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Monthly Groundwater Budget for the Aquifers in the Kelowna BC Area

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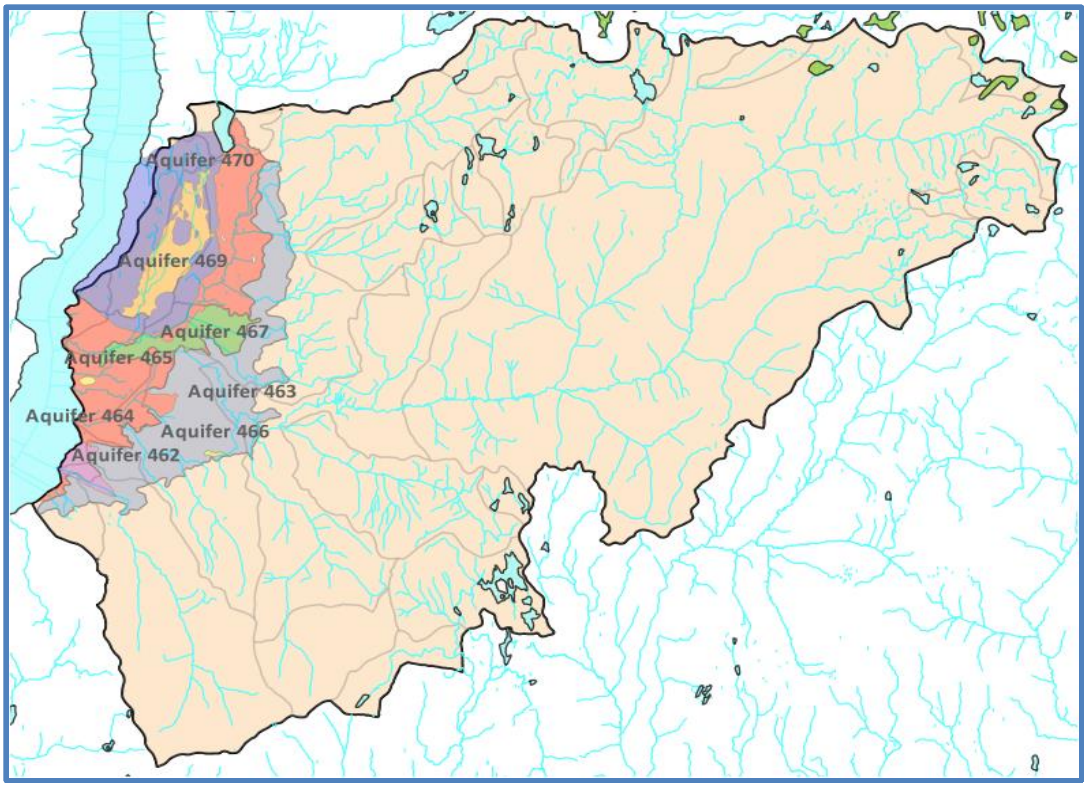

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EXECUTIVE SUMMARY

This report describes the development of a monthly groundwater budget model for the main aquifers underlying the City of Kelowna. The development of the groundwater budget model was requested by the BC Ministry of Environment (SRFP No RFPGS16JHQ-013) and commissioned to Fresh Water Solutions Ltd. in January 2016 (Contract No GS16JHQ-170). The purpose of the model is to allow an estimation of the current groundwater resources available in these aquifers and to evaluate the effect of future increase in groundwater abstraction on groundwater levels and streamflows along the Mill Creek, Mission Creek, Bellevue Creek and their tributaries.

The City of Kelowna is located in the Central Okanagan Valley, one of the driest regions of Canada. The Kelowna area has experienced significant population growth and expansion in agriculture over the last few decades, and projections to 2030 indicate that water demand is set to increase at an average annual rate of approximately 0.7 %. Mill Creek, Mission Creek and Bellevue Creek, which run through the Kelowna area, are ecologically important as they support the last creek-spawning grounds for Kokanee Salmon (*Oncorhynchus nerka*) and Rainbow Trout (*Oncorhynchus mykiss)*. The need for an effective integrated water management strategy for the Kelowna area is therefore viewed as imperative to allow the sustainable development of the region without compromising its valuable fish habitat. The groundwater budget model described herein provides water managers with a tool to support the assessment of the current status of groundwater resources in the Kelowna aquifers, and to evaluate the potential impacts of future groundwater abstraction, under the new groundwater licensing system for British Columbia introduced with the Water Sustainability Act (Bill 18-2014).

The British Columbia Ministry of Environment (ENV, 2007) described the Kelowna Aquifers based primarily on existing well records. The ENV aquifers included Aquifers, 462, 463, 464, 465, 466, 467 and 469. Additional bedrock aquifers were also described by the ENV. This study developed a water budget for Aquifers 463, 464 (which includes 465) and 467, as requested in the ENV RFP document.

A conceptual hydrogeological model of the Kelowna aquifers was defined based on the review of the relevant studies, maps and data available for the study area.

A key study is the geological characterization of the Kelowna - West bank – Mission Creek area completed by the Geological Survey of Canada after the ENV aquifer mapping (Paradis et al., 2009). The GSC study includes a surficial geology map and a three dimensional geological model of the Kelowna area, and provides a description of the several units that form the Kelowna aquifers. These include the following, from the deepest to the most surficial:

- Preglacial deposits consisting of sand, silt, gravel and till. A water bearing formation referred to as the Rutland Aquifer is located within this unit.
- The Fraser Till, which overlies the preglacial deposits and was formed at the base of the continental glaciation. This material is expected to be an aquitard, partially isolating the deeper permeable materials form the shallower materials.
- Glaciofluvial deposits, which mostly consist of stratified sediments deposited by meltwater near the glacier. They may be found at depth or at surface as glacial fan complexes or kame terraces. The main aquifer units mapped by Ministry of Environment (ENV) that are the subject of this study (463, 464 and 467) are located within this unit.
- Glaciolacustrine deposits are present over much of the aquifer study area. These are mostly silts and clays deposited in Glacial Lake Penticton, but may also include delta fan complexes along the boundary of the glacial lake. These deposits are likely to act as an aquitard partially isolating the glaciofluvial sediments from the surficial alluvium.

- Finally, Quaternary deposits are present throughout the study area, including alluvium in stream channels and fan deposits. The surficial materials vary from lacustrine silts and clays, to sands and sands and gravels. The alluvial fan that Kelowna is built on is the largest of these deposits.

Among the ENV-mapped Kelowna aquifer units, unit 467 is above 464 and unit 469 is above 470. Based on the GSC geologic mapping, most if not all of the aquifer units mapped by the ENV potentially comprise a vertical sequence of aquifers.

Although each aquifer unit may include aquifer materials at more than one depth interval, all aquifer materials located in vertical sequence within each aquifer was represented in the groundwater budget model as part of the same groundwater budget zone. This discretization is compatible with an adequate representation of surface water – groundwater interaction and acknowledges the probable vertical leakage expected across aquifers, especially over the size of each of the aquifers of interest.

Groundwater flowing in the upland catchments of the local streams discharges primarily into the creek channels, with part of the flow reporting to the Kelowna aquifers. Groundwater recharge to the Kelowna aquifers is mainly provided by water returned from irrigation, urban leakage and septic discharge, followed by streamflow leakage and groundwater inflow from the upland bedrock aquifers. Groundwater discharge mainly occurs to surface (including stream baseflow, wetlands vegetation and losses to drainage works), followed by groundwater withdrawal and with a relatively small discharge to Okanagan Lake. Groundwater discharge to Okanagan lake is believed to be limited based on seepage meter measurements and investigative modelling reported in (Pyett, 2015). Groundwater flow throughout the lower Mission Creek catchment has a general NE-SW direction and is affected by the cone of abstraction induced by the Rutland and Glenmore-Ellison Irrigation District water supply wells, as groundwater approaches Okanagan Lake.

The conceptual hydrogeological model was represented in quantitative terms by means of a semi-distributed parameter, spreadsheet-based groundwater budget model. The model was calibrated by identifying a representative climate data and selecting four unregulated catchments with continuous streamflow data sets. The calibration process consisted of attaining a reasonable match between the measured and modelled streamflows, by adjusting the model parameters that control local precipitation, stream baseflow, stream leakage, surface water detention and release. This provided an estimate of the range of expected surface and groundwater flow rates moving through the study area.

Following calibration, a monthly water budget was developed for each of the 42 zones defined in the study area, in different climatic conditions. Average, wet and dry conditions were represented by years selected from the calculated low and high water tables generated by the model using the historic climate data set between 1900 and 2015. The model was run for the entire climate record from 1900-2015 using estimates for current groundwater withdrawal and recharge from irrigation, mains leakage and septic tank infiltration, and results were output for the selected average, low and high groundwater periods (to represent dry and wet periods).

The groundwater budget results are consistent with the general groundwater flow pattern assumed for the Kelowna aquifers, whereby groundwater flows from Aquifer 463 into 467 and 464, where it discharges into Okanagan Lake. Streamflow recharge is prevalent in Aquifer 463, where it represents 33% of the total inflows to this unit. Conversely, groundwater discharge to surface is predominant in Aquifers 464 and 467, where it corresponds to 70% and 60% of the total outflows, respectively. Irrigation loss, urban leakage and septic tank infiltration are a considerable contribution to groundwater recharge in Aquifers 463 and 464, where they represent approximately 32% of the total inflows.

A comparison between the simulated average streamflows associated with the current water withdrawal conditions and estimated Environmental Flow Needs (EFN), indicates that current streamflows are lower than the EFN between August and April in Bellevue Creek and between December and April in Mission Creek, whereas they are always above the EFN in Mill (Kelowna) Creek.These results provide a general overview of the streamflow status along Mission Creek, Mill and Bellevue Creek throughout the year with respect to EFN, since they are based on the simulated streamflows at the mouth, and are affected by the model uncertainties. There is strong evidence, for example, that the Mission Creek channel area adjacent to the Benvoulin Water Users community intake has been systematically below EFN also between Aug and October, both in years with high and low precipitation records (FLRNO verb. comm., 2016). The spatial discretization used in the model does not allow an accurate simulation of streamflows along this reach of Mission Creek, as well as along others where local EFN may not be met.

Preliminary estimates of the groundwater resources available without further mitigation in Aquifer 463 and 464 for further allocation were generated based on the assumption that there is a direct correspondence between groundwater allocation and streamflow depletion, and that the time delay between groundwater withdrawal and streamflow leakage is less than the monthly time step used in the groundwater budget model. The estimates were obtained from the difference between the streamflow in dry conditions and the corresponding EFN in Mission, Mill and Bellevue Creek. When these differences are negative, an EFN deficit occurs and no groundwater is available for further allocation. When these differences are positive, an EFN surplus exists and the minimum average monthly EFN surplus was used to estimate a lower bound of the groundwater resources available for allocation. This value was used because, under the conservative assumption that all additional groundwater withdrawal may be supplied by streamflow leakage, the EFN would still be maintained or exceeded. Based on this approach and on the use of safety factor of 0.3, the water budget model indicates that 3.3 L/s (i.e. 30% of the minimum EFN surplus in Mill Creek at the mouth) are available for allocation throughout the year in the northern portion of Aquifer 464, 24.9 L/s (i.e. 30% of the minimum EFN surplus in Mission Creek at the mouth) are available in the southern portion of Aquifer 464 between May and November and 2.7 L/s (i.e. 30% of the minimum EFN surplus in Bellevue Creek at the mouth) are available in Aquifer 463 between May and July. The estimates of groundwater availability generated by the model provide a only a preliminary indication of the available groundwater resources in the aquifers under study, as they are based on simulated streamflows at the mouth, and do not consider distances and differences in hydraulic connection between potential new sources of groundwater withdrawal and stream reaches. Further assessments are therefore required to refine these estimates on a local scale.

The results of three prediction scenarios based on representing the 2030 projected increase in groundwater abstraction in Rutland and Glenmore Highlands, which correspond to an average annual 2.5% and 1% increase, respectively, show that the additional groundwater removal leads to an increase in streamflow recharge of up to 85% in Aquifer 464 and a reduction in stream baseflow and groundwater discharge to surface of up to 6.5%. The model indicates that these changes lead to negligible streamflow reductions, i.e. of the order of 3% in Mill (Kelowna) Creek at the mouth, and of the order of 0.1% in Mission and Bellevue Creek at the mouth. The modelled changes in streamflow leakage and baseflow have small (lass than 3%) effects on the total streamflow at the mouth in Mill Creek, Mission and Bellevue Creek because these groundwater contributions are relatively minor compared to the contributions to total streamflow occurring in the uplands, upgradient of Aquifer 463 and 464.

One of the main elements of uncertainty of the groundwater budget model pertains to the aquifer geometry, due to the lack of correlation between the ENV-mapped aquifer units and the geological characterization provided by the GSC (Paradis at al., 2010). It is therefore recommended that the Kelowna aquifer mapping be updated by accounting for the recent geological study, as well as for log data from newly drilled wells. Other sources of uncertainty are related to data gaps, namely the limited availability of hydraulic parameter estimates, groundwater level and pumping data, and of information related to surface water – groundwater interaction. The model reliability as a water management tool could benefit significantly from additional streamflow leakage and groundwater level data. Specifically, it is recommended that streamflow gauging stations be installed along the western and eastern edge of aquifer unit 463 as well as along the contact between aquifer unit 464 and Okanagan Lake, as these would provide estimates of the streamflow leakage recharge and stream baseflow discharge for the Kelowna aquifers, which represents significant groundwater inflow and outflow components of the budget. With regard to groundwater levels, the installation and regular monitoring of 10 to 20 additional groundwater observation wells is recommended, to allow an adequate characterization of the groundwater flow pattern in the Kelowna aquifers. The current water balance shows that other forms of groundwater discharge to surface, including diffuse seepage to wetlands, springs and infiltration of shallow groundwater into the water supply, sewage and storm drainage network, are a significant outflow component. The magnitude of these discharges is typically not easily measurable and therefore highly uncertain. However, it is recommended that an attempt be made to derive preliminary estimates, for example through wetland hydrologic studies including the installation of multi-level piezometers, through spring surveys and the measurement of dry weather flows in storm drains.

The low groundwater discharge estimates to Okanagan Lake should also be confirmed and refined by means of additional seepage meter measurements.

Anthropogenic recharge, related to irrigation, urban and septic leakage, is a significant component of the inflows to the Kelowna aquifers. As such, it is recommended that the estimates used in the water balance be validated by means of field assessments, such as percolation tests to assess irrigation efficiency and water supply network leak surveys.

The groundwater withdrawals represented in the model are also associated with significant uncertainty, since monthly records are available only for the major purveyors but not for the numerous private users and small water utilities. It is therefore recommended that, within the framework of the new Water Sustainability Act, reporting of groundwater withdrawal volumes should be made mandatory for all groundwater users in the Kelowna aquifers.

The groundwater budget model presented in this study is not only a helpful water management tool, but also provides valuable information on the surface water - aquifer dynamics in the study area.

CONTENTS

1. INTRODUCTION

The City of Kelowna and the surrounding areas in the lower Mission Creek catchment are heavily developed, and projections indicate that growth in the area will continue at significant rates. Effective water management is therefore of prime importance, not only in light of rapid development but also because of the semi-arid climate that characterizes this area. Groundwater is significantly relied on for domestic, commercial and agricultural water supply and, with many surface water licenses fully allocated, the demand for groundwater resources will most likely increase. Mission Creek, Mill (Kelowna) Creek and Bellevue Creek have significant ecological importance, as they support the last remaining creek-spawning grounds for Kokanee Salmon (*Oncorhynchus nerka*) and Rainbow Trout (*Oncorhynchus mykiss).* Consideration of the potential impacts of the current and future groundwater withdrawal on streamflow along these creeks is therefore a major concern.

This report describes the development of a monthly groundwater budget for the main Kelowna aquifers. The monthly groundwater budget, which was developed for average, dry and wet climatic conditions, provides a quantitative assessment of the available groundwater resources, as well as of the interaction between surface water and groundwater. The groundwater budget model is based on a semi-distributed parameter approach, where the number of parameters describing the groundwater system is limited to the minimum required to reproduce the key features of the aquifers under study. The model was developed on a set of MS Excel spreadsheets and can be used to investigate the effects of different scenarios of future groundwater allocation under different climatic conditions. With the introduction of a groundwater licensing system as part of the new British Columbia Water Sustainability Act, this model represents a valuable tool to assess the sustainability of current groundwater use in the Kelowna area, and to evaluate future groundwater allocation, in consideration of the projected water requirements and ecological objectives.

1.1 Objectives

The main objectives of this study are as follows:

- The development of a hydrogeological conceptual model for the Kelowna aquifers, which is based on the review of all existing relevant data and information, and consolidates the current understanding of the groundwater system dynamics.
- Development of a spreadsheet-based groundwater budget model for the Kelowna aquifers, which reflects the hydrogeological conceptual model.
- Use of the groundwater budget model to develop monthly groundwater balances for the Kelowna aquifers, in average, dry and wet climatic conditions.
- Interpretation of the model results to assess the available groundwater resources in the study area.
- Provide qualitative recommendations on future allocation of groundwater withdrawal in the Kelowna aquifers.
- Conduct a data gap analysis, where the key data and information to improve the conceptual understanding of the groundwater system and reduce the model uncertainty are identified.

1.2 Report Structure

This report is organized as follows:

Chapter 2 presents all the information and data sources that were compiled and used to develop the groundwater balance model.

Chapter 3 provides a characterization of the study area with reference to climate, topography and drainage, land use, geology and hydrogeology.

Chapter 4 is a presentation of the hydrogeological conceptual model.

Chapter 5 details the development, calibration and predictive use of the groundwater budget model.

Chapter 6 is an assessment of the available groundwater resources, interaction between surface water and groundwater and the potential effects of future groundwater allocations.

Chapter 7 is an overview of the data gap analysis and related recommendations.

2. COMPILATION AND REVIEW OF INFORMATION, MAPS AND DATA

Numerous water studies and investigations have been carried out in the Okanagan Basin, and specifically in the Kelowna area. The first part of this study was a compilation and review of the extensive set of the reports, maps and data that are relevant to the development of a groundwater budget model for the Kelowna aquifers. The material that formed part of this review is listed in the following sections according to the source type, i.e. reports, maps and data.

2.1 Background Information Reports

The reports that were compiled and reviewed during this study include the following:

- Neilson-Welch and Allen (2007). Groundwater and Hydrogeological Conditions in the Okanagan Basin, British Columbia – A State of the Basin Report. Submitted to the Okanagan Basin Water Board for Objective 1 of Phase 2 of the Groundwater Supply and Demand Project.
- Welch (2012). Modelling Topographically- Driven Groundwater Flow in Mountains. PhD dissertation, Simon Fraser University.
- Smerdon and Allen (2009). Regional-Scale Groundwater Flow Model of the Kelowna Area and the Mission Creek Watershed, Central Okanagan, BC. Submitted to the BC ENV.
- Carmichael et al. (2009). Compendium of Aquifer Hydraulic Properties from Re-Evaluated Pumping Test in the Okanagan Basin, British Columbia.
- Paradis et al. (2010). Surficial geology, geochemistry and 3D modeling of the Kelowna-Westbank-Mission Creek area.
- Thomson (2010). Quaternary Stratigraphy and Geomorphology of the Central Okanagan Valley, British Columbia. MSc dissertation, University of British Columbia (Okanagan).
- Pyett (2015). Physical measurements of groundwater contributions to a large lake. MSc dissertation, University of British Columbia (Okanagan).
- Lowen (1979). Mission Creek Groundwater study.
- Lowen and Letvak (1980). Mission Creek Flow Metering Project.
- Lowen and Letvak (1981). Report on groundwater-surface interrelationship, Lower Mission Creek BC.
- Wu (2014). Estimation of groundwater recharge from Mill Creek over alluvial fan sediments. BSc dissertation, University of British Columbia (Okanagan).
- Wu and Ashe (2014). A qualitative assessment of artesian wells in the Okanagan Valley, British Columbia
- Okanagan Water Supply and Demand Project reports:

  - Summit Environmental (2005). Okanagan Basin Water Supply and Demand Study: Phase 1
  - Dobson Engineering (2008). Water Management and Use Study – Phase 2 Okanagan Water Supply and Demand Project
  - Golder Associates and Summit Environmental (2009). Phase 2 Okanagan Water Supply and Demand Project – Groundwater Objectives 2 and 3. Basin Study.
  - Van der Gulik et al (2010). Agriculture Water Demand Model – Report for the Okanagan Basin.
  - Summit Environmental and DHI Canada (2009). Phase 2 Okanagan Water Supply and Demand Project. Surface Water Hydrology and Hydrologic Modelling Study. State-of-the-Basin Report.
- Mould (2005) Strategic Water Servicing Plan.
- WMC (2010) Mission Creek Water Use Plan.
- Kelowna Joint Water Committee (2012) Integrated Water Supply Plan.
- City of Kelowna (2010) City-wide Water Supply and Treatment Options Evaluations – Summary Report
- Northwest Hydraulic Consultants (2001) – Hydrology, Water Use and EFN for Kokanee Salmon and Rainbow Trout in the Okanagan Lake Basin, BC
- Reports downloaded from the BC Ecological Report Catalogue (http://a100.gov.bc.ca/pub/acat/public/) related to test hole drilling and local groundwater investigations. The downloaded reports were provided to the BC ENV as auxiliary material to this report.

2.2 Map Sources

A GIS project was developed as part of this study, which was populated with maps from the following sources:

- BC Geographic Warehouse Maps (Data BC Distribution Service, https://apps.gov.bc.ca/pub/dwds)
  - Topography 1:125,000
  - Meteorological Stations
  - Freshwater Atlas Watersheds
  - Freshwater Atlas Lakes and wetlands 1:125,000
  - Freshwater Atlas Stream Network
  - Hydrometric Stations
  - Aquifer Units
  - Water and Observation Wells
- Geological Survey of Canada
  - Surficial Geology 1:50,000 OF 6507
  - Geology cross-sections from OF 6507
  - 3D Geology Model from OF 6507
  - Topography base map (20-m contours)
- WMC (2010) Mission Creek Water Use Plan
  - Surface water diversions and reservoir locations
- Ron Fretwell (RHF Systems Ltd.)
  - Aquifer units employed in the Water Supply and Demand project
  - Node Basins employed in the Water Supply and Demand project
  - Water use Areas employed in the Water Supply and Demand project

    - Simplified Land Use Categories derived from the Water Supply and Demand project
- City of Kelowna
    - Topography 2015 (1-m contours)
    - Official Community Plan 2030 (http://www.kelowna.ca/CM/)

2.3 Data Sources

The data used in the development, calibration and prediction of the groundwater balance model were obtained from the following sources:

- Environment Canada – Data Access Tool – Historic Climate Data (http://climate.weather.gc.ca/index_e.html)
    - Meteorological stations
    - Precipitation and Temperature historic records
- Water Office Canada (https://wateroffice.ec.gc.ca/)
    - Streamflow data and hydrometric station details
    - HYDAT database
- Kelowna Joint Water Committee (2012) – Integrated Water Supply Plan
    - Water usage by Irrigation District
    - Monthly water usage for all Irrigation Districts
    - Projected water demand
- Black Mountain Irrigation District
    - Monthly groundwater withdrawals from 2010 for Wells 4 and 5
- Rutland Waterworks District
    - Monthly groundwater withdrawals from 2011 for the 10 active wells
- Southeast Kelowna Irrigation District
    - Monthly groundwater withdrawals from 2002 for O'Reilly Road Well, Wells 1 and 2
- Ron Fretwell (RHF Systems Ltd.)
    - Okaganan Water Demand Model database of historic water demand and deep percolation (1950-2015), exported for each calibration and prediction groundwater budget zone
    - Okanagan Water Demand database of historic total demand for water use areas
    - Source linkage table, which lists the water sources of each water use area with respective percentages.

3. SITE CHARACTERIZATION

3.1 Climate

The study area has a semi-arid continental climate, with wet mild winters and hot dry summers, as a result of lying in the rain shadow of the Coastal and Cascade Mountains (Summit and Golder, 2009). The precipitation and temperature regime for the study area was characterized by compiling precipitation and temperature records for the eleven meteorological stations listed in Table 1, which were downloaded from the Environment Canada Data Access tool website (http://climate.weather.gc.ca/index_e.html). Four of these stations were selected to create a long-term continuous record of monthly precipitation and temperature values (Kelowna, Kelowna A, Kelowna CDA, Kelowna MWSO), which were obtained from daily records, where available. The records were assembled without correction for elevation, since the double mass plots for these stations indicate minimal variation with location and elevation.

Table 1 Meteorological stations with records used for climate characterization

Station Name	Easting (UTM WGS84)	Northing (UTM WGS84)	Elevation (masl)	Record Frequency	Period of record
Kelowna	322864	5530430	353.6	monthly	Jan-01-1900 – Dec-31-1962
Kelowna A	329001	5537641	429.5	daily	Jan-01-1968 – Dec-31-2004
Kelowna AWOS	329445	5536461	429.5	daily	Jan-01-2007 – Dec-31-2007
Kelowna Bankhead	334831	5530049	-	monthly	Jan-01-1914 – Dec-31-1931
Kelowna Bowes Street	322803	5528577	350.5	monthly	Aug-31-1961 – 31-Oct-1969
Kelowna Burnetts Nursery	321560	5527598	349.9	monthly	Jan-01-1969 – Apr-30-2003
Kelowna CDA	326215	5522902	484.6	monthly	Jan-01-1950 – Apr-30-1970
Kelowna Dav-Spiers Road	323879	5524832	375.0	monthly	Jun-01-1978 – Sept-30-2004
Kelowna East	327746	5525764	491.0	monthly	Sept-01-1980 – Nov-30-2000
Kelowna MWSO	327744	5535823	456.0	monthly	Jan-01-1994 – Feb-28-2007
Kelowna Quails Gate	318900	5519433	417.0	daily	Jan-1-2014 – Dec-31-2014

The location of the compiled and selected stations is shown on Figure 1. The records from the selected stations were used to estimate the precipitation and temperature statistics described in the following sections. These precipitation and temperature data sets were also used in the water budget calibration, which is described in Section 5.2 and Appendix B.

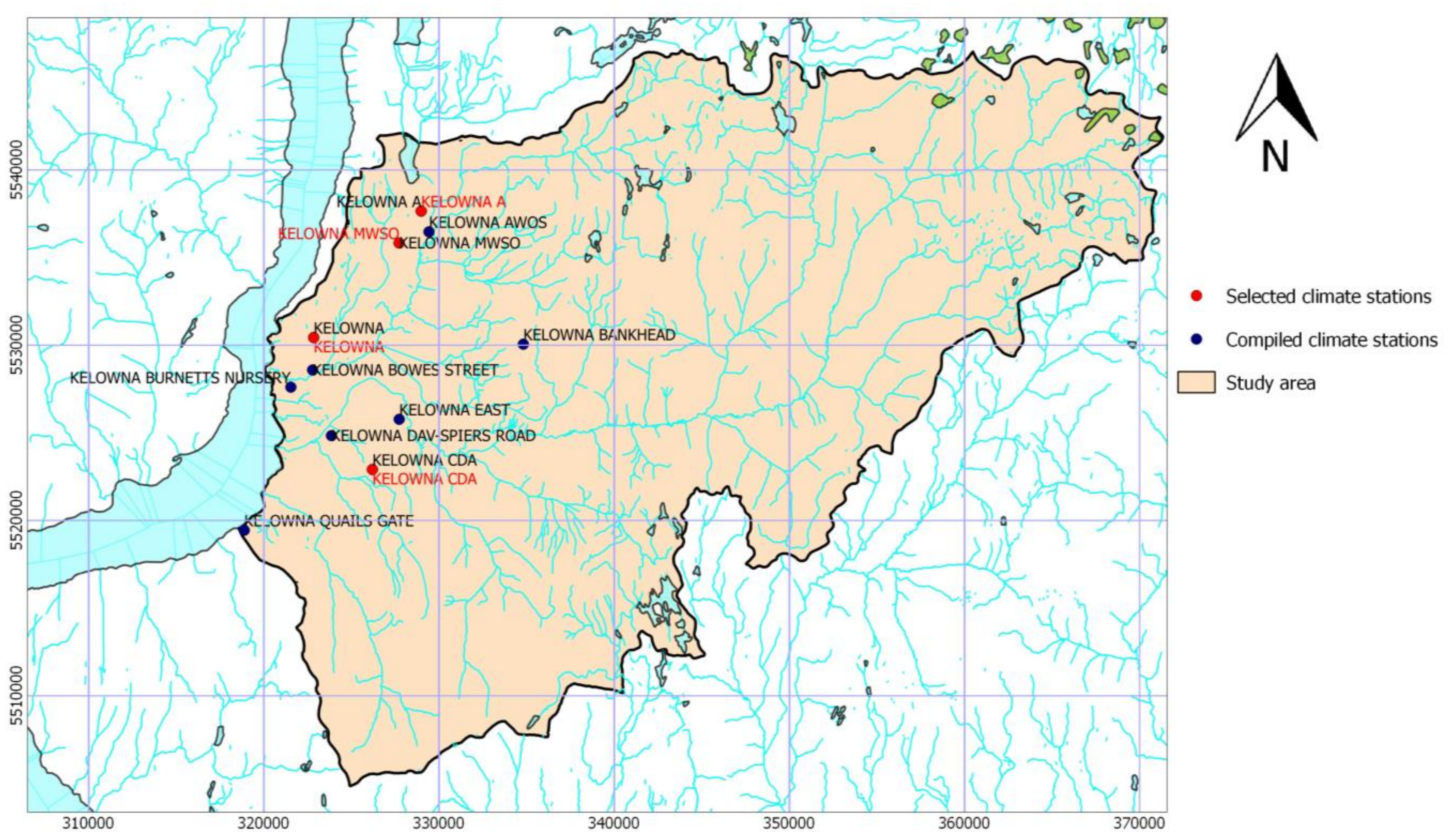


Figure 1 Meteorological stations in the study area.

3.1.1 Temperature

The selected temperature records were used to generate the plot of average monthly mean, 10-percentile and 90-percentile temperature for a year, which is shown on Figure 2. Based on the selected records, temperature in the study area ranges on average between -5°C and +20°C and has a mean value +8°C. The minimum and maximum temperatures are typically recorded in December-January and July-August, respectively. The 3-year moving average plot for the last 116 years of records (between January 1900 and December 2015) shown on Figure 3 indicates that temperature was highest in 1940-1942 and in 2015, and it was lowest in 1974-1976.

3.1.2 Precipitation

The selected precipitation records indicate that precipitation ranges on average between 8 mm and 118 mm/month and has a mean value of 47 mm/month. The seasonal variation of precipitation, which is shown on Figure 4, indicates that December and January are the wettest months and July and August are the driest months, respectively. The 3-year moving average and cumulative departure plot since 1900 for the last 116 years is shown on Figure 5. The 3-year moving average indicates that the driest 3-year period occurred in 1929-1932 and the wettest in 1982-1985. The cumulative departure indicates that the longest dry (low precipitation) and wet (high precipitation) periods ended in 1967-1969 and 1997-1999, respectively. This suggests that the lowest and highest groundwater levels are likely to have occurred in these two periods. Indeed, the groundwater levels calculated by the groundwater budget model have their minimum value at the end of the 1960s and their maximum at the end of the 1990s, as shown in the groundwater plots included in the budget model output spreadsheet. The periods 1967-1969 and 1997-1999 were therefore selected to represent the low groundwater level (referred to as '*dry*' in this study) and high groundwater level (referred to as '*wet*' in this study) scenarios in the model simulations completed in this project. The east facing-slopes of the upper reaches of the Hydraulic Creek catchment received the highest precipitation rates recorded in the Okanagan Basin, with an average annual precipitation of 727.8 mm recorded at the McCulloch climate station (Summit and Golder, 2009). Approximately 20-25% of precipitation occurs as snow in the valley and up to 50% at the highest elevations of the study area (Summit and Golder, 2009).

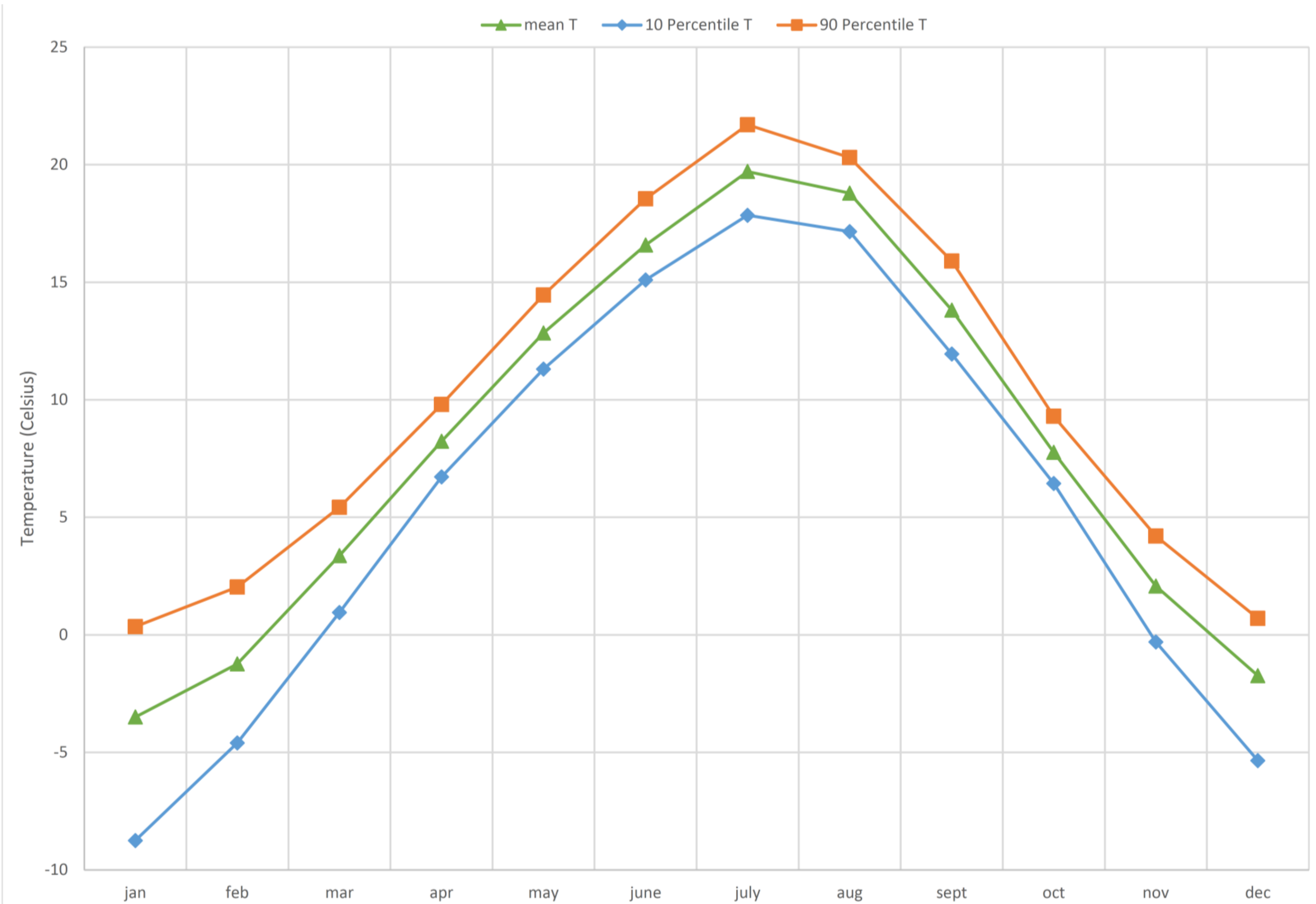


Figure 2   Average monthly temperature.

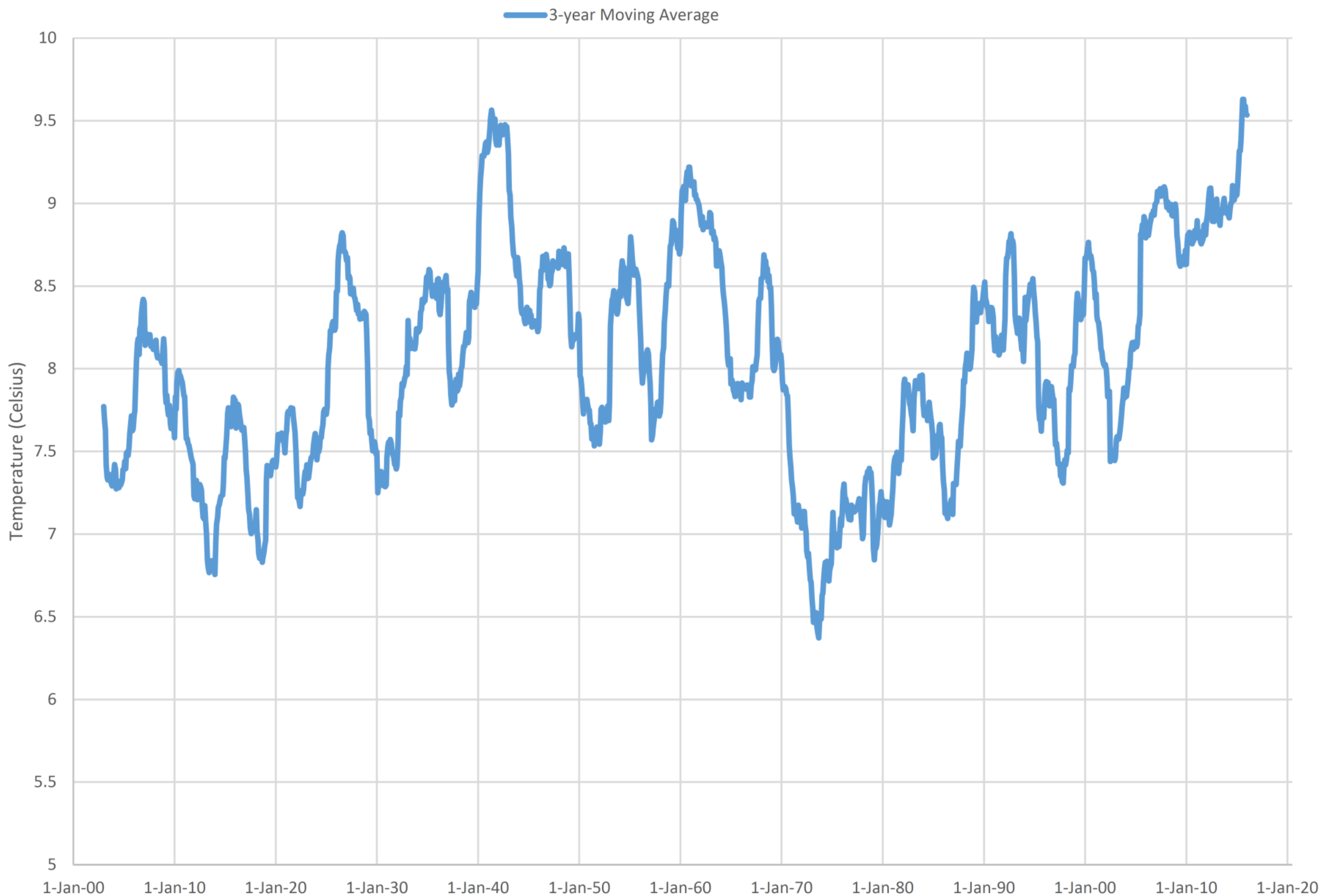


Figure 3 Temperature – 3-year moving average.

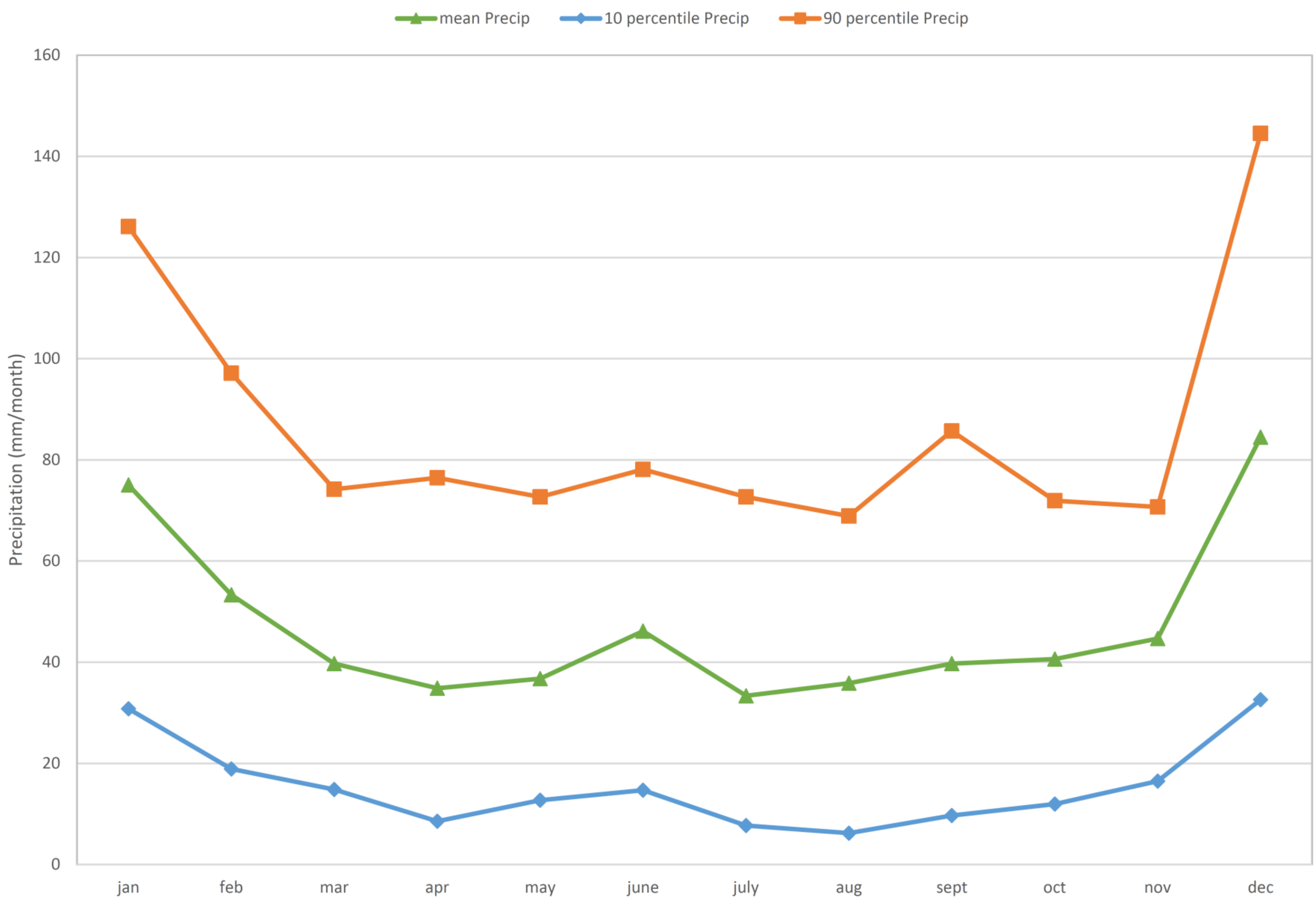


Figure 4   Average monthly precipitation.

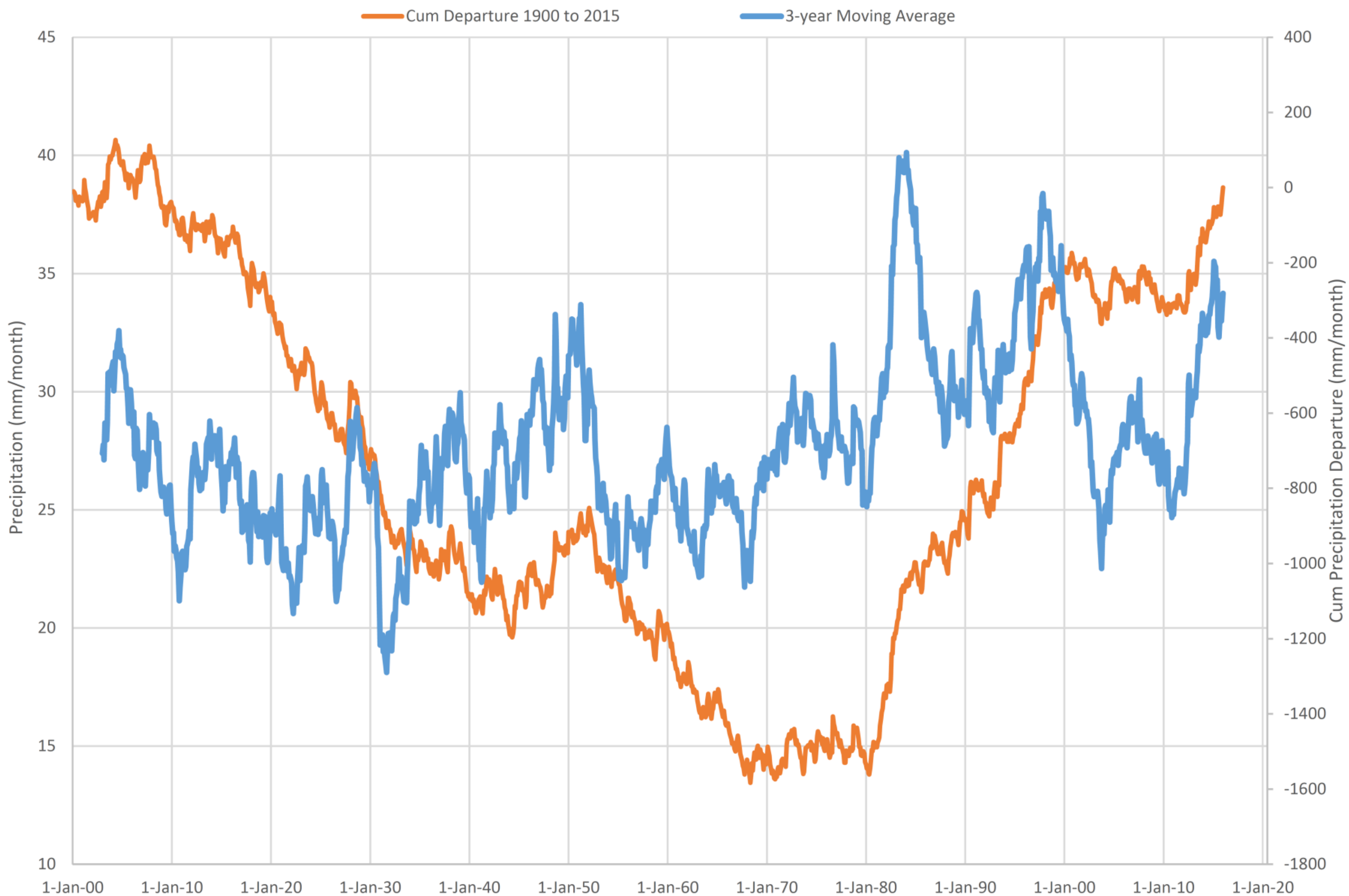


Figure 5   Monthly precipitation data – 3-year moving average and cumulative departure, 1900 to 2015.

3.2 Topography and Drainage

Topographic elevation within the study area ranges between 342 masl in the proximity of Okanagan Lake and above 2,000 masl in the headwaters of Mission Creek. The main catchments included in the study area are, progressing from North to South, those of Kelowna (Mill) Creek, Mission Creek and Bellevue Creek. The main tributaries of Kelowna Creek are Scotty and Brandt Creek, the main tributaries of Mission Creek include Hydraulic, Klo and Priest Creek, and Gillard Creek is the tributary of Bellevue Creek. The catchment areas and stream lengths associated with the Kelowna Creek, Mission Creek and Bellevue Creek are listed in Table 2.

Table 2 Main stream catchment areas and lengths

Stream	Total Stream length (km)	Catchment Area (km2)
Kelowna (Mill) Creek	59.4	261.7
Mission Creek	147.2	833.4
Bellevue Creek	28.5	92.9

Figure 6 shows the 200-m topographic contours and the streams, lakes and wetlands located in the study area.

All the daily and monthly streamflow records available for the 42 hydrometric stations located in the study area were downloaded from the Canada Water Office website (https://wateroffice.ec.gc.ca/). These stations are listed in Table 3. Of the 30 hydrometric stations that gauge unregulated streams in the study area, four stations (Bellevue Creek near Okanagan Mission, Joe Rich Creek near Rutland, Daves Creek near Rutland, Pearson Creek near the mouth) were selected for calibration of the groundwater budget model. Although both daily and monthly records are available for some of the stations, only monthly records were used in the model calibration. Figure 7 shows the hydrometric stations located in the study area and those selected for calibration.

Table 3 Hydrometric stations in the study area.

Station Name	Station Number	Easting (WGS84)	Northing (WGS84)	Period of record
KLO CREEK NEAR KELOWNA	08NM004	330051	5520925	1919 - 1922
HYDRAULIC CREEK NEAR THE MOUTH	08NM010	332292	5523513	1919 - 1982
HYDRAULIC CREEK AT OUTLET OF MCCULLOCH RESERVOIR	08NM011	342755	5516861	1919 - 1986
MISSION CREEK NEAR RUTLAND	08NM016	331995	5524820	1919 - 1946
BELGO CREEK NEAR RUTLAND	08NM017	351069	5541010	1920 - 1920
HILDA CREEK NEAR RUTLAND	08NM018	351307	5541064	1920 - 1920
VERNON CREEK AT OUTLET OF SWALWELL LAKE	08NM022	334728	5525262	1921 - 1996
KELOWNA CREEK NEAR RUTLAND (UPPER STATION)	08NM026	331305	5539740	1920 - 1922
BELLEVUE CREEK	08NM035	322898	5518620	1920 - 1986

Station Name	Station Number	Easting (WGS84)	Northing (WGS84)	Period of record
NEAR OKANAGAN MISSION				
SCOTTY CREEK NEAR RUTLAND	08NM036	332549	5533613	1919 - 1964
HYDRAULIC CREEK DIVERSION NEAR KELOWNA	08NM039	331009	5522749	1919 - 1968
HYDRAULIC CREEK SOUTHEAST KELOWNA DIVERSION	08NM040	329467	5522025	1920 - 1930
KELOWNA CREEK NEAR KELOWNA (LOWER STATION)	08NM053	326318	5529730	1922 - 1996
MISSION CREEK RUTLAND DIVERSION	08NM057	328202	5527475	1922 - 1930
KLO CREEK DIVERSION NEAR KELOWNA	08NM060	329591	5523444	1923 - 1968
KELOWNA CREEK NEAR RUTLAND	08NM061	331294	5538937	1924 - 1931
ELLISON LAKE NEAR WINFIELD	08NM067	328211	5539684	1968 - 1980
OKANAGAN LAKE AT KELOWNA	08NM083	320321	5528930	1943 - 2013
MISSION CREEK NEAR EAST KELOWNA (WCS gauge)	08NM116	326609	5527856	1949 - 2013
KELOWNA CREEK AT RUTLAND STATION	08NM117	328297	5532263	1950 - 1975
JOE RICH CREEK NEAR RUTLAND	08NM129	346855	5525243	1964 - 1987
DAVES CREEK NEAR RUTLAND	08NM137	336576	5526442	1965 - 1986
BULMAN CREEK AT THE MOUTH	08NM145	338633	5541563	1968 - 2004
BRANDTS CREEK NEAR THE MOUTH	08NM152	321026	5529254	1969 - 1975
BELLEVUE CREEK AT THE MOUTH	08NM156	320734	5521566	1969 - 1972
PEARSON CREEK NEAR THE MOUTH	08NM172	351903	5528098	1970 - 1987
MYRA DITCH BELOW KLO CREEK	08NM207	336267	5513624	1973 - 1985
POOLEY CREEK ABOVE POOLEY DITCH	08NM210	331632	5513179	1973 - 1979
STIRLING CREEK	08NM212	340278	5511032	1977 - 1984

Station Name	Station Number	Easting (WGS84)	Northing (WGS84)	Period of record
DIVERSION TO MCCULLOCH RESERVOIR				
MCCULLOCH RESERVOIR AT MCCULLOCH DAM	08NM213	342769	5516830	1973 - 1986
FISH LAKE AT THE OUTLET	08NM215	342220	5519257	1973 - 1977
BROWNE LAKE RESERVOIR ABOVE THE DAM	08NM216	342671	5520882	1973 - 1977
LONG MEADOW LAKE RESERVOIR ABOVE THE DAM	08NM217	343627	5519371	1973 - 1977
BELGO CREEK NEAR THE MOUTH	08NM225	345565	5526423	1976 - 1982
KLO CREEK AT MCCULLOCH ROAD	08NM226	329978	5521112	1976 - 1982
LOCH KATRINE CREEK AT OUTLET OF GRAYSTOKE LAKE	08NM229	365885	5538518	1977 - 1998
GRAYSTOKE LAKE AT THE OUTLET	08NM230	365883	5538443	1977 - 1998
IDEAL LAKE NEAR THE OUTLET	08NM231	349818	5541940	1963 - 1980
BELGO CREEK BELOW HILDA CREEK	08NM232	351448	5540612	1976 - 2010
MISSION CREEK ABOVE PEARSON CREEK	08NM233	351848	5528193	1977 - 1982
MOORE LAKE RESERVOIR AT THE DAM	08NM234	341225	5543765	1973 - 1986
MISSION CREEK BELOW B.M.I.D. INTAKE	08NM239	335861	5524454	1980

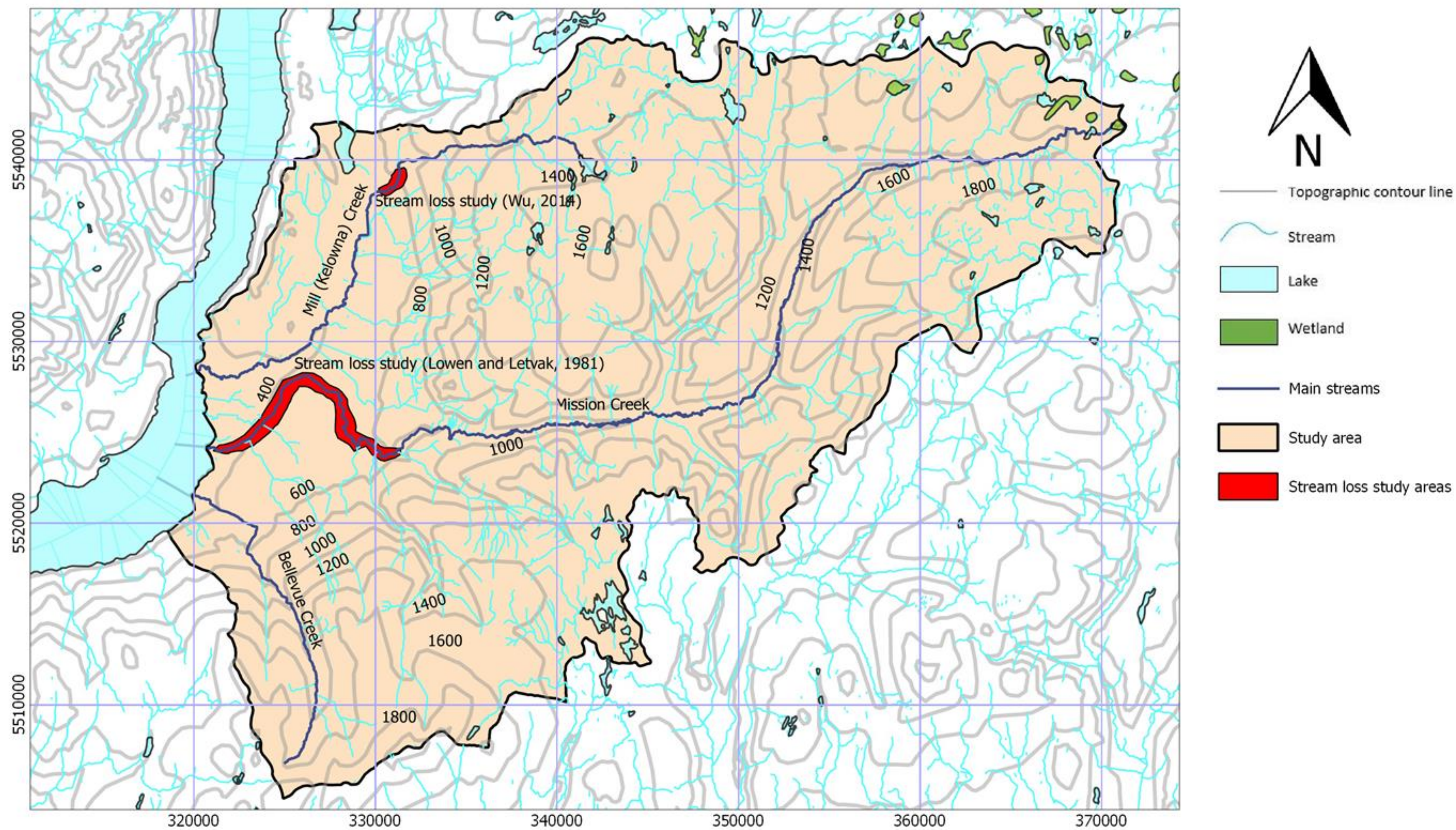


Figure 6 Topography and drainage.

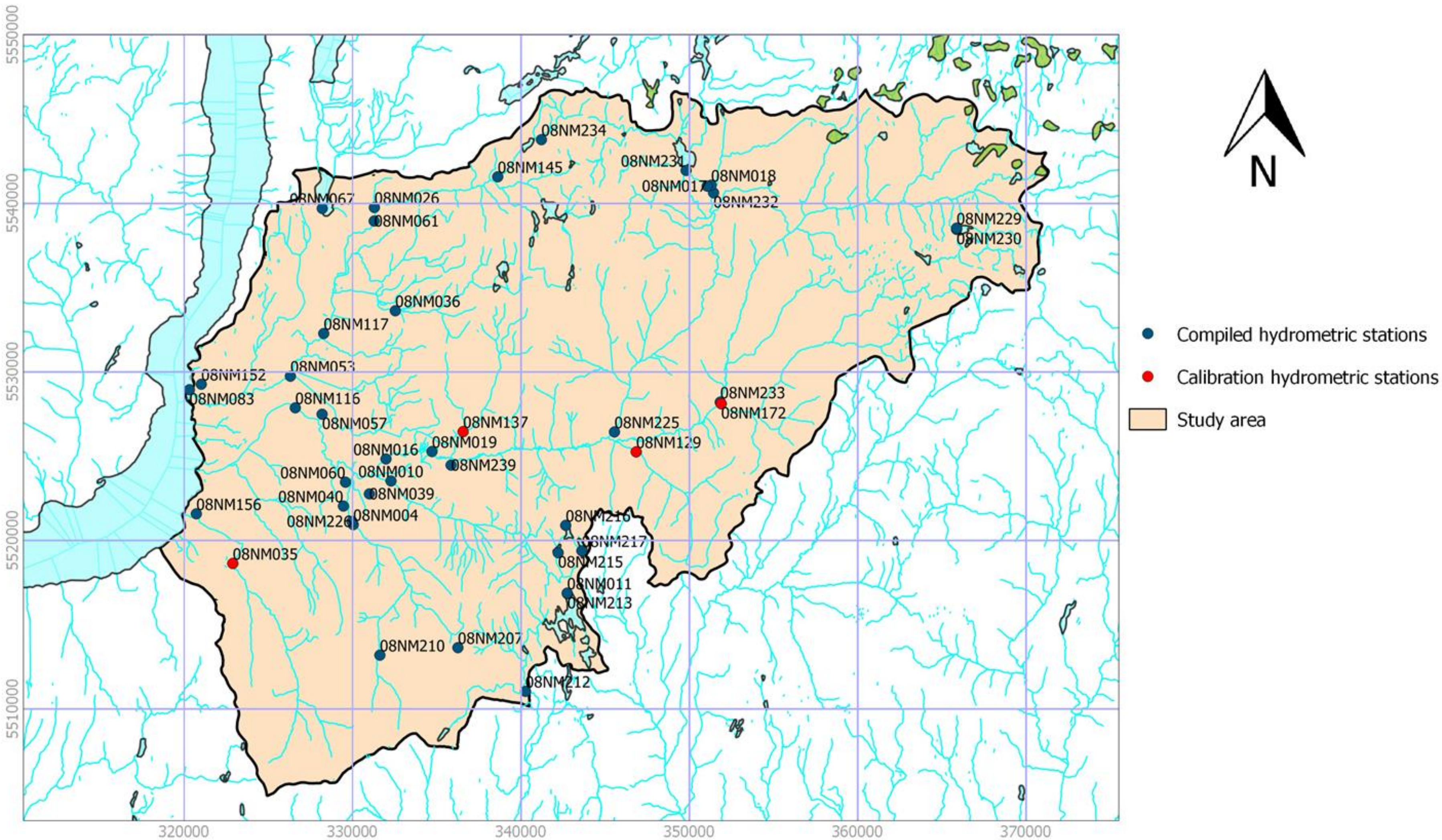


Figure 7 Hydrometric stations in the study area

Based on the regional hydrologic characterization for the Okanagan Basin (Summit and DHI, 2009), 75% of annual streamflow occurs between April and June as a result of snowmelt, with annual peak flows typically recorded in May – June and the lowest flows occurring in January – February. Runoff patterns vary considerably, depending on topographic slope, precipitation intensity, soil texture and land cover. The average annual runoff and streamflow rates for the three main catchments (Kelowna Creek, Mission Creek and Bellevue Creek) included in the study area, which were estimated based on the 1996-2006 records (Summit and DHI, 2009) are listed in Table 4.

Table 4 Average annual runoff and streamflow for the main catchments in the study area.

Catchment	1996-2006 normal Runoff (mm/year)	1996-2006 normal Streamflow (m3/s)
Kelowna (Mill) Creek	119	0.840
Mission Creek	292	7.82
Bellevue Creek	114	0.336

Of the 42 hydrometric stations located in the study area, 12 stations are for regulated sub-catchments of Kelowna Creek and Mission Creek, i.e. where streamflows are affected by diversions and storage in reservoirs.

In the Kelowna (Mill) Creek catchment, release of water from an intake on Scotty Creek and storage in James Lake is managed by the Black Mountain Irrigation District (BMID), and release from an intake on Kelowna Creek and storage in Moore (Bulman) Lake, South Lake and Postill Lake is regulated by the Glenmore-Ellison Irrigation District (GEID). This district mainly uses water from Okanagan Lake, with surface water intake from Kelowna Creek as a secondary source (Wu, 2014).

In the Mission Creek catchment, the BMID manages release from an intake on Mission Creek and storage in Belgo Reservoir (with Mugford Creek and Hilda Creek diversions), Fish Hawk Lake, Greystoke Lake and Loch Long, and the South Kelowna Irrigation District (SEKID) regulates discharge at an intake on Hydraulic Creek (with diversions from Pooley Creek and Stirling Creek) and storage in McCulloch Reservoir, Browne, Fish and Long Meadow Lakes.

Information on the operation rules for the reservoirs located in the Mission Creek catchment is reported in (MWC, 2010). Streamflow is maintained at the Mission Creek intake at a constant rate of 0.5 m^3/s throughout the year. Following the natural streamflow reduction after the freshet period, storage release occurs first from Belgo Reservoir (Ideal Lake) from the rate needed to meet demand to 0.14 m^3/s on July 15, when release starts from Fish Hawk Lake at the constant rate of 0.3 m^3/s and from Greystoke Lake at a variable rate. Release from Loch Long occurs at the rate of 0.2 m^3/s between September 1 and October 15 until storage is depleted. Flow at the Hydraulic Creek intake is maintained at rates ranging between 0.031 and 0.2 m^3/s, and storage release starts, based on an allotment defined according to the available water in storage, when the natural flow declines to less than the demand plus the minimum downstream discharge.

3.3 Surface water-Groundwater Interaction

Exchange of water between surface water bodies and the underlying aquifers in the study area mainly occurs as streamflow leakage, where the stream stage is higher than the groundwater level, and discharge to stream baseflow, where groundwater levels are higher than the stream stage. A significant part of the groundwater recharge entering the upper reaches of the model domain occurs as streamflow along local stream channels. Stream leakage also occurs as the streams pass over terraces, particularly the Mill Creek and Mission Creek alluvial fan sediments, whereas groundwater discharge to stream baseflow generally occurs in the valley close to where the streams enter Okanagan Lake. The magnitude of streamflow loss occurring over the Mill Creek alluvial fan sediments located to the southeast of Ellison Lake, which was estimated in terms of infiltration rate from temperature streambed profiles and differential stream gauging by Jordan Wu (Wu, 2014), is of the order of 6e-6 $m^3/s/m^2$. Over a length of stream of 1,000 m and a width of 5 m, this estimate corresponds to a streamflow loss of approximately 2,600 m^3/day, or 30 L/s. A study on the surface-groundwater interaction in the Lower Mission Creek based on a stream gauging program along six transects located in Rutland and Southeast Kelowna (Lowen and Letvak, 1981), led to the conclusion that the exchange of water between the Mission Creek and the aquifer downgradient of the BMID intake is a relatively minor component of total streamflows. These conclusions are consistent with the results of this study, where the groundwater discharge to surface represents a small component of the surface water budget. However, groundwater discharge to surface represents a very significant component of the groundwater budget, mainly due to the limited groundwater discharge to Okanagan Lake, which was estimated by means of seepage meter measurements and investigative modelling (Pyett, 2015). A surface water – groundwater interaction monitoring program is currently being initiated by the Okanagan Basin Water Board (verb. comm. Nelson Jatel, 2016).

3.4 Land Use

Based on the interpretation of the Terrestrial Ecosystem Mapping data (TEM: http://www.env.gov.bc.ca/fia/terrecomap.htm) reported by Taylor and Wilson (2013), natural areas, including wetlands and forests, represent, at nearly 49%, the largest share of the Mission Creek watershed. Cultivated fields and orchards (i.e. agricultural land) represent the second largest share at approximately 30%, and urban/suburban development occupy the remaining 21%. Natural areas are mainly located in the upper portion of the Mission Creek catchment, whereas agricultural land and urban developments are almost exclusively located in the lowlands.

3.5 Geology

A comprehensive geological characterization study of the Mission Creek area was undertaken by the Geological Survey of Canada and documented in Open File 6507 (Paradis et al., 2009). The study was based on the integration of previous work (e.g. Fulton and Smith, 1978) with the combined interpretation of an 88-m deep borehole drilled approximately 1 Km Southeast of the Mission Creek's outlet into Okanagan Lake, a geophysical survey and a field mapping campaign. The interpretation led to the development of a scale 1:50,000 surface geology map and a 3D block model constructed in GoCad©.

The geology of the study area is the result of the complex sequence of ice advancement and retreat episodes that took place in the Okanagan basin. The main geological units identified in the area, which are associated with the aquifers (and aquitards) of interest in this study, include the following, from the deepest to the most surficial:

Fractured Bedrock. This unit comprises the Eocene volcanism dacite and breccia rocks of the Maron, Marama, and Kettle River Formations, and the siltstone, sandstone and conglomerate of the White Lake Formation, which resulted from erosion and lithification of the volcanic rocks (Roed and Greenough, 2004).

Rutland and Bessette ('Old') sediments. This unit comprises a mix of glacial and interglacial unconsolidated deposits including sand, silt, gravel and till deposited prior to the last ice advancement. These sediments are visible on the east side of Okanagan Lake, underneath some subaerial proglacial fan sediments just south of Ellison Lake, and at the mouth of Mission Creek (at the exit of Gallagher's Canyon). At this location, the creek eroded through the lacustrine delta-fan complex cutting through the entire suite of sediments and exposing one of the only sections of what is known as the Rutland aquifer (Paradis et al., 2009).

Fraser Till. This is a diamicton with a gravelly-sandy matrix and varying degree of clay content. This unit is generally thicker than 1 m East of Kelowna and Southeast of Wood Lake.

Glaciofluvial sediments (Glacial contact). This unit comprises terraces deposited by meltwater in contact with or near the glacier. They are clearly visible in the upper part of the Mission Creek valley and form very important subaerial proglacial fan complexes (up to 10 m thick) at the mouth of the Mission Creek, on the west side of Kelowna/Ellison-Wood Lakes Valley. This unit is located at the southern edge of a delta-fan complex and forms a kame terrace with accumulation of moraine at the mouth of the Bellevue Creek and Priest Creek.

Glaciolacustrine sediments (Penticton). This unit consists of glaciolacustrine sediments associated with the presence of paleo-glacial lakes, which developed along hillside channels as the ice melted away in the Okanagan Valley. The deposits include (1) silt / clay bands and deltaic sands and gravels deposited in the paleo-proglacial Penticton Lake, which are located in the Kelowna/Ellison-Wood Lake valley, on the east shore of Okanagan Lake, and at the foot of the delta-fan complex just south of Kelowna; and (2) deltaic complexes associated with the outlets of the short-lived and shallow paleo glacial Mission Lake and Daves Lake, which are found along the current Joe Rich Creek and Daves Creek, respectively.

Old Alluvium (Fluvial Sediments). This is a post-glaciation unit consisting of sands, gravelly sands, gravels and organic debris ranging between 0.5 and 15 m in thickness, which form the surficial deposits of what is known as the Mission Creek delta-fan complex.

Modern Alluvium (Other Sediments). This is a post-glaciation unit comprising sands, gravelly sands, gravels, silts and organic debris varying in thickness from 0.5 to 3 m. It forms the extensive alluvial fan on which most of the town of Kelowna is built, as well as the smaller alluvial fan on the valley floor South of Ellison Lake, composed primarily of poorly sorted gravels, sand and clay.

3.6 ENV Aquifers

The ENV-mapped aquifer units of interest in the study area are shown in Figure 8 and include the following:

Aquifer 463. This aquifer is located in the Kelowna area and east, southeast and northeast of the city. The aquifer overlies a terrace-like feature at the foot of the mountain slopes. The total aerial extent is estimated as 61 Km^2. It is described as a confined sand and gravel aquifer of glaciofluvial origin, with estimated average thickness of 25 m and average depth-to-water of 19 m bgs (ranging between 91 m bgs and artesian). The overlying confining layer consists of glaciolacustrine sediments or till with an average thickness of 22 m (ranging between 1 and 100 m). The estimated hydraulic conductivity for this aquifer ranges between 10^{-4} to 10^{-3} m/s, and the storativity, estimated based on one hydraulic test only, is of the order of 10^{-4} to 10^{-3} (BC ENV, 2007). Aquifer 463 is estimated to have a confining layer that is 7 m thicker (on average) than Aquifer 464.

Aquifer 464. This aquifer is located in the central to northeast area of Kelowna area. The aquifer is located between Aquifer 463 and the Brandt Creek catchment to the north and between Aquifer 463 and Okanagan Lake to the south. The total aerial extent is estimated as 69 Km^2. It is described as a confined sand and gravel aquifer, with unconfirmed average thickness, an average depth-to-water of 6 m bgs (ranging between 20 m bgs and artesian), and an overlying confining layer consisting of glaciolacustrine or till with an average thickness of 15 m (ranging between 1 and 85 m). Aquifer 464 is estimated to have a confining layer than is 7 m thinner than Aquifer 463.

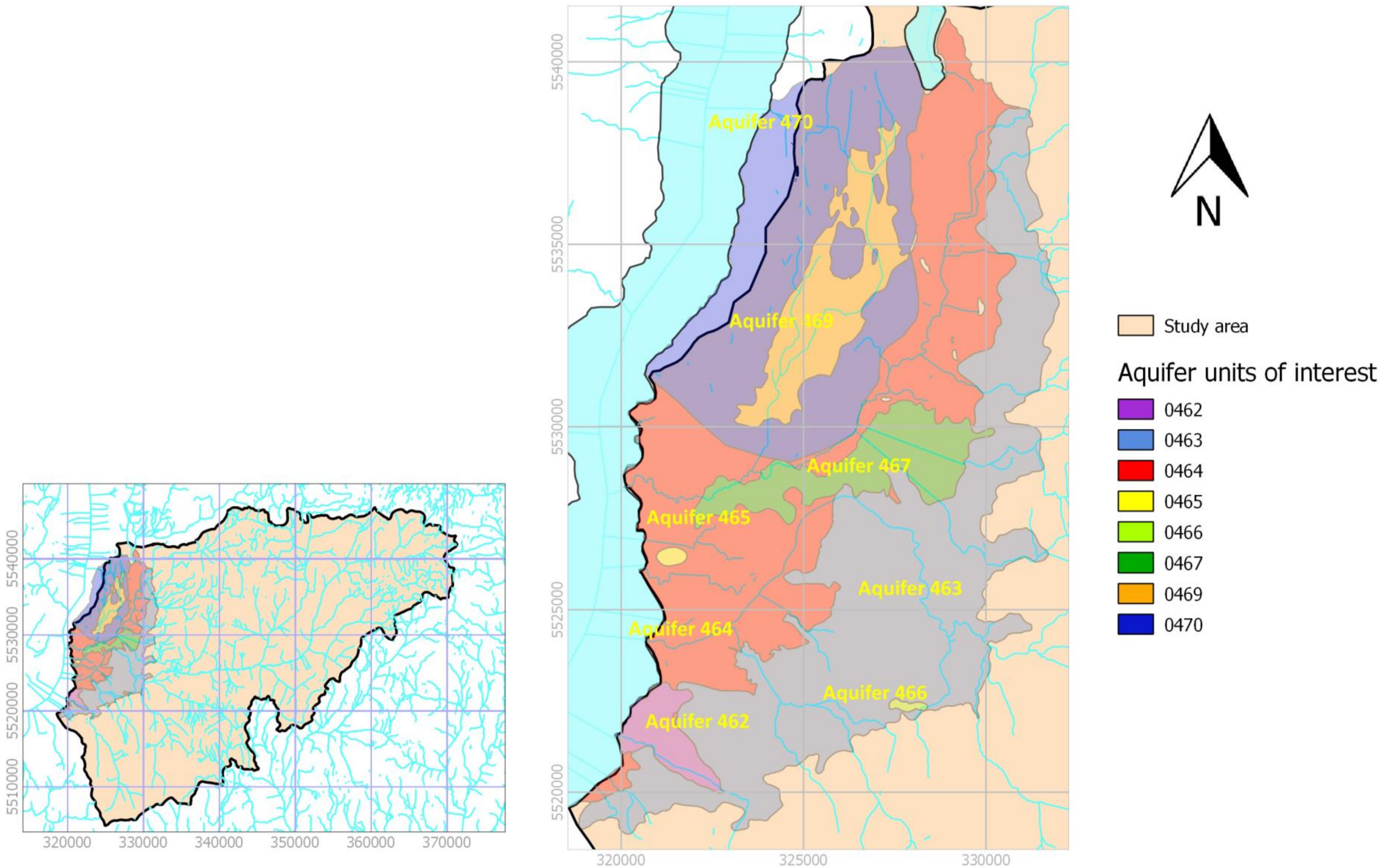


Figure 8 Aquifers of interest in the study area.

Aquifer 465 and 466. Aquifer 465 is a small (0.5 km^2) isolated, poorly characterized aquifer located in central Kelowna, associated only with one well. It is a confined sand and gravel aquifer overlain by 275 m of lacustrine silt. Aquifer 466 is also a small (0.5 km^2) unconfined sand and gravel aquifer in central Kelowna, with 8 wells ranging from 4 to 5 m in depth.

Aquifer 467. This unit is located in the Rutland area, East Kelowna, and has an estimated extent of 10 Km^2. It is described as an unconfined sand and gravel aquifer of glaciofluvial origin, with unconfirmed thickness and average depth-to-water of 3 m bgs. The unit is distinguished from the underlying Aquifer 464 due to the presence of semi-confining sediments, and is therefore likely to be hydraulically connected with these units. There are 129 wells recorded in this aquifer. The average well depth is 8 m (ranging from 1 to 163 m). The average yield is 4 L/s (ranging from 0.3 to 31 L/s) and the average depth-to-water is 3 m bgs (ranging from 0 to 11 m bgs).

Aquifer 469. Aquifer469 is located in Glenmore Valley, North Kelowna. The areal extent is estimated as 12 Km^2. This aquifer is described as confined sand and gravel, overlain by lacustrine clay material ranging between 4 and 44 m and averaging 19 m in thickness. The average depth-to-water is 5 m bgs (ranging between 2 and 11 m bgs). The average estimated yield is 3 L/s (ranging from 2 to 3 L/s). Aquifer 469 overlies Aquifer 470.

Bedrock aquifers in the Kelowna area are also described by the ENV. The degree of faulting and fracturing of the bedrock is considered sufficient to allow this unit to have sufficient groundwater flow to allow pumping (Lawson 1968, Voeckler and Allen 2008). There is potential yield from most bedrock aquifers in the area, but yields are considerably less than the overburden aquifers.

The aquifers described above are shown on Figure 8. They represent the current official characterization for the Kelowna aquifers presented in the Aquifer Information Tables (BC ENV, 2007). Geologic mapping that was undertaken by the GSC does not allow a direct correspondence between these aquifer units and the geological units reported in (GSC, 2009). The hydrostratigraphic interpretation of the lithological log Mission Creek test hole reported in (Harrington, 2013) and shown on Figure 9 indicates that ENV aquifer units 463 and 464 likely correspond with the lower portion of the glaciofluvial sediments, and aquifer units 465, 467 and 469 likely correspond with the upper portion of the glaciofluvial sediments

The hydrostratigraphic interpretation of the ENV test hole of Figure 9 shows that three zones of aquifer materials are present. These include the glaciofluvial sediments, the lower confined Rutland and Bessette sediments, which are separated from the overlying glaciofluvial aquifers by the Fraser Till aquitard, and a shallow unconfined aquifer corresponding with the Old and Modern Alluvium, which is separated from the underlying ENV-mapped glaciofluvial aquifers by the glaciolacustrine sediments (Penticton) aquitard.

3.7 Aquifer Properties

Summaries of the hydraulic conductivity (K) estimates for the Kelowna aquifers derived from pumping tests are reported in (Golder, 2004), (Smerdon and Allen, 2009) and (Carmichael et al., 2009). These indicate that hydraulic conductivity ranges between $1e^{-5}$ and $1e^{-3}$ m/s, which is consistent with literature values representative of clean sand deposits (Freeze and Cherry, 1979). This range is also consistent with the reference value of $1e^{-4}$ m/s used to represent effective hydraulic conductivity of the Kelowna aquifers in the water budget model described in (Summit and Golder, 2009). Mean hydraulic conductivity estimates of $2.2e^{-3}$ m/s and $1.7e^{-3}$ m/s, which are specific to aquifer units 463 and 464, respectively, are provided in (Smerdon and Allen, 2009).

Preliminary estimates of saturated thickness for the Kelowna aquifers are provided in Table 3 of the Groundwater Protection Plan for Kelowna (Golder, 2004). The estimated thickness in the Golder study ranges between 30 m, along the eastern edge of the valley, and 10 m, along the lake shore. In the Golder study, the vertical sequences of aquifers and aquitards located in the valley were grouped within one unit, referred to as the Greater Kelowna Aquifer. Similarly, all vertical sequences of aquifers and aquitards located in the same area were consolidated into one zone in the water budget model described in (Summit and Golder, 2009).

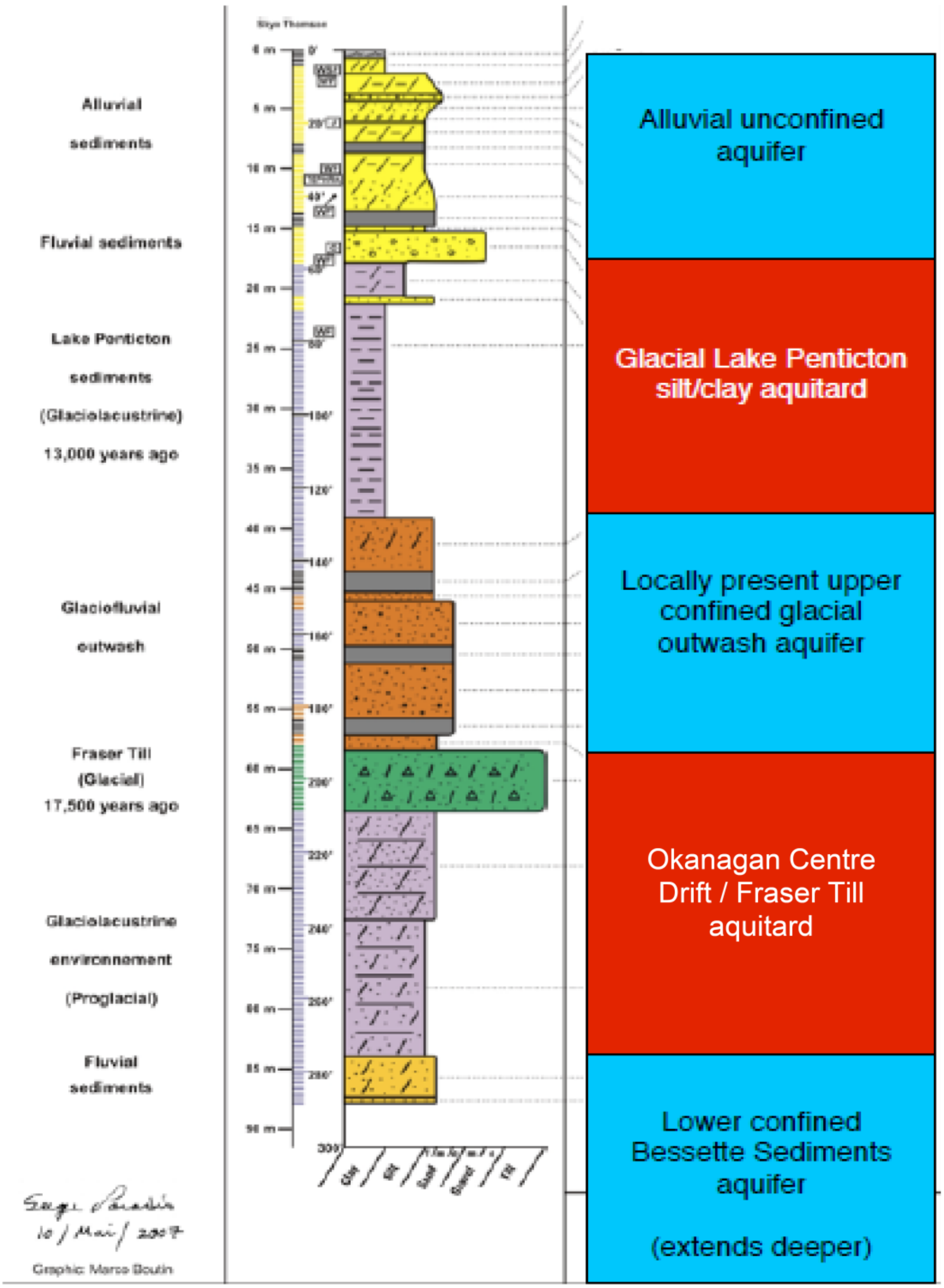


Figure 9 Hydrostratigraphic interpretation of the Mission Creek test hole lithology (from Paradis et al., 2010, and Harrington, 2013).

The model developed in this study follows the same approach, in that the vertical sequences of potential aquifers located in the area of the ENV-mapped Kelowna aquifers are considered as individual groundwater budget zones. The hydrostratigraphic interpretation of the Mission Creek test hole lithology (Harrington, 2013) suggests an overall thickness in excess of 100 m for the sequence of aquifers and aquitards located in the Kelowna area, with aquifer materials thickness of about 40 m. Analysis of the static water levels, well depths and lithologs for 15 water supply wells located in the Kelowna aquifers, which were obtained from the BC Wells database (https://a100.gov.bc.ca/pub/wells/public/) and selected for their large depth and detailed litholog, led to an average saturated thickness estimate for the Kelowna valley aquifers of 56 m. This value of saturated thickness was used as a reference to estimate the transmissivity values for the Kelowna aquifers that were used in the groundwater budget model.

3.8 Groundwater Levels

All available historic groundwater levels recorded up to March 2016 at the 7 observation wells located within or immediately outside the study area were downloaded from the BC Groundwater Observation Well Network database using the interactive map tool (http://www.env.gov.bc.ca/wsd/data_searches/obswell/map/). Of these, records for well 387 were not used as this well was installed in a very low-permeability environment that is not representative of aquifer conditions, and records from wells 410 and 413 were not used because they are not considered reliable (verb. comm. ENV, 2016). The remaining observation wells are listed in Table 5 and their location is shown on Figure 10.

Table 5 Groundwater observation wells with historic records in the study area

Well Number	Aquifer Unit	Easting (WGS84)	Northing (WGS84)	Screen depth (m bgs)	Period of record
236	464	325956	5525886	40 – 42.7	Aug-1980 to Mar-2016
262	463	327608	5527947	- (1)	Mar-1979 to Mar-2016
356	N/A (2)	330117	5541556	11 – 12.2	Jun-2004 to Mar-2016
442	463	330284	5535862	51 – 52.2	Nov-2014 to Mar-2016

(1) The screen depth for this well is not available. The total depth for this well is 84.4 m.
(2) Well 356 is outside the modeled watersheds, but was included as it is very close to the northern boundary of the modeled domain.

Hydrographs for the selected four wells, which are shown on Figure 11, were produced by removing unreliable records (values very close or equal to the well top of casing) to provide an indication of the historic groundwater level fluctuations in the Kelowna area. Groundwater elevation values were calculated by subtracting the depth-to-water records from estimates of the ground surface obtained from a 1-m contour topography map for the study area (downloaded from City of Kelowna Map Viewer, http://maps.kelowna.ca/public/mapviewer/). The plots indicate that groundwater levels have seasonal changes ranging between 0.5 and 2 m. The fluctuations recorded in wells 262 and 236, where minimum values occur in July-August, are likely related to groundwater pumping for irrigation, which takes place from nearby wells.

The correspondence between the cumulative precipitation departure and the groundwater levels in wells 236 and 262 indicates that the declining trend in groundwater levels observed in is these wells is likely the compounded result of a declining trend in precipitation between 2000 and 2010 and of adjacent groundwater withdrawal by the Rutland Water Works (RWW)and the Southeast Kelowna

Irrigation District (SEKID), respectively. The declines in groundwater levels range approximately between 0.1 and 1 m/year and are on average 0.2 m/year.

Average groundwater elevations for the selected observation wells were used in conjunction with the static groundwater levels from 85 wells listed in Table 2 of the Greater Kelowna Aquifer Groundwater Protection Planning Study (Golder, 2004), to produce representative groundwater level contours for the Kelowna aquifers by means of kriging interpolation. These contours were produced by using groundwater level data from wells screened at different depths, based on the assumption that the aquifers that are vertically stacked in one area are hydraulically connected and can be grouped as one groundwater budget zone. The resulting contours, which are shown on Figure 10, indicate that groundwater generally flows from the northeast to the southwest and is affected by the cone of depression related to groundwater withdrawal in Kelowna, with groundwater head gradient ranging between approximately 0.2 and 2%.

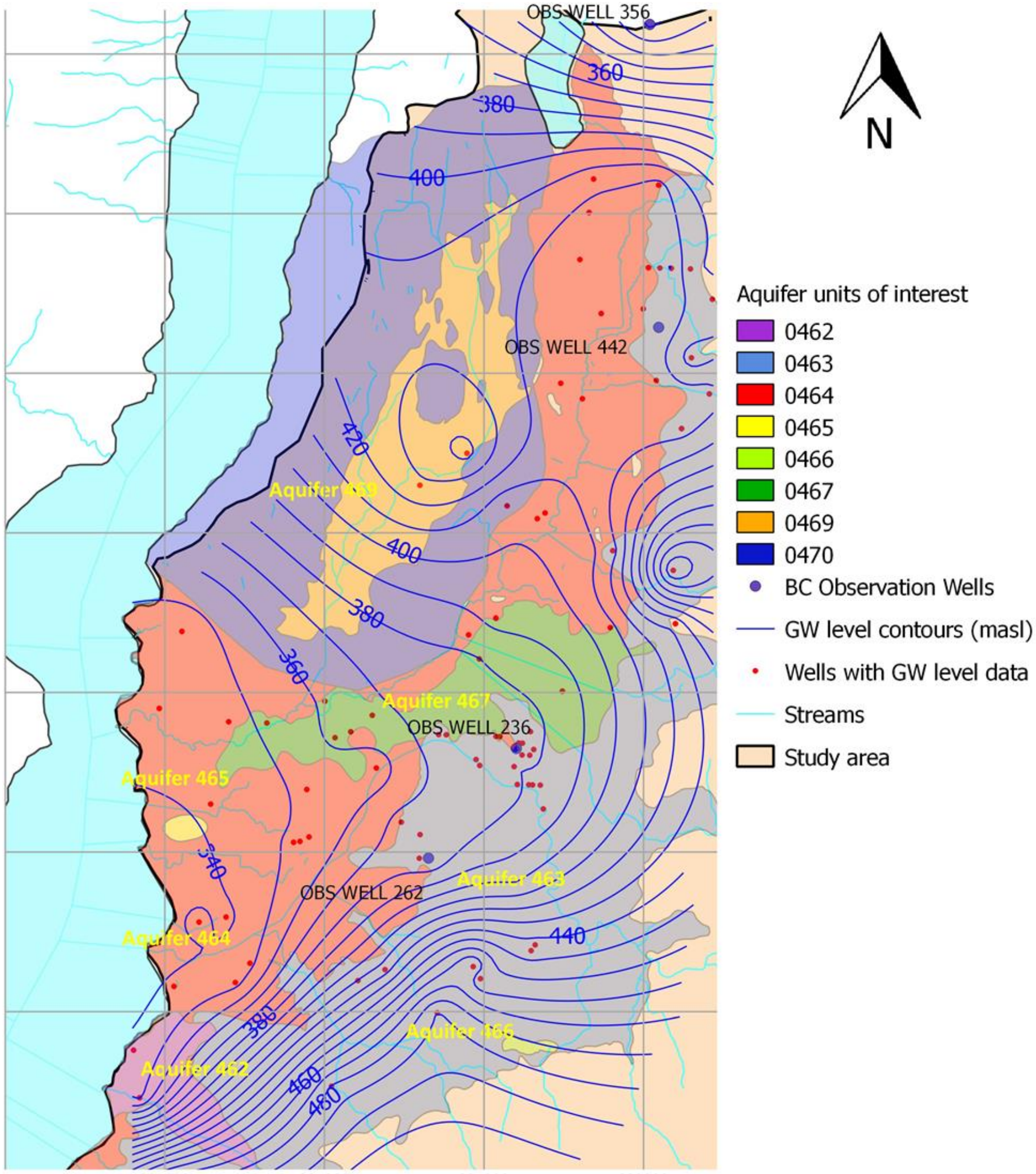


Figure 10   Groundwater level contours in the study area (based on groundwater level data from Golder, 2004).

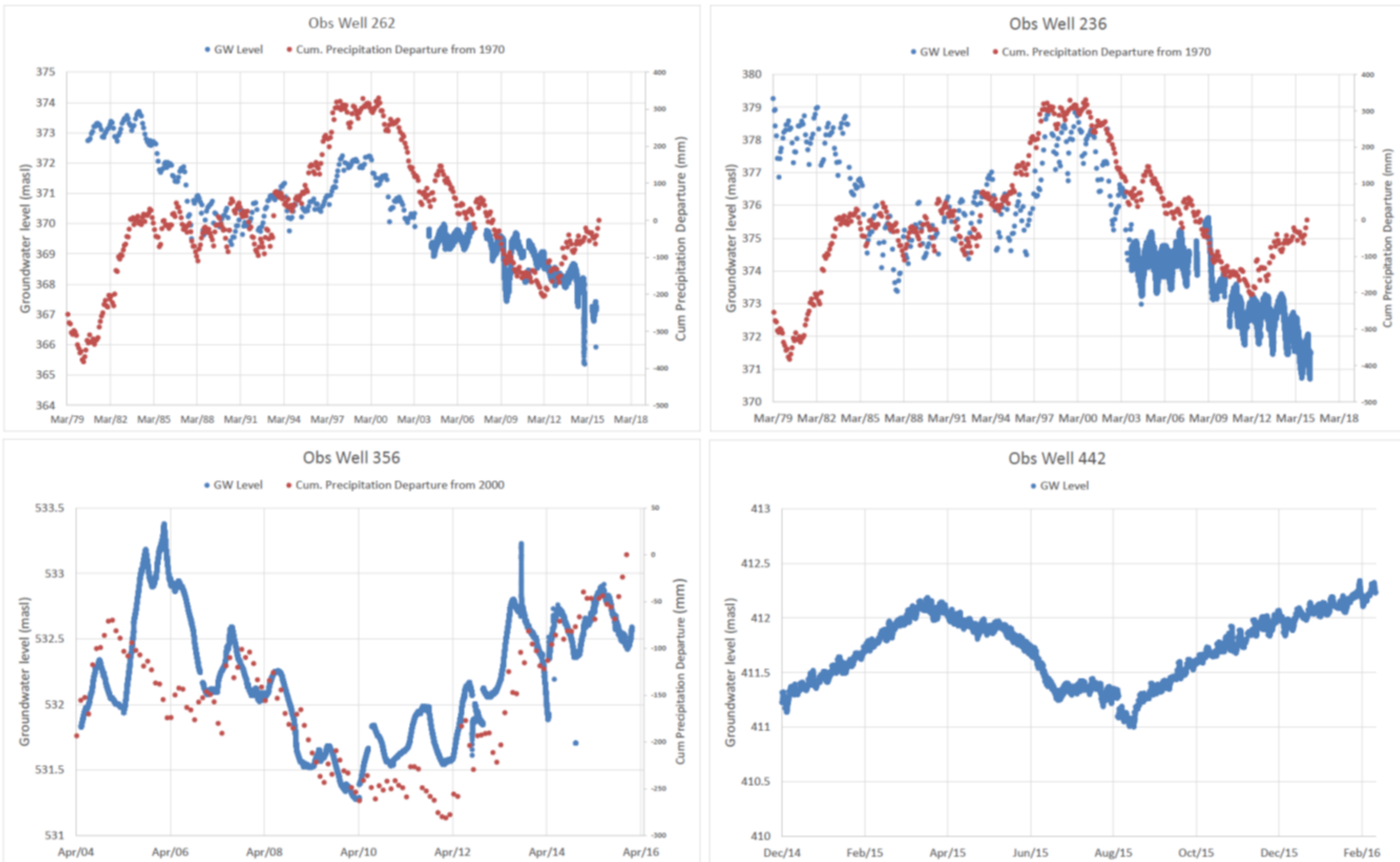


Figure 11 Hydrographs for the selected BC groundwater observation wells.

4. CONCEPTUAL HYDROGEOLOGIC MODEL

The information and data described in Section 3 were used to develop a hydrogeological conceptual model for the study area. This consists of a set of assumptions related to the geometry, hydraulic properties, flow and water balance components of the groundwater system. The main features of the conceptual model are described in the following sections, and a schematics of the conceptual groundwater budget model is shown on Figure 12.

4.1 Aquifer Geometry

The geological 3D model and the hydrostratigraphic interpretation of the Mission Creek litholog indicate the presence of a vertical sequence of aquifers and aquitards In the Kelowna area. Among the ENV-mapped Kelowna aquifer units, unit 467 is above 464 and unit 469 is above 470. Based on the GSC geological interpretation (Paradis et al., 2010), a vertical sequence of aquifers may be present in all the ENV-mapped aquifer units. In this groundwater budget model, each ENV-mapped aquifer unit is represented as one or more groundwater budget zones, and each zone includes the entire vertical series of aquifers that may be present at the zone location. As such, only lateral groundwater flow occurs among the zones. Investigative analytical modeling conducted during this study, which was based on the use of the equation for steady-state flow to a well in a leaky aquifer (Steggewentz and Van Nes, 1939), showed that groundwater withdrawal from a semi-confined or confined aquifer induces vertical flow from an overlying shallow unconfined aquifer as well as from underlying confined aquifers, with flow occurring as leakage through the aquitard separating the aquifers. The vertical flow in the unconfined aquifer induces additional leakage from a connected stream, or a reduction in groundwater discharge as stream baseflow. The representation of a series of stacked aquifers that are vertically hydraulically connected (not reflected in the current ENV-mapped aquifer units) therefore allows the surface water - groundwater interaction mechanism to be reproduced adequately. The 'single bucket' approach to represent a vertical stack of aquifers was therefore selected to develop the water balance. An understanding of the vertical flows between each of the stacked aquifers requires a three-dimensional groundwater model with a level of complexity that is beyond the scope of this study.

Figure 12 shows a schematic representation of how aquifers 463, 464 and 467 were represented in the model as unit comprising a sequence of likely stacked aquifers. Each aquifer is laterally sub-divided into a set of budget zones: Aquifer 463 consists of 6 zones, Aquifer 464 consists of 9 zones and Aquifer 467, which is of limited lateral extent, is represented only by one zone.

An initial average hydraulic conductivity of $1e^{-4}$ m/s, which is representative of the most permeable glaciofluvial sediments, and an average saturated thickness of 50 m, which is consistent with the average saturated thickness estimated from wells in the Kelowna aquifers, and with the overall saturated thickness of the vertical sequence of aquifers based on the hydrostratigraphic interpretation, were assigned to each of the units representing the valley aquifers. The initial values of K and saturated thickness correspond to a Transmissivity of 432 m^2/day. The transmissivity of the valley aquifers was subsequently reduced during the model calibration to values of less than 100 m^2/day. These values are consistent with the range of hydraulic conductivity and saturated thickness values available for the study area. Although considerably lower than the initial estimates, transmissivity values of less than 100 m^2/day are deemed reasonable, given that the aquifer units close to Okanagan Lake likely consist of fine sediments, due to the low topographic gradient and therefore reduced sediment-transport energy of the streams.

In the uplands, the thin veneer of unconsolidated sediments overlying weathered shallow bedrock and deep fractured bedrock were also grouped into one aquifer unit for each of the zones considered in the groundwater budget model. The deep fractured bedrock is considered to receive limited recharge and allow limited groundwater flow towards the Okanagan Valley. Most of the groundwater recharging the uplands discharges to the local stream channels. This assumption is consistent with the exponential decrease in effective hydraulic conductivity in the crystalline rocks of the study area reported in (Lawson, 1968). The list of transmissivity values used in all model budget zones is included in sheet 'Area factors' in the groundwater budget model spreadsheet (GW Budget Model.xlsm).

4.2 Groundwater Recharge

Precipitation recharge to the Kelowna aquifers is considered to occur mainly along the transition between bedrock-dominated terrain and unconsolidated deposits to the East of Kelowna, in the form of shallow groundwater flow from the thin upland alluvial and weathered bedrock, and as streamflow infiltration (as shown on Figure 12).

Precipitation recharge is almost exclusively generated in the uplands, where higher precipitation rates and lower temperatures provide a soil moisture surplus, and is negligible in the drier and warmer valley, where potential evaporation is typically greater than precipitation, thus generating a soil moisture deficit.

Deep percolation from irrigation, leakage from the water supply distribution system and septic field infiltration also contribute significantly to recharging the valley aquifers.

4.3 Groundwater Flow Directions

Conceptual groundwater contours across the entire study area, based mainly on topography and to transition between the upland bedrock and valley alluvial aquifers are shown on Figure 13. Groundwater flow is mainly topography-driven in the eastern portion of the study area, due to the presence of a considerable elevation difference (of up to 1,800 m) between the highland areas and the Kelowna valley. The incised stream valleys, particularly of Mission Creek and tributaries, result in much of the upland groundwater reporting to stream valleys, rather than the Kelowna aquifers or Okanagan Lake. A change in groundwater gradient generally occurs in the transition between the thin alluvial and bedrock upland aquifers and the more transmissive valley aquifers. Although not accounted for in the conceptual contours shown on Figure 13, the groundwater gradient and flow direction are also affected by groundwater pumping within the Kelowna aquifers, particularly in the vicinity of the largest water supply wells, as shown in the valley contours of Figure 10.

4.4 Groundwater Discharge

The main mechanisms of groundwater discharge in the study area are: (1) stream baseflow, which mainly occurs in the incised streams in the upland areas; (2) evaporation and, where phreatophytes are present, evapotranspiration of the shallow groundwater table; (3) diffuse groundwater discharge to wetlands in the low valley areas; (4) leakage of shallow water table into the drainage network overlying the Kelowna Aquifers; (5) groundwater withdrawal from pumping wells; and (6) groundwater flow into Okanagan Lake.

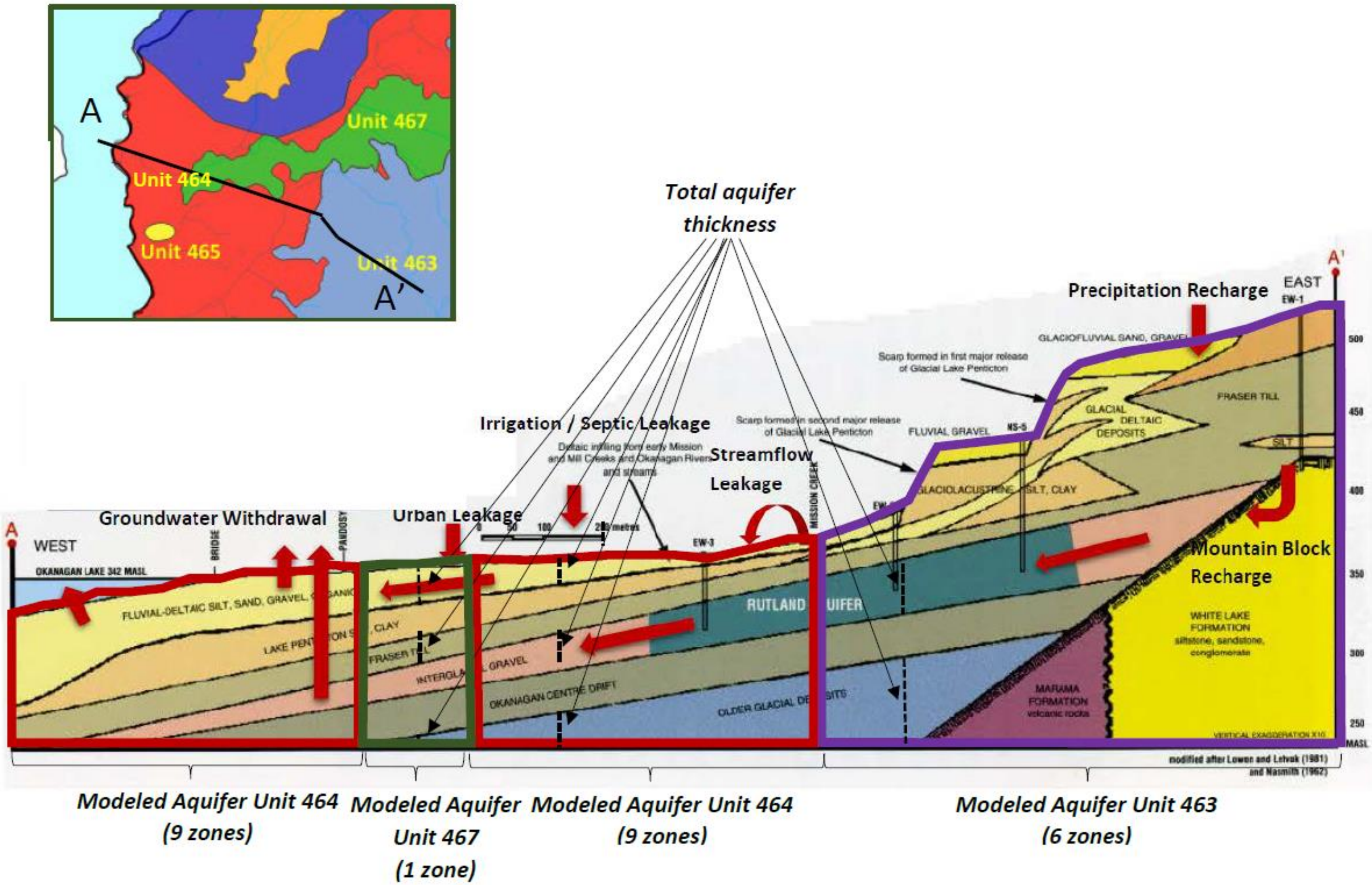


Figure 12 Schematics of the conceptual groundwater budget model for the Kelowna aquifers.

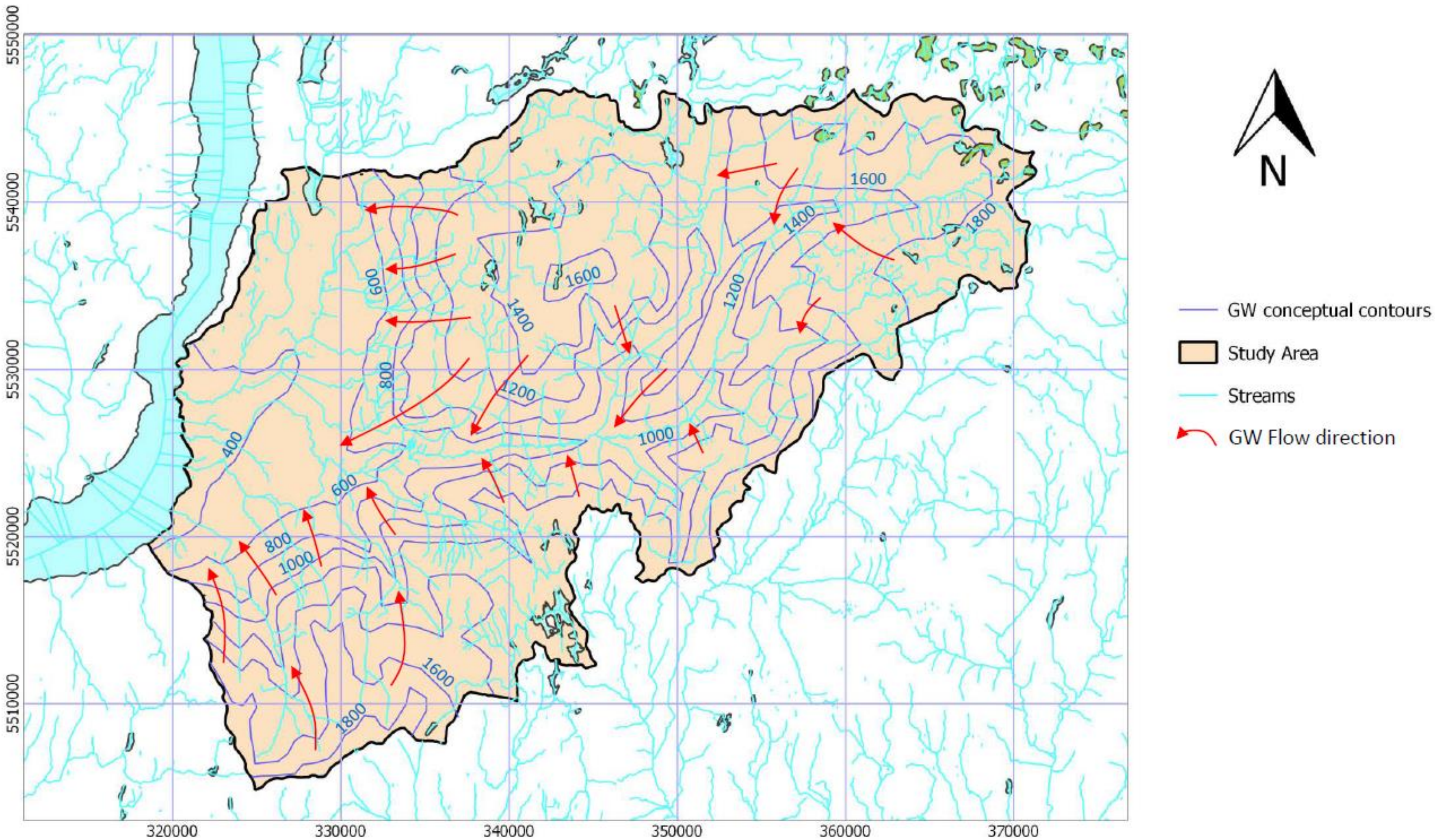


Figure 13   Conceptual groundwater flow pattern in the study area.

5. GROUNDWATER BUDGET MODEL

5.1 Model Description

The water budget model used in this study is based on a semi-distributed parameter approach, whereby a limited number of parameters is considered to characterize the watersheds of interest. This approach is similar to the groundwater budget method reported in USGS OF 2007-1088 (USGS, 2007). The model employs a monthly time step, which is adequate to represent temporal variations in groundwater flow as a result of changes in recharge and groundwater withdrawal, and to estimate seasonal fluctuations in stream baseflow. Both the surface water and groundwater components are considered in the model, and surface water - groundwater interaction is reproduced as one of the elements of the water budget. Figure 14 shows a schematics of the processes represented in the model. The groundwater budget zones defined in the model domain are associated with sub-watershed and aquifer units and are connected, so that the surface and groundwater outflows generated from one or more units are assigned as inflows to other units, according to the routing pattern defined for the study area. The general water budget model methodology, which was developed in a set of MS Excel spreadsheets, is described in detail in Appendix A.

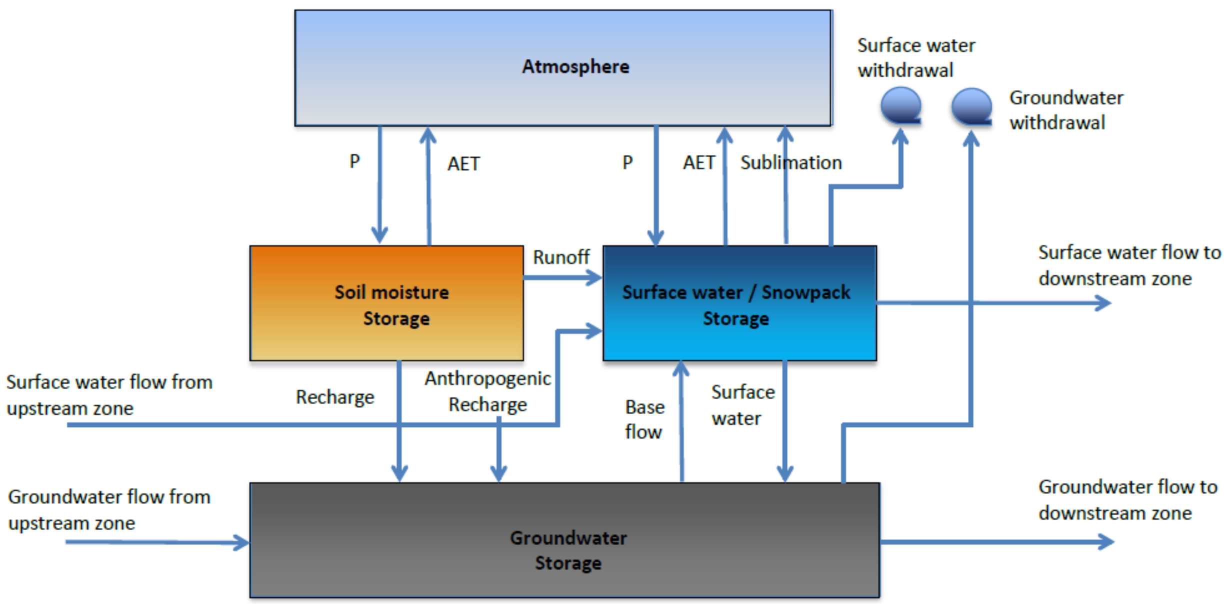


Figure 14 Schematic of the groundwater budget methodology.

5.2 Model Calibration

The water budget model was calibrated in the uplands by identifying a representative climate data set (monthly precipitation and average monthly temperature) and selecting unregulated continuous streamflow data sets, i.e. not affected by water withdrawal or storage. The climate and streamflow data sets selected for calibration are those recorded at the climate and streamflow gauging stations listed in Table 6 and Table 7, respectively, and shown on Figure 15 with the corresponding calibration catchments.

Table 6   Climate stations selected for model calibration

Station Name	Easting (UTM WGS84)	Northing (UTM WGS84)	Elevation (masl)	Record Frequency	Period of record
Kelowna	322864	5530430	353.6	monthly	Jan-01-1900 – Dec-31-1962
Kelowna A	329001	5537641	429.5	daily	Jan-01-1968 – Dec-31-2004
Kelowna CDA	326215	5522902	484.6	monthly	Jan-01-1950 – Apr-30-1970
Kelowna MWSO	327744	5535823	456.0	monthly	Jan-01-1994 – Feb-28-2007

Table 7   Hydrometric stations selected for model calibration.

Station Name	Station Number	Easting (WGS84)	Northing (WGS84)	Period of record
Bellevue Creek near Okanagan Mission	08NM035	322898	5518620	1920 - 1986
Joe Rich Creek near Rutland	08NM129	346855	5525243	1964 - 1987
Daves Creek near Rutland	08NM137	336576	5526442	1965 - 1986
Pearson Creek near the mouth	08NM172	351903	5528098	1970 - 1987

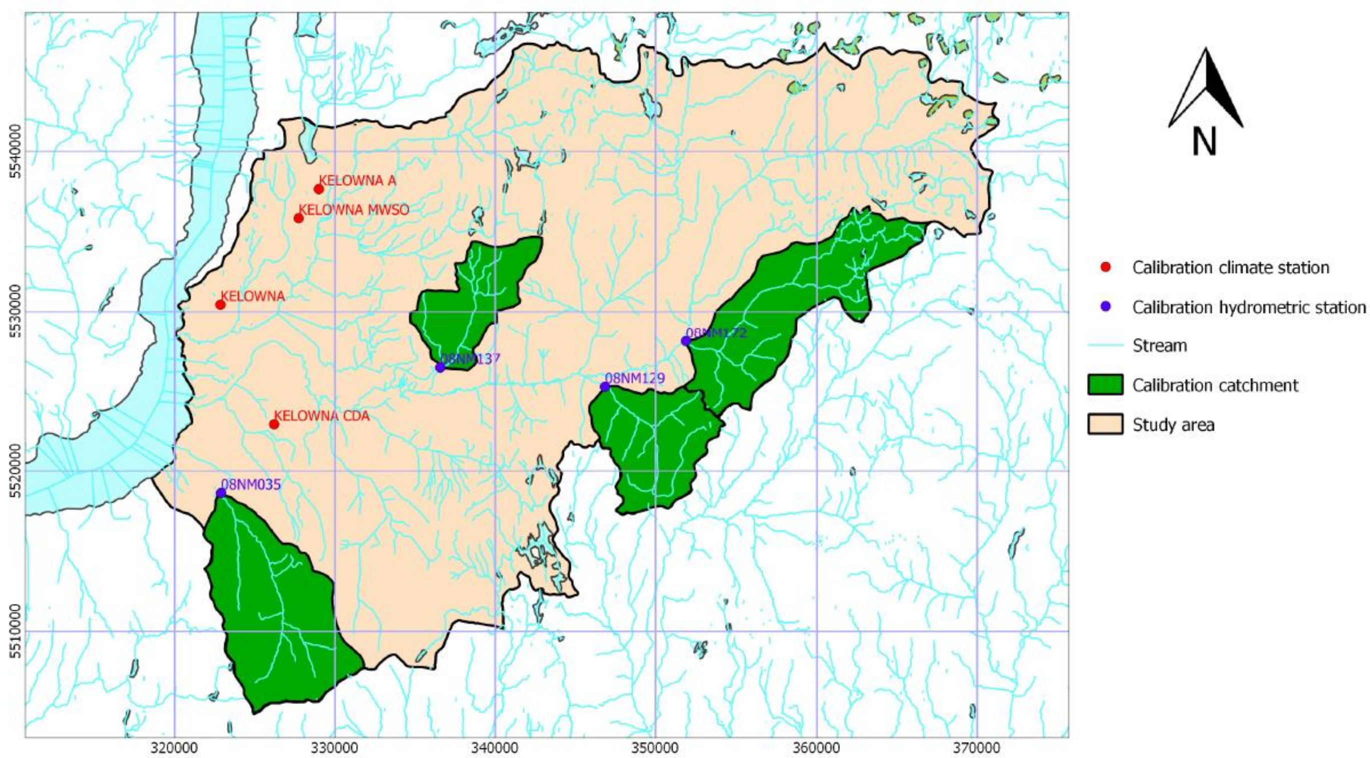


Figure 15   Catchments, climate and hydrometric stations selected for model calibration.

The calibration process consisted of attaining a reasonable match - based on visual inspection of the streamflow plots (including unit mass plots, flow duration curves and monthly time series - between the measured and modelled monthly streamflow time series, which are a function of the climate data, by adjusting the following model parameters:

- winter / summer orographic factors;
- local precipitation factor;
- factors controlling groundwater discharge into streams and stream leakage;
- surface water detention and release factors.

The upland zones in the model were calibrated mainly for streamflows and only for non-regulated flows. The primary purpose of this calibration was to provide a reasonable source of water that could provide groundwater recharge when the streams flowed over the aquifers.

For the zones that include Kelowna Aquifers, calibration targets were discharge to Okanagan Lake based on the estimated reported in (Pyett, 2015), data on stream losses and gains based on the estimates reported in (Wu, 2014), and approximate groundwater levels. The reason why observed groundwater levels were considered only as approximate values is that groundwater levels in situ vary substantially within one budget zone, whereas the model calculates only one representative groundwater level for each zone. Calibration parameters were primarily transmissivity controlling inter zone groundwater flow and the streambed conductance parameters, which control groundwater/surface water interaction. The groundwater gradient associated with the discharge to Okanagan Lake was calculated based on the calculated groundwater level in the budget zones adjacent to the lake and the lake elevation, which was assumed to be a constant value at 342 masl. The vertical hydraulic gradients between streams and aquifers were calculated based on the calculated groundwater levels and assigned surface elevations along stream channels. The list of calibrated parameters is included in sheets 'Area factors' and 'Stream Losses' of the groundwater budget model spreadsheet (GW Budget Model.xlsm).

The calibration process is described in Appendix B.

5.3 Model Prediction

Following calibration of the water budget model in the selected zones, the model was used to develop monthly water budgets for each of the zones defined in the study area. Average, wet and dry conditions were represented by years selected from the calculated low and high water tables generated with the model using the historic climate data set between 1900 and 2015. The model was run for the entire climate record from 1900-2015 using estimates for current groundwater withdrawal and recharge from irrigation, leakage from the water supply distribution system and septic field infiltration, and results were output for the selected average, *dry* (low groundwater level) and *wet* (high groundwater level) periods.

5.4 Definition of Groundwater Budget Zones for Prediction

The study area, which coincides with the water budget model domain, was divided into zones. Each zone was defined based on topography and drainage, for the purpose of calibrating modelled streamflows, and based on the presence of aquifer units and other specific areas of interest. A total of 42 water budget zones were defined in the model. These zones are listed in Table 8 and shown on Figure 16. Each zone has a unique identifier, which consists of a number related to the main catchment the zone belongs to, and a letter that represents an aquifer unit or surface water reservoir / diversion within the catchment. For example, all the zones with identifiers ending in A are associated with aquifer unit 463, all those ending in B and D are associated with aquifer unit 464, and aquifer unit 467 corresponds to zone 5C. The zones were further sub-divided into six 300-m topographic elevation bands, which were considered to adequately represent the topographic elevation range and the change in climate conditions within the study area.

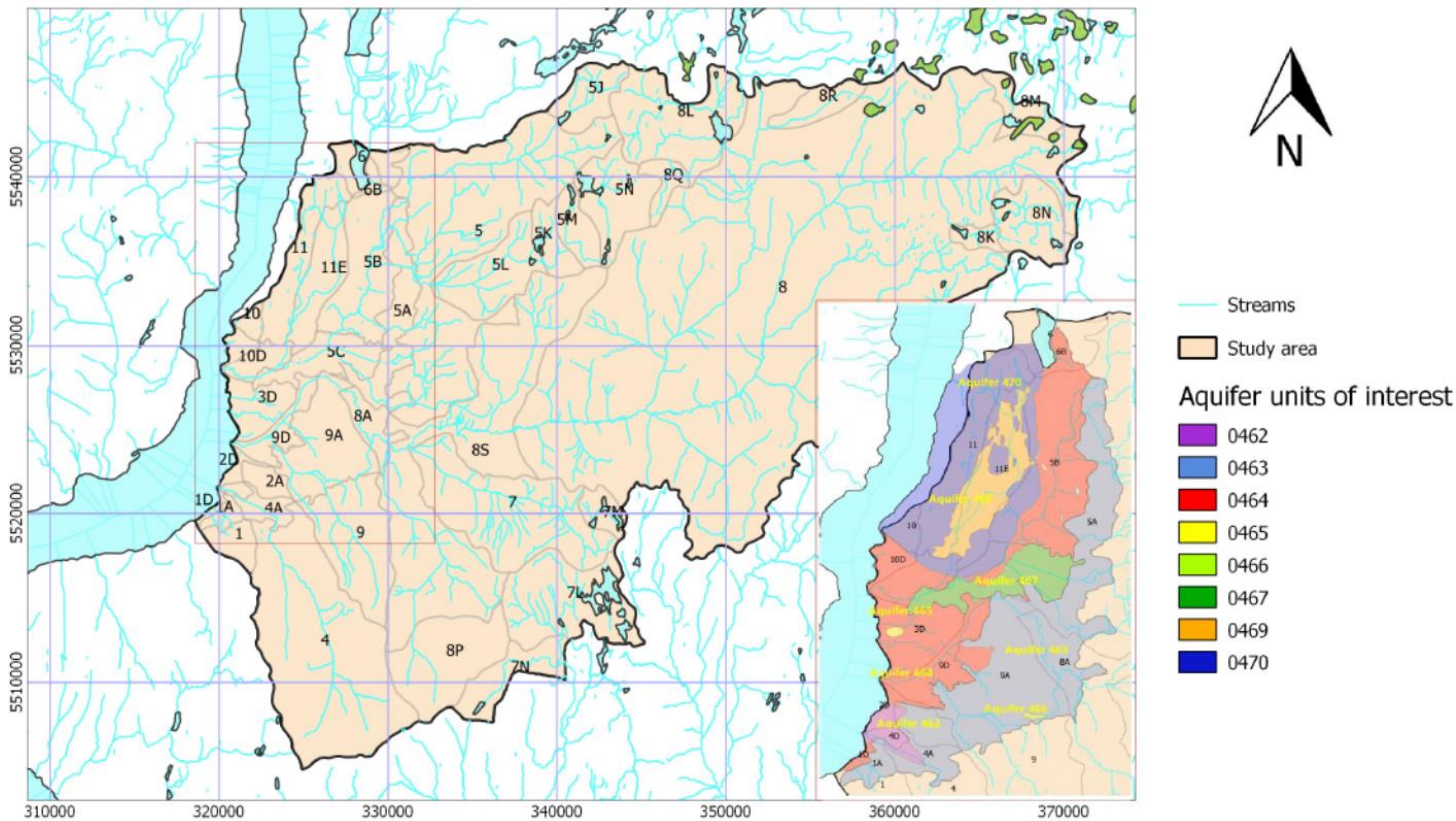


Figure 16   Zones defined in the prediction water budget model.

Table 8 Zones defined in the prediction water budget model.

Zone ID	Aquifer Unit	Description	Dominant Surficial Geology	Area (km2)
1	-	Residual from South of Bellevue Creek	Bedrock, till and ice contact	5.9
4	-	Bellevue Creek upstream of study aquifers	Bedrock and till	86.8
5	-	Mill Creek and tributaries, including Whelan, Scotty and Dilworth Creeks	Bedrock and till	96.4
6	-	Catchment for Ellison Lake(1)	Bedrock and till	7.8
7	-	Hydraulic Creek	Bedrock and till	49.6
8	-	Upper Mission and Klo Creeks	Bedrock and till	478.4
9	-	Upper Priest Creek	Bedrock and till	29.3
10	-	Residual from north of Mission Creek	Bedrock and till	2.3
11	-	Brandt Creek	Bedrock / Till	16.4
10D	464	Residual from North of Mission Creek	Alluvium	2.7
11E	469	Brandt Creek	Bedrock / Till	15.6
1A	463	Residual area south of Bellevue Creek	Ice contact deposits	2.7
1D	464	Residual area south of Bellevue Creek along lake	Alluvium as part of Bellevue Creek fan	1.0
2A	463	Residual area between Bellevue and Mission Creeks	Alluvial terrace over ice contact deposits	4.2
2D	464	Residual area between Bellevue and Mission Creek	Alluvium	2.0
3D	464/463	Residual area between Mission and Mill Creek	Alluvium	10.6
4A	463	Bellevue Creek	Alluvial Terrace over ice contact	4.9
4D	464	Bellevue Creek Fan	Alluvium	1.2
5A	463	Sloped land downslope of Area 5	Till, ice contact, glacio-lacustrine deposits	19.8
5B	464	Area between 5A and West divide of Mill Creek	Bedrock outcrop on W margin, alluvium fan from Scotty Creek, glacio-lacustrine	25.8
5C	467/464	Surficial aquifer with some adjacent surfaces	Alluvium represents Aquifer 467 overlying Aquifer	13.5

Zone ID	Aquifer Unit	Description	Dominant Surficial Geology	Area (km2)
			474	
5D	464	Mission Creek catchment - from 5C to mouth	Alluvium	5.7
5J	-	Moore Reservoir	-	11.5
5K	-	James Reservoir	-	7.7
5L	-	Scotty Creek Intake	-	21.1
5M	-	South Lake	-	8.3
5N	-	Postill Lake	-	19.9
6B	464	Catchment for Ellison Lake(1)	Ice contact deposits	1.8
7L	-	McCulloch Reservoir	-	33.7
7M	-	Browne / Fish / Long Meadow Lakes	-	5.7
7N	-	Stirling Creek Diversion	-	13.9
8A	463	Mission Creek and Lower Klo Creek over 463 Aquifer	Alluvial terrace over ice contact deposits	7.3
8K	-	Long Loch	-	3.7
8L	-	Belgo Reservoir	-	34.9
8M	-	Fish Hawk Lake	-	8.6
8N	-	Greystoke lake	-	17.0
8P	-	Pooley Creek	-	35.0
8Q	-	Mugford Creek	-	5.4
8R	-	Hilda Creek	-	8.2
8S	-	Mission Creek d/s of BMID intake	Bedrock and till	98.2
9A	463	Priest Creek over Aquifer 463	Alluvial terrace over ice contact deposits	25.9
9D	464	Lower Mission Creek over aquifer 464	Alluvium	8.0

(1) Zones 6 and 6B were included in the model domain even though part of the recharge generated in these zones is likely to discharge north of the model domain. The contribution of flow from these zones to the adjacent zone 5B is approximately 3% of the total inflows to the zone, which is negligible considering the uncertainty associated with the modelled flow components.

5.5 Representation of Aquifer Units for Prediction

Based on the hydrogeological conceptualization of the study area (Section 4.1), the groundwater component of each water budget zone was assumed to represent the vertical sequence of unconsolidated, weathered and fractured bedrock aquifer units located in each zone. One hydraulic conductivity (K) and saturated thickness value representative of each sequence of aquifers and aquitards was assigned to each zone. This was justified based on the large size of each calculation zone. Vertical connectivity over such large area is considered to provide sufficient leakage between aquifer layers to represent the multiple aquifers as a single aquifer. Aquifer 465 is included in Aquifer 464, due to the small size and lack of differentiating information. The aquifers considered in this study were therefore 463, 464 and 467. Although aquifer unit 467 overlies unit 464 according to the ENV mapping, the two aquifer units are considered to have a similar vertical extension and to be only in lateral contact in the model. The assumption at the base of this conceptualization is that the aquitard overlying unit 464 is sufficiently transmissive to allow hydraulic connectivity between the aquifer and the stream.

5.6 Selection of Average, Dry and Wet Scenarios for Prediction

Average, *dry* (low groundwater level) and *wet* (high groundwater level) scenarios were selected by considering climatic variables as well as the synthetic streamflows and groundwater levels generated by the groundwater budget model.

Average conditions were obtained by averaging the monthly groundwater budget components over the entire simulation period, between January 1900 and December 2015.

Dry (low groundwater level) conditions were selected to correspond with the period 1967 – 1969 when simulated groundwater levels were at their lowest in all key aquifer units.

Wet (high groundwater level) conditions were selected to correspond with the period 1997 – 1999, when simulated groundwater levels were generally at their highest in all key aquifers. These two periods correspond to the end of the longest low and high precipitation periods between 1900 and 2015, as shown on the cumulative departure plot of Figure 5. The averages of the monthly groundwater budget components simulated during the 1967-1969 and 1997-1999 periods therefore represent the *dry* and *wet* groundwater budget scenario, respectively.

5.7 Estimates of Surface and Groundwater Withdrawal for Prediction

Monthly groundwater withdrawal rates representing current conditions within each of the water budget zones for current conditions were estimated based on the following:

Withdrawal records provided by the four irrigations districts that use groundwater as a source of water supply (BMID, SEKID, RWT and GEID);

- The Kelowna Integrated Water Supply Plan (KJWC, 2012);
- Water demand data extracted from the Okanagan Basin Agriculture Water Demand Model.

Groundwater withdrawal rates for the wells managed by the main Irrigation Districts were estimated by averaging the historic records for each month, where available, and by multiplying the total water usage rates by the fraction of total water supply corresponding to groundwater, as reported in (KJWC, 2012), where no records were obtained.

Groundwater withdrawal rates for the private wells and those belonging to small water utilities, for which no historic records are available and limited water usage data are reported in (KJWC, 2012), were estimated based on data extracted from the Okanagan Basin Agriculture Water Demand Model, as follows:

- The total water demand rates for each *water use area* (as defined in the Agriculture Demand Model) located in the groundwater budget model domain were extracted from the Agriculture Water Demand Model.
- The Source Linkages Table included in the Agriculture Water Demand Model, which provides a percentage breakdown of the sources (streams, Okanagan Lake and aquifers) that supply water to each of the water use areas, was used to identify the water use areas where demand is met (partly or totally) by groundwater supply.
- The percentage associated with groundwater as supply source, as listed in the Source Linkages Table, was multiplied by the total water demand for each water use area. The resulting rates were assumed to be equal to the total groundwater withdrawal rates in the aquifer units supplying water to the water use areas.
- Since the aquifer units identified specifically for the Okanagan Basin Supply and Demand Project don't coincide with the ENV-mapped aquifer units, a correspondence based on visual inspection was established between the two sets of aquifers.

- The calculated groundwater withdrawal rates were allocated to ENV-mapped aquifer units based on the correspondence with the units defined for the Okanagan Basin Supply and Demand Project.

Monthly rates of surface water withdrawal representative of current conditions were estimated by multiplying the monthly total water supply rates reported in (KJWC, 2012) by the estimated fraction of total water supply that corresponds to surface water, also reported in (KJWC, 2012). The resulting rates were apportioned in each water budget zone according to the portion of irrigation district area included in the zone.

The groundwater and surface water withdrawal rates obtained as described above were used in the three climatic scenarios (average, wet and dry) associated with current conditions.

5.8 Estimates of Groundwater Recharge for Prediction

The monthly rates of groundwater recharge from precipitation were estimated within the water budget model, as described in Appendix A.

Anthropogenic groundwater recharge to the Kelowna aquifers occurs as losses from irrigation, leakage from the water supply distribution network and septic field infiltration.

Groundwater recharge from irrigation was estimated using the deep percolation rates extracted specifically for this study (RHF Systems Ltd., 2016) from the Okanagan Basin Agriculture Water Demand Model for the period 1950 – 2010, which is the demand model simulation horizon, and were extrapolated based on a statistical correlation with historic records of potential evaporation.

Groundwater recharge from water distribution system leakage was estimated using the average monthly Unaccounted For Water (UFW) data for each irrigation district reported in (KJWC, 2012), which were allocated to each water budget zone based on the percentage of the zone area belonging to each irrigation district.

Monthly rates of groundwater recharge from septic field infiltration were estimated by using the total indoor demand rates extracted spacifically for this study (RHF Systems Ltd., 2016) from the Agriculture Water Demand Model in the areas that are not served by the sewerage system.

The time series of anthropogenic groundwater recharge rates used in the groundwater budget model are included in sheet 'Water Returned' of the source / sink input spreadsheet to the groundwater budget model (GW_Withdrawal&Anthropogenic_Recharge.xlsx). The time series of groundwater withdrawal rates are included in sheet 'Water Removed' of the input spreadsheet.

5.9 Groundwater Budget Results

The groundwater budget model provides results in the following different formats for each aquifer (463, 464, and 467):

- Table of average annual budget
- Table of average monthly budget
- Hydrographs of average monthly groundwater budget, in average, dry and wet climatic conditions.
- Average annual streamflows at the mouths of Mill Creek, Mission and Bellevue Creek
- Average monthly streamflows at the mouths of Mill Creek, Mission Creek and Bellevue Creek
- Groundwater level hydrographs corresponding to representative average water levels in 14 of the 16 budget zones corresponding to the Kelowna aquifers (zones 1A-D, 2A-D, 3D, 4A-D, 5A-B-C-D, 8A and 9A-D).

The average annual groundwater budget components for Aquifer Unit 463, 464 and 467 are shown on Table 9, Table 10, and Table 11, respectively.

The groundwater budget for Aquifer 463 indicates that streamflow leakage represents a significant portion (33%) of the recharge to this unit. This is to be expected as the eastern boundary of this unit is in contact with the alluvial fans located along Mill Creek, Scotty Creek and Mission Creek, where most streamflow leakage occurs. Returns from irrigation, urban and septic leakage also are a significant (32%) component of recharge, since a considerable part of this aquifer is covered either by urban developments or by agricultural land. The contribution from precipitation is approximately 3.5%, which indicates the predominance of a soil moisture deficit in this area. Approximately 53% of the total discharge from unit 463 occurs as groundwater flow towards Aquifers 464 and 467, and the remaining 47% is intercepted by groundwater withdrawal.

More than 60% of the recharge entering Aquifer 464 is groundwater flow originating from the adjacent Aquifers 463, 467 and 469. Similar to unit 463, recharge from irrigation, urban and septic leakage forms 32% of the total, whereas both precipitation and streamflow leakage represent a small contribution, with 2.5% and 4.1%, respectively. Approximately 70% of the groundwater discharge occurs as stream baseflow and as other forms of groundwater discharge to surface, such as diffuse seepage to wetlands and springs which is plausible due to the flat topography and shallow groundwater levels present in this unit. The remaining discharge occurs mainly as groundwater withdrawal (at just over 16%) and groundwater flow to Aquifer 467 (at just over 11%). The modelled groundwater discharge to Okanagan Lake represents only 2.1% of the total outflows. The modelled discharge of 8.2 L/s closely matches the current lake discharge estimate of 11.7 L/s (3.7 x E5 m3/yr) (Pyett, 2015). The estimated value of 11.7 L/s relates to a longer stretch of the Okanagan Lake eastern shoreline than included in the groundwater budget model domain. Specifically, the stretch of shoreline considered in (Pyett, 2015) includes the southern portion of Mountain Park, which is estimated to contribute approximately 23% of the total discharge. The value of 8.2 L/s calculated in the updated groundwater budget model is therefore to be compared to 11.7 x (1 - 0.23) = 9 L/s based on (Pyett, 2015).

In order to reproduce the estimated discharge to Okanagan Lake, which corresponds to only approximately 2% of the total outflows to the aquifer, groundwater flow towards the lake had to be limited and additional forms of groundwater discharge to surface were introduced in the water balance model. These include diffuse groundwater seepage in wetlands, springs, evapotranspiration of the water table and infiltration of shallow groundwater into the leaky storm drainage and sewage network. The additional groundwater discharge to surface is included in the streamflow discharge component listed in Table 9, Table 10, and Table 11. Groundwater discharge was assumed to occur in the budget zones adjacent to Okanagan Lake, i.e. zones 1D, 2D, 3D, 4D, 5D, 9D and 10D (see Figure 16), where wetlands and springs are more likely to be located, due to the shallow water table and flat topography.

Recharge to Aquifer 467 originates as mainly groundwater flow from Aquifers 463, and 464, which provide nearly 90% of the total inflow, and from irrigation, urban and septic leakage with approximately the remaining 10%. No groundwater withdrawal is estimated to take place in this unit, based on the available information, so that discharge occurs as groundwater flow towards Aquifer 464 (40%) and as stream baseflow (60%).

The components of the average monthly groundwater budget in average, *dry* (low groundwater level) and *wet* (high groundwater level) conditions for Aquifer 463, 464 and 467 are shown on Figure 17(a,b,c), Figure 18(a,b,c), and Figure 19(a,b,c), respectively.

Table 9 Average annual groundwater budget – Aquifer Unit 463 (L/s).

	AQUIFER 463											
	INFLOWS						OUTFLOWS					
	Groundwater in from other 463 areas	Groundwater from Slopes	Stream bed recharge	Water returned (irrigation, urban and septic leakage)	Precipitation recharge	Total	Groundwater out to other 463 areas	Groundwater out to 464 areas	Groundwater out to 467 areas	Groundwater discharge to surface	Groundwater withdrawal	Total
Area 1A	4.6	6.5		5.4	0.7	17.1	0.0	10.3			6.8	17.1
Area 2A	34.3			12.3	1.0	47.6	0.0	11.9			35.7	47.6
Area 4A	0.0	4.9	11.2	10.3	1.2	27.6	16.9	10.7		0.0	0.0	27.6
Area 5A	12.7	19.5	47.6	38.6	6.6	124.9	9.6	29.0	44.2	0.0	42.1	124.9
Area 8A	0.0	99.8	81.7	11.8	1.4	194.8	177.3			0.0	17.4	194.8
Area 9A	174.3	0.0	0.0	57.1	4.0	235.4	21.9	100.1	17.1	0.5	95.7	235.4
TOTAL		130.8	140.4	135.4	14.9	421.6		162.0	61.3	0.5	197.8	421.6
Percentage		31.0%	33.3%	32.1%	3.5%			38.4%	14.6%		46.9%	

Table 10 Average annual groundwater budget – Aquifer Unit 464 (L/s).

	AQUIFER 464																
	INFLOWS									OUTFLOWS							
	Groundwater in from other 464 areas	Groundwater in from 463 areas	Groundwater in from 467 area	Groundwater in from 469 area	Stream bed Recharge	Okanagan Lake in	Water returned	Precipitation recharge	Total	Groundwater out to other 464 areas	Groundwater out to 463 areas	Groundwater out to 467 areas	Groundwater out to 469 area	Groundwater withdrawal	Groundwater discharge to surface	Okanagan Lake out	Total
Area 1D	4.7	10.3			0.0	0.0	2.3	0.2	17.5	0.0	0.0			0.4	15.9	1.2	17.5
Area 2D	26.4	11.9			0.0	0.0	4.4	0.5	43.2	0.0	0.0			1.0	39.6	2.5	43.2
Area 3D	30.6		18.0		0.0	0.0	31.2	2.1	81.9	0.0		0.0	0.0	0.1	78.6	3.2	81.9
Area 4D	0.0	10.7			0.6		3.2	0.3	14.9	14.9	0.0			0.0	0.0		14.9
Area 5B	3.2	29.0	0.0	12.5	15.7		42.6	3.9	106.9	0.0	0.0	44.9	0.0	62.0	0.0		106.9
Area 5D	0.0		19.7	20.8	0.0		21.5	0.8	62.7	42.4		0.0	0.0	0.0	20.4		62.7
Area 6B	0.0						2.8	0.4	3.2	3.2				0.0			3.2
Area 9D	0.0	100.1	10.5		0.0		14.2	1.2	126.0	41.8	0.0			0.0	84.2		126.0
Area 10D	37.4				0.0	0.0	3.7	0.4	41.5	0.0				0.0	40.2	1.3	41.5
TOTAL		162.0	48.2	33.3	16.4		125.9	9.8	395.5		0.0	44.9	0.0	63.6	278.8	8.2	395.5
Percentage		41.0%	12.2%	8.4%	4.1%	0.0%	31.8%	2.5%			0.0%	11.3%	0.0%	16.1%	70.5%	2.1%	

Table 11 Average annual groundwater budget – Aquifer Unit 467 (L/s).

	AQUIFER 467											
	INFLOWS							OUTFLOWS				
	Groundwater in from 463 areas	Groundwater in from 464 areas	Groundwater from Slopes	Stream bed recharge	Water returned	Precipitation recharge	Total	Groundwater out to 463 areas	Groundwater out to 464 areas	Groundwater discharge to surface	Groundwater withdrawal	Total
Area 5C	61.3	44.9		0.0	13.1	2.0	121.3	0.0	48.5	72.8	0.0	121.3
Percentage	50.6%	37.0%			10.8%	1.6%			40.0%	60.0%	0.0%	

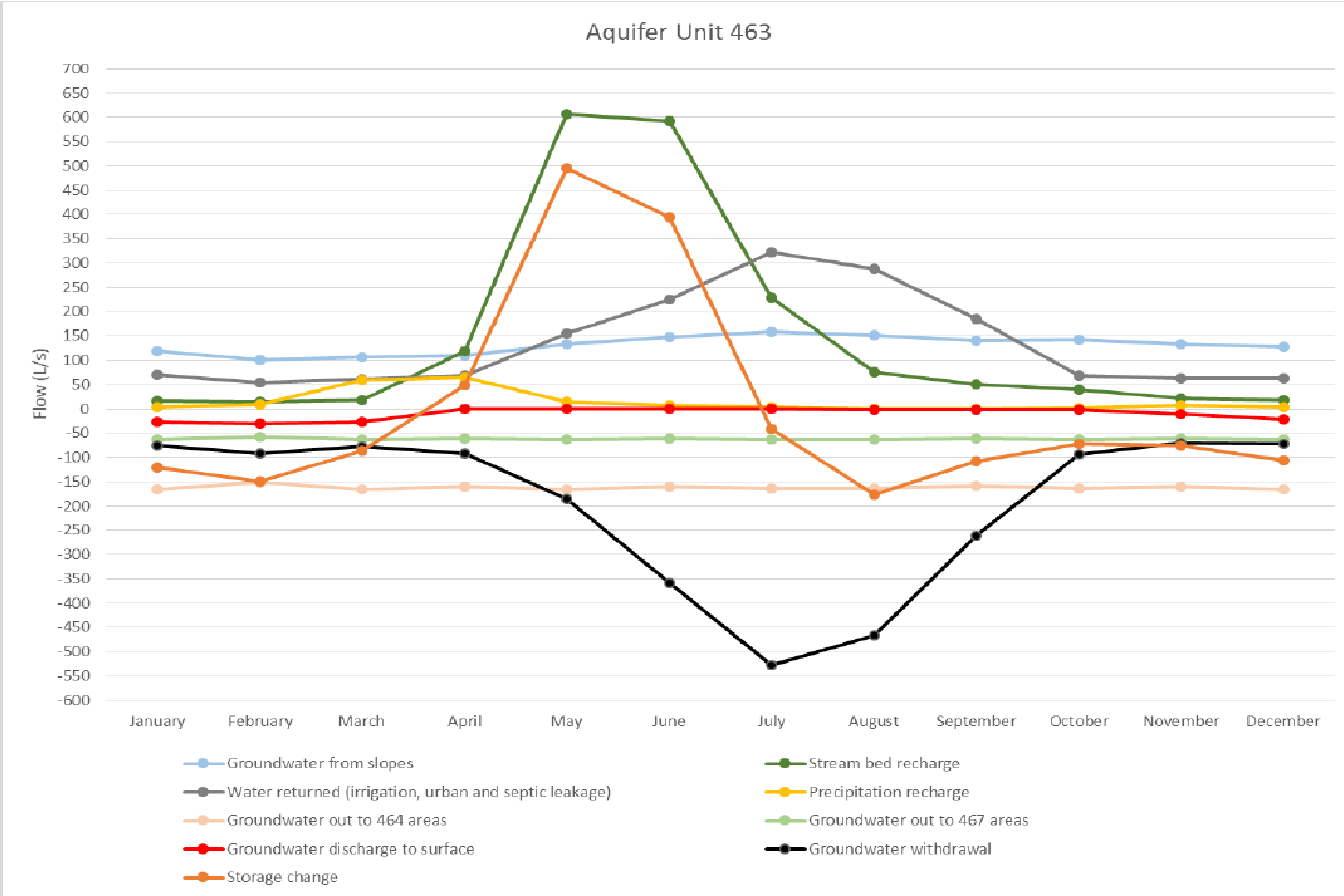


Figure 17a   Aquifer 463 – Monthly groundwater budget in average conditions.

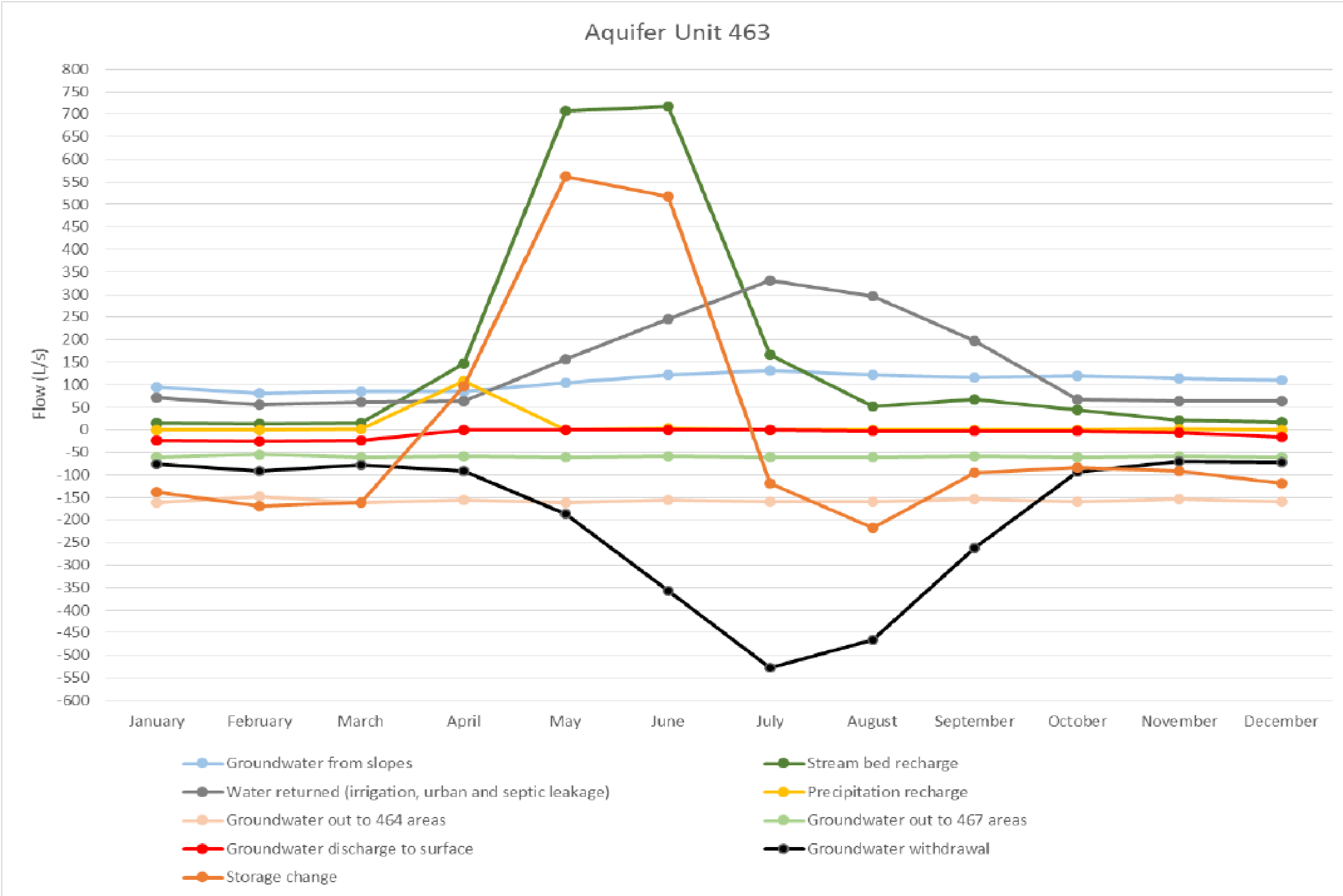


Figure 17b Aquifer 463 – Monthly groundwater budget in dry conditions.

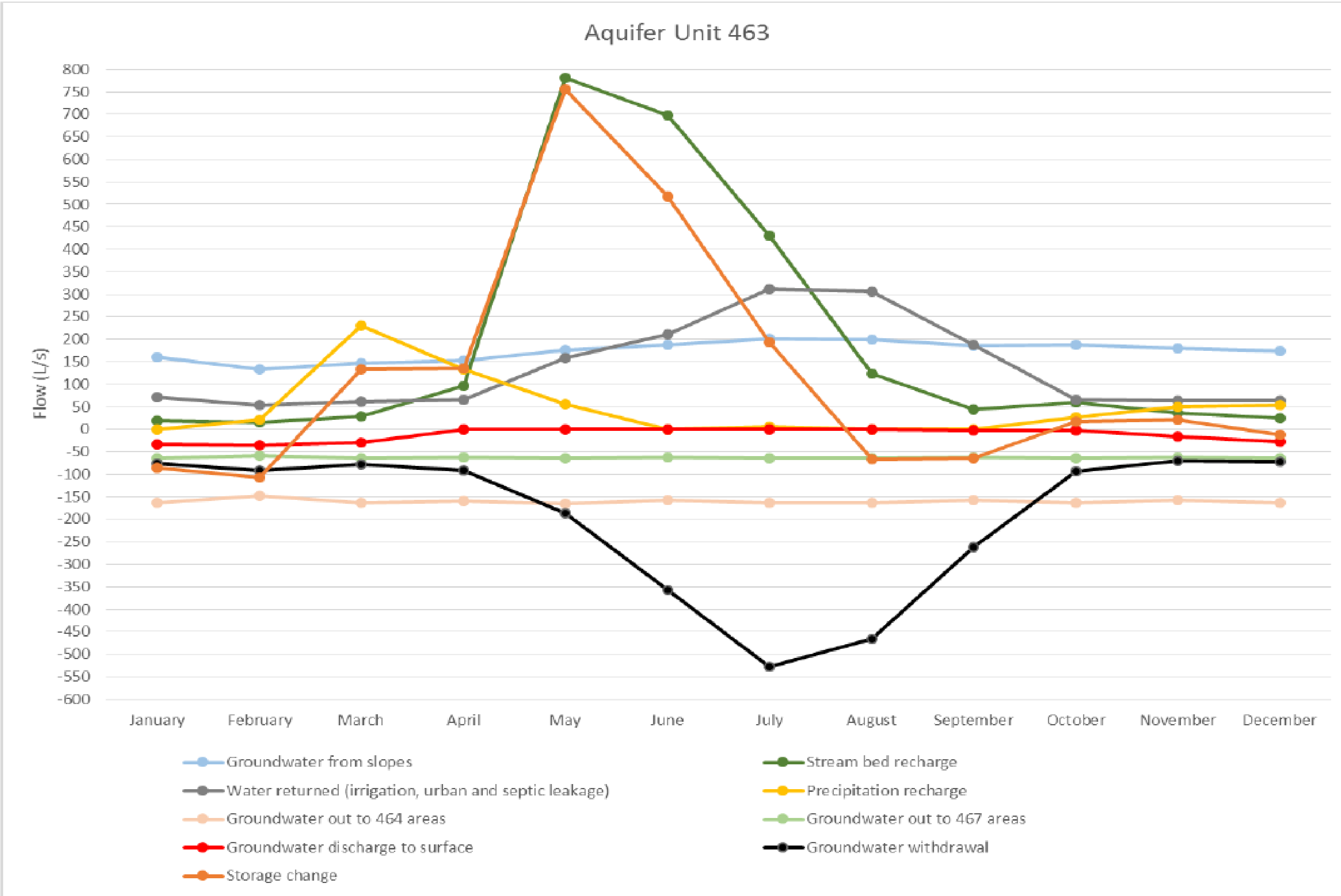


Figure 17c Aquifer 463 – Monthly groundwater budget in wet conditions.

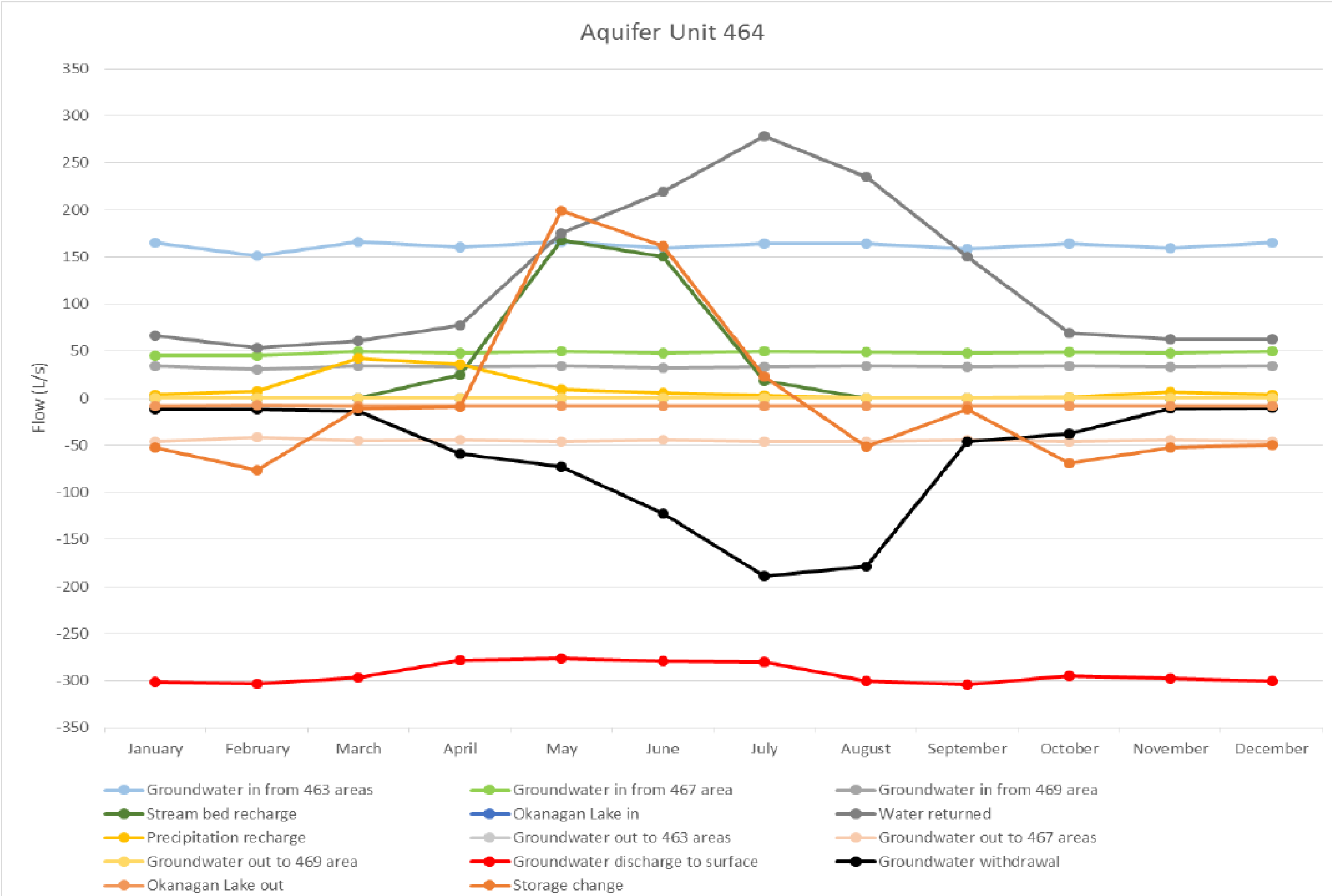


Figure 18a Aquifer 464 – Monthly groundwater budget in average conditions.

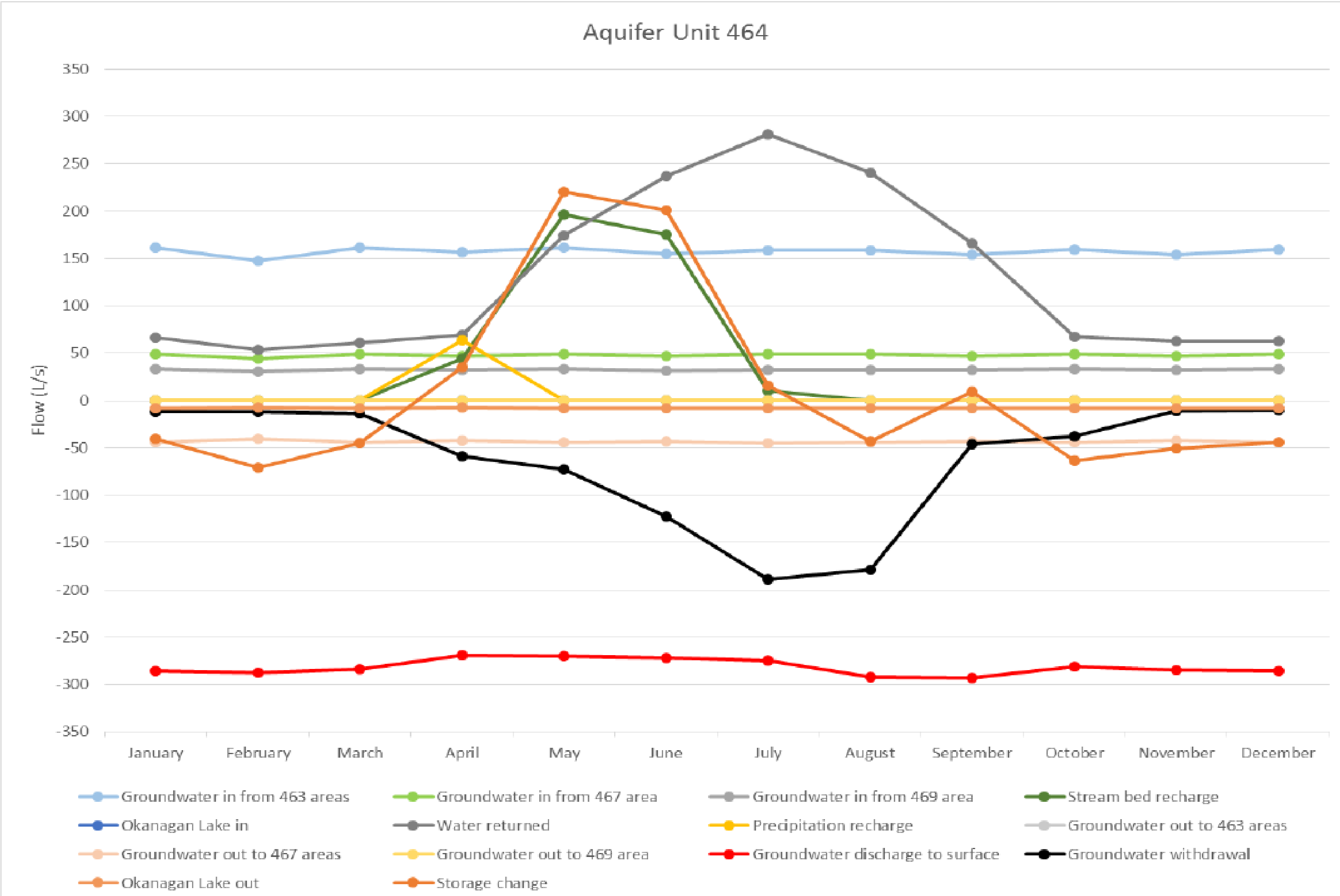


Figure 18b Aquifer 464 – Monthly groundwater budget in dry conditions.

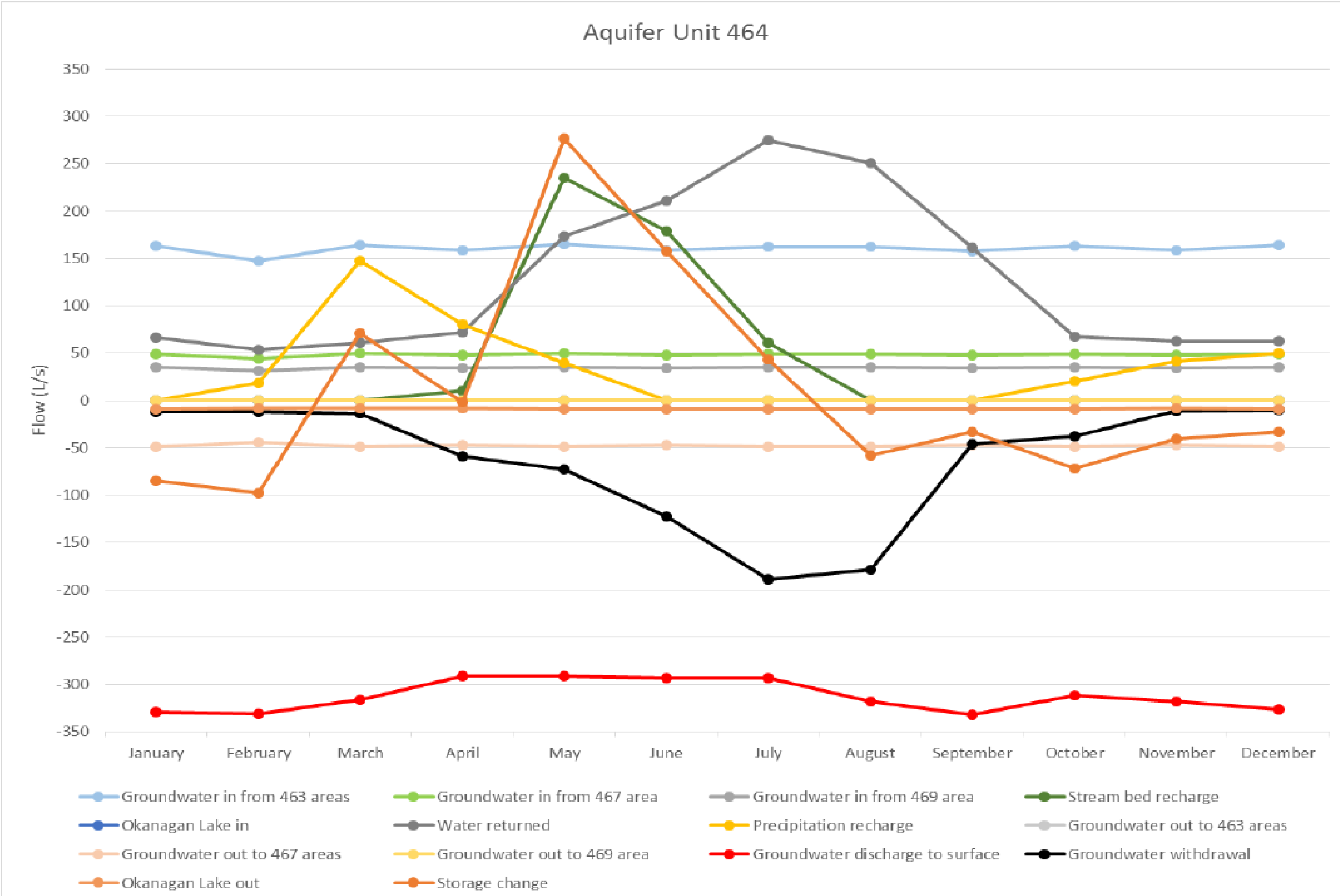


Figure 18c Aquifer 464 – Monthly groundwater budget in wet conditions.

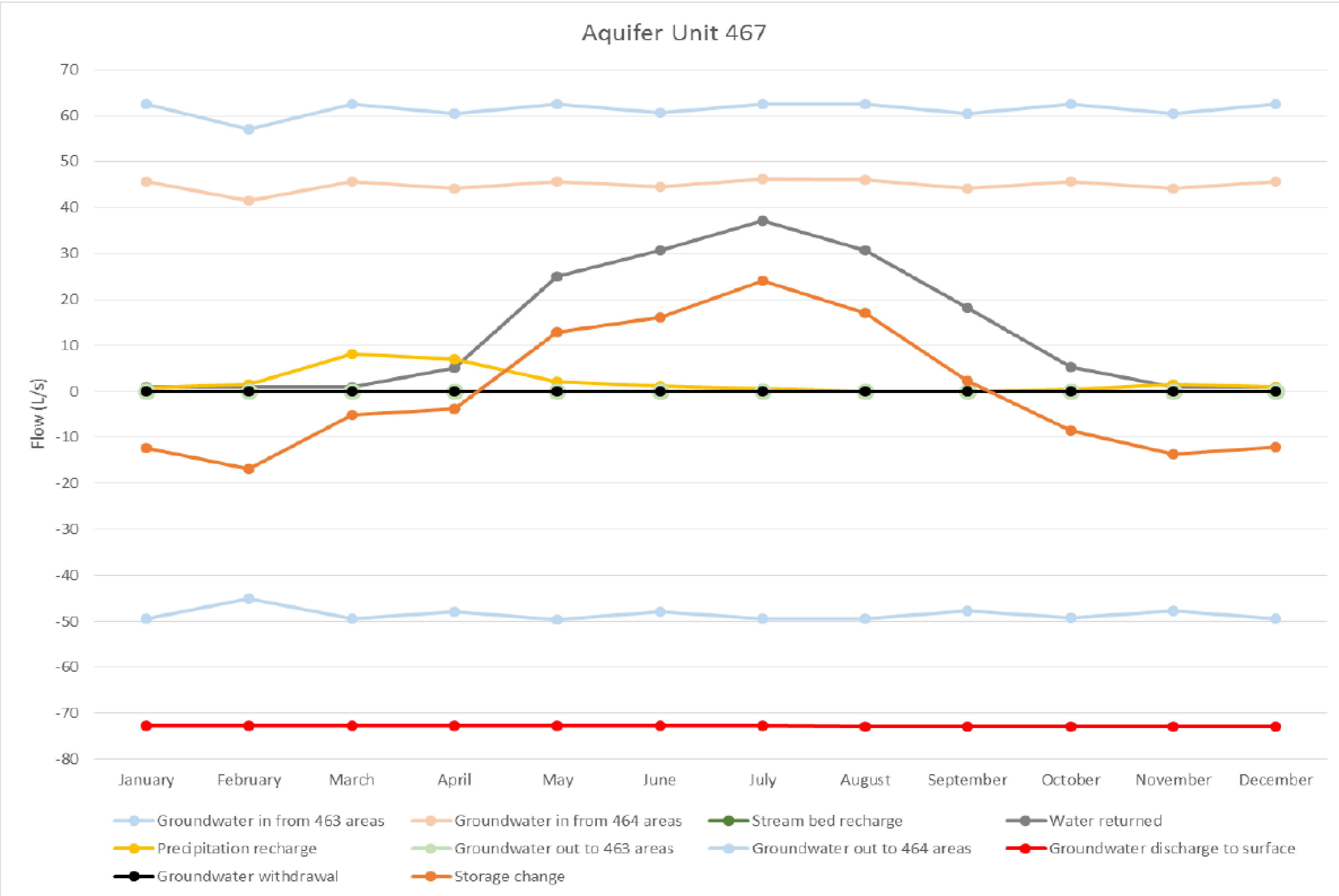


Figure 19a Aquifer 467 – Monthly groundwater budget in average conditions.

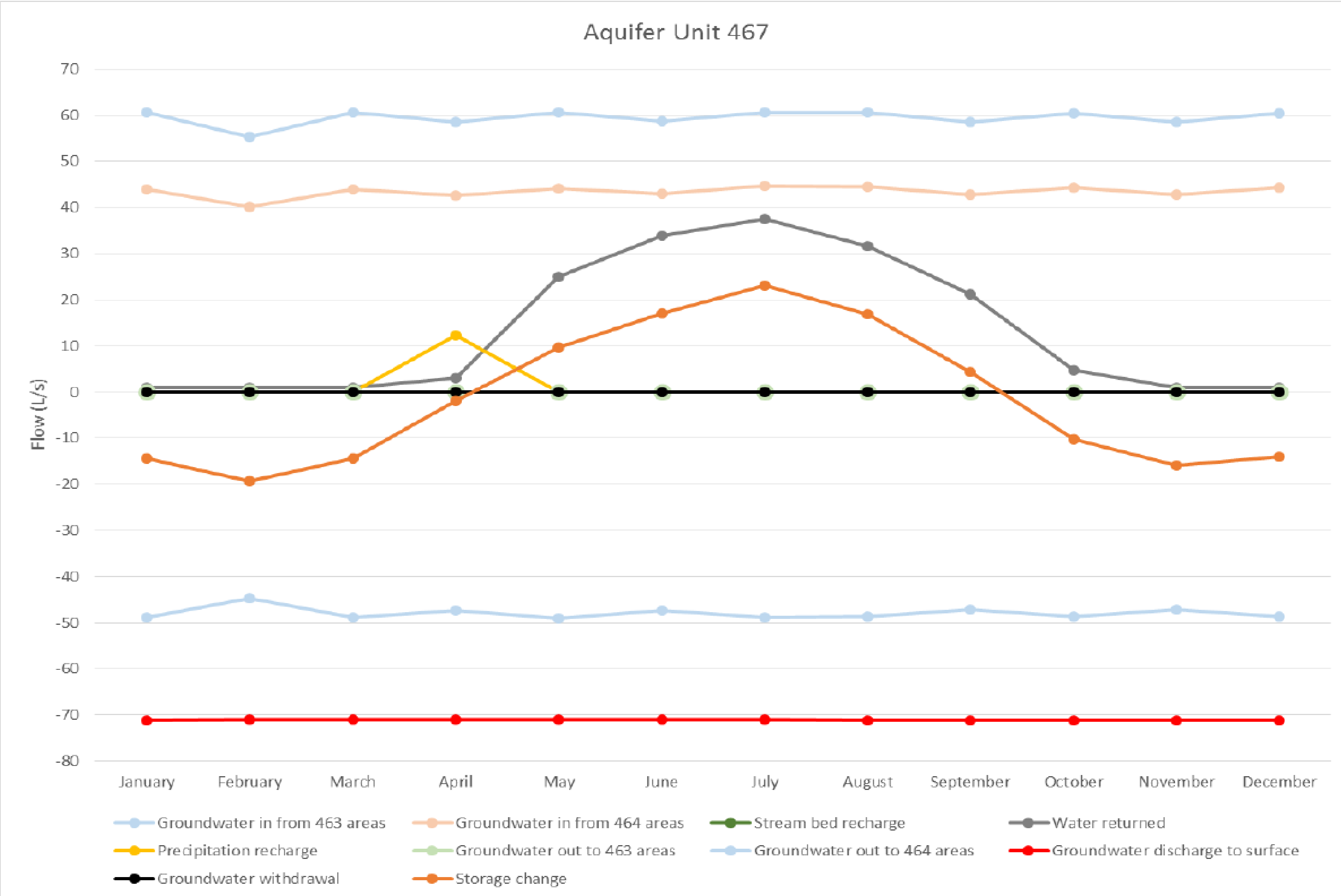


Figure 19b Aquifer 467 – Monthly groundwater budget in dry conditions.

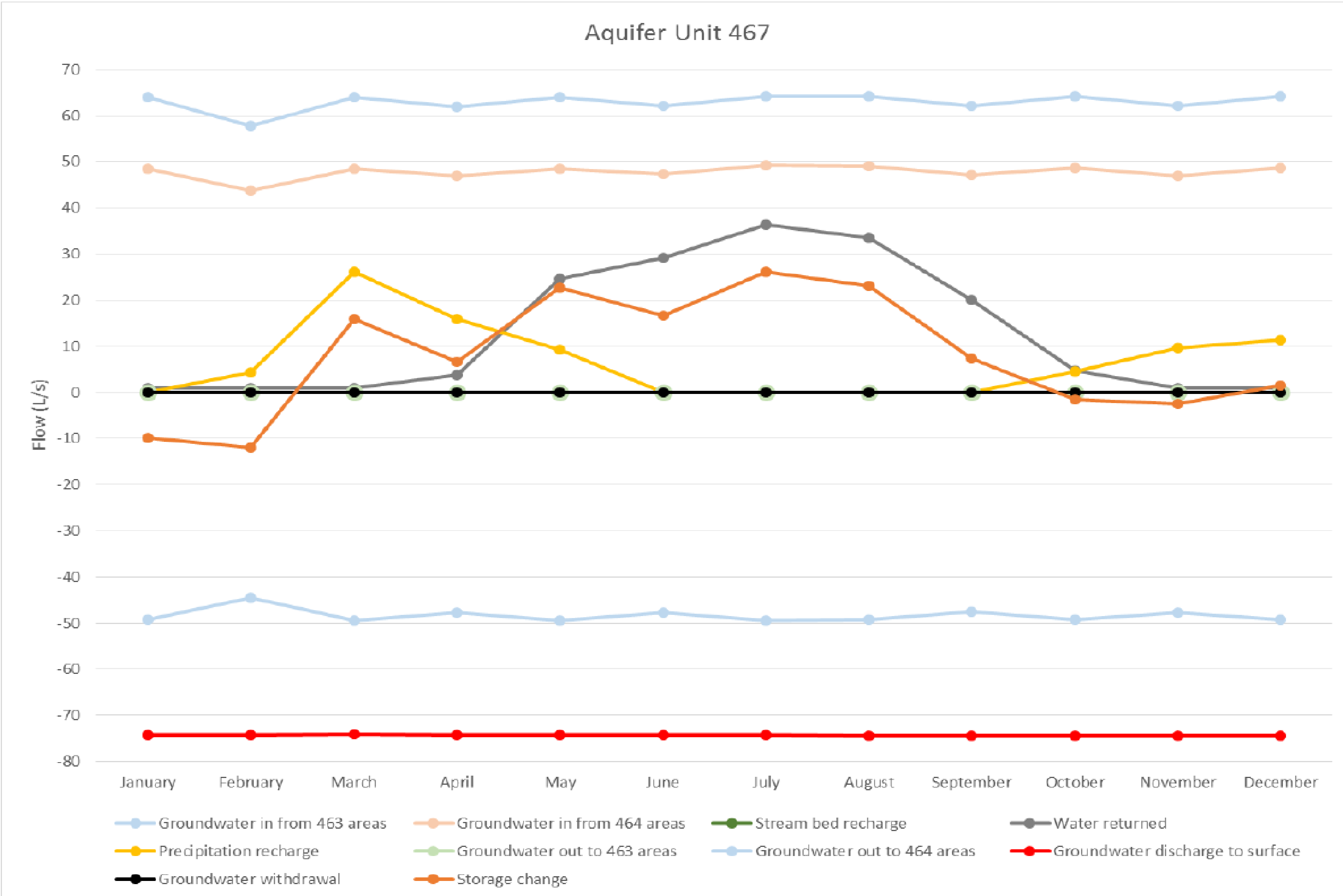


Figure 19c   Aquifer 467 – Monthly groundwater budget in wet conditions.

The average annual groundwater budget for average, dry and wet conditions for the three aquifers is shown in Table 12, Table 13, and Table 14. The groundwater balances indicate that changes from average to dry or wet conditions do not lead to reversal in flows (e.g. reversal from streamflow recharge to discharge or change from outflow to Okanagan Lake to inflow from the lake). For the average conditions there is no change in storage, since the model was set up to represent a state of dynamic equilibrium over the period 1900- 2015, where historic climate data were available. Changes in storage would indicate that the values provided did not represent an average condition.

In Aquifer 463, *dry* conditions (low groundwater level conditions) corresponds to changes from average of:

- an 18% reduction in flow from the slopes (from 130.8 to 107.1 L/s) due to decreased groundwater levels in the slopes;
- a 12% increase in streamflow recharge (from 140.4 L/s to 157.5 L/s) which occurs as a response to a lower groundwater levels;
- a 2.1% decrease (221.3 to 216.5 L/s) in groundwater discharge to Aquifers 464 and 467; and
- a decrease in water reporting to storage of an average of 1.6 L/s over the period.

In Aquifer 463, *wet* conditions (high groundwater level conditions) corresponds to changes from average of:

- over 50% increase in inflow from the slopes (from 130.8 to 173.6 L/s) due to higher groundwater levels in the slopes;
- a 19% increase in streamflow recharge (from 140.4 to 184.4 L/s), in this case associated with higher streamflows and wider perimeters. Specifically, higher streamflows occur in the low precipitation months of a *wet* (high groundwater level) year because the higher groundwater levels generate greater baseflow in the upland channels.
- a 1.9% increase in groundwater discharge (221.3 to 223.3 L/s) to Aquifers 464 and 467; and
- an increase in water reporting to storage of an average of 119.8 L/s over the period.

In Aquifer 464, both *dry* (low groundwater level) and *wet* (high groundwater level) conditions lead to a 2-3% change in inflow from aquifer 463, which is the largest inflow component and, similarly to aquifer 463, streamflow recharge increases in both scenarios. A relatively small change (less than 10%) in groundwater discharge to Okanagan Lake occurs as a result of dry and wet conditions. The increase in streamflow recharge in both low and high groundwater level conditions leads to an increase in groundwater storage of just over 10 L/s in both scenarios, which corresponds to approximately 2% of the total inflows to this aquifer.

Overall, the flow changes in aquifer 463 associated with dry and wet conditions are more significant than those occurring in aquifer 464 because precipitation recharge in unit 463 represents a greater portion of the total inflows compared to unit 464. Smaller changes occur in Aquifer 464 also because groundwater levels are closer to ground surface and Okanagan Lake levels.

The most relevant flow change occurring in aquifer 467 in the climate scenarios is a 10% increase in groundwater inflow from aquifer 464 (one of the two main inflow components to this unit) as a result of wet conditions. This increase leads to an increase in groundwater storage of 7.8 L/s, which corresponds to approximately 6% of the total inflows to this aquifer unit.

Table 12 Average annual groundwater budget for Aquifer Unit 463 in average, dry and wet conditions (L/s).

	AQUIFER 463										
	INFLOWS					OUTFLOWS					
	Groundwater from Slopes	Stream bed recharge	Water returned (irrigation, urban and septic leakage)	Precipitation recharge	Total	Groundwater out to 464 areas	Groundwater out to 467 areas	Groundwater discharge to surface	Groundwater withdrawal	Total	Storage Change
Average	130.8	140.4	135.4	14.9	421.6	162.0	61.3	0.5	197.8	421.6	0.0
Dry	107.1	157.6	139.2	9.5	413.4	157.1	59.4	0.7	197.8	415.0	-1.6
Wet	173.6	184.4	135.0	47.8	540.9	160.4	62.9	0.0	197.8	421.1	119.8

Table 13 Average annual groundwater budget for Aquifer Unit 464 in average, dry and wet conditions (L/s).

	AQUIFER 464														
	INFLOWS								OUTFLOWS						
	Groundwater in from 463 areas	Groundwater in from 467 area	Groundwater in from 469 area	Stream bed Recharge	Okanagan Lake in	Water returned	Precipitation recharge	Total	Groundwater out to 463 areas	Groundwater out to 467 areas	Groundwater out to 469 area	Groundwater withdrawal	Groundwater discharge to surface	Okanagan Lake out	Total	Storage Change
Average	162.0	48.2	33.3	16.4	0.0	125.9	9.8	395.5	0.0	44.9	0.0	63.6	278.8	8.2	395.5	0.0
Dry	157.4	47.9	32.3	26.5	0.0	128.5	5.3	397.8	0.0	43.4	0.0	63.6	272.6	7.9	387.6	10.3
Wet	160.1	48.4	34.6	20.0	0.0	126.3	31.9	421.2	0.0	47.7	0.0	63.6	288.5	8.5	408.4	12.8

Table 14 Average annual groundwater budget for Aquifer Unit 467 in average, dry and wet conditions (L/s).

	AQUIFER 467										
	INFLOWS						OUTFLOWS				
	Groundwater in from 463 areas	Groundwater in from 464 areas	Stream bed recharge	Water returned	Precipitation recharge	Total	Groundwater out to 463 areas	Groundwater out to 464 areas	Groundwater discharge to surface	Groundwater withdrawal	Total	Storage Change
Average	61.3	44.9	0.0	13.1	2.0	121.3	0.0	48.5	72.8	0.0	121.3	0.0
Dry	59.4	43.4	0.0	13.5	1.0	117.4	0.0	47.9	71.1	0.0	119.0	-1.6
Wet	62.9	47.7	0.0	13.1	6.7	130.5	0.0	48.4	74.3	0.0	122.7	7.8

The annual average streamflows generated by the groundwater budget model over the entire simulation period (January 1900 – December 2015) at the points where Kelowna (Mill) Creek, Mission and Bellevue Creek discharge into Okanagan Lake are shown on Figure 20.

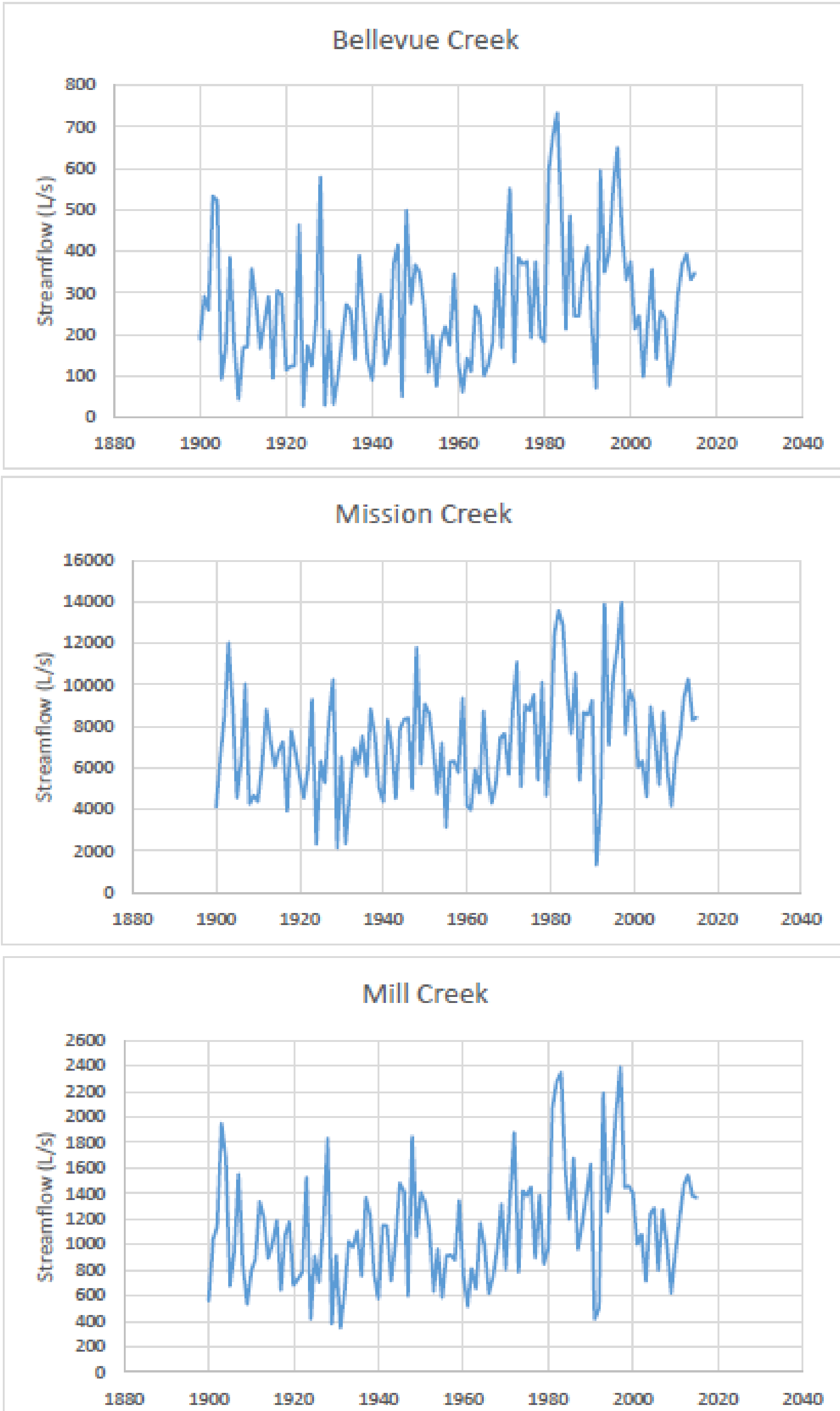


Figure 20   Average annual simulated streamflows.

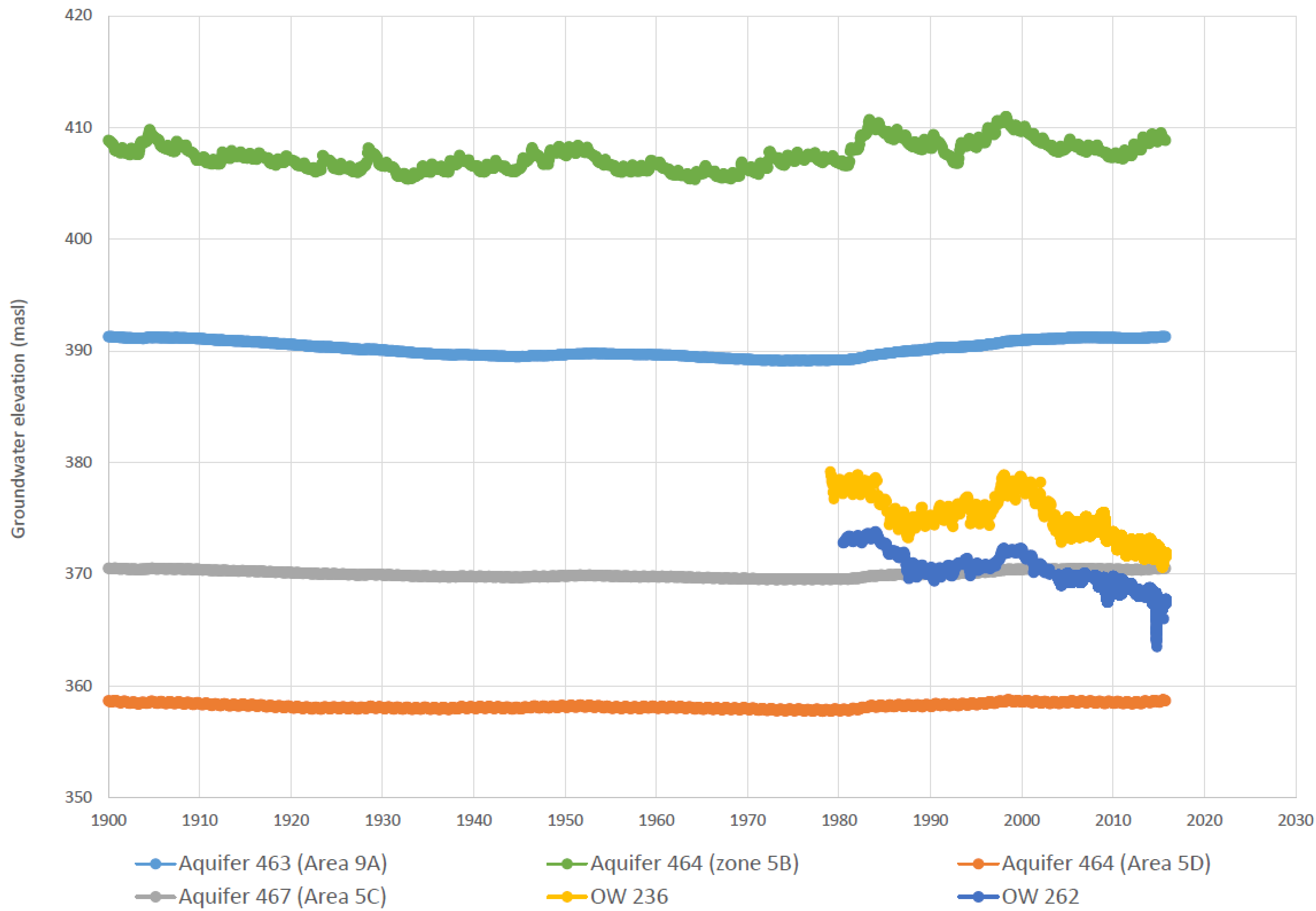


Figure 21 Simulated and observed groundwater hydrographs for Aquifer 463, 464 and 467

The groundwater elevation hydrographs for zones 9A, 5B, 5D and 5C, which are representative of Aquifer 463, 464 and 467, respectively, are shown on Figure 21. The plots indicate that groundwater levels generally decrease from Aquifer 463 to 464, with levels of 390 masl in zone 9A of Aquifer 463, 370 masl in zone 5C of Aquifer 467 and level ranging between 358 masl (zone 5D) in Aquifer 464. This is consistent with the general NE-SW direction of groundwater flow within the valley aquifers. Fluctuations in groundwater levels over the simulation period also decrease from 2 m in Aquifer 463 to just over 1 m in Aquifer 464 and 467. Groundwater levels in 5B of Aquifer 464 are higher (approximately 410 masl) and exhibit greater seasonal fluctuations as this zone is located in the upland portion of the aquifer, where the aquifer is likely thinner. The calculated groundwater elevations are plotted on Figure 21 alongside the observed groundwater elevations at monitoring wells OW 236 and OW 262. The plot shows that the calculated groundwater elevations in aquifer 467 (zone 5C) are the closest to the observed elevations. The calculated groundwater levels do not reproduce the downward trend observed at OW 236 and OW 262 since the model does not represent changes in groundwater withdrawal from year to year. This is because the intent of the model is to represent the current average conditions of groundwater withdrawal, where only monthly fluctuations are considered.

5.10 Uncertainty Analysis

The main elements of uncertainty in the groundwater budget model include the following:

- Aquifer geometry. The lack of correlation between the ENV-mapped aquifer units and the geological characterization provided by the GSC for the lower Mission Creek catchment introduces significant uncertainty on the extent and geometry of the Kelowna aquifers.
- Hydraulic test data. The hydraulic test data available for the aquifers are in limited quantity and of unknown reliability.
- Stream-aquifer interaction. There currently is limited information on the interaction between surface water and groundwater along the main creeks and their tributaries.
- Other groundwater discharge to surface. No information on groundwater discharge to surface associated with wetlands, springs, evapotranspiration of the shallow water table through phreatophytes and infiltration of shallow groundwater in leaky storm drainage and sewage network is currently available. These forms of groundwater discharge represent a significant component of the total groundwater discharge in the current water balance and are believed to be the greatest source of uncertainty, with a level of at least plus/minus 50%. The uncertainty of these forms of groundwater discharge therefore significantly affects the reliability of the water balance. Given that these forms of groundwater discharge are difficult to estimate, it may not be possible to improve the model reliability considerably, if they indeed amount to such an important component of the water balance.
- Water returns from septic fields, irrigation and losses from the water supply pipe network. This water budget results in water returns that represent 44% of the groundwater budget input. Relatively small changes to the assumptions that led to this input value may substantially change the understanding of the groundwater budget.
- Groundwater discharge to Okanagan Lake. The available estimate (Pyett, 2015) indicates that groundwater discharge to the lake represents only 1% of the total outflows. This estimate appears to be rather low, considering that approximately 50% of Aquifer 464 is in contact with Okaganan Lake. The water balance indicates that for this estimate to be realistic a significant portion (up to 70%) of the groundwater in Aquifer 464 has to discharge to surface, in forms that are not easily measurable such as diffuse seepage in wetlands and infiltration of shallow groundwater into the leaky water supply network.

- Very limited groundwater level records. Reliable groundwater hydrographs are available for only four groundwater monitoring wells in the entire study area.
- Groundwater withdrawal. As mentioned in Section 5.7, the groundwater pumping estimates for the Kelowna aquifers are based on the following: (1) a relatively extensive set of pumping records from the main irrigation districts, which are generally consistent with the estimates provided in (KJWC, 2012), and (2) water demand data and the water source-demand table that is part of the Okanagan Basin Agricultural Water Demand model, to estimate groundwater withdrawal from small utilities and private users. The estimates from source (1) appear to be relatively accurate, whereas those from source (2) are significantly more uncertain, due to lack of information on the spatial distribution and seasonal variation of pumping. According to the available data, groundwater pumping by the main districts is approximately 75% of the total. However, groundwater withdrawal from small utilities and private users could actually be as high as 50% of the total, based on the water demand data reported in (KJWC, 2012) for the main districts and small utilities. The estimate of groundwater withdrawal used in the model is therefore deemed to be affected by an uncertainty of up to 20%.

The key parameters controlling the model sensitivity are as follows:

- Water returned from irrigation, urban leakage and septic tank infiltration, which form the main contribution to groundwater recharge.
- Surface and groundwater withdrawal rates, which represent a significant component of the overall water balance; and
- The aquifer hydraulic parameters (transmissivity, storativity and specific yield), which control groundwater flow across different units;
- The variation of the main climate variables (precipitation and evapotranspiration) with location and elevation, as different spatial distributions can lead to significant changes in precipitation recharge and runoff.

6. WATER MANAGEMENT IMPLICATIONS OF GROUNDWATER BUDGET RESULTS

6.1 Streamflow Assessment

The synthetic streamflows generated by the water budget model were compared with the Environmental Flow Needs (EFN) for Kokanee Salmon and Rainbow Trout in the Okanagan Basin, which are reported in terms of percentage of naturalized Mean Annual Flow (MAF) in (Nhc, 2001). The purpose of this comparison was to determine whether the current surface and groundwater withdrawals lead to flows below the conservation requirements. The EFN reported in (Nhc, 2001) are defined as follows:

- Oct – Mar: 20% MAF
- Apr, Jun: 100% MAF
- May: 200% MAF
- July: 40% MAF
- Aug: 30% MAF
- Sept: 25% MAF

These EFN were considered to assess the current synthetic flows generated by the model for Mill (Kelowna), Mission and Bellevue Creek.

Estimates for the natural Mean Annual Flows were obtained by running the water budget model without groundwater and surface water withdrawals and returns. These MAFs were multiplied by the above percentages to obtain EFN. The comparison was then carried out between the synthetic EFN and current streamflows in average and dry climatic conditions. Figure 22 shows these flows for Bellevue Creek, Mission Creek and Kelowna (Mill) Creek. The plots show that streamflows associated with the current water withdrawal conditions are significantly lower than the EFN in Bellevue and Mission Creek, whereas they are always above the EFN in Mill (Kelowna) Creek. An increasing EFN deficit ranging between 50 and 150 L/s occurs in Bellevue Creek between January and April and a deficit of approximately 25 L/s occurs between August and December. In Mission Creek, an increasing EFN deficit ranging between 500 and 1,900 L/s occurs between December and April.

These plots of simulated streamflows indicate that additional groundwater withdrawal should be avoided between January and April and would be best kept to a minimum between August and December to not potentially further impact the streamflows. It is emphasized that these results only provide a general overview of the streamflow status with respect to EFN, since the assessment is based on streamflows at the mouth and results are affected by the model uncertainty. Significant field evidence has been gathered for the Mission Creek channel area adjacent to the Benvoulin Water Users community intake, which shows that EFN have not been met also between Aug and October, both in years with high and low precipitation records (FLRNO verb. comm., 2016). Local conditions such as those along Mission Creek in the Benvoulin area cannot be reproduced due to the coarse model spatial discretization.

6.2 Assessment of Available Groundwater Resources for Allocation

The assessment described in this section assumes that the groundwater resources that are considered available for allocation are those that are not needed to support the Environmental Flow Needs of the streams in hydraulic contact with the aquifer.

Figure 22 shows that under the current regime of groundwater withdrawal EFN are not being met in Mission Creek between December and April. As such, no groundwater resources in the southern portion of Aquifer 464, where the lower reach of Mission Creek is located, are currently available for further allocation during these periods, and the current groundwater use should be reduced to limit and ideally eliminate the EFN deficit. The EFN deficit in Mission Creek at the mouth ranges between 500 in December to 1,900 L/s in April. A preliminary estimate of the groundwater available for allocation between May and November is given by the minimum of the EFN surplus, i.e. difference between the current streamflow and the EFN, in dry conditions. A safety factor of 0.3 was applied to the minimum EFN surplus to estimate the available groundwater resources. The minimum EFN surplus between May and November in Mission Creek at the mouth in dry conditions is 83 L/s. The rate of 83 x 0.3 = 24.9 L/s therefore represents a lower bound for the available groundwater resources in the southern portion of Aquifer 464 during periods of EFN surplus. The estimate is a lower bound because it refers to dry conditions, and because, under the conservative assumption that all additional groundwater withdrawal may be supplied by streamflow leakage, equal or greater rates of groundwater withdrawals applied during periods of EFN surplus may be possible without inducing an EFN deficit.

No EFN deficit was estimated to occur in Mill (Kelowna) Creek under the current regime of groundwater withdrawal. Groundwater resources are therefore available for allocation throughout the year in the northern portion of Aquifer 464, where the gaining reach of Mill Creek is located. As for the southern portion of Aquifer 464, a preliminary estimate of available groundwater resources is given by 30% of the minimum EFN surplus in Mill Creek at the mouth in dry conditions (11 L/s), which is 3.3 L/s.

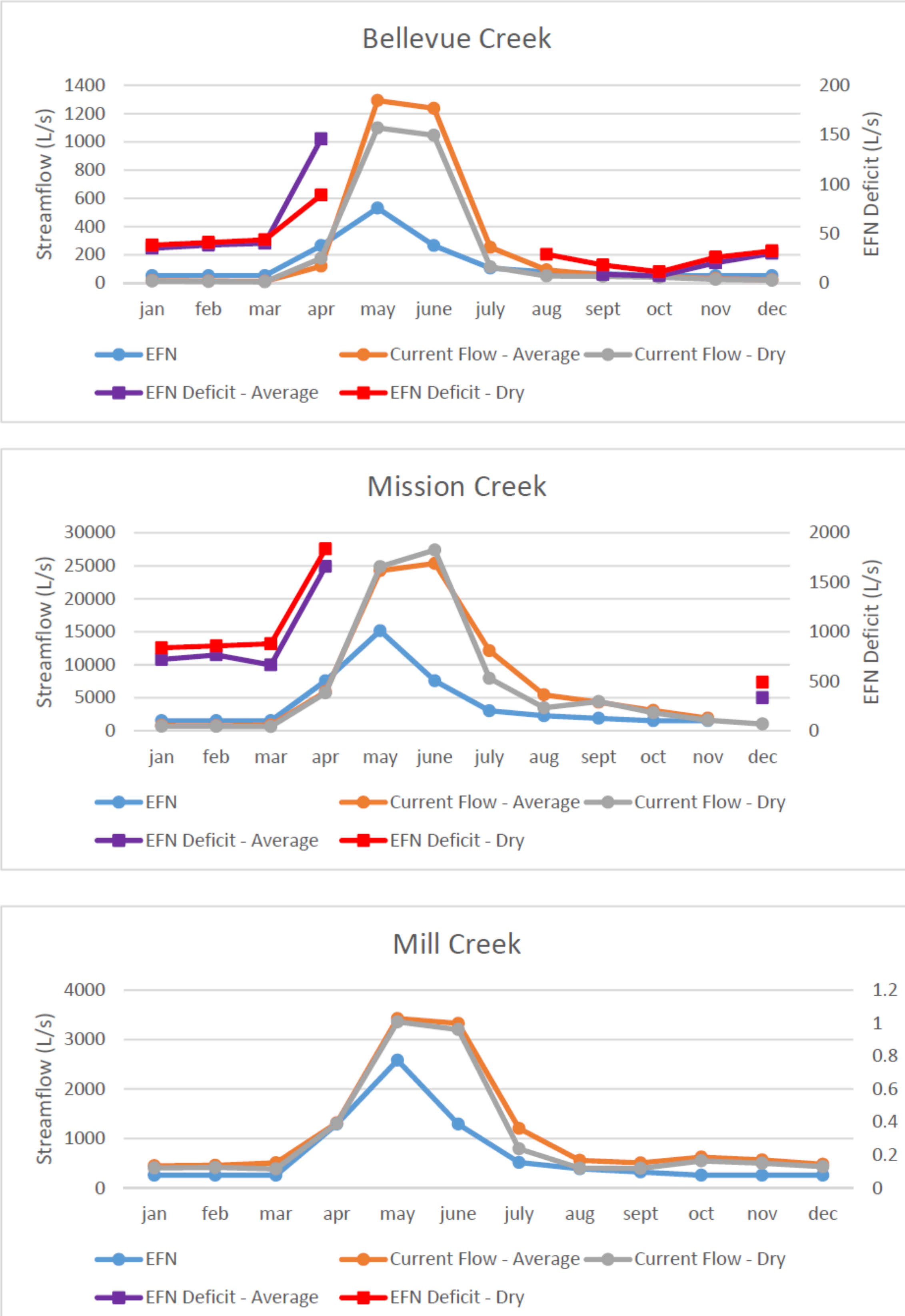


Figure 22 Simulated current streamflows versus Environmental Flow Needs (EFN).

The EFN deficit in Bellevue Creek increases from 50 to 150 L/s between January and April, and is approximately 25 L/s between August and December. No groundwater resources in Aquifer 463, where the gaining reach of Bellevue Creek is located, are therefore available for further allocation in these periods, and groundwater withdrawal should be reduced to limit and ideally to eliminate the EFN deficit. As for Aquifer 464, a preliminary estimate of the groundwater available for allocation in Aquifer 463 between May and July is given by 30% of the minimum EFN surplus in dry conditions (9 L/s), which is 2.7 L/s.

The above estimates of groundwater availability represent only a preliminary indication of the available groundwater resources in the aquifers under study, as they are based on simulated streamflows at the mouth, and do not consider local spatial variability. Specifically, the water budget model does not allow a more refined estimate of available groundwater resources in the Kelowna aquifers, because it is based on a semi-distributed parameter approach, which does not represent the exact location of pumping wells and streams. As such, the effect of groundwater pumping on streamflows, which requires consideration of the distances between wells and streams, cannot be adequately estimated. A groundwater numerical model is required for an adequate estimation of available groundwater resources and sustainable groundwater withdrawal schemes, as it allows the assessment of the effects of time variant groundwater pumping from several wells in different locations on streamflows along a creek.

6.3 Assessment of Future Groundwater Allocations

Projections of future water demand in the Kelowna area are reported in (KJWC, 2012). These projections were developed using the information provided in the Kelowna 2030 Official Community Plan (OCP), which identifies twenty main growth areas. Of these, all but two of the areas with the greatest projected growth are located along the shores of Okanagan Lake, where additional water demand will be met most likely by supplying lake water. The two areas with a large projected growth that are not located along Okanagan Lake are Rutland and Glenmore Highlands (Figure 23). While the average annual water demand increase rate in the Kelowna area is estimated as 0.69%, increase rates of 2.6% and 1% were estimated for these two areas, respectively. The annual rate of 2.6% was estimated by considering the current groundwater withdrawal volume, as provided by the Rutland Waterworks District (approximately 0.93 Mm3/yr) and the additional water demand estimated for Rutland in 2030 (0.467 Mm3/yr), as reported in (KJWC, 2012). Accordingly, groundwater withdrawal is estimated to increase by a factor 1.5 by 2030.

The annual rate of 1% was estimated by considering the current groundwater withdrawal volume from all Glenmore-Ellison Irrigation District wells and other wells located in the area of Glenmore Highlands (approximately 1.96 Mm3/yr), as reported in (KJWC, 2012), and 35% of the additional total water demand estimated for Glenmore Highlands in 2030 (0.954 Mm3/yr), also reported in (KJWC, 2012). Of the total water demand in the GEID, 65% is currently provided by surface water and 35% by groundwater. For the estimate of the additional groundwater demand, it was assumed that surface water and groundwater will continue to supply future water demand in the same 65%-35% proportion. Accordingly, groundwater withdrawal is estimated to increase by a factor of 1.15 by 2030.

Based on these projections, the groundwater budget model was used to simulate the following three groundwater withdrawal scenarios:

- Scenario A: Increase groundwater withdrawal by a factor 1.5 in all the RWW wells, which are located in zone 5A, 8A and 9A (Aquifer 463). It is noted that many of the RWW wells are located on the boundary between Aquifer 463 and Aquifer 464 and may potentially extract water from either aquifer. This should be confirmed during an update of the Kelowna aquifer mapping.

- Scenario B: Increase groundwater withdrawal by a factor of 1.15 in all the GEID and other wells located in zone 5B (Aquifer 464)
- Scenario C: Increase groundwater withdrawal by a factor 1.5 in all the RWW wells (zone 5A, 8A and 9A – Aquifer 463) and by a factor of 1.15 in all the GEID and other wells located in zone 5B (Aquifer 464).

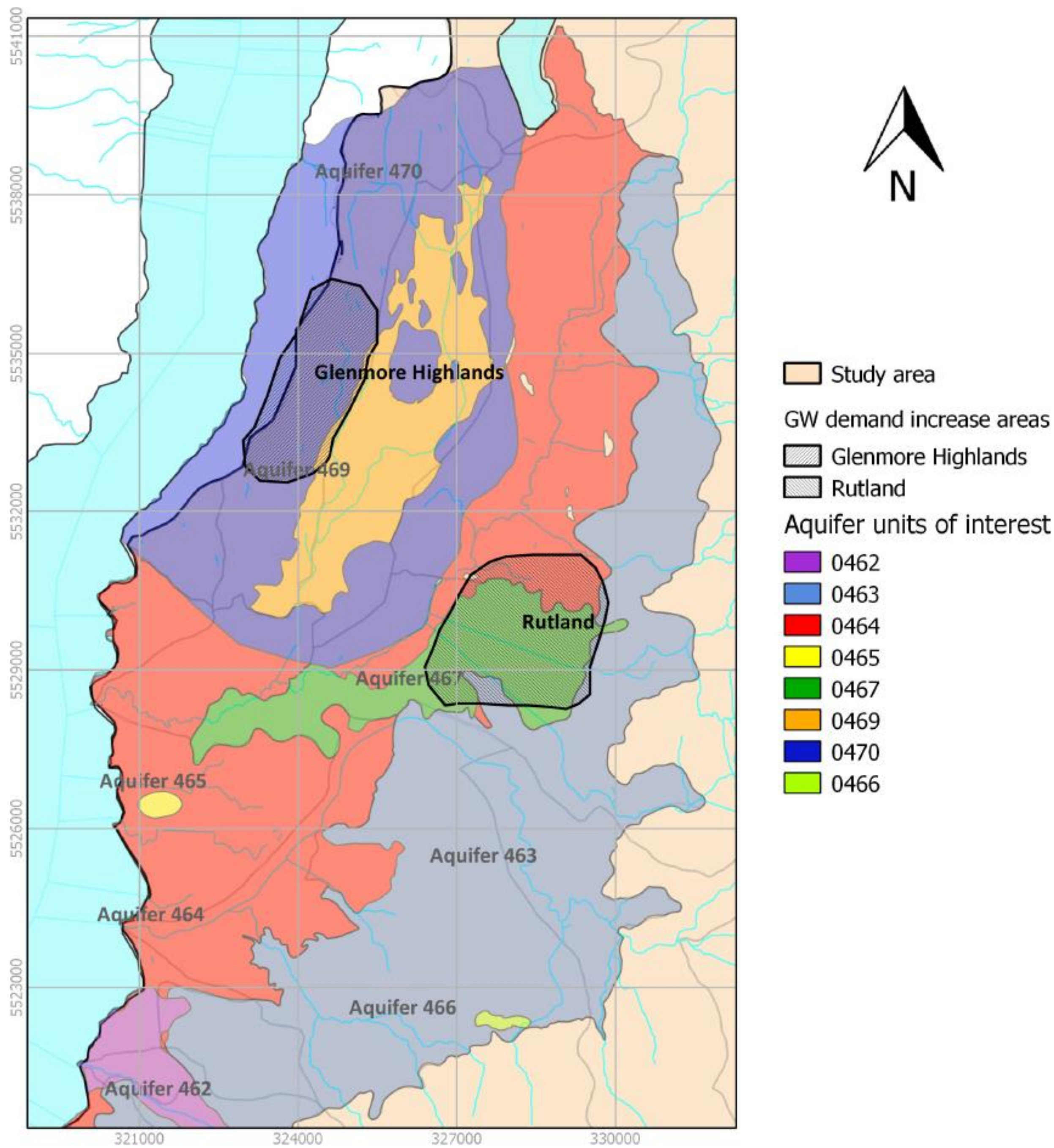


Figure 23 Areas with projected increase in groundwater demand.

Table 15, Table 16, and Table 17 summarize the groundwater balances resulting from these predictions for Aquifer 463, 464 and 467.

In Aquifer 463, the results indicate that the projected 25% increase in groundwater withdrawal (from approximately 198 to 245 L/s) leads to an increase in streamflow recharge (from approximately 140 to 160 L/s, i.e. 15% in both Scenario A and C), which occurs mainly in zone 8A, and to a decrease in streamflow discharge (from 0.5 to 0 L/s) in zone 9A.

In Aquifer 464 the projected 15% increase in groundwater withdrawal (from approximately 64 to 73 L/s) leads to an increase in streamflow recharge (from approximately 16 to 24 L/s in Scenario B, and to 30 L/s, i.e. of the order of 85% of the current value in Scenario C, due to the added effect of withdrawal from Aquifer 463) and to a decrease in streamflow discharge and other groundwater discharge to surface (from approximately 279 to 261 L/s, i.e. 6.5% in both Scenario B and C).

The projected groundwater withdrawal from Aquifer 463 and 464 has a limited effect on Aquifer 467, where groundwater inflows from 463 and 464 decrease from approximately 106 to 101 L/s, and this translates into a reduction in streamflow discharge from approximately 73 to 69 L/s, i.e. 5%.

These results therefore suggest that the projected increase in groundwater allocation in Aquifers 463 and 464 is likely to lead to a less than 10% reduction in stream baseflow and other groundwater discharge to surface but to an increase in streamflow recharge ranging between 15 and 85% of the current estimates.

The corresponding reductions in the monthly average streamflows at Mission Creek and Mill Creek, which run along zones 5A, 8A, 9A and 5B, where the projected groundwater abstraction increase occurs, and at Bellevue Creek are shown on Figure 24. The plots indicate that the streamflow reduction occurring in Mill (Kelowna) Creek resulting from the increase groundwater withdrawal ranges between 25 and 45 L/s, i.e. of the order of 3% of the current flows. The streamflow reduction in Mission Creek ranges between 5 and 30 L/s, i.e. approximately 0.1% of the current streamflow. A streamflow reduction of less than 1 L/s, i.e. 0.1% of the current streamflow occurs throughout the year at the mouth of Bellevue Creek as a result of the increased groundwater abstraction. The reason why the calculated changes in streamflow leakage and baseflow have small (lass than 3%) effects on the total streamflow at the mouth in Mill Creek, Mission and Bellevue Creek is that groundwater contributions are relatively minor compared to the total streamflows, which are subject to significant accretion in the uplands upgradient of Aquifer 463 and 464.

The model results therefore indicate that the projected increase in groundwater withdrawal in the Kelowna aquifers is unlikely to reduce streamflows significantly. The main reason for this appears to be the presence of high anthropogenic recharge (irrigation, water supply network losses and septic infiltration) to these aquifers, which has similar magnitude as the groundwater inflows originating from the upland portion of the Mission Creek basin. Given the magnitude of anthropogenic recharge, it is recommended that the data extracted from the Okanagan Basin Agriculture Demand Model to estimate irrigation losses and septic infiltration be further validated.

Table 15 Average annual groundwater budget for Aquifer Unit 463 with current and projected groundwater withdrawal (L/s).

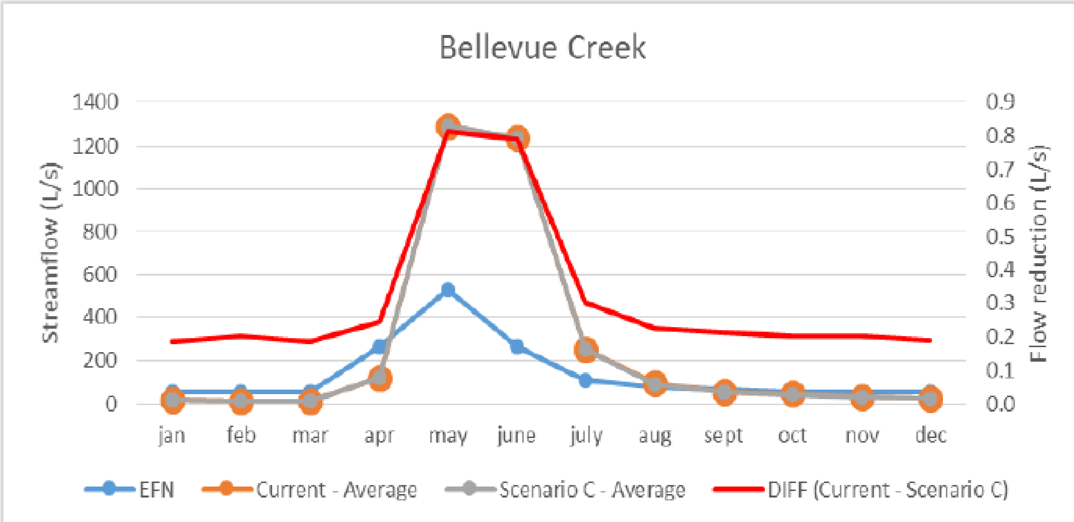
	AQUIFER 463									
	INFLOWS					OUTFLOWS				
	Groundwater from Slopes	Stream bed recharge	Water returned (irrigation, urban and septic leakage)	Precipitation recharge	Total	Groundwater out to 464 areas	Groundwater out to 467 areas	Groundwater discharge to surface	Groundwater withdrawal	Total
Current	130.8	140.4	135.4	14.9	421.6	162.0	61.3	0.5	197.8	421.6
Scenario A	130.8	159.6	135.4	14.9	440.8	139.2	56.2	0.0	245.3	440.8
Scenario B	130.8	141.0	135.4	14.9	422.1	162.9	61.0	0.5	197.8	422.1
Scenario C	130.8	160.2	135.4	14.9	441.3	140.1	55.9	0.0	245.3	441.3

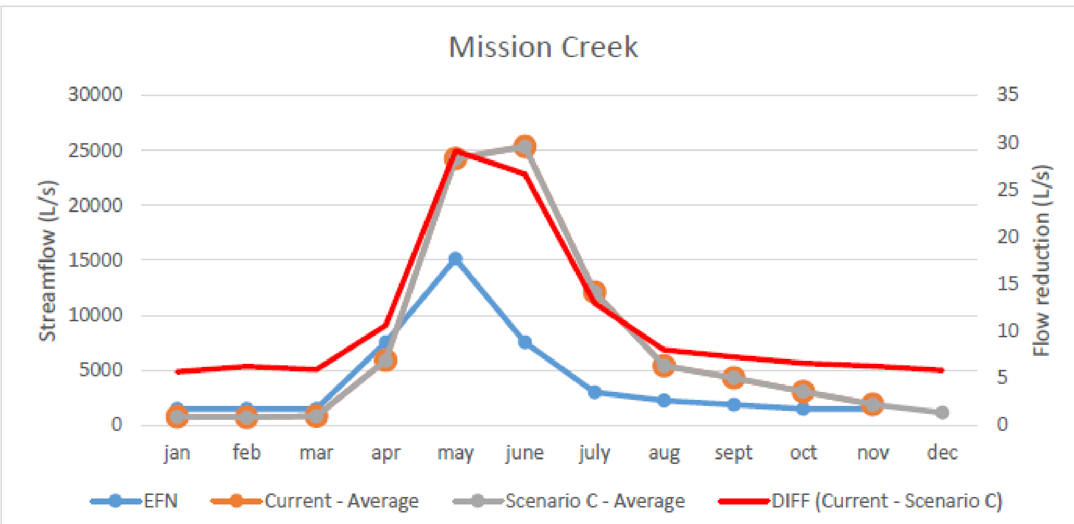
Table 16 Average annual groundwater budget for Aquifer Unit 464 with current and projected groundwater withdrawal (L/s).

	AQUIFER 464														
	INFLOWS								OUTFLOWS						
	Groundwater in from 463 areas	Groundwater in from 467 area	Groundwater in from 469 area	Stream bed Recharge	Okanagan Lake in	Water returned	Precipitation recharge	Total	Groundwater out to 463 areas	Groundwater out to 467 areas	Groundwater out to 469 area	Groundwater withdrawal	Groundwater discharge to surface	Okanagan Lake out	Total
Current	162.0	48.2	33.3	16.4	0.0	125.9	9.8	395.5	0.0	44.9	0.0	63.6	278.8	8.2	395.5
Scenario A	139.2	47.1	33.3	22.7	0.0	125.9	9.8	378.1	0.0	45.1	0.0	63.6	261.6	7.9	378.1
Scenario B	162.9	47.8	33.3	23.6	0.0	125.9	9.8	403.3	0.0	44.1	0.0	72.9	278.1	8.2	403.3
Scenario C	140.1	46.7	33.3	30.0	0.0	125.9	9.8	385.8	0.0	44.2	0.0	72.9	260.8	7.9	385.9

Table 17 Average annual groundwater budget for Aquifer Unit 467 with current and projected groundwater withdrawal (L/s).

	AQUIFER 467									
	INFLOWS					OUTFLOWS				
	Groundwater in from 463 areas	Groundwater in from 464 areas	Stream bed recharge	Water returned	Precipitation recharge	Total	Groundwater out to 463 areas	Groundwater out to 464 areas	Groundwater discharge to surface	Groundwater withdrawal	Total
Current	61.3	44.9	0.0	13.1	2.0	121.3	0.0	48.5	72.8	0.0	121.3
Scenario A	56.2	45.1	0.0	13.1	2.0	116.4	0.0	47.4	68.9	0.0	116.4
Scenario B	61.0	44.1	0.0	13.1	2.0	120.2	0.0	48.1	72.1	0.0	120.2
Scenario C	55.9	44.2	0.0	13.1	2.0	115.2	0.0	47.1	68.1	0.0	115.2





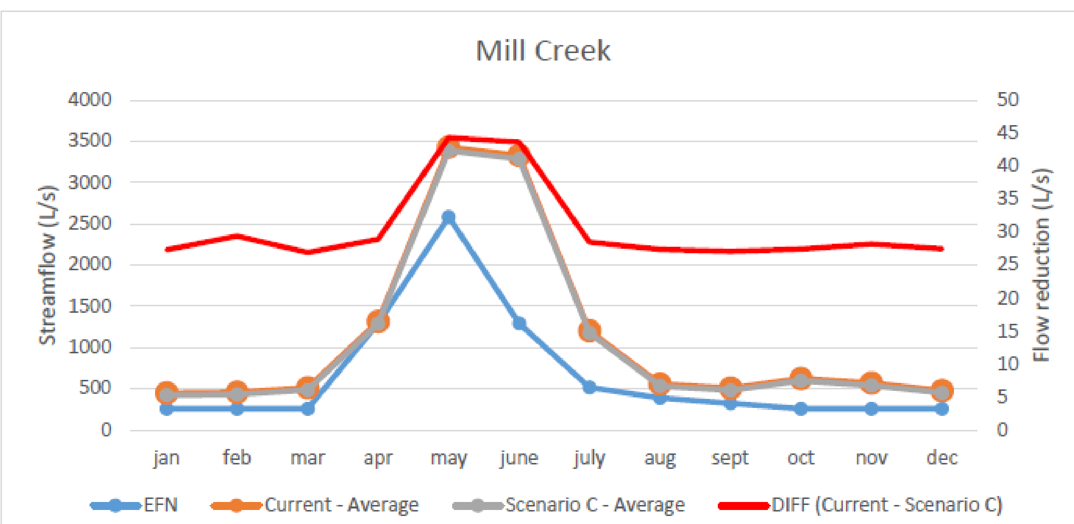


Figure 24 Current, Projected (Scenario C) streamflows and flow reductions.

7. DATA GAP ANALYSIS

The review and use of the all available information and data that were relevant to the development of the groundwater budget model led to identifying a number of gaps, which are believed to control the uncertainty of the model results. These gaps relate to the aquifer characterization, groundwater levels, streamflow and groundwater withdrawals and are described in the following sections.

7.1 Aquifer Characterization

The groundwater budget model was developed in this study by using the aquifer units mapped by the BC Ministry of Environment (ENV, 2007). While these units provide the current official representation of the Kelowna aquifers, their outline in plan view is significantly different from that of the main geological units characterized in the later GSC study (Paradis et al., 2009), which are associated with the main aquifers in the area. These discrepancies were identified by comparing the 3D GSC geological model (3D PDF and GoCad files), where main hydrogeological units (aquifers and aquitards) can be visualized, with the shapefiles associated with the official aquifer units.

7.2 Groundwater Levels

As mentioned in Section 3.7, reliable groundwater level records are available from four of the six BC Groundwater Observation Wells located in the study area. The remaining two wells, Well 410 and 413, are currently considered to have unreliable records (verb.comm. FLNRO Okanagan Region, 2016).

The litholog of Well 410 indicates that this well penetrates approximately 100 m of tight bedrock, and moisture was detected in bedrock during drilling. Nevertheless, the groundwater records are shallow (4 -6 m range) and have seasonal fluctuations of about 1 m, which may be representative of a confined bedrock aquifer.

The litholog of Well 413 indicates that this well penetrates unconsolidated deposits to a depth of approximately 100 m and is screened just above a potential aquitard. The average groundwater elevation estimated from the available records for this well is approximately 400 masl and appears reasonable, as it is consistent with a hydraulic gradient of 2% between Well 413 and Well 262 (located approximately 1.7 Km to the West of 413), where the groundwater elevation is approximately 370 masl. Groundwater level records at Well 413 do not show the declining trend observed in Well 262. This could be due to the records unreliability, but may also occur because Well 262 is located in the proximity of pumping wells and its groundwater level is significantly affected by the cone of withdrawal.

A further assessment of both Well 410 and Well 413 as viable monitoring wells is recommended.

Observation wells 262 and 236 are installed in aquifer unit 463, in the proximity to clusters of pumping wells. Since water demand is projected to increase in Rutland (Section 6.2), the Rutland Waterworks District may consider installing additional pumping wells in the southeastern sector of aquifer unit 463, where no groundwater withdrawal is currently taking place. The installation of an additional observation well in this area is recommended. Also, one additional observation well is recommended in Aquifer 464, where considerable groundwater withdrawal is currently taking place and is likely to increase going forward. A suggested location for this well is at 1 – 2 km downstream of the confluence of Scotty and Kelowna Creek, to allow monitoring of the combined effect of groundwater withdrawal from the GEID wells located nearby the confluence and of surface water removal from the Scotty Creek intake.

To improve the understanding of groundwater movement, adequate groundwater level monitoring is required to establish groundwater gradients. A network of monitoring points, probably in the range of ten to twenty more than those mentioned above would likely be adequate to provide that information.

7.3 Stream-Aquifer Interaction

The streamflow gauging program that is currently being undertaken in seven transects along lower Mission Creek will provide valuable data to characterize surface water-groundwater interaction on this segment, which represents a creek-spawning ground for the Kokanee salmon and is therefore ecologically important. Development of similar streamflow gauging programs are recommended along the lower reaches of Kelowna Creek and Bellevue Creek, which also support the habitat for the Kokanee Salmon and the Rainbow Trout.

In order to directly assess the impact of groundwater withdrawal along these ecologically critical reaches, one pumping well (if nearby pumping wells do not exist or are not available for hydraulic testing) and at least one monitoring well should be installed in the proximity of the stream channel along the lower Mission, Kelowna and Bellevue Creek, and pumping tests should be conducted. These wells, jointly with a stream gauging station, should be ideally installed at the eastern edge of aquifer unit 463, as these would provide estimates of the recharge contributed by streamflow leakage and discharge to stream baseflow for the Kelowna aquifers, which are significant components of the groundwater budget.

7.4 Groundwater Discharge to Surface

Diffuse groundwater seepage in wetlands, springs, evapotranspiration of the water table through phreatophytes and infiltration of groundwater into the leaky storm drainage and sewage network represent a significant component of the current water balance. Although not easily measurable, preliminary estimates for these forms of groundwater discharge could be obtained, for example through the following: (1) wetland hydrologic studies including the installation of multi-level monitoring wells; (2) spring surveys; (3) phreatophytes mapping; (4) measurement of dry season flows in the storm drainage network.

7.5 Discharge to Okanagan Lake

The currently available estimate of discharge to Okanagan Lake represent only 1% of the total outflows. Considering that approximately 50% of Aquifer 464 is in contact with Okanagan Lake, this estimate appears rather low. Additional data collection is therefore recommended to confirm and refine this estimate.

7.6 Anthropogenic Recharge

Anthropogenic recharge comprises percolation losses from irrigation, urban leakage and septic tank infiltration. Of the total anthropogenic recharge represented in the water balance model, approximately 45% is associated with irrigation losses, 30% with urban leakage and 25% with septic tank infiltration. The percolation losses from irrigation and the indoor water demand for areas off the sewage grid used in the water balance were obtained from the Okanagan Basin Agricultural Water Demand Model, whereas estimates of urban leakage were obtained from the Unaccounted For Water (UFW) values reported in (KJWC, 2012). Anthropogenic recharge represents the main component of the inflows to the Kelowna aquifers alongside groundwater flow originating from the uplands of the Mission Creek basin. As such, it is recommended that the estimates generated in the Water Demand Model be validated. This could be accomplished through field studies to assess the efficiency of the current irrigation practices and field leak surveys of the water supply network.

7.7 Groundwater Withdrawal

While the records collected by the four irrigation districts (BMID, GEID, RWW and SEKID) are adequate to estimate monthly groundwater withdrawal, no records on groundwater pumped volumes by small water utilities and private users are currently either available or practically accessible. In this study, the groundwater removed by these purveyors was estimated to be of the order of 40% of the total groundwater withdrawal. As such, a set-up of a system of groundwater withdrawal data collection, which forms part of the Water Sustainability Act, would substantially improve the understanding of the groundwater resource in the Kelowna area.

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APPENDIX A: GROUNDWATER BUDGET METHODOLOGY

A.1 Introduction

Water balance models can be classified into lumped, distributed, or semi-distributed parameter models. A lumped-parameter model includes a limited number of parameters to characterize the whole basin where the balance is carried out. The lumped parameter approach limits the number of parameters that require calibration, but can often lead to an over-simplistic and therefore inadequate representation of the system. A distributed-parameter model is constructed by discretizing the basin using a grid or mesh, and applying parameters specific to each grid cell or mesh element. The distributed parameter approach provides the possibility to represent spatial variations in the basin properties, inflows and outflows, but requires the calibration of a large number of parameters, which is generally a very complex process. A semi-distributed model includes both lumped parameters (i.e. applied to the entire balance domain) and distributed parameters (i.e. varying within the basin) within the same calculation. The advantage of the semi-distributed parameter approach is that it provides the flexibility to sub-divide the balance domain into as many zones as deemed suitable to capture the key features of the basin, therefore optimizing the trade-off between ease of calibration and adequate representation of the system. The groundwater budget method employed in this study is based on a semi-distributed parameter approach.

The methodology includes both groundwater and surface water components and accounts for groundwater and surface water interaction, thereby providing an opportunity to include both groundwater level data and surface water flow data in the assessment of groundwater recharge and discharge rates. A schematic illustrating the proposed methodology is shown on Figure A-1.

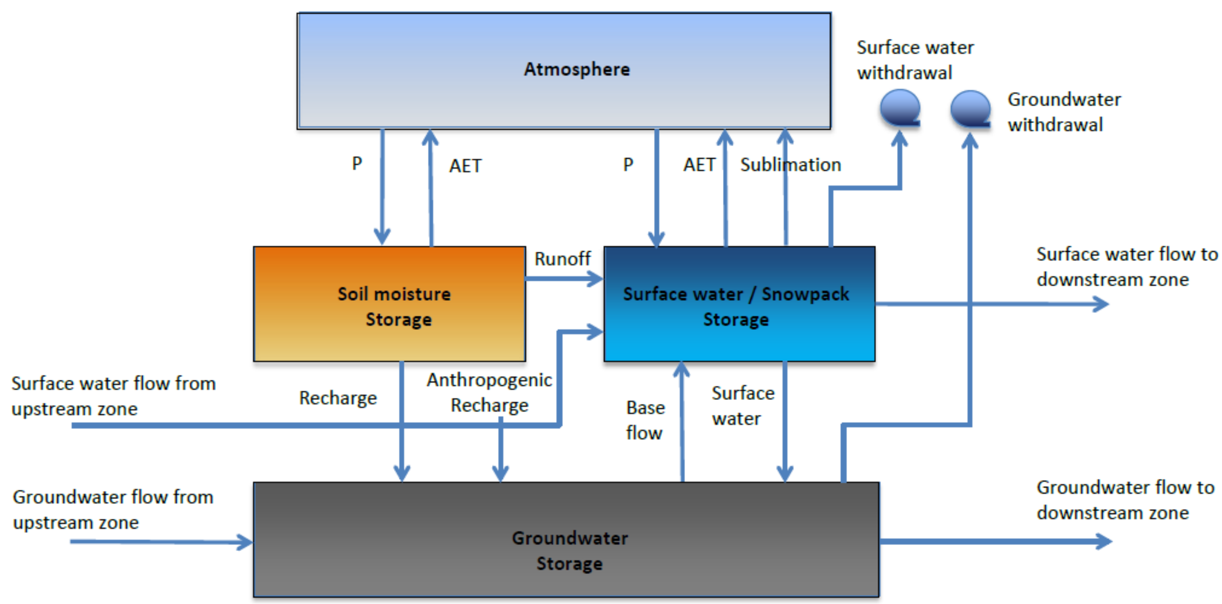

Figure A-1 Schematic of groundwater budget methodology.

This water balance methodology includes consideration of:

- Discretization of the study area into zones based on surface water catchments, location of surface water gauges, location where information is desired, geometry of aquifers etc. Each zone is further divided by elevation bands to allow distribution of climate parameters within the zone.

- Assignment of climate factors, primarily monthly temperature and precipitation by month and by elevation band. Based on the basic factors, snowfall, snowpack, snowmelt, rainfall, potential evapotranspiration, actual evapotranspiration etc is calculated. Often, local climate data is over limited time periods. In those cases, the available local data is compared with longer regional records, primarily using mass plots. Synthetic records are then developed for the study site based on the regional data. The main output is the monthly rainfall and snowmelt available for runoff and recharge.
- The monthly rate of 'surplus water' available for runoff and recharge is converted into a flow by multiplication by the area of each elevation band within each zone. It is at this stage that pumping records are included along with reservoir storage where present.
- The resulting flow is distributed within the budget zone into the following components: groundwater recharge; groundwater storage; groundwater discharge; groundwater outflow; immediate runoff; surface water detention; surface water storage; detention discharge; and total surface water outflow.
- In the upland catchments, groundwater discharge to surface and to downstream is related directly to the volume of water in storage. The volume reporting downstream is defined by assigning a transmissivity, gradient and width. The remaining discharge volume reports to surface water within the zone.
- In the zones representing Kelowna Aquifers, groundwater reporting to surface and to surrounding zones is estimated using relative differences in calculated representative groundwater elevations for each zone and the surface discharge features. Groundwater pumping, septic field contributions, irrigation contributions and contributions from water supply lines are added to the groundwater in storage.
- Surface water discharge from each zone is then calculated based on immediate runoff, release from surface water detention, groundwater discharge and stream losses in the zone, and surface water from up slope zones.
- The surface water portion of the upland budget is balanced by adjusting precipitation rates (the data from the selected gauges may not adequately represent the watershed under consideration), groundwater recharge and discharge rates (based on measured low flows, where possible) and surface detention rates within reasonable bounds. This adjustment of these rates is carried out by comparing the measured streamflows with the synthesized (modelled) flows. Although the focus of the water balance model is on groundwater, the groundwater component of the upland portion of the model is calibrated using monthly streamflow data, since groundwater level data are typically available in very few locations and for limited periods.
- The groundwater portion of the zones with Kelowna Aquifers were calibrated by adjusting the surface water/groundwater interaction, the interaction between zones and between zones and Okanagan Lake to approximately meet measured groundwater levels and measured groundwater discharge to Okanagan Lake.
- Typically the model can only be calibrated over a relatively short time span, where streamflow and groundwater level data are available. Once calibrated, the complete precipitation record can be used to develop appropriate averages, as well as series representatives of drought and wet conditions.

The following sections describe the processes and equations used in the water balance methodology. A description of the parameters included in the equations, which are associated with the physical properties of the surface and groundwater system, is also provided. The parameter values used in the model to develop a groundwater budget for the Kelowna aquifers are included in the MS Excel spreadsheet files SW_Budget_Model.xlsx and GW_Budget_Model.xlsm, which implement the surface and underground components of the water balance methodology.

A.2 Discretization

The study area is divided into zones, such as those shown on Figure A-2, defined by topographic controls on drainage and the need to calibrate to measured water flow rates and volumes. At this stage, the need for definition at particular points and the location of aquifers of interest can be included in the discretization. GIS software assists in correlating important elements of the conceptual hydrogeological model with the water balance calculations. For example, discretization can include consideration of bedrock and surficial geology, water features, surface water gauges, aquifer boundaries, vegetation, slopes, aspect, etc. The area of a balance zone typically ranges from a few to hundreds of square kilometers.

Each of the zones are further discretized by elevation. The elevation bands are selected according to the topographic range in the study area and the potential variation of conditions with elevation. In this study, 300-m elevations were selected to define the spatial variation of climate variables. A schematic representation of water budget zones is shown on Figure A-2. The discretization is completed be defining surface areas for each elevation band in each zone using GIS software.

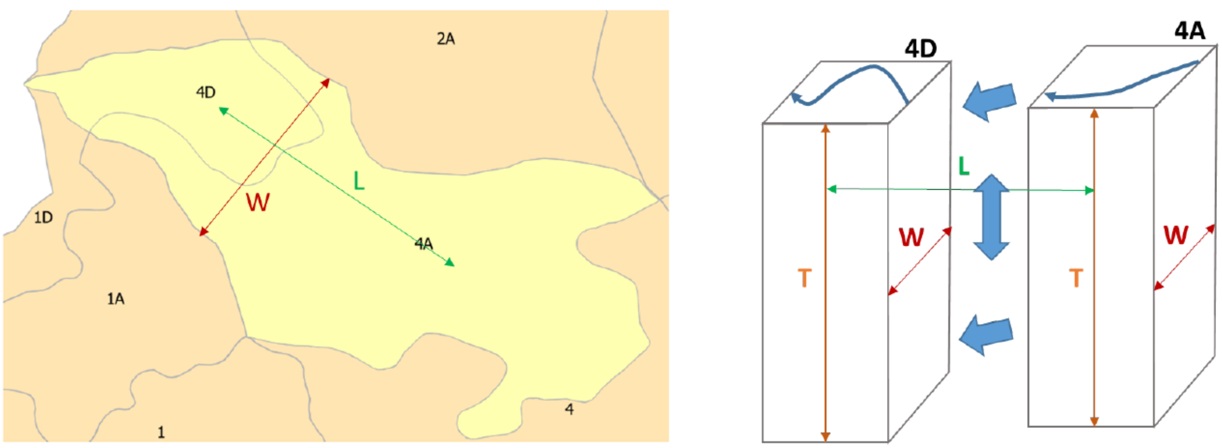

Figure A-2 Schematic of water budget zones.

A.3 Climate Inputs

A.3.1 Meteorological Stations

Meteorological data are collected for all regional and local stations within the study area. No individual station is generally expected to perfectly suit the conditions for all of the study area. The objective therefore is not to find the perfect record, but to develop a continuous record over a long period, which is broadly representative of the study area. This typically requires comparison of several stations to define differences. For precipitation, this is often done using mass plots, both over the full record and for comparing seasonal differences.

A.3.2 Temperature

Monthly temperature data are defined based on the long term climate record developed as described above. During this process, temperature variations by elevation and laterally can be investigated. For most studies, the available information is insufficient to determine changes laterally, but it can be generally assumed that the temperature will vary locally by elevation. If local data is available, the temperature change with elevation would be defined.

In the absence of local data, the temperature of each elevation band in the water balance is calculated using the following formula, assuming a temperature gradient of 6.5 ºC per kilometer (km):

$$T = T_s - 6.5(E-E_s)/1{,}000$$

Where:

- T = temperature of middle of elevation band (^oC).
- T_s = temperature at Reference site (^oC).
- E = elevation of middle of elevation band (m).
- E_s= elevation of Reference site (m).

A.3.3 Precipitation

The monthly precipitation data from a regional station or a synthetic string based on regional data are adjusted for location and elevation. Variations in precipitation are expected as a result of factors such as:

- Orographic effects resulting in more precipitation at higher elevations. This is an important factor for major storms approaching the area but is not a factor for small local storms, more common in summer.
- Rain shadow effects resulting in less precipitation on the lee side of mountains.
- Catch efficiency, particularly for northern latitudes and sites above the tree line.
- Transfer of snow into and out of drainages as a result of blowing snow.

Variations across the study area can be derived based on available knowledge of precipitation regionally and examination of available records. There may also be an opportunity to refine the precipitation model based on available streamflow and aquifer performance data during the calibration phase.

To account for orographic effects of precipitation, a non-linear relationship is applied as follows.

$$P = P_i a^{(H/100)}$$

Where:

- P = the monthly precipitation at the selected elevation (mm).
- P_i = the monthly precipitation at the reference site (mm).
- a = the orographic factor.
- H = the difference in elevation from the reference station (m).

Orographic factors of 1 to 1.1 are common in British Columbia, with higher values generally applied in the winter. To account for rain shadow and wind transfer of snow, each water balance zone was allowed a multiplier of precipitation from 1.0 to 1.5, to allow the precipitation and measured flows to be balanced.

To distribute precipitation between snow and rain, precipitation is defined as rain if the average monthly temperature was greater than a high base value (for example, 2^oC) and as snow if the average monthly temperature was below a low base value (for example, -2^oC). Between these temperatures, the ratio of precipitation as snow was varied linearly with the temperature. These temperature values can be adjusted to meet measured snowpack and runoff data.

A.3.4 Sublimation

Sublimation is complex and requires tabulation of a number of variables for a rigorous determination. This value is generally selected based on available published information for the region. In some studies, a value of 0.5 mm/day has been selected. Sublimation is allowed to occur throughout the year, and the snow is assumed to sublimate at the set rate until none remains on the ground.

A.3.5 Snowmelt

Although snowmelt can be estimated, the required meteorological parameters are often not available. Therefore, the snowmelt is estimated using a temperature index method. The first order estimate of the apparent snowmelt is as follows:

$$\text{Potential snowmelt (mm water equivalent per month)} = M(T-1).$$

Where:

T = the average monthly temperature in ^{o}C, and
M = the quantity of snow melted per ^{o}C per month

This equation is used to estimate the potential snowmelt for each month. The actual snowmelt is up to the potential after considering the available snow after sublimation. The water available each month is calculated as the sum of snowmelt and rainfall.

Snowpack is calculated for each elevation band based on snowfall, sublimation and snowmelt. Calculated snowpack can be compared to measured snowpack, available at many sites in British Columbia. This comparison needs to recognize that measured snowpack is for a specific site and may not represent the overall catchment. However, it is expected to be representative of the variation in snowpack over the years. The primary indicator of the snowpack is the spring runoff.

A.3.6 Evapotranspiration

Evapotranspiration can be estimated with a number of methods. Often it is calculated with a methodology following Thornthwaite (1948). This method is included in the water budget spreadsheet. First, the potential unadjusted monthly evapotranspiration (PET) is estimated based on the average monthly temperature in degrees Celsius.

$$\text{PET (mm/month)} = 16\left(\frac{10T_m}{I}\right)^{\alpha}$$

Where:

T = average daily temperature of middle of elevation band for the month (^{o}C).
$I = \sum_{i=1}^{12}\left(\frac{Ti}{5}\right)^{1.514}$ for $T > 0$.
$\alpha = 6.751\text{x}10^{-7}(I^3) - 7.71\text{x}10^{-5}(I^2) + 1.792\text{x}10^{-2}(I) + 0.49239$.

The unadjusted rate is then adjusted for the number of days in the month and the average number of hours in the day between sunrise and sunset, which varies with season and latitude. The number-of-days correction was achieved by multiplying by the number of days in the month and dividing by 30.

The equation used for the number-of-hours, latitude-based correction (H/12) is given by Glarner (2006) as follows:

$$H/12 = (24\cos^{-1}(-\tan(L)\tan(0.4093\sin(2\pi \text{int}(30.4m-15)/365-1.39))))/12\pi$$

Where:

H = average length of day (hours) for the month
L = latitude
m = month number (1 to 12).

Typically, the PET represents the evapotranspiration for a full vegetation cover on relatively flat tilled ground with no shortage of water. It is normal for the PET not to represent realistic conditions within monthly time spans, as soil moisture conditions can vary over the month. As a result, a factor (f) is provided to reduce the available PET. Actual evapotranspiration, AET, is related to PET but varies depending on landform, soil type, rainfall distribution, and vegetation type. In the Kelowna water budget study, two climate types were defined, which represent the different climatic conditions in the uplands and in the valley, and two estimates of AET were therefore considered.

AET is limited by the sum of snowmelt and rainfall in a given month, W, and also by the soil moisture content. Below the soil moisture capacity of the soil, the AET is reduced linearly with soil moisture. AET is therefore calculated as follows:

$$AET = \min(W, (S_2 + S_1)\, f\, (PET)/(2S_m))$$

Where:

W = sum of rainfall and snowmelt for the month.
S_m = soil moisture capacity. This represents the water-holding capacity of saturated soil, and generally ranges between 400 and 600 mm per meter of soil depth. A value of 400 mm was considered in this study, which generally corresponds to fine soil with relatively high clay content, which is representative of both the upland and valley soil in the vicinity of Okaganan Lake.
S_1 = soil moisture at the beginning of the month.
S_2 = soil moisture at the end of the month.
PET = the calculated PET for the elevation band.
f = the reduction factor for non-ideal conditions for evapotranspiration (0.7 is a reasonable starting value).

The resulting PET is typically compared against published values and against pan evaporation values, where available. In the groundwater budget model for the Kelowna aquifers, the calculated PET for an elevation for 450 masl, which is approximately 605 mm/yr, was compared to the Penman-Monteith estimate for evaporation from Okanagan Lake, which is 918 mm/yr. PET is typically 70% of lake (open water) evaporation, or about 640 mm. The calculated PET of 605 mm/yr is therefore reasonably close to this value.

A.4 Flow Distribution

A.4.1 Soil Water Balance

The monthly soil water balance is calculated assuming the soil profile can retain moisture from month to month. A maximum soil moisture retention is assumed to represent average site conditions. Consideration of sublimation, snowmelt, rainfall, and AET allow for an estimation of water available for infiltration and runoff. The soil moisture is calculated for the end of each month (S_2) based on the following formula:

$$S_2 = W + S_1 - (S_2 + S_1)\, f\, (PET)/(2S_m)$$

Where:

W = sum of rainfall and snowmelt for the month.
S_m = soil moisture capacity.
S_1 = soil moisture at the beginning of the month.
S_2 = soil moisture at the end of the month.
PET = the calculated full PET.
f = the reduction factor for non-ideal conditions for evapotranspiration.

Solving for S_2

$$S_2 = (W + S_1(1 - f\,(PET)/(2S_m)))/(1 + f\,(PET)/(2S_m))$$

Knowing the soil moisture at the beginning and the end of the month provides an estimate of the soil moisture change.

A.4.2 Surplus Water

The surplus water or water available for runoff and recharge (V) is then calculated by subtracting the actual evapotranspiration and soil moisture change from the rainfall and snowmelt for the month (W).

$$V = W - f(PET)(S2 + S1)/\ (2S_m) - (S2 - S1)$$

Where:

V = surplus water.
W = rainfall and snowmelt for the month.
f = the reduction factor for non-ideal conditions for evapotranspiration.

This unit value of surplus water is multiplied by the zone area for each zone defined in the model domain, to provide input to the water balance calculation.

A.4.3 Groundwater Recharge

Groundwater recharge of the water available for runoff and recharge is estimated with an adjustable rate to allow variation in response to effects from surface conditions, soil permeability, and available storage capacity. The infiltration (I) is set equal to available surplus water, V, up to a volume equal to the product of an infiltration rate, k_1, and the zone area, A (k_1A). For wetter months, a fraction (k_2) of the remaining available water is also infiltrated ($k_2(V - k_1A)$). Therefore:

For surplus water less than or equal to k_1A

$$I\ (m^3/month) = V$$

For surplus water greater than k_1A

$$I\ (m^3/month) = k_1A + k_2(V - k_1A) = k_2V + k_1A(1 - k_2)$$

This procedure provides an estimate of groundwater recharge that is evident with a monthly water balance. Interflow and groundwater on very short paths is included with surface water with this monthly time increment.

A.4.4 Upper Catchment Groundwater Storage and Discharge

A relatively simple linear reservoir model is used in the zones corresponding to the upper sub-catchments of the model domain to store and release groundwater, since these zones correspond to minor bedrock and alluvial aquifers. Water is recharged into storage in each water balance zone. The recharged water accumulated within groundwater storage is released at a rate determined by the product of the average volume of water in storage (Z1/2 + Z2/2) and a discharge factor (j). The factor, j, is adjusted to account for the number of days in the month. Monthly discharge was therefore set equal to:

$$D = j(Z_1/2 + Z_2/2)$$

In this way, month-to-month storage is accounted within each zone and groundwater discharge increases with increasing storage. The volume of water in storage is, therefore, a sum of the storage in the preceding month (Z_1) plus the volume of water entering the system (I) minus the quantity discharged (D). Therefore:

$$Z_2 = Z_1 + I – D = Z_1 + I – j(Z_1/2 + Z_2/2)$$

Solving for Z_2:

$$Z_2 = (I + Z_1(1-jZ_1/2))/(1 + jZ_1/2)$$

Lower Discharge factors results in more consistent discharge rates over the year.

Groundwater is discharged from a water balance zone either as groundwater flow into a downstream zone or as discharge to surface water within the zone. The groundwater leaving the zone as groundwater is calculated with Darcy's Law, taking the product of estimated values for transmissivity (T), width (w), and hydraulic gradient (i):

$$D_{off\text{-}site} = Tiw$$

The remainder is discharged on site to join the surface water:

$$D_{on\text{-}site} = D - D_{off\text{-}site}$$

A.4.5 Surface Water Detention and Storage

The quantity of water reporting to surface water corresponds to runoff, which is the difference between the available surplus water and recharge. Some of this water is expected to run off within the month and some would be detained in storage. Surface water storage is included to accommodate areas such as ponds and wetlands that are not modeled as distinct water bodies, as well as rainfall and snowmelt that occurs late in the month. Within this water balance methodology, these detention features were managed with the same type of detention and linear reservoir model as groundwater storage. However, the discharge factor is always higher for surface water.

A.4.6 Summary of Flow Calculations in Upper Catchments

For each water balance zone associated with the upper sub-catchments of the model domain, where minor bedrock and alluvial aquifers are located, the water available for runoff and recharge is calculated using the linear reservoir release method described in Section 1.4.2. Recharge is calculated and added to groundwater in storage. Groundwater is stored and released at a rate proportional to the average volume in storage. The groundwater released is passed on to the next zone downstream as groundwater up to an amount defined by Darcy's Law. The remainder of the released water is discharged within the zone and is passed on to the next zone downstream with the surface water. The water that is not recharged is either passed on to the next water balance zone downstream as immediate runoff or is added to surface water detained in the water balance zone. In the cases with surface water detention, the water not detained is passed on as immediate runoff. Detained water is released as a proportion of the average volume of water detained.

A.5 Kelowna Aquifer Groundwater and Surface Water Interchanges

A.5.1 Groundwater Interchange between Aquifer Areas

Contributions to and discharge from groundwater in the Kelowna Aquifer Areas include:

- Upslope groundwater zones
- Adjacent aquifer areas
- Stream beds
- Meteoric recharge
- Water wells
- Water returns (irrigation and septic discharge)

The direction of flow from one water budget zone to another is not necessarily known in advance. Flow directions may be influenced by the surface water paths (eg., Lake Okanagan, Mill Creek, Mission Creek, Bellevue Creek) or by the location and rate of pumping or the application location of irrigation. This is an especially important consideration with different development scenarios. To accommodate this uncertainty, the volume of water in storage (Z) in each zone was converted to a representative water level (h) as:

$$h = Z/A/n$$

Where A is the surface area of the zone, n is the drainable porosity, and Z is the stored volume calculated for the end of the previous month. The following values of drainable porosity were used in the model: 0.02 for bedrock aquifers, 0.3 for the overburden aquifers near the uplands and 0.2 for the alluvial aquifers close to Okanagan Lake.

The groundwater exchange (Q) was then calculated by:

$$Q = T\,(h_{1-}\,h_2)W/L$$

Where h_1 and h_2 represent the heads in each zone, W represents the width of the contact surface between the two zones and L is a representative distance between the mass centre of the zones. This is calculated for each possible connection. Automatic iterations leading to a set of groundwater levels that meet the water balance conditions are carried out in the spreadsheet associated with the groundwater budget model.

A.5.2 Groundwater - Surface Water Interaction

Groundwater in some cells will also interact with the streams and the lake. This groundwater/surface water interaction was estimated with consideration of water levels and the direction of flow. Stream flow losses to groundwater were assumed to depend primarily on the flow rate in the stream as the higher flow will result in deeper flowing water and a longer wetted perimeter.

The maximum inflow to groundwater was calculated when the calculated groundwater level was below the lowest stream elevation. The formula used to calculate this inflow was:

$$I = Bn + (Q – Bn)P$$

Where B and P are factors dependent on ground and channel conditions as well as the length of the channel and n is the number of days in the month.

The maximum flow discharging from the aquifer to the steam channel was calculated when the groundwater level was above the highest stream elevation. The flow was estimated based on a conductance value (c) and the elevation of the groundwater level with respect to the level of the streambed. The wetted perimeter and the height of the stream stage were assumed to have limited effect on this estimate. The formula for this was:

$$J = C$$

Where C is the conductance value multiplied by the length of the stream.

The calculated groundwater level may be between the maximum and minimum stream elevation. In general, some of the stream will be losing and some of the stream will be gaining. A net change was estimated with the formula:

$$\text{Net interchange} = I\,(h_{max} - h_r)/(h_{max}-h_{min}) - J\,(h_r - h_{min})/(h_{max}-h_{min})$$

A.6 Reservoir Storage and Release

There are a number of reservoirs at the headwaters of Hydraulic, Mission, Mill and Scotty Creeks. Water is stored in these reservoirs to provide a reliable water supply during the dry season. The reservoir at Hydraulic Creek and Mission Creek were operated according to the guidelines reported by Water Management Consultants (2010). For Scotty Creek and Mill Creek, the reservoir valves were closed for May and June. For the rest of the year, discharge was a constant amount, except for July and August when the discharge was double the standard amount. The standard discharge rate was then adjusted to provide the maximum amount without the reservoir drying.

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APPENDIX B: STREAMFLOW BUDGET MODEL CALIBRATION

B.1 Introduction

The water budget or watershed model adopted for this project is very similar to that described in USGS OF 2007-1088 (USGS, 2007), and to the method employed in the Water Budget Project for the Regional District of Nanaimo (Waterline Resources, 2013). The methodology includes both groundwater and surface water components, thereby providing an opportunity to include both groundwater data and streamflow data in the assessment of groundwater recharge and discharge rates. A key output of this water budget methodology is therefore an understanding of the groundwater-surface water interaction in the study area. The model methodology is presented in detail in Appendix A.

As the Kelowna Aquifers are recharged in part by stream losses to groundwater, an understanding of the surface water budget is required. The surface water budget requires calibration in order to simulate representative water management scenarios.

Calibration targets were selected based on the presence of continuous flow data for streams within unregulated catchments, i.e. without surface water withdrawal and preferably without reservoir storage.

The calibration targets were monthly streamflows. The model was calibrated by attaining as close a match as possible between the modelled and measured streamflows. Calibration parameters included:

- Multiplier of precipitation record to account for deviation of developed precipitation string to average conditions over the study site. This may include seasonal adjustment.
- Temperature range of snowfall versus rainfall.
- Snowpack melting rate.
- Factor adjusting evapotranspiration.
- Groundwater recharge and discharge rates.
- Surface water detention and discharge rates.

The process included:

- Collection of climate data (monthly precipitation and average monthly temperature) from climate stations in the study area.
- Collection of natural stream flow data in the study area and measurement of the corresponding catchment areas, sub-divided into elevation bands.
- Input of climate and area data to the water budget model spreadsheets.
- Adjustment of precipitation estimates to attain a reasonable correlation of modelled to measured water volumes. Correlation of the measured and calculated streamflow mass (Unit Mass). The calibration may include adjustment of precipitation, evaporation and groundwater outflow to the model domain. The primary factors to complete this step were:
    - Adjustment of the winter and summer orographic factors to mirror the expected precipitation increase with elevation in the basin; and
    - Adjustment of a local precipitation multiplier to define the natural variation of precipitation with location within the basin.
- Correlation of measured and calculated monthly streamflows (Flow Monthly History). This includes hydrographs and a plot of measured versus calculated flows. Improvement in the correlation may require changes in snow versus rain parameters and snowmelt parameters, so that the precipitation hydrographs are similar. Deviations of some months is not unusual as the

rainfall records are not perfect for each part of a study area. Dry period flows are adjusted by varying the groundwater and surface water discharge factors.

- Adjustment of groundwater recharge estimates for each of the calibration basins so that base flows (particularly winter low flows) quantities and drain down rates were appropriately modeled. This primarily involved correlation of measured and calculated flow distributions (Flow Duration Curves). Correlation of these plots allows the correct representation of the statistical distribution of flows rather than of streamflows in individual months. Groundwater recharge and discharge is adjusted by fitting to the low flow portion of the curves. Surface water detention and discharge is adjusted by focusing on the middle portion of the curves. The factors used to achieve this for each catchment were:
    - A factor controlling the recharge rate which defined the volume of water discharged to the stream; and
    - A factor controlling discharge rate, which controls the modeled drain down rate.
- Comparison of measured groundwater level records with calculated storage change values with consideration of expected aquifer storage parameters. Often, a poor correlation between measured and modelled groundwater levels is attained in terms of magnitude of seasonal changes, even when the model reproduces a realistic water budget for a zone. This is because measured groundwater levels may be significantly affected by nearby pumping, whereas modelled groundwater levels reflect average conditions within the zone.
- Adjustment of the surface water detention and release for each of the calibration basins. This was calibrated using a method similar to groundwater recharge, storage and discharge.
- The results of the calibration process can be presented graphically by means of the plots described above.

B.2 Selection of Calibration Climate and Streamflow Data

B.2.1 Climate Data

Monthly precipitation and average monthly temperature data were collected from sites in the study area from the Historic Climate Data section of the Environment Canada Data Access Tool, with the objective to create a continuous long term record. The record selected was composed of data from the four stations presented in Table B-1 and shown on Figure B-1.

Table B-1 Climate stations selected for model calibration.

Station Name	Easting (UTM WGS84)	Northing (UTM WGS84)	Elevation (masl)	Record Frequency	Period of record
Kelowna	322864	5530430	353.6	monthly	Jan-01-1900 – Dec-31-1962
Kelowna A	329001	5537641	429.5	daily	Jan-01-1968 – Dec-31-2004
Kelowna CDA	326215	5522902	484.6	monthly	Jan-01-1950 – Apr-30-1970
Kelowna MWSO	327744	5535823	456.0	monthly	Jan-01-1994 – Feb-28-2007

The data was assembled with no correction for elevation. Double mass curves were created where possible. These curves indicated that there was minimal variation with location or elevation for these four stations.

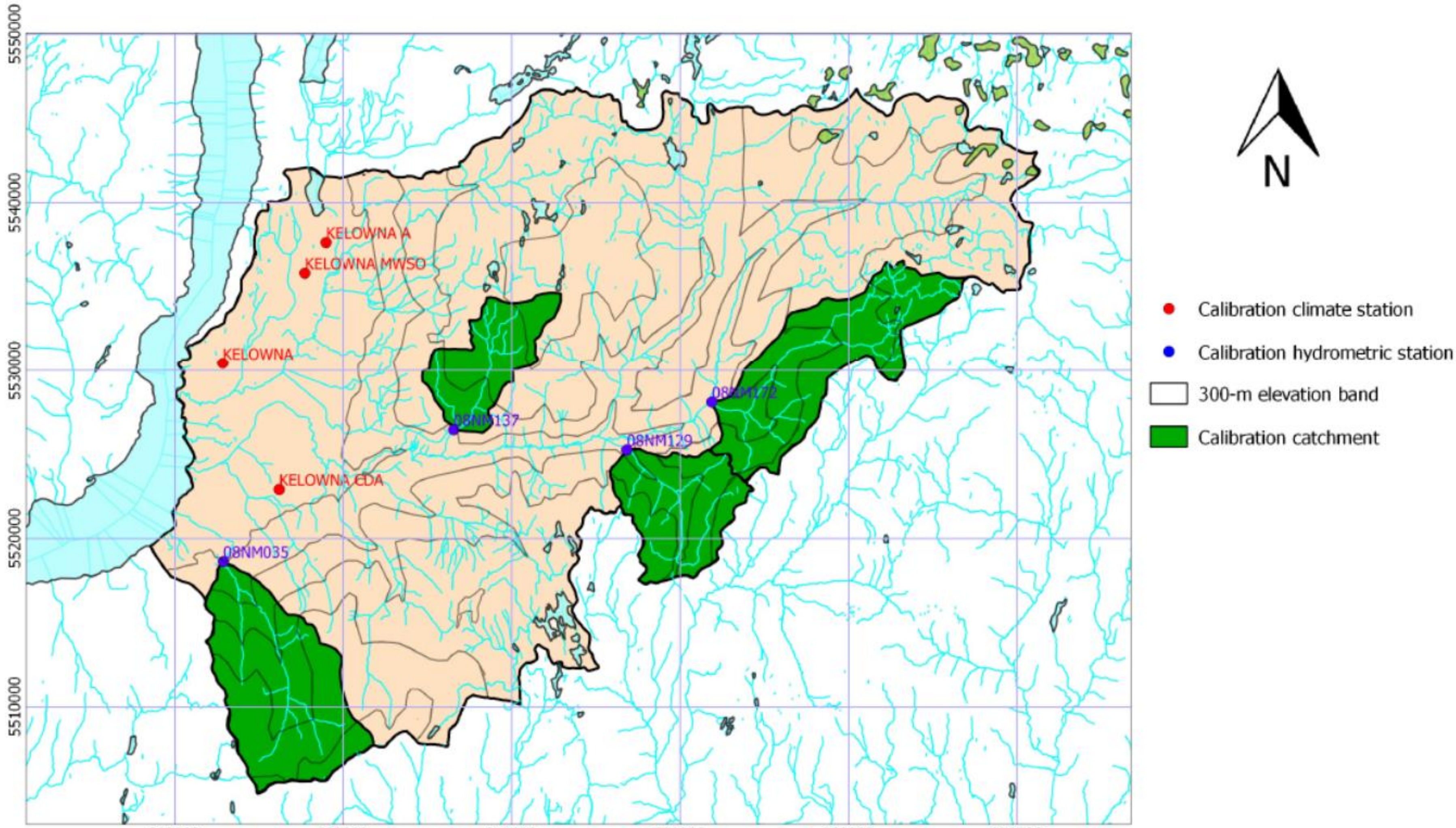

Figure B-1 Calibration catchments with elevation bands, climate and hydrometric stations.

No climate data was available for 19 months within the period January 1900 – December 2015, which was considered for the model calibration. For these 19 months, an average of the corresponding months in the following five years was used to calculate infill precipitation values.

B.2.2 Stream Flow Data

All Water Survey of Canada (WSC) data for gauged flows within the study area were downloaded from the Environment Canada Data Access Tool. The gauges with natural flows records spanning over several years were selected for calibration of the climate model. The four selected gauges, which represent natural (i.e. unregulated) flows and have a continuous data set, are presented in Table B-2 and shown on Figure B-1.

Table B-2 Hydrometric (WSC) stations selected for model calibration.

Station Name	Station Number	Easting (WGS84)	Northing (WGS84)	Period of record
Bellevue Creek near Okanagan Mission	08NM035	322898	5518620	1920 - 1986
Joe Rich Creek near Rutland	08NM129	346855	5525243	1964 - 1987
Daves Creek near Rutland	08NM137	336576	5526442	1965 - 1986
Pearson Creek near the mouth	08NM172	351903	5528098	1970 - 1987

B.2.3 Discretization

Each of the budget zones associated with the catchments selected for calibration was discretized by 300-m interval topographic elevation bands, starting from the elevation of 300 masl, as shown on Figure B-1. Representative climate conditions (temperature and precipitation) were calculated for the mid-value of each elevation band. Table B-3 presents the areas of each of the calibration zones and each of the elevation bands used in the calibration process.

Table B-3 Calibration zone areas (Km^2) by elevation band.

	300m to 600m	600m to 900m	900m to 1200m	1200m to 1500m	1500m to 1800m	1800m to 2100m	TOTAL
Bellevue Creek near Okanagan Mission	-	3.89	8.97	22.83	35.27	6.83	77.80
Joe Rich Creek near Rutland	-	1.17	13.34	13.21	15.79	-	43.51
Daves Creek near Rutland	-	-	10.45	18.28	5.22	-	33.95
Pearson Creek near the mouth	-	-	8.76	23.73	25.56	15.07	73.12

B.3 Flow Calibration

For each calibration zone, the water available for runoff and recharge was calculated. The calibration process allows a reasonable estimate of flow to be applied to the streams flowing over the Kelowna study aquifers.

B.3.1 Mass Calibration

The model calibration was accomplished by plotting the mass (cumulative flow volume) with time for both measured flows and modelled flows. The precipitation contributions to the budget zones were adjusted primarily by varying the precipitation base elevation and the orographic factor. These were set equal to the same for all zones. A precipitation multiplier was assigned to each calibration zone until the measured and synthesized mass plots were similar. The resulting unit mass plots are shown on Figures B-2a,b,c,d.

The selected universal factors were:

- A climate base elevation of 800 m.
- An orographic factor of 1.1 in winter (December through April) and 1.05 for the remainder of the year.
- A factor reducing PET to 70% of calculated.
- Soil moisture capacity of 400 mm.

Table B-4 presents the factors and resulting precipitation by elevation for each calibration zone.

Table B-4 Precipitation Multiplication Factor and Resulting Precipitation (mm) in Elevation Bands

Zone	Multiplication Factor	300m to 600m	600m to 900m	900m to 1200m	1200m to 1500m	1500m to 1800m	1800m to 2100m
Bellevue Creek near Okanagan Mission	0.82	-	255.0	312.8	385.6	477.6	594.5
Joe Rich Creek near Rutland	0.93	-	289.2	354.8	437.3	-	674.3
Daves Creek near Rutland	0.89	-	-	339.5	418.5	-	645.3
Pearson Creek near the mouth	1.22	-	-	465.4	573.7	710.6	884.5

B.3.2 Groundwater Recharge and Discharge Calibration

The groundwater recharge, storage and discharge were estimated by fitting calculated to measured stream flow time histories and stream flow duration curves. The inputs are essentially the estimated groundwater recharge, which is based on the first fixed quantity of available water plus a percentage of the remaining available water. The discharge rate is adjusted based on a fixed percentage of the volume of water in storage. The resulting groundwater recharge rates varied substantially between the various budget zones. The highest average rate was 66 mm/ year for Pearson Creek which was 23% of the water available for recharge and runoff. The lowest was Bellevue at 9 mm/yr which was 8% of the water available for recharge and runoff. The plots of observed and modelled flow duration curves and streamflow monthly time histories are shown on Figures B-3a,b,c,d and B-4a,b,c,d, respectively.

B.3.3 Surface Water Detention and Storage

The surface water detention, storage and release includes small ponds and interflow. This factor also provides averaging of the effects of rainfall and snowmelt late in the month that is measured in the following month. The average annual volume of water estimated for surface water detention and interflow ranged from near zero for Pearson to 58 mm/yr for Joe Rich.

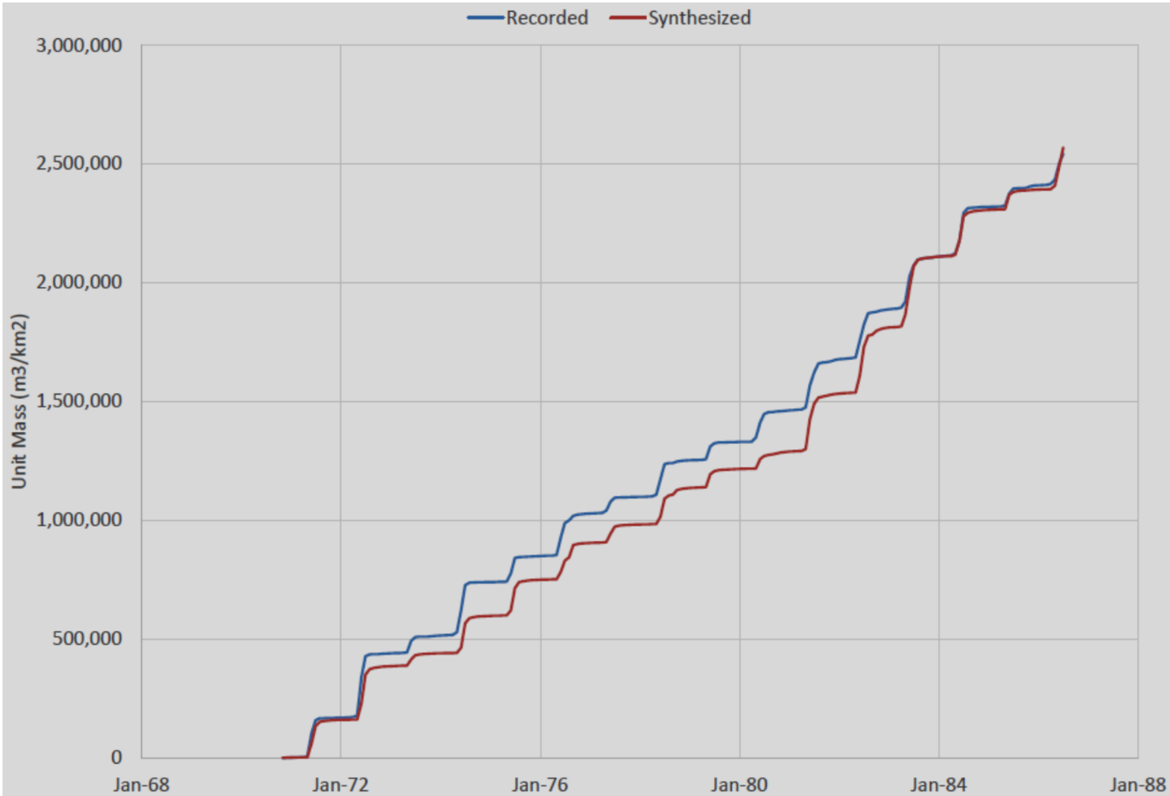

Figure B-2a Bellevue Crk gauge – unit mass.

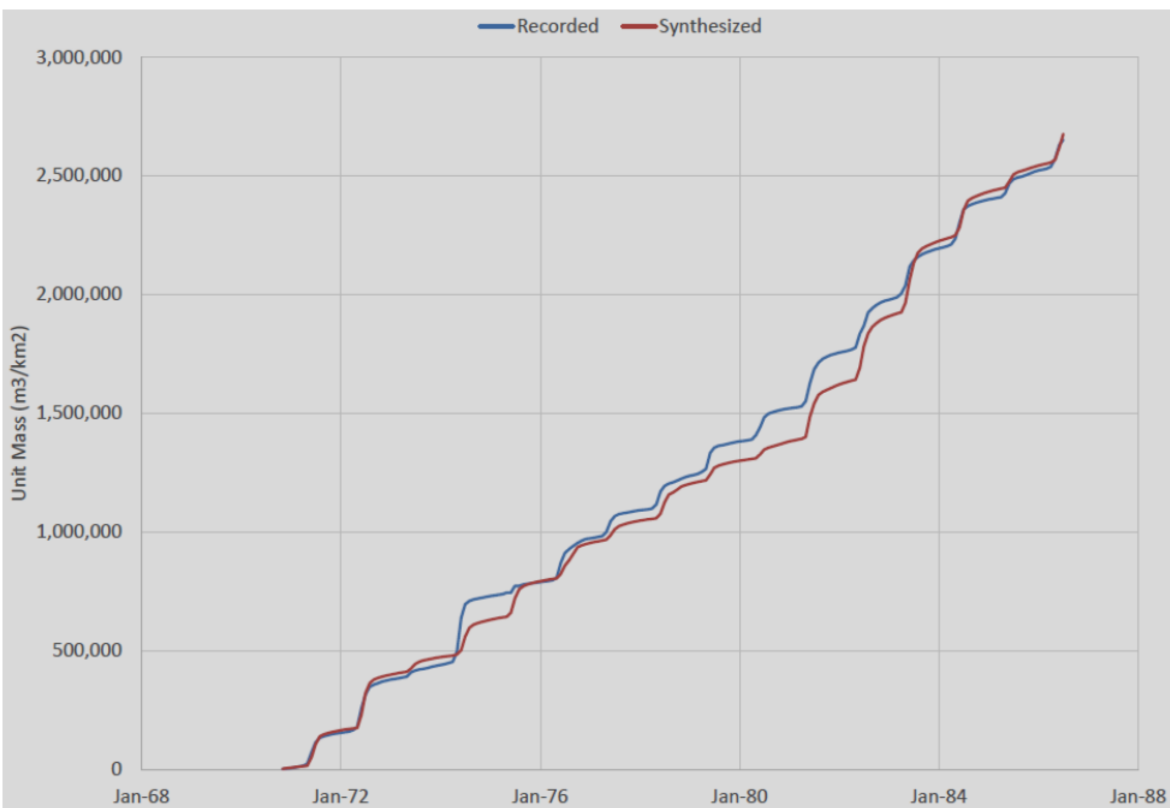

Figure B-2b Joe Rich Crk gauge – unit mass.

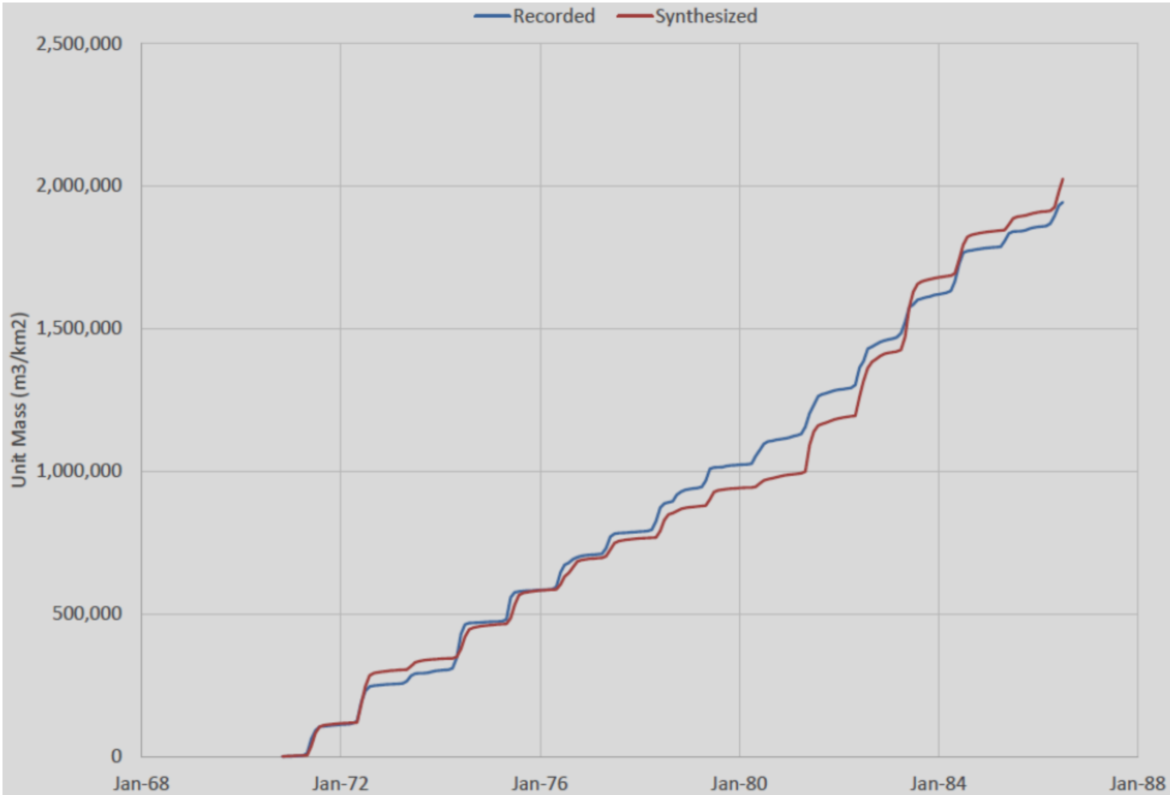

Figure B-2c   Daves Crk gauge – unit mass.

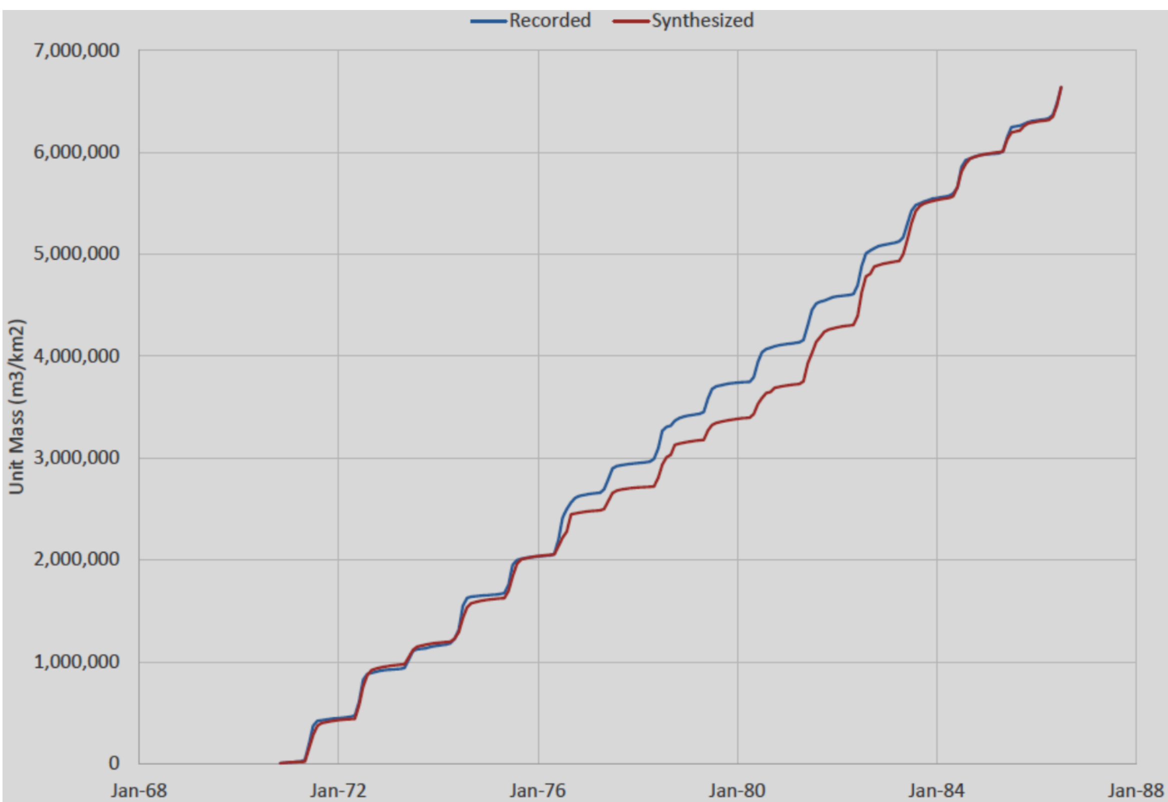

Figure B-2d   Pearson Crk gauge – unit mass.

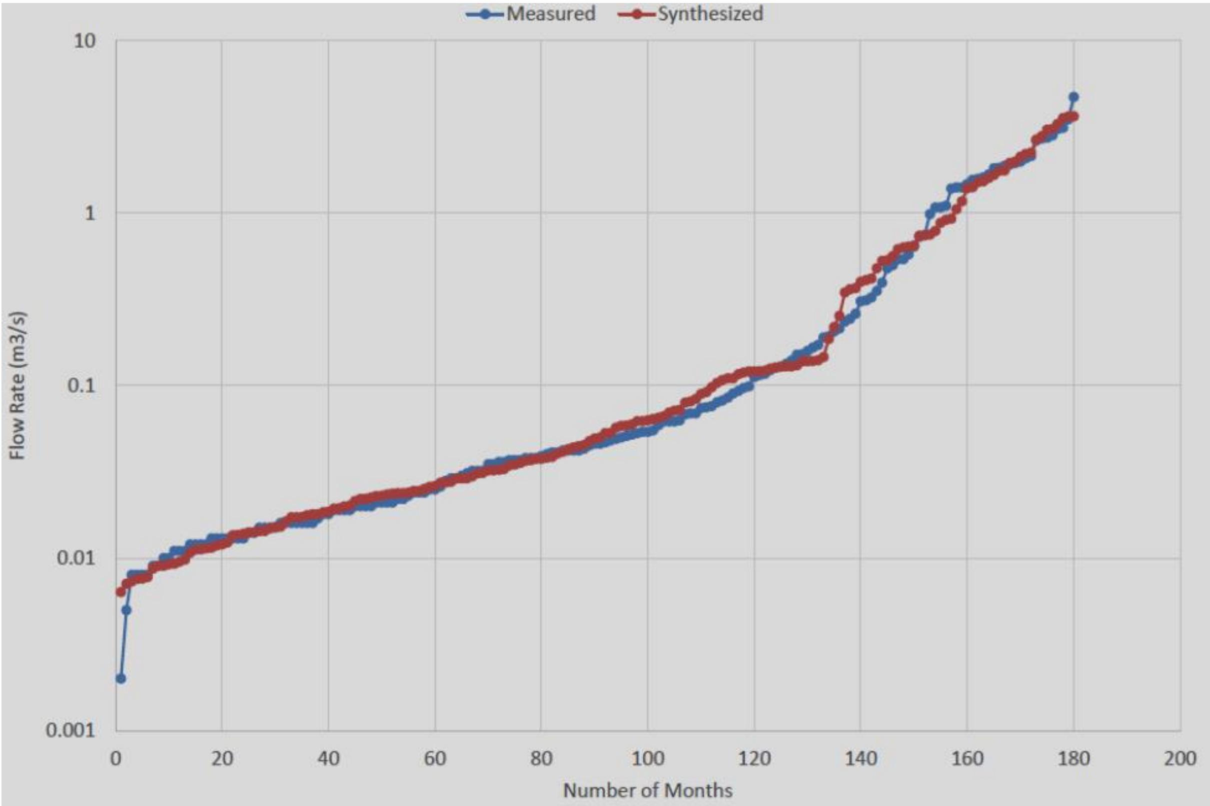

Figure B-3a   Bellevue Crk gauge – Flow duration curve.

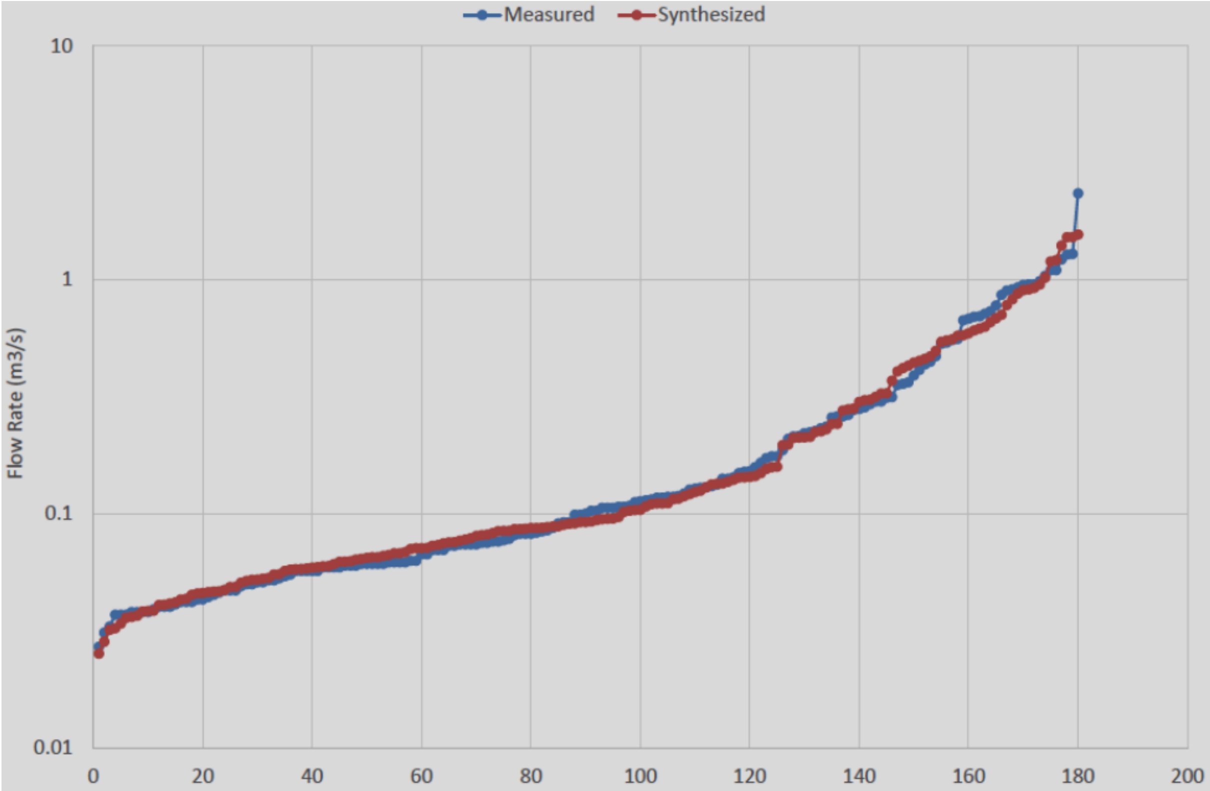

Figure B-3b   Joe Rich Crk gauge – Flow duration curve.

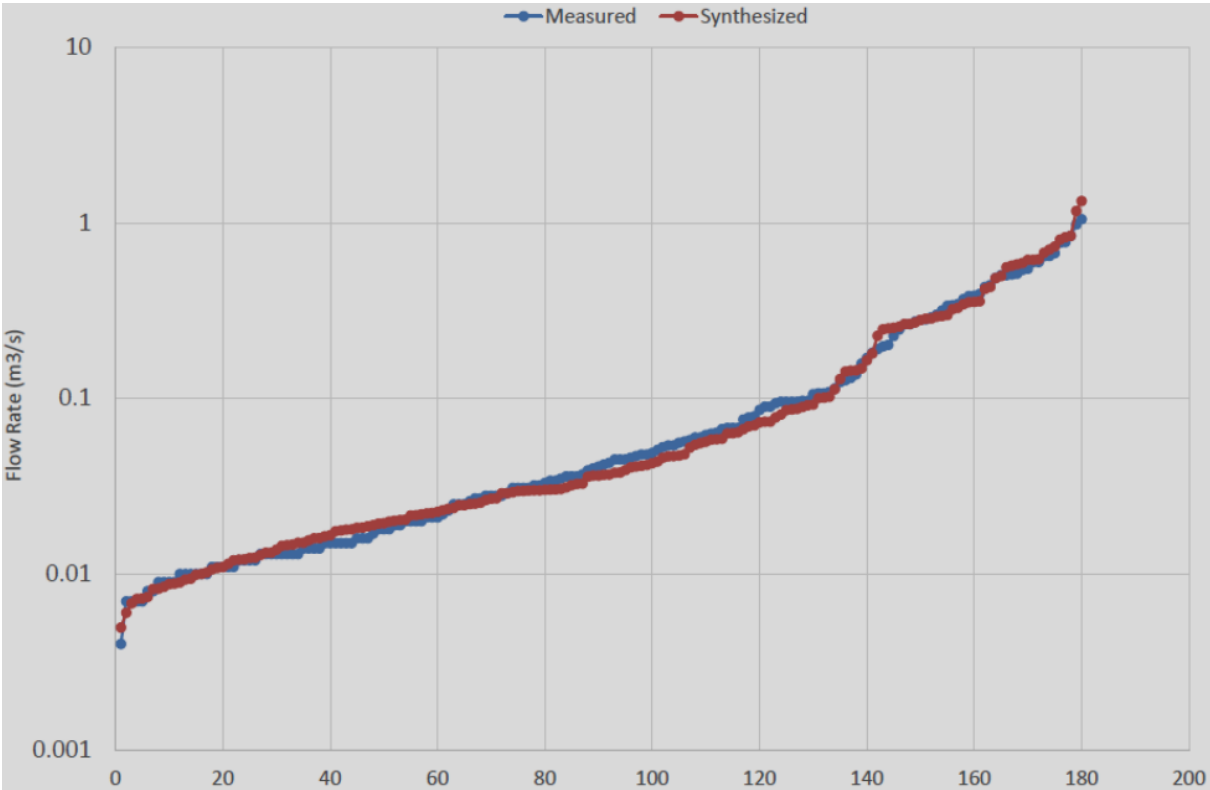

Figure B-3c   Daves Crk gauge – Flow duration curve.

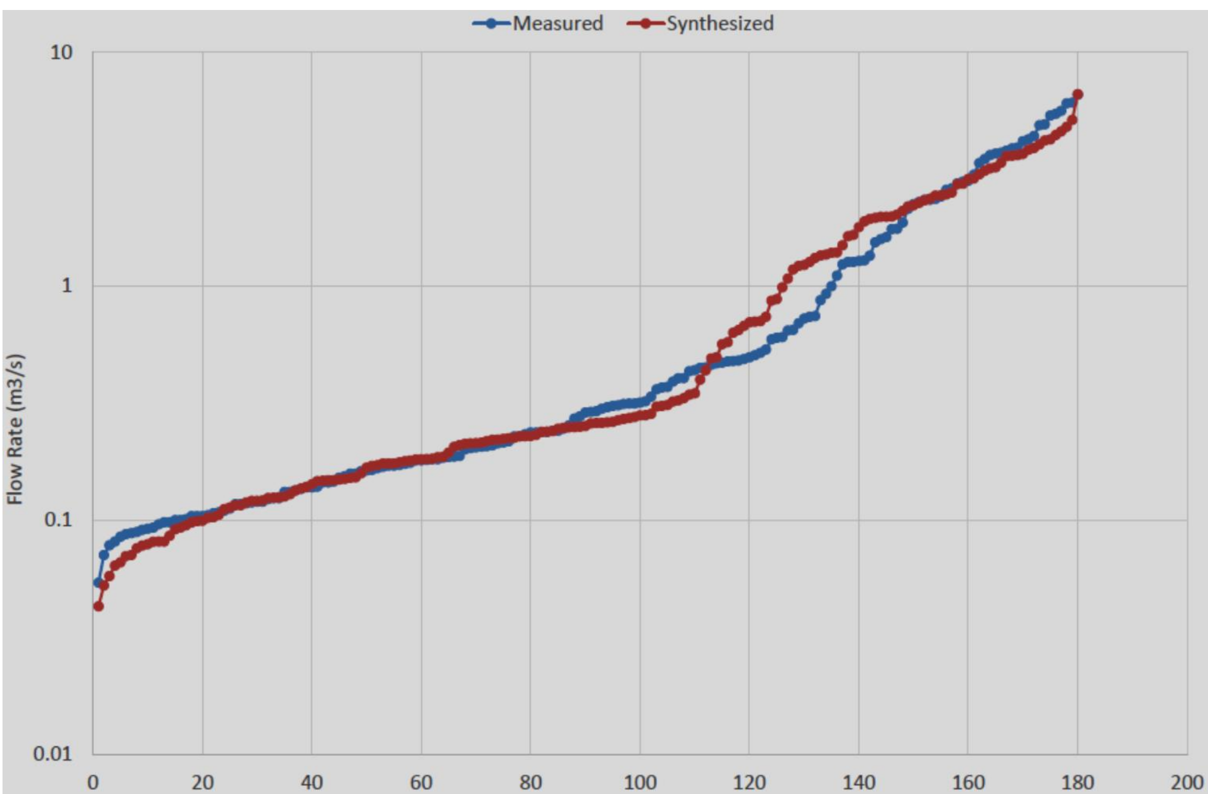

Figure B-3d   Pearson Crk gauge – Flow duration curve.

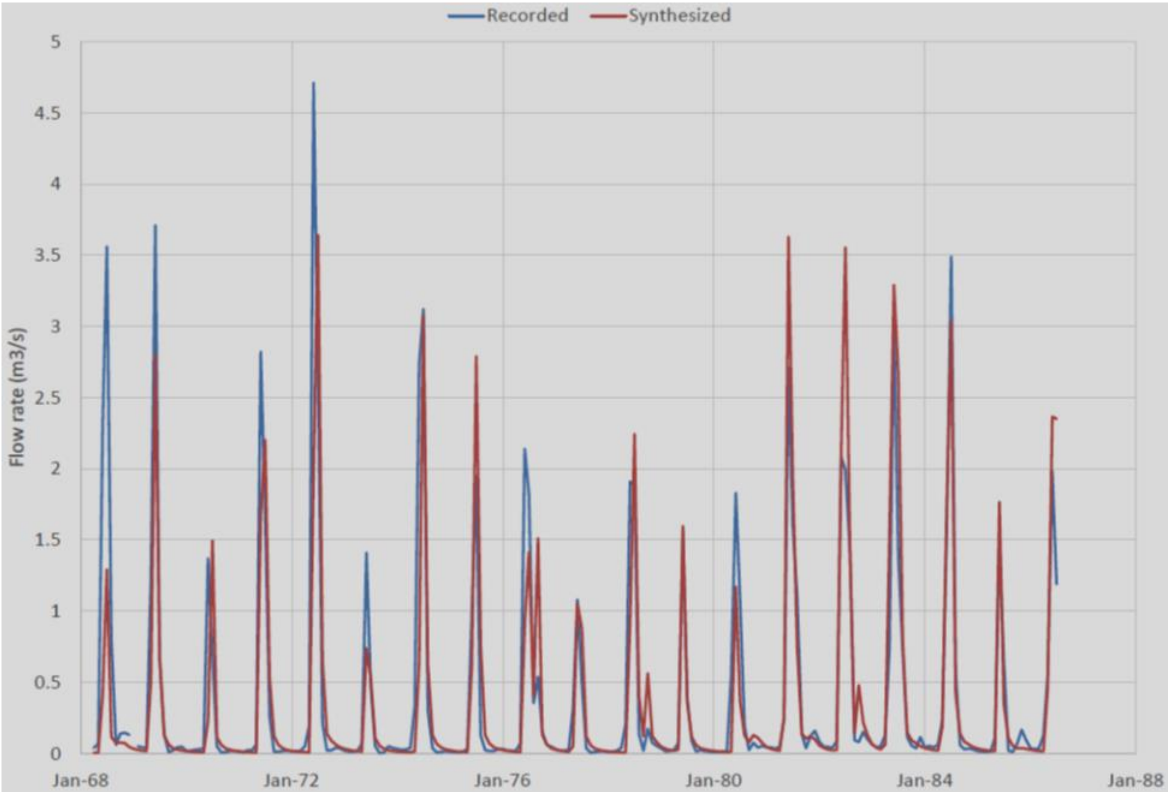

Figure B-4a   Bellevue Crk gauge – Monthly time series.

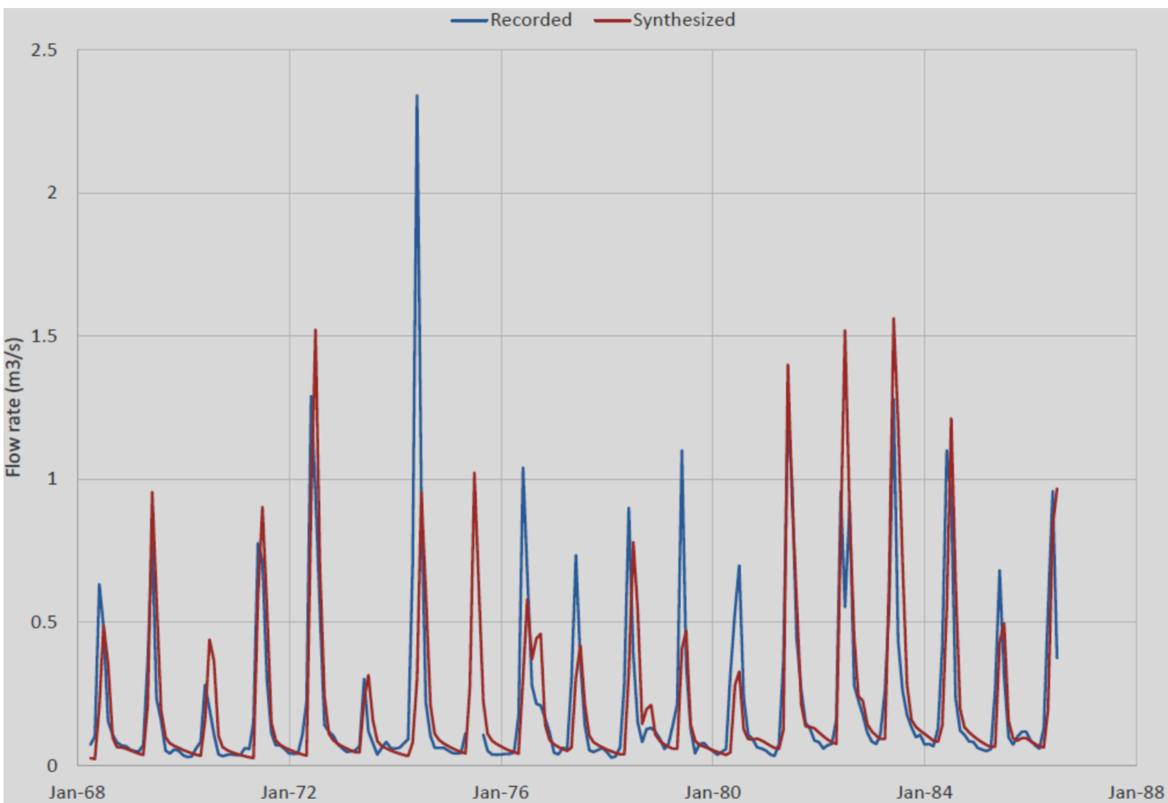

Figure B-4b   Joe Rich Crk gauge – Monthly time series.

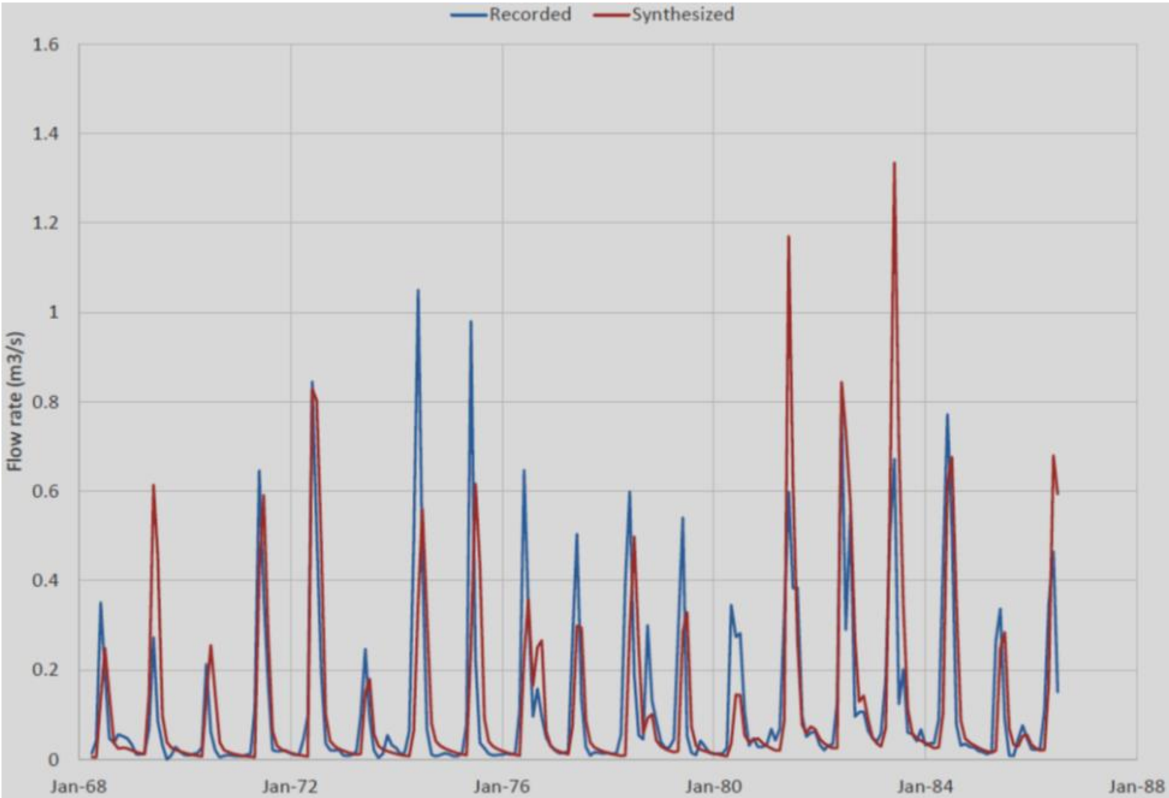

Figure B-4c Daves Crk gauge – Monthly time series.

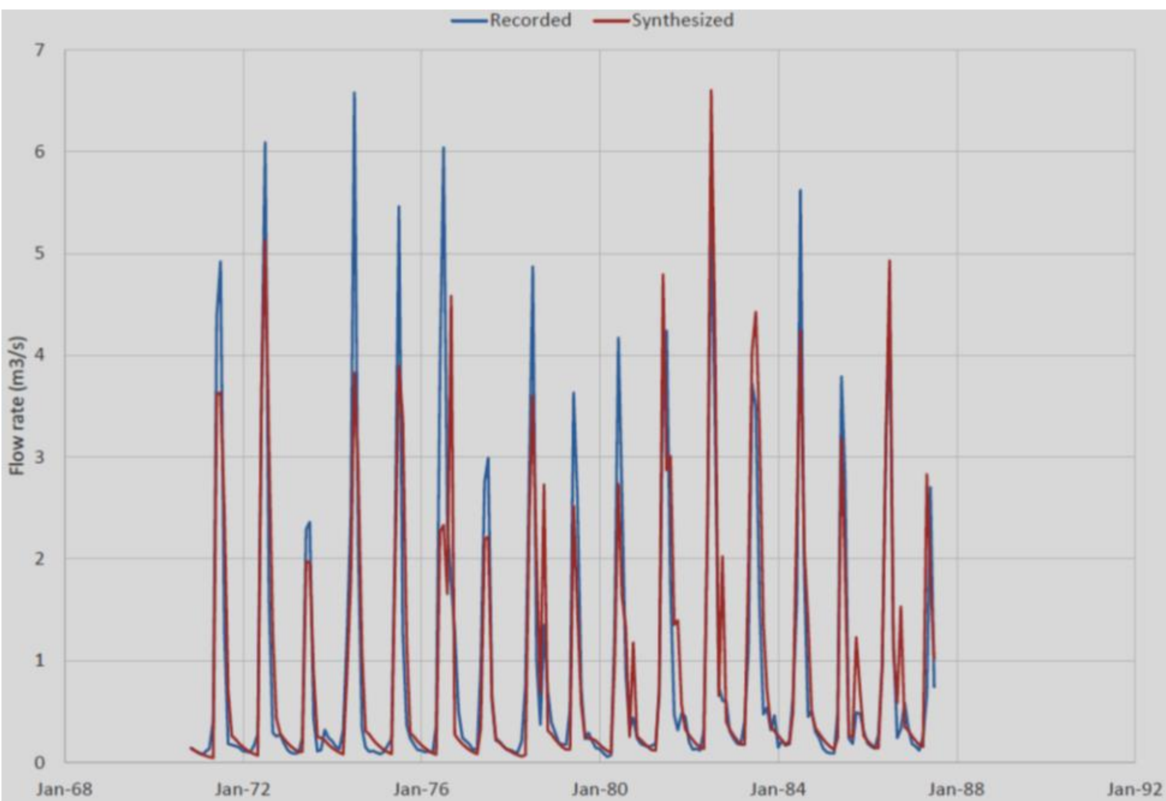

Figure B-4d Pearson Crk gauge – Monthly time series.