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Hydrogeological Characterization of Springs in the Bighill Creek Watershed

by

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Abstract

Bighill Creek, located near Cochrane Alberta, gains over half of its downstream discharge from Big Hill Springs. However, local residents and landowners have suggested that additional input is gained from a variety of smaller springs situated along the valley through which Bighill Creek flows. This thesis examines the occurrence and distribution of these small springs, characterizing them based on discharge, spring type, and water chemistry near the source. Discharge of Bighill Creek was measured upstream and downstream of the small springs to determine their contribution to the creek. Springs with discharge greater than 1L/min were mapped and the elevation of many of these was determined. Twenty-three springs (eight bedrock springs, fifteen contact springs) were located between the confluence of Big Hill Springs with Bighill Creek and the Fourth Avenue bridge that crosses Bighill Creek (approximately 7.7km southwest of Big Hill Springs). Contact springs were generally found at greater elevations than bedrock springs, though two springs were outliers in this trend. Spring flow was highly variable and in sum contributed approximately 725L/min between the 23 springs. Ion composition and electrical conductivity also varied among springs with higher electrical conductivity measured at spring clusters in the downstream portion of the study site. Isotope composition of the springs and Bighill Creek reflect the annual mean for local precipitation signifying that both winter and summer precipitation are the source of recharge.

Introduction

Bighill Creek is situated in a glacial valley north of Cochrane, Alberta. It is of particular interest because of the substantial input it gains from various springs in the valley. The discharge increases dramatically after receiving input from the well-known spring complex, Big Hill Springs, which has been examined in multiple studies (Borneuf, 1983; Caron, 2004; Poschmann, 2007). This large spring complex has become well known for its large calcareous tufa deposits, occurring due to degassing of carbon dioxide as the spring water comes to the surface (Borneuf, 1983). Big Hill Springs discharge from gravel overlying the bedrock and are part of a local flow system (Caron, 2004; Poschmann, 2007).

Big Hill Spring generally contributes over half of the creek flow measured 6.5km downstream of the confluence between the Big Hill Spring outlet and Bighill Creek (Garcia Larez, 2021), however it does not fully account for increased discharge along the 6.5-km reach of the creek. Small springs are known to exist throughout this downstream reach as identified through communication with residents in the area, including a rancher who uses some of these springs for cattle watering. However, the location and physiochemical characteristics of these springs have not been documented, and there may be many other springs that have not been known to the residents and the rancher. This inspired the investigation into the cumulative input from these small springs as a potential source for the increase in discharge that is not from Big Hill Springs.

Understanding the contribution of springs towards the discharge of Bighill Creek may be used for groundwater monitoring given the relationship of spring flow and aquifer storage. When water is extracted from an aquifer, where there is natural discharge via local springs, an increase in extraction is balanced by an increase in recharge or decrease in discharge from the springs as the hydrogeological system works towards reaching equilibrium. When this is not the case, increased extraction can lead to a change in aquifer storage as the removed water is not balanced by changes in discharge or recharge. (Sophocleous, 2000).

There are two objectives of this study:
(1) Locate and document the springs that contribute to the increase in discharge in the lower part of Bighill Creek Watershed below the outlet of Big Hill Springs.
(2) Characterize significant springs (with discharge above 1L/min) based on discharge, water chemistry, and geologic setting (bedrock and surficial geology).

As this study investigates the springs in a previously un-examined area, the scope of the analysis is intended to build a foundation for future research. This study aims to obtain multiple lines of evidence to determine where patterns may exist. A similar investigation was done by Mutual (2014), locating, and characterizing springs in Glenbow Ranch Provincial Park, which is located about 9km south of the Bighill Creek study site. Similar measurements were taken by Mutual (2014) and the results from the two studies are compared in the discussion section.

Study Site

The study site (Figure 1) includes the lower reach of Bighill Creek from about 500m upstream of the confluence of Big Hills Springs outlet and Bighill Creek to 8500m downstream of this same confluence. The Bighill Creek watershed is located in Rocky View County, near Cochrane, Alberta (Figure 1). The average monthly air temperature measured at the Springbank Airport in Rocky View County ranged from -14.3°C to 18.0°C based on data from January 2020 to November 2022 (Government of Alberta, 2022).

Surficial geology in the Alberta foothills region consists primarily of till from the Cordilleran and Laurentide icesheets. Bighill creek is located west of the Laurentide limit thus the surficial geology includes Cordilleran glacial deposits that are poor in pyrite and rich in quartzite and carbonates. The groundwater associated with these deposits tends to have low total dissolved solids (TDS) and low sulphate concentrations (Grasby et al., 2010). The bedrock unit underlying this deposit is the Paskapoo Formation consisting of sandstone and mudstone, which is widespread across this district. The aquifers in Rocky View Country include both surficial and bedrock aquifers, however based on the available well data, all aquifers within the study site (Figure 1) appear as bedrock aquifers (Hydrogeological Consultants, 2002). Surficial aquifers may exist in the region, though they have yet to be drilled and incorporated into the Alberta Environment database.

Methods

Locating Springs and Recording Geographic Coordinates

In the beginning of the study, several spring locations were obtained from residents and the Rancher who were familiar with the prominent groups of springs. Once each of the known springs was found, the study site was re-examined using satellite images on Google Earth to determine other areas where springs may be found. As described by Ozoray and Barnes (1978), springs of the interior plains are found in gullies, at the feet of slopes and at the head of side-valleys. These settings were the target areas when searching for springs in the field.

Coordinates for each spring were recorded using a handheld global navigation satellite system (GNSS) device (Garmin, eTrex) and later plotted on Google Earth (GE) to obtain and approximate elevation. More precise elevation was obtained using a GNSS device (Hemisphere, C631 Smart Antenna) with differential correction for higher flow springs with discharge measured above 1L/min. Due to the time constraints of this study, not all springs above this discharge threshold were able to be surveyed. The elevation obtained using differential GNSS was not absolute as there were no convenient survey markers or points with known coordinates to use for reference. Instead, the base station was run for 45 minutes to obtain coordinates using GNSS. After comparing the elevations acquired from the survey with those in GE, the base station elevation was clearly inaccurate causing all survey points to be below their actual elevation. Figure 2 shows the difference between elevations from the survey and GE, where the linear trendline indicates the offset of 23.6m below the actual elevation. Elevations from the survey were corrected by adding 23.6m to each elevation.

Classification of Springs

In this study, springs were categorized into spring types based on surficial observations, and later verified by comparing the elevation of the spring with the associated unit or contact described in the well records (Alberta Environment, 2013). All springs in this study area were either bedrock or contact springs (Figure A9). When spring flow emerged from fractured bedrock, these were classified as bedrock springs, and when it emerged from till, these were classified as contact springs. Contact springs occur at a contact between two lithologies with large differences in permeability such as the contrast between till and sandstone (Borneuf, 1983).

Discharge Measurements and Analysis

As springs were located, discharge was measured where possible using different methods depending on the size of the spring and amount of flow. Discharge was measured using the "volumetric method" (Mutual, 2014) or a transportable weir (two triangles with 45° angles that align to form a 90° v-notch) for shallow surface flow, or an electromagnetic flow meter (OTT, MF Pro) for deeper surface flow. The volumetric method involves recording the time taken to fill a container of a known volume. To ensure consistent flow, the water is funnelled into a PVC pipe using substrate from the surrounding area (Mutual, 2014).

Discharge was also measured at four stream gauging stations (GS_1, GS_2, GS_3, GS_4), two measuring the outflow from Big Hill Springs, and two measuring flow in Bighill Creek (Figure 1). For all four stations, flow was measured using the velocity-area method with the electromagnetic flow meter. The percent contribution of major inputs into Bighill creek are shown for each date of flow data collection. Major inputs included the flow from Big Hill Springs (measured at GS_3), the upper reach of Bighill Creek (measured at GS_1) and the small springs located during this study. The sum of all newly located springs (with discharge >1L/min) was used for the percent contribution calculations as discharge was only measured once.

Water Sample Collection and Analysis

Water temperature (Omega Engineering, HH-25TC), pH (Barnant, 559-3800), electrical conductivity (EC) (Traceable, 4169), dissolved oxygen (YSI, ProODO), were measured when locating springs. Both the pH and EC meters were calibrated before each field day and the pH was calibrated in the field using standard solutions with pH of 7 and 10. EC is highly dependent on temperature; therefore, the raw data was standardized to reflect the electrical conductivity at a temperature of 25°C (EC_{25}) using:

$$EC_{25} = EC_t / [1 + a(t - 25)] \quad (1)$$

where ECt is the raw EC value measured at temperature t (°C) and a (°C^{-1}) is an empirical coefficient, which is taken to be 0.0187 °C^{-1} (Hayashi, 2004).

Water samples were collected from all gauging stations and springs (where possible) in 125mL plastic bottles and filtered in the field using a 0.45-μm membrane filter and a plastic syringe. All samples were refrigerated once brought back from the field and were stored in the refrigerator. Samples were analyzed for hydrogen and oxygen isotopes using mass spectrometry at the Environmental Isotope Laboratory as well as the major ion composition using ion-exchange chromatography at Environmental Sciences Laboratory, both at the University of Calgary. Alkalinity of water samples were determined by the Gran titration method within ten days after the samples were collected. Bicarbonate ion concentration (in mg/L) was calculated by multiplying the alkalinity values (meq/L) by 61mg/meq.

Results

Spring Occurrence

23 springs were located (Table 1) between GS_3 and the Fourth Avenue bridge that crosses Bighill Creek (approximately 7.7km South-West of Big Hill Springs). These springs were found in clusters (Figures 1 and 3), particularly in side-valleys and gullies that branch from the glacial valley that Bighill Creek runs through. Zones were determined based on these clusters as shown in Figure 1. The spring environments coincide with common spring environments described by Ozoray and Barnes (1978). For this site, most springs occurred in densely vegetated or forested areas excluding Zone 2. Springs in Zone 2 were found at the foot of a hillside, below a large Paskapoo sandstone outcrop, with small, curved seepages approximately 30-60cm wide (Figure A4 in Appendix). Zones 3, 5 and 6 are all situated in gullies and side valleys off the main glacial valley through which Bighill creek flows. Zone 1 is the Big Hill Springs complex, which also occurs in a side valley though the spring flow occurs as a combination of point flow and seepages near the top of the side valley.

In addition to the springs shown in Figure 1, several smaller springs were identified, however the discharge was either un-measurable or was below 1L/min, and thus were excluded from the analysis. Dry springs were also found in Zones 3, 5, and 6, usually appearing at the top of the side valley. These dry springs indicate that spring discharge would occur under wetter conditions. Ice rivers were observed in Zone 7 converging with a stream running parallel to Bighill Creek (Figure A8).

Spatial Trends: Elevation, and Spring Type

Figure 4 shows the relationship between elevation and spring type for each zone, which are ordered from 1-7 (1 is the most upstream and 7 is the furthest downstream along Bighill Creek). Contact springs generally occur at higher elevations compared to the bedrock springs in this study site, with two major outliers: Spring 5.2, a bedrock spring with an elevation of 1268m and Spring 4.1, a bedrock spring with an elevation of 1248m. Both of these bedrock springs fall within the elevation range of the contact springs, yet the observed surficial geology clearly indicates that these cannot be contact springs due to the Paskapoo sandstone visible at the source of the spring (Table 2).

Discharge in Springs and Bighill Creek

The discharge in the small springs was highly variable and generally dependent on the size of the spring. These springs contributed on average 8% of the flow measured at the downstream gauging station (GS_4) (Figure 5a). Zone 8 was omitted from the percent contribution calculations as these springs occur downstream of GS_4 and do not contribute to the total discharge. For newly located (small) springs, discharge was only measured once thus there is potential for seasonal variation that was not captured in this dataset. The discharge of Big Hill Springs was measured periodically from June to July at the source (GS_2) and downstream before it joins Bighill Creek (GS_3). The discharge components of Bighill Creek are shown in Figure 5b, where the sum of these components is the discharge measured at GS_4 (the downstream reach of Bighill Creek). Flow added to the creek by Big Hill Springs and the Small Springs was consistent throughout the data collection period. Peak discharge of Bighill Creek occurred in late June though discharge in Big Hill Springs (GS_2 and GS_3) remains relatively constant over this period (Figures 6a-b). The peak precipitation coincides with the peak flow measured at GS_4 indicating a rise in creek flow due to runoff and interflow. The input from the upper reach of Bighill Creek (GS_1) was greatest on June 20th , aligning with the increased precipitation in mid-late June (Figure 5a, Figure 6a-b) further identifying the effect of runoff and interflow during peak precipitation.

Water Chemistry and Isotopic Composition

Water chemistry results (Table 3) for newly located springs shows variability in ion composition and total dissolved solids (TDS). The mean TDS was 551.1 mg/L and ranged from 443.1 to 677.4mg/L. Correlations between TDS and major ions is shown in Figure 7 along with the relationship between calcium and magnesium. Nitrate levels were consistently below 5mgN/L though sulphate levels varied from <10mg/L to >100mg/L. Both Ca and SO_4 are positively correlated with TDS (Figure 7a-b). Magnesium plots similarly to Ca when compared to TDS (data not shown) and ranges from 32.8 to 62.1mg/L, with an average value of 44.8mg/L. Figure 7c shows that bicarbonate concentrations were highly variable for similar sulphate concentrations suggesting no strong relation between these two species. Chloride varies greatly between springs from 1.43mg/L to 114mg/L, though no strong correlation with TDS was apparent (Figure 7d).

EC is correlated with TDS (Figure 8); thus, approximate values of TDS (mg/L) could be estimated by multiplying EC (μS/cm) by 0.71 for springs that were not analyzed for ion composition. TDS estimations were not needed for this study but could be used in future studies that include springs in the upper region of the Bighill Creek watershed. EC is similar for contact and bedrock springs in the same zone, excluding one outlier in Zone 5 (Figure 9). Higher EC was mesured at springs in Zone 7 and 8, with the lowest values measued in Zones 4 and 5, excluding Spring 5.3 which yeilded the highest EC among all samples. Overall, EC values varied from 0.508 to 1.15 mS/cm (Table 3).

Isotope data plot in a tight cluster (Figure 10) excluding one major outlier: Upper Bighill Creek (GS_1) sample. The cluster plots just below the local meteoric water line (LMWL) for this region (Peng et al., 2006) and close to the annual mean precipitation. Since the isotopes for the samples in this study plot near the annual mean, the groundwater appears to be recharged by both rainfall and snowfall (Hayashi and Farrow, 2014).

Subsurface Analysis

Figure 11 shows a cross sectional view through two spring zones (Zone 2 and 3) and the geologic units described in the well report for Well 1600688 (Alberta Environment, 2013). The geologic units (in sequence of upper to lowermost) include till and gravel overlying alternating sandstone and shale, of the Paskapoo formation (Grasby et al., 2010). Springs 2.1, 3.1, 3.3, and 3.4 are bedrock springs (Table 2) and their elevations align with the alternating sandstone and shale unit identified in the well report (Figure 11). The static water level in the well is 29.93m below the surface and two water bearing units were identified at depths of 46.02m and 59.74m. Sandstone and shale are shown in Figure 11 as a single unit; however, the well report separates sandstone from shale resulting in two water bearing sandstone units being identified.

Discussion

Characterization of Big Hill Springs

There was no clear correlation between spring type and water chemistry based on the 23 springs examined. Instead, surficial geology, elevation and well reports were used to determine the spring type (Table 3). These lines of evidence suggest that Big Hill Springs is more likely a contact spring as opposed to a bedrock spring as noted in previous studies (Borneuf, 1983; Caron, 2004; Poschmann, 2007). The presence of Paskapoo sandstone in the Big Hill Springs source area was noted as fragments in some areas, though the Paskapoo outcrops occur in some regions, most of the spring flow emerges from till and gravel. To fully discern the type of spring, subsurface data would need to be obtained for a location closer to the springs as the well reports available may not reflect the precise geology that underlies Big Hill Springs source area.

Distribution and Classification of Small Springs

The elevations and observed surficial geology usually supported the classification as either a contact or bedrock spring, where contact springs were found at higher elevations and bedrock springs at lower elevations (Figure 5). The elevation of Spring 4.1 (1248m) and Spring 5.2 (1268m) does not support their classification as bedrock springs, however in this instance the surficial geology is more likely to accurately identify the type of spring. The Paskapoo sandstone was observed to outcrop at two elevations along small segments of the main glacial valley. Therefore, it is possible that these two springs are bedrock springs from the upper layer of sandstone, thus the elevation would be greater than the bedrock springs from the lower sandstone unit.

Discharge in the Springs and Creek

Discharge measured at newly located springs (Table 1) shows a noticeable variability within springs zones. The discharge in small springs ranged from 0.67L/min, which is an exception to the 1L/min threshold, to 175L/min, similar to the range reported at Glenbow Ranch Provincial Park (Mutual 2014), located approximately 9km south of the study area. Based on the stability of Big Hill Springs, it is not anticipated that the spring flow would fluctuate drastically during the data collection period, though it is possible that run off may have added to some of the measurements leading to a slight overestimation of flow. In addition, there is potential error for these measurements that could explain part of the “other” category in Figure 5.

Water Chemistry of Springs

The higher EC values measured in Zones 7 and 8 (Figure 9) may reflect the land use in lower reaches of the study site. Sub-urban development to the east of Zone 7 may account for this increase due to runoff from roadways adding additional salts to the springs located downhill. The highest EC value was obtained from Spring 5.3; however, this may be affected by sediment disturbance as this spring was particularly difficult to sample due to silty clay deposits at the surface. Spring 6.1 (A5b) was modified to be used for cattle watering, though the EC appeared to be unaffected by this alteration as it fell in the middle of the range for this sample set (Figure 9).

TDS range for Cordilleran till (375-2500 mg/L) was determined by Grasby et al (2010). The TDS for springs in the Bighill Creek watershed were on the lower end of this range suggesting that the till in this region is most likely from the retreat of the Cordilleran ice sheet (Grasby et al., 2010). TDS values were well below the threshold to cause harm to livestock for all samples analyzed in this study (Agriculture and Agri-Food Canada, 2020).

Grasby et al. (2010) determined that the Cordilleran tills located in the western part of their study site were associated with lower TDS as compared to the Laurentide tills in the east. These Cordilleran tills were also associated with lower SO_4 and Na concentrations. The surficial geology of this study site is mainly glacial till deposited from the Cordilleran ice sheet; thus, the location supports the TDS range obtained from springs and creek samples. Additionally, SO_4 concentrations remained below 120mg/L which is low compared to the results from both tills examined by Grasby et al. (2010). The SO_4 concentrations in the small springs near Bighill Creek were comparable to the springs in Glenbow Ranch Provincial Park (Mutual, 2014), but overall were slightly lower. According to the guidelines by Agriculture and Agri-Food Canada (2020), sulphate concentrations below 500mg/L should have no adverse effects on livestock, posing no apparent risk for cattle using the springs as a primary water source.

Comparing nitrate levels to the nearby springs in Glenbow Ranch Provincial Park which varied from 0.8-48.6mgN/L, the springs in the Bighill Creek watershed have significantly lower nitrate levels remaining below 5mgN/L across all locations. This range fall well below the recommended limits for cattle of 100mgN/L (Agriculture and Agri-Food Canada, 2020).

Future Studies

The number of newly located springs implies there could be several more springs located in the upper part of the Bighill Creek watershed. Future research in the upper reach of the creek could be done to both locate additional springs and characterize them based on type and water chemistry.

Due to time constraints, only select springs were included in the survey, which entirely excluded well locations. To further the understanding of the subsurface geology in the Bighill Creek watershed, wells could be added to the survey of springs to generate cross sections like Figure 9. Many drilling reports were available for wells in this study site but could not be used for analysis as their elevations were imprecise or entirely absent from the report. Incorporating additional subsurface information would enhance the accuracy of spring classifications and potential be used to predict potential locations of additional springs.

Spring 4.1(Figure A3) is an interesting spring complex that can be compared to Big Hill Springs for both the spring type and complexity of the area. The outflow at Spring 4.1 occurs from one main seepage point but gains input from multiple smaller outflow points in the side-valley. The surficial geology is mainly clay and till with some areas of Paskapoo sandstone outcrops and with scattered sandstone and shale fragments. The main outflow of Spring 4.1 occurs in an area of sandstone and shale fragments, though some of the smaller outflow points appear to emerge as seepages from clay and till. This spring would be an interesting site study with greater detail given the similarities with Big Hill Springs and its differences as compared to the other newly located springs.

Conclusions

Many small springs were found to contribute to the Bighill creek discharge in addition to Big Hill Springs. The locations of these springs were commonly in side-valleys and at the base of hillslopes. The small springs (with discharge greater than 1L/min) accounted for an average of 8.5% of the total flow in Bighill Creek measured downstream of these springs. On average, Big Hill Springs contributes about 57% of the discharge in Bighill creek, adding a consistent amount of flow throughout the study period. Elevation is an indicator of spring type in this sub-watershed as contact springs appeared in higher elevations and bedrock springs at lower elevations. TDS was relatively low at all springs and consistent with previous studies (Grasby et al. 2010; Mutual, 2014). Isotope composition reflected the annual mean for local precipitation (Peng et. al.) indicating that recharge occurs from the combination of summer and winter precipitation. EC varies across the study site and is highest in Zones 7 and 8. Ion composition and discharge vary by spring though no strong spatial correlation could be determined.

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Tables

Table 1: Field data collected at sprig source as they were located. Note that the pipe and cup method is a version of the "volumetric" method using a small pipe and small cup to measure discharge (Q). Spring ID is written as the Zone#.Spring# (i.e. Spring 8.1 is the first spring in Zone 8). Big Hill Springs (Spring 1.1) is included in this table, though this location doubled as a gauging station given the known location and high discharge from the springs. EC25 is the electrical conductivity (EC) corrected to 25°C. Dissolved oxygen (DO) is reported as the actual concentration measured in the spring water. Note that grey highlighting indicates a discharge measured downstream of the confluence of two springs. When the spring ID is repeated but water chemistry differs slightly, this indicates that two outflow points occur at the same spring and were measured individually for water chemistry.

ID	Zone	Easting	Northing	Date	Temp (C)	pH	Alkalinity	EC25 (mS/cm)	DO mg/L	Q (L/min)	Method
1.1	1	681782	5681277	2022-05-16	5.3	7.29	4.837	0.605	9.08	4480	EM flow meter
2.1	2	683172	5679958	2022-05-25	4.6	7.41	5.45	0.605	6.08	14.1	Weir
2.2	2	683177	5679942	2022-05-25	4.6	7.48	5.45	0.605	6.46	86	Weir
2.3	2	683173	5679930	2022-05-25	4.7	7.46	5.45	0.606	7.22		
2.4	2	683169	5679931	2022-05-25	4.3	7.48	5.45	0.622	6.23	32.1	Weir
2.5	2	683169	5679925	2022-05-25	4.9	7.16	5.45	0.636	3.79	14.8	Weir
2.6	2	683167	5679920	2022-05-25	5.1	7.13	5.45	0.628	5.13	38.2	Weir
3.1	3	683716	5679934	2022-05-25	4.5	7.36	5.13	0.649	8.88	30.2	Weir
3.2	3	683682	5679876	2022-05-25	4.3	7.61	5.13	0.662	10.2	1.9	Pipe and cup
3.3	3	683580	5679901	2022-05-25	4.7	7.28	5.24	0.753	6.42	175	EM flow meter
3.4	3	683478	5680075	2022-05-25	6.4	7.54	6.24	0.695	9.13	24.5	Pipe and cup
4.1	4	683250	5679326	2022-07-03	4.8	7.55	5.38	0.546	10.2	60	EM flow meter
5.1	5	680233	5678903	2022-06-01	5	7.2	4.82	0.508	9.05	30.9	EM flow meter
5.1	5	680233	5678903	2022-06-01	5.5	7.15	4.82	0.511	8.55		
5.2	5	680327	5678905	2022-06-01	5.4	7.1	5.29	0.525	8.9	127	EM flow meter
5.3	5	680671	5678694	2022-06-01	6.6	7.02	5.13	1.15	3.86	8.8	Pipe and cup
5.3	5	680671	5678694	2022-06-01	5.8	7.14	5.13	0.919	6.01		

6.1	6	679554	5677828	2022-06-01	5.7	7.2	4.58	0.764	9.88	29	Pipe and cup
6.2	6	679550	5677823	2022-06-01	2.8	7.63	4.63	0.651	11	0.69	Pipe and cup
7.1	7	679765	5676637	2022-05-06	4.2	7.84	4.2	0.867	10.1	4.8	Pipe and cup
7.2	7	679799	5676624	2022-05-06	3.7	7.55	4.7	0.873	10.6	1.9	Pipe and cup
7.3	7	679840	5676476	2022-05-09	2.8	7.7	4.58	1.01	11.4	2	Pipe and cup
7.4	7	679817	5677017	2022-05-09	4.1	7.2	4.48	0.87	4.3	10	Pipe and cup
8.1	8	678303	5675849	2022-05-06	4.3	7.08	4.67	1.02	10	8.1	Pipe and cup
8.2	8	677386	5675518	2022-07-04	6.4	7.63	5.61	0.962	10.7	24.2	EM flow meter

Table 2: Elevations and spring types characterized by observed surficial geology. Elevations are from GNSS survey or from GEP DEM (*). The elevation of nearest contact geologic contact and formation data from local wells was obtained from Alberta Well Information Database (Alberta Environment, 2013).

Spring Name	**Spring Type**	**Spring Elevation (m)**	**Surficial Geology of Spring (& related observations)**	**Nearby geologic contact: elevation (m)**
Spring 8.1	Contact Spring	1261*	Glacial till deposit at the spring with Paskapoo sandstone and tufa found ~10m downstream.	
Spring 7.1	Contact Spring	1248	Spring flows out of sandy clay and gravel.	Till/Sandstone: 1283.5
Spring 7.2	Contact Spring	1250	Spring flows out of sandy clay and gravel. Fractured Paskapoo sandstone and shale noted along the flow path and on either side of the gully.	Till/Sandstone: 1283.5
Spring 7.3	Contact Spring	1292	Spring emerges near the top of the side-valley from underneath wood debris; thus, the surficial geology of the source was not visible. Sandy gravels and clay found along the flow path with more soil and vegetation noted than other springs in Zone 7	Till/Sandstone: 1283.5
Spring 7.5	Contact Spring	1277*	Spring flow out of sandy clay gravel. Paskapoo and shale fragments found along the flow path.	Till/Sandstone: 1283.5
Spring 7.4	Bedrock Spring	1194*	Spring appears to flow out of fractured Paskapoo sandstone. There is a notable outcrop just above the seepage point where flow was measured.	Till/Sandstone: 1283.5
Spring 1.1 (BHS)	Contact Spring	1250*	Boulders and gravel along spring flow path with fractured Paskapoo at some of the larger spring outflow points.	Gravel/Sandy Clay: 1193
Spring 3.1	Bedrock Spring	1232	Geology at source appears to be fractured Paskapoo sandstone with rounded boulders and pebbles found along the flow path. Spring flow was altered at the main seepage point to flow through a metal culvert.	Gravel/Sandstone: 1233

Spring 3.2	Contact Spring	1243*	Spring flow emerged from shale and sandstone fragments embedded in sandy clay deposit. This sandstone would not be the underlying bedrock unit and is identified in the well report.	Till/gravel: 1241 Gravel/Sandstone: 1233
Spring 3.3	Bedrock Spring	1213	Spring flows from fractured Paskapoo Sandstone outcrop.	Gravel/Sandstone: 1233
Spring 3.4	Bedrock Spring	1228	Spring flows from fractured Paskapoo Sandstone outcrop.	Gravel/Sandstone: 1233
Spring 2.1, 2.2, 2.3, 2.4, 2.5	Bedrock Spring	1204	Springs occur at a uniform elevation below a large Paskapoo outcrop with visible fractures.	Gravel/Sandstone: 1233
Spring 6.1	Contact Spring	1270	Flow was heavily modified for cattle watering at source. Surficial geology nearby the source is sandy clay deposit.	
Spring 6.2	Contact Spring	1253	Flow measured from metal culvert as spring flow was re-directed to flow underneath a gravel pathway. Surficial geology at the source was not visible under the heavy vegetation.	
Spring 5.3	Contact Spring	1252*	Seepage out of clayey till at two locations within two meters of one another.	
Spring 5.2	Bedrock Spring	1268	Springs flow from below large Paskapoo Sandstone outcrop.	
Spring 5.1	Contact Spring	1275	Spring flow at the top of a side-valley. Source appears to be clay and gravels with sandstone and shale fragments scattered near the spring.	
Spring 8.2	Bedrock Spring	1205*	Fractured Paskapoo at spring. Tufa found under tree roots and moss at the spring source as well as along the first two meters of the flow path.	
Spring 4.1	Bedrock Spring	1248*	Spring emerges from fractured Paskapoo sandstone outcrop with clay mixed with shale fragments throughout the area. The sandstone seen here appears to be the soft sandstone identified in the well reports between clay units and gravel.	Till/gravel: 1241 Gravel/Sandstone: 1233

Table 3: Isotope and ion composition of springs in the Bighill Creek watershed and gauging spots along Bighill creek. Bicarbonate ions were calculated based on the alkalinity reported in Table 1. Samples were taken from springs as close to the spring source as possible. Blank spaces indicate no data for the spring.

Location	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	NO_3 (mg N/L)	PO_4 (mg P/L)	SO_4 (mg/L)	HCO_3 (mg/L)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	TDS (mg/L)
Upper BHC	26.4	5.44	66.5	36.8	0.2	15.1	<0.1	0.12	0.18	28.1	332.6	-16.9	-139	511.5
BHS/BHC confluence	12.9	<0.5	62.6	35	0.16	15.3	<0.1	2.01	<0.1	14.4	331.1	-17.4	-139	473.5
BHC GS	15.4	<0.5	66.7	37.1	0.18	16	<0.1	1.09	0.33	18.4	302.4	-17.5	-139	457.6
Spring 1.1 (BHS)	7.27	<0.5	77.2	35.3	0.17	15.5	<0.1	3.17	0.46	8.95	295.1	-17.7	-139	443.1
Spring 2.2	12.3	<0.5	69.7	34.2	0.14	12.7	<0.1	2.24	0.12	15.7	332.5			479.6
Spring 3.1	12.3	<0.5	70	37.7	0.15	167	0.155	0.954	<0.1	27.4	312.9			628.6
Spring 3.2	12.1	<0.5	75.7	42.9	0.16	7.75	<0.1	0.705	0.69	24.7	312.9			477.6
Spring 3.3	20.3	<0.5	81.6	41.8	0.13	18.7	<0.1	1.16	<0.1	34.7	319.6			518.0
Spring 3.4	8.53	<0.5	75.8	37	0.13	59.8	0.792	2.45	<0.1	17.6	380.6			582.7
Spring 4.1	16.5	5.7	90.6	51.7	0.121	17.1	<0.1	1.1	<0.1	43	328.2	-17.8	-140	554.0
Spring 5.1	14.2	5.48	89.6	47.1	0.13	26	0.102	3.43	<0.1	35.4	294.0			515.5
Spring 5.2	23.3	<0.5	87.9	47.7	0.15	12.2	<0.1	1.72	0.11	43.5	322.7			539.3
Spring 5.3	72.9	<0.5	79.8	43.6	0.38	1.43	<0.1	0.48	<0.1	74.8	312.93			586.3
Spring 6.1	40.8	<0.5	76.4	38.2	0.2	5.2	<0.1	1.9	0.21	46.7	279.38			489.0
Spring 6.2	34.4	<0.5	60.8	32.8	0.21	10.5	<0.1	1.83	0.18	53.4	282.43			476.6
Spring 7.1	26.9	<0.5	78.1	55.5	0.18	82.6	0.214	2.42	<0.1	41.2	256.2	-17.9	-140	543.3
Spring 7.2	23.9	<0.5	80	56.9	0.15	87	0.16	2.46	0.12	42.2	286.7	-18	-141	579.6
Spring 7.3	20.4	<0.5	116	66.1	0.14	114	0.149	4.34	0.57	39.5	279.38	-17.9	-141	640.6
Spring 7.4	43.6	5.04	80.9	50.4	0.19	28.7	<0.1	0.898	<0.1	65.9	273.28	-17.7	-139	548.9
Spring 8.1	31	<0.5	101	58	0.13	92.4	<0.1	1.6	0.22	70.5	284.87	-17.9	-142	639.7
Spring 8.2	44.8	<0.5	80.6	55.3	0.32	53.9	0.116	3.02	<0.1	97.1	342.21	-17.7	-141	677.4

Figures

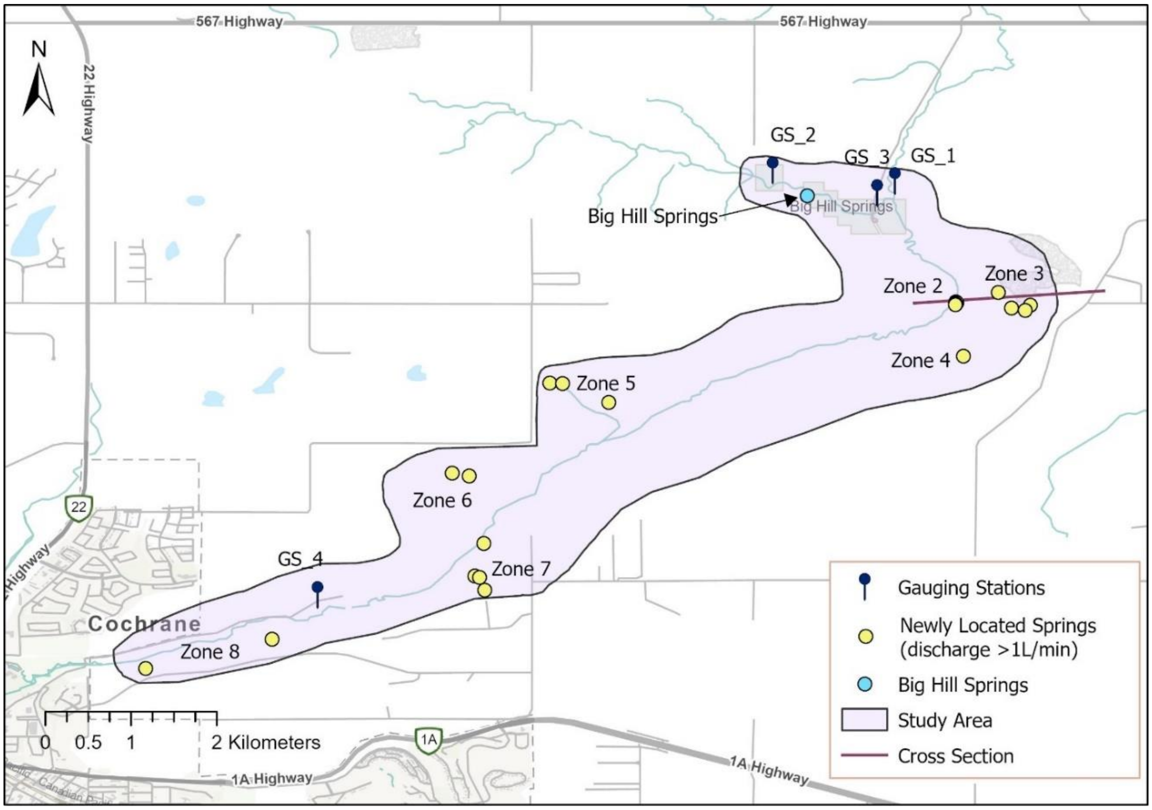

Figure 1: Study site and local topography of the surrounding area with springs plotted by zone and gauging stations shown. Big Hill Springs is shown as a separate point on this figure but is also referred to as Spring Zone 1. Map data: Esri, Canada.

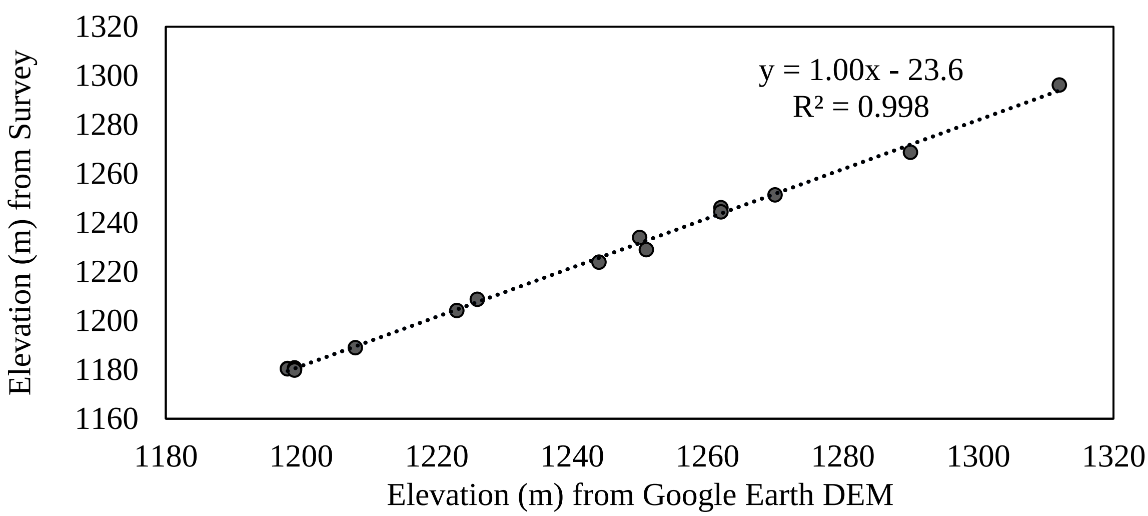

Figure 2: Comparison of spring elevation determined by differential GNSS measurements and estimated from Google Earth digital elevation model (DEM).

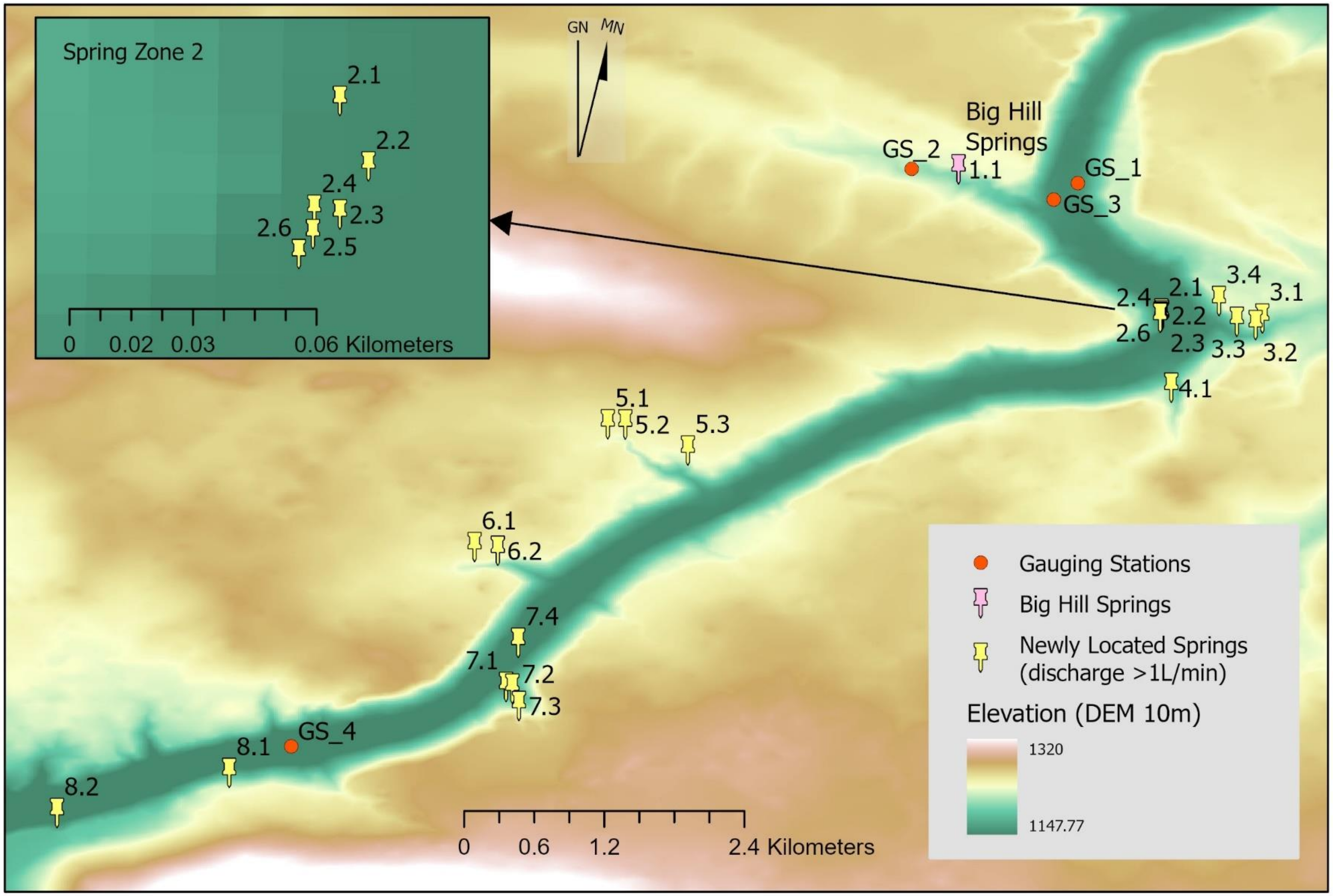

Figure 3: Site map including the locations of springs with discharge above 1L/min and gauging stations (GS 1-4) associated with discharge shown in Figure 4. The main map scale is 1:55500 and the insert map scale is 1:1600. Spatial reference: NAD 1983. DEM source: AltaLIS Ltd. 2002. Created in ArcGIS Pro 3.0.3 (Esri, 2022

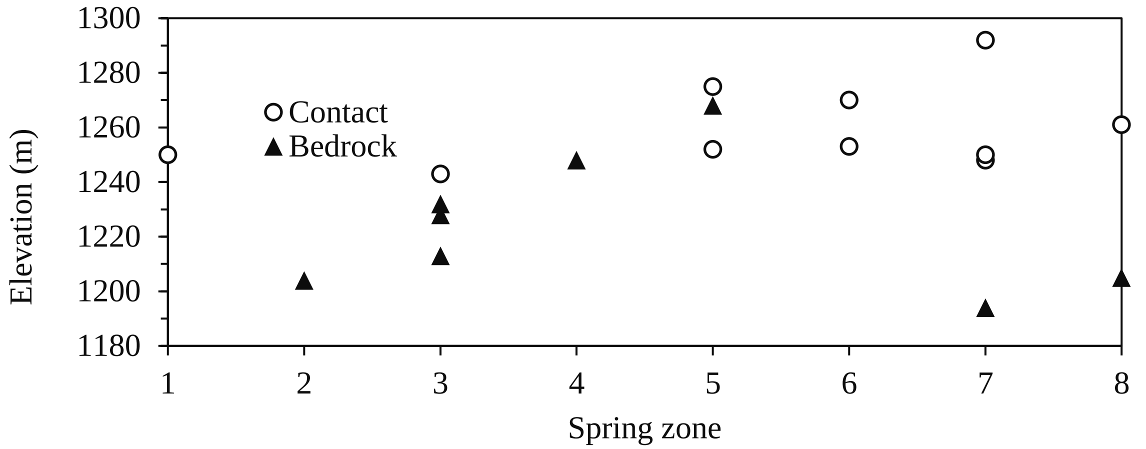

Figure 4: Elevation of newly found springs and spring types for each zone.

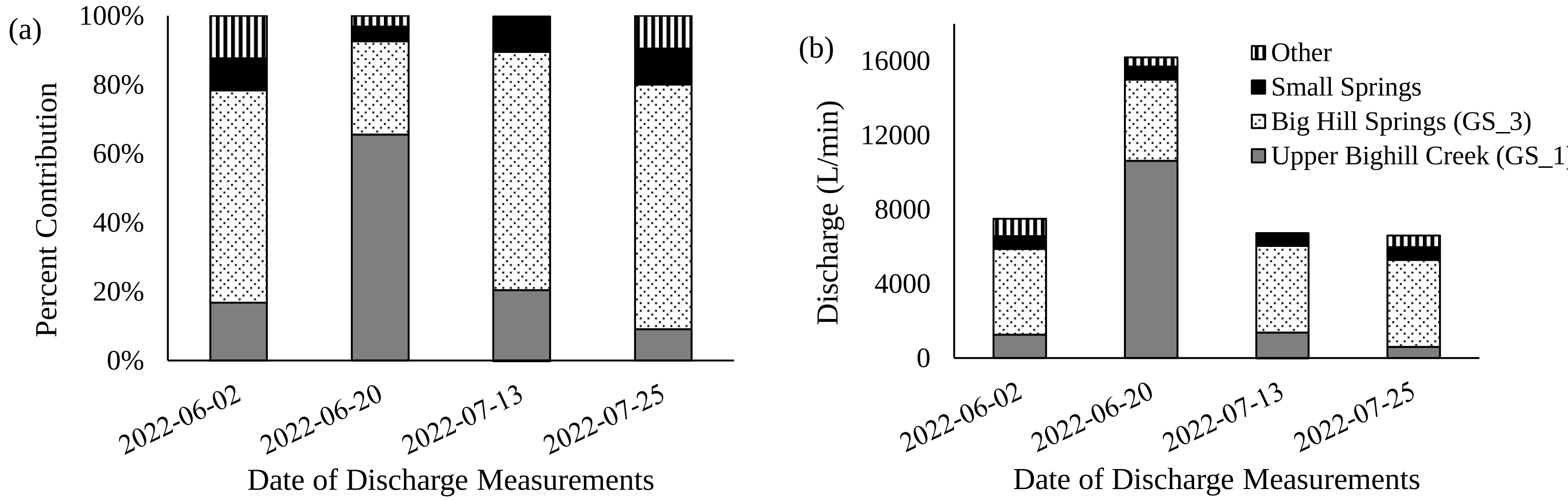

Figure 5: (a) Percent contribution and (b) distribution of flow components in the lower reach of Bighill Creek. Small springs refers to all small springs measured between GS_1 and GS_4. The category "Other" may reflect measurement error or the cumulative flow from springs that were too small for discharge to be recorded.

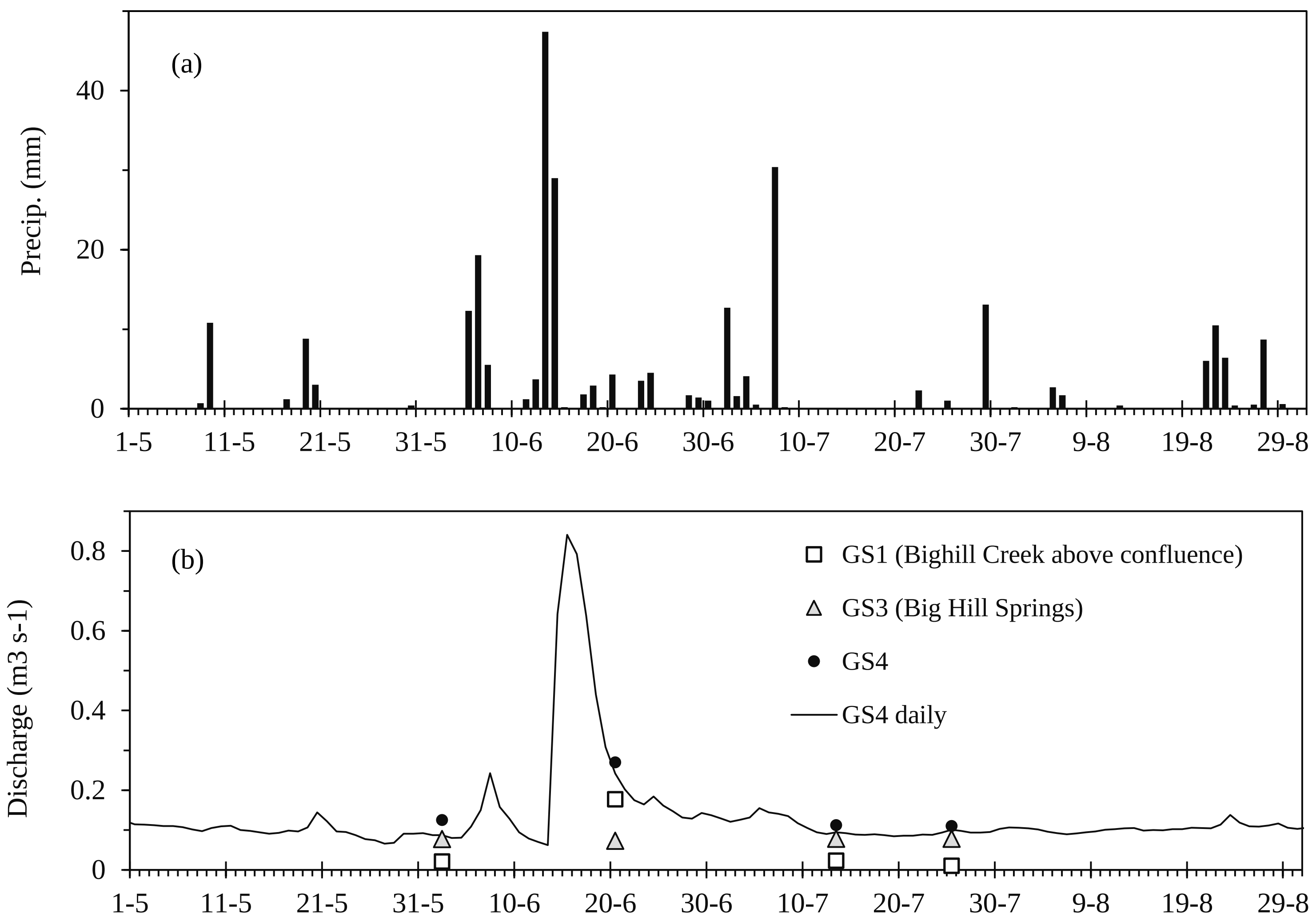

Figure 6: (a) Daily total precipitation and (b) daily mean discharge measured at Bighill Creek and Bighill Springs in May-August 2022.

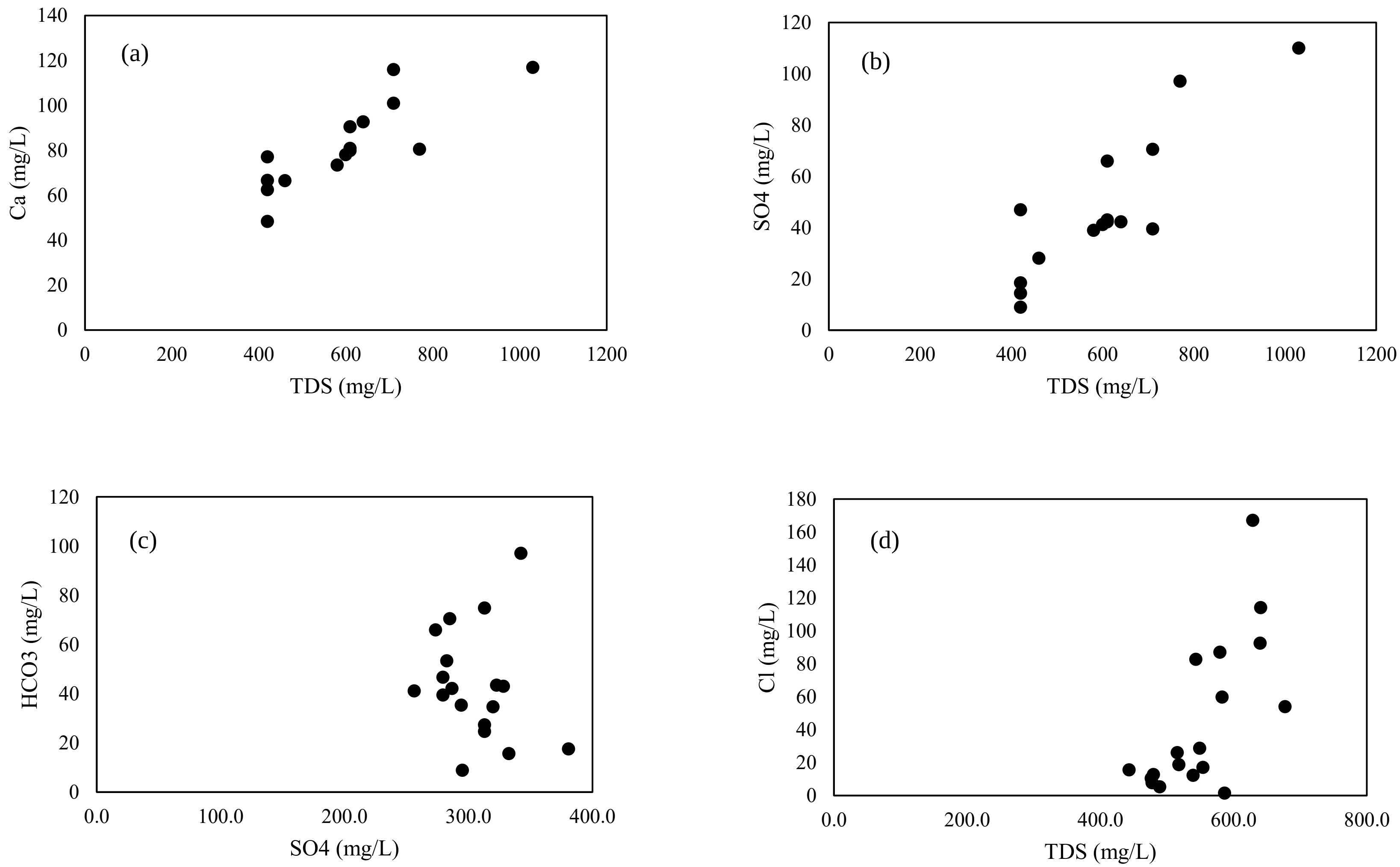

Figure 7: Correlation between total dissolved solids (TDS) and major ions (calcium, sulphate, and chloride) (a) TDS vs Calcium concentration, (b) TDS vs SO_4, (c) SO_4 vs HCO_3, (d) TDS vs Cl. Values plotted here are listed in Table 2.

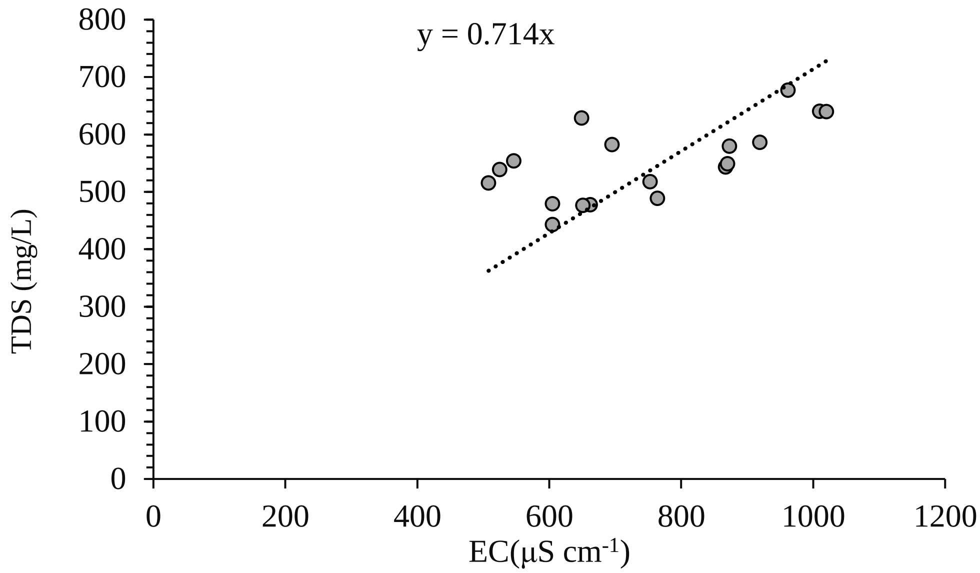

Figure 8: Correlation between total dissolved solids (TDS) and electrical conductivity (EC) using data collected from springs in Bighill Creek (Table 1 and Table 2).

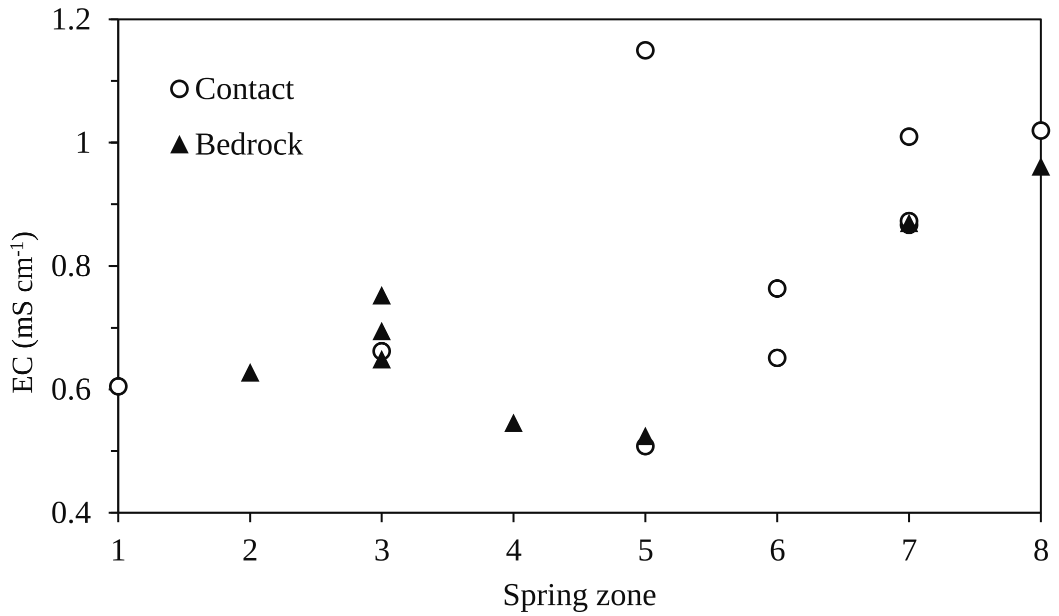

Figure 9: Comparing electrical conductivity (EC) with Spring zone to determine spatial trends.

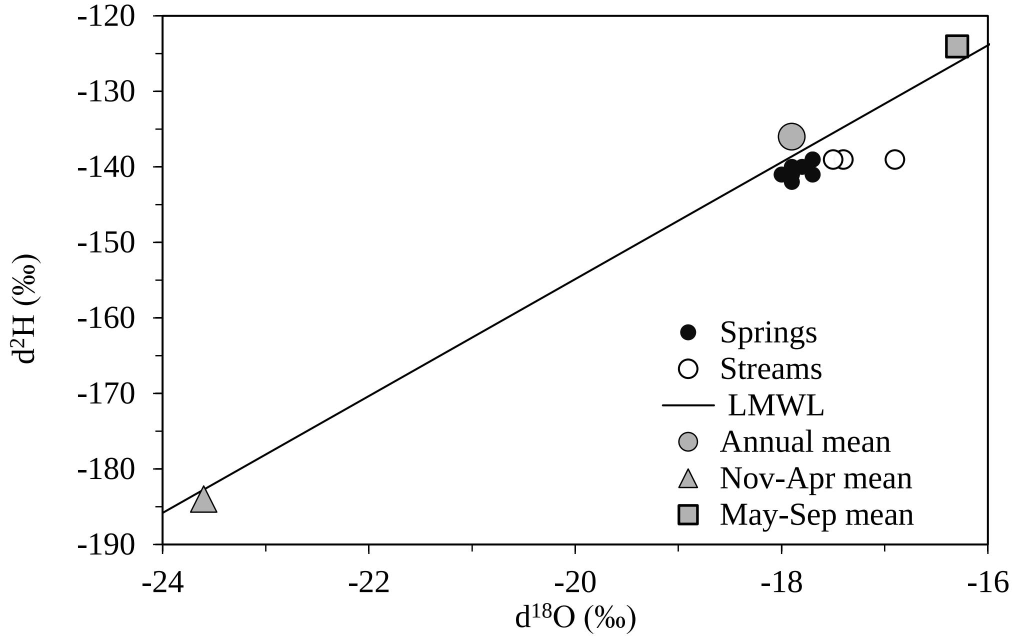

Figure 10: Stable isotope composition of springs and streams in the study area. The solid line shows the local meteoric water line (LMWL) with seasonal averages and annual mean isotope compositions for precipitation in this region (Peng et al. 2006; Hayashi and Farrow, 2014).

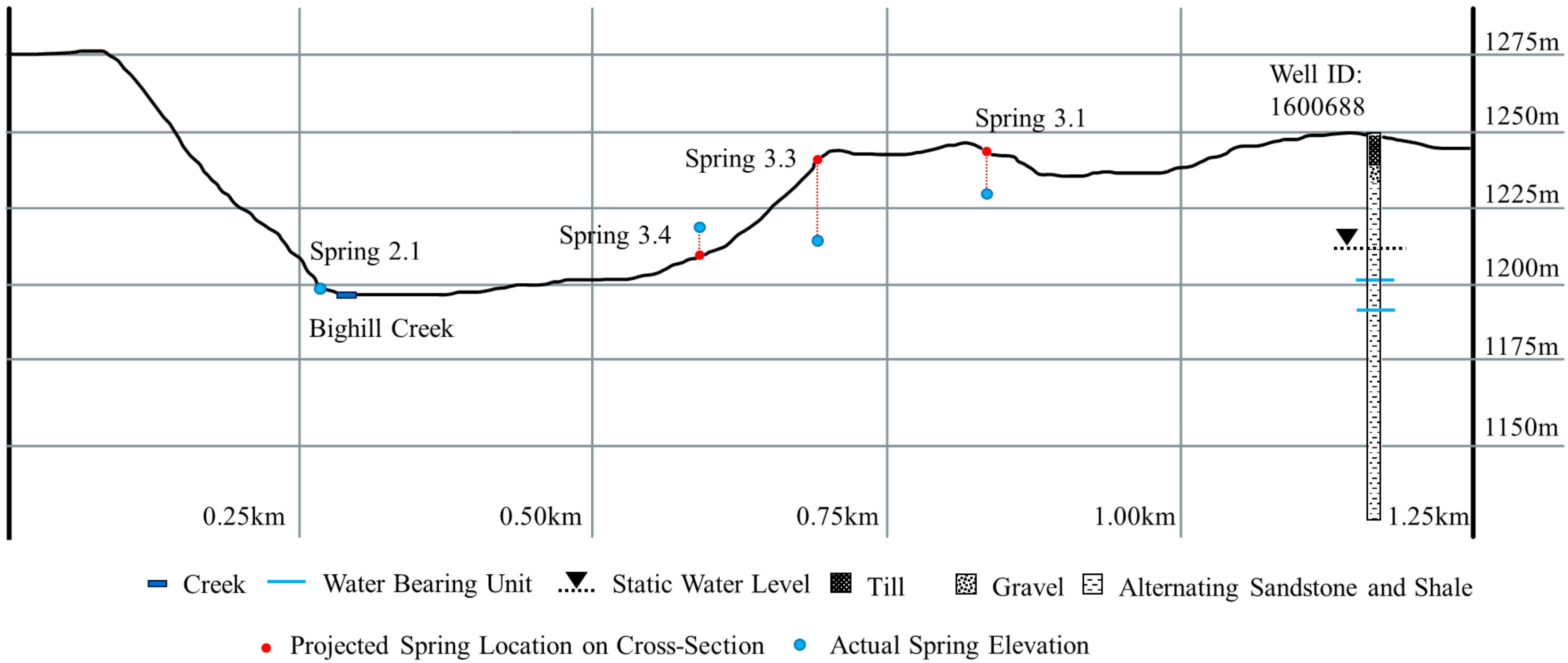

Figure 11: Cross-Section through Bighill creek and Well 1600688 with projected locations (red points) of springs from Zones 2 and 3. The actual elevation of the spring differs from the surface location due to variable topography along the projected axis (blue points).

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Appendix: Photographs

Figure A1: GNSS survey base station set-up. Not that there is a metal pin which the tripod is centered over so that the same base station was used for the multi-day survey.

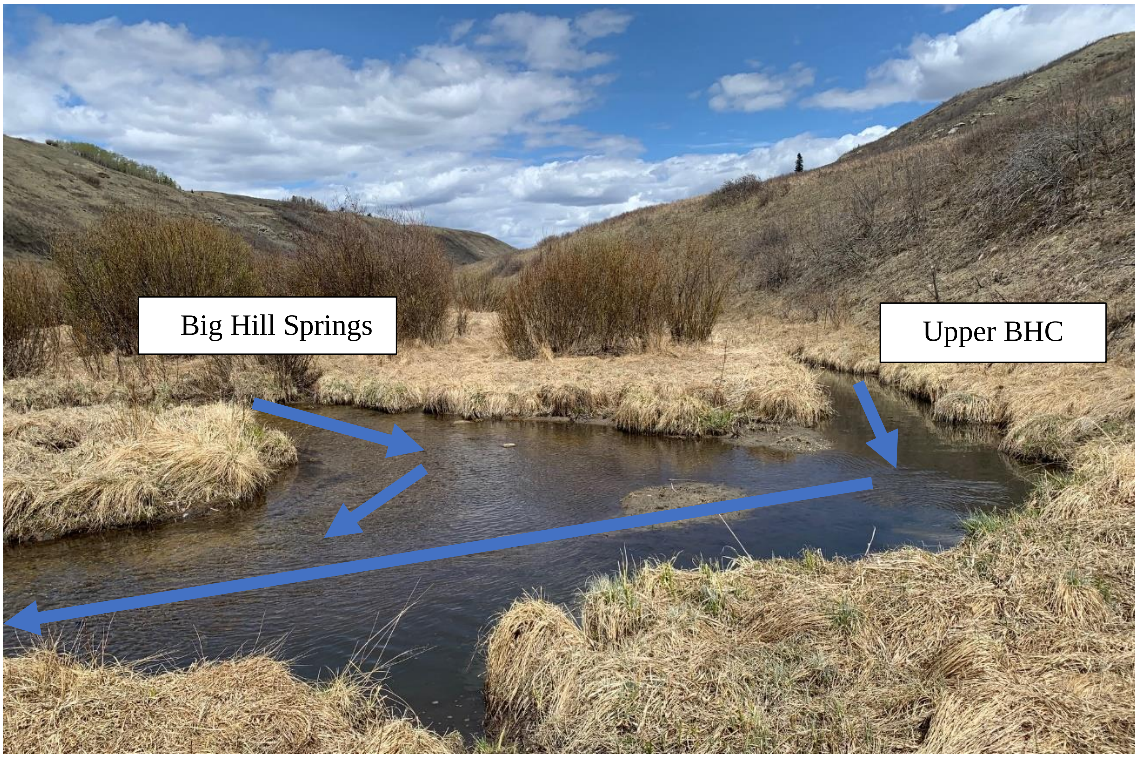

Figure A2: Confluence of Big Hill Springs with Bighill Creek. Upper Bighill Creek is the creek on the right and flows to the bottom left of the image. The blue arrows denote the direction of flow. The gauging station for Big Hill Springs (GS_3) is located about 10m upstream of this confluence point.

Figure A3: (a) Spring 4.1, note the Paskapoo sandstone behind the fallen tree. This is the main outflow point for this spring complex. (b) Location of flow measurement for Spring 4.1 complex. This location is about 10m downstream of the spring source as it captures the small seepage springs surrounding the main outflow point (A4a). Photos taken July 3, 2022.

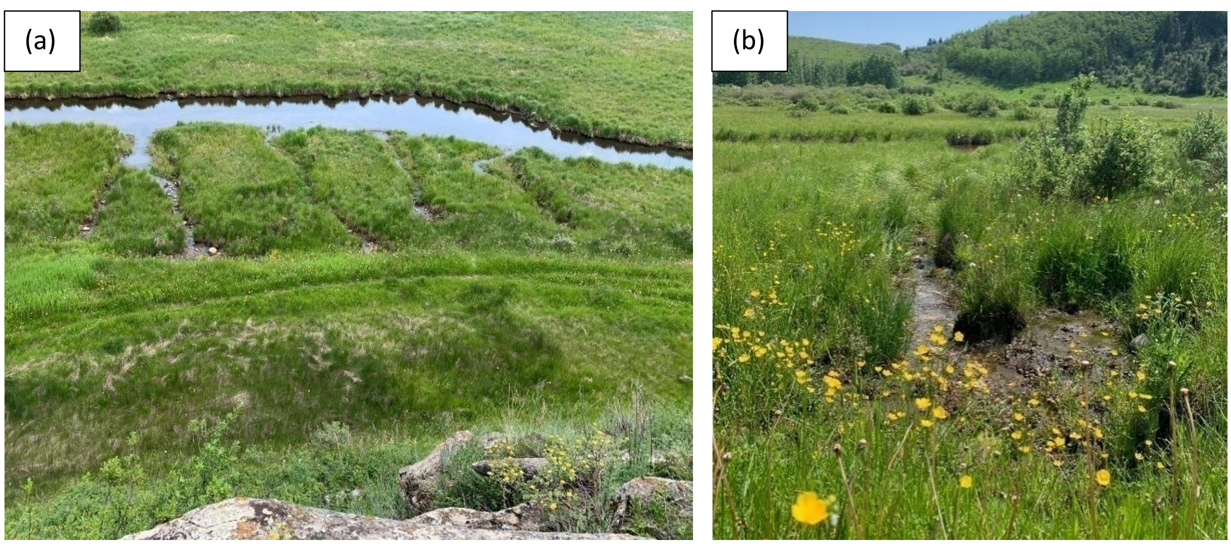

Figure A4: (a) View of Zone 2, Springs 2.2-2.6 from the top of the Paskapoo sandstone outcrop (looking down on the springs and Bighill Creek). (b) Spring 2.1 pictured at the source looking down the flow path to where it meets Bighill Creek. Photos taken July 1, 2022.

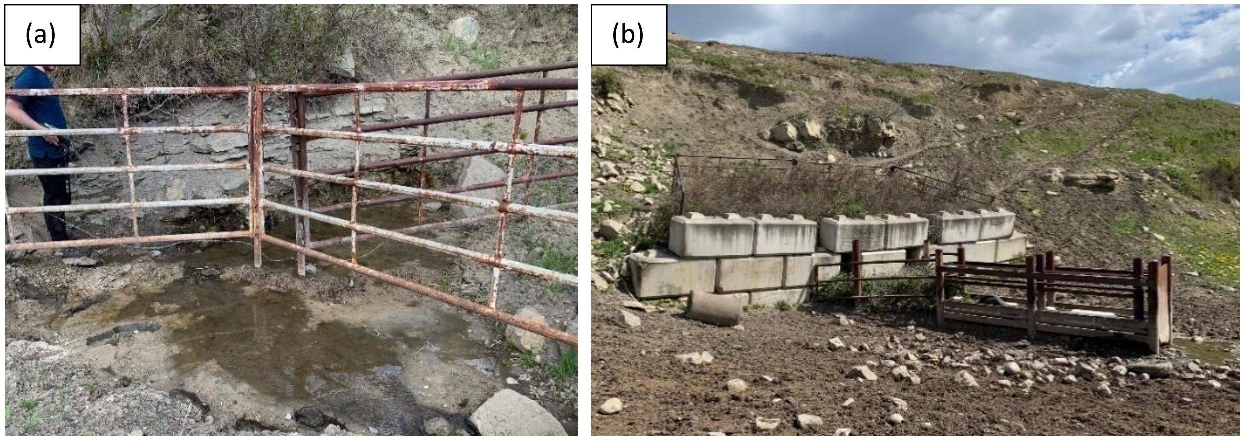

Figure A5: (a) Spring 5.2, bedrock spring with added fencing to protect from cattle. (b) Spring 6.1, contact spring, modified for use as water source for cattle. Photos taken June 1, 2022.

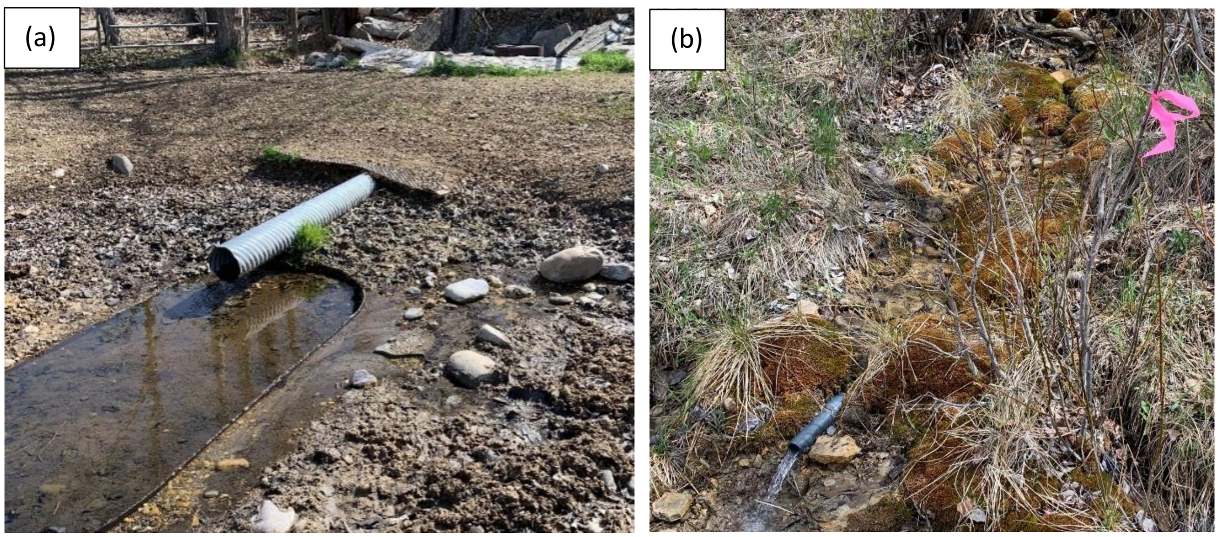

Figure A6: (a) Spring 3.1, contact spring, flowing under gravel pathway through culvert. (b) Spring 3.4 with pipe inserted to capture flow for discharge measurement. Photos taken July 13, 2022.

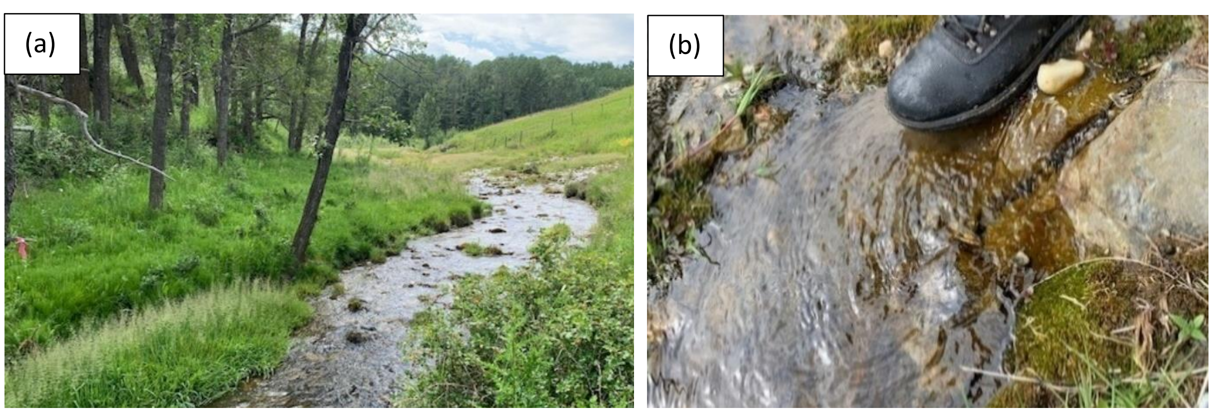

Figure A7: (a) Gauging location for Big Hill Springs Source (GS_2). (b) Spring flow from point source on the North side of Big Hill Springs flow. Photo taken June 20, 2022.

Figure A8: Ice rivers observed on the East side of Bighill Creek in the forested area downstream of Spring Zone 7. Notice the two ice rivers converging to meet one another. The ice appears to align with the spring flow from Springs 7.1 and 7.2 but this was not able to be confirmed.

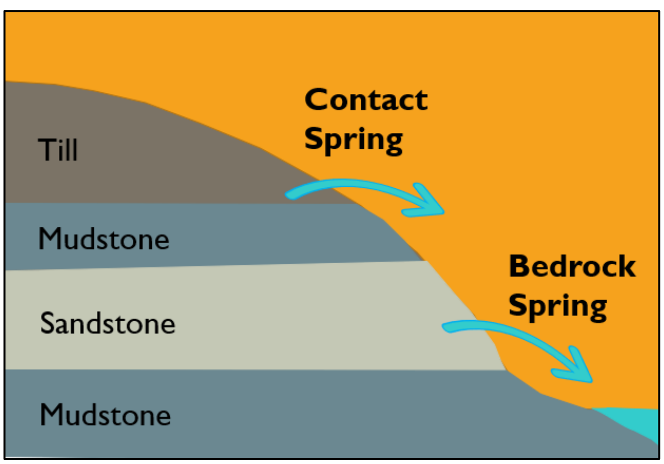

Figure A9: Conceptual diagram illustrating contact versus bedrock springs in a glacial valley. Adapted from Glenbow Ranch Provincial Park (Hayashi, et al. 2014).