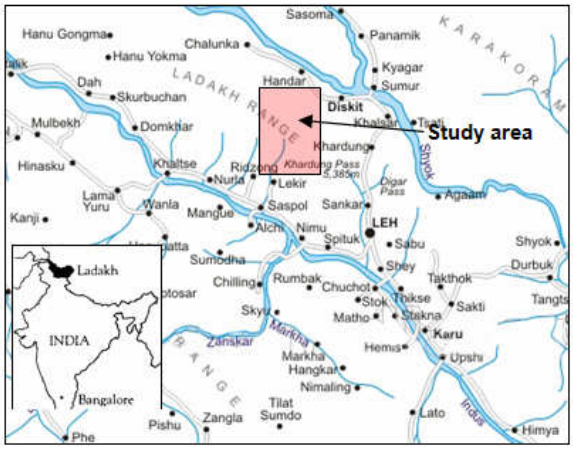
A study into the behaviour of glacier runoff with respect to weather and climate in the Nubra valley region of Ladakh

The most northern Indian state of Jammu and Kashmir contains the remote Himalayan region of Ladakh. It is a particularly arid environment with low levels of precipitation, meaning that the ecosystem is largely reliant upon glacial melt water as its primary water source. Any change in glacier extent could, therefore, significantly impact the water supply for the ecosystems in the area. This, coupled with the fact that very little is known about the glaciers there, particularly in the Nubra valley region of Ladakh, made it a very desirable area to study how fluctuations in glacier runoff are related to climatic variations. Three different glaciated catchments were studied, all within the Thanglasgo valley area, allowing us to also investigate whether different glacial morphology results in a different response to weather patterns.

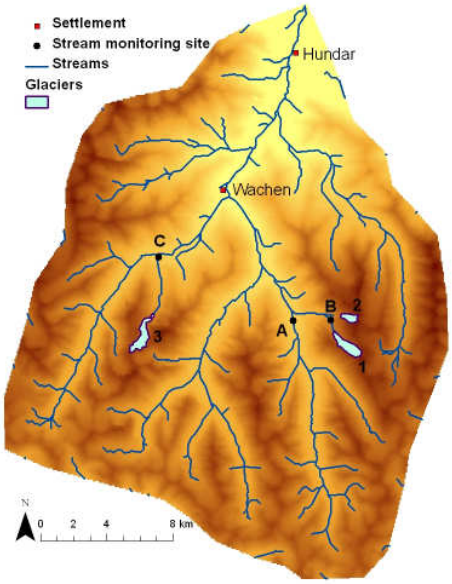


The expedition to study this area was run by The British schools Exploring Society (BSES). BSES are the leading youth development charity which runs scientific expeditions; they have been running expeditions to extreme wilderness environments across the globe since 1932 and collaborate with a wide range of leading scientific institutions to bring back data on a wide range of subjects. The Royal Meteorological Society lent the expedition two Kestrel 4000 weather stations which were used to collect weather data in the study area.

The five main objectives the expedition had for the study were: to measure discharges for two weeks in three glacially fed rivers; investigate how fluctuations in discharge relate to meteorological factors over daily and sub-daily timescales; to sample suspended sediment concentrations in each river in order to investigate

how sediment transport responds to changes in discharge; to use mapping and GIS analysis to study the characteristics of three glaciers and the feature of their pro glacial areas; to compare the discharge and suspended sediment characteristics of each catchment and use the mapping information to explain any differences observed between the catchments; and finally to use the results to suggest how discharge and suspended sediment yield in these catchments might respond to future climate change.

Measurements from the rivers were made of flow level, river depth, surface flow velocity and suspended sediment concentration. A range of meteorological variables were also measured, consisting of: temperature, humidity, wind speed, cloud cover and daily rainfall levels. The snouts and proglacial zones of glaciers 1 and 2 were mapped in detail, the summer snowline of glacier 1 was marked and geomorphological maps of each glacier's snout were drawn, these were then used alongside data from Google Earth. This provided us with data of altitude of the glaciers, glacial profile gradient, glacial area and aspect of the glaciers.



Analysing river discharge over time we can see some common features; they were all subject to diurnal discharge variation, this was because of changes in glacial melt-rate due to the diurnal insolation cycle. Later in the study this diurnal variation began to break down at site B with discharge slowly decreasing. This was due to increased cloud cover which reduced levels of insolation on the glacier, showing that cloud cover is a significant variable to consider when assessing the impact of climatic variation on glacier extent. It was also found that with increasing distance from the glacier to the sample site a later discharge peak was recorded, due to the time taken for the meltwater from the glacier to travel the increased distance; however it was also found to be dependent on specific glacial structure such as quantity of subglacial and englacial conduits, as expected. No clear relationship was

found between suspended sediment concentration and discharge, indicating that sediment input into the system is supply limited. This is a common feature of glaciated basins and further reinforces the importance of understanding the effects of climatic change on glacial melt for the regions downstream of the glaciers, as the sediment is released by glacial melting and will continue to be transported downstream until supply from the glacier runs out.

River discharge was shown to be dependent upon temperature and insolation, with cloud cover the major influence on the amount of insolation upon the glaciers. The results show that the specific relationship between them is very complex as they are all inter-related; however the data from the latter parts of the monitoring period suggests that glacier melting and runoff are more dependent upon cloud cover than temperature. This can be implied as discharge levels at site B do not peak despite a peak in temperature, during an associated period of increased levels of cloud cover. This was further supported by river levels at site B dropping, despite an increased temperature during this same period of increased cloud cover, thus showing that cloud cover has influence over both long and short term levels of glacial melt, although much more significantly at the long term. Data from site C also supports this with mean discharge showing a decrease towards the end of the study which is coincidental with increased mean cloud cover.

Comparing the altitude of snout, area of the glacier, aspect of the glacier and gradient along the glacier profile for all three glaciers we can see that: the altitude of the snout correlated negatively with the glacier surface area, suggesting that the larger a glacier the further it can extend down a valley. The gradient along the profile of the glacier was shown to be an important factor as for a given increase in equilibrium line and snout altitude, the area of glacier lost would be lower if the snout area is steeper. This suggests that, at least initially, glacier 2 would lose less glacier area for a given increase in temperature than glaciers 1 and 3 as it had a much steeper snout. It is important to consider gradient in predictions of glacial response to climatic change. Glaciers 1 and 3 showed different responses to the diurnal temperature cycle, one possible explanation for this is the difference in aspect between the two glaciers which could have influenced runoff timings; however this could also have been due to the presence of a large recessional moraine and pro glacial lake at glacier 1.

In summary, the study has shown the glaciers of the Thanglasgo Valley to be sensitive to meteorological variations. While temperature exerts a strong influence over melt rates, cloud cover is also an important factor affecting glacial runoff and

therefore should not be overlooked when predicting the effects of climate change on glacier behaviour. Glacier configuration and proglacial morphology affect meltwater runoff dynamics in the short term and are also likely to exert an influence over glacier response to longer-term changes in climate.