# An Analysis of Downstream Changes in Temperature, Electrical Conductivity and Total Dissolved Solids of the Illecillewaet River and Asulkan Brook in Glacier National Park, B.C.

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# Abstract

The objective of this study was to measure changes in temperature, total dissolved solids (TDS) and electrical conductivity (EC) of the Illecillewaet River and the Asulkan Brook moving downstream from their respective glaciers. These parameters were measured at several locations along the Illecillewaet River and the Asulkan Brook progressing downstream towards the Meeting of the Waters. The measures of temperature remained constant between the Asulkan and the Illecillewaet and did not dramatically change moving downstream. The Asulkan Brooke demonstrated few changes in EC moving downstream whereas the Illecillewaet River had increasing measures of EC moving downstream. TDS followed a similar trend as EC for both the Asulkan and the Illecillewaet. The Asulkan Brook showed fairly consistent and high TDS values and while values for the Illecillewaet River were lower, they increased downstream. These results suggest that the Asulkan receives the bulk of its dissolved solids further upstream. The processes by which this happens are unclear but are considered different for the Illecillewaet River. At the Illecillewaet study sites, contamination was lower; however, the downstream increase in EC and TDS indicates weathering processes as a source for dissolved ions. The implications for this study include future resource management and understanding environmental consequences of climate and human impacts.

# 1 Introduction

## 1.1 Geographic Setting

The location of this study was at the confluence of the Illecillewaet River and Asulkan Brook, referred to as the Meeting of the Waters, near Roger's Pass in Glacier National Park (Figure 1). Glacial National Park, centered at 51˚ 15' N, 117˚30' W, is located within the Kootenay District in the south-eastern corner of British Columbia, Canada. Glacier National Park is located within the Selkirk Mountains and has an elevation ranging from 800 m in the valleys to 3400 m at the highest peaks (Figure 2) (Delparte et al., 2008; Department of Justice, 2011; McCleave, 2008).


**Figure 1.** Glacier National Park, located within the Selkirk Mountains in southeastern British Columbia. (Planet Ware, 2011)

The Selkirks, within the North American Cordillera, extend approximately 965 km inland from the Pacific Ocean and cover an area of 40 183 km$^2$ (Bivouac, n.d.; Wheeler & Parker, 1912). Glacial National Park, covering approximately 1349 km$^2$, provides protection for about 1350 km$^2$ of the Selkirk and adjacent Purcell Mountains (McCleave, 2008). Roger's Pass, at the summit of Mount McDonald in Glacial National Park, runs along the Trans-Canada Highway. The pass continues 18 km between Loop Brook to the west and Stoney Creek to the east, providing access to many summer and winter activities such as backcountry hiking and skiing in the park (Delparte et al., 2008; Parks Canada, 2011; Shangaan Webservices, 2011).

**Figure 2.** The Selkirk Mountains extend from southeastern BC into Washington and Idaho (Wikipedia, 2006).

Glacier National Park (GNP) has many steep, angular mountains adjacent to deep, narrow valleys. Ice fields and glaciers cover the area along with waterfalls and avalanche paths (Parks, 2011). The closest communities to GNP are Revelstoke 70 km to the west and Golden 80 km to the east (Shangaan Webservices, 2011).

The Meeting of the Waters is located near Roger's Pass, Glacial National Park, at an elevation of 3700 m above sea level and centered around 51° 15' N, 117°29' W (Downs, 1980). The meeting of the waters is where the Illecillewaet River and Asulkan Brook meet. They are fed by their respective glaciers, the Illecillewaet and the Asulkan Glaciers, and other tributaries from the surrounding mountains and valleys. Historically, these two glaciers used to form one single glacier. They were eventually divided into two separate glaciers by an arête, referred to as Glacier Crest (Summitpost, 2010).

## 1.2 History of Area

With the operation of Glacier House from 1887-1925, the Canadian ‘Alps’ have historically been a popular attraction. In addition, the construction of the Canadian Pacific Railway drew attention to these mountains and thus began the wilderness exploration in the area that still continues today. The members of the Vaux family from Philadelphia were frequent visitors to the Canadian Rockies (Morris, 2002). Pioneers in studying the region, they contributed extensive photographic documentation and scientific research on the area and surrounding glaciers (Morris, 2002). After her initial visit to the Illecillewaet Glacier in 1887, Mary Vaux noticed upon her return seven years later that the glacier had retreated (Morris, 2002). Keen to study this remarkable feature, the Vaux family documented the glacier every summer until 1913; as a result, their studies demonstrate that since then, the toe of the glacier has receded over two kilometers (Morris, 2002). Further research on lichenometry, dendrochronology, and hydrology has been done in this portion of the Selkirk Mountain range in an attempt to explain and study past and present environmental change (Morris, 2002).

## 1.3 History of Related Studies

Glaciers have been considered important indicators of climate change, are a substantial source of renewable energy, and are an important natural resource in Canada. While glaciers cover 3% of British Columbia’s landmass, their significance to the natural environment and humans have made them a key focus in scientific study (Moore et al., 2009). Studies on glacial run-off have been important for resource management and with the growing concerns around climate change; glacial shrinkage is also an ongoing topic for research.

Studies have been continuously done around climate change and stream properties. Moore et al. (2009) proposed that glacial shrinkage results in an increase in stream temperatures, change in sediment load, and an overall change in streamwater chemistry. In addition, with climate change projected to continue, warming, hydrology, geomorphology, and water quality trends should also continue, leading to water resource availability and management implications (Moore et al., 2009).

Moore et al. (2009) also looked at stream flow in relation to seasonal glacier melt and Singh & Kalra (1984) investigated solute fluxes in relation to stream flow. Additional areas of research also include linking hydrology and biogeochemistry to complex land issues and investigating hydrology issues in regards to land management and ecosystem studies (Pinay & Burt, 2005). This history of related hydrological studies with respect to glaciers has provided a foundation for further studies on the impacts of glacier behavior and stream flow. Today, glaciers continue to be of interest for researchers studying the impacts of climate change and implications of stream flow.

## 1.4 Stream Characteristics

Hydrological studies draw on several key stream characteristics including temperature, discharge, stream flow velocity, total suspended sediment, and water chemistry (Moore et al., 2009). This study does not take all of these properties into consideration but the ones that are directly observed, as well as those which have significant bearing on the research topic, are discussed in this section.

### 1.4.1 Physical Stream Characteristics

*Temperature*

Temperature measurements of glacier-fed streams are useful for understanding glacier and local weather conditions and can allow for the study of other stream characteristics without measuring them directly (Moore et al., 2009). Because higher temperatures facilitate higher chemical reaction rates, water temperature can be used to determine possible chemical weathering processes which in turn affects water chemistry.

Glaciers have a substantial effect on downstream temperatures. The extent of their influence depends on: distance downstream; climate and flow conditions; glacier size, which negatively correlates with stream temperature; and flux of non-glacial water to the streams, which can have a warming effect (Moore et al., 2009).

*Discharge*

Discharge is a fundamental driving variable in fluvial systems. It is defined by the following equation:

$$Q = vA \qquad \text{Eqn. 1}$$

where the instantaneous discharge $Q$, is a function of the average velocity $v$, of water passing through the cross-sectional area $A$, of a river. It is expressed in units of $m^3/s$. The total discharge calculated using Equation 1 is an estimate of the instantaneous discharge (Raghunath, 2006). To determine discharge over longer periods of time, data obtained using a stage recorder is correlated to a rating curve (Raghunath, 2006).

Discharge is affected by factors that influence flow velocity and volume such as precipitation, base flow, vegetation, tributaries, and resistance of streambed material (Trenhaile, 2004). As a result, streamwater chemistry and temperature are also affected (Singh & Kalra, 1984). Discharge is also affected by glaciers, making it a useful indicator of climate. A warming climate initially increases meltwater runoff and therefore discharge; prolonged warming eventually reduces meltwater runoff as glaciers become too small (Moore et al., 2009).

*Suspended sediments*

Often considered as the most important measure of water quality, suspended sediments are filterable solids comprised of either inorganic or organic components. Inorganic clay, silt and soil particles are common in streamwater as are organic matter such as plant debris, algae and bacteria (Davie, 2002; Srinivas, 2008). A range of sources supply suspended sediments to streams including overland flow, mass wasting, debris flows, stream erosion, and sediments stored in glacier ice; suspended sediments are therefore useful indicators of the origin of streamwater (Davie, 2002; Moore et al., 2009).

Glacier cover is the key factor governing the amount of suspended sediments carried by glacier-fed streams (Moore et al., 2009). Glacier cover is proportional to basal erosion; as a glacier shrinks, the eroded sediments stored in the glacier are released and increase streamwater sediment load (Moore et al., 2009).

Suspended solids often lend a murky appearance to streams and other bodies of water, making it often easy to observe relative amounts of suspended solids in the field (Figure 3). A quantitative measurement can be carried out in a laboratory where water samples are filtered and the dried residue is then weighed (Srinivas, 2008).

**Figure 3.** The murky, brown waters of the Asulkan Brook indicate high levels of suspended solids.

### 1.4.2 Chemical Stream Characteristics

Two chemical parameters commonly used to indicate the collective concentrations of dissolved substances are total dissolved solids and electrical conductivity. These parameters do not specify the distributions of the contributing ions and organic compounds but are still helpful in determining their presence.

*Total dissolved solids*

Total dissolved solids (TDS) are comprised of both inorganic salts and small amounts of dissolved organic matter (Davie, 2002; Health Canada, 1991; Kadlec & Wallace, 2009). Common ions include $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $CO_3^{2-}$, $HCO^{-}$, $Cl^{-}$, $SO_4^{2-}$, $HSO_4^{-}$ and $NO_3^{-}$.

TDS concentrations are measured using gravimetry or specific conductivity. Gravimetry is a more accurate method when dealing with high TDS concentrations (Kadlec & Wallace, 2009). It is, however, more time consuming as it involves filtering the water sample, evaporating the residue and measuring the mass of the leftover salts. An easier method is to use a TDS meter which detects the presence of ions in a water sample and converts it to a measure of TDS in units of mg/L or ppm (parts per million).

The concentrations of TDS can vary significantly in streamwater and is an important water chemistry parameter for water quality management. A higher TDS concentration indicates higher contamination levels, or higher levels of dissolved constituents (Davie, 2002). The presence and concentrations of certain dissolved solids depend on weathering and erosion processes, mineral solubility in different climatic and geologic settings, sources of anthropogenic contamination such as agriculture, and organic sources such as plants and animals (Srinivas, 2008). For example, water which has been in contact with relatively insoluble materials such as granite, siliceous sand and leached soil will have TDS levels no higher than about 30 mg/L (Weiner, 2008). These levels can be as high as 195-1100 mg/L in sedimentary rocks because of the presence of carbonates, chlorides, calcium, magnesium and sulphates (Weiner, 2008).

*Electrical conductivity*

Electrical conductivity (EC) is similar to TDS in that it is a measure of ions and while they are nearly proportional, they are two different parameters (Davie, 2002). EC, measured in units of μS/cm, is strictly a measure of how conductive a water sample is; it is not a measure of the total dissolved constituents in the water. EC and TDS are proportional and can be related by:

$$K = \text{EC} / \text{TDS} \qquad \text{Eqn.2}$$

where $K$ is a constant which can be estimated by taking several measurements of conductivity with different TDS levels (Davie, 2002).

Similar to TDS, EC can vary significantly in streamwater and is often between 10 and 1000 μS/cm in rivers (Davie, 2002). Because it is an effective measure of salts in streamwater, it is useful for indicating the dilution and concentration effects of rainfall, runoff and evapotranspiration (Kadlec & Wallace, 2009).

# 2 Study Site

*Climate*

Glacier National Park is within the Interior Wet Belt region of British Columbia (Parks Canada, 2011). The area is characterized by heavy precipitation, mainly as rain in the summer and snow in the winter (Schaerer, 1972). The months of June, July, and August receive the most significant rainfall with approximately 92-96 mm (Figure 4; The Weather Network, 2011). The months of December and January receive the most snowfall of approximately 207-217 mm (Figure 5; The Weather Network, 2011). The Selkirks force the moist, warm air from the Pacific Ocean to rise and as a result, higher altitudes can receive significantly more precipitation; the Roger's Pass area receives up to 17 m each year resulting in a 2 m snow pack (Parks Canada, 2011).

Compared to the adjacent community of Revelstoke, Roger's Pass experiences temperature fluctuations that are usually 5-10℃ lower in temperature (Parks Canada, 2011). During September, the month in which our field data was collected, the region experiences cooler nights and greater chances of rain and snow (Parks Canada, 2011).


**Figure 4.** Average monthly rainfall in Roger's Pass (The Weather Network, 2011).

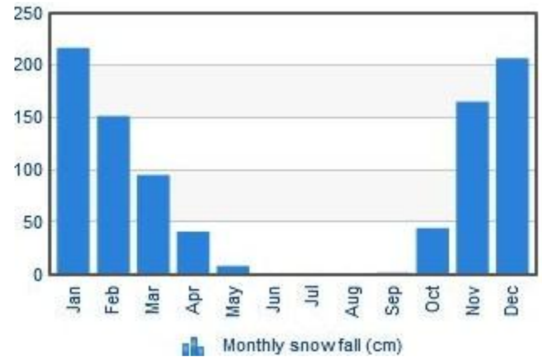


**Figure 5.** Average monthly snowfall in Roger's Pass (The Weather Network, 2011).

*Flora & Fauna*

The vegetation found within the Selkirks consists mostly of Douglas fir, Cedar, Engelmann Mountain Spruce, Hemlock, and Balsam (Green, 1889). The length of the Illecillewaet River within Glacier National Park is contained in the Interior Cedar-Hemlock Ecoregion. Vegetation present in the region includes alder trees and skunk cabbage (Achuff et al., 1984).

The high elevation determines the ecosystems in this area; old growth forest of Western Red Cedar and Western Hemlock populate the valley bottoms while Engelmann Spruce, Sub-Alpine Fir and Mountain hemlock populate the upper slopes. Parkland meadows transition to Alpine Tundra further upslope (Parks Canada, 2011).

More than half of Glacier National Park is Alpine Tundra, rock and glaciers and about 12 % of the total area is glaciated (Downs, 2005; Parks Canada, 2011). In the valley bottoms, diseases and insects play the largest role in natural disturbances while areas higher in elevation are subject to avalanches, fires, and mudslides (McCleave, 2008; Parks Canada, 2011).

The Meeting of the Waters is in the Interior Cedar/Hemlock zone and as the elevation increases, it turns into the Engelmann Spruce/Subalpine Fri zone. In this region, Western and Mountain Hemlock, Engelmann Spruce and Soldier Lichens and Map Lichens are common (Parks Canada, 2011).

Glacier National Park is home to many wildlife species such as wolverine, mountain caribou, grizzly bear, painted turtle, and short-eared owl. The river systems are home to many species including bull trout, cutthroat trout, and great blue heron. These wildlife species depend on the surrounding vegetation as a source of nutrition and shelter (McCleave, 2008).

*Geology*

The Illecillewaet moraine is made up of quartzite of large dimensions (Green, 1889). The bedrock of Glacial National Park is primarily acidic or non-calcareous (Achuff, et al., 1984). The geology of the Selkirks is different from the Purcells and Rockies with some rocks dating back about 600 million years. Prior to the Rockies being subjected to continental drift, which thrust them to their present location, the Selkirks stood alone as an island off the Canadian Shield (Bivouac, n.d.).

The peaks of the Selkirks are mostly comprised of gneiss, granite, marble, quartzite, and schist. The arêtes, cirques, hanging valleys, horns and ridges are created as these very hard rocks slowly erode and fracture along the softer sedimentary rock fault lines. The deep valleys are created by the erosive force of water (Great Canadian Parks, 2007).

*Glacier Characteristics*

To classify a glacier, the morphology (size and location), thermal properties (temperate or polar) and flow dynamics (active, passive or dead) must be known. Both the Illecillewaet and the Asulkan Glaciers are temperate valley glaciers. Because temperate glaciers are classified as having ice that is at or near their melting point, both the Illecillewaet and the Asulkan are in constant threat of ablation processes (Ritter et al., 2002).

*Stream Source*

The main sources of the Illecillewaet River and the Asulkan Brook are the Illecillewaet Glacier and the Asulkan Glacier. Both glaciers are fed by the Illecillewaet névé (Hulio, 2011; Vaux & Vaux, 1899). Other sources include: summertime surface runoff, groundwater, and glacial melt from the many tributaries flowing from the surrounding valley sides. The central and south-western portion of GNP is drained by the Illecillewaet River in addition to Bostock Creek, Flat Creek, Asulkan Brook, Cougar Brook, and Loop Brooks (Achuff et al., 1984). The Illecillewaet River is confined to a single channel even though it is glacier fed and sometimes bordered by early postglacial terraces. It is a high-energy system that is confined by a steep-sided, narrow valley and is eroding rather than depositing material along most of its length (Achuff et al., 1984).

# 3 Methodology


**Figure 6.** Garmin GPS map CSx unit.


**Figure 7.** Using the HACH conductivity meter to measure temperature, conductivity and total dissolved solids.

Field data collection was conducted on September 15th and 16th of 2011 using a Garmin Global Positioning System borrowed from the University of Victoria Geography Department. The GPS enabled us to determine the coordinates and elevation at each sampling site. The first day, a Garmin GPSmap 76CSx unit with serial number #1QFOO1987 was used (Figure 6). The second day, a Garmin etrex vista H with serial number #00520 was used.

The first day in the field consisted of taking control measurements of temperature, conductivity (EC), and total dissolved solids (TDS) using a conductivity meter borrowed from the University of Victoria Geography Department. The unit used was a HACH unit with serial #0058687 was used (Figure 7).

Control measurements were taken at the meeting of the waters at locations prior to mixing, locations of partial mixing, and locations of total mixing. Measurements were then taken along the Illecillewaet River at several locations going down stream from source towards the Meeting of the Waters. Measurements were also taken at several tributaries along the way. Study site locations were selected based on their accessibility from the trail.

GPS coordinates were recorded at each study site and their locations are indicated in Figure 8. Temperature, EC, and TDS were also recorded at each site in addition to a brief description of the surrounding vegetation and physical geography.

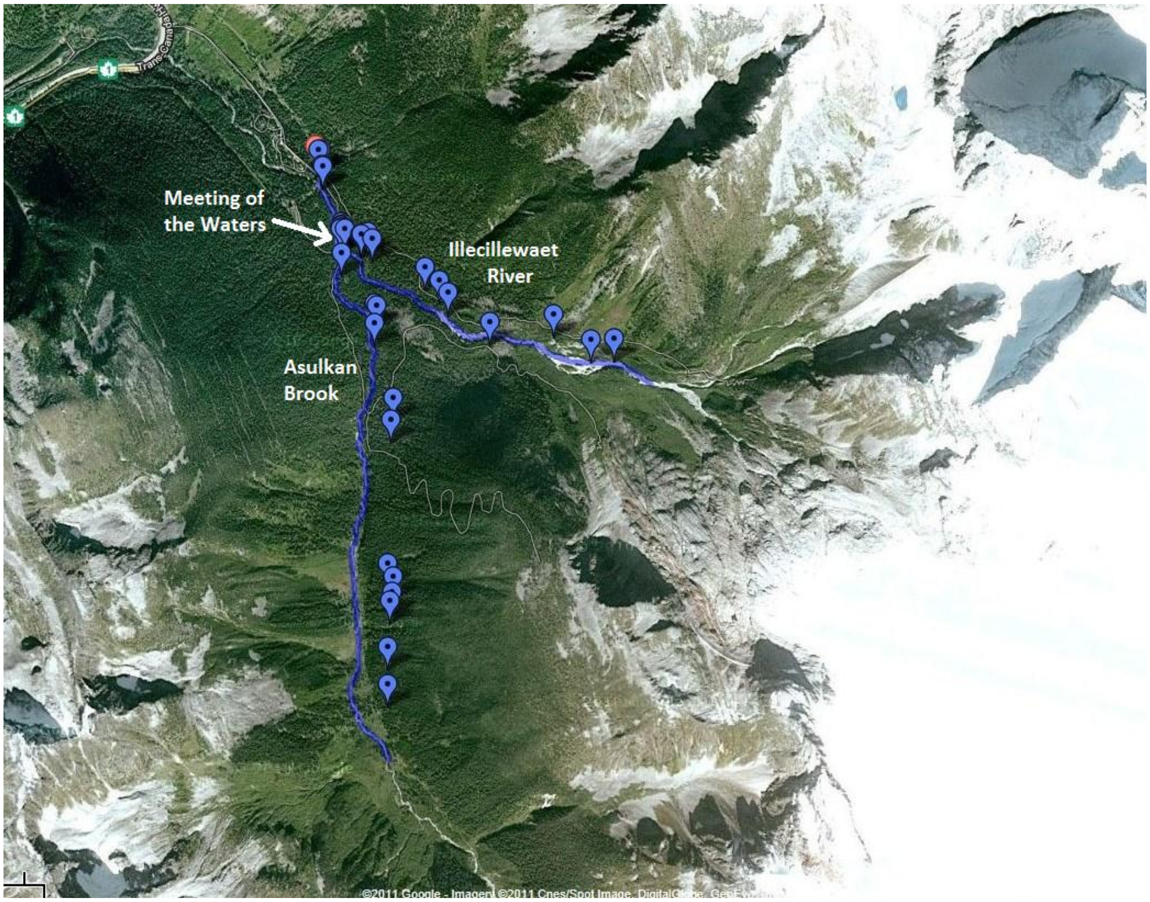


**Figure 8.** Map of study area with sample site locations (Google, 2011).

Field data collection concluded on the first day by measuring control points once again at the meeting of the waters. Measurements were also taken at a location further downstream where complete mixing was evident.

On the second day of data collection, measurements of T, EC, and TDS were taken immediately in the morning at the Meeting of the Waters control points. Measurements were taken at several locations progressing up the Asulkan towards the source as well as at the occasional tributary. In addition, surrounding vegetation and physical geography were recorded. In the afternoon, measurements were taken again at the control sites around the Meeting of the Waters.

# 4 Results

Temperature, EC, and TDS were measured along the Illecillewaet River between 1470 m and 1253 m elevation. According to Figure 9, temperatures decreased downstream from 5.4 ºC to 4.6 ºC.  EC increased from 3.9 μS/cm to 10.6 μS/cm as illustrated in Figure 10. TDS increased from 1.7mg/L to 5.3 mg/L as shown by Figure 11.

Measurements for temperature, EC and TDS along the Asulkan Brook were taken between elevations of 1420 m and 1263 m. Temperature decreased by 0.7ºC between the lowest and highest elevation (Figure ). Figure 10 shows fluctuations in EC until an abrupt decrease at 1278 m.  Similarly, as shown by Figure 11, TDS values fluctuated until a decrease at 1278 m. Afternoon measurements of T, EC, and TDS taken at the same locations exhibited similar trends to morning measurements.

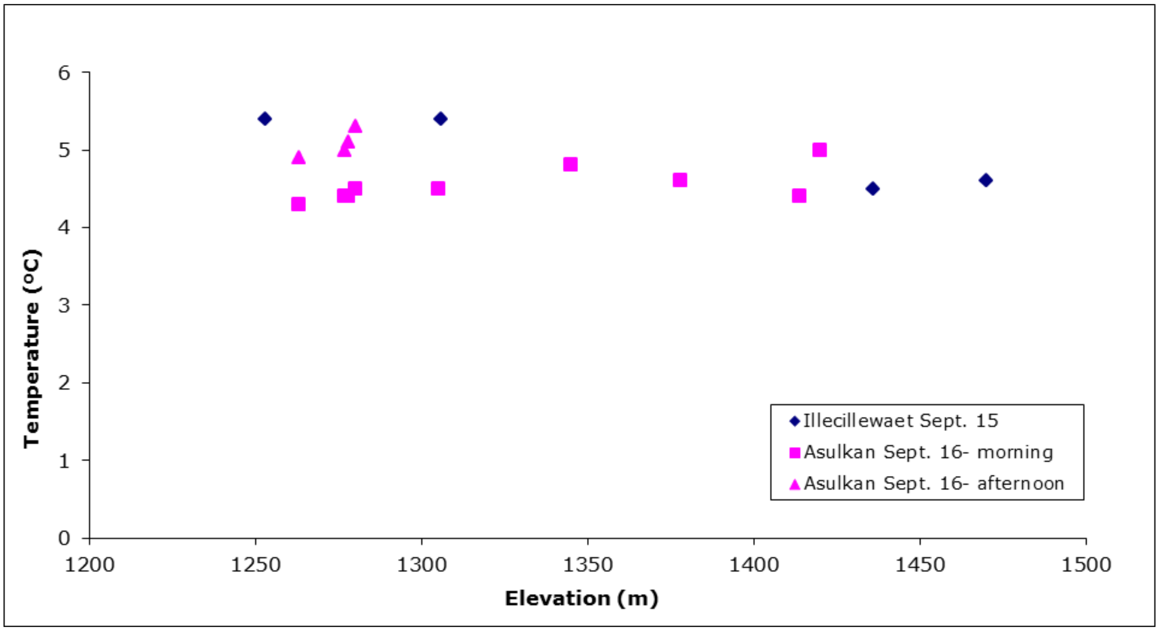


**Figure 9.** Temperatures of the Asulkan Brook and Illecillewaet River at various elevations.

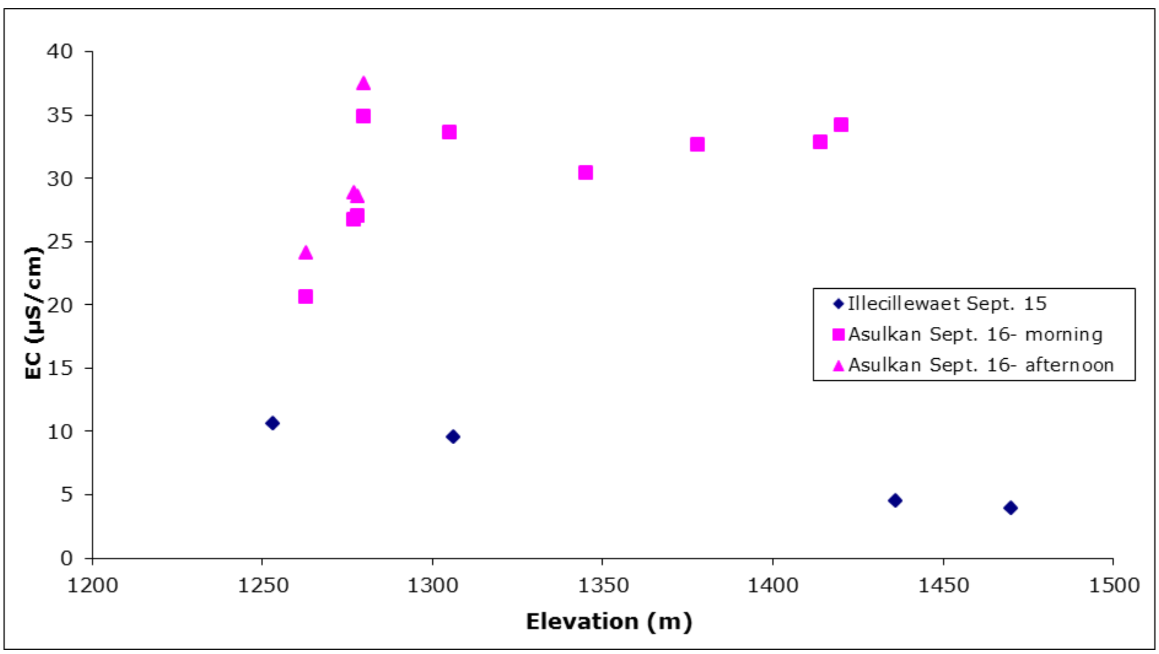


**Figure 10.** Electrical conductivity measurements of the Asulkan Brook and Illecillewaet River at various elevations.

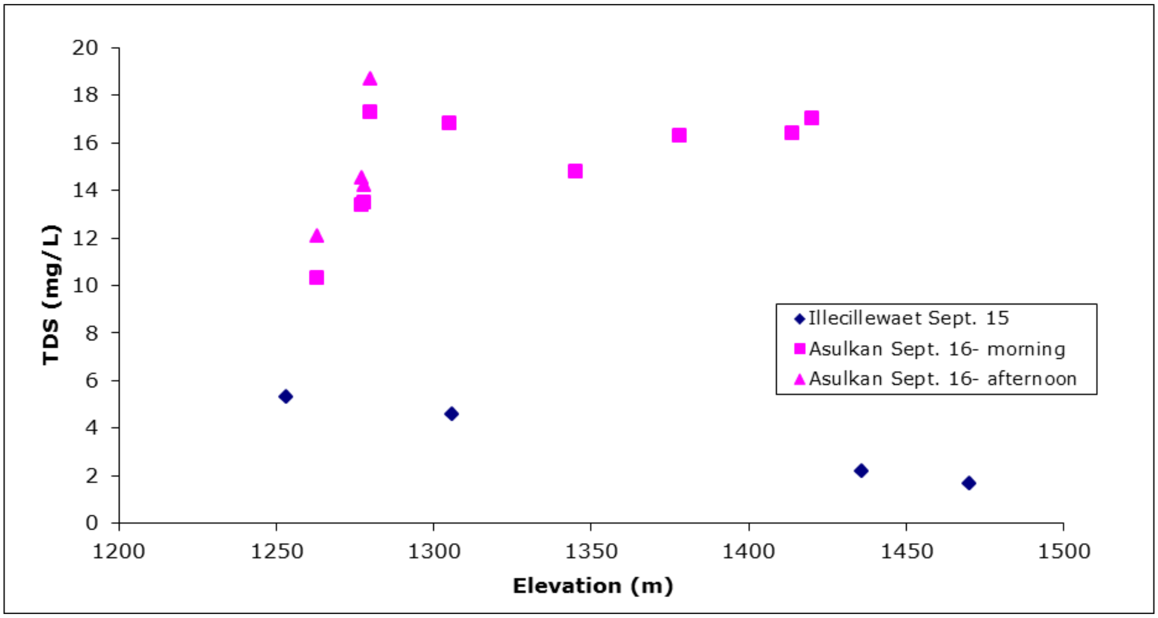


**Figure 11.** Total dissolved solids levels in the Asulkan Brook and Illecillewaet River at various elevations.

# 5 Discussion

## 5.1 Interpretation of Results

The objective of this study was to measure changes in temperature, TDS, and EC of the Illecillewaet River and the Asulkan Brook moving downstream from their respective glaciers. Resulting trends are compared with those identified in the literature. Explaining these trends will hopefully aid in understanding the hydrological, glacial, and ecological impacts on water quality in Glacial National Park.

Temperature was measured as an indicator of local glacier conditions and weathering capabilities. Temperature is a controlling factor in chemical and physical weathering processes, possibly making it useful for explaining TDS and EC measurements. Temperatures of both the Illecillewaet River and Asulkan Brook remain relatively constant at approximately 5 °C (Figure ). Based on past studies, it was expected that stream temperatures would increase with distance from the glaciers (Moore et al., 2009). The absence of a distinct warming trend in this study's results may be an indication that the data points were not covering a large enough area to see a clear relationship between temperature and distance. This relationship, however, could be inferred by the difference in average temperatures between the Illecillewaet and the Asulkan. The Asulkan, which exhibited warmer temperatures than the Illecillewaet, covers a greater distance between its respective glacier and the Meeting of the Waters and may exemplify how temperature gradually increases over greater distances. Another explanation for the warmer Asulkan Brook can be related to its higher electrical conductivity and potentially higher thermal conductivity (Figure 10; Brown et al., 2011).

The results exhibit an abrupt change in temperatures at approximately 1300 m elevation which is where the Meeting of the Waters is located. As the Illecillewaet waters mix with the warmer Asulkan waters, water temperatures on the Illecillewaet side of the junction increased. Conversely, the Asulkan Brook temperatures are slightly warmer upstream of the junction and decrease upon meeting the colder Illecillewaet waters.

Electrical conductivity and total dissolved solids were measured in order to analyze and compare the water chemistry of the two streams. The results in Figure show that despite small fluctuations, EC values of the Asulkan Brook remained fairly consistent with elevation before meeting with the Illecillewaet. On the other hand, EC levels increased slightly downstream from the Illecillewaet Glacier. An abrupt change is apparent at approximately 1300 m where the Asulkan and Illecillewaet meet and mixing of the waters occurs. A similar trend is apparent in the TDS results in Figure 11 because TDS is linearly proportional to EC.

An increasing trend in EC and TDS with distance from the glacier was hypothesized for both the Asulkan Brook and Illecillewaet River. Factors contributing to a downstream increase in EC and TDS include: contact time between streamwater and channel lithology leading to chemical weathering processes; biological activity; and influxes of highly conductive groundwater through feeding tributaries (Moore et al., 2009; Sueker et al., 2001; Webb et al., 2003; Weiner, 2008; Williams et al., 2001).

An increase in EC and TDS with distance from the glaciers was apparent in the Asulkan Brook but not the Illecillewaet. This suggests that at our study sites, chemical weathering processes play a larger role in providing dissolved solids in the Illecillewaet River than they do in the Asulkan. Lithology is a main determinant for which chemical processes occur along a stream's length. It can be inferred from the results that the lithology between the Illecillewaet and Asulkan are different and that a potentially less resistant geology of the Illecillewaet channel bed makes it more susceptible to chemical weathering processes.

Another stark difference between the two water channels is that EC and TDS values on a whole were much higher for the Asulkan Brook than for the Illecillewaet River. Just upon qualitative observation, it was noted that the Asulkan Brook carried more suspended solids than the Illecillewaet (Figure 12); this difference was reflected in the quantitative analysis of the water chemistry between the two channels. Different glacier conditions could be one possible reason for this variation. As stated by Moore et al. (2009), larger glaciers are associated with increased basal erosion, providing more physical and chemical weathering products to the meltwater; however, the fact that the Asulkan Glacier is much smaller than the Illecillewaet challenges this argument. Other conditions at the glaciers such as soil development, erodibility, rock type and topography may instead account for these differences (Sueker et al., 2001).

**Figure 12.** The Meeting of the Waters, where the murky, brown Asulkan waters mix with the clearer waters of the Illecillewaet.

Another reason why the values for the Asulkan Brook were so much higher could be because it travels a greater distance from the Asulkan Glacier to the Meeting of the Waters than the Illecillewaet River from its respective glacier. Therefore, by the time the streamwater has reached the sampling sites for this study, it has already facilitated a considerable amount of weathering and has thus received more ions and dissolved solids.

A third possible explanation for high EC and TDS values in the Asulkan Brook could be that there were lithological differences and therefore different weathering processes occurring upstream from the study sites (Weiner, 2008). The Illecillewaet River TDS readings never exceeded 30 mg/L whereas those taken from the Asulkan Brook were generally 30-40 mg/L. According to Weiner (2008), TDS below 30 mg/L are characteristic of resistant lithologies; this suggests that the upstream lithology of the Illecillewaet is more resistant than the Asulkan.

While there are numerous possible factors that may affect water chemistry, it is difficult to determine what exactly is responsible for the variations between the Asulkan Brook and Illecillewaet River without further studies.

## 5.2 Future Implications

Stream properties are indicative of the processes occurring in an alpine environment. Moore et al. (2009) concluded that increased glacier retreat results in an increase in stream temperature, transient increases in suspended sediment and stream concentrations, and a change in overall water chemistry. Consequentially, this leads to implications for water management as a resource as well as hydroecology (Moore et al., 2009). Results linking sediment load to erosion processes associated with glacial shrinkage suggest the potential effect of future glacial changes on channel morphology and water quality (Moore et al., 2009).

Specific impacts of glacier retreat include: decline in stream flow, increase in stream temperature; increase in concentration of organic matter; changes in concentration of nutrients in stream water; increased hazards such a mass movement and outburst floods; and changes in suspended sediment load (Moore et al., 2009). Moore et al. (2009) noted that there is a lack of historical water quality records in Western North America; it is therefore difficult to analyze the effects of historic glacier change in order to make accurate inferences of how water quality will be affected in the future. The research that was conducted on the Illecillewaet River and the Asulkan Brook has the potential to add to these water quality records and help understand change in water quality as a result of environmental change.

In addition to water quality and management, Webb et al. (2003) indicated that understanding the role of solutes in watersheds is key for effective environmental management. Evaluating the current state of a watershed and understanding the forecasted climatology allows for the accurate prediction of solute deposition as well as the impacts of natural and anthropogenic stressors on the existing equilibrium (Webb et al., 2003).

Webb et al. (2003) noted concern over the scarcity of pristine waters with increased development in close proximity to remote headwaters. Similar ideas on water and environment management can be applied to Glacier National Park, specifically around the Illecillewaet River and Asulkan Brook, as the number of park visitors increases. Although the park has been established to protect and preserve the natural environment, developments and increased visitor access have consequences on the surrounding environment and watershed. For example, an Alpine Club of Canada Hut is located near the Asulkan Glacier and a public campground with joining facilities is located near the Meeting of the Waters. In addition, the trails are often in close proximity to both the Illecillewaet River and the Asulkan Brooke. Reducing erosion from trails is important for mitigating sediment load in stream water (Figure 13).

**Figure 13.** Trail in close proximity to the Asulkan Brook.

The implications of this study and its significance for water resource and environmental management indicate that understanding current hydrology is crucial for understanding systems as a whole. Glacier National Park would benefit from increased conservation and land management, as well as Parks Canada trail rebuilding, maintenance, educational programs, and visitor regulations. This research study emphasizes the importance of preserving the watershed and continuing hydrological studies on the Illecillewaet River, Asulkan Brook, and surrounding glaciers. Future actions may include the support for more funding directed towards maintenance, preservation, and upkeep of the Park and partnering research.

## 5.3 Limitations and Errors

One limitation to the study is that some key stream properties were not measured. Stream discharge is a key stream property and provides useful information about the hydrological and glacial conditions when used in conjunction with temperature, EC and TDS readings. It was not measured because of safety concerns and time constraints. Another property that was not measured was total suspended solids. Water samples were taken in hopes of analyzing suspended solids; however, lack of funding and booking time prevented the analysis of suspended load.

Data collection inconsistencies limited comparisons between the Illecillewaet and Asulkan. For example, not selecting study sites at equal or systematic intervals due to inaccessibility resulted in the inability to perform comparative qualitative spatial or temporal analysis. In addition, having only two days to collect data did not give an accurate representation of the true long-term stream characteristics. Taking measurements over a longer period of time would have been useful to see trends and identify causes of differences. Moreover, measurements for the Illecillewaet and Asulkan were taken on different days at different times which could introduce uncertainties when comparing the two streams.

Malfunctioning or inadequate equipment was a source for systematic errors. On the first day of data collection, the Garmin GPSmap 76CSx unit was not working properly; as a result, elevation was not recorded for the sample sites on the first day. The GPS unit on the first day was only accurate within ± 3-10 m and on the second day it varied throughout the day between ± 6-30 m. Another technical limitation was the length of the length of the cord on the HACH conductivity meter which, along with high stream velocities, prevented us from holding the probe still during measurements. Due to inaccessibility to the river and the short cord, most of the readings were less than 1 m off the shoreline and may not have been characteristic of the whole body of water.

# 6 Conclusion

Three stream parameters were studied along the Asulkan Brook and Illecillewaet River: temperature, EC and TDS. Contrary to results from previous studies, temperature remained relatively constant with distance from the glaciers. This may be because the study area did not cover the stream distance required to observe any noticeable temperature changes. In the Asulkan Brook, EC and TDS remained more or less steady while values for the Illecillewaet River increased gradually downstream. In addition, TDS and EC for the Asulkan were considerably higher than for the Illecillewaet. These results suggest that the bulk of the dissolved solids in the Asulkan were added to the streamwater further upstream; by which means, and whether glacier conditions play a role, remains unclear. It appears that these processes are different for the Illecillewaet River, which, at the study sites, was less contaminated; the downstream increase in EC and TDS indicates weathering processes as a source for dissolved ions. Additional studies are required to further investigate the different factors affecting hydrological characteristics. A better understanding of how water quality is affected by natural and anthropogenic factors is critical for regulating and protecting invaluable water resources.

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# 8 References


Achuff, P.L., Holland, W.D., Coen, G.M., Van Tighem, K. (1984). *Ecological land classification of Mount Revelstoke and Glacier National Parks, British Columbia*. Alberta Institute of Pedology, University of Alberta, Edmnton; Canadian Wildlife Service and Canadian Forestry Service, Environment Canada.

Bivouac (n.d.). Selkirk Mountains: Selkirks. Retrieved November 4, 2011, from Bivouac: http://bivouac.com/ArxPg.asp?ArxId=1359.

Brown, T.E., LeMay, H.E., Bursten, B.E., Murphy, C., Woodward, P. (2011). *Chemistry: The Central Science, 12th Ed*. Prentice Hall.

Davie, T. (2002). *Fundamentals of Hydrology, 2nd Ed.* Routledge.

Delparte, D., Jamieson, B., Waters, N. (2008). Statistical run-out modeling of snow avalanches using GIS in Glacier National Park, Canada. *Cold Regions Science and Technology* 54(3) 183-192. doi: 10.1016/j.coldregions.2008.07.006.

Department of Justice (2011). Canada National Parks Act: National Parks of Canada: Glacier National Park of Canada. Retrieved November 4, 2011, from Department of Justice Canada: http://laws-lois.justice.gc.ca/eng/acts/N-14.01/page-20.html#h-19.

Downs, A. (Editor) (1980). *Incredible Rogers Pass.* Frontier Books: Surrey, British Columbia.

Google (2011). Google Maps. Retrieved December 7, 2011, from Google: http://maps.google.ca/maps?hl=en&tab=wl

Great Canadian Parks (2007). Glacier National Park. Retrieved November 30, 2011, from Great Canadian Parks: http://www.greatcanadianparks.com/bcolumbia/glacinp/index.htm.

Green, W.S. (1889). Explorations in the glacier regions of the Selkirk Range, British Columbia, in 1888. *Proceedings of the Royal Geographical Society* 11, 153-170.

Health Canada (1991). Total dissolved solids (TDS). Retrieved November 2011, from: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/tds-mdt/index-eng.php

Hulio (2011). Summit Post: Selkirk's: Glacier Crest. Retrieved November 4, 2011, from Summit Post: http://www.summitpost.org/glacier-crest/749887.

Kadlec, R. H., Wallace, S. (2009). *Treatment Wetlands, 2nd Ed.* CRC Press.

McCleave, J.M.; (2008). The Regional Integration of Protected Areas: A Study of Canada's National Parks. [Unpublished PhD dissertation] University of Waterloo, Waterloo, Ontario. 198-229.

Moore, R. D., Fleming, B. M., Wheate, R., Fountain, A., Stahl, K., Holm, K., Jakob, M. (2009). Glacier change in western North America: influences on hydrology, geomorphic hazards and water quality. *Hydrological Processes* 23, 42-61.

Morris, M. (2002). Glaciers, lichens, and the history of the Earth. Retrieved November 4, 2011, from http://www.cmiae.org/Resources/glaciers-lichens.php.

Parks Canada (2011). Glacier National Park of Canada: Weather and Climate. Retrieved November 3, 2011, from Parks Canada: http://www.pc.gc.ca/eng/pn-np/bc/glacier/visit/visit4.aspx.

Pinay, B., Burt, T.P. (2005). Linking hydrology and biogeochemistry in complex landscapes. *Progress in Physical Geography*, 29(3) 297-316.

Planet Ware (2011). Glacier National Park Map. Retrieved December 7, 2011, from Planet Ware Inc. Website: http://www.planetware.com/map/glacier-national-park-map-cdn-cdn228.htm

Raghunath, H.M. (2006). *Hydrology: Principles, Analysis, Design, 2nd Ed.* New Age International Publishers: New Delhi.

Ritter, D.F., Kochel, C.R. Miller, J.R. (2002). *Process Geomorphology, 4th Ed.* Waveland Press, Inc.: Long Grove, Illinois.

Schaerer, P.A. (1972). Terrain and vegetation of snow avalanche sites at Rogers Pass, British Columbia. In: *Mountain Geomorphology: Geomorphological Process in the Canadian Cordillera.* Slaymaker, O. (Editor). McPherson, H.J. Tantalus Research Ltd: Vancouver.

Shangaan Webservices (2011). Roger's Pass. Retrieved November 12, 2011, from Vancouver Island: http://vancouverisland.com/regions/towns/?townid=3496.

Singh, T., Kalra, Y. P. (1984). Predicting solute yields in the natural waters of a subalpine system in Alberta, Canada. *Arctic and Alpine Research* 16(2), 217-224.

Srinivas, T. 2008. *Environmental Biotechnology*. New Age International Publishers.

Sueker, J. K., Clow, D. W., Ryan, J. N., Jarrett, R. D. (2001). Effect of basin physical characteristics on solute fluxes in nine alpine/subalpine basins, Colorado, USA. *Hydrological Processes* 15, 2749-2769.

Summitpost (2010). Glacier Crest. Retrieved December 7, 2011, from Summitpost: http://www.summitpost.org/glacier-crest/749887.

The Weather Network (2011). Statistics: Glacier NP/Rogers Pass, BC, Canada. Retrieved November 2011, from The Weather Network: http://www.theweathernetwork.com/statistics/cl1173191.

Trenhaile, A.S. (2004). *Geomorphology: A Canadian Perspective, 2nd Ed.* Oxford University Press: Don Mills.

Vaux Jr., G.; and Vaux Jr. W.S. (1899). Some observations on the Illecillewaet and Asulkan Glaciers of British Columbia. *Proceedings of the Academy of Natural Sciences of Philadelphia* 51(1), 121-124.

Webb, R.M.T., Peters, N.J., Aulenbach, B.T., Shanley, J.B. (2003). Relations between hydrology and solute fluxes at the five water, energy, and biogeochemical budget (WEBB) watersheds of the United States Geological Survey: [in] Renard, Kenneth G., McElroy, Stephen A., Gburek, William J., Canfield,H. Evan and Scott, Russell L. (2003). *First Interagency Conference on Research in the Watersheds.* U.S. Department of Agriculture, Agricultural Research Service, 332-339.

Weiner, E.R (2008). *Applications of Environmental Aquatic Chemistry: A Practical Guide, 2nd Ed*. CRC Press: Boca Raton.

Wheeler, A.O.; and Parker, E. (1912). *The Selkirk Mountains: A Guide for Mountain Climbers and Pilgrims.* Stovel Company: Winnipeg.

Wikipedia (2006). Map of Selkirk Mountains. Retrieved December 7, 2011, from Wikipedia: http://en.wikipedia.org/wiki/File:South_BC-NW_USArelief_Selkirks .png#filelinks

Williams, M.R, Leydecker, A., Brown, A.D., Melack, J.M. (2001). Processes regulating the solute concentrations of snowmelt runoff in two subalpine catchments of the Sierra Nevada, California. *Water Resources Research* 37(7), 1993-2008.