Assessing how the water quality of Alpine streams within the Borgne d'Arolla catchment varies with altitude through conductivity measurements

Student ID:38332264 [1]

Conductivity serves as a crucial parameter for evaluating the quality of aquatic environments. Alpine streams support diverse ecosystems and are often used for potable water, good water quality in Alpine streams is crucial for ecosystem and human health. Here we present an assessment of stream health through conductivity measurements within the Borgne d'Arolla catchment and the relationship between conductivity and altitude Our analysis revealed a significant correlation between altitude and stream conductivity. However, it's important to note that numerous other factors, such as the water's origin and its course through the landscape, also influence conductivity and overall stream health. Hydroelectric installations within the Borgne d'Arolla catchment also have effects on the conductivity and other factors associated with hydrological installations such as turbidity and flow rates can have effects on biodiversity within Alpine streams.

Alpine streams are often pristine freshwater ecosystems however increased global climate change is occurring at higher altitudes, above the permanent treeline in Alpine environments[1]. Alpine ecosystems are especially vulnerable due to the combined effects of high mountaintop insularity and upslope shifts of distributional ranges into smaller areas of habitat [2]. Alpine snowfields and glaciers are also retreating significantly, causing hydrological shifts in existing streams and the creation of new streams where there was previously perennial ice[3].

Alpine streams are often very unique and streams within the same catchment can have high variations in temperature, sediment load and chemistry[4]. This leads to alpine streams having high beta diversity in terms of genetic and species diversity. Many species within alpine streams are specially adapted to cold, harsh environments and they are often endemic[5]. Understanding the health of Alpine streams and how conditions such as altitude and geology affect them is crucial for further research and understanding into how we can protect them from the various effects of climate change that these delicate ecosystems experience.

Conductivity has been shown to be a reliable indicator of stream health. Studies have shown that among physical and chemical measurements, specific conductivity best distinguished between waterways that scored a good or excellent on biological index scores compared to waterways that scored poorly[6] . Specific conductivity is a measure of the capacity of water to conduct electricity making it a useful way to estimate the total dissolved ionic species in solution. Specific conductivity can vary with the composition of the dissolved ions and hence only approximates the total dissolved ion concentration[7].

The lithology of the region is varied, the bottom of the upper valley around Arolla town is dominated by clay, silts and sabbie, moving down the valley towards Les Haudères, it is dominated by basic rocks and marly shales and calcareous phyllites. The highest altitudes of the valley are dominated by granites and syenites[8].

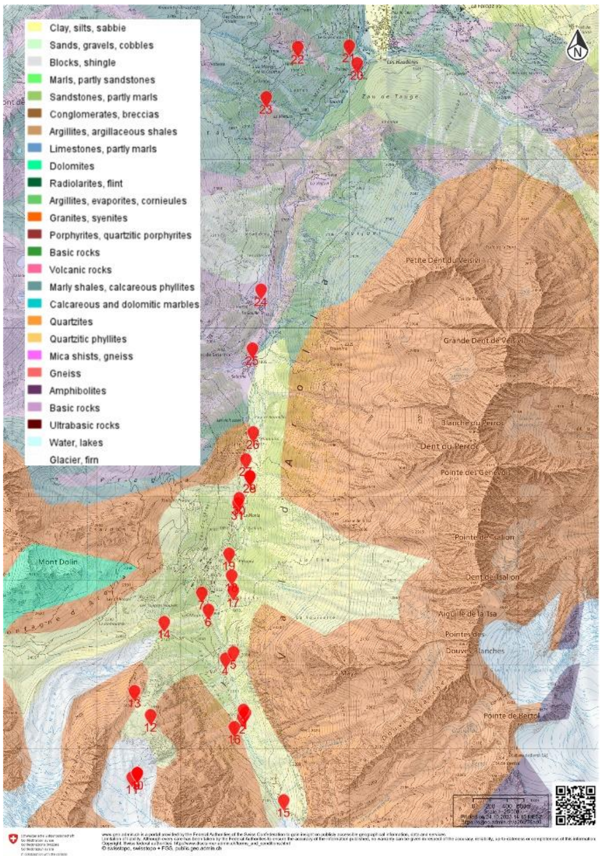

Figure 1 | The lithology of the study area including the locations of each study site.
Lithology data and map provided by map.geo.admin.ch[8]

[1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YW, UK.

Over five days, 31 sites at different altitudes across the Borgne d'Arolla catchment were studied. Sites were chosen based on their accessibility and altitude. The GPS location of each site was determined using What Three Words[9] and measurements of conductivity and water temperature were taken along a cross section of each stream. Air temperature and time of day were also recorded, the width of each stream was measured, or estimated where precise measurement was not safe or possible. The altitude of each site was later obtained using the longitude and latitude and dcode.fr[10].

A Pearsons corelation was used to assess the relationship between altitude, mean temperature and mean conductivity. Results showed a significant ($R = -0.706$, $p < 0.001$) negative linear relationship between the mean conductivity at each site and altitude. No significant relationship was found between the mean conductivity and mean temperature ($R = 0.279$, $p = 0.128$) however a significant negative linear relationship was found between the mean temperature and altitude ($R = -0.578$, $p < 0.001$).

Sites were located between altitudes of 1450 and 2758 m and mean conductivity results were between 3.6 and 300.6 µS/cm. Temperature ranged between 15.0 and 0.5 ° C. The site with the highest altitude of 2758 m, Site 11, also had the lowest conductivity and temperature, this site was a stream directly on the Glacier de Pièce, it also had one of the smallest widths at 0.4 m. The majority of sites were located between 2200 and 1800 m with just 9 of 31 sites outside of this range. The lowest site was on the outskirts of Les Hauderes, at 1450m, located on the main channel of the Borgne d'Arolla and had a mean conductivity of 189.9 µS/cm. In total, five sites were located on the Borgne d'Arolla and the remaining 25 sites were located on 18 different tributaries to the Borgne d'Arolla. Sites 8, 9 and 10 were all located at the base of the Glacier de Pièce as two visibly distinct main flows were emerging from the glacier in one place. The conductivity here ranged from 6.36 to 63.57 µS/cm across the cross section of Site 10. Sites 21 and 22 were located on the same tributary with approximately 300m difference in altitude, mean conductivity increased from 224.8 to 226.6 µS/cm across this 300m difference and this was shown to be significant through an independent samples t-test which returned a p value <0.001. Sites 14 and 6 also lay on the same tributary with approximately 150m difference in altitude. There was a mean conductivity increase of 48 µS/cm between these sites.

Table 1 | The altitude, longitude and latitude, mean conductivity, mean water temperature, stream width and air temperature at each site. *The stream was approximately 10 m wide however measurements were only taken across a 5 m cross section for safety reasons.

Site	Mean Conductivity µS/cm	Mean Water Temp. ° C	Altitude m	Longitude	Latitude	Stream Width m	Air Temp. ° C
1	74.35	12.0	2022	7.487169	46.009287	1.9	26
2	111.56	11.5	2027	7.486778	46.0088	0.7	25
3	73.65	11.1	2028	7.486894	46.009554	2.9	27
4	60.68	14.0	2018	7.484215	46.015052	0.6	32
5	30.63	15.0	2014	7.485341	46.015699	0.2	27
6	110.51	12.0	1979	7.481535	46.020254	1.3	21
7	229.19	8.9	1989	7.480526	46.022087	1.5	19
8	46.85	0.9	2738	7.470662	46.00287	1.2	19
9	25.79	1.2	2738	7.470662	46.00287	1.1	19
10	30.32	0.6	2738	7.470662	46.00287	8.0	19
11	3.62	0.5	2758	7.469847	46.002385	0.4	19
12	51.57	9.8	2528	7.472643	46.008988	0.4	23
13	22.83	8.5	2504	7.470196	46.011603	2.8	24
14	62.51	3.6	2132	7.47474	46.01896	10 (5)*	14
15	45.43	6.7	2124	7.493075	45.999852	6.0	20
16	273.50	12.1	2052	7.485496	46.007748	1.1	20
17	144.43	8.5	1965	7.485302	46.022302	0.3	23
18	187.17	7.2	1934	7.485108	46.023892	3.0	26
19	118.97	12.8	1930	7.484681	46.026264	2.2	22
20	189.90	8.9	1450	7.504412	46.07863	7.0	12
21	226.57	12.0	1480	7.503168	46.080517	1.3	17
22	224.80	11.4	1770	7.495278	46.080355	2.0	14
23	300.63	10.9	1800	7.490458	46.074992	0.4	16
24	230.68	5.5	1840	7.489642	46.054455	0.6	15
25	210.98	7.8	1810	7.48832	46.048175	1.8	17
26	134.16	6.9	1840	7.48837	46.039201	1.6	12
27	81.65	6.2	1854	7.487321	46.036317	2.8	14
28	191.05	5.8	1883	7.487865	46.034511	0.6	14
29	245.22	5.8	1873	7.487943	46.034457	0.6	15
30	168.77	9.0	1883	7.486273	46.032193	1.2	17
31	149.77	7.5	1889	7.486079	46.0316	0.7	18

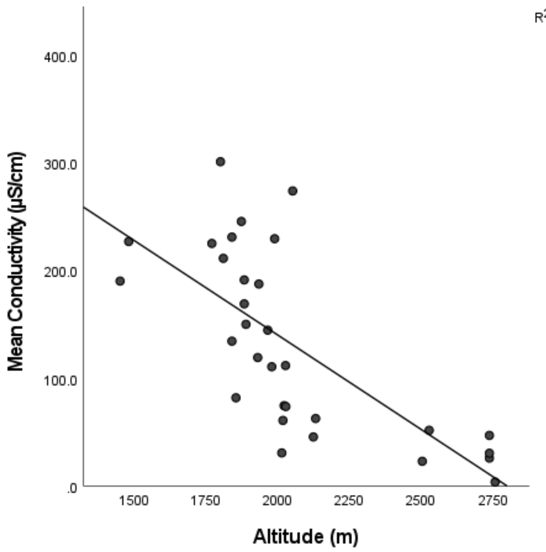

Figure 2 | Comparing the mean values of conductivity for each site with altitude.

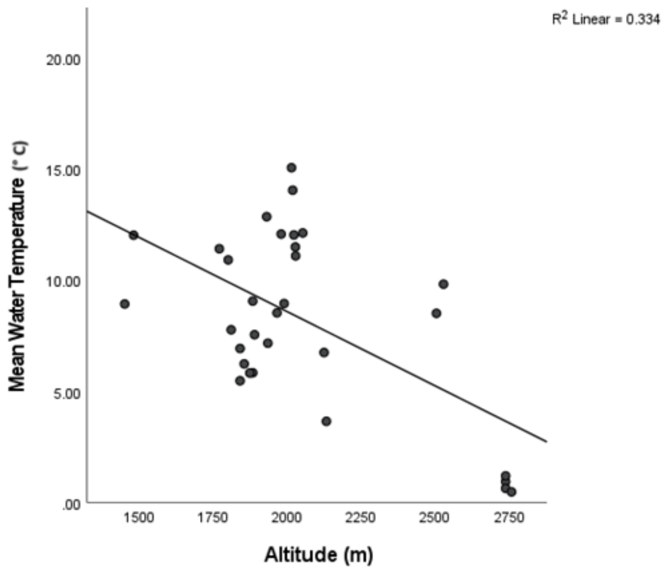

Figure 3 | Comparing the mean water temperature for each site with altitude.

This study revealed a significant relationship between Alpine stream conductivity, altitude and various other factors within the Borgne d'Arolla catchment. These findings contribute to existing knowledge on the complex dynamics of Alpine stream health in high-altitude environments. As altitude decreased, conductivity increased, this was expected due to a number of factors.

Conductivity in freshwater is generally influenced by the concentration of dissolved solids and ions[11.] At higher altitudes in alpine environments, the sources of water such as glacial melt often have lower ion concentrations due to lower exposure to weathering processes, weathered rocks and minerals. At lower altitudes, streams receive inputs from a larger catchment with more time for chemical weathering, causing higher ion concentrations. The geological composition of the region could have also significantly impacted results. Higher altitude regions within the Borgne d'Arolla catchment are dominated by less reactive rock types including granite and synaites which produce water with lower ion concentrations[12]. At lower altitudes, the region is dominated by finer sediments, basic rocks, marly shales and calcareous phyllites, this creates water with higher ion concentrations and hence higher conductivity[12].

Hydrologically, at higher altitudes there is often less groundwater input leading to less mixing with water from deeper geological formations which can contribute ions to the water[13]. At lower altitudes, more extensive groundwater flow can introduce ions to the stream. In Alpine regions, glacial meltwater often contributes significantly to stream flow. Glacial meltwater is typically low in dissolved ions[14], this was seen at Sites 8,9,10 and especially 11 which had some of the lowest conductivity measurements and were located at the highest altitudes, just below or on the Glacier de Pièce.

Stream temperature was found to be significantly lower at higher altitudes, lower temperatures can slow down chemical reactions including ion dissolution, thus causing lower stream conductivity. Lower temperatures also influence the metabolic activity of aquatic organisms which can influence ion cycling and water quality. Human activity and agricultural land use at lower altitudes can also influence water quality. Cattle grazing can cause an influx of nitrogen, phosphorus and organic carbon, increasing bioactivity of streams and conductivity[15]. All of these above mentioned factors are likely to be responsible for the variations in conductivity within different streams and at different altitudes.

Results at Sites 14 and 6 were of particular interest as they were situated on the same stream but had significantly different results. The stream flowed approximately 1km between sites with an elevation difference of around 150m. Between sites a significant increase in conductivity was found. This is likely due to a combination of previously explained reasons. Figure 4 shows that just below Site 14 is a hydroelectric instillation designed to divert water to a reservoir in the adjacent valley. It's possible that this has also contributed to the observed increase in conductivity between Sites 14 and 6. Part of the river at Site 14 wasn't sampled as no safe access was available. It's also possible that this had some influence on the difference between conductivity at Site 6 and 14.

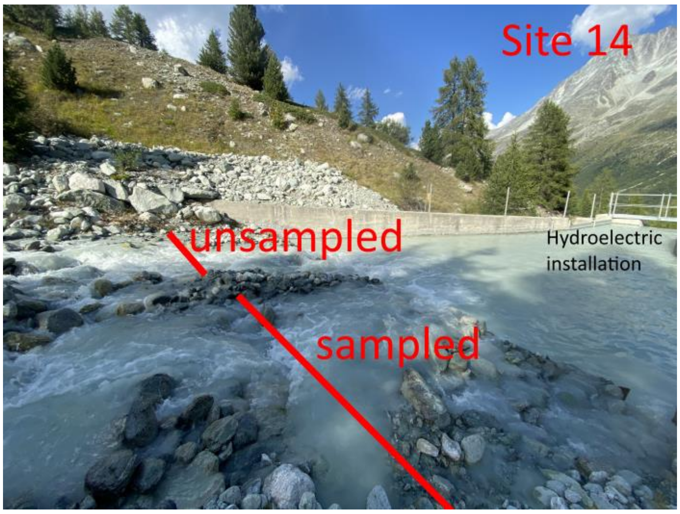

Figure 4 | A photograph showing the hydroelectric installation below site 14 and the widths of river which was sampled and not sampled due to safety concerns.

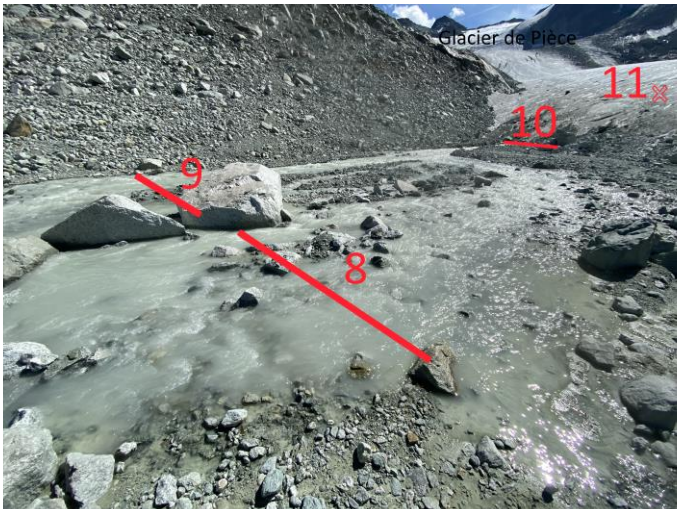

Figure 5 | A photograph showing the location of Sites 8,9,10 and 11.

Sites 8, 9 and 10 were also of significant interest due to their proximity to each other but different results. As shown in figure 5, Site 10 was a cross section across the main stream emerging from below the Glacier de Pièce. Sites 8 and 9 were around 20 meters downstream of Site 10 where the stream split in two around an island. The turbidity of the water was visibly different each side of the island. The conductivity significantly increased across the cross section of Sites 8, 9 and 10, it's believed that this is due to the mixing of two or more different sources of water.

It's possible that the side of the stream with the highest conductivity was from meltwater of a higher altitude which had flowed below the glacier for a longer period of time. This subsurface flow could be a reason for this increased conductivity because as the water flows through or over sub-glacial till, it may carry small particles in suspension, increasing the concentration of dissolved ions, and hence conductivity. The side of the stream with the lowest conductivity could be glacial melt which originates closer to the head of the glacier or has flowed through the glacier instead of underneath it. This would mean it had less or no time to flow beneath the glacier and would be in less contact with the subglacial till, decreasing the concentration of dissolved ions.

Site 23 had the highest mean conductivity of 300.63 µS/cm and sitting at an altitude of 1800 m, it was the fourth lowest site investigated. Site 23 was interesting as it was emerging from a small pipe next to a road as seen in Figure 6. It is likely that the stream in Site 23 originated from a high amount of subsurface flow as no stream was visible above the outflow. Also, it was raining on the day that measurements were taken at Site 23. It is possible that this stream is only present during periods of rainfall. The relatively small discharge of Site 23 means that it is unlikely to have a significant impact on the wider catchment but it may be a good example of how streams with a large amount of subsurface flow behave.

Five sample sites were chosen directly on the Borgne d'Arolla, the highest was Site 15 at an altitude of 2124 m and the lowest was site 20 at an altitude of 1450 m. Over an altitude difference of nearly 700 m, the conductivity increased from 45.43 to 189.90 µS/cm. Site 15 was situated just above a hydroelectric installation which diverts much of the streamflow. This could be part of the reason that the conductivity is so much higher at Site 20 as the diversion of water with low conductivity could mean that inputs from tributaries with high conductivity along the Borgne d'Arolla are less diluted and cause a greater increase in the mean conductivity of the river.

This research demonstrates the potential impacts that hydroelectric instillations may be having on the Borgne d'Arolla catchment and other similar catchments. The Val d'Arolla is similar to other valleys within this region so it's likely that the relationship observed in this research is similar within other Alpine valleys. By assessing the relationship between altitude and conductivity, the impacts of future climate change can be predicted. As temperatures rise, glaciers retreat and upslope shift increases Alpine environments will change. It's likely that rising temperatures and upslope shift will increase stream conductivity. Some specially adapted species may become extinct if they can't adapt quickly enough to changing temperatures and conditions.

This study contributes to the limited research into how the conductivity of alpine streams varies at high altitudes. The relationship between altitude and stream conductivity within alpine streams, specifically within the Borgne d'Arolla catchment hasn't yet been studied and this research adds to existing knowledge of alpine environments.

Due to the established relationship between stream conductivity and stream health, it could be concluded from this study that as altitude increases, so does stream health. This is a sweeping generalisation and hasn't necessarily been proven true for the complex alpine streams which have been studied here. Alpine streams are complex ecosystems and without further research into the relationship between stream health, altitude and conductivity within alpine streams we cannot necessarily say that alpine streams at higher altitudes are generally healthier. Full assessments of alpine stream health through kick sampling is necessary to determine if the relationship between conductivity and stream health is the same for Alpine streams.

Figure 6 | A photograph just above Site 23 showing the pipe from which the stream was emerging.

Acknowledgements

Work was supported by the students and staff of Lancaster University and the University of Lausanne

References

1. Bradley, R. S., Vuille, M., Diaz, H. F. & Vergara, W. (2006). Threats to water supplies in the tropical Andes. Science 312, 1755–1756.
2. Walther, G., Beissner, S. & Burga, C. (2005). Trends in the upward shift of alpine plants. Journal of Vegetation Science 16, 541–548.
3. Finn, D. S., Räsänen, K. & Robinson, C. T. (2010). Physical and biological changes to a lengthening stream gradient following a decade of rapid glacial recession. Global Change Biology 16, 3314–3326.
4. Ward, J. V. (1994). Ecology of alpine streams. Freshwater Biology 32, 277–294.
5. Muhlfeld, C. C., Giersch, J. J., Hauer, F. R., Pederson, G. T., Luikart, G., Peterson, D. P., Downs, C. C. & Fagre, D. B. (2011). Climate change links fate of glaciers and an endemic alpine invertebrate. Climatic Change 106, 337–345.*
6. Wenner, D., Ruhlman, M., & Eggert, S. (2003). The importance of specific conductivity for assessing Environmentally impacted streams
7. Hem, J.D., 1992. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water Supply Paper 2254. 263pp

8. Swiss Federal authorities. ND. https://map.geo.admin.ch/ Accessed 24.10.2023
9. what3words Ltd. ND https://what3words.com/ Accessed 10.09.2023 – 14.09.2023
10. GPS Elevation on dCode.fr ND https://www.dcode.fr/earth-elevation/ Accessed 10.09.2023 – 15.09.2023
11. Lindberg, T. T., Bernhardt, E. S., Bier, R., Helton, A. M., Merola, R. B., Vengosh, A., & Di Giulio, R. T. (2011). Cumulative impacts of mountaintop mining on an Appalachian watershed. Proceedings of the National Academy of Sciences of the United States of America, 108(52), 20929–20934.
12. Naganna, S.R., Deka, P.C., Ch, S. et al. (2017). Factors influencing streambed hydraulic conductivity and their implications on stream–aquifer interaction: a conceptual review. Environ Sci Pollut Res 24, 24765–24789.
13. Somers, LD, McKenzie, JM (2020). A review of groundwater in high mountain environments. WIREs Water. 0; 7:e1475.
14. Singh, V.B., Ramanathan, A., Sharma, P. et al. (2015) Dissolved ion chemistry and suspended sediment characteristics of meltwater draining from Chhota Shigri Glacier, western Himalaya, India. Arab J Geosci 8, 281–293
15. Rice, A.R. et al. (2021) “Fine-scale quantification of stream bank geomorphic volume loss caused by cattle access,” The Science of the total environment, 769, p. 144468.