Spatial and Temporal Changes in Groundwater Flux to Gaining Streams

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Overview

In many areas of Canada, stream flow is sustained by groundwater inputs (baseflow) during the annual summer low flow period. As a result, streams can be sensitive to changes in groundwater fluxes during this period. Low flows can be critical for aquatic habitat. The low flow period coincides peak demand for groundwater and surface water. Therefore, understanding the groundwater processes and the timing of events influencing low flows is important for water management. Seasonal and interannual variations in climate, particularly precipitation, have the potential to alter patterns of groundwater recharge, groundwater contributions to baseflow, and stream discharge.

This study aims to quantify and compare changes in the groundwater flux during the low flow period to two gaining streams (Fishtrap and Bertrand Creeks) situated in the Lower Fraser Valley of British Columbia, Canada. These two streams are located approximately 8 km apart, both within the Abbotsford-Sumas aquifer (Figure 1).

Stream hydrometric data for the period 2008 to 2010 show marked differences in the stream response and discharge between the years, particularly over the low flow period. During this period, annual precipitation amounts increased slightly; there was increased winter precipitation, but decreased summer precipitation in 2009 and 2010 relative to 2008. Results suggest that these streams respond to a combination of the summer runoff and the groundwater recharge from the preceding winter period.

Climate and Hydrology

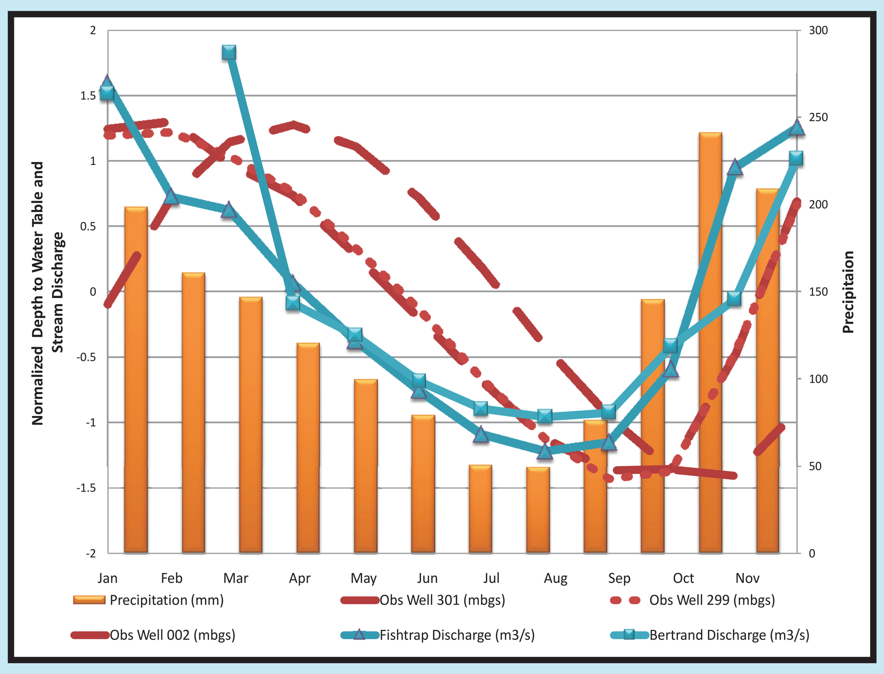

Figure 2: Mean annual precipitation, stream discharge, and groundwater levels for the study area.

Fishtrap and Bertrand creeks originate at low elevation and have rainfall dominated flow regimes. In the area of the watersheds, the average annual precipitation is 1500 mm, with 70% falling between October and May, and less than 100 mm as snow.

Figure 2 summarizes the annual patterns in the climate and hydrology:

- Minimum stream discharge occurs in late summer, approximately one month after the minimum precipitation.
- Groundwater levels lag minimum stream discharge by approximately three months.

During the low flow period, stream flow is assumed to be sustained dominantly by groundwater discharge.

Bertrand Creek

Fishtrap Creek

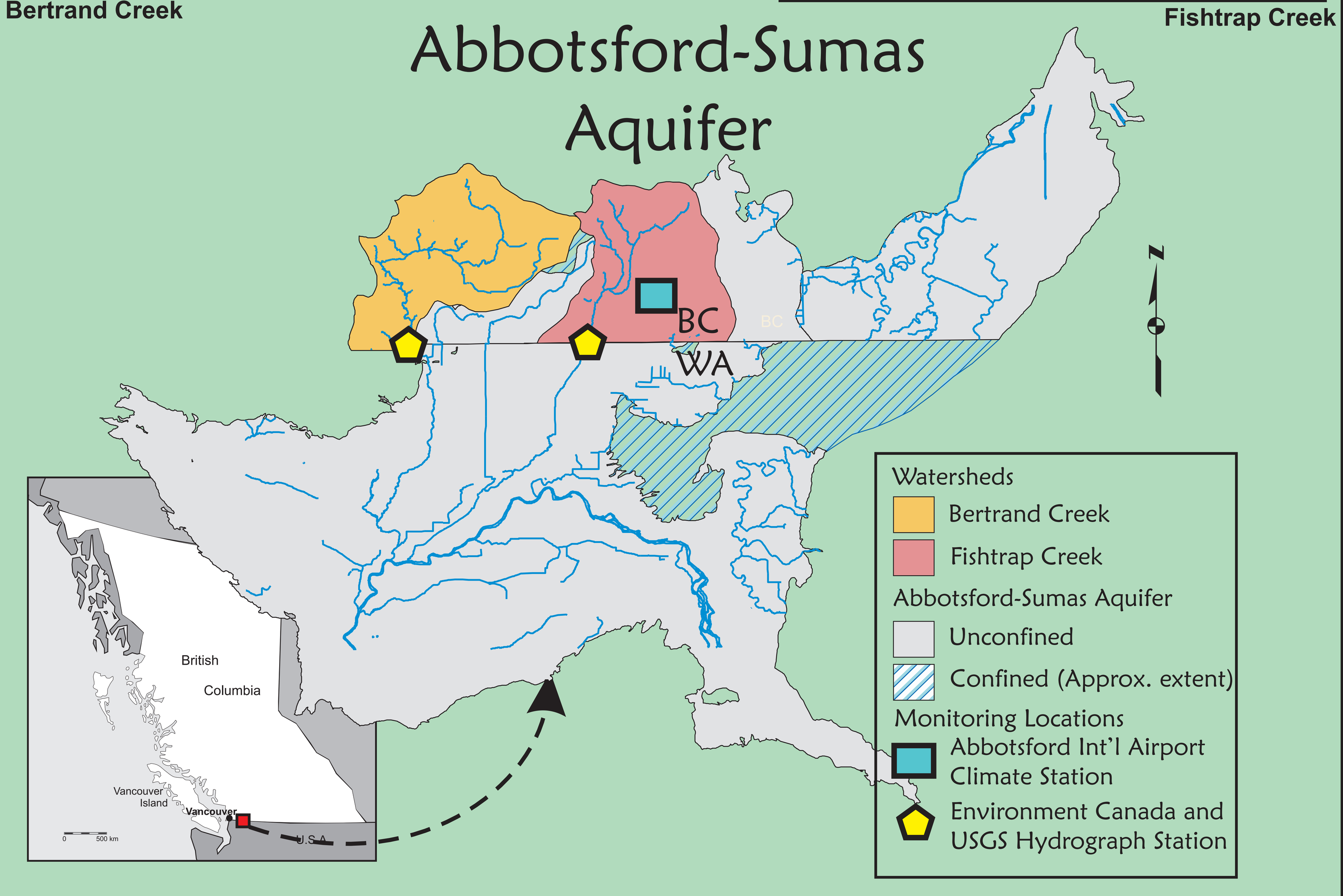

Figure 1: Abbotsford-Sumas aquifer and the location of the study watersheds on the Canadian side of the Abbotsford-Sumas aquifer. In the Canadian portion of the aquifer, the area of Bertrand Creek watershed is 51.4 km^2 and Fishtrap Creek watershed is 46.9 km^2

Conceptual Model

Fishtrap and Bertrand are small, rainfall dominated watersheds. Summer streamflow is thought to originate from a combination of groundwater discharging as baseflow and small inputs from summer runoff. The dominant groundwater recharge period is winter given high precipitation. Groundwater recharge in summer is limited due to limited summer precipitation and high summer evapotranspiration. Therefore, the baseflow component of summer stream discharge is expected to derive from the preceding winter recharge. However, the relative proportions of baseflow and runoff in each season are uncertain.

This study used a combination of approaches, including baseflow separation, a graphical technique to determine summer baseflow, and a water balance approach to characterize interannual variability.

Data Summary

Table 1: Annual groundwater flux exiting the watersheds

Annual GWout	Period	Volume (m^3)
Bertrand Watershed	2008	2.87E+06
	2009	0.00E+00
	2010	5.78E+06
Fishtrap Watershed	2008	7.61E+06
	2009	2.31E+06
	2010	3.67E+06

Table 3: Comparison of water balance baseflow volumes with other estimates

Summer Baseflow (m^3)	Bertrand Creek	Fishtrap Creek
Mean Calculated - Water Balance	**5.06E+05**	**1.68E+06**
Baseflow Separation	4.02E+05	8.76E+05
Intercept (Figure 4)	1.50E+05	4.40E+05
Summer Baseflow - Regional Model	2.01E+04	1.34E+04

Table 2: Precipitation and evapotranspiration.

Parameter	Period	Full Year	Winter	Summer
Precipitation (mm)	2008	1316	1074	241
	2009	1277	1165	112
	2010	1447	1336	111
Evapotraspiration[1,2] (mm)	2008	686	456	230
	2009	740	633	107
	2010	739	633	106

[1] Annual ET from Farmwest (www.farmwest.com)

[2] Summer ET calculated from the ratio of summer precipitation/ET established from 2008 data.

Contributions to Summer Low Flows

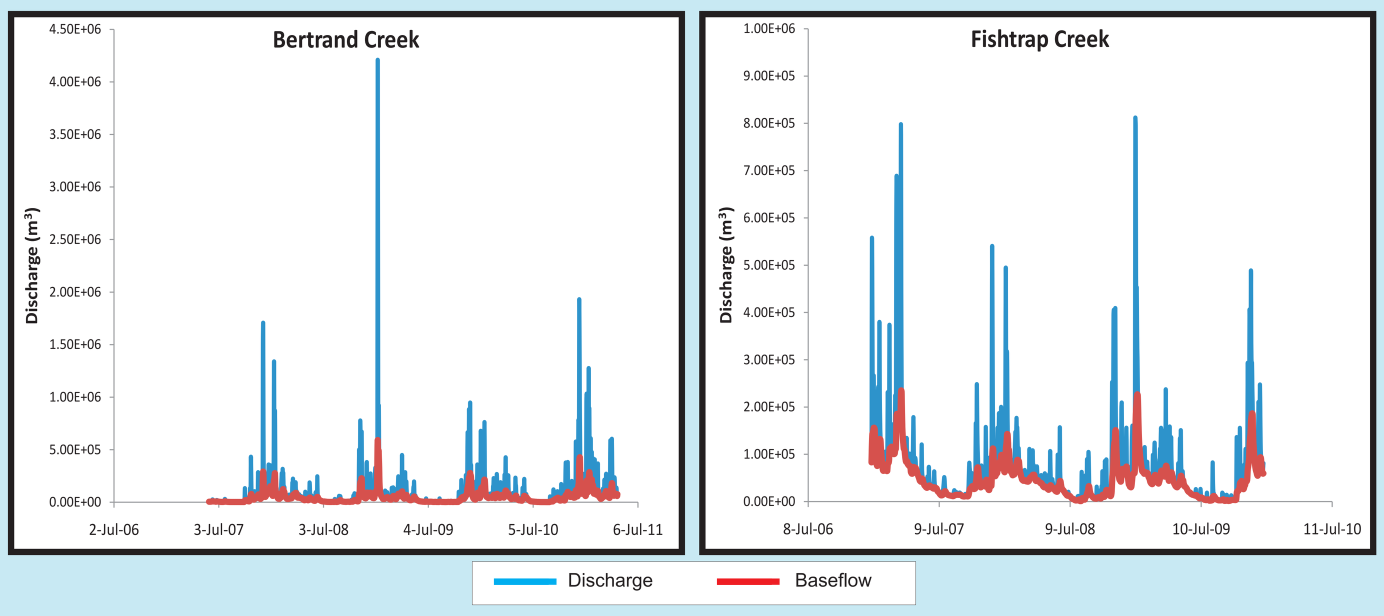

Figure 3: Hydrograph separation for the two streams showing the annual discharge and the baseflow contribution. Periods shown for Bertrand Creek (2007-2011) and Fishtrap Creek (2007-2009) are to illustrate the different flow patterns in the streams and the season patterns for each. Summer flow periods are June-August. Hydrograph separation was performed using "WHAT" (https://engineering.purdue.edu/~what/).

During the summer low flow period, baseflow is the main contributor to discharge; however the streams receive additional input as runoff from summer precipitation (Figure 3). The relationship between summer precipitation and discharge (Figure 4) illustrates the combined effects (baseflow and summer runoff). For both Bertrand and Fishtrap Creeks, summer discharge increases with increasing summer precipitation. The mean summer baseflow contribution to each stream is represented by the intercept.

Fishtrap Creek, which has a smaller watershed area, has a summer baseflow contribution that is an order of magnitude greater than Bertrand Creek. The difference in baseflow between the streams suggests a regional variability of stream connectivity to groundwater, related to watershed characteristics. Fishtrap Creek passes through a permeable glacial outwash deposit, while Bertrand Creek passes through a glaciomarine deposit.

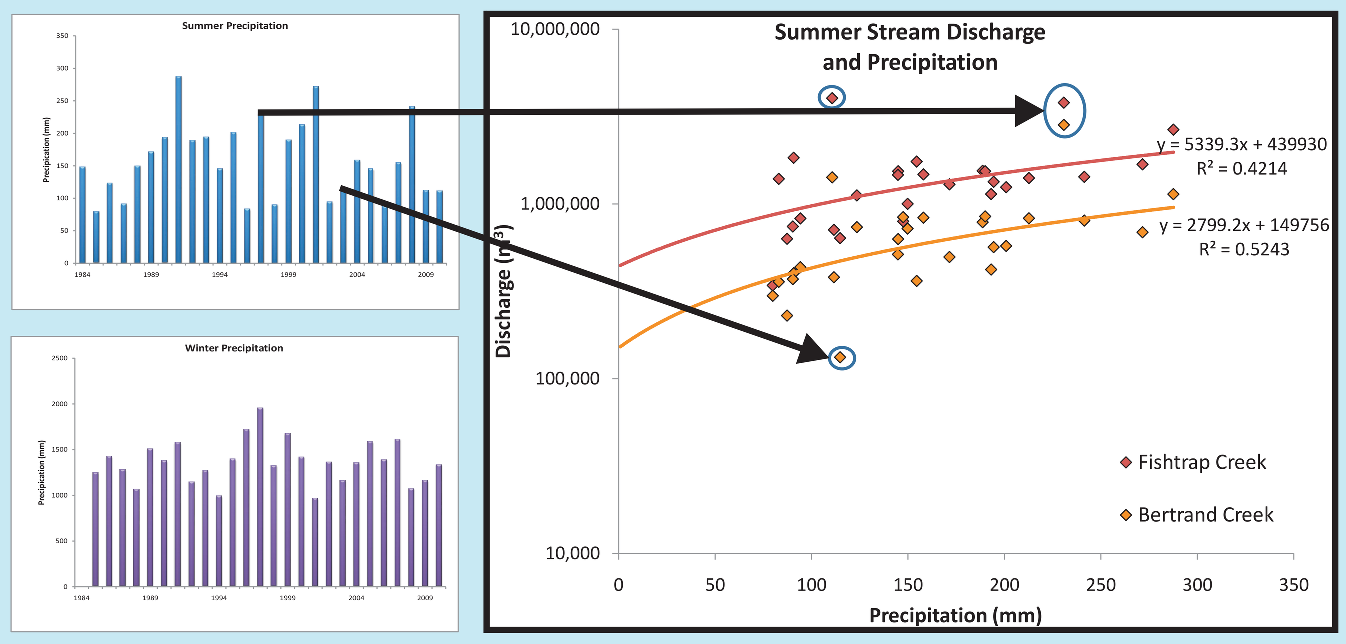

Figure 4: Summer and winter precipitation (left) show high seasonal and interannual variability. This variability is reflected in the relationship between summer precipitation and discharge for Fishtrap and Bertrand Creeks (right). While there is an overall good correlation over the summer period, the peaks and lows circled show that extremes exist. This variability is driven by changes in the summer precipitation (indicated by the arrows), and variation in recharge from the previous winter precipitation. The circled data are not included in the linear regressions. Precipitation periods are offset earlier by one month from discharge.

Interannual Evaluation of Stream Discharge - A Water Balance Approach

On an annual and seasonal basis, a water balance approach can be applied to conceptually identify and quantify groundwater fluxes.

In these watersheds, annually:

Discharge= Precip - ET- GWout

where Discharge = Baseflow + Runoff

GWout = groundwater flux south out of the watershed into the US

On a seasonal basis, GWout (Table 1) is likely only significant during the winter, during peak groundwater levels. Therefore, the water balance for the summer season can be used to quantify the baseflow, which has been shown in Figures 3 and 4 to comprise the component of summer precipitation that is able to enter the stream (runoff) and baseflow discharging to the stream from the previous winter recharge. Assuming summer recharge is zero, the summer baseflow can be found as (Figure 6):

Summer Discharge - Runoff = *Summer Baseflow*

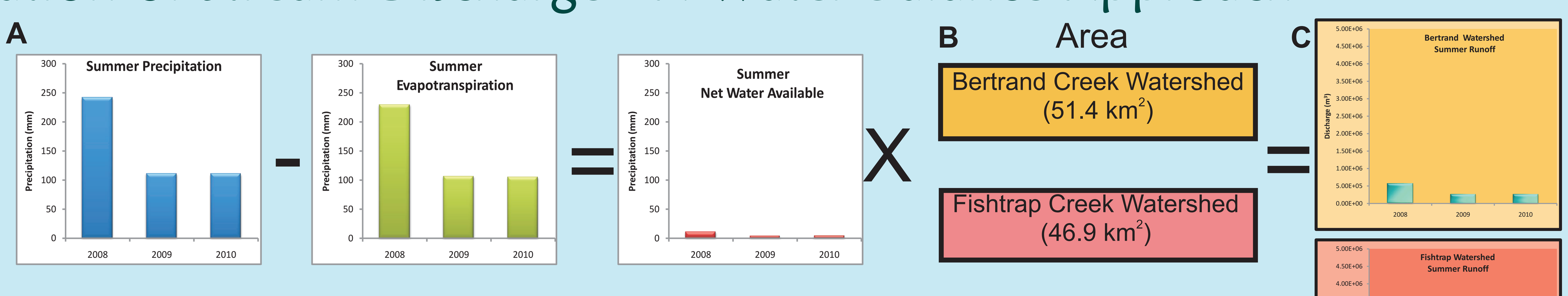

Figure 5: Calculation of net available summer water (A) from the precipitation and the evapotranspiration. Applied across the watershed area (B), this provides the summer runoff (C) for each watershed.

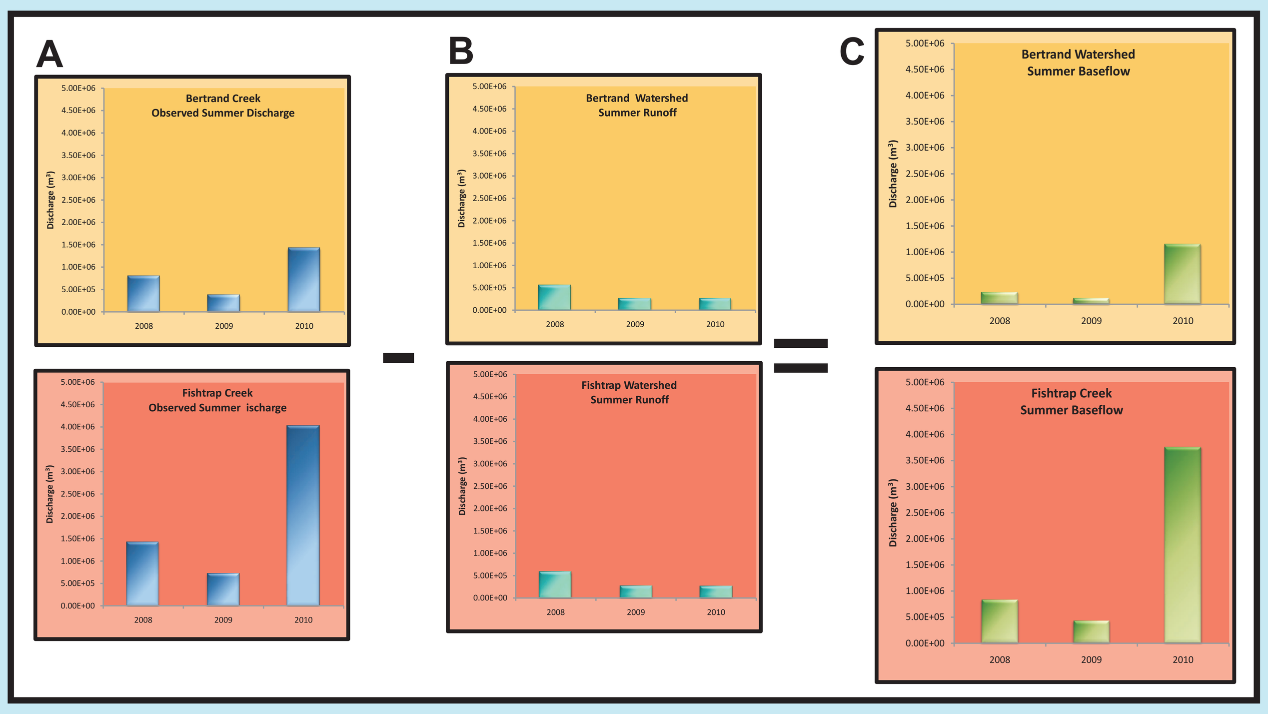

Figure 6: Subtracting the watershed runoff (B) from the observed summer discharge (A), provides the summer baseflow (C) in each stream.

Actual evapotranspiration (AET) values were required but not directly available for calculating the runoff as shown in Figure 5. To estimate these values, values from the 2008 baseflow separation were used to estimate the 2008 AET values. The ratio of summer precipitation to summer AET was then established, and this ratio was applied to calculate AET for 2009 and 2010 (Table 2). Resulting calculated baseflow values (Figure 6 C) were compared to estimates from the baseflow separation, the mean annual summer baseflow (Figure 4), and baseflow estimates from a regional MODFLOW model for the Abbotsford-Sumas aquifer (Table 3). The values compared well, indicating that the ratio method of estimating summer AET for calculating runoff and baseflow is appropriate for these watersheds.

Conclusions

In order to understand the processes that drive the low flow patterns in streams it is necessary to comprehensively evaluate the interaction between precipitation, groundwater fluxes, recharge, and stream discharges throughout the annual cycle and on a seasonal basis, not just during critical low flow periods.

A strong conceptual model of the water balance of the system as well as the connectivity between groundwater and surface water is necessary to understand the processes driving summer low flows and the timing and magnitude of surface water response to the inputs.

A combination of methods is important for estimating baseflow due to the sensitivity of the water balance approach to AET.

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