A Water Budget for the Westwold Valley Aquifer

West of Salmon Arm, BC

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Executive Summary

An empirical water budget was developed for the Westwold aquifer to assess the feasibly of using a simplified spreadsheet water budget to quantitatively determine the primary components of groundwater recharge and discharge to an aquifer. An additional goal of the project was to have the water budget model function as a tool to examine allocation (licensing) options and their general impact on the groundwater resource. To quantify water budget inputs and outputs, the project included establishing four hydrometric stations on the Salmon River and installing groundwater monitoring wells to examine surface water-groundwater interactions. Estimated inflow to and outflow from the aquifer was used to generate a theoretical groundwater hydrograph. The theoretical hydrograph was compared to an average aquifer hydrograph developed from four monitoring wells to calibrate and evaluate the water budget model. The study determined that river loss was the primary source of recharge to the aquifer comprising approximately 70% of the total annual recharge. Natural groundwater outflow into the Salmon River as baseflow was the largest outflow from the aquifer representing approximately 50% to 60% of the total groundwater outflow. The next largest outflow was groundwater pumping at approximately 35% of the total outflow. This report consists of three documents:

1. Written text and figures describing the project and the results.
2. An Area Plan – Figure 2
3. The water budget spreadsheet in Excel format.

1.0 Introduction

One of the Province's commitments in Living Water Smart is to regulate large groundwater use. Allocation of groundwater should incorporate sustainable groundwater extraction. Analysis of sustainable extraction could be completed by developing complex groundwater-surface water numerical flow models however, the provincial government faces the following technical challenges to develop numerical flow models:

1. For many aquifers, there is insufficient hydrogeologic and hydrologic data necessary to build numerical flow models where existing and proposed groundwater extraction may impact the sustainability of the groundwater resource or cause surface water depletion.
2. The funding and personnel necessary to acquire the field data required to build detailed numerical flow models are currently not available.
3. The human resources required to undertake numerical flow modeling including revaluating and updating the models as new information becomes available or additional groundwater extraction is proposed.

The purpose of the project was to develop a simplified water budget that could function with readily available data and assess the applicability of a simplified budget to support water resource allocation decisions. The simplified budget should identify the primary components of groundwater recharge and discharge in the study area and distinguish parameters that may require monitoring or further refinement. The budget should also facilitate an examination of allocation options and their general impact on the groundwater resource using a methodology that regional staff could implement, evaluate and update without requiring extensive numerical modeling software and expertise. Representing the Westwold aquifer as a simplified "linear reservoir" for ease of computation and understanding does mean that the water budget cannot be used to assess spatial variation of groundwater conditions within the study area.

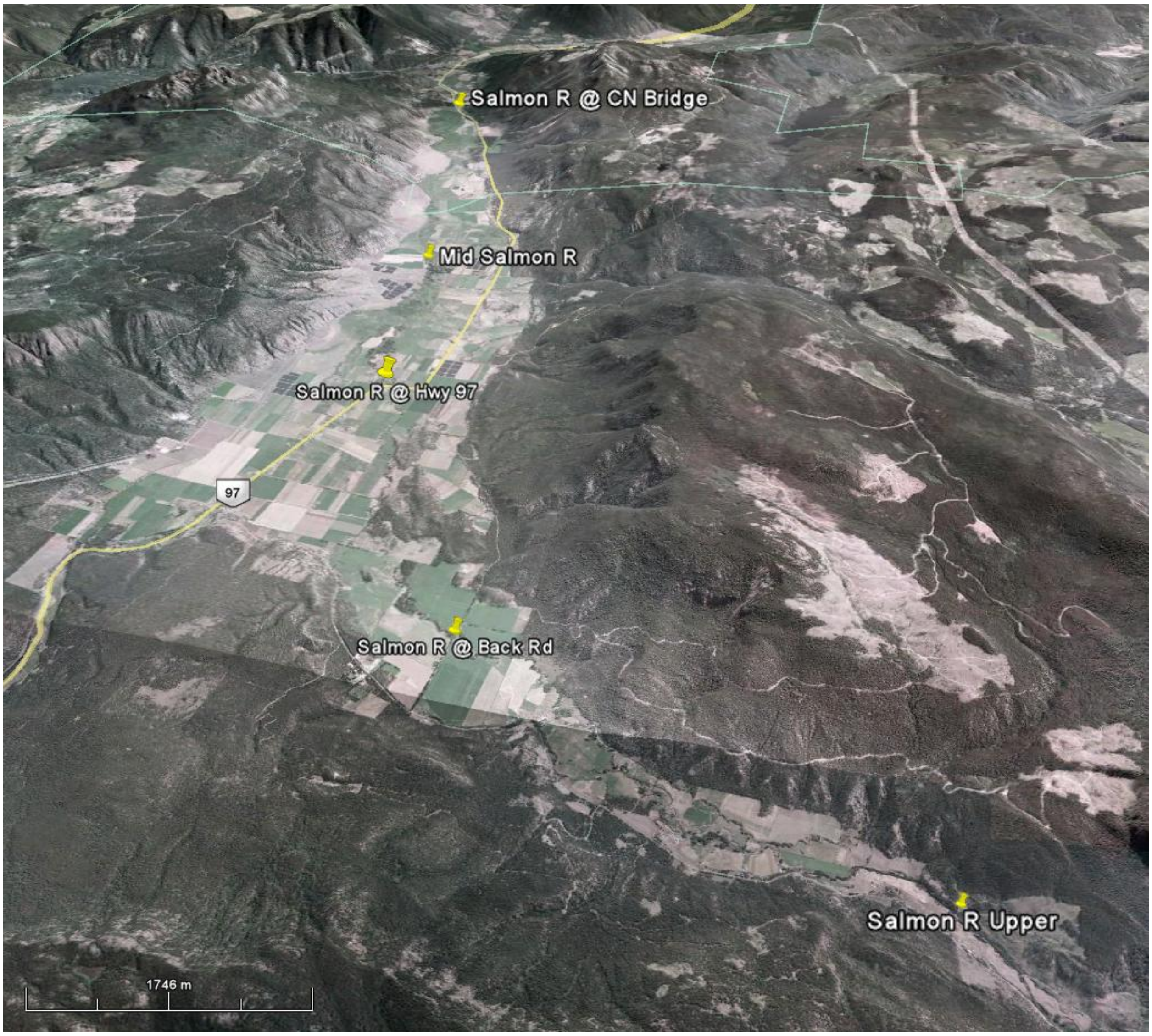
2.0 Study Area

A water budget was developed for the Westwold Valley located midway between Kamloops and Vernon. Westwold was chosen due to its importance as an agricultural area, its extensive use of groundwater and surface water for irrigation and high degree of surface water - groundwater interaction. The Westwold valley bottom encompasses approximately 2,500 hectares which are almost entirely developed for forage crop and turf production. A Google Earth© image looking east (downriver) through the Westwold Valley is provided on Figure 1.

2.1 Hydrogeology

The majority of the valley in the study area is bordered by steeply sloping bedrock to the north, south and west. The surficial geology of the valley consists of modern alluvium in the southern end of the valley grading into alluvium fan complexes in the center and eastern portions of the valley. The alluvium fan deposits terminate into bog deposits at the east end of the valley corresponding to the end of the study area. The alluvium forms an unconfined to partially confined aquifer that has been the primary source of groundwater for irrigation and domestic use with wells generally drilled from 9 m (30 ft) to 30 m (100 ft) in depth.

Figure 1 – Looking East through Westwold Valley



The quaternary valley bottom deposits include low permeable confining clay and till deposits as well as permeable aquifer formations. Wells have been drilled to a depth of 90m (300 ft) into the permeable formations. The Province has mapped two aquifers in the Westwold valley. The aquifers are outlined in red in Figure 2 (separate document). Aquifer No 289 is classified[1] as a IIB (12) aquifer and terminates at the bog deposits at the east end of the study area. Aquifer 289 is underlain by aquifer No 98 (12) which is classified as a IIC aquifer. The linear reservoir model treats both aquifers as one aquifer unit.

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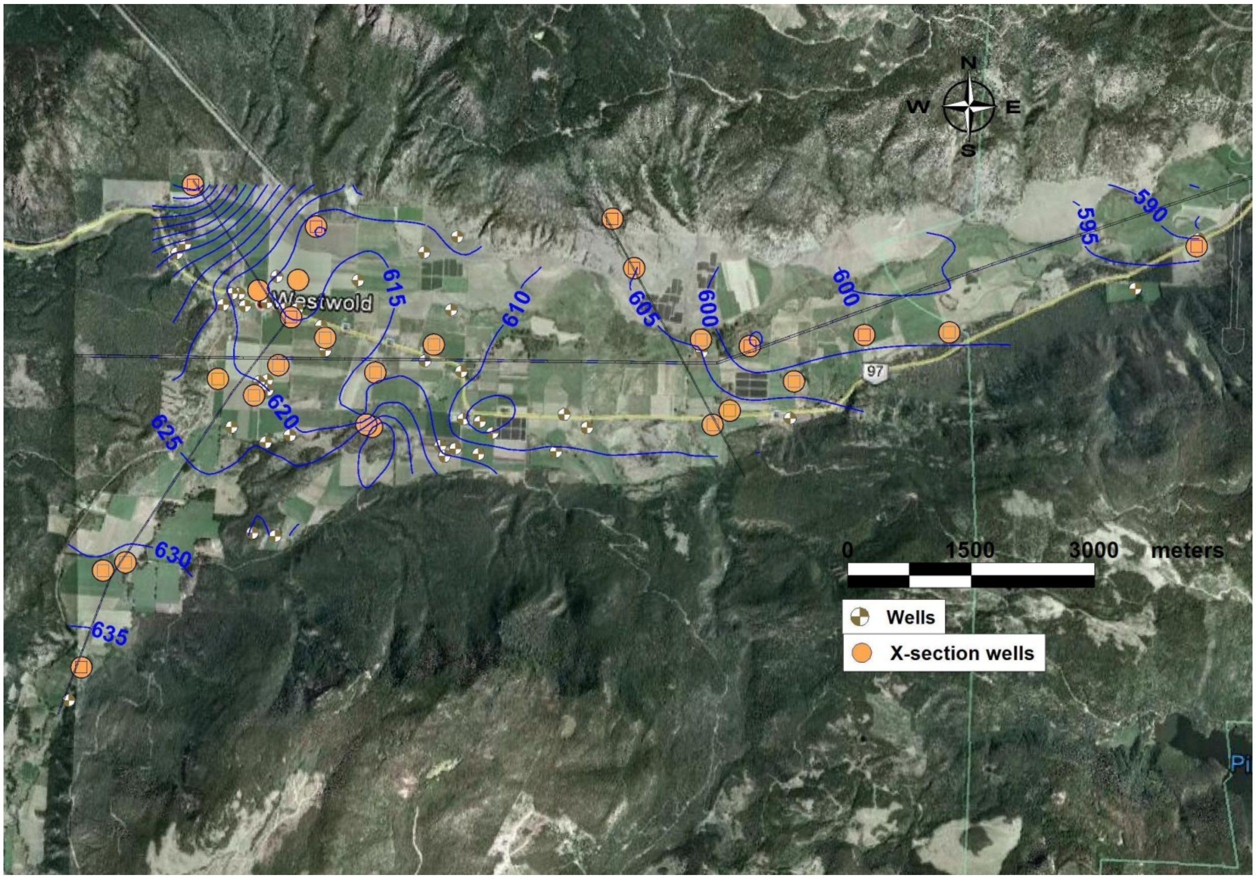
[1] J. Berardinucci and K. Ronneseth, *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*, Ministry of Water, Land and Air Protection, June 2002.

Available water well records for the eastern portion of the valley suggest rising bedrock with overburden deposits thinning from the west to east. Two flowing wells are present in the central-east portion of the valley near “Mid Salmon R”. The gradual constriction of the aquifer moving eastward along the valley is creating an upward groundwater gradient with increasing groundwater discharge into the Salmon River downstream of “Salmon R @ Hwy 97”.

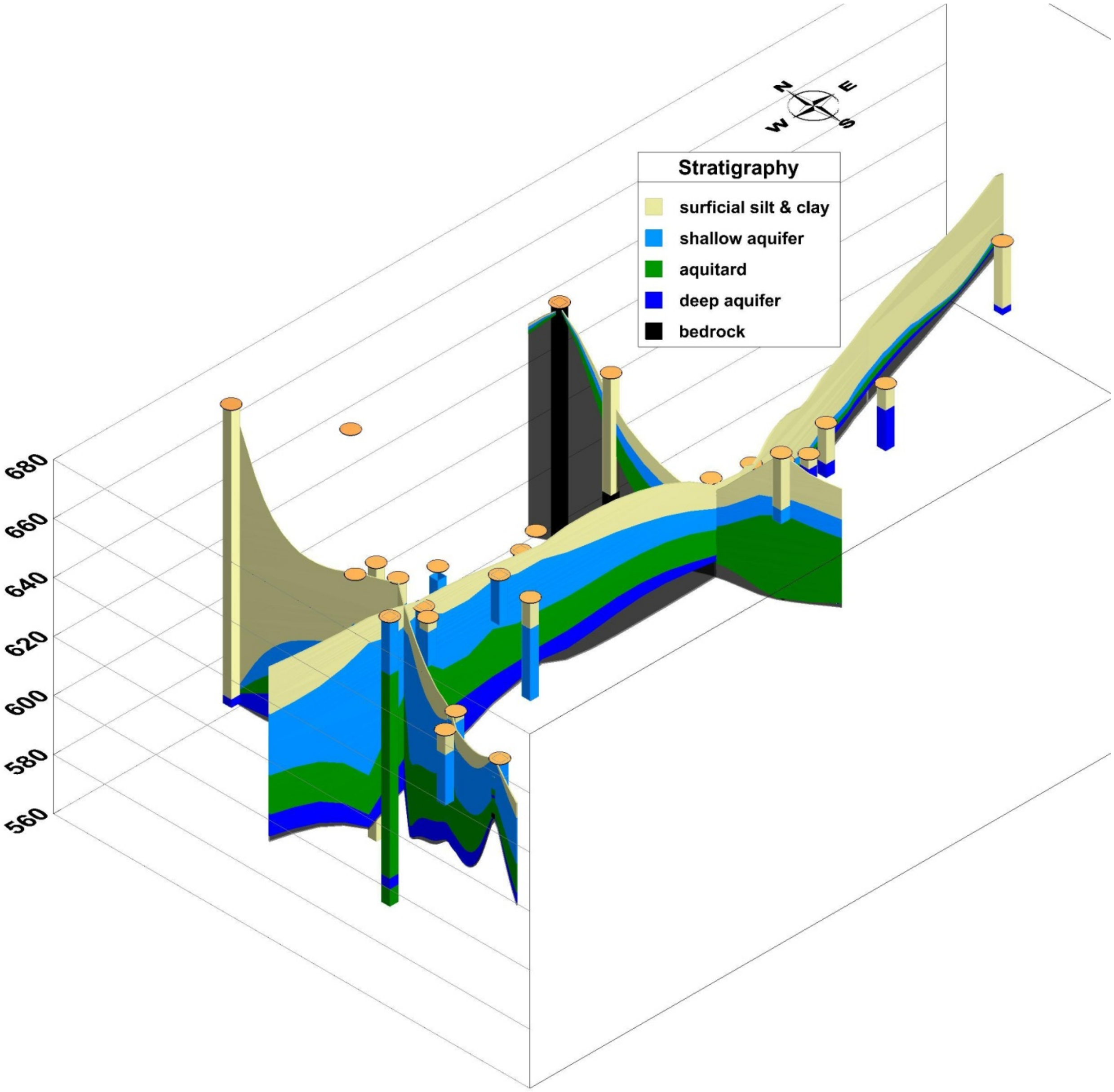
Hydrogeological cross-sections through the Westwold Valley are provided on Figures 3, 4 and 5. The cross-sections were generated using the software EnviroInsite. Figure 3 illustrates the axis’s of the hydrogeological cross-sections (fence diagrams), the water wells used for interpretation and the piezometric surface in meters above sea level (mASL) through the valley. Figure 4 and Figure 5 illustrate the stratigraphic profile looking from the southwest and southeast respectively.

Figure 3 - Hydrogeological Cross-Sections Axis’s and Piezometric Surface (mASL)



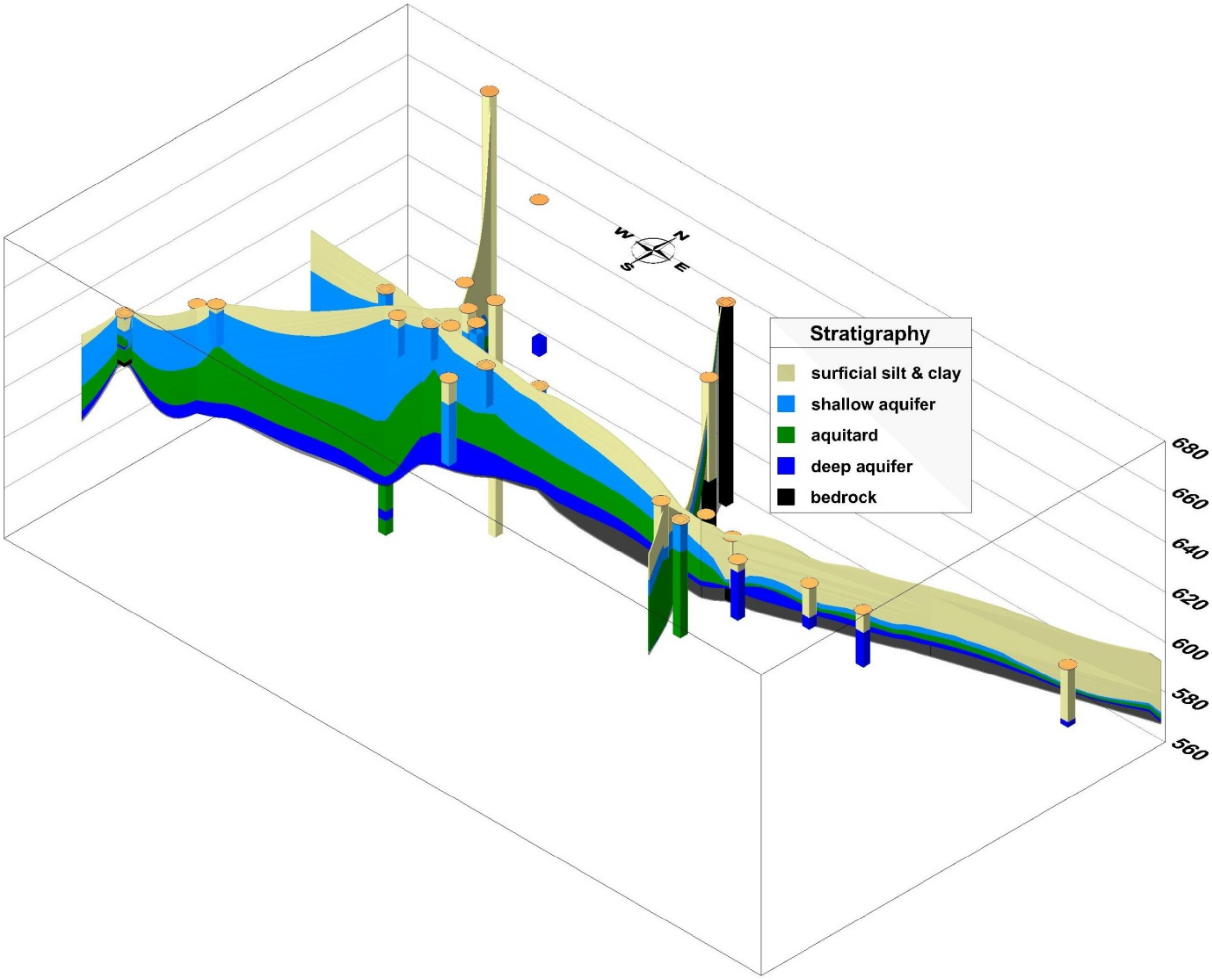
The stratigraphic model illustrated on Figures 4 and 5, is comprised of a “surficial silt and clay” unit overlying the “shallow aquifer” (Aquifer No 289), with an “aquitard” separating the “shallow aquifer” and the “deep aquifer” (Aquifer No 98). The overburden units are underlain by bedrock. The shallow aquifer is partially confined by the surficial silt and clay unit in the central and eastern portions of the valley but is continuous to the surface i.e. unconfined, in the upstream portions of the valley where losing stream conditions exist. Figures 4 and 5 show the aquitard separates the shallow aquifer and the deep aquifer however, not all water wells intersect the aquitard and it is likely that the aquitard pinches out in places connecting the shallow and deep aquifers. The connection of the two aquifers supports the application of both aquifers as a single unit in the water budget model.

Figure 4 - Hydrogeological Cross-Section Looking From Southwest



The cross-sections also illustrate that the aquifers become thinner and narrower moving east along the valley and become more confined by the surficial silt and clay layer. The confining conditions create an upward groundwater gradient as evidenced by the presence of flowing wells, perennial river flows, and extensive surface ponding following freshet.

Figure 5 - Hydrogeological Cross-Section Looking From Southeast



2.2 Hydrology & Climate

The Salmon River drains a 1,440 square kilometre basin from its source in the Douglas Plateau to its mouth on Shuswap Lake at Salmon Arm. Beginning at an elevation of 1800 m at Bouleau Mountain, the river flows west to Salmon Lake, northwest to Westwold (elevation 615 m), east to Glenema and then north to Shuswap Lake for a total distance of 150 kilometres.

The Salmon River Basin climate is characterized by a warm and dry summer, a fairly long growing season, and a cool winter. The watershed lies in the rain shadow created on the leeward side of the Coast and Cascade Mountains. Westwold normally experiences four winter months with a daily average temperature below 0^{o}C and five summer months with a daily average temperature above 10^{o}C. Mean annual precipitation in the Westwold valley is around 390 mm with approximately 25% of the precipitation coming as snow. Most stream flow in the Salmon River Basin originates from depletion of the winter snowpack at high elevations with high runoff in May and June, a rapid recession during July and baseflow for the remainder of the year.

Water Survey Canada operates a permanent hydrometric station on the Salmon River at Falkland downriver of the study area. Beginning In 2008, MOE measured the flow at five locations along the river. These five hydrometric locations separate the river into four reaches. The locations of the five hydrometric stations are illustrated on Figures 1 and 2. Photographs of the five stations are also provided in Figure 2. The four reaches were:

Reach 1. Upper Salmon River to Back Road – 6.0 km long losing reach

Reach 2. Back Road to Highway 97 Bridge Crossing – 5.1 km long losing reach

Reach 3. Highway 97 Bridge Crossing to Salmon River Mid – 3.8 km long transitional reach

Reach 4. Salmon River Mid to CN Bridge Crossing – 8.1 km long gaining reach

The Salmon River flows year round at the Upper Salmon River station. Except during freshet which usually occurs from April 15 to July 15, all flow in Reach 1 “Upper Salmon River to Back Road” is lost to the aquifer and/or diverted for irrigation before reaching Back Road. Flow through all four reaches of the river only occurs during freshet. In 2009, flow in Reach 2 “Back Road to Highway 97 Bridge Crossing” only occurred during freshet, with the reach dry during the remainder of the year. This phenomenon is typical for the river and is believed to be due to a combination of highly permeable stream bed (fines annually scoured from stream bed by freshet), highly permeable aquifer materials, and reduced stream flow after freshet.

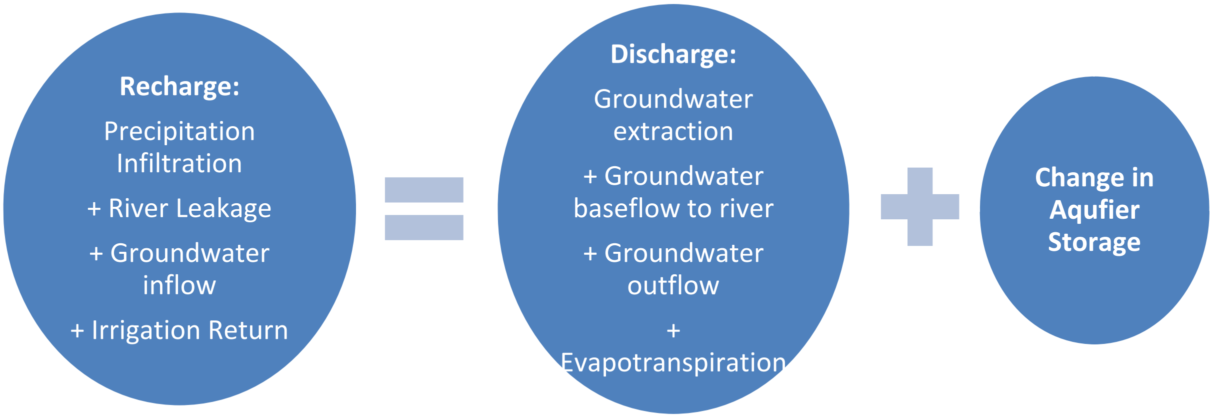
Outside of the freshet period, the river starts to flow again midway along Reach 3 “Highway 97 Bridge Crossing to Salmon River Mid” with the entire flow derived from groundwater. The Salmon River flows year round in Reach 4 “Salmon River Mid to CN Bridge Crossing” with all flow (except during freshet) derived from groundwater.

The two other surface water sources of irrigation in the Westwold Valley are Monte Lake and Ingram Creek (Figure 2). Water is stored in Monte Lake and released during the irrigation period and conveyed to the Westwold Valley via Pringle Creek (perennial). Ingram Creek flows into the mid section of the Valley from the south. Ingram Creek normally flows from approximately May 1 to July 15 and is dry the remainder of the year.

3.0 Conceptual Water Budget

Prior to human development the groundwater system in the Westwold Valley was in general equilibrium where the amount of water entering or recharging the valley aquifer was approximately equal to the amount of water leaving or discharging from the aquifer. Because the system was in equilibrium, the quantity of water stored in the aquifer was constant or varied about some average condition in response to annual or longer-term climatic variations. Possible inflows (recharge) include precipitation recharge and loosing streams. Possible outflows (discharge) of the groundwater system under natural (equilibrium) conditions include groundwater evapotranspiration and discharge to surface waters as base flow.

Pumping groundwater changes the pre-development equilibrium. The source of water for pumping must be supplied by (1) more water entering the aquifer (increased recharge), (2) less water leaving the aquifer (decreased discharge), (3) removal of water that was stored in the aquifer, or a combination of these three.[2] The water budget can be expressed as:



The change in storage in the aquifer is reflected as the change in groundwater level. A conceptual water budget illustrating the sources of recharge and discharge from the valley aquifer is provided in Figure 6 and can be expressed as:

Precipitation infiltration + Groundwater inflow + River and stream leakage + Irrigation return = Groundwater extraction + Surface water extraction + Evapotranspiration + Groundwater discharge to river + Groundwater outflow +/- Change in storage in the aquifer.

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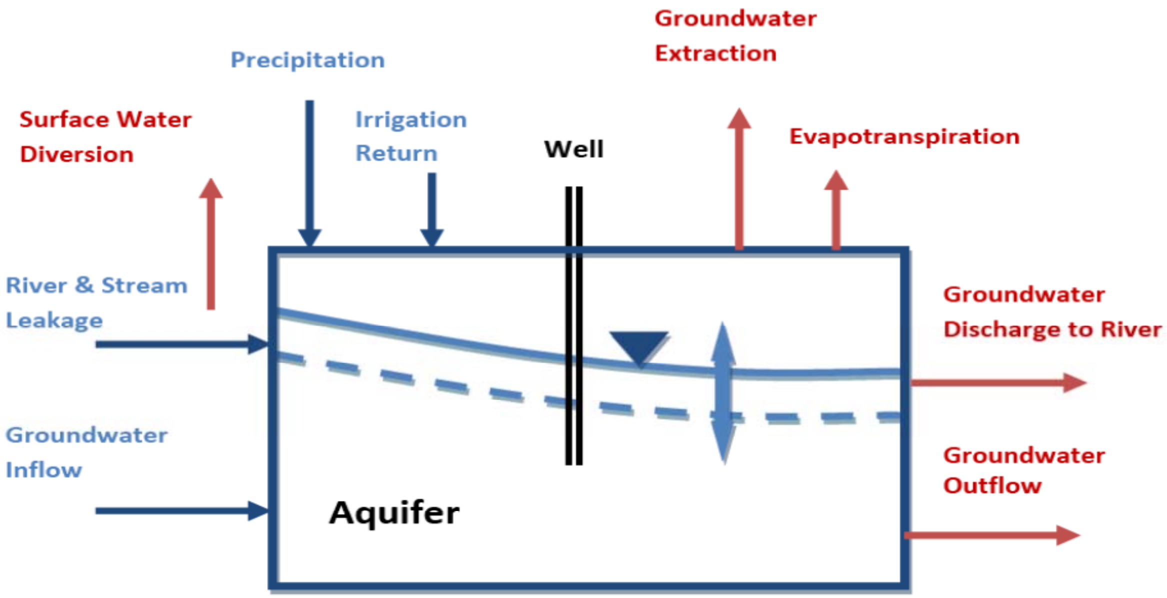
[2] William M. Alley, et.al, *Sustainability of Ground-Water Resources*, U.S. geological Survey 1186, Denver Colorado, 1999.

Figure 6 – Conceptual Water Budget



4.0 Groundwater Monitoring

MOE has operated one provincial observation well (OW 45) in the Westwold Valley since 1965. The observation well is located on Station Road (see Figure 2). Long term hydrometric data are provided on Figure 7 and historical trend data are provided on Figure 8. Cumulative precipitation departure (CPD) data for the period of record are also plotted on Figure 7[3]. CPD indicates precipitation trends relative to normal precipitation, over the period of interest. When the CPD line slopes down, precipitation is below normal, when the line slopes up, precipitation is above normal and when the line is flat, precipitation is near normal. CPD on Figure 7 illustrate a period of below normal precipitation from 1965 to 1980, above normal precipitation from 1980 to 1998 and near normal precipitation from 1998 to 2006. Where precipitation forms the primary source of aquifer recharge, the groundwater level in the aquifer exhibits a similar trend to the CPD. The hydrograph at OW45 does not show similar trends to the CPD suggesting that direct precipitation is not a significant source of recharge to the aquifer relative to other potential sources of recharge such as river loss.

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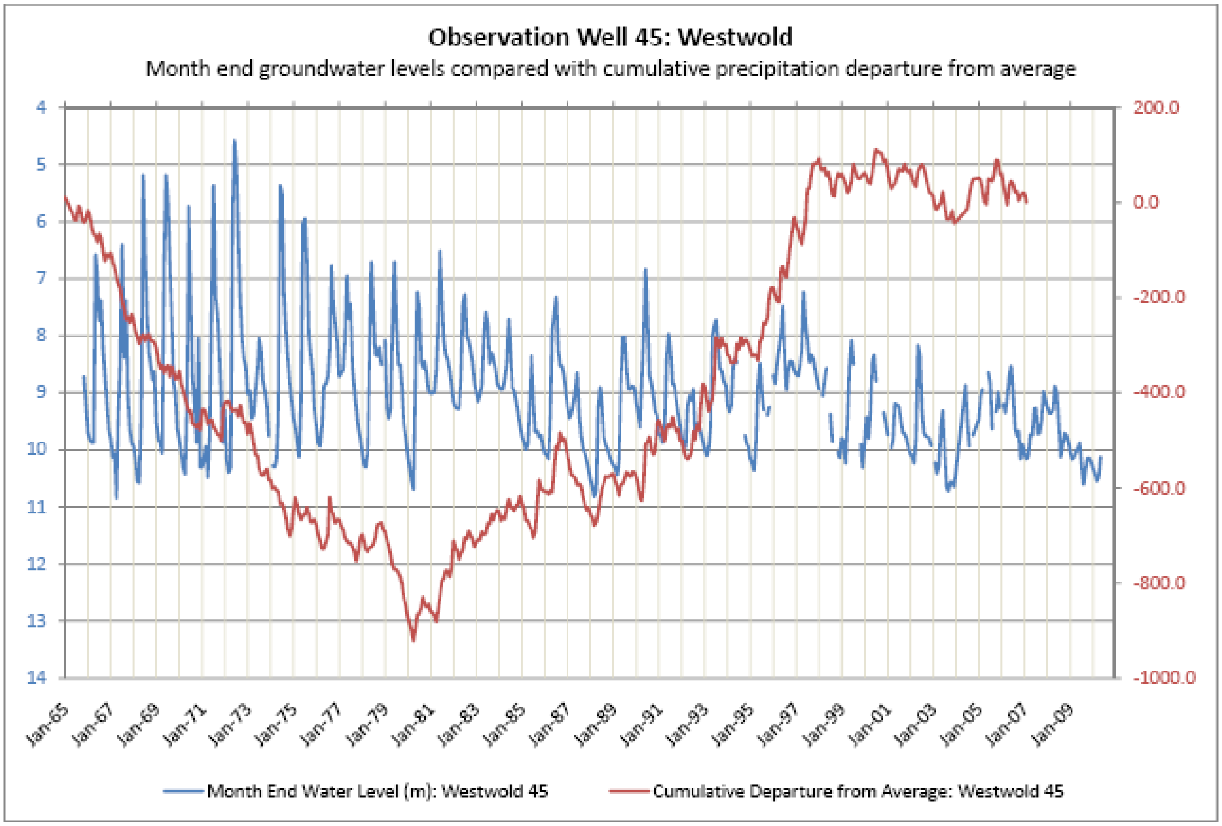
[3] *British Columbia Observation Well Network. Improving the Reporting Of Observations Well GroundWater Data*, BC Ministry of Environment Report, February 2010.

Figure 7 – Long Term Hydrometric Data

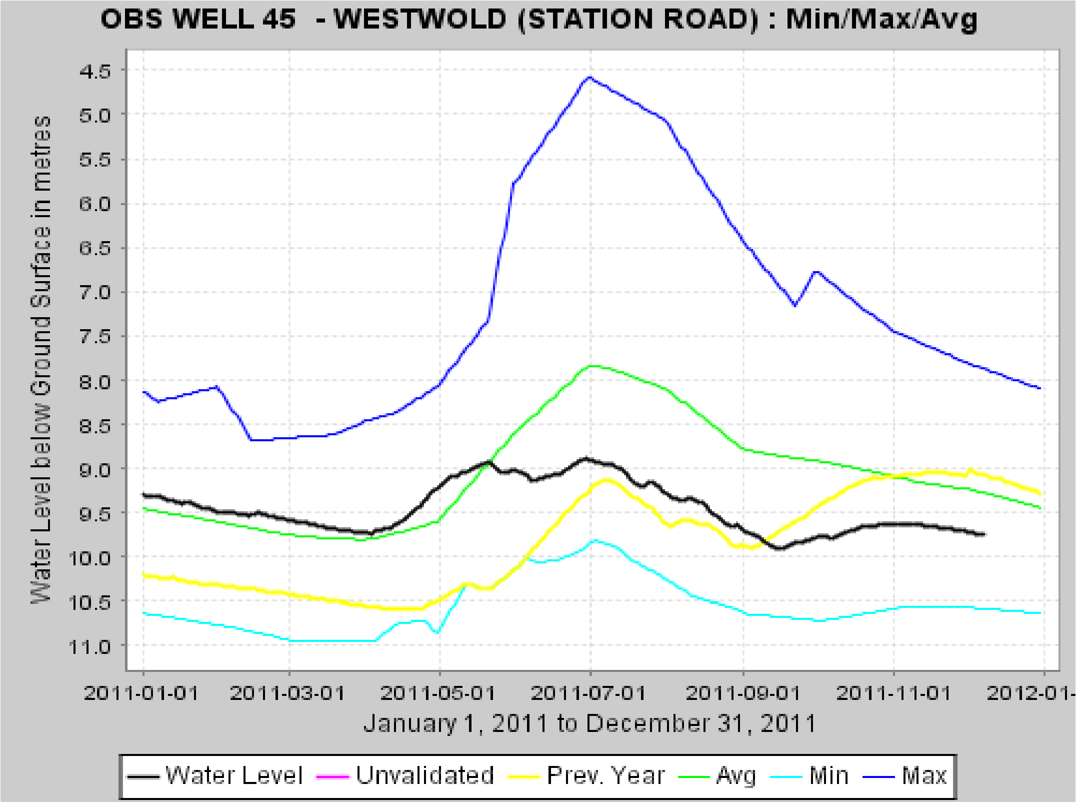


Historical groundwater level lows at OW 45 occurred in 2009 (summer) and 2010 (late spring). Figure 8 illustrates that in 2010 (yellow line) the groundwater level in OW45 was well below the long term average for most of the year but rose substantially over the fall period and was at a long term normal winter elevation by the end of 2010. The relatively low groundwater table rise during freshet 2011 (black line) and fluctuating groundwater level during the irrigation period suggests that increased groundwater withdrawals proximate to OW 45 may be causing drawdown at the observation well. A net decline in the groundwater table occurred over the course of 2011 (black line).

Figure 7 also illustrates a substantial decline in the season fluctuation of the groundwater table since the 1970s. The decline in seasonal fluctuation indicates that either aquifer recharge has decreased, outflow from the aquifer (river baseflow, groundwater pumping) has increased, or a combination of both has occurred.

Up until the 1970s and early 1980s, the primary method of irrigation was surface water flooding and areal application. A review of irrigation wells in the MOE WELLS database indicated that approximately 50% of the wells in the database were drilled in the 1970s and 1980s with the remaining 50% drilled since 1990. Flood irrigation is now uncommon with areal application the primary method of irrigation. The change in irrigation methods has likely resulted in a decrease in irrigation loses and associated recharge to the aquifer.

Figure 8 – Historical Hydrometric Trend Data



A review of 1960 through 2009 river flow data from the Environment Canada's hydrometric station at Falkland (approximately 3.5 km downstream of "Salmon R @ CN Bridge") indicates that there has not been a declining trend in annual average flow or freshet flow in the Salmon River. The hydrometric data for the Falkland station suggest that although a seasonal decline in aquifer storage has occurred, it has not yet resulted in a decline in river baseflow. In summary the hydrometric and groundwater monitoring data suggest that:

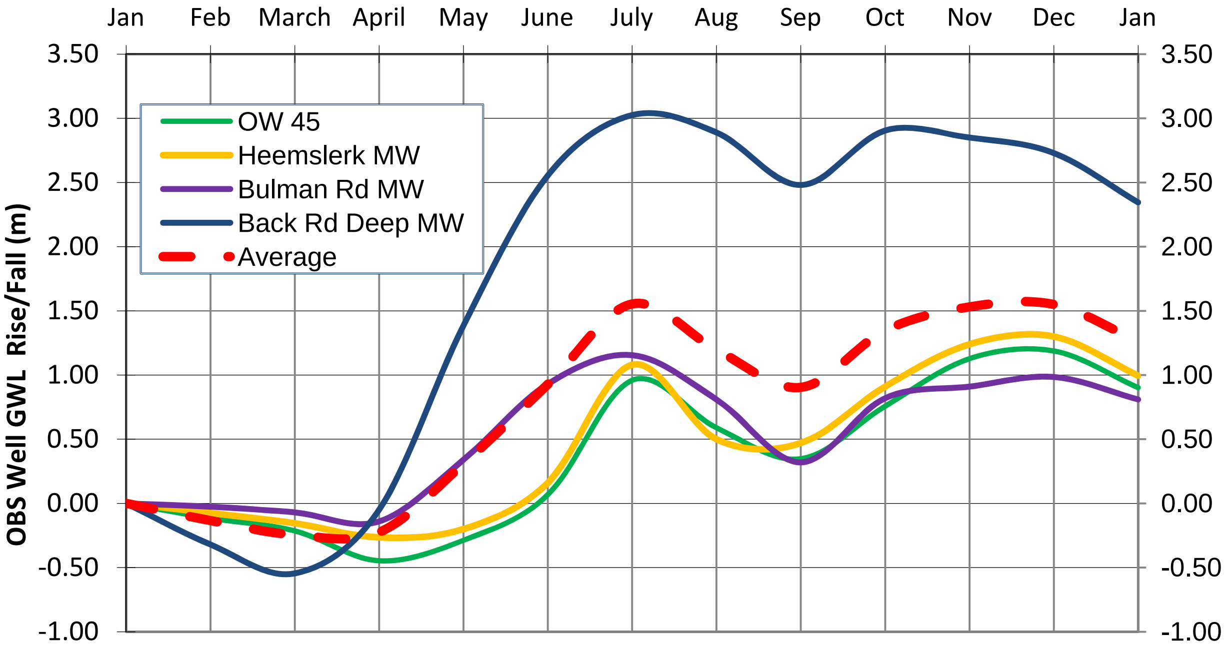
1. Changing irrigation methods have reduced aquifer recharge.
2. Increased groundwater pumping is capturing recharge and reducing aquifer storage.
3. The seasonal reduction in storage has not yet reduced river baseflow.

5.0 Field Work & Observations

5.1 Monitoring Well Installation

In the summer of 2009, MOE installed additional groundwater monitoring wells beside the Salmon River at Back Road and Bulman Road/Hwy 97 bridge. An unused irrigation well along the north side of Hwy 97 "Heemskerk MW" was also added to the monitoring network. The additional wells were constructed to further examine groundwater-surface water interactions, investigate the position of the groundwater table in relation to the river bed, and approximate an average annual fluctuation in the aquifer from four locations rather than just OW 45. Each new monitoring well was instrumented with a pressure transducer to measure and record the depth to groundwater hourly. The monitoring well locations are illustrated on Figure 2. Normalized groundwater monitoring data from the four locations are illustrated on Figure 9.

Figure 9 - Individual and Average Groundwater Fluctuations in 2010



The monitoring well elevations were surveyed relative to the adjacent river bed. The survey and groundwater elevation data indicated that an unsaturated zone was continuously present between the river bed and the unconfined aquifer at both the Back Road and Bulman Road monitoring well locations throughout 2010 and 2011. The unsaturated zone thickness below the river bed ranged from 3 m (freshet) to 6 m at Back Road and 4 m (freshet) to 6 m at Bulman Road.

5.2 Measuring River Flows

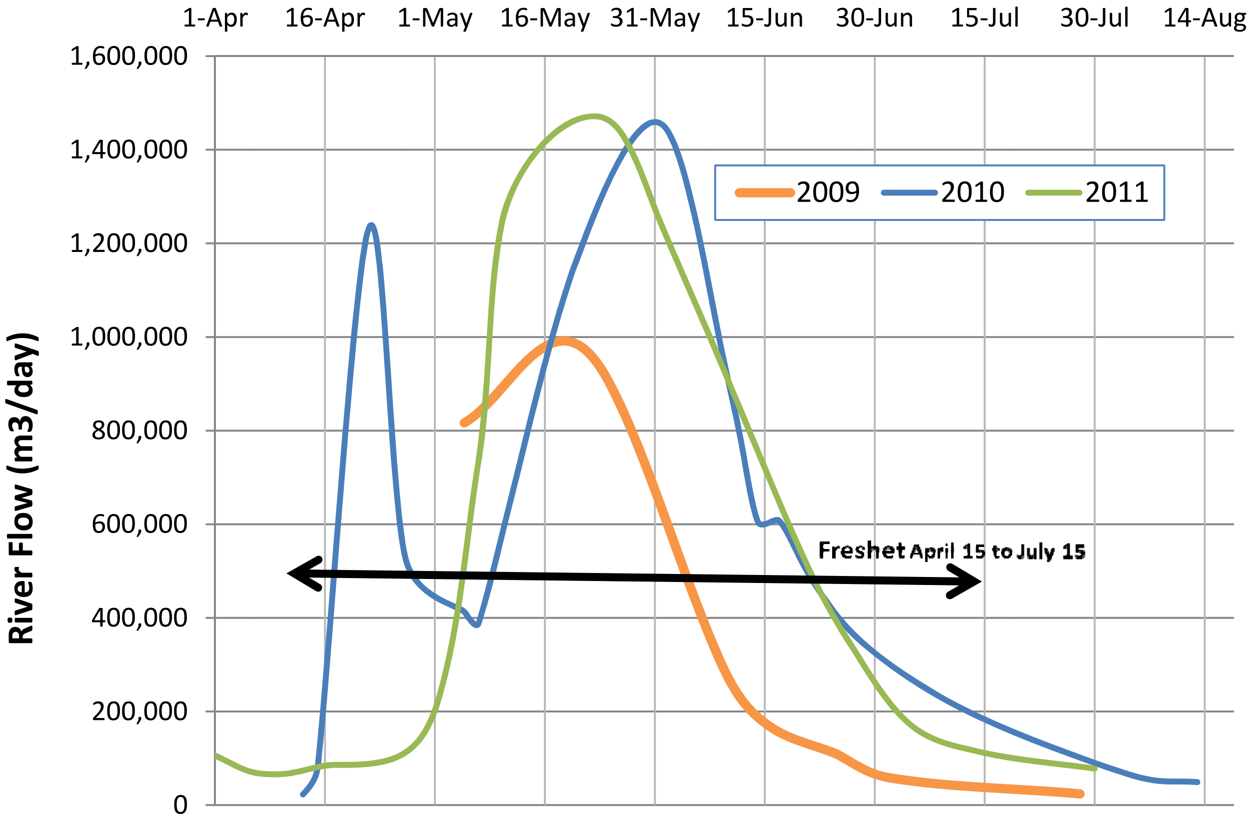
In fall 2008, MOE installed two automated hydrometric stations on the Salmon River and one hydrometric station at the outlet control structure from Monte Lake. A third automated hydrometric station was installed on the Salmon River (at CN Bridge) in February 2011. The hydrometric stations were located at the upstream, mid valley and downstream ends of the study area and are identified as “Salmon R Upper”, “Mid Salmon R” and “Salmon R @ CN Bridge” on Figures 1 and 2. The hydrometric stations were instrumented with pressure transducers to recorded river stage and water temperature hourly. MOE took manual flow measurements to develop rating curves for the three automated stations. The hydrometric station at “Mid Salmon R” was damaged during the spring 2009 freshet and was not re-established due to the unstable nature of the river bed at that location.

MOE also completed manual flow measurements at "Salmon R at Back Rd", Salmon R at Hwy 97" and Salmon R @ CN Bridge". Manual flow and automated flow measurements from the station at Salmon River Upper and Mid Salmon River are illustrated on Figure 7. MOE periodically measured flows in Ingram Creek at Hwy 97.

Freshet flow typically starts April 15th and ends July 15th based on long term average flow data at Water Survey Canada Station - Salmon River at Falkland (http://www.wateroffice.ec.gc.ca/index_e.html). The 2009 period of freshet was consistent with the historical time frame, however, the 2010 freshet extended to the end of July and the 2011 freshet did not start until the beginning of May. Figure 10 illustrates that the 2010 and 2011 freshets produced higher flows over a longer time period than the 2009 freshet. The increased flows in 2010 are attributed to relatively higher than normal late spring precipitation, with higher flows in 2011 attributed to a greater snowpack as compared to 2009.

Losses in flow from Salmon R Upper to Salmon R @ Back Road, Back Road to Salmon R @ Hwy 97, and Salmon R @ Hwy 97 to Mid Salmon R, generate recharge to the aquifer. The river reach of Salmon R @ Hwy 97 to Mid Salmon R, is a losing reach during a portion of the freshet period and is primarily dry or gaining through the remainder of the year. Figure 10 illustrates that potential recharge/river loss to the aquifer was greater in 2010 and 2011 than in 2009.

Figure 10 – 2009, 2010 & 2011 Salmon River Upper Freshet Flow Measurements



5.3 Estimating water extraction and use

Sources of irrigation in the valley, i.e., surface water, groundwater or a combination of both were estimated by interviewing selected land owners, reviewing water licences and points of surface water diversion, field observations of points of diversion, proximity of land to the dry reach of the river, known irrigation well locations (WELLS) and observed irrigation wells and drive-by observations.

The methods of irrigation in the valley are illustrated on Figure 2 using color coding as indicated in the map legend. The source of irrigation upstream of Back Road is surface water diverted from the Salmon River (green). The western portion of the valley is primarily irrigated by groundwater (pink). The mid section of the valley is primary irrigated by Salmon River and Ingram Creek (green). The very eastern end of the valley is naturally irrigated by seasonal flooding and a high groundwater table (yellow). Areas that utilise both groundwater and surface water are illustrated in blue. The surface water source for the blue area in the north-western portion of the valley is Monte Lake located approximately 3.5 km west of the valley.

Based on field reconnaissance, water licence records, land owner interviews and areal mapping it is estimated that there are 2266 cultivated hectares (5,600 acres) in the valley with approximately 1026 hectares (45%) irrigated by groundwater, 940 hectares irrigated by surface water diversion (41%) and 300 hectares (14%) naturally flood irrigated.

6.0 Water Budget Spreadsheet

The water budget was developed using a spreadsheet where monthly recharge to and discharge from the aquifer were quantified along with a resulting monthly surplus or deficit. Monthly data were totalled into annual volumes. The water budget examines the movement of water into and out of the aquifer but not the movement of water within the aquifer; it essentially treats the aquifer in the study area as a “linear reservoir” (see Figure 6). The water budget does not consider transmissivity and cannot predict well interference or estimate the effects of individual wells on surface water loss or gain. An overview of the spreadsheet is provided below. Descriptions on how individual monthly recharge and discharge volumes are calculated are provided in sections 6.1 and 6.2.

Parameters used to calculate volumetric inflow and outflow are provided at the upper portion of the spreadsheet. These parameters include: irrigated area, precipitation infiltration, irrigation duty[6], theoretical crop requirements, irrigation return, aquifer specific yield and groundwater inflow and outflow at the study boundaries. Some parameters are based on field work and desktop review such as irrigated area while other parameters are assigned values such as aquifer specific yield (assumed to be 0.25 for an unconfined sand and gravel aquifer), the percentage of annual precipitation that enters the aquifer and irrigation return. Parameters have also been inferred from hydrometric, topographical and water well information such as the volume of groundwater flowing into and out of the study area along the valley floor. All of the input parameters can be modified to examine their effect on the water budget, evaluate the sensitivity of individual parameters to the overall budget or refine estimated parameters as more detailed information on these parameters are obtained. The spreadsheet

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[6] Duty - depth of water applied over the irrigation season

recalculates recharge, discharge and surplus/deficit volumes as parameters are changed allowing different scenarios of water supply and/or water use to be explored.

6.1 Water budget Inflows – Recharge

6.1.1 Precipitation Infiltration

Monthly precipitation data for Westwold was obtained from Environment Canada weather normals for 1971 to 2000 http://climate.weatheroffice.gc.ca/climate_normals/index_e.html

Precipitation recharge to the aquifer was divided between precipitation falling on the valley floor and infiltrating vertically into the underlying aquifer, and precipitation on the valley sides and upland area that would provide deep seated lateral recharge through the aquifer-bedrock contact along the valley sides. The valley bottom infiltration area was estimated at 3,700 hectares with 10% of the precipitation assumed to infiltrate past the rooting zone and recharge the aquifer. Infiltration as a percentage of precipitation is a modifiable parameter in the spreadsheet.

Groundwater recharge from the upland areas to the valley floor aquifer was estimated based on numerical hydrogeological modeling of conceptual mountainous watersheds by Neilson-Welch and Allen, 2010. [[1] The modeling results suggest that recharge to the saturated zone in an upland area would partition into surface runoff, stream base flow (via deep groundwater discharge at stream valleys) and deep-seated groundwater flow that replenishes valley bottom aquifers via Mountain Block Recharge (MBR). This deep groundwater recharge would provide a continuous flux of MBR to a valley bottom aquifer through the bedrock-valley sediment contact along the valley bottom sides. Neilson-Welch and Allen determined that the rate of flux was primarily controlled by the mountain geology rather than climate (annual precipitation). Neilson-Welch and Allen estimated that 35 to 50 mm/year of available precipitation across their conceptual watersheds could migrate as deep groundwater flow through the mountain bedrock to a valley bottom aquifer. The total annual recharge to the Westwold valley aquifer from the surrounding bedrock was estimated by multiplying a flux rate (50 mm/year) multiplied by the valley length (21 km x 2 sides) multiplied by the valley aquifer thickness (100 m). Recharge was also considered to occur uniformly throughout the year.

6.1.2 Groundwater Inflow at Upstream Study Boundary

Groundwater was assumed to flow into the upstream study boundary through the valley bottom alluvium alongside the Salmon River. Flow was calculated using Darcy's Equation $Q = K \times i \times A$ where:

Q = volumetric flow rate,

K= hydraulic conductivity (e.g. 10^{-2} m/s assumed for sand and gravel),

i = hydraulic gradient (2.5m/km based on ground topography), and

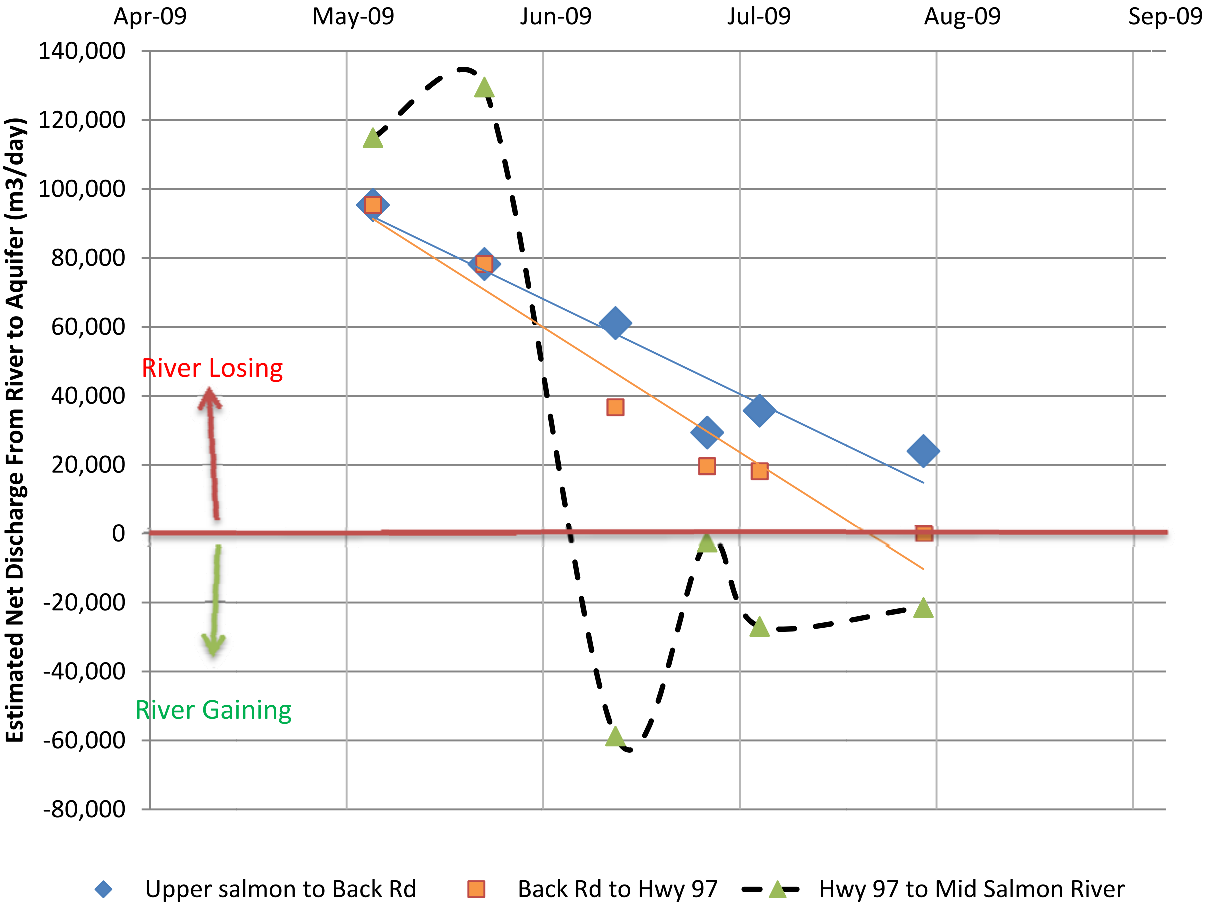
A = saturated cross-sectional area (estimated at 400 m wide by 8 m deep, based on the width of the mapped aquifer and known thickness from well logs).

6.1.3 River Loss

Changes in flow between hydrometric stations adjusted for estimated surface water diversions and tributary flow, were assumed to be recharge or discharge from the aquifer along that reach of the river. River loss data (2009) from the three reaches that recharge the aquifer are plotted on Figure 11. Uncertainty in a river loss measurement is the product of the uncertainty in the flow measurements at the beginning and end of each reach, compared to the measured river loss. The uncertainty in a single river loss measurement can be up to 50%.

The most upstream reach in the study area - "Upper Salmon to Back Road" is the only reach of the river that flows year round and provides continuous aquifer recharge (never plots below zero in Figure 11). During freshet the estimated daily recharge to the aquifer is the average river loss from the data plotted in Figure 11. For example, the daily loss at the beginning of May (Upper Salmon to Back Rd) is approximately 90,000 m^3/day and 70,000 m^3/day at the end of May, so the total recharge for the month of May would be the average – 80,000 m^3/day multiplied by 31 days. Similarly, the average daily river loss flow for June was estimated at 55,000 m^3/day.

Figure 11 – Freshet River Loss & Gain (Salmon River - 2009)



Recharge from Upper Salmon River to Back Road outside of the freshet period was based on the average monthly flow recorded at the Upper Salmon hydrometric station. The station is not operated in the winter when the river freezes over and December and January flow rates are estimates from one flow measurement in December 2009.

The river reach “Back Rd to Hwy 97” only flows in freshet typically ending in mid July. Recharge to the aquifer (river loss) from this reach is estimated in the same manner as described above.

Figure 11 illustrates that in 2009, the reach “Hwy 97 to Mid Salmon River” was a losing reach until the end of May, when it then became a gaining reach. In 2009, recharge to the aquifer from this reach was estimated to occur from the start of freshet (April 15) to May 30th. In comparison, 2010 river loses occurred from April 15th to June 15th and in 2011, river loss was estimated to occur over the shortest period from the end of April to the end of May.

During the irrigation season, water is released from Monte Lake and conveyed to the Westwold Valley for application. The average rate of release in 2009 was 16,000 m^3/day. Releases from Monte Lake were not measured in 2010 and 2011 but were assumed to be the same as 2009 in the budget. It was also assumed that 20% of the released water would recharge the aquifer through ditch losses representing roughly 2% of the total annual recharge to the aquifer.

Ingram Creek typically only flows to the valley bottom during freshet. Based on periodic flow measurements it was estimated that 80% of the flow was diverted for irrigation and 20% of the flow infiltrated the aquifer. It was also estimated that hyporheic flow was occurring beneath Ingram Creek as it flowed over its alluvial fan extending from the valley side to the valley bottom. Hyporheic flow was estimated to generate recharge to the valley bottom aquifer of a similar magnitude as direct stream loss from Ingram Creek. Aquifer recharge from Ingram Creek was estimated to represent roughly 4% of the total annual recharge.

6.1.4 Irrigation Return

A percentage of the applied irrigation water may pass through the rooting zone and recharge the aquifer. Agriculture and Agri-foods Canada has been working with farmers in the valley to improve irrigation efficiency and reduce water consumption by establishing on farm weather stations and monitoring soil moisture. Preliminary findings by Agriculture and Agri-foods Canada indicted that soil moisture was not increasing during the irrigation season and that irrigation return where irrigation was applied aerially, was negligible. However, areas where open ditches were used, line breaks or other conveyance loses would provide irrigation return to the aquifer. An irrigation return of 5% was used for the model. The irrigation return percentage can be easily varied in the spreadsheet water budget.

Irrigation return in row 71 of the spreadsheet represents return from irrigation sourced from groundwater and Salmon River diversions. Irrigation return sourced from Monte Lake and Ingram Creek are considered to be accounted in the 20% ditch loss/stream loss applied to these sources (rows 69 & 70).

6.2 Water Budget Outflows - Discharge

6.2.1 Irrigation Withdrawals

The irrigation season occurs from mid April to mid September. Based on advice from MOE's surface water allocation section and Agriculture and Agri-Foods Canada, it is estimated that 5% of the total irrigation volume is applied in April, 10% in May, 20% in June, 30% in July, 30% in August and 5% in September.

The surface water allocation duty for Westwold is 914 mm (3 ft) for the growing season. Anecdotal information from Agriculture and Agri-foods Canada indicated that the actual depth of water applied during the 2010 irrigation season was 0.76 m (2.5 ft) or less. The volume of surface water diverted for irrigation in 2010 was estimated based on the irrigated area multiplied by the application rate of 0.76 m per acre. The application rates for surface and groundwater can be varied to examine their effects on the water budget such as how much reduction in an annual deficit may occur by increasing irrigation efficiency and using less water.

Outside of the freshet period, the water budget assumes that irrigation diversions in the upper reach of the river (Upper Station to Back Rd) is water prevented from becoming aquifer recharge and diversions are subtracted from the flow measured at the Upper Station (values in green font). During freshet, irrigation diversion (values in orange font) represents a small percentage of river flow and do not change the rate of river loss. Diversions are not subtracted from river loss during freshet but are included in the spreadsheet to calculate irrigation return.

Downstream of Hwy 97 where all flow outside of freshet is derived from groundwater, surface water diversions are considered to be baseflow not measured at the downstream model boundary (Salmon River @ CN Bridge) and are modeled as aquifer outflow (values in green font). Diversions for this section of river during significant river loss such (May 2011 - indicated in orange in spreadsheet) are not modeled as aquifer outflow.

For groundwater, the budget assumes that the volume of groundwater pumped from the aquifer for irrigation is the irrigated area multiplied by the estimated application rate. The other option for estimating groundwater extraction is to complete a detailed well inventory and estimate pumping rates and duration. Staff resources were not available to complete a field inventory and MOE was unsure of the willingness of all well owners to participate in an inventory. It should be noted that as the submission of well records or groundwater use is not mandatory, it is difficult to accurately estimate groundwater use in a geographic area.

6.2.2 Domestic and Livestock Withdrawals

Domestic and livestock groundwater consumption was estimated based on 5,000 head of cattle eight months per year[7] (October through May) consuming 70 L/day (15 gallons/day each) and 300 residents consuming 340 L/day (75 gallons/day) each.

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[7] Personal communication with feed lot operator

6.2.3 Evapotranspiration

Estimates of evapotranspiration (ET) are based on Farmwest's climate web site http://www.farmwest.com/ . The budget assumes that during the irrigation season all ET in irrigated areas is satisfied by the applied irrigation water, so there is no ET outflow in the irrigation season. The exception to this is the east end of the study area where there is a high groundwater table that supplies the crops with water and no surface application of water occurs. The theoretical ET in this area is 750 mm/year. The budget assumes that no ET occurs during period of snow cover – December through February. ET is also considered a discharge from the aquifer in the non-irrigation season where the groundwater table is < 2m below surface i.e., from Salmon River mid to the CN Bridge.

6.2.4 Groundwater Outflow at Downstream study boundary

Groundwater was assumed to flow out of the study boundary through the sediments at the east end of the valley. Flow was estimated using Darcy's Equation $Q = K \times i \times A$ where:

Q = volumetric flow rate,

K= hydraulic conductivity of 5×10^{-5} m/s assumed for silty sand,

i= hydraulic gradient of 2 m/km based on ground topography, and

A = saturated cross-sectional area estimated at 750 m wide by 30 m deep, based on the width of the mapped aquifer and known thickness from well logs.

6.2.5 River Gain

River gain in the two reaches downstream of "Salmon R @ Hwy 97" is due to groundwater discharge to the river as base flow. The reach from Mid Salmon R to Salmon R at CN Bridge, is a gaining reach year round including freshet. The monthly base flow volume is derived from the data recorded at the Salmon River Mid and Salmon R @ CN Bridge hydrometric stations.

Monthly base flow estimates in 2010 and 2011 ranged from 40,000 to 60,000 m^3/day. For comparison, the average daily freshet flow in May 2011 at the CN Bridge hydrometric station was 960,000 m^3/day. The increase in freshet flow downstream of Salmon R @ Hwy 97 was assumed to be due to overland flow into the river and not a substantial increase in groundwater discharge to the river by rising groundwater levels.

The minimum average flow measured at the CN Bridge was an average of 32,000 m^3/day in August 2011 and considered to reflect irrigation withdrawals from this reach of the river reducing flow at the CN Bridge.

6.3 Budget Surplus or Deficit

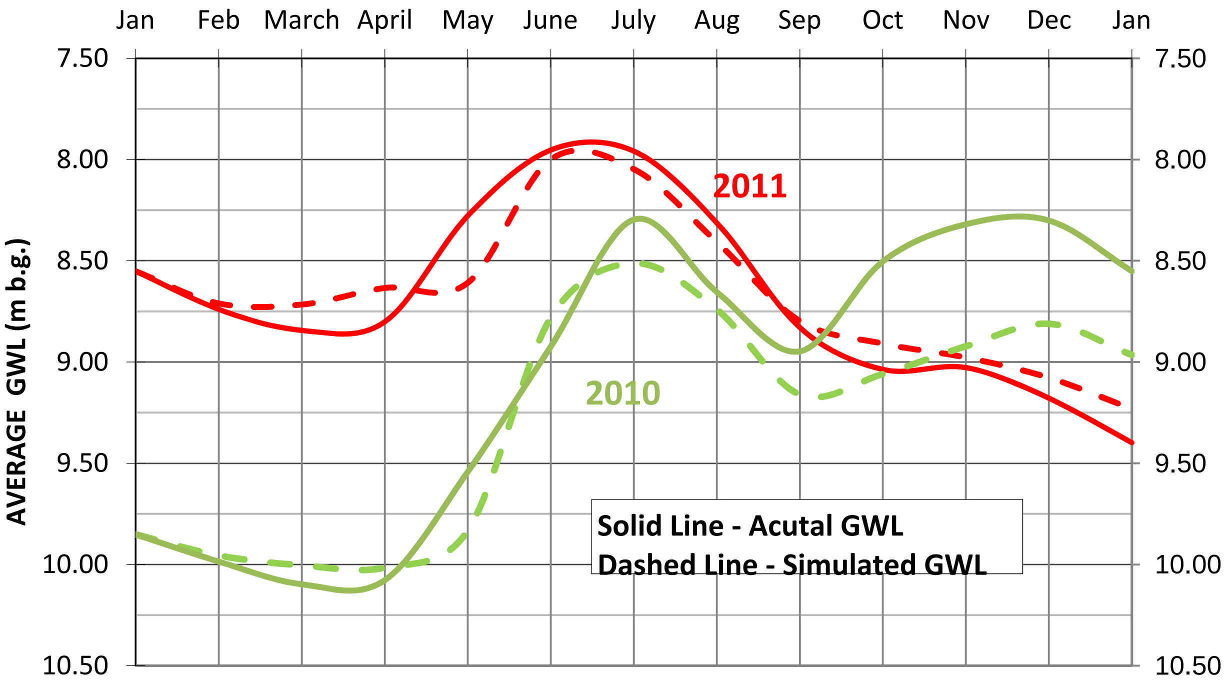
A surplus or deficit results in a change in water stored in the aquifer. The volumetric surplus or deficit can be equated to a water level rise and fall in the aquifer using a simplifying assumption that the deficit occurs uniformly over the entire aquifer. The change in water level in the aquifer is calculated based on the estimated areal extent of the aquifer and the estimated specific yield of the aquifer (there were no available pumping test data for the study area to calculate specific yield).

The simulated (or predicted) change in the water level in the aquifer (based on 2009, 2010 and 2011 river and creek flow data) was compared to 2010 and 2011 hydrographs to validate or calibrate the water budget model – Figure 12. The actual 2010 and 2011 aquifer hydrographs are based on the average of four groundwater monitoring locations.

The simulated water table (or hydrograph) assumes that the entire deficit results in a change in storage, where in reality, a portion of the budget deficit may result in decreased outflow (or river baseflow) from the aquifer. A specific month's water level is calculated based on the previous month's surplus or deficit which simulates a one month time delay for river leakage or precipitation recharge to travel through the unsaturated zone and enter the aquifer. Upland precipitation recharge through the valley side bedrock-aquifer contact was estimated to be at a constant rate throughout the year.

Figure 12 illustrates a notable rise or recovery in the groundwater table in the fall of 2010 as compared to the fall of 2011. River flow in the upper (losing) reach of the Salmon River was at least 50% higher in fall 2010 than fall 2011. The 2010 hydrograph and longer term hydrograph data for the provincial observation well (Figure 4) suggest that groundwater extraction for irrigation may be influencing groundwater levels at the provincial observation well and contributing to groundwater recovery in late September after irrigation has ended. However, a comparison of historical and recent data suggests that river flow in the losing reaches of the Salmon River has a larger influence on groundwater recover than shutting off irrigation wells.

Figure 12 - Actual and Simulated Groundwater Fluctuation



A net water level rise of approximately 1.26 m occurred in the aquifer in 2010 indicating that recharge to the aquifer exceeded discharge and groundwater was added to storage as a result of the surplus as compared to a marked increase in aquifer outflow (downstream river baseflow).

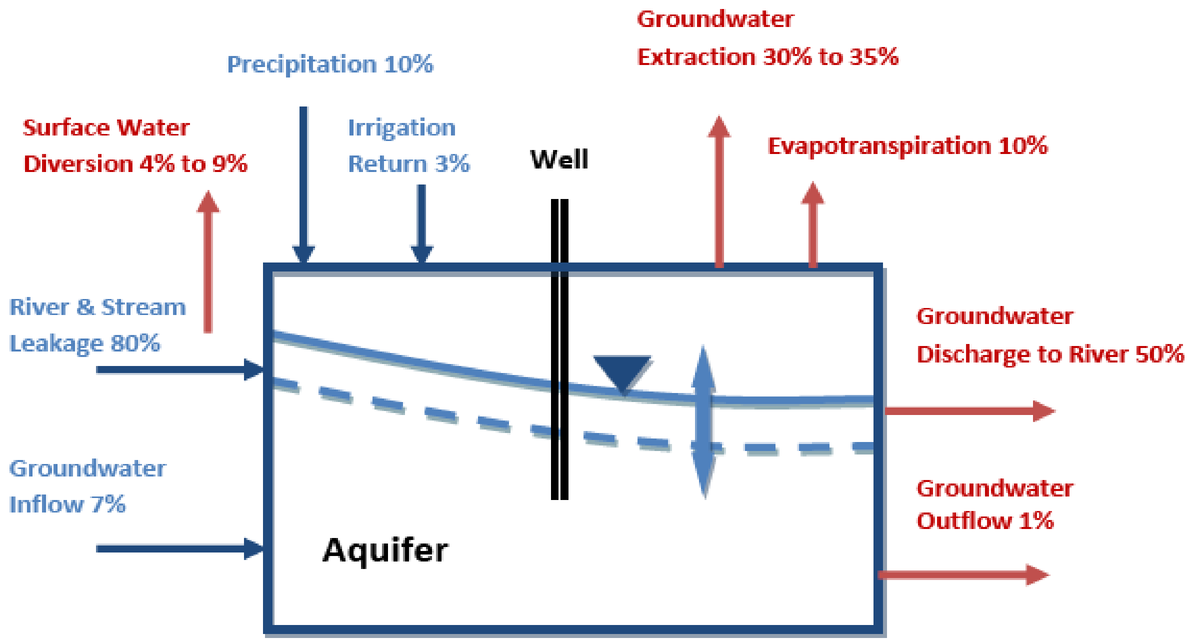
The 2010 year end average depth to groundwater was 8.59 m below grade compared to a simulated groundwater depth of 8.97 m below ground. Based on the estimated aquifer area and assumed specific yield, the difference of 0.38 m between the actual and simulated year end groundwater table depth represented 2.15 Mm^3 (1,745 acre-feet) of groundwater. The difference between the simulated and actual groundwater table represents an underestimate of recharge, an overestimate of discharge, or a combination of both. The volumetric difference between the actual and simulated groundwater table (2.15 Mm^3 of groundwater) represented roughly 7% of the total estimated annual groundwater flow through the valley aquifer. The greatest deviation between the actual and simulated groundwater table occurred during the fall period after the irrigation season had ended, which suggested that the model underestimated fall recharge rather than overestimated aquifer discharge.

A net water level decline of approximately 0.85 m occurred in the aquifer in 2011 which indicated that discharge from the aquifer exceeded aquifer recharge and groundwater was removed from storage to meet outflow requirements (river base flow, pumping). The 2011 groundwater level decline suggests that removal of water from storage is a primary result of an annual water deficit (i.e., the aquifer is being mined and drained). The 2011 year end average depth to groundwater was 9.40 m below grade compared to a simulated groundwater depth of 9.23 m below ground. Based on the estimated aquifer parameters, the difference of 0.17 m between the actual and simulated year end groundwater table depth represented a difference of roughly 3% of the total estimated annual groundwater flow through the valley aquifer.

7.0 Results

Estimated recharge and discharge from the Westwold aquifer as percentages of total inflow (blue) and outflow (red) are illustrated on Figure 13.

Figure 13 – Conceptual Water Budget: Inflow and Outflow Percentages



Examining the water budget results with the estimated and measured recharge and discharge parameters indicate that:

7.1 Inflows to Aquifer

- Total annual Inflow to the aquifer was estimated at 32.8 Mm^3/year in 2010 and 27.6 Mm^3/year in 2011.
- The most significant inflow contribution to the aquifer was surface water losses from the Salmon River representing approximately 26.7 Mm^3/year or 80% of the total inflow in 2010 and approximately 21.6 Mm^3/year or 75% of the total inflow in 2011.
- Approximately 60% of the surface water recharge occurred during the freshet period from mid April to mid July. This freshet inflow also represented roughly 50% of the total annual inflow to the aquifer in 2010 and 2011.
- Precipitation recharge that falls directly onto the aquifer or infiltrates the upland areas and recharges the aquifer as groundwater flowing into the valley bottom is estimated at 2.0 Mm^3/yr or approximately 6% to 7% of the total inflow.

7.2 Outflows from Aquifer

- Outflow from the aquifer as river base flow was estimated at 15.9 Mm^3/yr in 2010 and 18.7 Mm^3/yr in 2011. The increase in outflow in 2011 was considered to be due a general rise in the groundwater table from fall 2010 to spring 2011 resulting in an increase in base flow in the gaining reach of the Salmon River.
- Total annual outflow from the aquifer was estimated at 27.8 Mm^3/year in 2010 and 31.5 Mm^3/year in 2011.
- Outflow by irrigation combining groundwater pumping, surface water diversion and sub irrigation was estimated at 10.7 Mm^3/yr.
- Groundwater pumping, sub-irrigation (high groundwater table) and surface water diversion represent approximately 70%, 20% and 10% respectively of irrigation outflow from the aquifer.

8.0 Conclusions and Recommendations

The Westwold study holds promise that a simplified water budget model can characterise water quantity in a small scale watershed in enough detail to support groundwater allocation decisions. The water budget also indicates that groundwater and surface water must be managed conjunctively to achieve sustainable water use in the Westwold Valley. Water users need to recognize how entwined surface water and groundwater are in the valley and that use or availability of one form directly impacts the other.

Predicting and measuring river loss is the most crucial **inflow** parameter to predict and assess the likelihood of a water deficit. The river loss data suggest that the river bed has a finite ability leak water into the underlying aquifer and that an increase in freshet river flow may not necessarily result in an increase in the rate of river loss. Furthermore, the data suggest that the duration of freshet may be more influential on aquifer recharge than the intensity of the freshet by providing a longer period for river loss. A comparison of the freshet periods of 2010 (net increase in storage) and 2011 (net decrease in storage) on Figure 10, indicate that the 2010 freshet lasted approximately 4 weeks (33%) longer than the 2011 freshet.

The water budget reveals that a difference of 10% to 20% between total inflow and total outflow will result in a notable rise or decline in the groundwater table. A 2010 theoretical annual surplus of 18% (inflow 118% of outflow) corresponded to an average water table rise of 1.2 m. A 2011 theoretical annual deficit of 11% (inflow 89% of outflow) corresponded to a water table decline of approximately 0.8 m.

Net water table declines at the provincial observation well OW45 in 2008 and 2009 were 746 mm and 416 mm respectively, for a 2 year cumulative water table decline of over 1.1 m. Relatively longer duration freshet flows in 2010 coupled with higher fall precipitation and river flow, reversed the previous 2 year deficit and brought the aquifer level in line with the long term average winter elevation (Figure 8). This illustrates that a storage deficit can be made up by increased stream flow/loses and that the aquifer possesses a restorative capacity. However, persistent annual water table declines of 400 mm to 700 mm per year could result in reduced yield from shallower wells, increased pumping costs and ultimately a decline in the Salmon River baseflow downstream of Westwold which would impact downstream licences.

Natural outflow into the river is largest **outflow** parameter in the water budget comprising approximately 50% to 60% of the total annual outflow. The second largest outflow was irrigation use of surface water and groundwater pumping representing approximately of 35% to 40% of the annual outflow. It should be noted that although irrigation use of water is the second largest outflow parameter, actual use of water is not known and not monitored. Knowing water use is a key component for effective model prediction and ultimately managing the water resource in the valley. The need to monitor and reporting water use aligns with Living Water Smart's commitment for large water users to monitor and report water use.

River loss during the freshet period provides approximately 55% or more of the estimated annual recharge to the aquifer. The water budget may also function as an early indication tool to predict the likelihood of a water deficit for the summer irrigation period. Improvements to the water budget model would reduce the uncertainty in predicting an annual surplus or deficit and could include:

1. Developing a river flow forecasting model based on snowpack.
2. Monitoring river loss during several more freshet periods and comparing the predicted annual deficit to the actual annual deficit or surplus.
3. As a management target, develop a hydrograph or desirable water table condition that maintains river baseflow and provides for groundwater extraction.
4. Input actual water use data to the model when the data becomes available.
5. Complete a pumping test at one or more locations in the aquifer to refine the estimated specific yield of the aquifer.
6. Refining estimates of precipitation recharge.
7. Incorporating the results of Agriculture and Agri-foods Canada's study of irrigation efficiency and refining the estimate of irrigation return.