,288	-1,152,588	3,935,812
Deficit not provided by aquifer recharge	m^3/year	8,292,991	7,436,941	1,159,241	surplus
Groundwater withdrawals as a percentage of mean annual groundwater recharge	%	681%	426%	114%	71%
Estimated groundwater withdrawals for the month of July[2]	m^3/s	0.911			
Similkameen River median monthly net flow in September	m^3/s	14.2			
July groundwater withdrawals as a percentage of median monthly net Similkameen River flow in September	%	6.4			
Similkameen River 50-year return period mean monthly net low flow for September[3]	m^3/s	4.88			
July groundwater withdrawals as a percentage of the Similkameen River 50-year return period monthly net low flow for September	%	18.6			

Notes
1. Sum of estimated median annual groundwater withdrawals (1981-2010) for Sub-basin #9 from Summit (2015a). The groundwater withdrawals include actual water use from KID, Fairview Heights Irrigation District, and estimated private irrigation water use by the AWDM.
2. Sum of estimated median July groundwater withdrawals (1981-2010) for Sub-basin #9 from Summit (2015a).
3. 50-year return period low flow value for September from Summit (2015a).

Net Groundwater Discharge for Aquifer 935 (Keremeos Creek valley)

Table 3-6 presents annual groundwater recharge estimates for Aquifer 935 (located in Sub-basin #7; Figure 2-1) under low, moderate, and high groundwater recharge conditions from direct precipitation and creek losses.

Table 3-6 Annual groundwater recharge estimates for Aquifer 935 located in Sub-basin #7

Variable	Units	Groundwater Recharge from Precipitation Only			Groundwater Recharge – Precipitation and River Losses
		Low	Moderate	High	
Estimated surface area of Aquifer 935 within Sub-basin #7[1]	m^2	5,200,000			5,200,000
Mean annual precipitation[2]	mm	397			397
Estimated fraction of mean annual precipitation recharging aquifer[3]	%	5	8	30	8
Mean annual precipitation contribution to recharge	mm	20	32	119	32
	m	0.020	0.032	0.119	0.032
Annual recharge volume from direct precipitation	m^3/year	104,000	166,400	618,800	166,400
Annual recharge volume from Keremeos Creek losses[4]	m^3/year	n/a			5,913,000
Annual groundwater recharge of Aquifer 935 within Sub-basin #7	m^3/year	104,000	166,400	618,800	6,079,400
	m^3/s	0.003	0.005	0.020	0.193

Notes:
1. Surface area of Aquifer 935 located in Sub-basin #7 estimated from available mapping.
2. Mean annual precipitation (1981-2010) measured at the Hedley climate station (Meteorological Service of Canada Station No. 1123360).
3. Assumed low and high recharge estimates and intermediate recharge estimate from Golder (2008).
4. Assumed river losses from Keremeos Creek based on estimates from numerical modeling results from Golder (2008).

Table 3-7 presents the net groundwater discharge estimates for Aquifer 935. Similar to the Similkameen River, more than 90% of aquifer recharge is estimated to come from creek losses to the aquifer. However, it appears that for Keremeos Creek, groundwater withdrawals have a larger potential effect on streamflows because the volume of aquifer recharge is smaller. The groundwater extraction rate in July was 158% of the median monthly net flow in Keremeos Creek for the month of September. This is consistent with the results from Section 3.1.2 that indicated that Keremeos Creek has had periods of zero and very low flows in September in some years (Table 3-2).

Table 3-7 Estimates of net groundwater discharge from Aquifer 935 located in Sub-basin #7 compared to Keremeos Creek flows at POI #7

Variable	Units	Groundwater Recharge from Precipitation Only			Groundwater Recharge – Precipitation and River Losses
		Low	Moderate	High	
Annual groundwater recharge of Aquifer 259 within Sub-basin #9	m^3/year	104,000	166,400	618,800	6,079,400
	m^3/s	0.003	0.005	0.020	0.193
Groundwater Withdrawals[1]	m^3/year	1,545,264	1,545,264	1,545,264	1,545,264
Net groundwater discharge	m^3/year	-1,441,264	-1,378,864	-926,464	4,534,136
Deficit not provided by aquifer recharge	m^3/year	1,441,264	1,378,864	926,464	surplus
Groundwater withdrawals as a percentage of mean annual groundwater recharge	%	1486%	929%	250%	25%
Estimated groundwater withdrawals for the month of July[2]	m^3/s	0.169			
Keremeos Creek median monthly net flow in September	m^3/s	0.107			
July groundwater withdrawals as a percentage of median monthly net Keremeos Creek flow in September	%	158%			
Keremeos Creek 10-year return period mean monthly net low flow for September[3]	m^3/s	0.010			
July groundwater withdrawals as a percentage of the Keremeos Creek 10-year return period monthly net low flow for September	%	1690%			

Notes
1. Sum of estimated median annual groundwater withdrawals (1981-2010) for Sub-basin #7 from Summit (2015a). The groundwater withdrawals include actual water use from Olalla Community Water System and estimated private irrigation water use by the AWDM.
2. Sum of estimated median July groundwater withdrawals (1981-2010) for Sub-basin #7 from Summit (2015a).
3. 10-year return period low flow value for September from Summit (2015a). The 10-year return period was selected, as the 50-year return period low flow was estimated by Summit (2015a) to be 0 m^3/s.

3.2 OBSERVATION WELL ASSESSMENT

3.2.1 Comparison of Observation Well Data to Surface Water Data

The comparisons revealed that none of the active or discontinued WSC hydrometric stations are located in ideal positions with respect to the observation wells (e.g. directly upstream, downstream, or both) to assess GW-SW interaction. However, near Keremeos and Princeton there was some available groundwater level and hydrometric station records available for a general review of groundwater level and streamflow trends.

Keremeos

The only WSC hydrometric station located within the general area around the Keremeos and Cawston observation wells is discontinued WSC Station No. 08NL044, which operated from 1971 to 1977. The station is approximately 6 km northwest of active Well 203 (Cawston), which is likely too far away to reveal any relationship between the two (Figure 3-1). However, active Well 75 (Keremeos) and inactive Well 77 (Keremeos) are both located within 2 km of WSC Station No. 08NL044, which is likely within the area of potential influence (Figure 3-1). Inactive Well 77 (Keremeos) is located approximately halfway between Well 75 (Keremeos) and WSC Station No. 08NL044; therefore, it has more potential to be hydraulically connected to Keremeos Creek than active Well 75 (Keremeos).

Figure 3-2 shows the 1971-1977 mean daily discharge hydrograph recorded at WSC Station No. 08NL044, mean daily groundwater levels at inactive Well 77 (Keremeos), and mean daily groundwater levels at active Well 75 (Keremeos). As expected, groundwater levels fluctuated over the period of record, with the highest observed groundwater levels generally coinciding with the highest periods of river flow. This indicates that groundwater and surface water trends are generally the same, suggesting hydraulic connectivity between the two.

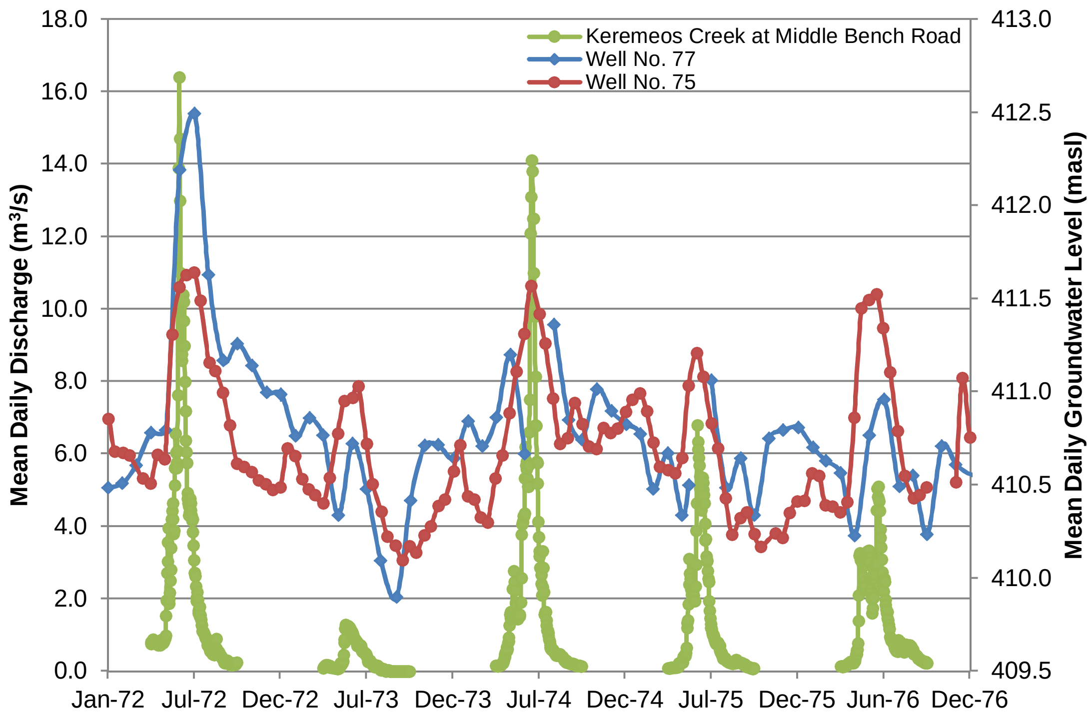

Figure 3-2 Keremeos Creek discharge and nearby observation well groundwater level comparison, 1971-1977

Princeton

In addition to observation well data for inactive Well 220 (Princeton) and active hydrometric stations on both the Similkameen and Tulameen rivers at Princeton, some groundwater withdrawal information is also available for the Town of Princeton. The Town of Princeton obtains its water supply from four groundwater wells and has recorded daily withdrawal rates from late 2011 to 2014. Two of these wells (Well 10046 and 10047) are located directly across the Similkameen River from inactive observation Well 220 (Princeton). Unfortunately, there is no overlapping period of water use and groundwater level data since Well 220 (Princeton) has been inactive since 2000. As a result, the effects of the Town of Princeton's withdrawals on groundwater levels cannot be directly assessed within the observation well record.

Approximately 700 m upstream of inactive Well 220 (Princeton) is the WSC hydrometric station on the Similkameen River near Princeton (Station No. 08NL007) (Figure 3-1), for which water levels are available since 1914. Another WSC hydrometric station is located upstream on the Tulameen River (Station No. 08NL024) (Figure 3-1). Both of these WSC hydrometric stations are located upstream of the confluence of the Similkameen and Tulameen rivers, while Well 220 (Princeton) is located below the confluence. Figure 3-3 shows the change in groundwater and surface water levels (Similkameen and Tulameen rivers) over the period of record for which there is overlapping data. Figure 3-3 indicates that the groundwater fluctuations follow surface water fluctuations with peaks occurring at similar times, illustrating apparent hydraulic connectivity between surface and groundwater.

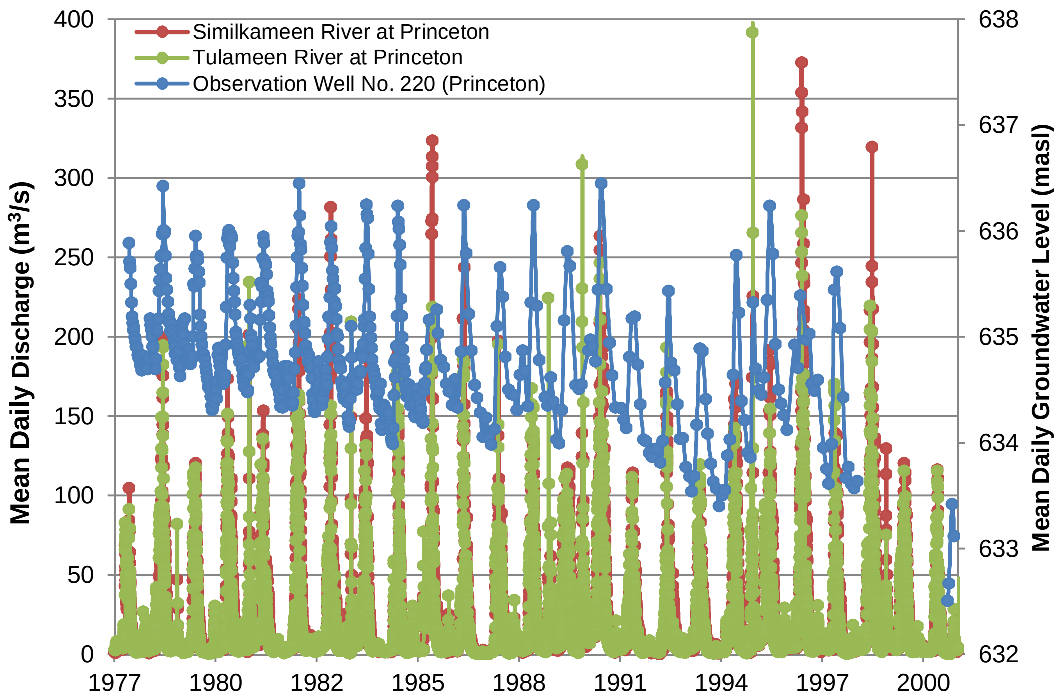

Figure 3-3 Similkameen River discharge and nearby observation well groundwater level comparison, 1971-1977

3.2.2 Changes in Groundwater Level over Time - Trend Analysis

The Mann-Kendall trend test results for each observation well are summarized in Table 3-8. For each observation well, a significant downward trend was observed over the period of record. However, the Sen's

Slope value, which provides an indication of the magnitude of the trend, is small. Note that when the trend analysis was restricted to the data since 2000 (to assess changes over the more recent period), either no trend (Well 77 [Cawston]) or a slight upward trend (Well 75 [Keremeos]) was observed.

Table 3-8 Presence and absence of trends in observation well groundwater levels

		Period	Direction tested	*p* value[1]	Sen's Slope estimator	Significant trend observed
Observation Well No.	**Keremeos Well 75**	March 1963 - January 2014	Downward	<0.0005	<0.0005	**Downward**
		January 2000 - January 2014	Upward	0.001	<0.0005	**Upward**
	Cawston Well 203	March 1977 - December 2012	Downward	<0.0005	<0.0005	**Downward**
		January 2000 - December 2012	Downward	0.089	<0.0005	None
	Princeton Well 220	June 1977 - January 1999	Downward	<0.0005	<0.0005	**Downward**

Note:
1. Trends are considered statistically significant at $p<0.05$.

Figures 3-4 to 3-7 show the changes in groundwater levels over time at the three observation wells. For Well 75 (Keremeos) and Well 203 (Cawston), average monthly groundwater levels are shown. For Well 220 (Princeton), in which water levels were only tested periodically, all individual measured levels are shown in Figure 3-8. Consistent water level monitoring of the Well 220 (Princeton) ceased in January 1999. However, select measurements were also collected in September, October, November, and December 2001. These additional measurements were not included in the trend analysis because the gap in time violates the underlying assumption of a consistent sampling interval. However, the measurements are shown on the figure.

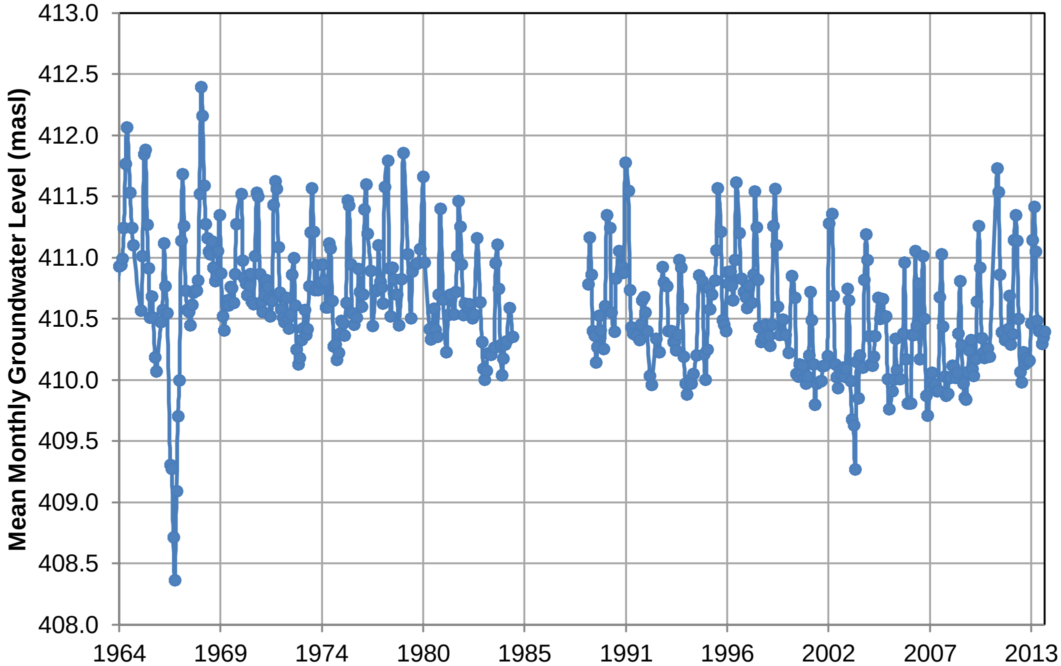

Figure 3-4 **Well 75 (Keremeos) mean monthly groundwater levels, 1963-2013. Note downward trend is significant (p<0.05)**

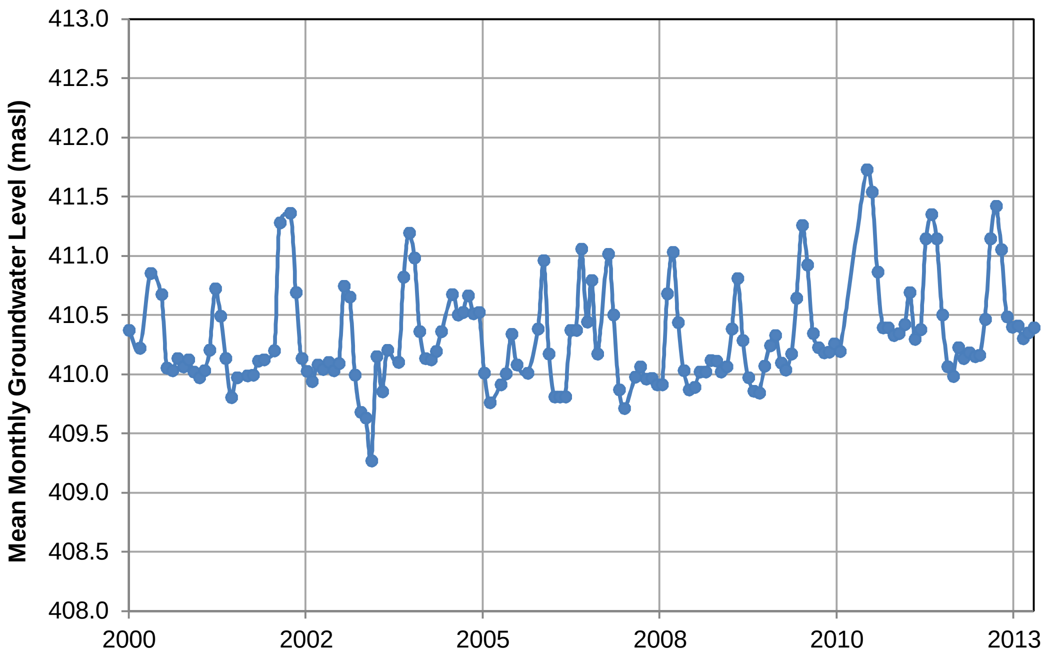

Figure 3-5 **Well 75 (Keremeos) mean monthly groundwater levels, 2000-2013. Note upward trend is significant (p<0.05)**

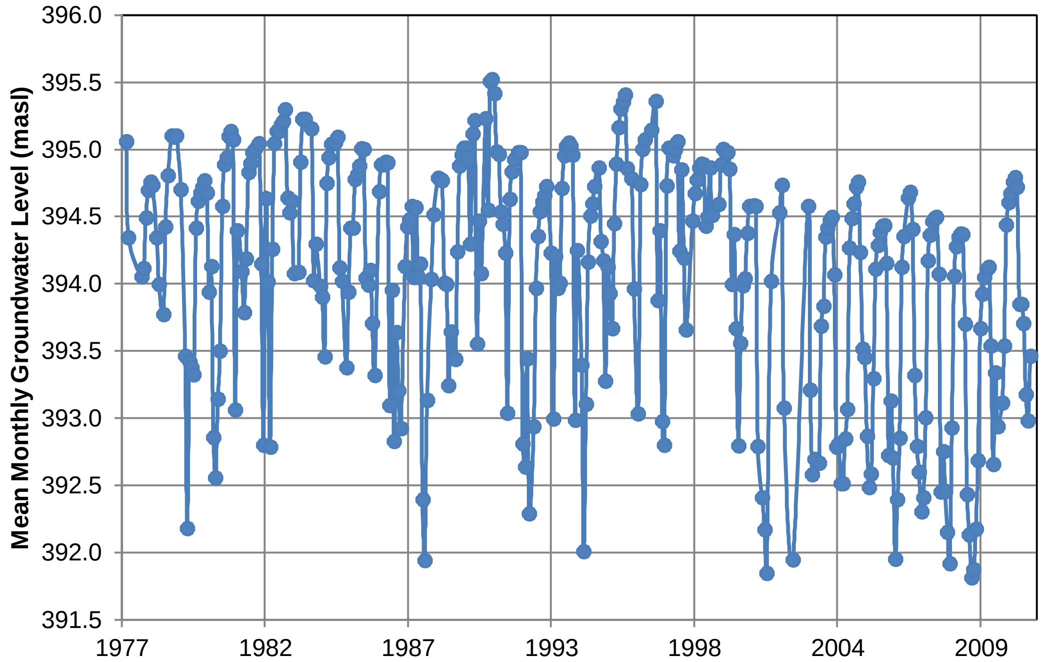

Figure 3-6 Well 203 (Cawston) mean monthly groundwater levels, 1977-2011. Note downward trend is significant (*p*<0.05)

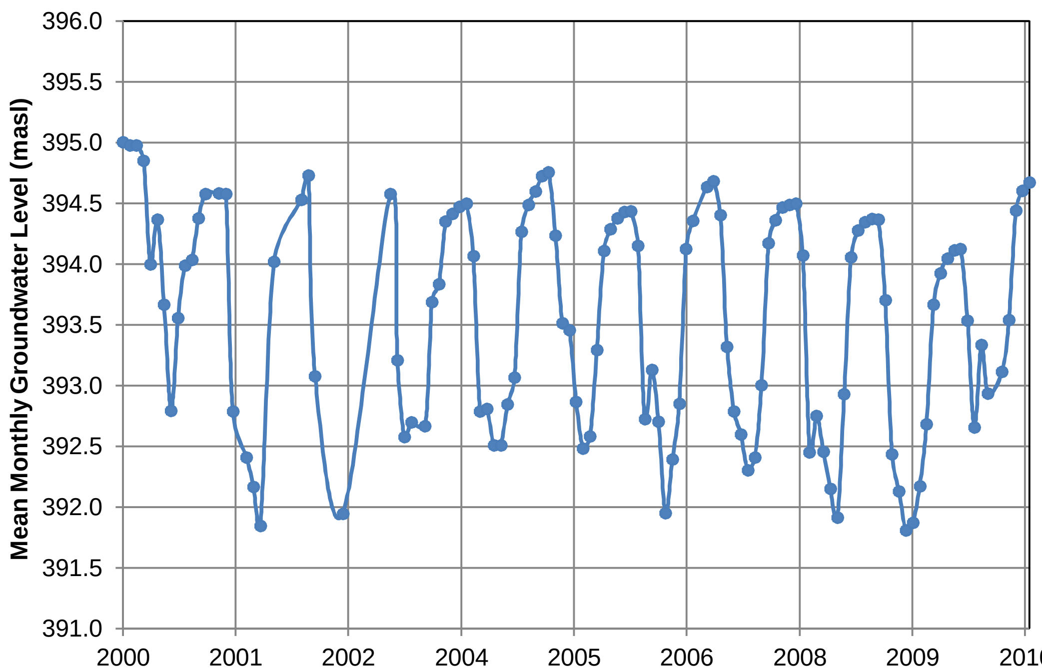

Figure 3-7 Well 203 (Cawston) mean monthly groundwater levels, 2000-2011. Note no significant trend (*p*>0.05)

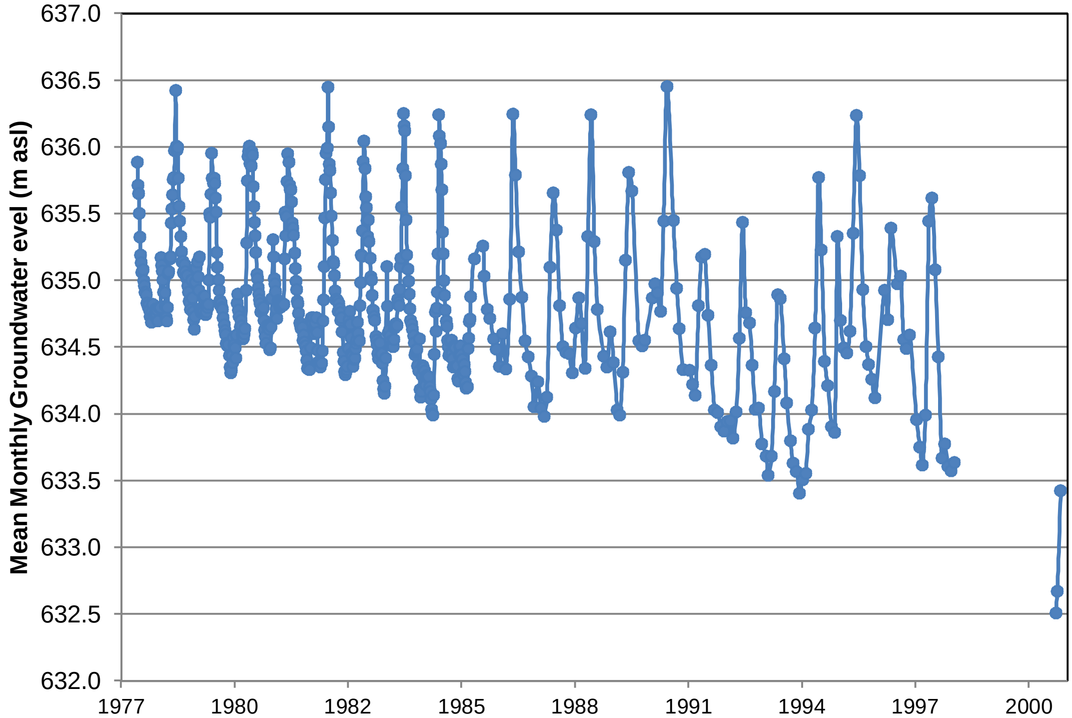

Figure 3-8 Well 220 (Princeton) mean monthly groundwater levels, 1977-2000. Note downward trend is significant (*p*<0.05)

To investigate whether the groundwater level downward trends identified for Well 75 (Keremeos), Well 203 (Cawston), and Well 220 (Princeton) in Table 3-8 could be related to a decrease in precipitation over the same time period, Mann-Kendall trend tests were completed on monthly total precipitation data (rain and snow) for the following climate stations:

- Princeton A (Meteorological Service of Canada Station No. 1126510), which is located approximately 1 km northwest of Princeton Well 220; and
- Hedley (Meteorological Service of Canada Station No. 1123360), which is located approximately 25 km northwest of Keremeos Well 75 and 33 km northwest of Cawston Well 203.

These locations represent the closest climate stations to the observation wells with available data for the generally the same time period. There are two climate stations located in Keremeos, but both have data gaps and neither have data past 2000. Therefore, the Hedley station was selected as the next closest station that has a relatively similar elevation and a continuous dataset. For the Hedley station, no data was available past 2005; however, it was still considered acceptable for this assessment because there is data for the main period over which downward trends were observed in the observation wells.

The Mann-Kendall trend test results indicated there was no trend in precipitation at the Princeton climate station (i.e. p=0.111) and a statistically significant upward trend in precipitation at the Hedley climate station (i.e. p <0.0005). This finding is depicted graphically in Figures 3-9 and 3-10, which show the annual total precipitation and mean annual groundwater levels for Princeton and Hedley, respectively. In both cases, a very slight decrease is evident in groundwater levels whereas precipitation either remains relatively consistent (Princeton) or shows a slight increase (Hedley).

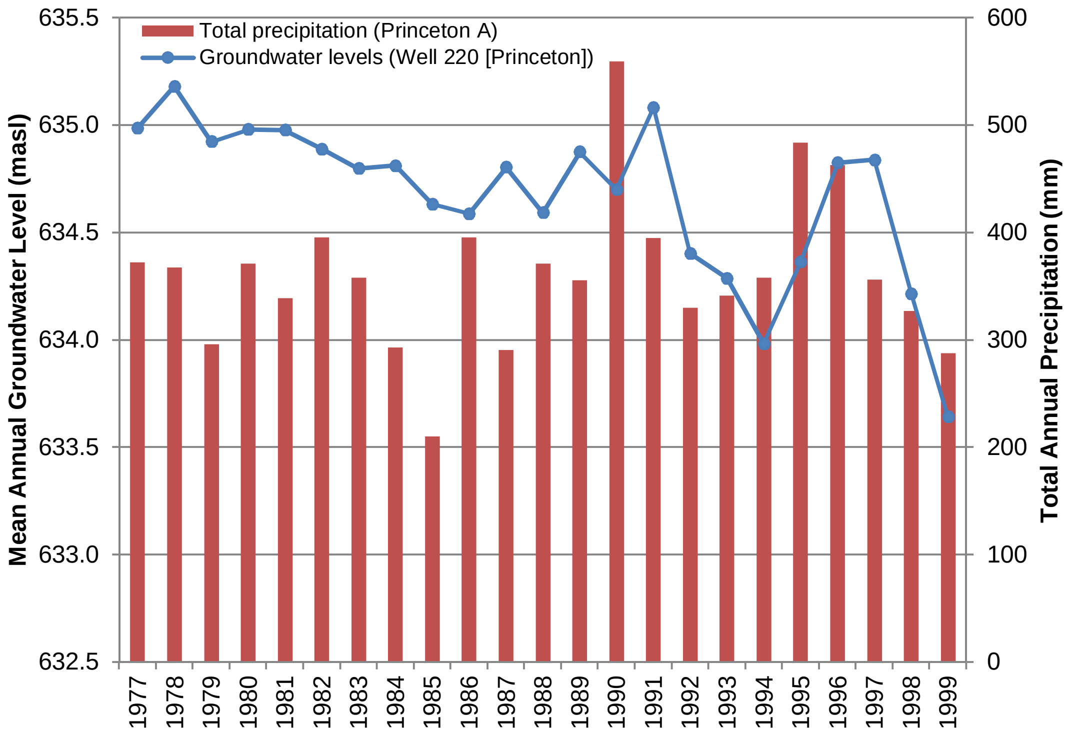

Figure 3-9 Mean annual groundwater level and total precipitation variation at Princeton, 1977-1999

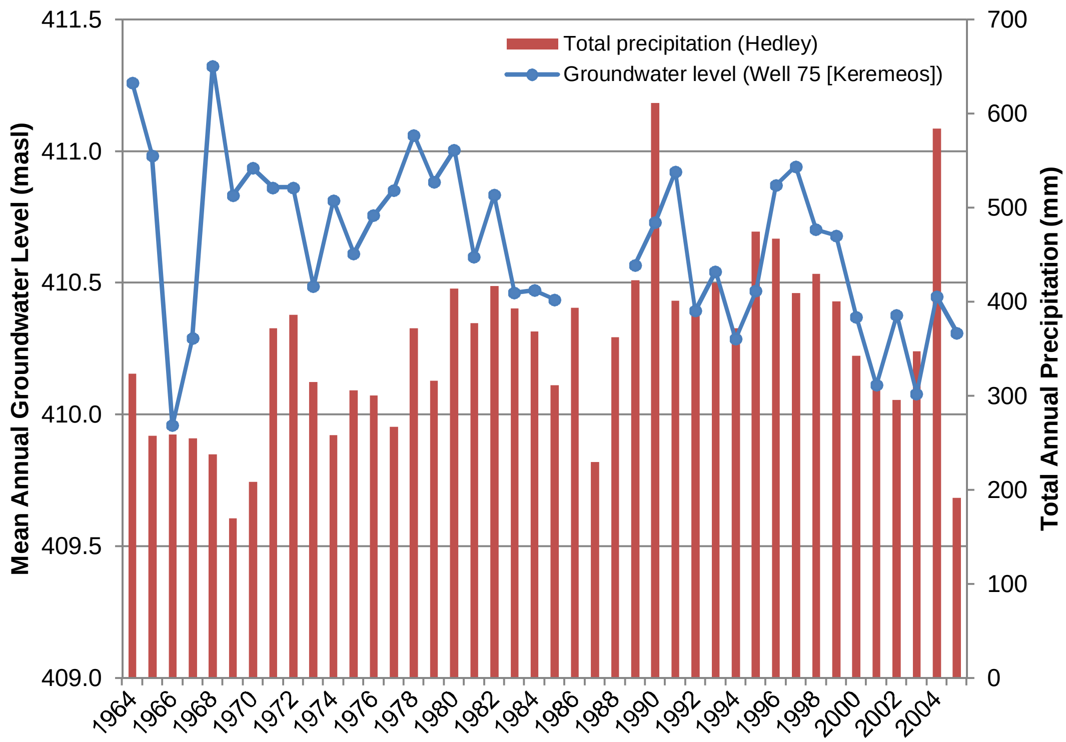

Figure 3-10 Mean annual groundwater level and total precipitation variation for Keremeos, 1965-2005

The observation that precipitation did not decrease over the same time period suggests that the decrease in groundwater levels is likely not related to climatic influences and may be a result of groundwater withdrawals exceeding the rate of groundwater recharge. However, as noted previously, the magnitude of the decrease in groundwater levels was relatively small. Additionally, the lack of a trend since 2000 suggests that even if groundwater withdrawals were the cause of the decrease, it may be reaching more sustainable rates. This may reflect more efficient irrigation methods, crop changes, vineyards using less water, or land use changes (D. Neilsen, personal communication, 2015).

3.3 GROUNDWATER – SURFACE WATER QUALITY COMPARISON

Tables 3-9 and 3-10 show the calculated descriptive statistics (mean, minimum, and maximum) for selected surface and groundwater quality parameters for the EMS sites near Princeton and Hedley, respectively. The parameters noted in the tables include those that were tested at both surface and groundwater sites and had results above the detection limits. For the groundwater sites, sampling only occurred three times and not all parameters were tested each time. The results show that, in many cases, the mean concentrations in surface and groundwater are similar, which suggests there is some interaction between waters.

Table 3-9 Comparison of groundwater and surface water quality at selected monitoring sites near Princeton

Parameters	Surface water: Similkameen River at Princeton (Station ID# BC08NL0001)			Groundwater: Princeton Observation Well 220 (Station ID# 1401423)[1]		
	Mean	Min	Max	Mean	Min	Max
Conductivity (µs/cm)	139	39	359	120	84	184
Hardness (total) (mg/L)	61	22	126	32	29	36
pH (pH units)	7.90	7.00	9.19	7.64	7.59	7.70
TDS (mg/L)	100	40	180	79	50	116
Nitrogen (total) (mg/L)	0.12	<0.02	0.6	0.17	0.06	0.27
Phosphorus (total) (mg/L)	0.02	<0.0006	0.6	0.02	0.009	0.025
Aluminium (total) (mg/L)	0.33	0.002	11.9	0.54	0.52	0.55
Aluminium (dissolved) (mg/L)	0.10	0.0009	3.0	0.06	<0.05	0.08
Arsenic (total) (mg/L)	0.00048	0.0001	0.005	-	<0.001	0.0012[2]
Arsenic (dissolved) (mg/L)	0.00046	<0.0002	0.0012	-	<0.0005[3]	-
Copper (total) (mg/L)	0.003	0.0002	0.11	-	<0.006	0.02[2]
Copper (dissolved) (mg/L)	0.0012	0.00054	0.0083	-	<0.0005[3]	-
Iron (total) (mg/L)	0.32	0.004	12.1	13.9	0.86	33.7
Iron (dissolved) (mg/L)	0.078	0.002	2.6	0.013	<0.005	0.02
Manganese (total) (mg/L)	0.0094	<0.0006	0.38	0.081	0.012	0.19
Manganese (dissolved) (mg/L)	0.0029	0.0004	0.069	0.004	0.001	0.01
Zinc (total) (mg/L)	0.0014	<0.00005	0.06	0.010	0.003	0.02
Zinc (dissolved) (mg/L)	0.0004	<0.0002	0.004	0.023	0.019	0.031

Note:
1. "-" indicates no result.
2. Only detectable concentration.
3. All results below detection limit.

Table 3-10 Comparison of groundwater and surface water quality at selected monitoring sites near Hedley

Parameters	Surface water: Similkameen River at 20 Mile Creek (Station ID# BC08NL0008)[1]			Groundwater: Candorado Mines Ltd. Well (Station ID# E212954)[1]		
	Mean	Min	Max	Mean	Min	Max
Conductivity (µs/cm)	163	61	274	171	153	181
Hardness (total) (mg/L)	76	28	124	-	-	70[2]
pH (pH units)	8.0	7.4	8.3	7.6	7.2	7.8
Nitrogen (dissolved, NO_3 and NO_2)	0.04	<0.002	0.26	0.43	0.25	0.66
Aluminium (total) (mg/L)	0.31	0.007	8.4	-	-	1.3[2]
Aluminium (dissolved) (mg/L)	-	-	-	-	<0.02[3]	-
Arsenic (total) (mg/L)	0.0004	<0.0001	0.0035	-	-	0.13[2]
Arsenic (dissolved) (mg/L)	-	-	-	-	<0.05[3]	-
Copper (total) (mg/L)	0.002	<0.001	0.019	-	-	0.064[2]
Copper (dissolved) (mg/L)	-	-	-	-	<0.005	0.0041[4]
Iron (total) (mg/L)	0.3	0.010	13.1	-	-	7.1[2]
Iron (dissolved) (mg/L)	-	-	-	0.18	0.007	0.51
Manganese (total) (mg/L)	0.009	<0.001	0.28	-	-	0.139[2]
Manganese (dissolved) (mg/L)	-	-	-	0.026	0.002	0.063
Zinc (total) (mg/L)	0.0014	<0.0002	0.020	-	-	0.017[2]
Zinc (dissolved) (mg/L)	-	-	-	-	<0.002	0.004[4]

Note:
1. "-" indicates no result.
2. Only tested once.
3. All results below detection limit.
4. Only detectable concentration.

3.4 CONCEPTUAL MODEL OF GROUNDWATER FLOW

Section 3.1 identified two key locations of GW-SW interaction in the Similkameen River watershed. Based on cross-sections drawn for each sub-basin that key locations were located within, and the understanding of total fluxes in a sub-basin with a large river (Similkameen River) and a smaller creek (Keremeos Creek), a conceptual model of groundwater flow was developed for the entire watershed to provide the basis for additional evaluation of GW-SW interaction to support water management planning.

3.4.1 Cross-Sections

Geological cross sections were completed at two locations (Similkameen River downstream of Keremeos [A-A')] [Figure A-2] and Keremeos Creek [B-B'] [Figure A-3]) identified on Figure A-1 in Appendix A. The cross-sections from these two sub-basins are similar as follows:

- There are no major confined aquifers beneath the valley streams;
- Unconsolidated deposits in valley bottoms are made up of clay, silt, sand, gravels, and cobbles; and
- The water tables are shallow (i.e. mostly within 5 m of ground surface).

3.4.2 Total Groundwater and Streamflow Flux

Total groundwater and streamflow flux at any cross-section through a valley is comprised of the flow through the aquifer and the flow in the river/creek. The total flux was calculated at three locations in the Similkameen River valley, and at one location in the Keremeos Creek valley.

Total Groundwater and Streamflow Flux through the Similkameen River Valley
For the Similkameen River valley, groundwater and streamflow in the down-gradient direction is through the Similkameen River and Aquifer 259. To account for the variability of aquifer size, the total flux was estimated at three locations within Sub-basin #9 as follows (Figure 3-1):

- At a narrow point of Aquifer 259 upstream of Keremeos;
- At the widest point of Aquifer 259 near Keremeos and Cawston (through cross-section A-A'); and
- At a narrow point of Aquifer 259 near the International Border (POI #9).

Tables 3-11 provides the estimated groundwater flux through Aquifer 259 compared to the streamflow flux in the Similkameen River at three locations within Sub-basin #9. The streamflow value for the month of September was selected because this is the lowest flow in irrigation months and would be when most GW-SW interaction issues could arise. The percentage of the total flux that is comprised of groundwater varies depending on the selected location, ranging from 0.2% to 3.1% at the narrowest (upstream of Keremeos) and widest (Keremeos and Cawston) valley locations, respectively for the month of September. This indicates that the degree of GW-SW interactions vary at different locations in the watershed, consistent with expectations from the conceptual model. The Similkameen River makes up the bulk (>90%) of the down-gradient flow in the Similkameen valley.

Table 3-11 Calculation of groundwater flux through Aquifer 259 and comparison to total flux at three locations within the Similkameen River valley of Sub-basin #9

Variable	Units	Selected Total Flux Location through Aquifer 259		
		Upstream of Keremeos	Cross-Section A-A'	Near the International Border (POI #9)
Hydraulic conductivity (*K*)[1]	m/s	0.0016	0.002	0.001
Gradient (*I*)[2]	m/m	0.004	0.005	0.004
Width[3]	m	500	2500	1000
Thickness[4]	m	7.3	16.0	22.4
Aquifer Area (*A*)	m^2	3,650	40,000	22,400
Discharge (Q) through Aquifer 259[5]	**m^3/s**	**0.023**	**0.400**	**0.090**
Similkameen River median net monthly flow for September [6]	m^3/s	12.4	12.5	14.2
Total flow (GW and SW)	m^3/s	12.4	12.9	14.3
Percentage of total flow (GW and SW) made up of GW during the month of September	**%**	**0.2%**	**3.1%**	**0.6%**
Similkameen River 50-year return period mean monthly net low flow for September [7]	m^3/s	4.21	4.21	4.88
Total flow in September during a 50-year return period (GW and SW)	m^3/s	4.23	4.61	4.97
Percentage of total flow (GW and SW) made up of GW during a 50 year return period September low flow	**%**	**0.5%**	**8.7%**	**1.8%**

Note:

1. Values from pumping test results for KID wells (Golder 2008) for the upstream of Keremeos and cross-section A-A' locations. For the international border location, value is midrange for clean sand, based on texture description from well log 36714 – sand and gravel (25 ft. to 100 ft.) and fine sane (100 ft. to 172 ft.).
2. Gradients estimated for the upstream of Keremeos and near the international border locations using available digital elevation model information from Google Earth. Gradient for cross-section A-A' from Golder (2008).
3. Width of Aquifer 259 estimated from available provincial mapping as follows: (1) Upstream of Keremeos – 2 km east of the mouth of Ashnola River; (2) Cross-section A-A' – estimated width along the cross-section (Figure A-2); and (3) Near the International Border (POI #9) – 5 km north of the border.
4. Thickness of Aquifer 259 estimated assuming average thickness with respective well logs located at thickest part of aquifer and sides at 0 m (1) Upstream of Keremeos – from well log 39989 (GW level at 14 ft. to bottom of sand and gravel at 62 ft.); (2) Cross-section A-A' - from Fowerater 1967 log of KID Well 3; and (3) Near the International Border – from well log 36714 (GW level at 25 ft. to bottom of fine sand at 172 ft.).
5. Discharge through Aquifer 259 calculated following Eq. 2-2 (Section 2.5.2).
6. Estimated Similkameen River flows as follows: (a) Upstream of Keremeos – sum of POIs #5, #6, and #8 (Summit 2015a); (2) Cross-section A-A' – sum of POIs #5, #6, #7, and #8 (Summit 2015a); and Near the International Border – POI #9 (Summit 2015a).
7. 50-year low flow estimates for September following Note 6 (above) and low flows reported by Summit (2015a).

Total Groundwater and Streamflow Flux through the Keremeos Creek Valley

Table 3-12 provides the estimated flux through Aquifer 935 for cross-section B-B' (Figure A-3) compared to the streamflows at POI #7. The streamflow value for the month of September was selected because this is the lowest flow in irrigation months and would be when most GW-SW interactions issues could arise. From Table 3-12, it is estimated that groundwater comprises 50% of median net flow and 100% of the total flux during 50-year return period low flows. This suggests that in sub-basins with smaller creeks, the total flux through groundwater can be significant.

Table 3-12 Calculation of groundwater flux through Aquifer 935 and comparison to total flux at POI #7 of Sub-basin #7

Variable	Unit	Estimate
Hydraulic conductivity (*K*)[1]	m/s	0.0005
Gradient (*I*)[2]	m/m	0.0125
Width[3]	m	750
Thickness[4]	m	22.4
Aquifer Area (*A*)	m^2	16,800
Discharge (Q) through Aquifer 935[5]	**m^3/s**	**0.105**
Keremeos Creek median net monthly flow for September [6]	m^3/s	0.107
Total flow (GW and SW)	m^3/s	0.212
Percentage of total flow (GW and SW) made up of GW during the month of September	**%**	**50%**
Keremeos Creek 50-year return period mean monthly net low flow for September [6]	m^3/s	0.000
Total flow in September during a 50-year return period (GW and SW)	m^3/s	0.107
Percentage of total flow (GW and SW) made up of GW during a 50 year return period September low flow	**%**	**100%**

Note:

1. From Olalla Community Water System pumping test, converted from Transmissivity (Golder 2005).
2. Gradient estimated from groundwater levels available from well logs near Olalla (Golder 2005).
3. Width of Aquifer 935 estimated from available provincial mapping along cross-section B-B' (Figure A-3).
4. Thickness of Aquifer 935 is estimated from the depth to the bottom of the Olalla Community Water System well (Golder 2005) divided by 2 to represent the average aquifer thickness.
5. Discharge through Aquifer 935 calculated following Eq. 2-2 (Section 2.5.2).
6. Values from Summit (2015a).

3.4.3 Conceptual Model of Groundwater Flow

The results from all the sections above help to develop a conceptual model of groundwater flow for the Similkameen watershed as follows:

- Rain and snowmelt falls on the mountainous terrain on both sides of the valleys, as well as in the valleys. Some precipitation is stored in shallow sand and gravel deposits on top of bedrock, and a smaller amount is stored in bedrock. However, most net precipitation (total precipitation minus evapotranspiration) in the mountainous terrain eventually discharges to streams or creeks and into the Similkameen River. Most of the flow from the valley sides would travel directly to the main valley-bottom without recharging valley bottom aquifers first; however, a portion of rain and snowmelt recharges these aquifers through stream losses.

- In the valley bottoms, the Similkameen River aquifer and other valley aquifers are present. These aquifers are located in unconsolidated materials that were deposited during glacial retreat consisting of silts, sands, and gravels.
- Precipitation (net of evapotranspiration) falling on to the valley aquifers recharges the aquifers.
- There are no known confined aquifers within the Similkameen River watershed. At any cross-section, the total flow passing by is made up of the flow in the river and the flow in the aquifer beneath the river. The valley narrows and widens. Therefore, so does the aquifer. The Similkameen River would act as both a discharge zone for the aquifers (normal groundwater flow conditions), but then also act as recharge source of water for the aquifers at difference times of the year and at different locations in the basin.

Based on this conceptual model of groundwater flow, all groundwater withdrawals should be considered to be sourced from the same recharge that supplies the Similkameen River. Details on the timing between when the groundwater being withdrawn and when that water would naturally flow to the Similkameen River are presently unknown.

To determine if groundwater withdrawal would affect surface water flows, the highest groundwater extraction rates for the wells across the entire aquifer (not just the wells close to the river) were compared to the low flow periods for each sub-basin. Table 3-13 present a summary of the groundwater withdrawal rates during the month when groundwater withdrawal is the highest (i.e. July or August) to when streamflows are lowest during the irrigation season (i.e. September) for each sub-basin (based on data from Summit [2015a]). From this comparison, the results indicate that in the Similkameen watershed, groundwater use is small compared to flow in the main streams in nine of the ten sub-basins (i.e. generally less than 10% of streamflow during mean conditions). Similarly, even during the estimated 50-year return period low flows (Table 3-13), only one sub-basin has groundwater withdrawals that are significantly higher than the streamflows (i.e. Keremeos Creek sub-basin); all other sub-basin have groundwater use that is generally less than 20% of the net streamflows.

Table 3-13 Comparison of groundwater withdrawal rates to selected sub-basin streamflows at Points-of-Interest #1-#10

Point-of-Interest (POI)[1]	Groundwater Withdrawal Rate (m^3/s)[2]	Streamflow at POI during the Month of September		Percentage of Groundwater Withdrawal compared to Selected Streamflows	
		Median Net (m^3/s)	50-year Net Low Flow (m^3/s)	Median Net (%)	50-year Net Low Flow (%)
POI #1	0.008	4.53	1.84	0.2	0.4
POI #2	0.054	2.76	0.904	2.0	6.0
POI #3	0.011	0.214	0.072	5.1	15.2
POI #4	0.045	0.987	0.333	4.6	13.5
POI #5	0.143	9.39	3.23	1.5	4.4
POI #6	0.011	0.802	0.271	1.4	4.1
POI #7	0.169	0.107	0.000	157.9	-[3]
POI #8	0.000	2.21	0.708	0.0	0.0
POI #9	0.911	14.2	4.88	6.4	18.6
POI #10	0.003	13.8	4.27	0.02	0.07

Note:

1. As noted in Figure 2-1.
2. For POI #10, the groundwater withdrawal rate only reflects groundwater use by the Canadian portion of the sub-basin, as water use in the United States was not available (Summit 2015a).
3. The 50-year return period low flow was estimated to be zero; therefore, the percentage was not available since the withdrawal rate is independent of the streamflow in this sub-basin.

4 Summary and Recommendations

4.1 SUMMARY

The main results of the GW-SW interaction investigation are summarized as follows:

1. The Similkameen watershed is made up of mountainous terrain with steep valley walls and narrow u-shaped valley bottoms. The valley bottoms are made up of high permeability sand and gravel aquifers. The sand and gravel aquifers beneath the valley streams are hydraulically connected to those streams. Evidence to support this is as follows:
    a. Water levels in groundwater near Keremeos and in the nearby Similkameen River have been compared and are close to each other (Golder 2008).
    b. Measured groundwater flow is both towards the Similkameen River and parallel to river. In addition, streamflow losses have been documented between upstream and downstream locations in Similkameen River and Keremeos Creek near Keremeos (Golder 2008). Modelling results show that a large portion of groundwater was being recharged by natural streamflow losses from both these surface water bodies.
    c. Keremeos Creek was identified to be a losing stream between upstream and downstream WSC hydrometric stations during at least one month of each of the seven years (1971-1977) both stations were recording data.
    d. At two key locations of GW-SW interaction, Location 1 – Similkameen River near Keremeos and Cawston and Location 2 – Keremeos Creek Valley, a simple water balance model showed that without the natural inflow of water from the stream beds, the groundwater pumping would exceed the aquifer recharge from other sources.
    e. Water levels in observation wells go up and down at similar times as river levels at nearby WSC hydrometric stations, with only slight lags between peaks.

2. Even though the aquifers and streams/rivers in the Similkameen River watershed are closely linked, and the losing streams are recharge sources for groundwater in the valley bottom, the magnitude of the total streamflow compared to total water withdrawals were assessed as a first step in determining whether groundwater use would significantly affect streamflows. The results indicate that in the Similkameen watershed, groundwater use is small compared to flow in the main streams in nine of the ten sub-basins.
    a. Comparisons of streamflows during the month with the lowest flow (typically September) to the groundwater withdrawals during the month with the highest extraction (typically July) show that groundwater withdrawals are currently less than 10% of the streamflows in all but one sub-basin (i.e. Keremeos Creek sub-basin).
    b. Even when comparing groundwater withdrawals to a 1 in 50-year return period low flow, groundwater withdrawals are currently less than 20% of streamflows in all but one sub-basin (i.e. Keremeos Creek sub-basin).

3. Statistical trend analysis indicated that groundwater levels decreased slightly over the period of record in the three observation wells: Well 75 (Keremeos) (since 1963), Well 203 (Cawston) (since 1977), and Well 220 (Princeton) (between 1977 and 2000). During the same periods, precipitation did not decrease, suggesting that the slight decrease in groundwater levels was likely not related to climatic influences and may have been a result of groundwater withdrawals exceeding the rate of groundwater recharge. However, the groundwater level records since 2000 indicate flat to slight increasing water level trends, which suggests that groundwater withdrawals may be reaching more sustainable rates reflecting more efficient irrigation methods, crop changes to those that use less water, or land use changes.
4. Despite the indication of sustainable rates of groundwater use since 2000, the overall data record indicates that the aquifers in this part of the watershed are sensitive to groundwater use, and that an increase in use from current conditions could again cause a decline. Additional investigations are needed to confirm this and to develop quantitative estimates of changes in groundwater levels.

4.2 RECOMMENDATIONS

Based on the results of the GW-SW interaction investigation, the following recommendations should be considered:

Management Recommendations for the SWP

- Generally consider groundwater and surface water to be a single source of water in the valley bottom portions of the Similkameen watershed where there is agricultural land use and where most people reside
- The SWP should include requirements for proposals for new groundwater or surface water withdrawals to be supported by assessments of potential effects on both surface water and groundwater, recognizing their connected nature.
- As recommended in the Water Availability study (Section 2.1), develop environmental flow needs for each sub-basin, starting with Keremeos Creek and Similkameen River near Keremeos/Cawston. This will assist developers with determining how much groundwater or surface water withdrawals are reasonable for each area.
- The SWP should consider a requirement to monitor water levels in any new well that is 6 inches in diameter or larger. In addition to adding to the database of water levels, it will enable the water user to make management decisions based local information.
- In Sub-basin #7 (Keremeos Creek), consider limiting additional groundwater use until there is evidence that streamflow levels are stable. Installation of a new observation well and hydrometric station in the lower portion of the Keremeos Creek sub-basin is recommended to enable monitoring of this sensitive area.
- New groundwater withdrawals in Sub-basin #9 should also be limited until a detailed study of GW-SW interaction is complete. The can make use of the existing observation wells, but would likely require additional field investigations (see below).

Research, Planning Studies, and Monitoring Network Recommendations

- Currently Aquifer 259 is a mapped aquifer in the main Similkameen River valley bottom extending from the U.S. border to Princeton. It is mapped as one single unit of sands and gravels, but it unlikely homogeneous for the entire mapped spatial extent. As a result, updated mapping and creation of unique numbered system of aquifers underlying all lands in the watershed is recommended to support management decisions throughout the watershed. This will enable groundwater management to be tailored specifically to aquifer characteristics and the demand on that aquifer.

- The current FLNRO observation well program includes three active monitoring wells within the Similkameen River watershed. This number of observation wells should be considered as the minimum number to enable a basic program of monitoring of groundwater levels within the watershed. To provide additional groundwater monitoring support and to provide additional GW-SW interaction information, consider augmenting the FLNRO observation well network as follows:
    - Keremeos Creek was identified to lose streamflows through the Keremeos Creek valley. To support GW-SW interaction investigations, hold discussions with the WSC and FLNRO to consider reactivating WSC hydrometric station 08NL044 on Keremeos Creek and to install an observation well next to the station;
    - Work with the FLNRO to reactivate the discontinued observation well in Princeton (Well 220). This well showed a downward trend in groundwater levels prior to being discontinued.
    - In future, if large groundwater withdrawals are planned for aquifers where an observation well is not located, meet with FLNRO to discuss installing an observation well.

- Although the available data and previous studies provide some understanding about the nature of groundwater-surface water interaction in the Similkameen watershed, the topic has not been studied in detail. As a result, only estimates exist for many of the key fluxes of the groundwater component of the hydrologic cycle. There would be value in addressing this lack of quantitative information by carrying out 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 modelling. Keremeos-Cawston is the suggested location because it is the area most likely to see an increase in water demand, but also because information obtained there is applicable to other areas in the valley where tributary stream have created an alluvial fan in the valley bottom. The recharge processes that would be examined include stream losses (tributaries and main stem), mountain block recharge, and direct precipitation.

  Completion of the Similkameen Watershed Plan can proceed without the information that would be obtained from the recommended GW-SW study. However, given the importance of groundwater in the valley, the detailed assessment should be considered for the next three to five years. SVPS and RDOS may wish to consider forming partnerships with other levels of government (including LSIB and USIB) and the university research community to carry out the work.

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