Variability of Streamflow Temperature in Two Groundwater-Fed Streams, Abbotsford-Sumas Aquifer, British Columbia

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ABSTRACT
A network of forty temperature loggers has been installed in two groundwater-fed streams in the Lower Fraser Valley of British Columbia to study the interaction between surface water and groundwater. Temperature data for the period of July to October 2008 are examined with hydrograph data for both streams and climate data to develop an empirical relation between stream flow temperature and air temperature. Stream temperatures varied between the sites, and the degree of attenuation relative the air temperature and groundwater temperature indicates that one site is dominated by groundwater discharge. A comparison of the temperatures provides a relative measure of the degree of groundwater-surface water interactions.

RÉSUMÉ

Un réseau de quarante enregistreurs de la température a été installé dans deux ruisseaux dans la vallée Fraser de la Colombie-Britannique pour étudier l'interaction entre les eaux de surface et les eaux souterraines. Des données de température pour la période de juillet à l'octobre 2008 sont examinées avec des données d'hydrogramme des deux ruisseaux et des données climatiques pour développer une relation empirique entre la température d'écoulement des ruisseaux et la température de l'air. Les températures variées entre les emplacements, et le degré d'atténuation suggèrent que la température de l'air et la température des eaux souterraines indiquent qu'un emplacement est dominé par une décharge d'eaux souterraines. La comparaison des températures fournit une mesure relative du degré d'interactions entre les eaux souterraines et celles de surface.

1 INTRODUCTION

Groundwater – surface water interactions are integral to the understanding of riparian ecosystems, as well as water quality and quantity in the stream and the aquifer. Groundwater inputs to stream baseflow have been recognized as an important function of groundwater – surface water interactions. There are three main categories that define how groundwater may interact with surface water: it may discharge to a stream (gaining stream); it may be recharged by the surface water (losing stream); or there may be no interchange between the systems (neutral steam) (Silliman and Booth 1993, Winter et al. 1998, Sophocleous 2002, Constantz 2008). Groundwater discharge to streams provides baseflow that may sustain stream flow during low flow periods. Low flow periods are an important element in the flow regime of any stream or river, and are generally a regular seasonal occurrence (Smakhtin 2001). During this period, surface water is strongly reliant on the behaviour of groundwater in the vicinity of the stream channel, and the system can become very sensitive to changes in groundwater flux.

For ecosystem health, groundwater upwelling impacts stream habitats in three main ways: by maintaining water levels and flow rates in lakes and streams; by providing thermal refugia where temperatures are stable; and by supplying nutrients and inorganic matter. Management of sensitive streams, riparian habitats, and water resources rely on understanding the interactions between groundwater and surface water in hydrologic systems.

Stream temperature variations have been used as a proxy for identifying groundwater discharge to streams, and in combination with other methods have been employed to quantify water movement (Silliman and Booth 1993, Becker et al. 2004, Anderson 2005, Kalbus et al. 2006, Schmidt et al. 2006, Arrigoni et al. 2008, Constantz 2008). Groundwater temperatures generally maintain stability throughout the year, and fluctuations observed in temperature are attenuated in comparison to surface waters, which can have large diurnal and seasonal variations (Kalbus et al. 2006, Schmidt et al. 2006). Temperature is therefore a robust and easily measured parameter to assess groundwater interactions with surface water. In gaining streams, the temperature response will be dampened, and thus, the greater the groundwater influx to the steam, the more the temperature extremes of the sediment water interface will be attenuated. In losing or disconnected streams, the stream temperature patterns will more closely follow air temperature. During the warm season, stream temperatures will be elevated in streams with less connectivity to groundwater.

This paper focuses on the preliminary results of a study aimed to investigate groundwater – surface water interactions through the use of detailed temperature monitoring for two streams in the Abbotsford-Sumas aquifer in southwest British Columbia (Figure 1). These streams experience low flows in the late summer and fall, and during this time are thought to be sustained by groundwater, in the absence of any other significant inputs. Using stream temperature and comparing to groundwater and air temperature, an empirical relationship between the groundwater and surface water can be developed. Stream temperatures are expected to be moderated by groundwater influxes to the channel. The detailed temperature monitoring will test the relative impacts of riparian cover, which can buffer the water surface from insolation, and the interaction with the bed material, which is a key factor in groundwater fluxes. The resulting relation between air and water temperature will be a useful tool for water resource planning for water use and ecosystem management.

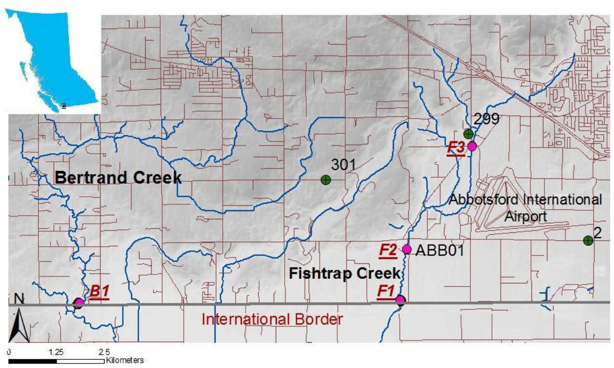

Figure 1: Study sites on Fishtrap and Bertrand Creek. The study area is situated on the Canadian side of the Canada/US border in southwest BC

2 STUDY SITE

The Abbotsford-Sumas aquifer is a trans-boundary aquifer that is approximately bisected by the Canada-US border. The aquifer is approximately 160 km^2 and is situated within the Lower Fraser Valley in southwest British Columbia (BC). The Abbotsford-Sumas aquifer is a very productive aquifer, supplying agricultural irrigation water, and drinking water to approximately 100,000 people in Canada, and 10,000 people in the US. The aquifer is a predominantly unconfined and comprised of sand and gravel, with an average thickness of 15 to 20m (Mitchell et al., 2003). Groundwater flow in the aquifer is generally southwest, with flow locally controlled strongly by topography and interaction with surface water.

The study area comprises two streams that drain the Abbotsford-Sumas aquifer, Fishtrap Creek and Bertrand Creek (Figure 1). The streams flow in a southerly direction from their origin in Canada to the Nooksack River in Washington. They provide sensitive habitat for salmon and two fish species listed as endangered in Canada, the Nooksack Dace and the Salish Sucker (Pearson, 2004). These creeks have been identified as having potentially variable interaction with groundwater both between them, and along their lengths (Johanson, 1988). The variability of interaction with groundwater in the vicinity of the streams is thought to be related to differences in surficial geologic units underlying the streams.

The streams were selected because each has a monitored stream gauge at the International Border (Located at F1 and B1, See Figure 1) and, for comparison purposes, each has a different setting. Fishtrap Creek, within the study area, flows through predominantly agricultural berry fields, with sparse riparian vegetation and has a relatively open channel resulting from past dredging (Pearson 2004). Bertrand Creek flows through mixed development, dominantly residential in the study area. The channel is naturally vegetated with mixed deciduous and coniferous forest established.

2.1 Surficial Geology

The surficial geology of the area comprises Quaternary glacial sediments overlying Tertiary bedrock (Scibek and Allen, 2005). The dominant units in the vicinity of the study area are the Fort Langley Formation and the Sumas Drift, and lesser amounts of Salish Sediments. Fort Langley Formation is a glaciomarine unit, comprising pebbly silt in clay, which has been interpreted as a confining layer (Mitchell et al., 2003). Sumas Drift comprises glaciofluvial sands and gravels, with discontinuous lenses of till. The sand and gravel of the Sumas Drift are the sediments that host the Abbotsford-Sumas aquifer. Salish Sediments occur in isolated locations in the study area, and comprise fluvial, lacustrine, and colluvial sediments (Scibek and Allen, 2005; Johanson, 1988). Fishtrap Creek flows over predominantly Salish Sediments and Sumas Drift - higher permeability sediments. The surficial sediments along the Bertrand Creek channel are more variable, with Sumas Drift in the lower reaches, and Fort Langley Formation dominating in the upper reaches and intermittently along the lower reaches

2.2 Climate and Hydrology

The climate of the Abbotsford area is dominated by moderate annual temperatures and high precipitation. The annual average precipitation is 1500 mm/yr, with approximately 70% occurring between October and May (Figure 2) (Berka et al., 2001; Zebarth et al., 1998; Environment Canada, 2002).

Fishtrap Creek watershed is approximately 37 km^2, and the Bertrand Creek watershed is approximately 51 km^2 (Pruneda, 2007). Both streams originate at low elevation and have flow regimes that are controlled by precipitation and interaction with groundwater. The flow regime has an approximately one month lag time following precipitation, with minimum flows occurring in August, shortly after the minimum precipitation in July and August. Groundwater recharge in the Abbotsford-Sumas Aquifer is primarily by precipitation, and groundwater levels fluctuate seasonally and annually (Scibek and Allen, 2005). Groundwater levels have an approximate 3 month lag behind precipitation, and the annual variation in water levels is approximately 2 m (Figure 2).

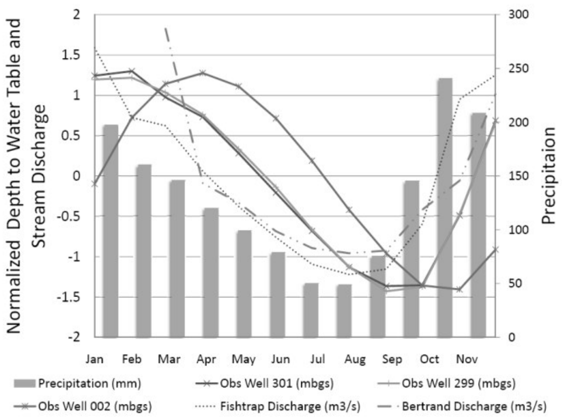

Figure 2: Normalized mean monthly discharge for Fishtrap and Bertrand Creeks (dashed lines) with mean monthly depth to water for three BC observation wells (solid lines). Mean monthly precipitation for the Abbotsford Airport is shown as columns. Mean values were calculated for data available from 1962 to 2007.

3 METHODOLOGY

To determine local-scale distribution of temperature, a dense network of dataloggers was installed within a single reach at each site. The sites are situated near the International Border (Figure 1) to take advantage of existing stream gauging stations. The dense network of dataloggers were installed over a distance of approximately 100 m or less, to obtain temperature profiles both laterally and longitudinally within the channel. The placement of the dataloggers was designed to collect temperatures through representative bed materials, riparian flow paths, and riparian cover. In Fishtrap Creek, dataloggers were installed at two additional locations to sample regional temperature variations within the watershed (Figure 1). Site F2 is approximately 1.4 km north of site F1 and lies within the same riparian cover and surficial geology setting. Therefore, only sites F1, F3, and B1 will be considered for comparative proposes in this study. The number of dataloggers at each location and the mean difference in temperature recorded between them is summarized in Table 1.

Table 1: Summary of dataloggers at each site (see Figure 1 for locations).

Creek	Site ID	Number of Data Loggers	Mean Temperature Difference (^{o}C)
	F1	15	0.98
Fishtrap	F2	4	0.32
	F3	2	0.21
Bertrand	B1	19	0.51

Stream temperatures were recorded using small temperature dataloggers (TidbiT® v2 Temp). The dataloggers have an accuracy of ±0.2^{o}C, and a resolution of 0.02^{o}C. These dataloggers were affixed to rebar, and installed at the sediment-surface water interface. Data were collected from early July to late October, 2008, representing the low flow period in each stream. At each site, the dataloggers were situated to collect temperature data from a comprehensive range of stream conditions, and within the localized scale, measurable differences in water temperature were recorded. These mean differences are shown in Table 1. To account for the local scale variability in water temperature within each site, the mean value for temperature at each time interval was calculated and used to represent the average temperature within the stream across the range of stream conditions.

Stream hydrograph data were provided by Water Survey of Canada and the US Geological Survey. Stream discharge data for upper Fishtrap Creek, site F3, were provided by Piteau Associates. Groundwater temperature was measured in an Environment Canada monitoring well, ABB01, situated on the bank beside Fishtrap Creek (see Figure 1). This well is currently equipped with a datalogger, but logging was disrupted for unknown reasons. Therefore, the groundwater temperature at this well was obtained during regular water quality sampling by Environment Canada using a low flow Grundfos pump with the temperature sensor emplaced in a flow-through cell. Temperatures were measured at approximately one month intervals. The depth to the bottom of the screen is 8 m, and when compared to several other wells near the lower reaches of Fishtrap Creek, this well appears to be representative of groundwater temperature in the area. The maximum variability between wells with available data is approximately 1.5^{o}C. At the time of this study, there were no groundwater temperature data available at any locations close to Bertrand Creek. Therefore, this well was selected to represent the three sample locations as it has the most complete record of groundwater temperature and is assumed to be representative of the area.

Air temperature and climate data were obtained from Environment Canada for the Abbotsford International Airport.

4 RESULTS

The temperature and discharge data for the study period (July 11 to October 23, 2008) are shown in Table 2. The table summarizes the mean, minimum and maximum values for all of the parameters examined for each study location.

Minimum values for stream discharge for both sites on Fishtrap Creek are suspect. At site F1, the minimum flow value of 0.0 m^3/s is likely incorrect. The in-stream temperature dataloggers were not exposed at surface; therefore it is likely that the water levels were below the depth of the stage recording equipment, or there was a brief equipment malfunction. It is not uncommon for low flows to be inaccurately measured due to the limitations of standard stream gauging equipment. At site F3, the negative values are the result of the calculation from the rating curve in which the reference elevation was chosen for a point above the minimum water level. Because discharge is used only to represent the pattern of discharge from the streams (not the magnitude), the hydrographs are considered appropriate for comparison with stream temperature data. Future work will aim to collect discharge measurements at these sites during low flow conditions rather than relying only on Environment Canada gauging data.

Groundwater temperature throughout the study period remained stable near 12°C, varying less than a degree over the four month period. It is hoped that higher resolution groundwater temperature data will become available in later phases of this study through the use of a datalogger programmed to measure daily temperature.

Throughout the study period, the air temperature exhibited diurnal and seasonal variation, ranging from a daily high of 32.4°C to a low of 0.1°C. The mean value for the length of the study was 15°C. The air temperature gradually declined from mid-August to the end of the study period. Air temperature dropped significantly after October 8, 2008.

Stream temperatures at the three sites ranged from approximately 7°C to a maximum of 22°C. The mean values for each of the three sites were below the mean air temperature, ranging from 0.3°C to 2°C below the air temperature mean. Site F1 had the least variability in stream temperature, while F3 had the highest variability and reached the highest temperatures. Site B1 had similar variability to F3, but remained slightly cooler, with the lowest minimum temperature of the sites.

Table 2: Summary of temperature and discharge data.

Parameter	Mean	Min	Max
F1 Stream Temperature (°C)	13.12	8.38	17.18
F3 Stream Temperature (°C)	14.82	7.03	21.87
B1 Stream Temperature (°C)	14.30	6.97	20.01
Air Temperature (°C)	15.11	0.10	32.40
F1 Discharge (m^3/s)	0.22	0.00	1.63
F3 Discharge (m^3/s)	0.10	-0.07	0.71
Bertrand Discharge (m^3/s)	0.14	0.02	1.42

The relation between stream water temperature and air temperature for the three sites is shown in Figure 3. The slope and intercept of the linear regression of air and water temperature has been shown to be related to the interaction between streams the groundwater inputs (Caissie 2006). Caissie (2006) reports that streams not dominated by groundwater inputs generally have steeper slopes than groundwater dominated streams. The y-intercept is also closer to the origin over an annual cycle of monitoring.

Sites F3 and B1 both plot very similarly in Figure 3 with a similar slope and intercept. The intercepts of all three lines fall in between 9-10°C as the period of record was only the summer and fall season. The linear regression for Site F1, in the lower reaches of Fishtrap Creek, has a lower slope than the other sites. The higher slopes of F3 and B1 suggest that these two locations are receiving less input from groundwater that F1. It also indicates that F3 and B1 have similar groundwater-surface water interactions, and that these differ from F3.

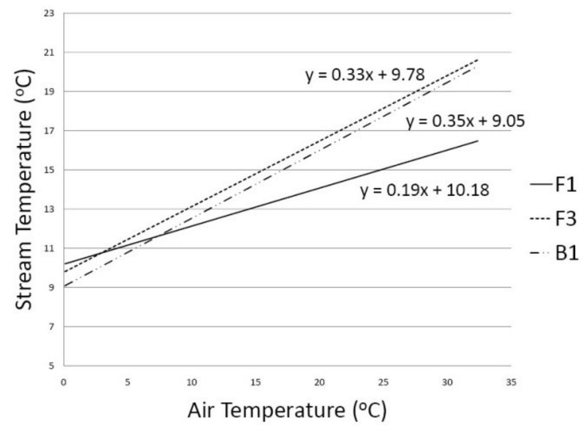

Figure 3: Linear regression model of air temperature and stream temperature for the three study sites. Data for each regression line (2489 points each) not shown for clarity.

4.1 Fishtrap Creek

Continuous time series of stream and air temperature were plotted with discharge for F1 and F3 (Figure 4). The monthly groundwater temperature from well ABB01 is represented by the red boxes on the figure.

The discharge for both sites follows a similar pattern throughout the study period, with F3 exhibiting slightly more variability through July. Fishtrap Creek at F3 is smaller and shallower, and therefore the fluctuations in discharge are likely more pronounced for smaller precipitation events.

The stream temperatures at both sites on Fishtrap Creek exhibit diurnal variation that is attenuated relative to the daily air temperature variations. At F1, the average water temperature is generally lower than at F3. This is an interesting result because site F1 is situated further downstream, and thus, the results are contrary to the general trend of increasing mean daily temperature in the downstream direction (Caissie 2006). The water temperature at F1 shows a muted signal that remains similar to groundwater temperatures, with only a minor component of seasonal air temperature variation. This suggests that there is a greater contribution of groundwater further downstream. The attenuated signal also suggests that riparian cover is not a dominant factor in stream temperature at these two sites as F1 has limited stream shade, most of which occurs in the form of in-stream vegetation. The riparian cover at F3 is more mixed upstream of the site, and at the site, is dominated by mixed deciduous trees and shrubs.

The water temperature at F1 exhibits less variability than at F3 throughout the length of the study period. The water temperatures at F3 fluctuate in response to daily air temperature variations, and also increase slightly in response to peaks in the hydrograph which relate to precipitation events. The water temperature signal at F3 responds more strongly to both the maximum and minimum seasonal fluctuations in air temperature as well.

Stream temperatures at F1 have only a muted response to precipitation events.

The more reactive nature of the hydrograph at F3, and the greater temperature variations are comparable to a scenario presented by Constanz (2008) which may suggest disconnection between the surface water and the groundwater at least during the lowest flow periods in the stream.

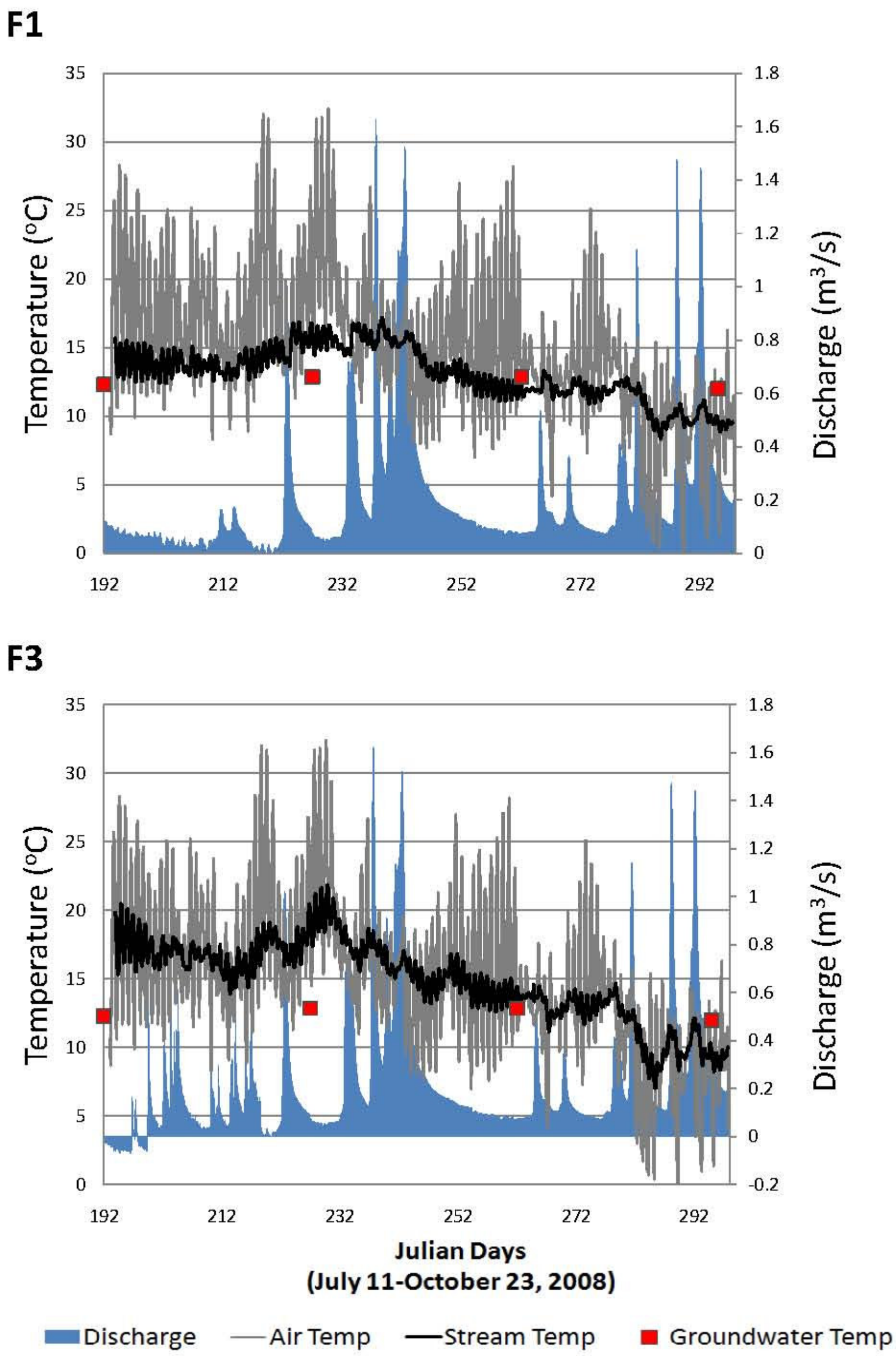

Figure 4: Stream, groundwater, and air temperature, with stream discharge for the two study sites on Fishtrap Creek (F1 and F3).

4.2 Bertrand Creek

The discharge in Bertrand Creek at the International Border (B1) has a pattern that closely matches the discharge in Fishtrap Creek at the border (F1). This is expected as the flow regimes for both streams are precipitation driven, and the sites are separated by only approximately 8.5km. Bertrand Creek at this location appears to have slightly lower discharge overall, but has significantly lower discharge during low flow periods. This observation is supported by discharge measurements previously done at these sites, reported by Berg and Allen (2007). The results suggest that Bertrand Creek receives less groundwater inflow during the low flow season that Fishtrap Creek – a factor that may influence stream temperature.

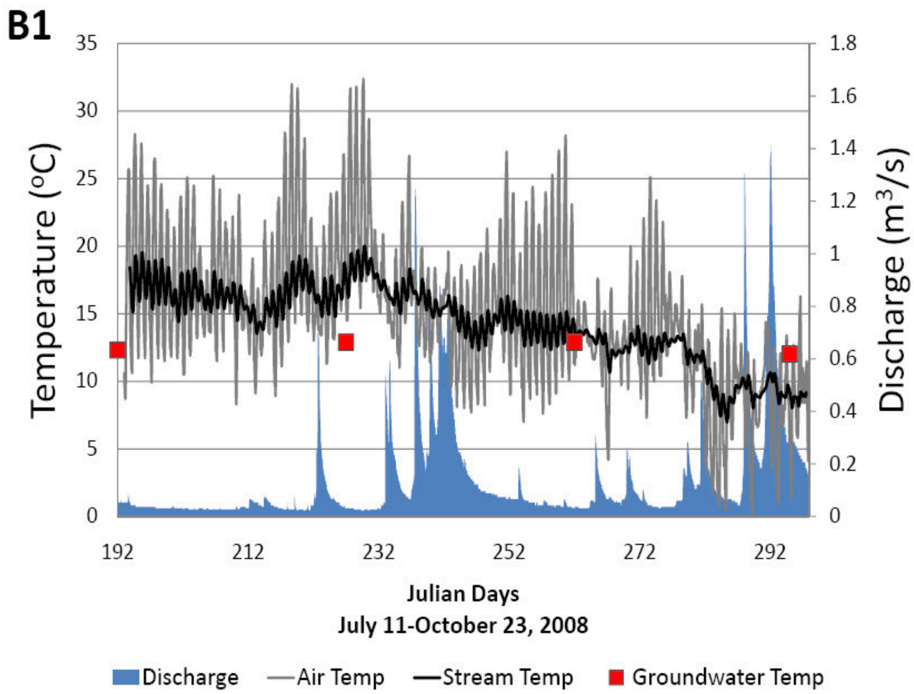

Figure 5: Stream, groundwater, and air temperature, with stream discharge for the Bertrand Creek site (B1).

The water temperature at B1 exhibits a pattern similar to F3. Mean and maximum stream temperatures exceed those of F1, but minimum stream temperature is lower. The diurnal variation in water temperature is somewhat attenuated relative to air temperature, but remains elevated above groundwater temperature during the summer months. The water temperature at B1 shows increases that correspond to peaks in the hydrograph, similar to the response at F3. The attenuated nature of the stream temperatures at both F3 and B1 indicate that there is some groundwater input to the channel at these locations and that the surface water is not entirely isolated or disconnected from the aquifer.

5 DISCUSSION

The stream temperature at the site in the lower reach of Fishtrap Creek (F1) has the lowest temperature variation, and maintains the lowest water temperatures. This site also does not fit into the general trend of increasing water temperature with downstream distance noted by Caissie (2006), nor does the lack of riparian cover appear to be dominating the temperature response. The results suggest that this site has the strongest connection with the aquifer, and the most significant groundwater influxes. This supports the suggestion by Johanson (1988) that Fishtrap Creek appears to be a groundwater discharge zone, at least in the lower reaches where the surficial material enhances the connection with the aquifer (Berg and Allen 2007). The similarity of response between F3 and B1 suggests that the corresponding similarity in the surficial geology at these two sites may also be having the strongest influence on the groundwater-surface water interactions at these sites. Although, there is notably less buffering of stream temperature in Bertrand Creek due to its higher average and mean temperature as compared to Fishtrap. This result is somewhat un-expected because Bertrand Creek has a substantial riparian cover, which would suggest cooler stream temperatures. Although the results of this study are very preliminary, they suggest that riparian cover along these two streams is of lesser importance than the magnitude of the groundwater flux.

The magnitude of groundwater flux in the study is influenced by the dominant surficial material in the vicinity of the stream channel. Lower reaches of Fishtrap Creek are situated in a unit of Salish Sediment in an area dominated by Sumas Drift, which are both higher permeability sands and gravels. In contrast, sites F3 and B1 flow through sections of varied surficial material comprised of alternating sections of Sumas Drift and Ft. Langley Formation. The areas around these stream sections are dominated by the lower permeability Ft. Langley glaciomarine clays, and are characterized by decreased thickness of the higher permeability units. The prevalence of the low permeability material around the F3 and B1 sites may limit groundwater influx to the channel. Regionally, the dominance of the low permeability unit may also act to decrease the recharge and increase surface runoff. In this case, there would be less groundwater available to discharge to the streams, and that would lead to less attenuation of the temperature fluctuations.

Future work in these two streams will include mapping the riparian cover using aerial photos and ground-truthing, in-stream seepage measurements through the use of seepage meters and piezometry, and numerical modeling of stream-groundwater interaction through the use of a numerical code (e.g., MIKE SHE). The research will also attempt to develop a methodology to map sensitive areas of these streams in respect of the buffering capacity of groundwater and riparian cover for moderating stream temperature. Ultimately, the research will apply these results more broadly to the study of climate change impacts on groundwater – surface water interaction and freshwater habitat.

6 CONCLUSIONS

Groundwater-surface water interactions are complex relationships that are dependent on many site-specific factors. Variations in aquifer and streambed sediment type, local groundwater gradients, riparian cover, and stream geometry are likely the main factors controlling these interactions (Cey et al. 1998, Winter 1999, Woessner 2000). In this study, stream temperature measurements were compared with air and groundwater temperature to illustrate differences in groundwater – surface water interaction at these sites. Stream temperatures appear to be a robust method that can be easily applied to a surface water environment to gain insight into the relative connection with groundwater at a local scale. It also can allow a preliminary assessment of potential influencing factors that can assist in directing further investigations into developing a comprehensive understanding of groundwater-surface water interactions at a site.

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