# Hazardous Hydrology: Developing a Monitoring Program for the Garibaldi Lake/Rubble Creek Hydrological System, British Colombia

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Abstract:

Garibaldi Lake is located in a valley north of Squamish, BC above highway 99. This alpine lake is held in by an archetypically unstable ice-contact volcanic deposit, The Barrier. Springing from the base of The Barrier is Rubble Creek, which is assumed to be the primary outflow from the lake (besides a seasonal overflow stream). Very little is known about the dynamics of this hydrological system, hence I propose to design a monitoring system for Garibaldi Lake to measure the lake level as well as inputs and outputs of the system. Data collected from the monitoring will serve as primary inputs into a hydrodynamic model for the Garibaldi Lake-Barrier-Rubble Creek system. The goal of this will be to determine the water balance for the system. In other words, is all water entering the lake eventually flowing out from underneath The Barrier? If not, where does the water go and why? This project is of significant academic interest to me and, fortunately, it will work symbiotically with Steve Quane's research assessing the bathymetry of Garibaldi Lake.

Introduction:

During the Pleistocene epoch the land around Garibaldi Park was covered by the Cordilleran Ice Sheet (Clague, J., Ward, B., 2012). These massive traveling ice forms sculpted valleys and waterfalls as they moved. About 11,000 years ago the combination of both valley and mountain glacier retreat resulted in an ice free window between 1000m and 1500m elevation (Mathews, W.H., 1952). An eruption from Clinker Peak caused a lava flow which collided with the remnant valley glacier. The flow solidified in a wall against the glacier, forming the geological phenomenon we call The Barrier. The Barrier acts as a dam in the valley, allowing run off water to collect behind it and form Garibaldi Lake.

Garibaldi Lake is composed of a combination of glacial run off from eastern Sphinx and Sentinel Glaciers and small mountain streams. These small mountain run offs arise mostly from precipitation and snow melt. Lake water input/output locations are outlined on Figure 1. Rubble Creek, located to the west of Garibaldi Lake is the main output of this alpine lake hydrological system, however there is also a seasonal overflow output on the western bank of Garibaldi Lake that flows into Lesser Garibaldi and Barrier lakes.

Additionally, Garibaldi Lake is held in only by the notoriously unstable ice-contact volcanic deposit, The Barrier. Increased water input (either from increased precipitation or glacial melt), would theoretically increase the output at Rubble Creek, thus increasing the pressure on this system, and risk of The Barrier collapsing.

Rubble Creek springs from the base of The Barrier and flows directly into the Cheakamus River (under highway 99). It has an average flow rate between 2 and 4 $cm^3/s$ (Quane, S.L. and Stockwell, J. 2014), which theoretically, would be equivalent to input to Garibaldi Lake from both glacial streams and precipitation run off minus any evaporation, if the lake level stays constant. However, very little is actually known about this incredibly interesting and important hydrological system. For example, does all water entering the lake eventually flow out from underneath The Barrier? Is the measurable water flowing out from the base of The Barrier equivalent to the water input into the system? To investigate this I propose to design a monitoring program for the Garibaldi Lake/Rubble Creek hydrological system. The objective of this monitoring system will be to answer the above questions which provide information on water levels and associated risks from Barrier stability. This will entail modeling the hydrodynamics including precipitation, glacial run off, evaporation, Rubble Creek discharge and absolute lake level.

Designing and implementing a monitoring system is a technical, logistical and scientific challenge. Because of the significant time requirement, this project would be divided into two stages; design and implementation.

Stage 1: Design of Montioring Program

Determination of the most efficient and effective modeling and measurement techniques and their locations will encompass the first component of this project. An individual monitoring method will need to be determined for each component of the model, including the discharge of Rubble Creek, glacial run off, input from small streams and the volume of Garibaldi Lake.

Rubble Creek Assessment:

Discharge can be calculated using two different methods. First, one can use a flow meter to measure the velocity of the water, and multiply that by the cross sectional area of the creek to achieve volumetric discharge (United States Geological Survey, 2014). A secondary technique known as salt dilution method can be used due to the small size and rocky nature of Rubble Creek. In this method a tracer, usually salt, is injected (either as a salt 'slug' or streamed in constantly) at a set point on the creek. The concentration is then measured at a point downstream using a conductivity meter (owned by Quest) where the salt will be fully, uniformly mixed into the water (Moore, 2003). Location for Rubble Creek measurement would need to be as close to the base of the barrier as possible so the volume is not affected by influences outside the system. The average glacial input from Sphinx Bay and Sentinel Bay can be established in a similar way.

Small Mountain Stream Assessment:

Multiple streams enter the north bank of Garibaldi Lake from Gentian Pass and Panorama Ridge. This inflow can be estimated using a weather station to quantify precipitation levels. A weather station is also necessary to approximate evaporation levels of lake water. Fortunately, Quest owns a portable weather station which will be deployed to the lake. In addition, Quest owns another weather station in the region at the same elevation (1400 m) as Garibaldi Lake (Tyler Heilman's Project). Comparing inflow volume, lake level and outflow volume will help determine the dynamics of this complex system.

Garibaldi Lake Assessment:

Fluctuations in lake volume would be a direct result of inflow/outflow dynamics. The average volume can be quantified by multiplying the average lake depth with the area, which would be established in correlation with Steve Quane's current research creating a bathymetric map of Garibaldi Lake. Quantifying fluctuations will require calculating from the fluxes in lake height through the use of a depth gauge (acquired through Steve Quane's research funds in collaboration with Lorax Environmental in Vancouver). Additionally, we can determine the absolute volume of the lake; at a certain point the lake level will stop rising as it begins to flow over the barrier, forming an additional outflow location. Location for water level measurement system would need to be in a sheltered area so as to not be disturbed by weather, in a relatively shallow area for ease of set up and be easily accessible (on the western coast). Possible locations to be investigated include Price bay, Driftwood bay and the area around Battleship Islands.

Stage 2: Implementation of Monitoring Program

The second component of this project would entail the set up and execution of the designed monitoring system. Once locations have been established equipment will need to be set up and monitored regularly. Lake level gauge would be read at least once a week and within 24 hours of a substantial rainfall to determine the correlation between precipitation, lake levels and Rubble Creek output (Minnesota Department of Resources, 2007).

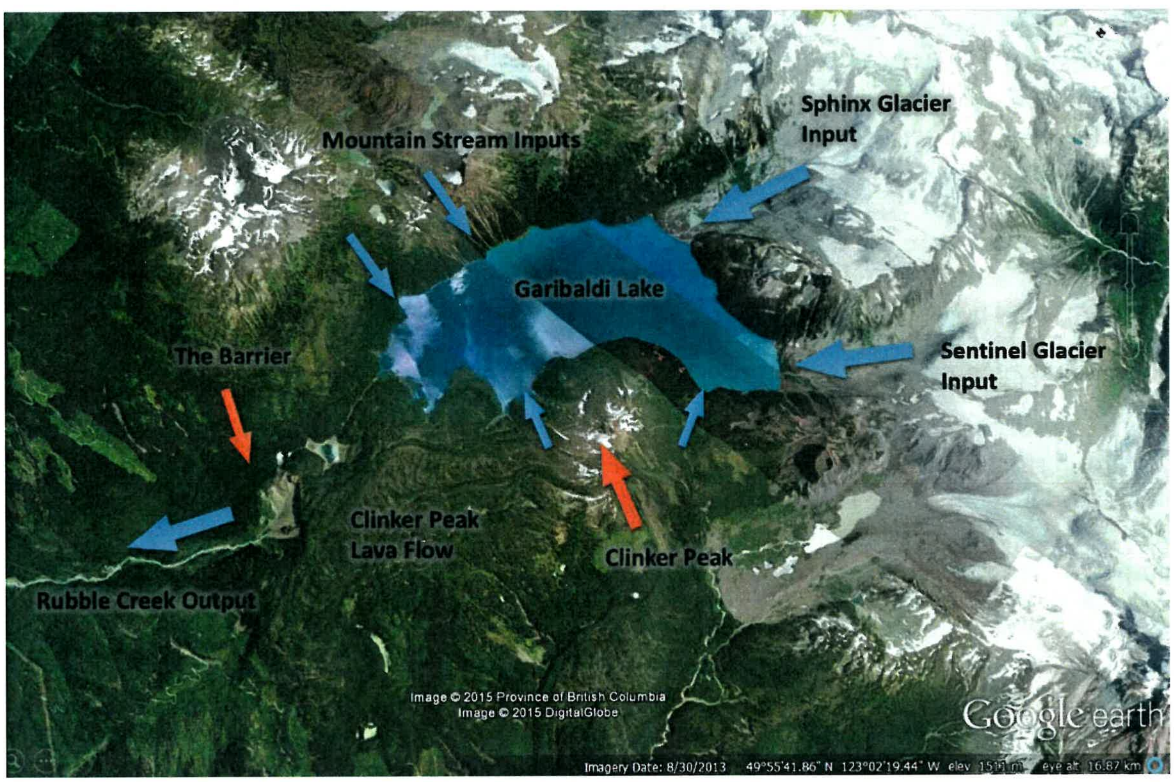
Several pieces of equipment would be necessary for this project, most of which are already in possession of Quest University Canada. In order to measure the salt dilution in Rubble Creek and calculate the discharge, access to a conductivity meter every 3-5 days would be necessary. Additionally a weather station would allow me to quantify precipitation and evaporation levels as they affect the volume of Garibaldi Lake. Salt and a fence post for the water level gauge can easily be obtained personally or in conjunction with Steve Quane for minimal financial investment.

Exploration of the study area and subsequent monitoring can be easily achieved via the on location motor boat and can be done in conjunction with other students/Steve as he conducts his research on Garibaldi Lake. Access to Rubble Creek is fairly easy as there is an established trail system nearby and current plans for construction of a direct path. Transportation around the lake has been previously established as an agreement between Quest University and BC Parks has granted access to a motor boat on location.

Conclusion:

Using data collected during Stage 2, a model will be created to compare the transfer of water throughout the system. From here we can extrapolate where and how the water is traveling, determining whether all water entering the lake will eventually flow out from underneath The Barrier and if the measurable water flowing out from the base of The Barrier equivalent to the measurable water flowing out.

Figure 1: Aerial view of Garibaldi Lake and surrounding geological features (49°55'N, 123°02'W) obtained from Google Earth (2015). Top right hand corner shows the magnetic orientation. On the eastern side, Sphinx and Sentinel Creeks are fed by their respective glaciers. Several kilometres to the west of Garibaldi Lake resides The Barrier and Rubble Creek. In between Garibaldi Lake and The Barrier reside Lesser Garibaldi Lake and Barrier Lake. Along the northern shore multiple mountain streams can be observed feeding into the lake from Gentian Pass, Panorama Ridge and Driftwood Bay. On the South shore small streams feed from Price Bay and Table Bay. Blue arrows indicate water flow direction. Orange arrows indicate specific features.



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