WATER SCIENCE SERIES

Mission Creek Groundwater – Surface Water Interactions Project: Analysis of Discharge and Water Level Records

Natasha Neumann

December 2018

No. 2018-06

The **Water Science Series** are scientific technical reports relating to the understanding and management of B.C.'s water resources. The series communicates scientific knowledge gained through water science programs across B.C. government, as well as scientific partners working in collaboration with provincial staff. For additional information visit: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series.

ISBN: 978-0-7726-7295-7

Citation:
Neumann, N. 2018. Mission Creek groundwater – surface water interactions project: Analysis of discharge and water level records. Water Science Series, WSS2018-06. Province of British Columbia, Victoria.

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Cover Photographs:
Mission Creek at high flow, looking downstream from the bridge at Gordon Drive, Kelowna. (Neumann, N.)

Acknowledgements

The Mission Creek Groundwater-Surface Water Interactions Project is a collaborative effort of the B.C. Ministry of Forests, Lands, Natural Resources Operations and Rural Development (FLNRORD) Groundwater Science Section, the Okanagan Basin Water Board (OBWB), the Black Mountain Irrigation District, the City of Kelowna, Rutland Waterworks, the South East Kelowna Irrigation District and the Okanagan Nation Alliance Fisheries Department (ONAFD).

Field data was collected and managed by Associated Environmental, Natasha Neumann, ONAFD and Piteau Associates. The data are stored in a central database maintained by the OBWB. Valuable technical and planning advice was provided by Remi Allard, Don Dobson and Craig Nichol.

EXECUTIVE SUMMARY

Mission Creek is the largest tributary to Okanagan Lake, and provides habitat to a variety of valued species as well as drinking and irrigation water to a large number of users in and near Kelowna. The degree of connectivity between the surface water in the creek and groundwater must be quantified in order to assess the sustainability of future groundwater extraction projects as well as the sensitivity of the aquatic ecosystem to changes in the local aquifers and streamflow. In 2016, the Okanagan Basin Water Board partnered with the B.C. Ministry of Forests, Land, Natural Resources Operations and Rural Development (Groundwater Science Section) and local collaborators to collect hydrometric and piezometer data from Mission Creek in 2016 and 2017. This report summarises analyses of these data and compares results with a similar study reported by Lowen and Letvak (1981).

Two methods were adopted. First, stream surface elevation was compared to groundwater levels in adjacent piezometers (shallow wells) to identify upwelling or downwelling conditions. Second, a water balance approach was used where flow was measured at multiple points along the main channel of Mission Creek, and flow at a station was subtracted from flow measured at the next downstream one. The water balance method identifies sections of the stream channel where there are gains and losses.

Piezometers were installed at five locations to allow calculation of vertical hydraulic gradients (VHG). When groundwater levels in the piezometers were compared to stream water levels, downwelling conditions dominated at all stations except at KLO Road, where conditions varied between downwelling and upwelling.

Streamflow data were collected at ten hydrometric stations installed on the main channel of Mission Creek in Kelowna, along with records from a Water Survey of Canada (WSC) station and one maintained by the Black Mountain Irrigation District. The records used in this analysis were collected between summer 2016 and the end of 2017, and, because of measurement errors at high flow rates, focussed on periods when flow in Mission Creek was consistently less than 10 m^3/s.

Results from the water balance analysis were largely consistent with those of Lowen and Letvak (1981) and the piezometer measurements. Generally, gaining conditions were measured upstream of Hollywood Road where the stream flows through narrow incised valleys, and losing conditions occurred downstream of KLO Road where Mission Creek flows along alluvial fan deposits. Gaining and losing conditions were more variable in the region between KLO Road and Hollywood Road where there was no dominant control on the direction of the hydraulic gradient.

CONTENTS

1. INTRODUCTION

Mission Creek is the largest tributary of Okanagan Lake. It is an important salmonid spawning stream, and provides water to thousands of domestic and agricultural users in and around Kelowna, B.C. In order to assess the impacts of expanded surface and groundwater use, the degree of connectivity between Mission Creek near its mouth and adjacent aquifers must be resolved. In spring 2016, a collaborative effort to quantify hydrologic connectivity in and around the lower reaches of Mission Creek was initiated. This work was spearheaded by the Okanagan Basin Water Board (OBWB) and the Groundwater Science Section of the British Columbia Ministry of Forests, Land, Natural Resources Operations and Rural Development (FLNRORD) in collaboration with numerous local partners.

This report presents details on the analysis of gains and losses along Mission Creek using data collected between fall 2016 and spring 2018, and compares results with those of a field study conducted in 1979-80 (Lowen and Letvak, 1981). Two approaches were adopted for this project: comparison of water level elevations in the creek with groundwater levels in adjacent piezometers, and calculation of differences in discharge between consecutive hydrometric stations (as was done by Lowen and Letvak, 1981) with an accounting of major inflows and diversions. Gains and losses were evaluated relative to surface water flow in Mission Creek.

2. SITE DESCRIPTIONS AND METEOROLOGICAL CONTEXT

For this study, ten hydrometric stations were installed on the lowest 25 km of the Mission Creek main channel and in three ungauged inflow and outflow channels or structures. In addition, hydrometric data for two stations on the main channel, one inflow tributary and one diversion were obtained from third parties or project partners. The stations were lettered starting from the most downstream location to that with the highest elevation (Figure 1). For this project, seven paired hydrometric and piezometer stations and one hydrometric station were installed in spring 2016 (stations A, C, G, I, M, O, P and S) (Figure 1 and Table 1). Six additional hydrometric stations were installed in summer 2016 (stations D, E, F, K, N and Q). Figure 2 summarizes the configuration of hydrometric stations on the main channel and the known and gauged inflows and outflows described below.

The most downstream station was installed near the bridge at Gordon Drive (station A). Shortly upstream of this site is a recently widened part of the main channel, and the FLNRORD Fish and Wildlife group in Penticton maintained a hydrometric station downstream as part of their monitoring (B). The next upstream site is at the Casorso Road Bridge (C). There were no expected major surface water inflows to or diversions from the main channel between stations A and C.

Upstream of Casorso Road, two named creeks entered the main channel: Priest Creek (station D) and Rumohr Creek (ungauged). The area southeast of the station was a natural wetland, suggestive of groundwater inputs to Mission Creek. Further upstream was the South Kelowna Water Users Community (WUC) point of diversion (E). A WUC pools their water allocations and shares the same point of diversion on a stream, reducing the amount of equipment and infrastructure needed. Multiple water licenses are therefore associated with a single point of diversion. The volume of water extracted by this group was very small; measurements of this diversion ranged from 0 to 0.028 m^3/s (six measurements, <0.5% of mean annual discharge in Mission Creek). Therefore, a hydrometric station was not installed to monitor the South Kelowna WUC. The next station on the main channel was downstream of the KLO Road bridge (F).

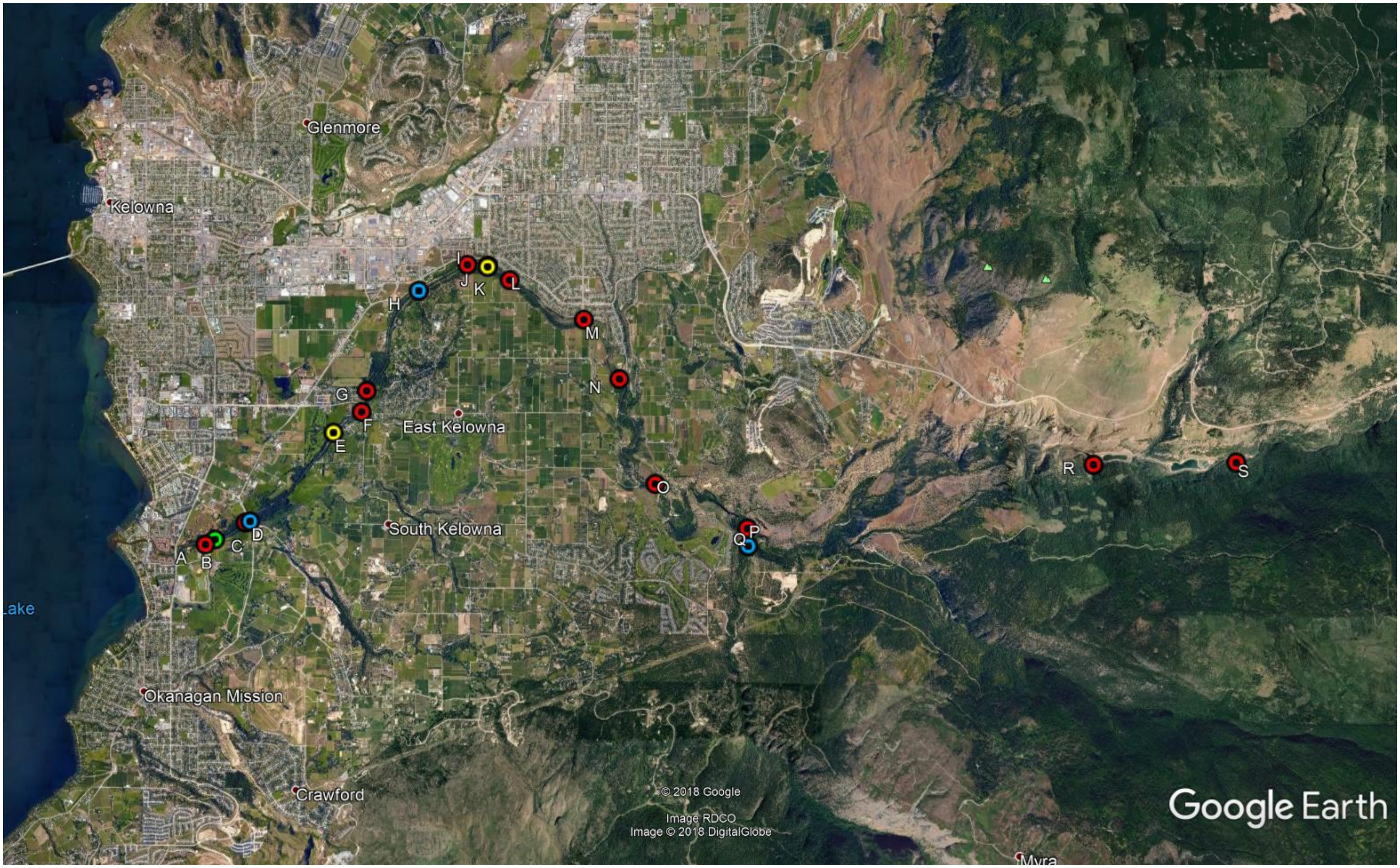


Figure 1: Map of Mission Creek stations used for this project. Stations on the main channel are shown in red, inflows in blue, and outflows/diversions in yellow. A main channel station used for validation is shown in green (operated by FLNRORD Fish and Wildlife). Image: Google Earth.

Table 1: Hydrometric stations used in this project. Stations that had groundwater measurements (piezometers) are noted.

Station	Location	Details
A	Upstream of Gordon Drive	Two piezometers (screen depths 5.5 m, 6.4 m).
B	Downstream of restored oxbow	Hydrometric station operated for Mission Creek Restoration Initiative monitoring. Data provided by FLNRORD (Fish and Wildlife).
C	Casorso Road Bridge	Two piezometers (4.0 m, 7.6 m).
D	Priest Creek (inflow)	No piezometers.
E	South Kelowna Water Use Community (WUC) (diversion)	Manual water level observations only. No piezometers.
F	Downstream of KLO Road	No piezometers.
G	Upstream of KLO Road	One piezometer (10.7 m).
H	Mill Creek Diversion (inflow)	Water diverted from Mill to Mission Creek. Data provided by City of Kelowna.
I	Downstream of Ziprick Road	Surface water station only. Groundwater station installed near Gerstmar Road (23.3 m).
J	Spawning Channel (diversion)	Kokanee salmon spawning channel at Mission Creek Regional Park. The majority of this water returns to Mission Creek.
K	Benvoulin Water Use Community (WUC) (diversion)	No piezometers.
L	Near Kiniski Road	WSC gauge 08NM116 real-time, unvalidated discharge data.
M	At Hollywood Road	Two piezometers, though problems with shallow logger record (10.7, 21.2 m).
N	East Kelowna Road Bridge	No piezometers.
O	At 12km Bridge	One piezometer (2.9 m).
P	Downstream of KLO Creek	One piezometer (9.1 m).
Q	KLO Creek near the Mouth (inflow)	No piezometers.
R	Downstream of BMID Intake	Hydrometric station operated by Black Mountain Irrigation District (BMID).
S	Upstream of BMID Intake	No piezometers.

Springs have been reported in the vicinity of the KLO Road bridge, so another station was installed upstream of the bridge (G) to account for these inflows.

Upstream of the KLO Road bridge, water was diverted south out of Mill Creek during periods of high flow and entered Mission Creek at station H. Inflow rates varied between 0 and 10.7 m^3/s, so it was critical to account for this input. The next upstream station on the main channel was at Ziprick Road (I).

Upstream of Ziprick Road, water was diverted out of Mission Creek into a parallel kokanee salmon spawning channel. The spawning channel was lined during the early 1990's, so most of this water re-entered Mission Creek upstream of station H (Jason Webster, Chara Consulting, pers. comm., 4 July 2018). Water level in the spawning channel is monitored by the Regional District of Central Okanagan for FLNRORD, but the daily manual observations cannot be converted to a flow rate. Because it is an important diversion, flow in the spawning channel was referred to as station J in this analysis. In addition, springs flowing into the spawning channel have been observed (Jason Webster, Chara Consulting, pers. comm., 4 July 2018).

Just upstream of the spawning channel diversion was the Benvoulin WUC irrigation ditch (K). The amount of water diverted by this WUC ranged between 0 and 0.25 m^3/s, so a recording hydrometric station was installed in the irrigation ditch.

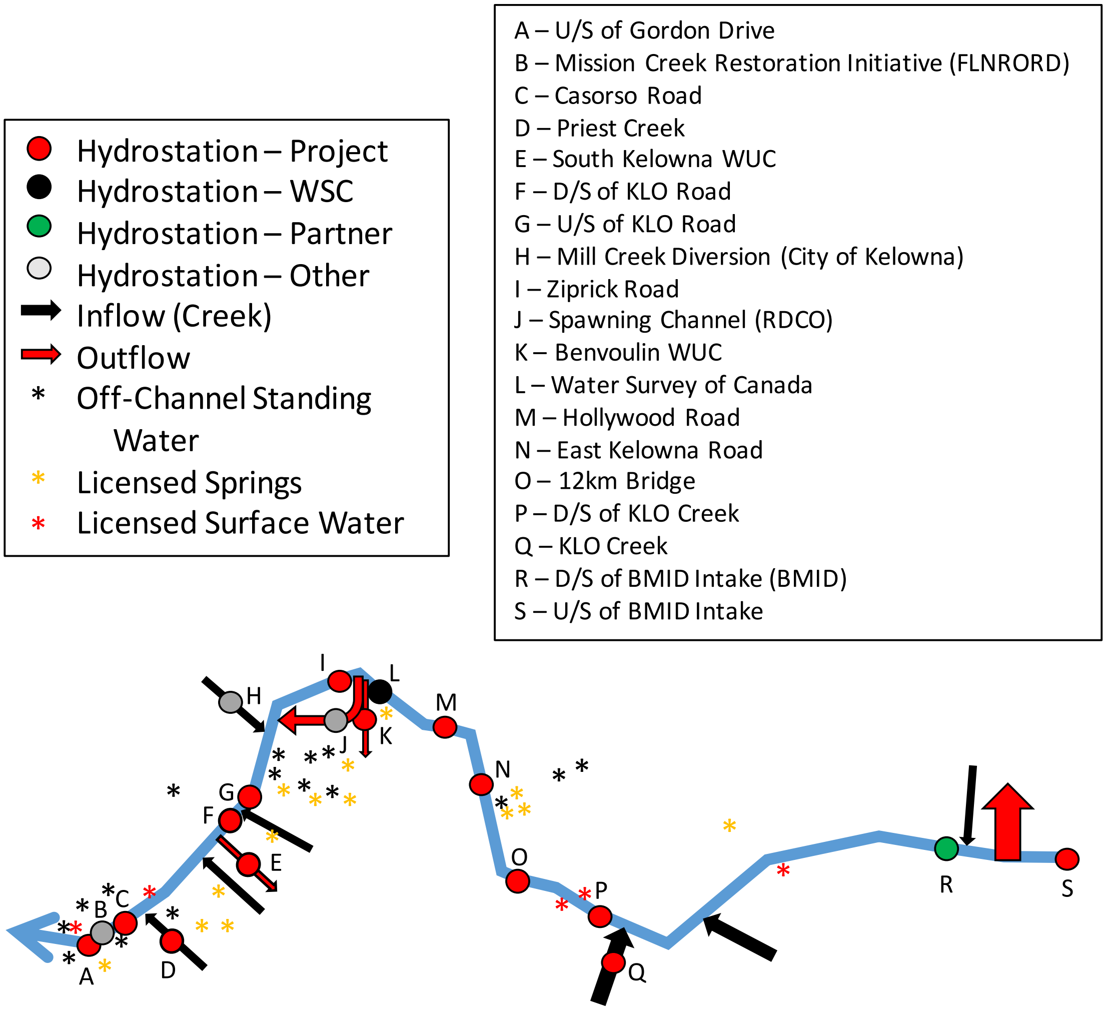


Figure 2: Conceptual model of lower Mission Creek showing hydrometric stations (hydrostation), inflows and outflows. The agencies operating partner and 'other' stations are given in brackets in the station list (FLNRORD = BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development; SEKID = South East Kelowna Irrigation District; BMID = Black Mountain Irrigation District). Surface water licenses on Mission Creek aside from the ones explicitly considered as outflows are shown.

Upstream of these two outflows was the Water Survey of Canada (WSC) gauge 08NM116 Mission Creek near East Kelowna (L). At the time of this analysis, only real-time, unvalidated discharge data was available for the time period of analysis (2016-2018).

A hydrometric station was installed on the main channel near Hollywood Road (M). There were no expected major surface water inflows to, or diversions from, the main channel between stations L and M.

The next upstream station on the main channel was at the East Kelowna Road bridge (N). There were no expected major surface water inflows to, or diversions from, the main channel between stations M and N.

Springs have been reported immediately upstream of the East Kelowna Road bridge, but there were no major inflows or outflows along the main channel to the next station near the 12km bridge (O). There were two water licenses between the 12km bridge and the next upstream site downstream of the KLO Creek tributary (P), with a total allocation of over 317 000 m^3/y (averaging 0.02 m^3/s during the irrigation season) but the status of these diversions is unknown. There were no known inflows between stations O and P.

Between station P and the next upstream station on the main channel downstream of the BMID intake (R), KLO Creek (Q) and Hydraulic Creek delivered significant volumes of water to Mission Creek. There was a relatively small irrigation water license diversion (0.009 m^3/s during the irrigation season) approximately halfway between stations P and R.

Diversion by BMID was the only, but substantial, expected outflow of water from Mission Creek between stations R and S. Inflow from Dave's Creek occurred between these stations.

2.1 Precipitation and Air Temperature

Shallow groundwater in this region is recharged primarily by infiltration of water from snowmelt and rain, so the meteorological context can be useful in understanding seasonal water table variations and therefore potential patterns of surface and groundwater interactions. The direction of water movement between two locations depends on their relative water levels; water moves to areas where the level is lower. Understanding patterns in the water table, then, can provide insight into potential directions of water movement between groundwater and streams.

In a natural system, the water table in the Okanagan valley rises during the spring and early summer in response to spring snowmelt and rain inputs, and falls during the late summer, autumn and winter in response to high evaporation and transpiration demand and lower precipitation inputs. As an example, the well record for provincial Observation Well 154 - Summerland (Hwy 97 and Thornber St) is shown in Figure 3. This well is located in the valley bottom in the District of Summerland, and it was expected to show similar patterns to conditions in the lower part of Mission Creek and other unconfined aquifers in the valley bottom. A higher prevalence of paved and other very low permeability surfaces within developed neighbourhoods of Kelowna would reduce the actual amount of infiltration relative to the Summerland area.

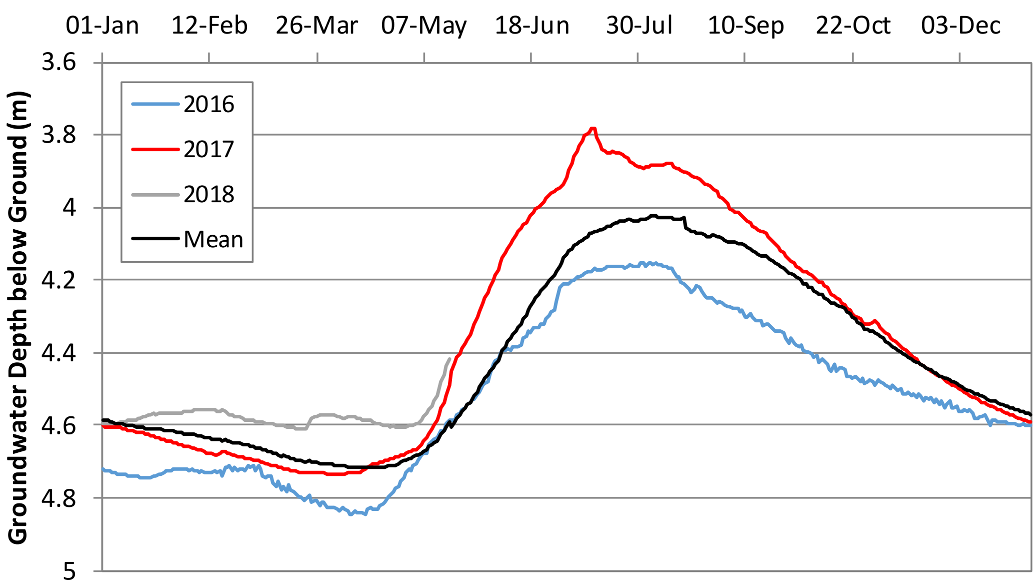


Figure 3: Water table patterns in 2016, 2017 and 2018 for provincial Observation Well 154 - Summerland (Hwy 97 and Thornber St). The station mean water level was calculated for the period when continurous data is available (2010-2018) and is shown in black. Data source: Government of British Columbia https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-observation-well-network/groundwater-level-data-interactive-map

The effects of large groundwater withdrawals would be superimposed on the seasonal rise and fall of the water table. In the lower part of Mission Creek there are some highly productive groundwater wells used for domestic consumption and irrigation; these wells draw water from deeper aquifer(s) but the degree of connectivity between the deep aquifers and the unconfined aquifer near the surface is unresolved. The long-term, cumulative effect of groundwater withdrawal would be indicated as a multi-year or decadal downward trend in water level. These two topics, i.e. groundwater pumping effects on the water table, are not addressed in this study.

Weather observations and 1981-2010 normals for the station at the Kelowna UBC Okanagan station were downloaded from Environment Canada (http://climate.weather.gc.ca/).

Total annual precipitation measured in 2016 was 87% (338 mm) of normal, respectively. There were three months with precipitation above the 1981-2010 normals, and only three months (April, July and September) had precipitation values substantially below average (Figure 4). Monthly average air temperature for 2016 was warmer than normal every month except December (Figure 5). This temperature pattern suggested that winter precipitation would have melted relatively quickly and entered the soil, or fell as rain, and that there were higher-than normal evaporation and transpiration rates during the growing season. The 2016 precipitation pattern, then, probably reflected near-normal recharge conditions, although because the fall of 2015 was dry the water table in January was lower than average (Figure 3). By the end of the calendar year, the water table was back up close to average.

In 2017, higher than normal amounts of precipitation fell between the months of February to May, but these were followed by extremely low precipitation totals between June and September (Figure 4). Total annual precipitation in 2017 was 70% (272 mm) of normal. The spring precipitation fell as both rain and snow, and combined with already wet soils from autumn rains to contribute to higher than average water tables and extreme flooding in the region. Okanagan Lake reached a peak surface elevation of 343.27 m ASL in early June. This was followed by an extremely hot and dry summer (Figure 5). These meteorological conditions contributed to higher water table levels during the spring and early summer, and a relatively rapid decline during the late summer and fall (Figure 3). By the end of the calendar year the water table was close to the station average.

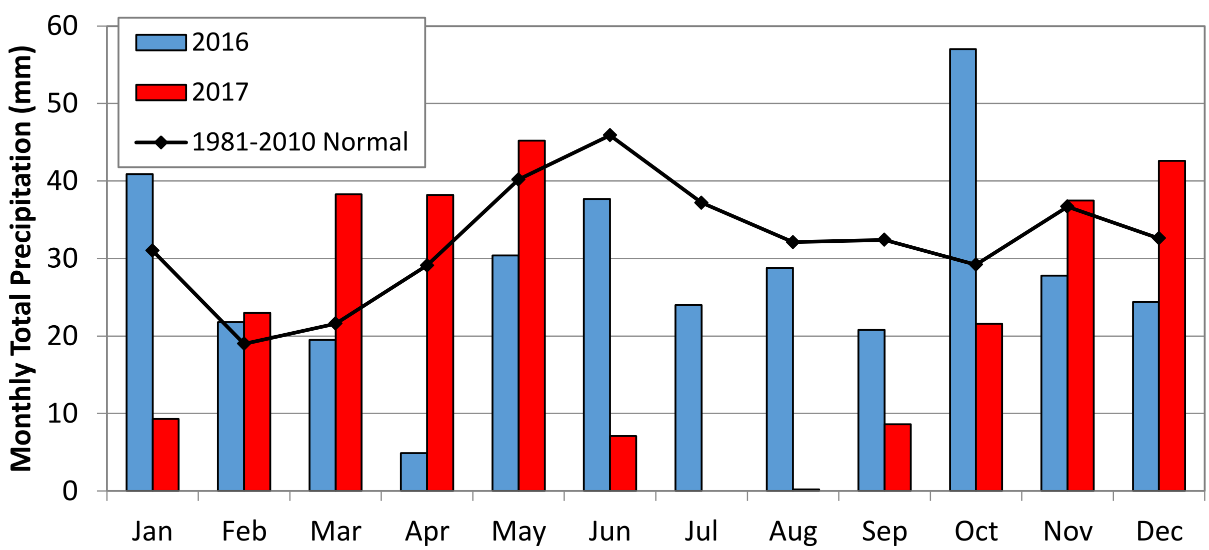


Figure 4: Monthly total precipitation in 2016 and 2017 compared to the 1981-2010 normals at the UBC Okanagan climate station, Kelowna. Data source: climate.weather.gc.ca.

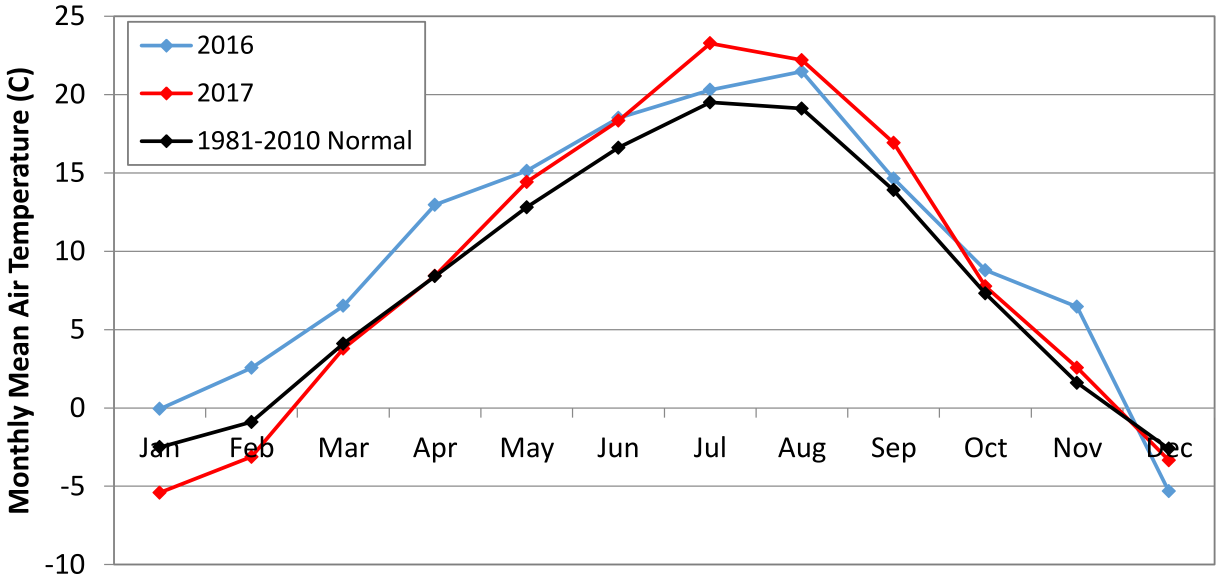


Figure 5: Monthly mean air temperature in 2016 and 2017 compared to the 1981-2010 normals at the UBC Okanagan climate station, Kelowna. Data source: climate.weather.gc.ca.

3. DATA

Water level in the creek and the piezometers was monitored continuously using pressure transducers. The hydrometric stations installed for this project consisted of an unvented pressure transducer suspended inside a stilling well (Figure 6). Piezometers were drilled adjacent to seven of the hydrometric stations (Table 1); well tops were level with the ground surface, and unvented pressure transducers were suspended inside the piezometers (Figure 7). Total pressure (P_{Total} in kPa) was measured every 15 minutes.

Figure 6: Hydrometric station showing a stilling well anchored to a boulder in a relatively calm pool. An unvented pressure transducer is suspended inside the stilling well. Photo credit: ONA.

Figure 7: Piezometers flush-mounted with the ground surface near the Hollywood Road hydrometric station. Unvented pressure transducers are suspended in the piezometers. Photo credit: Piteau Associates.

Barometric pressure loggers were installed at stations C, I, O and S; values for atmospheric pressure (P_{Atmo} in kPa) at the remaining stations were derived from these measurements based on differences in elevation. Water level (*WL*, in metres) for each pressure transducer location was calculated:

$$WL = (P_{Total} - P_{Atmo}) \times 0.10197$$

where 0.10197 is a factor used to convert kPa to m water depth. Data was ignored when the pressure transducer recorded a water temperature of 0°C, as this was often associated with ice formation and poor pressure measurement.

In addition to the continuous instrumental record, periodic field measurements were made of discharge (streamflow, in m^3/s), stream temperature and water level (both in the creek and the piezometers). Two to three benchmarks were established for each station, and were surveyed to a geodetic datum by Associated Environmental and ONA. The periodic creek and piezometer water levels were surveyed to the benchmarks, and the continuous records corrected to the field measurements. This allowed the continuous records to be converted to an elevation above sea level (ASL).

Discharge was measured based on 2009 British Columbia Resources Information Standards Committee (RISC) standards using the area-velocity method. Water depth and velocity was measured at 20 or more points across the width of the stream, and used to calculate total discharge across that section. Channel conditions affecting the discharge measurement were described in field notes. Most measurements were made by wading across the channel, which was only possible at low flow rates. A single measurement was made at high flow using a salt dilution method.

The periodic discharge and creek water level measurements were used to generate rating curves for the hydrometric stations. A rating curve is a mathematical relationship between the water level in the creek and total flow, and is used to estimate a continuous record of discharge from the water level record. The rating curves are described in the methods and results sections.

At station E, the South Kelowna WUC station, only periodic manual water level readings were made (no pressure transducer was installed).

All data was entered and managed using Aquarius software, in a database administered by the OBWB.

4. METHODS

4.1 Vertical Hydraulic Gradients

Calculations of vertical hydraulic gradient (*VHG*) can provide a validation of the water balance results. VHG represents the potential for flow between two depths based on differences in water pressure (hydraulic head). The VHG between the piezometers and Mission Creek, and between piezometers, were calculated using the equation:

$$VHG = \frac{WL_D - WL_S}{z}$$

where WL_D is the water level elevation of groundwater in the deeper piezometer, and WL_S is water level elevation in the shallower water body, which was either the creek or the shallower piezometer (both in m ASL). The *z* value is the difference in elevation (the vertical distance) between the top of the piezometer screens measured at installation, or between the top of the piezometer screen and the lowest point of the streamed calculated from the discharge cross-section measurement (m). A positive gradient indicates upwelling (gaining) conditions, while a negative gradient indicates downwelling (losing) conditions. VHG should only be calculated if there is not a significant distance between the two measurement points. Ideally, piezometers should be side-by-side, and approximately perpendicular to the stream channel for local conditions to be represented accurately. For example, if a piezometer is located upstream of where the stream water level is measured and the level in the piezometer is higher than in the stream, the resulting VHG will be positive. However, it may represent the regional groundwater flow pattern rather than local conditions.

It is important to note that the VHG is only a measure of the potential flow of water between two points, not the actual rate of flow. To calculate the actual flow the sediment hydraulic conductivity must be known, which was outside the scope of this study.

4.2 Rating Curves

Rating curves were developed for each hydrometric station using paired stage-discharge measurements in the Aquarius software Rating Curve Development toolbox. The software's default form of the rating curve equation was used:

$$Q = \beta(H - e)^{\alpha}$$

where Q is discharge (m^3/s), β is a coefficient that integrates the effects of channel width, section slope, roughness and properties of the water, *H* is the measured water level elevation (m ASL), *e* is the elevation where discharge is zero (no flow) (m), and α is a measure of the shape of the channel and turbulence. The α term should be approximately 1.5-1.7 for a rectangular channel profile, and closer to 2.5-2.6 for a V-shaped channel. Turbulence increases the value of α. The no flow elevation (*e*), β and α were estimated by visually fitting a line through the available data and approximating the recommended range of values for α.

The rating curves were used to convert the continuous surface water level measurements (m) to discharge volumes (m^3/s).

4.3 Water Balance

The difference in discharge between consecutive hydrometric stations on the main channel of Mission Creek (downstream station minus upstream) was calculated to determine the gaining or losing condition along that stream reach. Therefore, the values represent the net change in discharge between two stations. Positive values indicate an increase in discharge between stations (gains), while negative values indicate a decrease (losses). Where inflows or outflows were gauged, these values were included in the water balance calculations to account for known inputs and losses and to get better estimates of net gains and losses between stations.

Uncertainty increases for sections where there were ungauged inputs and withdrawals from Mission Creek. In the fall of 2016, a survey of observable inputs and outflows was conducted to improve our understanding of these sources of error (Eyjolfson and Enns, 2017).

5. RESULTS

5.1 Vertical Hydraulic Gradients

Vertical hydraulic gradients (VHG) provide an indication of the direction of water flow into or out of Mission Creek. To calculate actual flow, the hydraulic conductivity of the sediments must be measured. Large magnitude VHGs are often the result of flow through very low permeability materials (e.g. clay and bedrock), and low magnitudes are often associated with high permeability materials (e.g. gravel and sand deposits). In this analysis VHG results will be used primarily to assess the direction of water movement. A positive VHG indicated upwelling (stream gaining) conditions, and a negative VHG indicated downwelling (stream losing) conditions. Graphs showing the water level elevations used to calculate VHGs are included in the appendix.

At Gordon Drive (station A), transient gaining and losing conditions were observed in 2016 (Figure 8) between the creek and the piezometers. These results may have reflected true conditions or may have been an artifact of the data. The occurrence of standing water and springs near station A indicates a shallow water table and the potential for transient conditions. However, the differences in water level elevation were on the scale of only a few centimetres, which is within the range of measurement error (see appendix for graphs of water level elevations). Calculating VHG from differences in water level that fall within the measurement error can result in values that fluctuate on either side of zero. With the available data it is impossible to assess which effect has a greater influence on the results.

From the VHG calculated between the stream and the two piezometers at station A we can conclude that the creek recharged groundwater throughout 2017-18, although the VHG between the two piezometers indicated consistent upwelling conditions. This discrepancy in results may be attributed to the physical locations of the piezometers relative to the stream and the hydrometric station, and the sediment properties. Because the piezometers were installed away from the channel in the south bank, they may not accurately reflect the connection between the stream and the underlying aquifer. A localised pattern of recharge directly beneath the stream channel may be superimposed on the regional groundwater flow pattern where upwelling conditions occur near the stream (Figure 9). The piezometers may be located outside of the localised recharge zone, and thus not represent the stream-aquifer connection. In addition, the stream water level monitoring site was located approximately 8 m downstream of the piezometers, so the calculated VHG between the piezometers and the stream may not be valid. Alternatively, sedimentary deposits may have created a shallow confining layer. When the piezometers were installed, a 2.9 m layer of clay was described above the screen in the deeper well and a 0.9 m layer above the screen in the shallower well (sediment logs are provided in the appendix). This low permeability material may have altered flow conditions, creating an upward gradient between the piezometers. The degree of connectivity between the creek and the confined sediments is unknown, but the coincidental occurrence of the peak VHG occurring during peak streamflow in 2017 suggested that there is a connection.

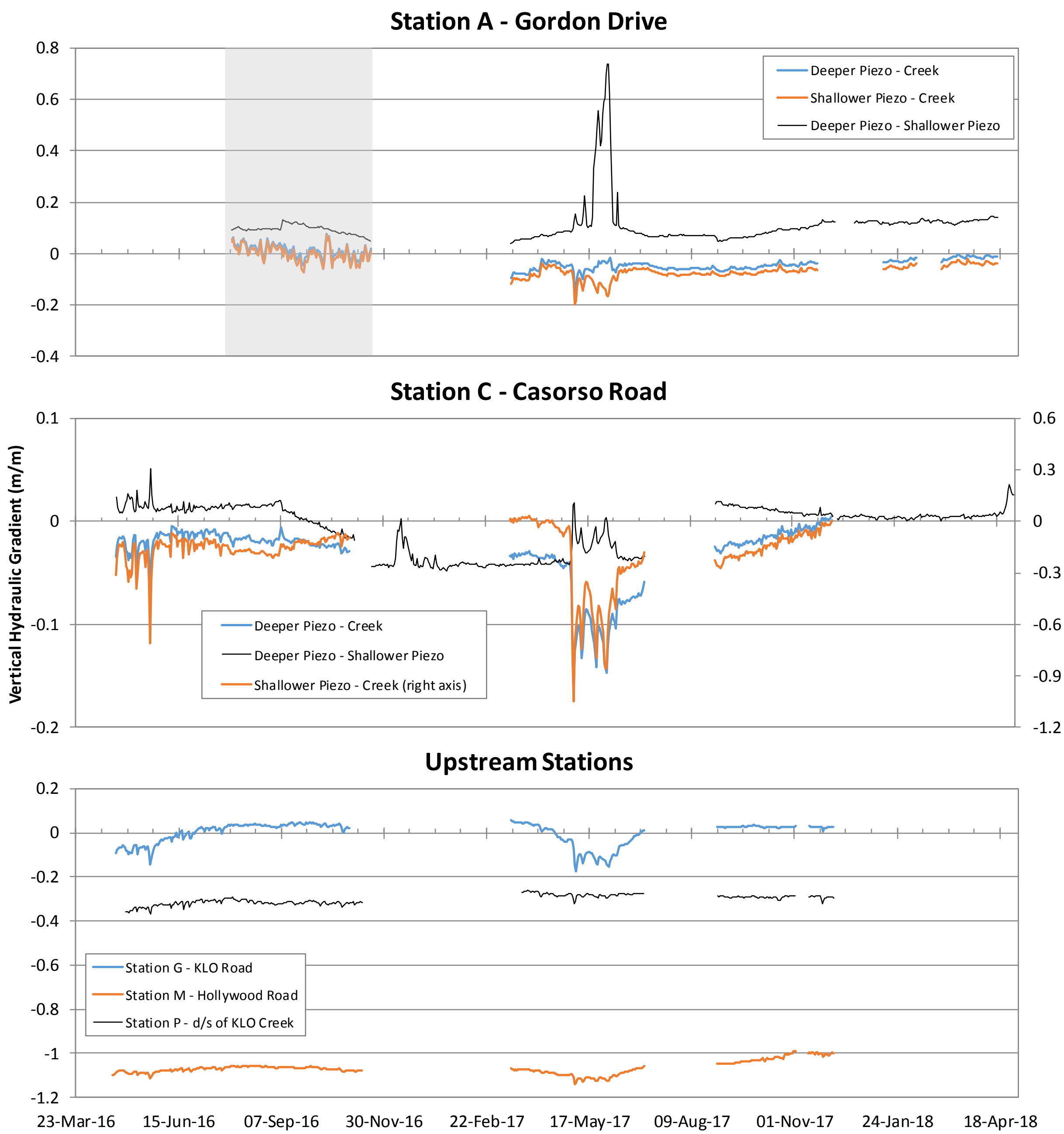


Figure 8: Calculated vertical hydraulic gradients at stations that had piezometers. In the top figure, the period of transient gaining and losing conditions is shaded. In the middle graph, VHG between the shallow piezometer and the creek is plotted on the secondary axis.

The VHG between the piezometers and the creek at Casorso Road (C) showed generally losing conditions while the VHG between the piezometers was more variable (Figure 8; middle graph). The area around Casorso Road is known to have springs and seeps which indicate a high water table, so losing stream conditions were unexpected. The elevation of this station was approximately 3m above the highest water level recorded on Okanagan Lake, and backwatering should not have occurred (Eyjolfson and Enns, 2017). However, the calculation of losing conditions at this location was probably influenced by the same factors as at Gordon Drive. Most importantly, the differences in water level elevation between piezometers were small (on the scale of a few centimetres) and within the measurement error. However, the piezometers may again not have accurately represented localised recharge beneath the stream (Figure 9). The large magnitude of the vertical hydraulic gradient between the shallow piezometer and the stream is likely due to a 1.8 m layer of low permeability clay that was found 4.3 m below the ground surface (sediment logs are in the appendix).

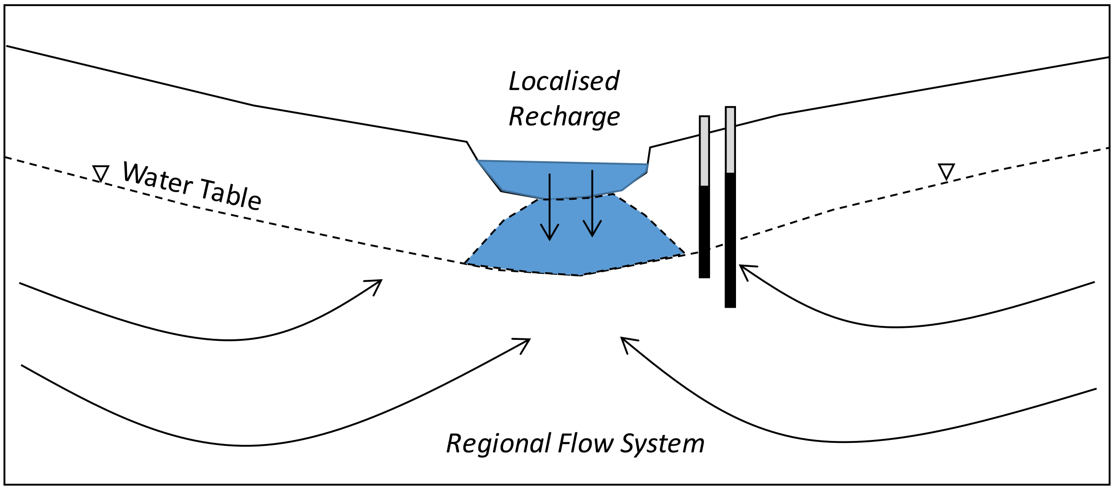


Figure 9: Potential localised recharge beneath a stream overlain on a regional groundwater flow pattern. In this diagram, the upwelling vertical hydraulic gradient between the piezometers does not represent downwelling conditions beneath the stream.

VHG calculated between the creek and the single piezometer upstream of KLO Road station (G) varied between losing and gaining conditions (Figure 8; lower graph). There were considerable gaps in the record through 2017, but losing conditions were calculated during the high flow periods and gaining conditions occurred during the low flow periods, as was expected. These results correlated with observed springs and seeps in this region, which would indicate an influence of high water table levels during the non-high flow period. The piezometer was located approximately 20 m upstream of the stream gauge.

Although two piezometers were installed at Hollywood Road station (M), the shallower one showed wide fluctuations and it was concluded that storm runoff affected the water level recorded in this well. Considering only the very deep piezometer (screened 13.9 m below the streambed), losing conditions were calculated at station M (Figure 8; lower graph). However, it may be problematic to use the results from this very deep piezometer to infer connectivity between Mission Creek and the water table at this location. An 8.5 m layer of brown till was found near the bottom of the drill hole, and the screen was installed above another till deposit. Till can have very low permeability; therefore, it is unknown how well this piezometer represented shallow water levels.

Downstream of where KLO Creek enters Mission Creek (station P), consistent losing conditions were expected and calculated (Figure 8; lower graph). The piezometer screen was approximately 5.1 m below the streambed at this location.

5.2 Rating Curves and Discharge

At most stations two rating curves had to be defined; one prior to the 2017 freshet, and another after. The spring freshet in 2017 had a significant effect on the Mission Creek channel, and erosion/deposition at various stations required changes to the rating curves. At most stations there were fewer points available before the 2017 freshet upon which to derive the rating curve, which increases the level of uncertainty in calculated discharge for that period.

The range of field measurements on which each rating curve was based is detailed in the appendix along with the elevation of zero flow (*e*), the values for α and β, and the root mean square error (RMS). The RMS is reported from the Aquarius Rating Curve Tool software should only be used as an estimate of line fit.

It is important to note that uncertainty in the rating curve relationship increases outside of the range of measured values and where few data points are available. At the hydrometric stations in the main channel of Mission Creek, most discharge measurements were made below 5 m^3/s, with a single high flow measurement (Figure 10). Extrapolating the rating curve to high flows is extremely problematic because the shape of the channel can change, which affects the α value.

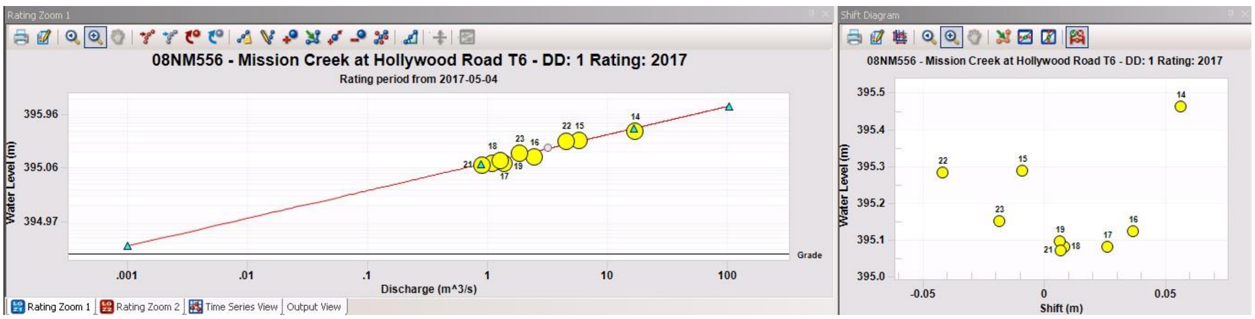


Figure 10: Example rating curve for the hydrometric station at Hollywood Road (M) for the period after the 2017 freshet. The graph on the left shows the relationship between discharge (horizontal axis) and water level elevation (vertical). The graph on the right shows how well the line fits the measured points.

The resulting hydrographs (plots of discharge over time) show typical shapes for snowmelt-dominated streams (Figure 11 and Figure 12, upper graphs). The highest flows in Mission Creek occur during the spring, declining rapidly to low rates through the summer and early fall. Flows during the fall season may increase due to rain, but generally stay low. There were gaps in the data when there was ice on the creek; the rating curves do not apply under these conditions. Differences between stations during low flows are clearer when discharge is plotted on a logarithmic scale (Figure 11 and Figure 12, lower graphs).

5.3 Water Balances

As noted previously, the potential error in calculating discharge increases outside of the range of measurements used to fit the rating curve (all measurements in the main channel except one high flow value were less than 5 m^3/s). Because the difference in discharge between consecutive hydrometric stations can be very small, it was necessary to use only data for which there was relatively high confidence. As a result, only periods when flow was consistently less than 10 m^3/s were used in the water balance analysis. In addition, there were gaps in the record during winter 2016-2017 due to equipment problems. The periods used in this analysis were: 29 June to 2 November 2016; 14 March to 18 April 2017; and 23 June to 3 December 2017.

A potentially significant source of inflows occurs as urban runoff after significant rain events. When daily total precipitation measurements for the weather station at University of British Columbia Okanagan were analysed for three arbitrary thresholds, there were three days with precipitation greater than 10 mm, six with greater than 8 mm and eight days with greater than 6 mm during the time periods used in this analysis (327 days). With this very low frequency of potential urban runoff, it was ignored in the following discussion.

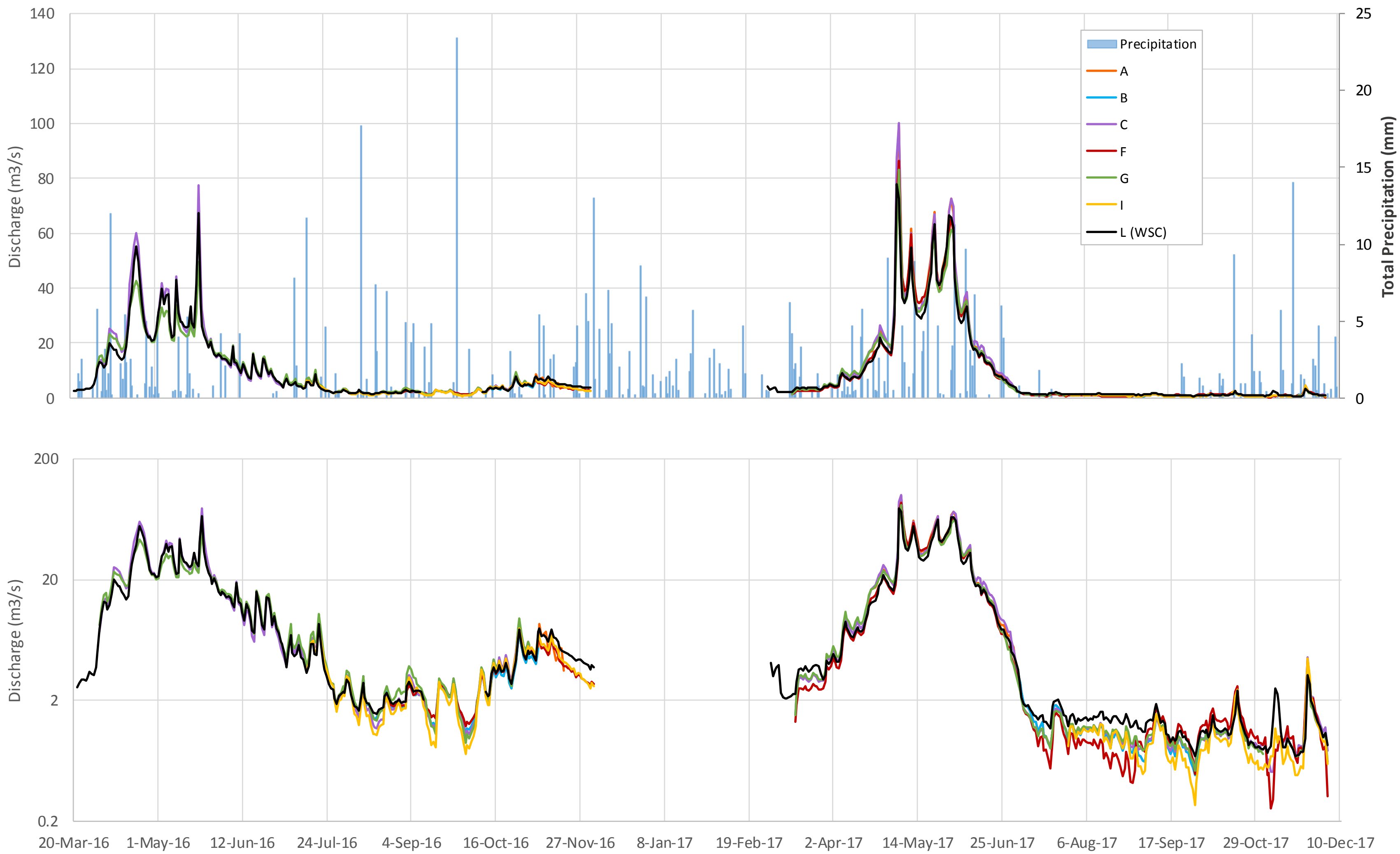


Figure 11: Daily average discharge (m^3/s) at hydrometric stations along the lower portion of the main channel of Mission Creek (stations A to L), using linear (top) and logarithmic (bottom) scales. Preliminary WSC data is presented for station L. Also shown is daily total precipitation measured at the weather station at University of British Columbia Okanagan.

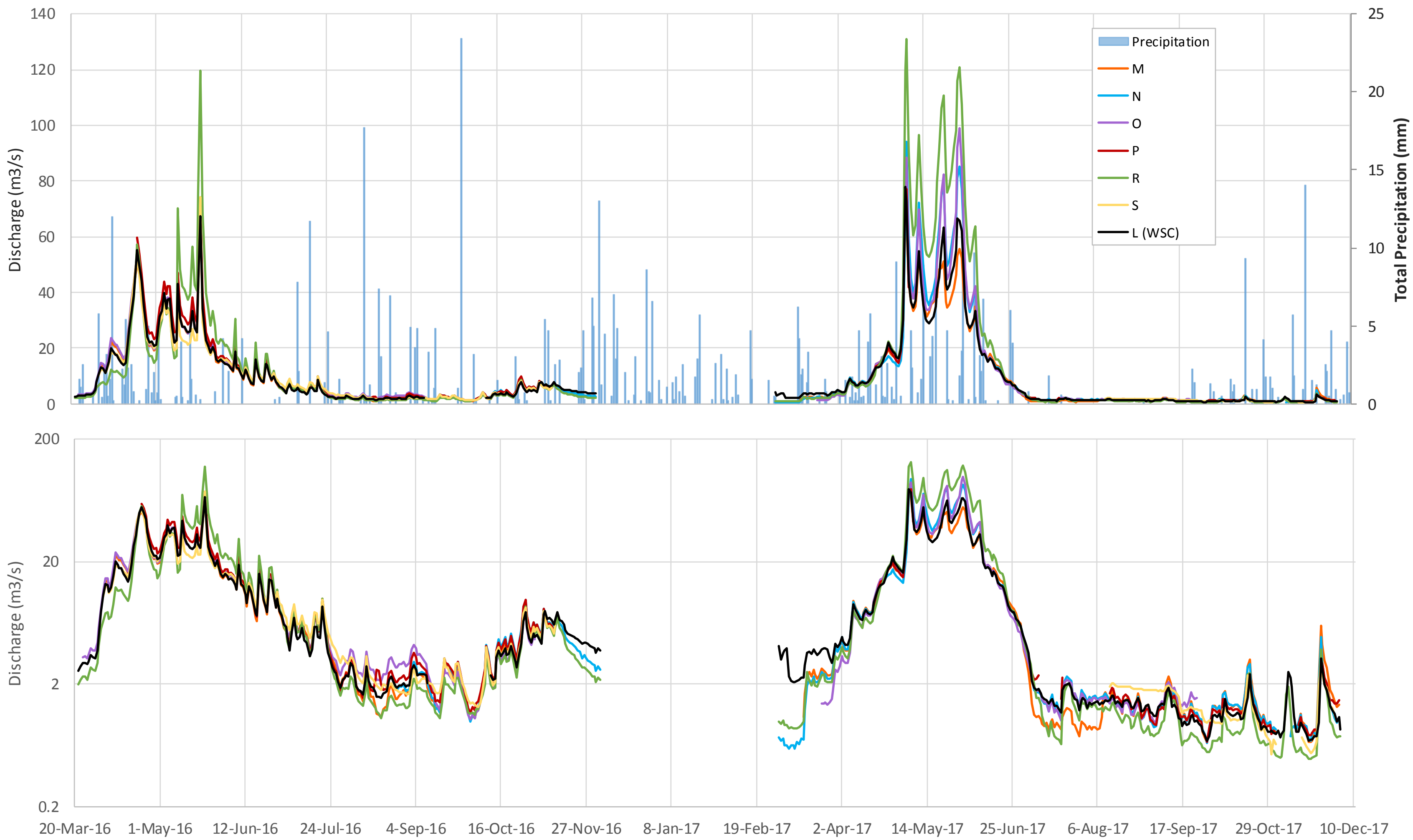


Figure 12: Daily average discharge (m^3/s) at hydrometric stations along the upstream portion of the main channel of Mission Creek (stations L to S), using linear (top) and logarithmic (bottom) scales. Preliminary WSC data is presented for station L. Also shown is daily total precipitation measured at the weather station at University of British Columbia Okanagan.

The transfer of groundwater to the atmosphere through evapotranspiration by vegetation in the riparian zone was not explicitly accounted for in this water balance approach. The density of vegetated streambank was relatively consistent over the entire study length, although vegetated width was lower in the segments between stations C and F, and L to N. Because of this consistency, the effect of riparian evapotranspiration was considered to be the same for all stream sections. Using estimated monthly values of potential evapotranspiration and an average riparian width of 15 m on both sides of the stream, riparian vegetation may have removed 0.052 m^3/s, 0.045 m^3/s and 0.027 m^3/s in July, August and September, respectively. The actual loss of water to the atmosphere would be highly variable and depend on vegetation type and density, width of vegetated area, weather and depth to the water table. The magnitude of these losses will be compared to the water balance results in the Discussion and Conclusion section.

A negative water balance indicates a loss of water from the creek between stations, while a positive value indicates gaining conditions.

Between most stations, gain/loss conditions were not consistent over time; seasonal variations were not unexpected and were also documented in a previous study of Mission Creek (Lowen and Letvak, 1981). The following discussion is organised by stream section, starting with the most downstream section. Gain/loss magnitudes calculated from Letvak and Lowen (1981) (Table 2, Figure 13 and Figure 14) are compared with the 2016-17 data. Comparisons with the VHG values are also provided, but with the caveat that VHG represents conditions at a single site while the water balance results represent net conditions for the full stream section between stations, and as such they cannot be directly compared.

Table 2: Discharge measurements reported by Lowen and Letvak (1981) (converted to m^3/s) (see Figure 13 for location map). Not all stations were visited on each date. Gaining/losing sections calculated from these measurements are presented in Figure 14.

Station*	Location	12 Dec 1979	27 Mar 1980	19 Aug 1980	9 Sept 1980	23 Sep 1980
Lowen H	Upstream of Lakeshore Drive	0.784	1.008		2.602	4.361
Lowen G (station C)	At Casorso Road	0.648	0.923		2.534	
Lowen F (station F)	At KLO Road	0.728	0.895			4.191
Lowen E (station L)	WSC Gauge	0.648	0.844			4.248
Lowen D (station M)	At Hollywood Road	0.654	0.850			
Lowen C (station O)	Near South East Kelowna Trailer Court	0.631	0.878	3.625		4.786
Lowen B	Upstream of Hydraulic Creek			3.879		4.106
Lowen A (station R)	Downstream of BMID Intake			3.681		3.964

**Lowen and Letvak stations were labelled alphabetically from upstream to downstream but are presented in the opposite order to match the current analysis. Where their stations occurred at the same location as those used in this analysis, our station identifier is given in parenthesis.*

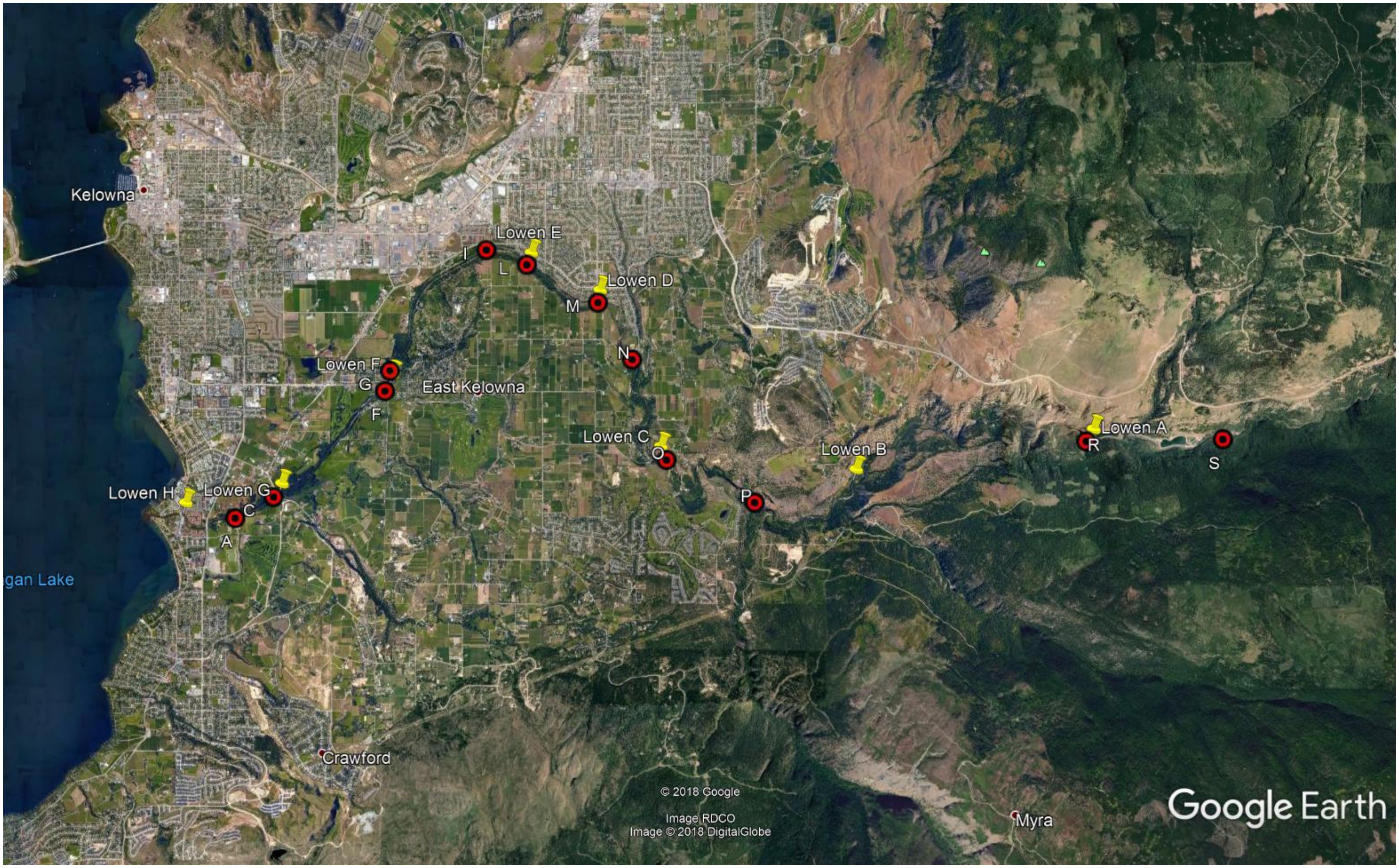


Figure 13: Map of lower Mission Creek showing hydrometric stations installed in the main channel for this project (circles) and those used by Lowen and Letvak (1981, yellow pins). Image: Google Earth.

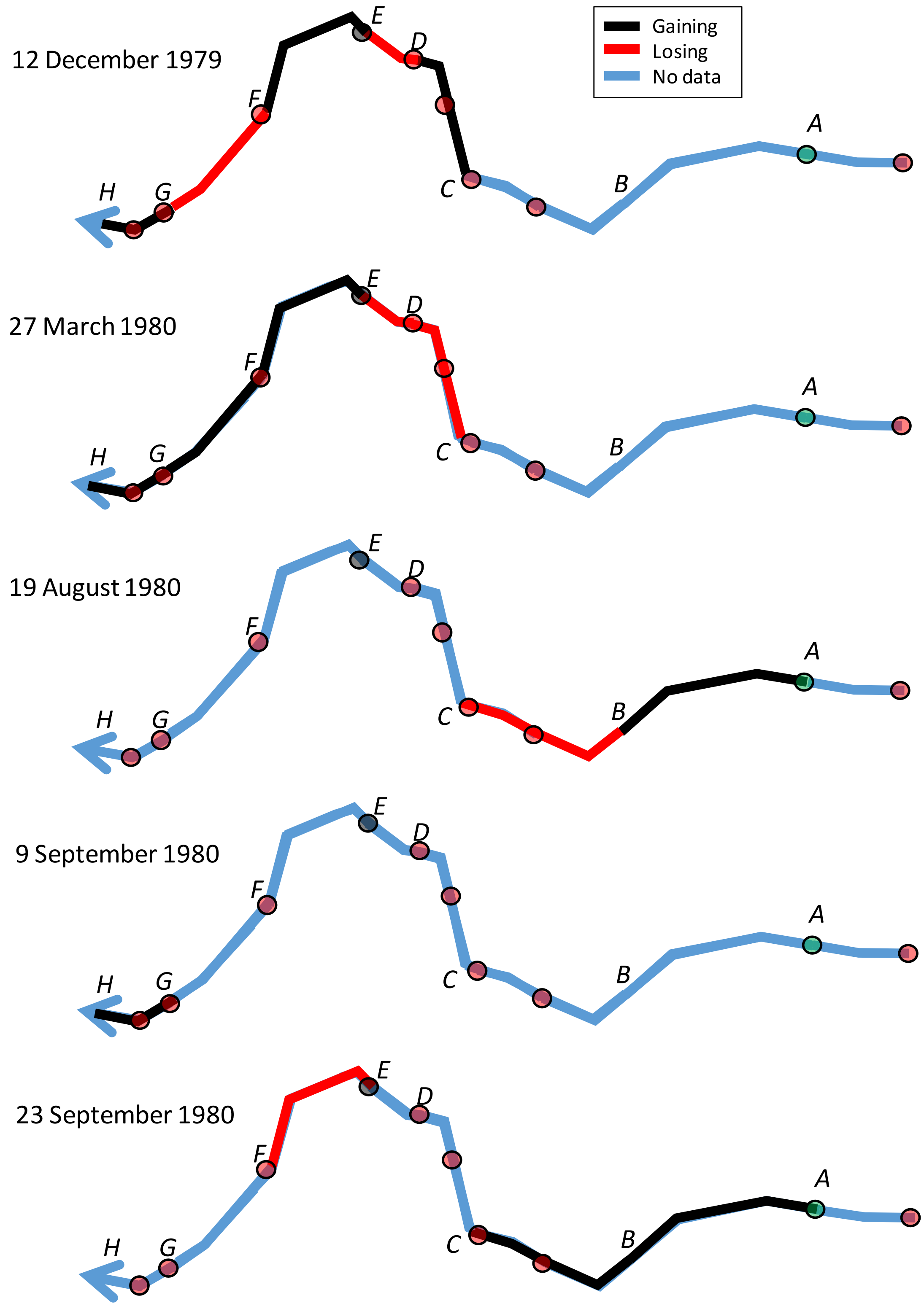


Figure 14: Gaining and losing sections of lower Mission Creek measured in 1979 and 1980 (Lowen and Letvak, 1981; see also Table 2). Locations of hydrometric stations used by Lowen and Letvak are lettered; stations used in the water balance for this study are shown as circles.

5.3.1 Downstream of KLO Road (stations A to G)

Along this section, Lowen and Letvak (1981) indicated gaining conditions of between 2 and 6.5 cfs (0.057-0.184 m^3/s) (Table 2). Inputs from Priest Creek and Rumohr Creek upstream of Casorso Road station C as well as springs near the Casorso and KLO Road bridges were expected, but also groundwater inputs due to a relatively high water table where the stream approaches the lake.

When discharge at station A was compared to that at C, flow was slightly higher at station C when discharge was greater than approximately 2 m^3/s (Figure 15, A vs. C). This indicated generally losing conditions between Casorso Road and Gordon Drive. Data gaps at station A limited the amount of data available, but these results were consistent with the VHG analysis. A walking survey during August-September 2016 did not identify any diversions or intake pipes between stations A and C (Eyjolfson and Enns, 2017).

Between stations C and F, there are inflows from Priest and Rumohr Creeks and springs upstream of Casorso Road (Eyjolfson and Enns, 2017), and diversions to the South Kelowna WUC. When discharge measured at the two stations was compared, flow at station C was generally greater than at F, indicating gaining conditions along this section (Figure 15, C vs. F). Inflow from Priest Creek ranged between 0.007 and 0.526 m^3/s, with an average of 0.103 m^3/s over the entire measurement period (compared to an average of 2.56 m^3/s at station E for the same period). Photographs taken during stream walks in August and September 2016 indicated two inflow locations upstream of Casorso Road (Eyjolfson and Enns, 2017, outlets 2239 and 2315). Assuming that these inflows were groundwater-fed and were similar in magnitude and pattern to Priest Creek, the total gains from Priest and Rumohr Creeks and other springs were assumed to be equal to twice the amount of flow in Priest Creek. When these gains were accounted for (Figure 15, bottom), conditions varied between gaining and losing, although losing conditions dominated the fall of 2017 when the water table was lower. The escalating gains calculated over spring 2017 occurred during the rising limb of the peak caused by snowmelt, and may be an artifact of uncertainty in the rating curve at relatively high flow rates. Losing conditions were consistent with the VHG values calculated for station C.

When discharge measured at stations F and G were compared, the more upstream station generally had higher flow rates (Figure 15, F vs. G). This contradicted evidence of springs and significant inputs between the two stations (Eyjolfson and Enns, 2017, outlets 4614, 4741, 4750 and 4944), which were only approximately 325m apart. During fall 2016 and spring 2017, conditions were generally losing along this section. The escalating losing conditions calculated during the spring of 2017 occurred during the rising limb of the hydrograph, and may be an artifact of uncertainty in the rating curve. The periods of gaining and losing conditions do not coincide with those calculated for the VHG at station G.

Discharge measured at station C was compared to that at G, and (with some exceptions) the records were more consistent than when each station was compared to station F (Figure 15, C vs. G). This suggested that there may be errors in the dataset for station F, but the cause of these errors was unknown. Flow at the upstream station (G) was generally slightly higher than at station C. When the difference in flow between station C and G was calculated and inflows accounted for, conditions were generally losing during the summer of 2017 (Figure 15). During the fall season of both 2016 and 2017, conditions became temporarily gaining. The strong losing conditions during spring 2017 may again be an artifact of uncertainty in the rating curve at high flow rates. The general pattern is reflected in the VHG record for station G, although the two datasets do not always show the same direction.

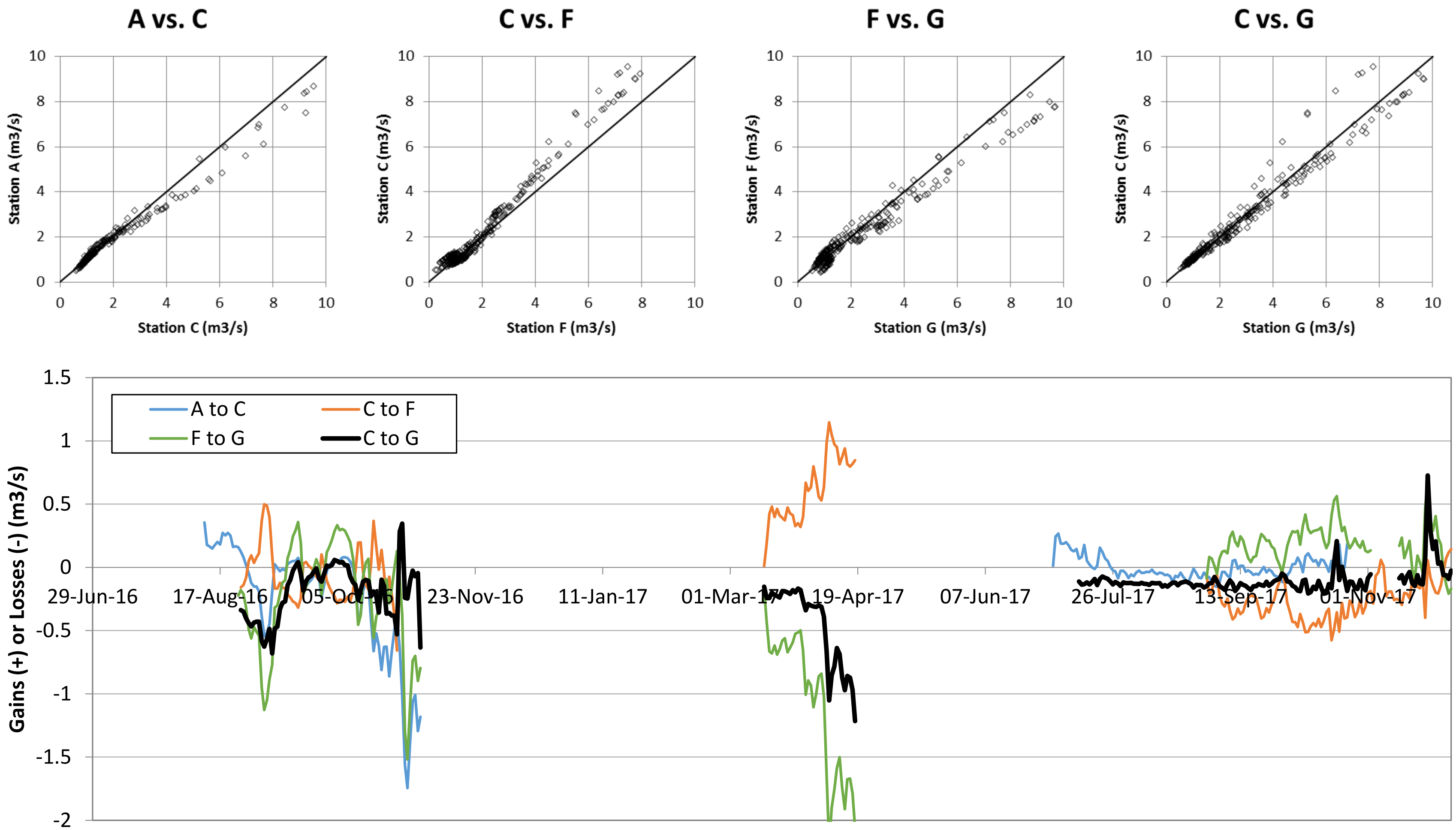


Figure 15: (Top) Comparison of daily discharge at adjacent hydrometric stations (not compensated for inflows/outflows), and (bottom) calculated daily gaining/losing conditions between adjacent stations compensating for inflows and outflows, between Gordon Drive (A) and KLO Road (G) stations.

5.3.2 *Between KLO Road and the WSC Gauge (Kiniski Road) (stations G to L)*

Lowen and Letvak (1981) found variable gain/loss conditions along this section, with gains near 3 cfs (0.085 m^3/s) and losses of 2 cfs (0.057 m^3/s). Some of the losses were attributed to water withdrawals (licensed and unlicensed), but the variable conditions were explained by changing water table elevations.

When discharge measured at station G (upstream of KLO Road) was compared with that at station I (downstream of Ziprick Road), flows at the downstream station were generally slightly larger (Figure 16, G vs. I) indicating gaining conditions between these stations. The Mill Creek and Mission spawning channel diversions enter the creek along this section, and there is a small pipe that potentially allows overflow from an adjacent pond (Eyjolfson and Enns, 2017, outlets 6666, 6677 and 5896, respectively).

Comparing discharge at station I with that at the WSC gauge (station L) showed that flow at the more downstream site was slightly higher than at the upstream station when flow was greater than approximately 2 m^3/s (Figure 16, I vs. L), despite two known diversions along this section (to the spawning channel, J, and the Benvoulin WUC, K). Approximately 100 m downstream of the WSC gauge (L) on the south bank, groundwater seepage and a pipe were observed during August-September 2016 indicating small sources of water to Mission Creek (Eyjolfson and Enns, 2017, outlet and unknown pipe 8085).

No data is shown for the individual sections during spring 2017 because the records for station I during that period were deemed unreliable due to ice damage to the station.

When flow at station G was compared to that at station L, there is slightly more variability in gaining and losing conditions (Figure 16, G vs. L). Because of the lack of flow data for the spawning channel, comparing these two stations should provide more reliable information on gaining/losing conditions. After accounting for inputs from Mill Creek, the fall 2016 record showed generally gaining conditions (Figure 16, bottom). There was a transition from losing to gaining during spring 2017, and the summer and fall 2017 record showed generally losing conditions. The range of values calculated before the 2017 spring freshet was much larger than after freshet; this may have been an artifact of having fewer points to build the rating curves for the pre-freshet period and the associated increase in uncertainty in the calculated discharge.

5.3.3 *Between the WSC gauge and Hollywood Road (stations L and M)*

Lowen and Letvak (1981) found losing conditions of 1 cfs or less (<0.028 m^3/s) along this section, concluding that there was recharge of the “upper water-bearing soils that overlie the Rutland aquifer”. However, they concluded that this section was near a balance point, where gaining and losing conditions could occur depending on seasonal variations in the local water table.

This was somewhat supported by the 2016-17 water balance calculations between station L (WSC gauge) and M (Hollywood Road) where conditions fluctuated between gaining and losing (Figure 17). Two potentially significant inflows occur between these stations. In 2016, a potentially groundwater fed tributary was observed approximately 500 m upstream of the WSC gauge (L) on the south bank, which could supply inflow to Mission Creek throughout the year (Eyjolfson and Enns, 2017, outlet 8684). A pipe was also observed on the north bank approximately 35 m downstream of station M (Eyjolfson and Enns, 2017, outlet 9116); the pipe is elevated above the streambed and occurs at the end of Hollywood Road, leading to the conclusion that this is for stormwater drainage. If this conclusion is correct, then contributions from this source would only occur following rain events.

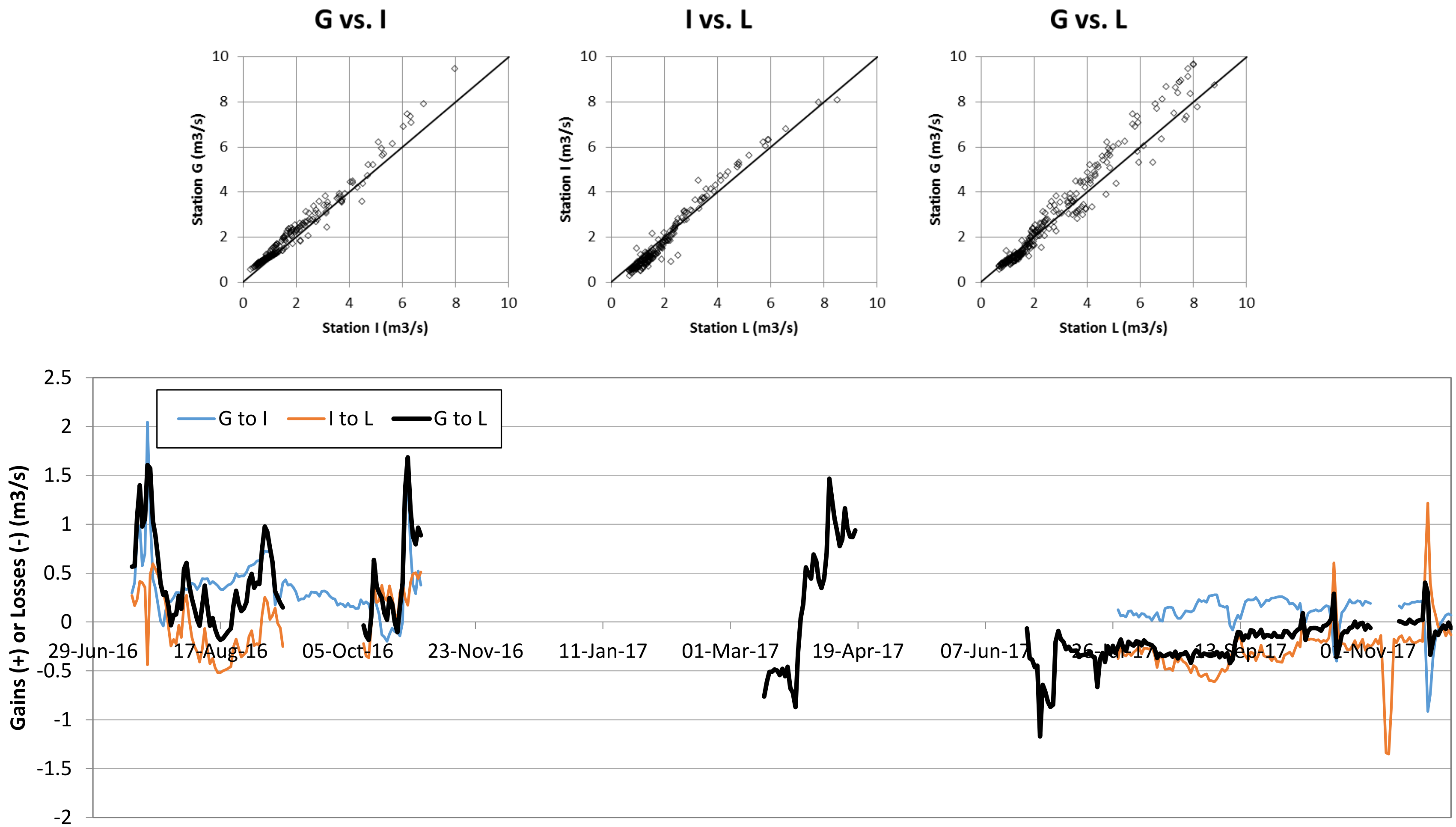
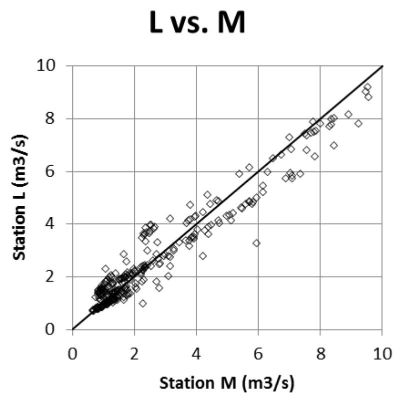


Figure 16: (Top) Comparison of daily discharge at adjacent hydrometric stations (not compensated for inflows/outflows), and (bottom) calculated daily gaining/losing conditions between adjacent stations compensating for inflows and outflows, between KLO Road (G) and the WSC Gauge (L).



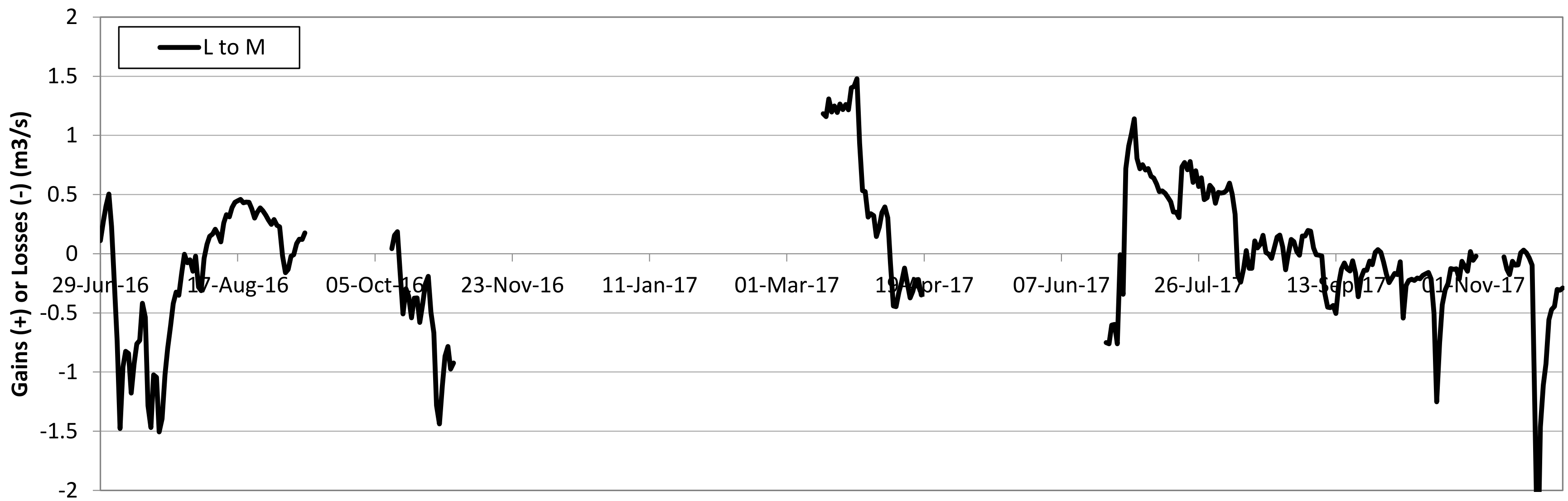


Figure 17: (Top) Comparison of daily discharge at adjacent hydrometric stations (not compensated for inflows/outflows), and (bottom) calculated daily gaining/losing conditions between adjacent stations compensating for inflows and outflows, between the WSC Gauge (L) and Hollywood Road (M).

5.3.4 *Between Hollywood Road and KLO Creek (stations M to P)*

Lowen and Letvak measured gaining and losing conditions between Hollywood Road and their site downstream of KLO Creek in December 1979 and March 1980, respectively.

When discharge measured at Hollywood Road (station M) was plotted against that at East Kelowna Road (station N), the records generally agree (Figure 18, M vs. N). Four potential inflow points were observed between these stations; three of the inflows were not observed to be flowing in August-September 2016 (Eyjolfson and Enns, 2017, outlets 9451 and 9598), but the one approximately 300 m downstream of station N was flowing and the design of the location suggested that this might be a substantial inflow at times (outflow from the pipe hits a wall of concrete blocks before entering the creek) (Eyjolfson and Enns, 2017, outlet 10171). One small intake was observed approximately 85 m downstream of station N. The calculated water balance between the two stations shows fluctuation between gaining and losing conditions, though losing conditions generally dominated.

Flow at station N was generally larger that at the 12km bridge (O) when flow was greater than approximately 2 m^3/s (Figure 18, N vs. O), attributed to known spring inflows upstream of the East Kelowna Road bridge. Temporary losing conditions were recorded at the end of the summer season in both 2016 and 2017.

A plot comparing discharge at stations O and P (downstream of KLO Creek) indicated variable gaining and losing conditions between these locations (Figure 18, O vs. P). The pattern was generally opposite to that for the section between N and O. There are two water licenses between these stations, but their use is unknown.

Looking at the full section between stations M and P, gaining conditions were calculated during the summer periods of 2016 and 2017, with a transition to losing conditions in the fall of 2016 (Figure 18).

5.3.5 *Upstream of KLO Creek (stations P to S)*

KLO, Hydraulic and Dave's Creeks contribute flow to this section, and BMID takes water from Mission Creek immediately below station S. Lowen and Letvak (1981) concluded that Mission Creek gained water below the BMID intake and where Hydraulic Creek enters Mission Creek, and that losses between Hydraulic Creek and their station near the 12km bridge were greater than inflows from KLO and Hydraulic Creeks.

With a few exceptions, discharge at station R (below BMID diversion) was always less than at station S (above BMID diversion (Figure 19, R vs. S) due to diversions for irrigation and domestic use. Because we were unable to account for inflows from Hydraulic and Dave's Creeks between stations P and S, only the direction of the water balance results are valid (the magnitudes will be underestimated). Between stations P and R, inflow from Hydraulic Creek would increase the magnitude of the gains calculated in this analysis. Between stations R and S, inputs from Dave's Creek somewhat offset withdrawals by BMID, so the actual losses between the stations were underestimated here.

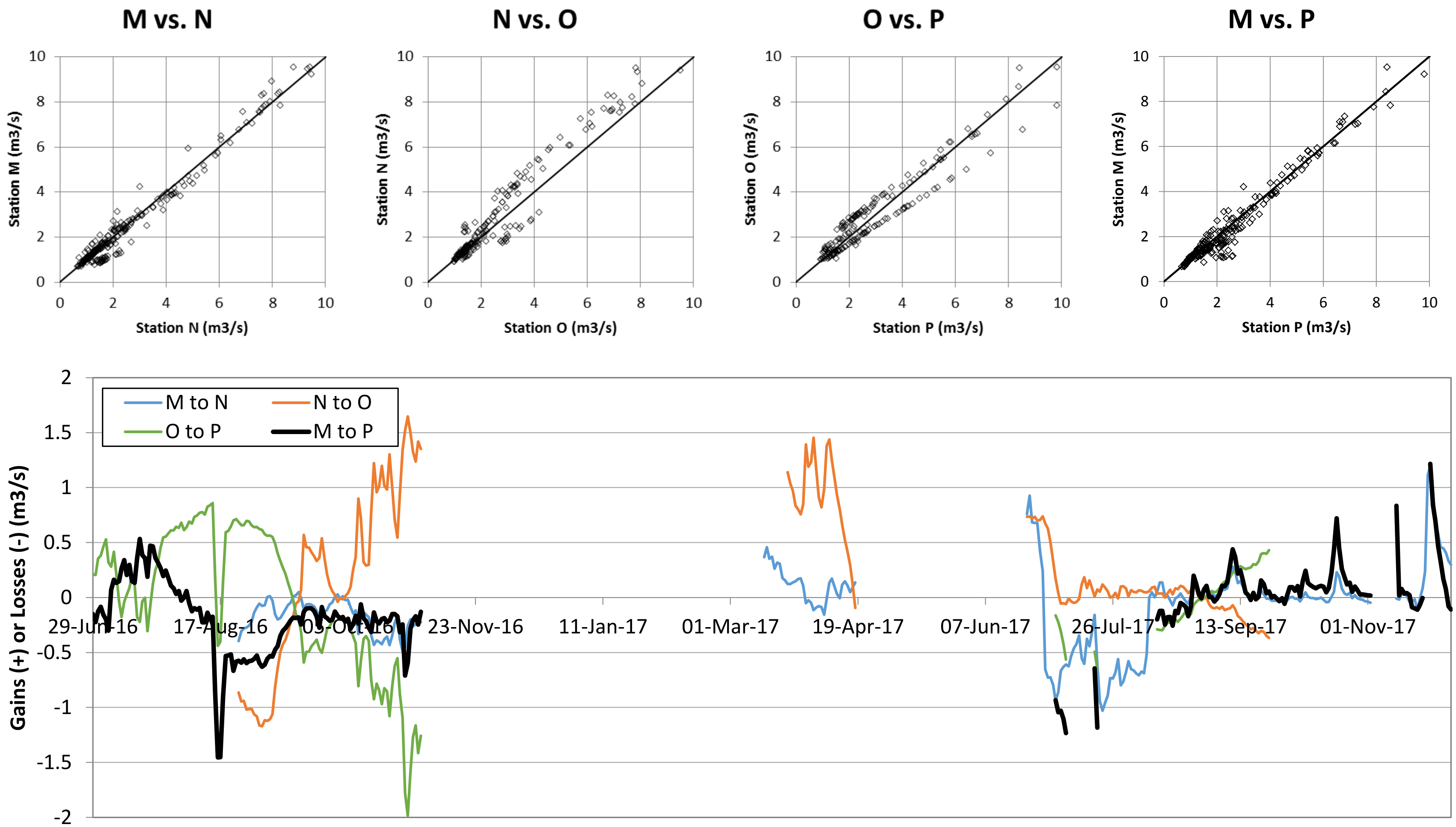


Figure 18: (Top) Comparison of daily discharge at adjacent hydrometric stations (not compensated for inflows/outflows), and (bottom) calculated daily gaining/losing conditions between adjacent stations compensating for inflows and outflows, between Hollywood Road (M) and downstream of the confluence with KLO Creek (P).

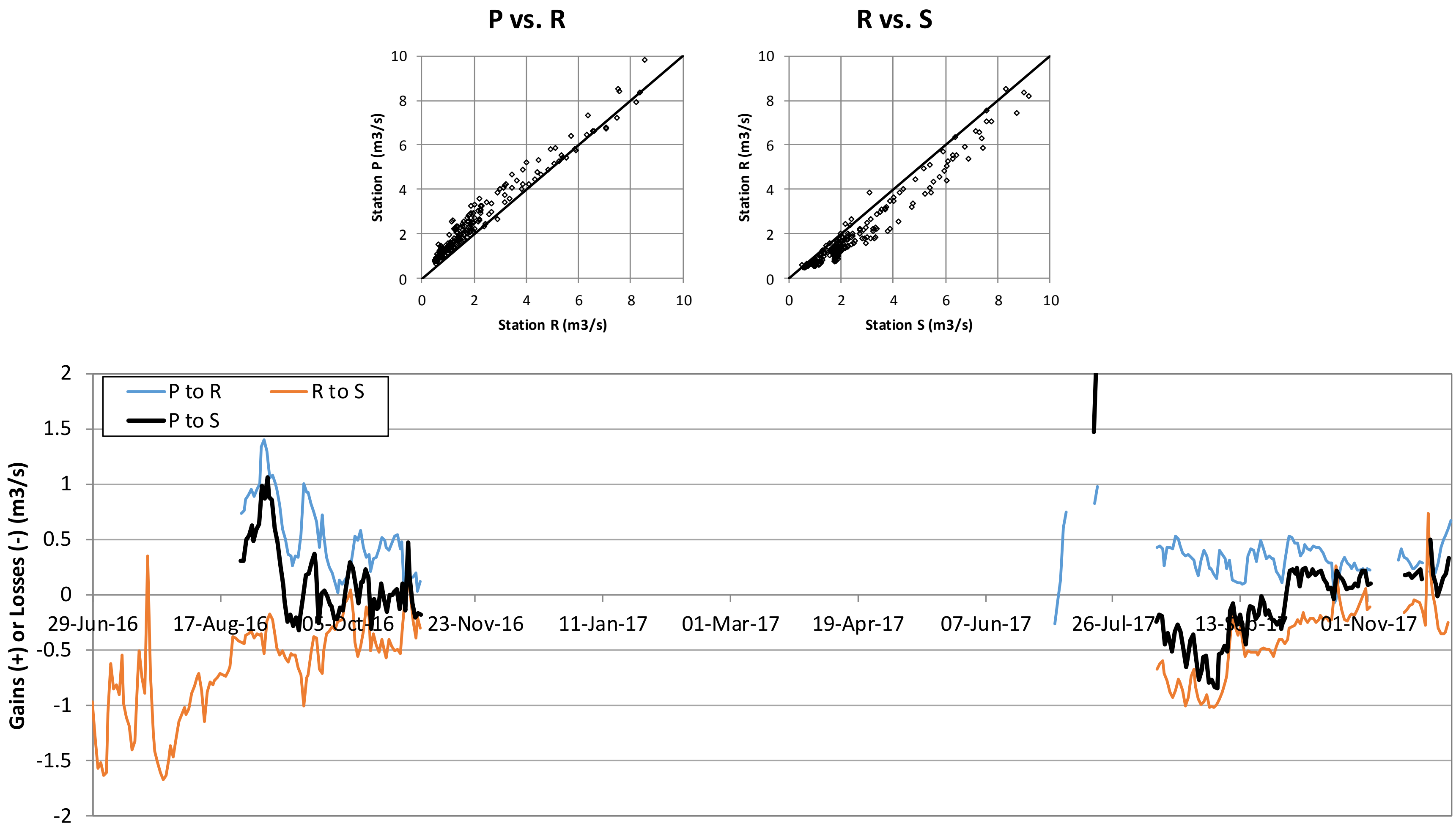


Figure 19: (Top) Comparison of daily discharge at adjacent hydrometric stations (not compensated for inflows/outflows), and (bottom) calculated daily gaining/losing conditions between adjacent stations compensating for inflows and outflows, between the confluence of KLO Creek (P) and the station upstream of the BMID intake (S).

6. DISCUSSION AND CONCLUSION

The gaining and losing conditions from the water balance are summarised for arbitrary dates through the study period (Table 3 and Figure 20). As expected, and as indicated by a previous study (Lowen and Letvak, 1981), surface and groundwater connectivity patterns along lower Mission Creek showed spatial and temporal variability. This work was an improvement on the previous analysis because it accounted for most of the major inflows and diversions occurring along Mission Creek, and because of the increased temporal coverage.

Losses of water to the atmosphere through evapotranspiration by riparian vegetation were estimated at 0.052 m^3/s, 0.045 m^3/s and 0.027 m^3/s for July, August and September (estimation of actual evapotranspiration would be extremely difficult and was outside the scope of this work). When the magnitude of these losses was compared to the magnitudes calculated using the water balance method, there were only a few sections and time periods where calculated gains/losses were close to zero and where consideration of evapotranspiration losses might be important. There was little spatial consistency in which sections of Mission Creek may be more affected, but temporally more sections (A to G, M to N and P to S) recorded near-zero gains during fall 2016; however, evapotranspiration losses decline to near zero in the fall. The effect of evapotranspiration by riparian plants, therefore, was ignored in this analysis.

The calculated gains and losses were of the same magnitude as those reported by Lowen and Letvak (1981). In general, during non-freshet flows gaining conditions occurred upstream of Hollywood Road (M) and losing conditions persisted downstream of KLO Road (G), although there were exceptions. These results were largely consistent with the findings of Lowen and Letvak (1981) (Figure 14 and Figure 20) and the vertical hydraulic gradients. Mission Creek incised post-glacial fluvial terrace and glacial lacustrine sediments where it entered the valley, and these deposits form steep slopes adjacent to the creek between Hollywood Road (station M) and the 12 km bridge (O) (Figure 21). Upstream of station O, the creek flows through a slightly wider valley with only slightly less steep slopes. Assuming that the elevation of the water table is related to the ground surface elevation, the hydraulic gradient upstream of Hollywood Road will always be towards the creek (gaining conditions).

Table 3: Calculated gains (positive) and losses (negative) for dates shown in Figure 20, accounting for known inflows and outflows. Losing conditions are highlighted in pink.

Section	1 Sept 2016	15 Oct 2016	15 Jul 2017	15 Aug 2017	15 Sept 2017	15 Oct 2017
A to C	-0.191	-0.664	0.178	-0.061	-0.035	0.055
C to G	-0.430	-0.191	-0.134	-0.141	-0.146	-0.208
G to L	0.388	0.637	-0.335	-0.347	-0.139	-0.041
L to M	0.215	-0.591	0.421	0.051	-0.183	-0.251
M to N	-0.055	-0.431	-0.603	0.010	0.033	-0.021
N to O	-0.055	1.222	0.184	0.001	-0.243	
O to P	0.623	-0.926		-0.256	0.258	
P to R	1.005	0.316		0.264	0.109	0.370
R to S	-0.365	-0.356		-0.718	-0.567	-0.233

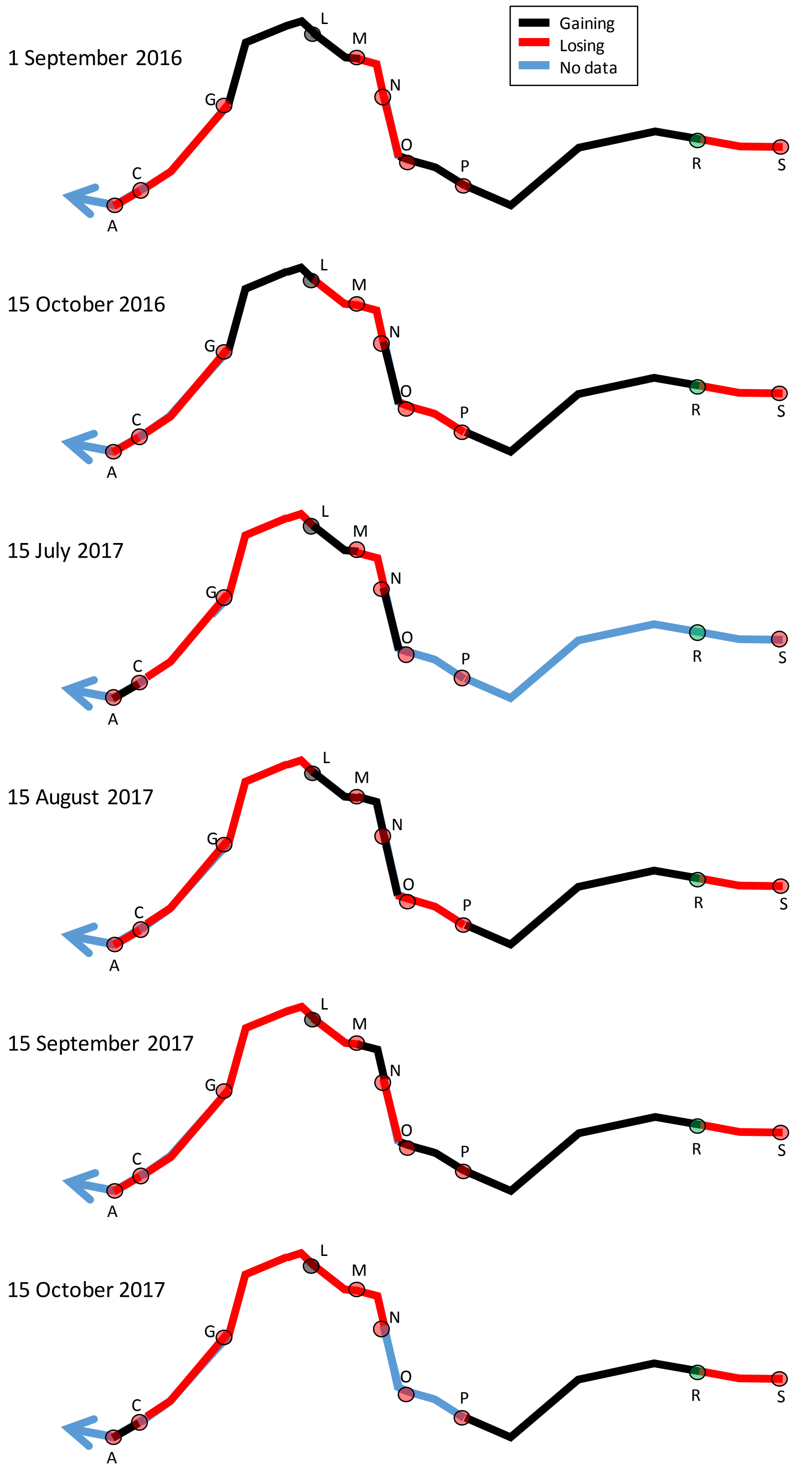


Figure 20: Gaining and losing sections along lower Mission Creek for arbitrarily selected dates in 2016 and 2017. Stations used in the calculations are labelled.

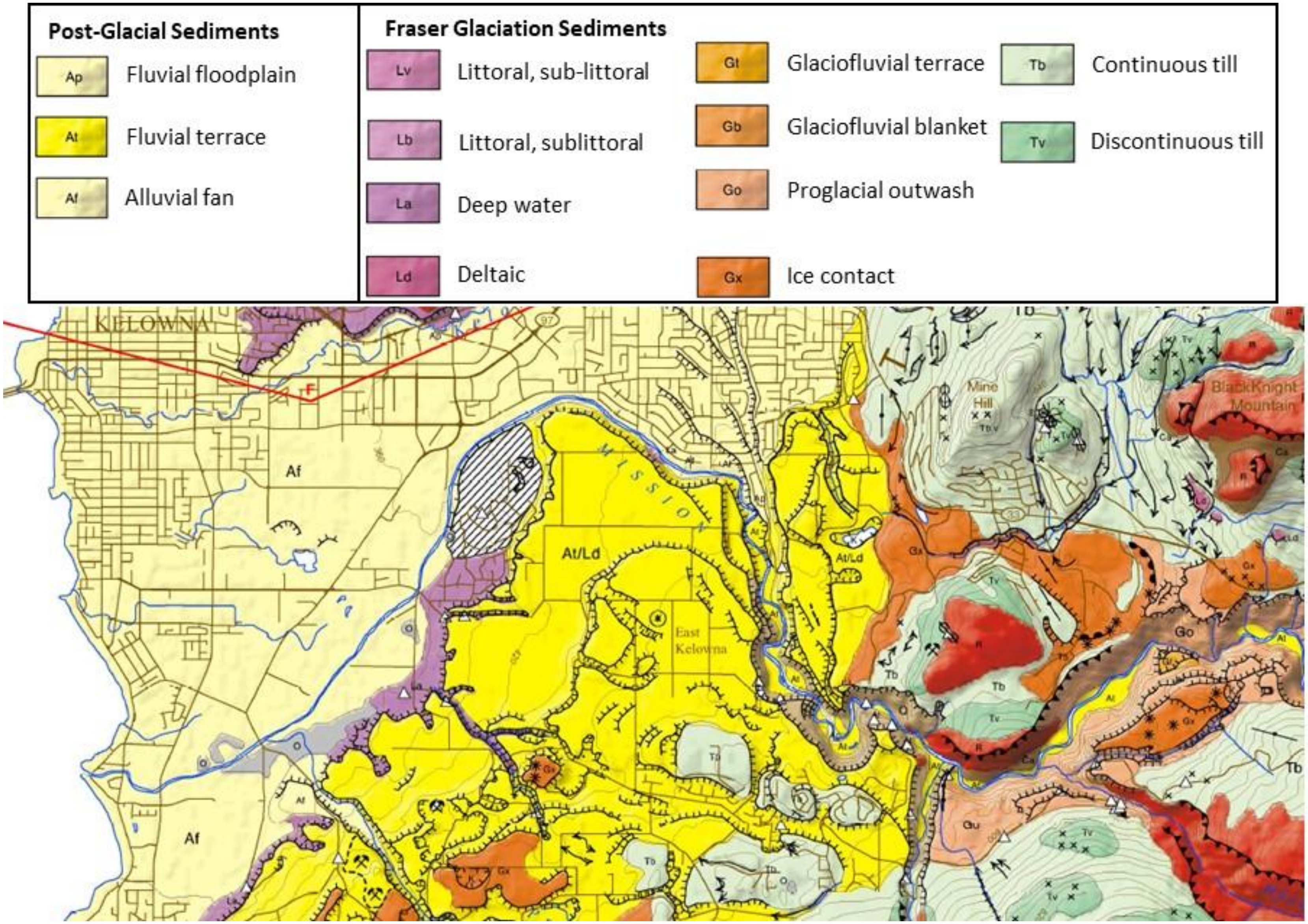


Figure 21: Surficial geology in the area around lower Mission Creek. Source: S.J. Paradis, 2009, Geological Survey of Canada Open File 6146 (https://doi.org/10.4095/248144).

Lowen and Letvak (1981) identified the middle section of the study reach as a transitional zone, where alternating gaining and losing conditions would be expected as the relative levels of the stream surface and the water table change through the year. From the 2016-17 measurements, the transitional zone appeared to occur between KLO Road (station G) and Hollywood Road (M). Between the station near Ziprick Road (I) and Hollywood Road (M), the slope on the south side of Mission Creek is steep and the hydraulic gradient maintains gaining stream conditions (springs and seep faces were identified across this slope). On the north side of the creek are flatter post-glacial alluvial fan deposits, where the direction of the hydraulic gradient will change depending on relative elevations of the water table and the stream. Without a dominant control, gaining and losing conditions were more variable along this section.

The prevalence of losing conditions downstream of KLO Road (station G) were somewhat counter to expectations. The water table rises in proximity to a large water body, and so gaining conditions were expected where Mission Creek approaches Okanagan Lake. The losing conditions may be the result of a near-surface layer of high permeability sediments that allows for losses to the hyporheic zone or to shallow groundwater.

The water balance method requires very good calculations of streamflow because the difference in discharge from one station to the next may be very small. Good streamflow data relies on high quality field measurements and well-defined rating curves, which can vary from one hydrometric station to the next. In addition, errors in measuring or estimating inflows and outflows can offset or magnify uncertainties in the calculated water balance values. Using piezometer measurements to verify water balance results is useful but has limitations; piezometers represent groundwater levels at a single point, while a water balance is calculated over a stream section. As well, variations in sediment properties and structures can affect how well piezometer data represent the water table and therefore the hydraulic connectivity between the surface and subsurface. The magnitudes of gaining and losing conditions calculated for Mission Creek need to be interpreted carefully, but the directions of flow (into the ground or into the stream) are considered robust.

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Resources Information Standards Committee (RISC). 2009. Manual of British Columbia Hydrometric Standards. B.C. Province of British Columbia: Victoria, B.C.

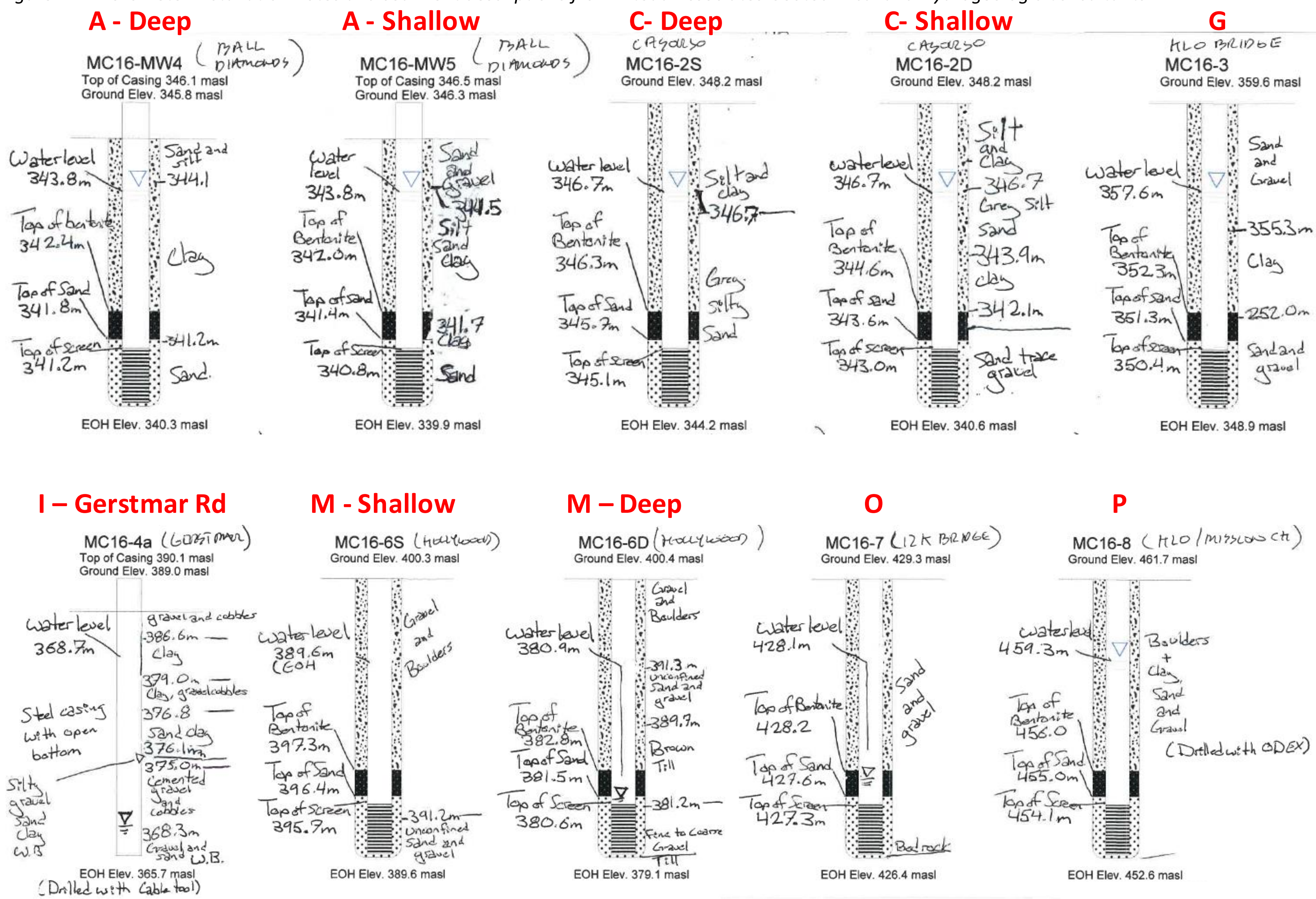
APPENDIX A: RATING CURVE DETAILS

Station	Period	Measured Range (m^3/s)	Zero-Flow Offset (e) (mASL)	Slope (α)	Coefficient (β)	RMS*
A	Before 2017 Freshet	1.38-56.9	343.54	2.44	13.12	20.1
	After 2017 Freshet	0.75-56.9	343.93	1.68	32.13	4.9
C	Before 2017 Freshet	1.30-10.30	345.78	2.30	37.95	3.7
	After 2017 Freshet	0.87-47.0	345.81	2.55	26.85	11.5
D	Before 2017 Freshet	0.04-0.06	346.365	2.59	4.63	14.6
	After 2017 Freshet	0.06-0.11	346.17	2.58	0.92	10.9
F	Before 2017 Freshet	0.89-59.9	354.40	2.41	26.58	5.9
	After 2017 Freshet	0.66-59.9	354.61	2.05	37.56	8.5
G	Before 2017 Freshet	1.31-10.02	356.60	1.59	36.61	3.6
	After 2017 Freshet	0.74-59.8	356.65	2.14	37.00	12.3
I	Full Record	0.68-48.4	376.24	1.80	40.12	11.0
K	2016	0.001-0.19	380.824	1.67	1.84	n/a
	2017a	0-0.16	380.854	2.33	8.73	63.3
	2017b	0-0.16	380.895	2.33	17.01	1.2
M	Before 2017 Freshet	1.33-3.15	394.84	2.54	40.41	19.8
	After 2017 Freshet	0.88-16.70	394.96	1.90	50.22	5.3
N	Before 2017 Freshet	2.15-7.82	409.83	2.28	23.63	13.5
	After 2017 Freshet	0.71-16.7	409.70	2.53	19.03	5.3
O	Before 2017 Freshet	1.39-14.2	430.05	2.51	33.89	14.6
	After 2017 Freshet	0.89-14.2	430.13	2.63	48.03	21.0
P	Before 2017 Freshet	1.50-2.90	459.39	3.04	25.72	5.3
	After 2017 Freshet	0.73-3.64	459.63	2.32	21.28	4.4
Q	Before 2017 Freshet	0.06-0.19	471.92	2.67	16.11	3.0
	After 2017 Freshet	0.01-0.09	471.74	2.74	3.97	16.5
S	2016	1.62-3.66	663.77	2.56	48.32	18.6
	2017	0.65-2.15	664.83	1.31	15.34	3.6

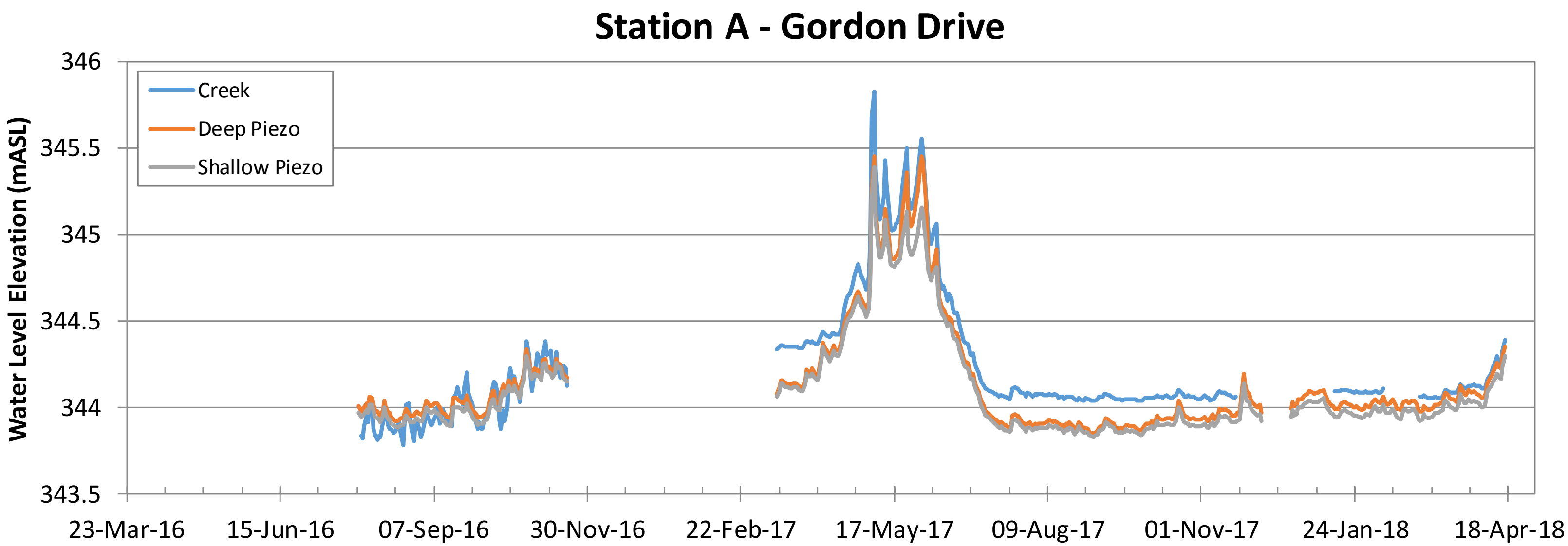
*As reported in Aquarius Rating Curve Tool (not a true RMS).

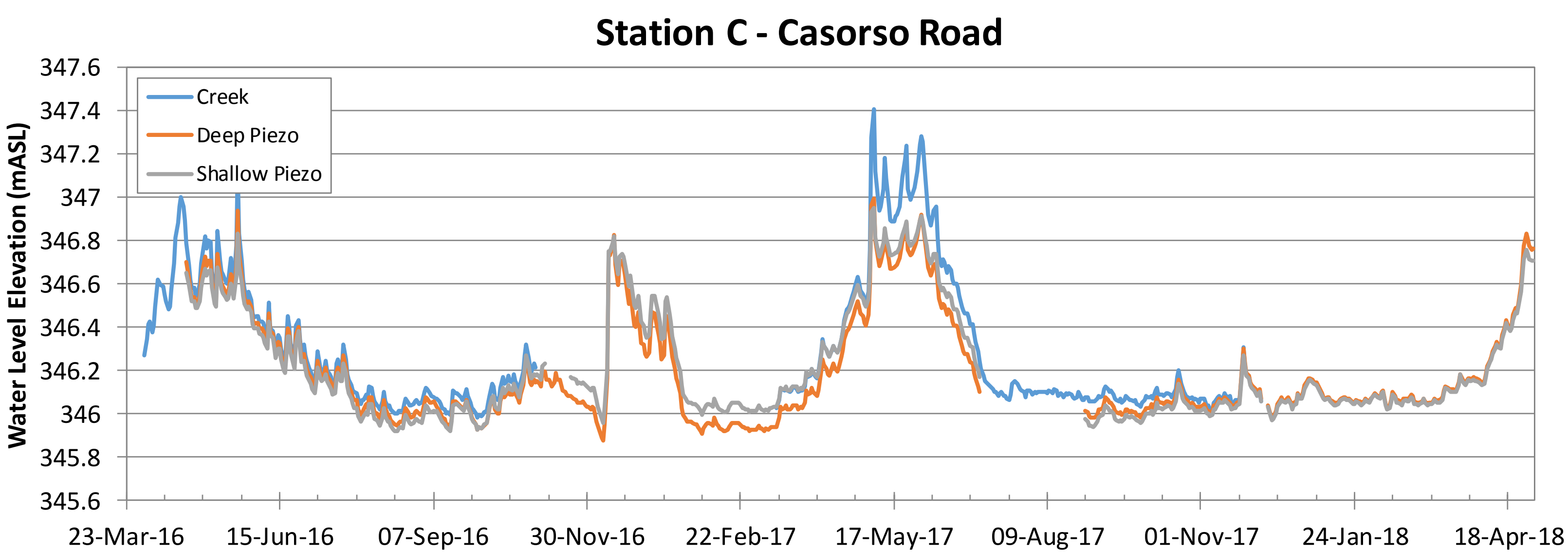
APPENDIX B: FIELD NOTES

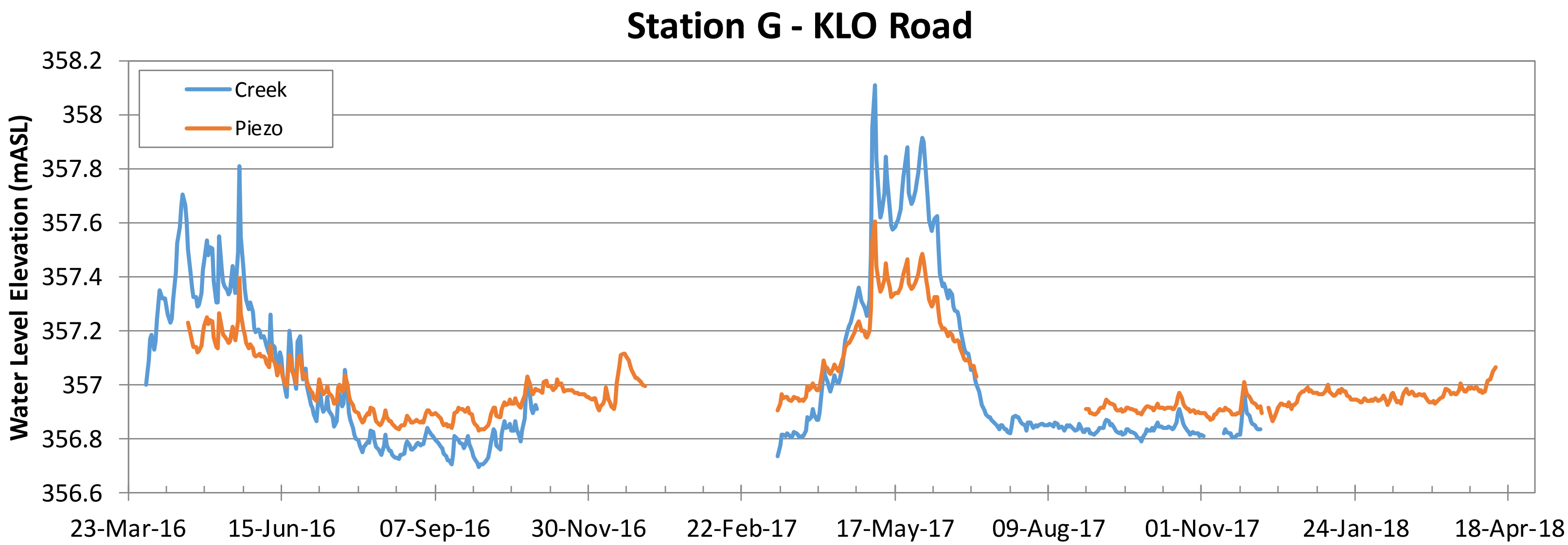
Figure B1: Piezometer installation notes and sediment descriptions from Piteau Associates Geotechnical and Hydrogeologic Consultants.

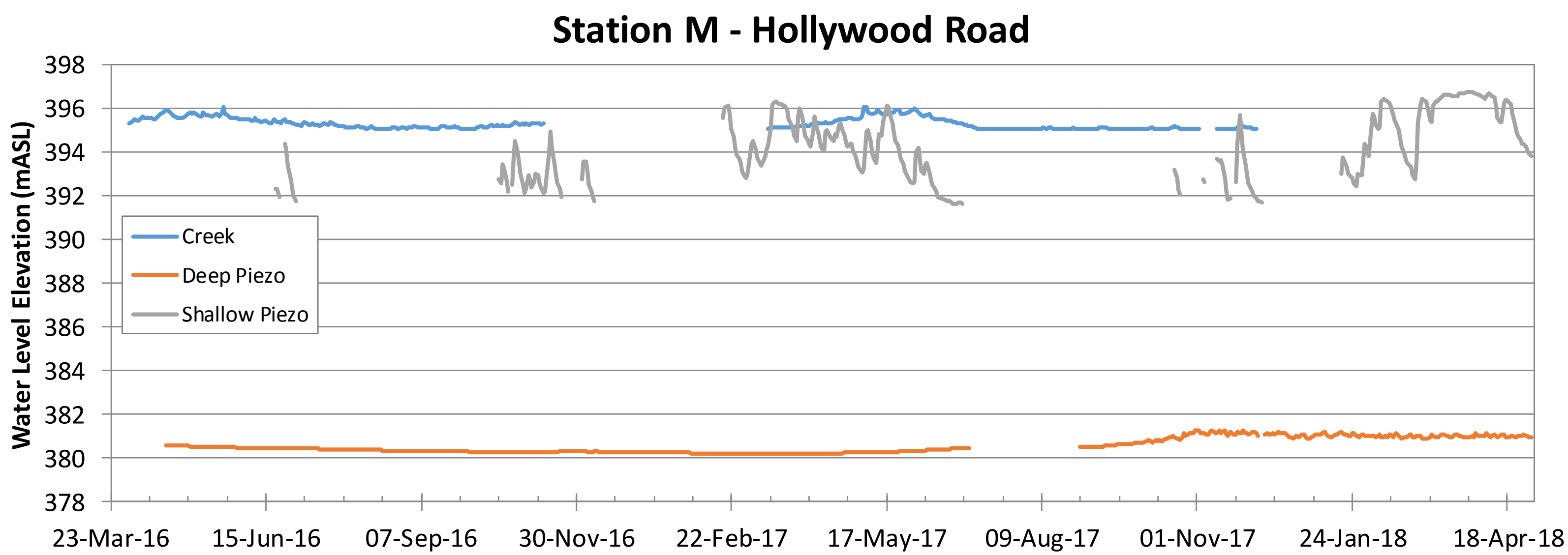


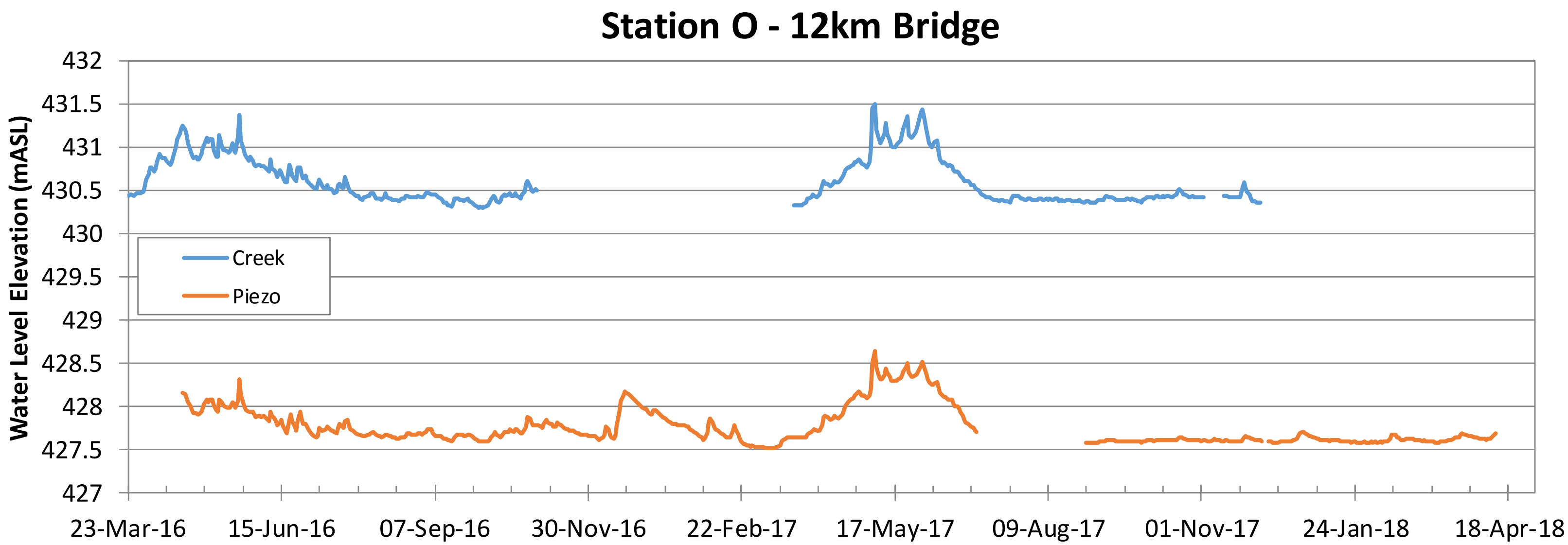
APPENDIX C: PLOTS OF STREAM WATER SURFACE ELEVATION WITH PIEZOMETER DATA

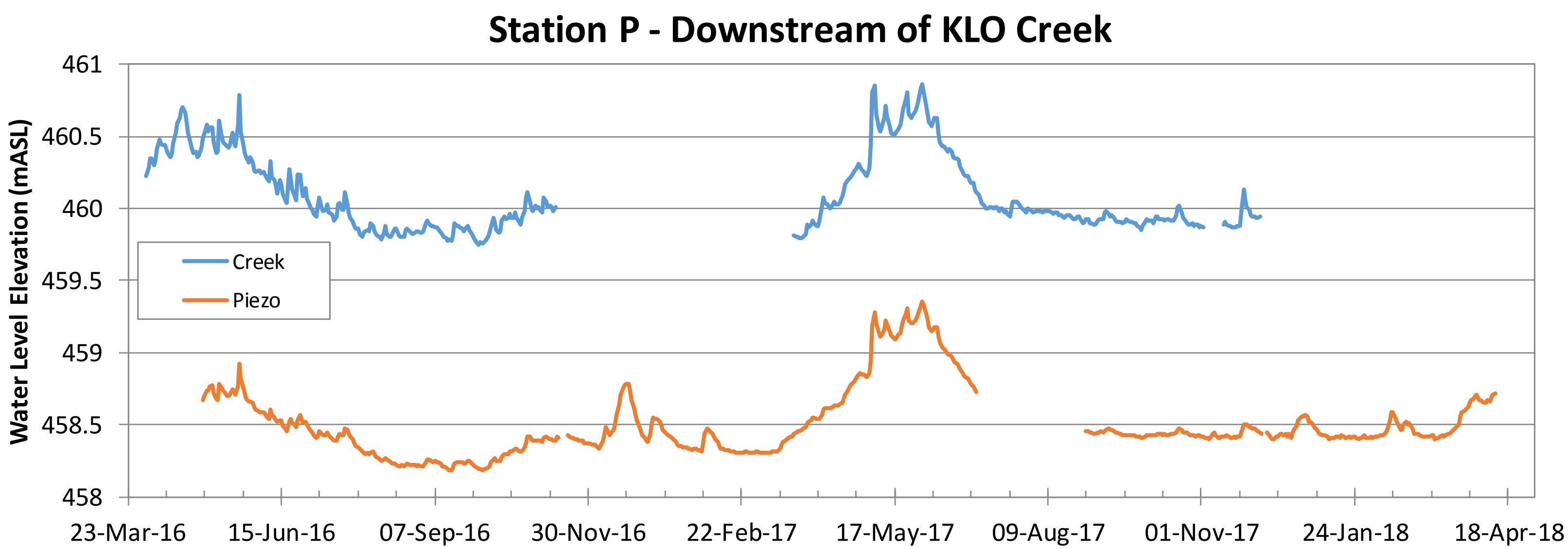





Station G - KLO Road
Creek
Piezo
Water Level Elevation (mASL)
358.2
358
357.8
357.6
357.4
357.2
357
356.8
356.6
23-Mar-16
15-Jun-16
07-Sep-16
30-Nov-16
22-Feb-17
17-May-17
09-Aug-17
01-Nov-17
24-Jan-18
18-Apr-18


Station M - Hollywood Road
Creek
Deep Piezo
Shallow Piezo
Water Level Elevation (mASL)
398
396
394
392
390
388
386
384
382
380
378
23-Mar-16
15-Jun-16
07-Sep-16
30-Nov-16
22-Feb-17
17-May-17
09-Aug-17
01-Nov-17
24-Jan-18
18-Apr-18


Station O - 12km Bridge
Water Level Elevation (mASL)
432
431.5
431
430.5
430
429.5
429
428.5
428
427.5
427
Creek
Piezo
23-Mar-16
15-Jun-16
07-Sep-16
30-Nov-16
22-Feb-17
17-May-17
09-Aug-17
01-Nov-17
24-Jan-18
18-Apr-18


Station P - Downstream of KLO Creek
Water Level Elevation (mASL)
461
460.5
460
459.5
459
458.5
458
Creek
Piezo
23-Mar-16
15-Jun-16
07-Sep-16
30-Nov-16
22-Feb-17
17-May-17
09-Aug-17
01-Nov-17
24-Jan-18
18-Apr-18