Preliminary Learnings from the Community Monitoring of Groundwater-Surface Water Interactions in the Xwulqw'selu Watershed for 2021/2022 Field Seasons

By Kristina Disney

Key Summary Points:

- Volunteer monitors are producing large amounts of quality data consistent with data logger and expert data
- Discharge is sustained during low flows by the higher elevation, fractured bedrock found in the upper watershed such that streamflow from the upper watershed is equivalent to gauged flow Water Survey of Canada (WSC) in the lower watershed through August and into September
- The 12 tributaries measured above the WSC gauge in mid-August 2022 accounts for 50-60% of mainstem streamflow
- Future work will focus on short- and long-term applications of the monitoring program
- We are requesting participation in monitoring program evaluation.

Monitoring work in the watershed to date

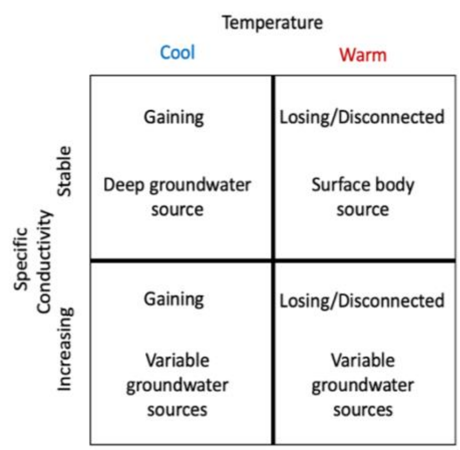
The intention of the community monitoring program is to provide opportunities for community to build relationship with the watershed and one another. While this engagement work is integral to the monitoring program, the focus of this document will be on the sharing of hydrologic insights from program data.

We want to express our gratitude to all of the volunteers for their efforts over the last two years! Between 2021 and 2022 there have been more than 1500 observations made at nearly 80 sites throughout the entire watershed (Fig. 1). Volunteers recorded water temperature, specific conductivity, stream width, and stream depth and took site photos throughout the low-flow season. A minimum of two sites were selected per major tributary where public road access allowed. Sites were selected in consultation with Cowichan Tribes to consider culturally sensitive areas. Cowichan Tribes is the owner of all data collected as part of the community monitoring program. University of Victoria is the steward of the data. The data are digitally hosted by Anecdata, an online community and citizen science platform (https://www.anecdata.org).

In addition to the community monitoring, in 2022 discharge measurements were taken at a 2-3 week intervals near the confluence of major tributaries. Data loggers measuring temperature and specific conductivity at 10-minute intervals were installed at 10 of the sites in 2021 and 20 sites in 2022 to provide a standard to compare with community data. Not all data and sites have been analysed yet. However, preliminary analysis shows no statistically significant difference by tributary between datalogger, researcher or community measurements. So again, thank you volunteers for your diligent work!

Groundwater-surface water interactions in the watershed as we understand them so far

Groundwater is important to maintaining streamflow in low flow season. Groundwater connection supplies a reliable source of water when there is limited precipitation and spring runoff has finished. Groundwater is not only important for the amount of flow, but for maintaining cool stream temperatures that are critical to river ecosystem health and function.

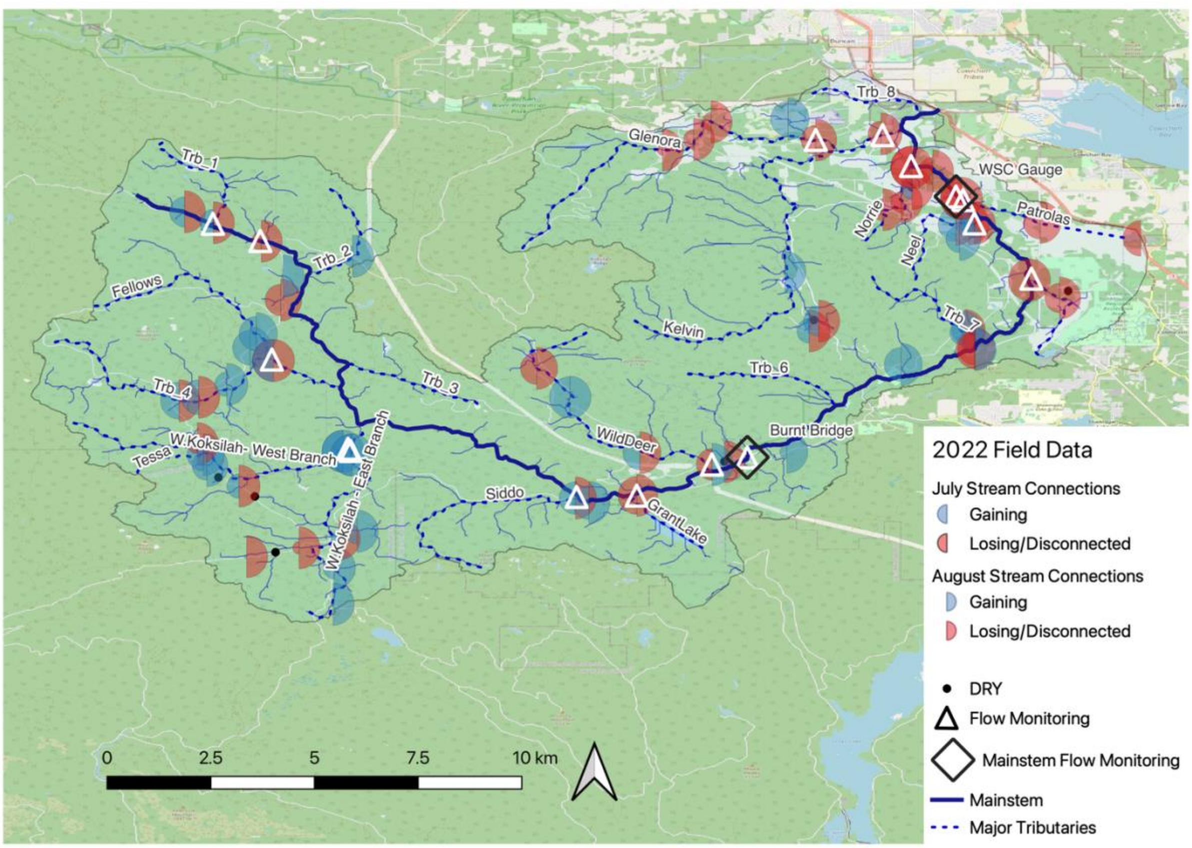


Stream monitoring focused on temperature and specific conductivity because these act as indicators of groundwater presence in streamflow. In the summertime, gaining streams have relatively stable, cool temperatures because groundwater coming up from depth stays close to the mean annual air temperature, which for this area is 10.6ºC (average from 2013-2022 at EC1017230 – Shawnigan Lake Station; Environment Canada, 2023). Losing and disconnected streams on the other hand are sensitive to solar radiation because the water has travelled from further upstream. On its journey, it takes on heat from its surroundings, thus it tends to be warmer and follow a trend similar to air temperature fluctuations.

Specific conductivity is a measure of dissolved ions in the water. It is predominately determined by the type of minerals water flows through and how much time the water is in contact with the minerals. While it does not tell you which minerals have dissolved in the water, it does give you an identifiable signature.

Groundwater-surface water interactions reflect the variation in geology, climate and land characteristics that the river experiences. Monitoring how these connections change throughout the watershed and understanding why can be one of the ways we work towards a healthier Xwulqw'selu Sta'lo. Establishing knowledge of groundwater connection throughout the watershed sets realistic expectations and goals of water yield from tributaries to maintain critical flows. In addition, the timing of flow is as critical as the flow volume, monitoring the seasonal transitions in groundwater-surface water interactions can guide low flow water management strategies.

The map below shows a subset of data collected from the monitoring program in 2022, comparing streamflow in mid-July to mid-August. Total precipitation from July 15th to the end of August was ~3.6 mm and therefore these contributions can be considered negligible. Streams that have transitioned from gaining to losing/disconnected show where the water table has dropped throughout the summer and the gradient has shifted so that streams are now giving rather than receiving water.



Groundwater-surface water interactions in the 2022 field season. Gaining or losing streams are determined by streams over 15ºC. Circle size is indicative of baseflow calculated from specific conductivity. The larger the circle, the larger the relative portion of streamflow sourced from baseflow.

In our Pacific Northwest coastal climate, the natural seasonal progression is such that aquifers recharge in high precipitation winter months and then slowly drain throughout the summer. The volume of flow and timing when this transition happens will be dictated by how much winter precipitation was able to recharge the aquifers and to what extent evapotranspiration occurs during the summer. Streams that are losing or disconnected from groundwater for the low flow season may have been connected earlier in the spring or winter but that has so far been outside the scope of the community monitoring program. Streams gaining the whole summer are sustained by groundwater and are more resilient to drought conditions. Streams with consistent baseflow values have a reliable source water, regardless of gaining or losing conditions.

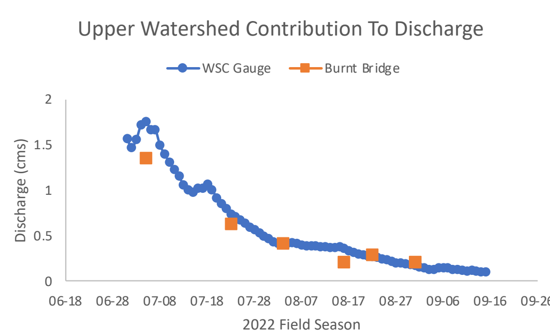
How much water are we talking about?

Note: All water we are monitoring is above surface, which is only a pale comparison to the volume of water moving subsurface through the aquifers themselves. Please keep in mind that while streams are a product of below ground processes, observing only streamflow cannot give us a full understanding of what is happening beneath our feet.

While we do not have historic records of flow at a sub-watershed level, we can look at expected discharge based on area to compare tributaries. Under spring conditions when runoff is abundant, tributaries contribute flow is proportional to their basin area. As runoff dwindles throughout the summer, the storage capacity of the sub-basin can sustain flow levels beyond what is available by surface area alone.

The largest sub-basin in the watershed is Kelvin Creek and Glenora Creek, which combined make up 19% of the whole watershed. Fellows Creek and the East branch of the West Koksilah are just under 10% and all other tributaries are ~5% or less of total area. Overall, the system is diffuse: no single tributary stands out as an overabundant supplier of water during low-flow season. However, some tributaries can be said to 'punch above their weight class'. In mid-August, Patrolas Creek, Wild Deer Creek and Siddo (Park) Creek all contribute nearly double the discharge one would expect based on basin area. Other tributaries of note are the West branch of West Koksilah and Grant Lake, both of which contribute more than expected. Fellows Creek is of note because while it represents nearly 10% of the watershed area, it only contributes ~4% of flow. Tributaries with surface water bodies, acting as a reservoir, can explain this sustained supply of streamflow. Those that do not, have aquifer characteristics that have greater storage capacity and thus create a subsurface 'reservoir'.

Total recorded tributary discharge accounts for 50-60% of flow recorded at the WSC gauge near Cowichan station during mid-August. Tributaries that join the mainstem upstream of Burnt Bridge account for 44% of mid-August flow. Kelvin Creek and Glenora Creek are not included as they join the mainstem downstream of the WSC gauge. Flow measurements of the mainstem at Burnt Bridge show that total discharge does not increase beyond this point under low flow conditions.



Tributary characteristics and conditions averaged from summer 2022 and a subset of dates from mid-August 2022. Temperature is delineated as gaining (<15ºC) or losing (>15ºC) by blue and red respectively, invalid baseflow indexes due to surface water bodies are indicated in grey. Tributaries contributing more to mainstem discharge than expected based on sub-watershed area are in green and those contributing less than expected are in orange.

Tributary Characteristics				2022 Summer Average				*Mid-August 2022*						
Tributary	Mapped and observed substrate	Surface waterbodies upstream	Tributary Sub-Basin Area as Percentage of Total Watershed (%)	Temperature (ºC) (gaining or losing/disconnected)	Specific Conductivity (uS/cm)	Tributary Discharge (cms)	Baseflow Index	*Date*	*Temperature (ºC) (gaining or losing/disconnected)*	*Specific Conductivity (uS/cm)*	*Baseflow Index*	*Water Survey of Canada discharge measurements of mainstem (cms)*	*Expected Discharge By Subbasin Area (cms)*	*Tributary Discharge (cms)*
Trb. 1	crystalline bedrock	none	1.76	13.7	65.73	0.01	0.60	*2022-08-16*	*15.1*	*64.9*	*0.58*	*0.36*	*0.006*	*0.004*
Upper Koksilah Mainstem	crystalline and sedimentary bedrock	wetland	4.48	18.63	103.73	0.03	0.87	*2022-08-16*	*21.2*	*102.0*	*0.84*	*0.36*	*0.016*	*0.008*
WK-East	crystalline and potentially sedimentary bedrock	unknown	9.36	12.90	111.45	0.07	0.53	*2022-08-16*	*13.6*	*117.0*	*0.57*	*0.36*	*0.034*	*0.028*
WK-West	crystalline and potentially sedimentary bedrock	unknown	4.90	13.08	136.40	0.06	0.44	*2022-08-16*	*13.4*	*177.0*	*0.63*	*0.36*	*0.018*	*0.026*
Trb. 2	crystalline bedrock	none	1.92	12.30	64.03	0.01	0.69	*2022-08-16*	*13.4*	*66*	*0.75*	*0.36*	*0.007*	*0.002*
Heatherbank Brook	sedimentary bedrock (anthropogenic influences from limestone quarry	quarry	1.54	16.04	244.60	0.00	0.61	*2022-08-18*	*17.0*	*229.0*	*0.56*	*0.31*	*0.005*	*0.005*
Fellows	crystalline bedrock	none	9.85	14.20	80.28	0.03	0.63	*2022-08-19*	*15.5*	*86.1*	*0.73*	*0.30*	*0.030*	*0.012*
Glenora	unconsolidated sediments e.g. sand and gravels	small lake	5.09	16.56	142.40	0.04	0.68	*2022-08-19*	*18.5*	*158.0*	*0.78*	*0.30*	*0.015*	*0.020*
Grant Lake	crystalline bedrock	small lake	3.93	17.72	72.24	0.01	0.89	*2022-08-19*	*20.0*	*72.6*	*0.91*	*0.30*	*0.012*	*0.016*
Neel	unconsolidated sediments e.g. sand and gravels, clay	none	1.60	16.92	190.00	0.00	0.64	*2022-08-19*	*18.9*	*198.0*	*0.67*	*0.30*	*0.005*	*0.000*
Norrie	unconsolidated sediments e.g. sand and gravels	none	2.37	17.38	140.68	0.00	0.61	*2022-08-19*	*18.7*	*157.0*	*0.72*	*0.30*	*0.007*	*0.000*
Patrolas	unconsolidated sediments e.g. sand and gravels, clay	small lake	4.35	18.50	216.17	0.05	0.75	*2022-08-19*	*18.7*	*227.0*	*0.79*	*0.30*	*0.013*	*0.028*
Siddo	crystalline bedrock	none	3.25	14.00	135.25	0.02	0.76	*2022-08-19*	*15.2*	*142.0*	*0.81*	*0.30*	*0.010*	*0.019*
Kelvin	unconsolidated sediments e.g. sand and gravels	none	19.00	16.47	145.03	0.02	0.68	*2022-08-19*	*19.5*	*159*	*0.65*	*0.30*	*0.057*	*0.033*
Wild Deer	crystalline and sedimentary bedrock	small lake	6.04	14.52	148.33	0.04	0.69	*2022-08-22*	*14.7*	*161.0*	*0.78*	*0.27*	*0.016*	*0.032*

Planned work

Community monitoring will resume summer 2023 and 2024 is planned as the final season as part of the Ph.D. research. Lots of work remains around assessing monitoring results in each tributary as well as validating the spatial representation of the point measurements. Models using stream temperature and the stream area data collected by volunteers will be used to estimate how far upstream these observations remain relevant.

Future work will be focused on investigating baseflow transitions relative to changes in discharge to determine if specific conductivity can be used to predict time remaining until mainstem discharge reaches the critical flow threshold. Recharge throughout the winter will vary with intensity and duration of precipitation. Specific conductivity values may indicate how much water has infiltrated into the aquifer and thus be used to forecast when aquifers will shift from shallow to deep groundwater sources.

This is a potential short-term application. More long-term applications may be the establishment of baseline data of baseflow contributions to compare to future changes in climate and land use. Future shifts in snow to rain or changing vegetation cover, for example, will alter baseflow contributions and these changes can be monitored and potentially managed by tributary. Future work will also take a deeper dive to investigate the climatic, geologic and landscape controls to groundwater-surface water interactions as they are today to better understand how they may react to future stressors or be managed for improvements.

Request your participation in an evaluation of the monitoring program

Those involved with the monitoring program as volunteers, collaborators, partners and rightsholders wish to see a healthier, more resilient watershed. The monitoring program has been guided by the intention of being useful and as helpful as possible in achieving this goal. Having just crossed over the halfway mark of the program's planned duration within the Xwulqw'selu Connections research project, it seems important to pause and reflect how the program may be able to better contribute to realizing a healthy watershed. Before meeting together on May 25^{th}, we would ask that you consider the following questions as we would like to discuss them together as a group:

1) Was the information shared here and in discussion helpful to you/your organization in understanding the watershed? What other information or perspectives might be important to improving our collective understanding of the watershed?
2) Will the learnings shared from the monitoring program be useful to how you/your organization approaches water resource management in the watershed?
3) Is there interest in continuing the monitoring program beyond the Xwulqw'selu Connections research project? What needs would continuation of the program fulfill?
4) If the community monitoring program were to continue past 2024, outside the scope of this current research project, what might be important to establish now that would create capacity for knowledge or skills developed in the monitoring program to be used in the future?

We are fortunate to have two more years ahead of us and we want to make the most of them! In alignment with the questions above, we are doing a formative evaluation of the monitoring program to assess its use as a tool for watershed stewardship. The evaluation will be focused around the efficacy, impact and transferability of the program within and beyond the watershed. We would like to ask for the participation of 1-2 people from each organization to participate in an evaluation of the program. This would be a 1-2 hour commitment in the fall of 2023 and likely a similar follow up session in 2024. These evaluations will likely take the form of semi-structured interviews while sharing a meal as a thank you for your time.

Glossary

Terms

Low flow season: There is no hard and fast definition. However, in the Pacific Northwest it's defined as an annual phenomenon that occurs during the prolonged dry period characteristic of the Mediterranean climate experienced in the region (Coble et al., 2020).

Sub-watershed: A watershed is defined as an area or region drained by a river, river system, or other body of water. A sub-watershed is any of several parts of a watershed that drain to a specific location, which for our context is the specific tributaries that feed the Xwulqw'selu. The terms sub-watershed and sub-basin are used interchangeably in this document.

Baseflow transitions: Baseflow is the portion of streamflow that contains groundwater flow and flow from other delayed sources. Baseflow transitions represent changes in that source water, from throughflow, shallow or deep groundwater (see shallow vs. deep groundwater below).

Critical flow threshold: The BC provincial government defines critical flow as a short-term flow threshold, below which significant or irreversible harm to the stream's aquatic ecosystem is likely to occur. In the Xwulqw'selu watershed 180 litres per second has been designated the threshold at which the survival of Coho salmon, steelhead and resident trout have become threatened.

Concepts

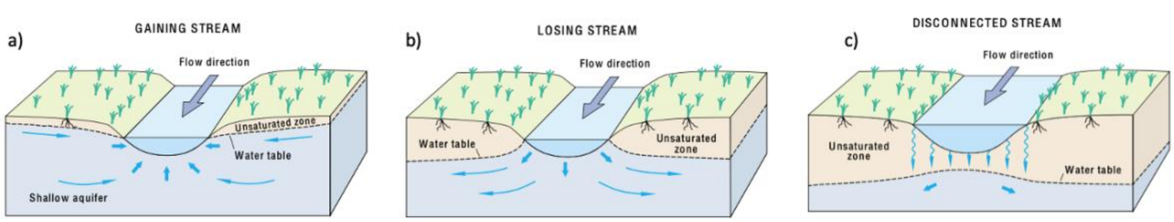
Groundwater Connection:

In general, groundwater and surface water have three distinct relationships. The direction of flow between them, or the absence of any connecting flow between them, is what distinguishes gaining, losing, and disconnected streams, as follows:

They might be:

A) In a gaining stream, they are connected and groundwater feeds water into the stream,
B) In a losing stream they are connected but the stream feeds water into the surrounding groundwater
C) In a disconnected stream, the water table has fallen below the stream bed such that groundwater and surface water are no longer connected. The stream is losing water, but a much smaller amount of water than the amount lost in a losing stream .

These connections naturally vary through space and time, where one spot of the river can change its connection as the seasons change or walking along the course of a river, it can change from one connection to another.



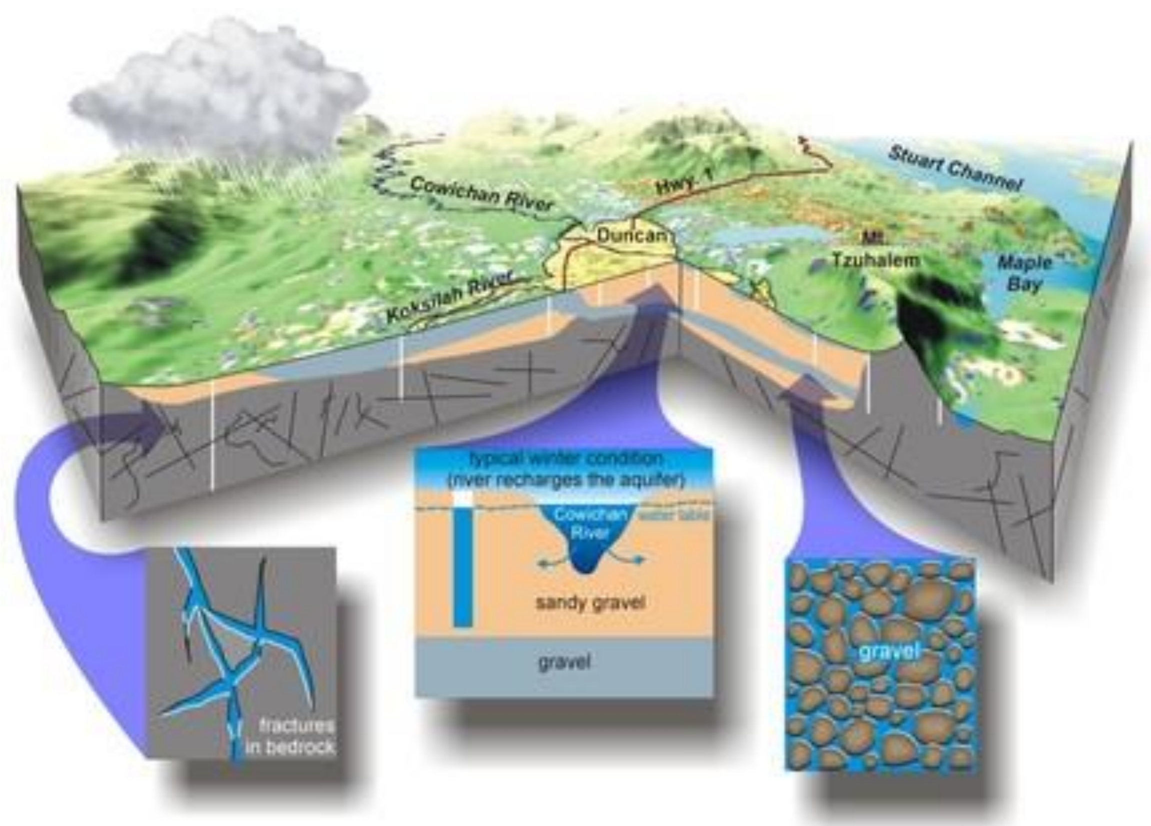
Conceptual models of groundwater-streamflow interactions; a) connected and gaining stream, b) connected and losing stream c) disconnected stream, losses through infiltration (Winter, 1998)

Shallow vs. deep groundwater sources:

Since precipitation is not a significant factor during the low flow period, water in the stream can be coming from up to four sources: throughflow (water in the soil that has not yet reached the water table), shallow groundwater (water that is likely recharged on an annual basis), deep groundwater (water that is likely recharged on interannual cycles) or a surface waterbody such as a wetland or small lake.

Shallow groundwater is roughly approximated as less than 5 m and deep groundwater is greater than 5 m below surface (Hare et al., 2021). What that translates into for Xwulqw'selu, is that the way groundwater recharge works here, it's likely that shallow groundwater is replenished on an annual cycle and deep groundwater is replenished on the scale of multiple years. What happens seasonally will alter shallow groundwater, but it will not have major consequences for deep groundwater (except groundwater extraction). Shallow groundwater is what can be managed in 'daily practices' and deep groundwater is what needs to be managed through land use and planning for future climate changes.

Xwulqw'selu Aquifer Characteristics:



https://www.cgenarchive.org/victoria-groundwater.html

Fractured bedrock has a low storage capacity, water can only flow along the fracture lines and only drains well when those fractures are well connected. Unconsolidated material like sand and gravel have spaces between the individual grains that provide more storage capacity and are generally well connected for water to flow through. Unconsolidated material is capable of holding more water than fractured bedrock. In the Xwulqw'selu, even though fractured bedrock holds less water, there is simply a far greater quantity of it, existing at a higher elevation. Even though it could be said to be less 'productive' it is still capable of acting as a natural water tower, slowly draining throughout the summer and providing streamflow.

The lower watershed requires more water to fill the pore spaces between the sand and gravel particles, these aquifers are 'more thirsty' and per cubic meter, need considerably more water to fill themselves than fractured bedrock aquifers in the upper watershed. Their ability to refill themselves seasonally is also inhibited by some types of sediments, like glacial till and marine clays, that act as a barrier to flow. For example, a farm field may be saturated or even flooded in the winter from rain, but if it's underlined by heavy clay that water is not reaching the aquifer below but flowing along the surface topography until it finds a weak point in the clay or reaches an outlet (stream).

References

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