Changes to Water Resources in a Tropical Mountain Watershed: a Hydrochemical Assessment of Glacier Meltwater Impact to Streamflow

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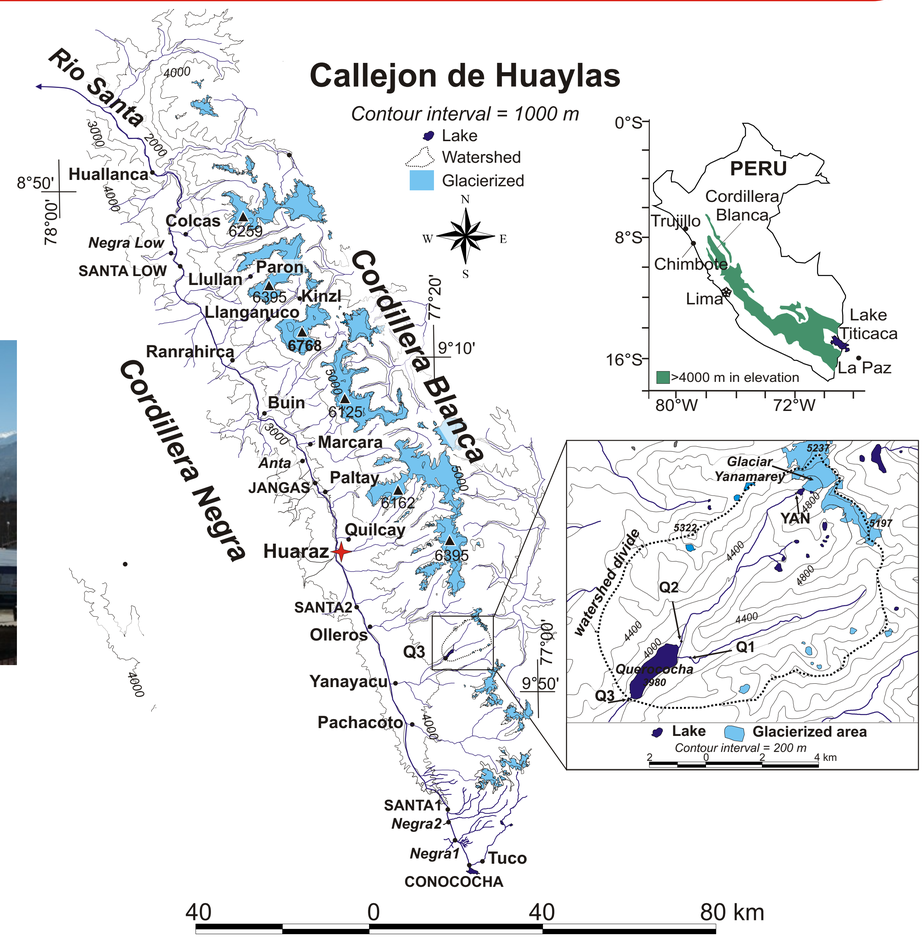
Abstract

The Callejon de Huaylas, Perú, is a well-populated 5000 km^2 watershed of the upper Rio Santa river draining the glacierised Cordillera Blanca, site of the Huascarán UNESCO Mountain Biosphere Reserve. Receding glaciers are causing concerns for future water supply. Distinct chemical signatures of source water end-members may provide a means of quantifying the volumetric contribution of glacier meltwater over time from first order basins to the entire watershed. Water samples from streams, springs and precipitation over a 2000 m vertical range within the watershed were analyzed for major dissolved ions and isotopic ($\delta^{18}O$) composition. There is a consistent trend towards lighter isotopes with greater percentage of glacier coverage in tributary stream catchments of the Rio Santa, with some exceptions due to evaporative enrichment in lakes. The hypsometry of the watershed and distribution of glacier mass causes a greater volume of glacial meltwater to join the Rio Santa at lower elevations. The water generally has a Ca-Mg-HCO_3 chemical signal. Samples along transects of tributary valleys show an increase in TDS and the Na:Mg concentration ratio with decreasing elevation. We see geochemical evidence for a small groundwater source in the tributaries and the Rio Santa.

Setting

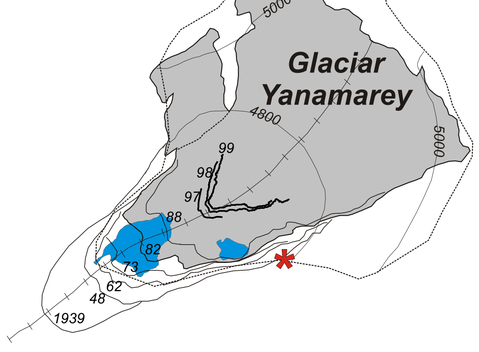
The Andean Cordillera Blanca of Perú is the most glacierized mountain range in the tropics. It spans 120 km along the South American continental divide, with 27 summits reaching over 6000 m including Huascaran **(a)**, the nation's highest. The majority of glacierized watersheds within the Cordillera Blanca discharge towards the SW, flowing via the Río Santa to the Pacific Ocean. The hydroelectric power plant at Huallanca **(b)** delimits the upper Río Santa watershed to an area of 4900 km^2 that is referred to as the Callejon de Huaylas, which receives surface runoff from both the glacierized Cordillera Blanca on the east and non-glacierized Cordillera Negra on the west (Fig. 1). The regional inhabitants rely on glacier-fed streams for municipal water to towns and cities, such as the provincial capital of Huaraz **(c)**.

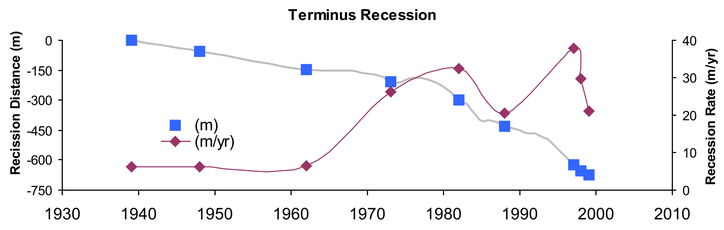


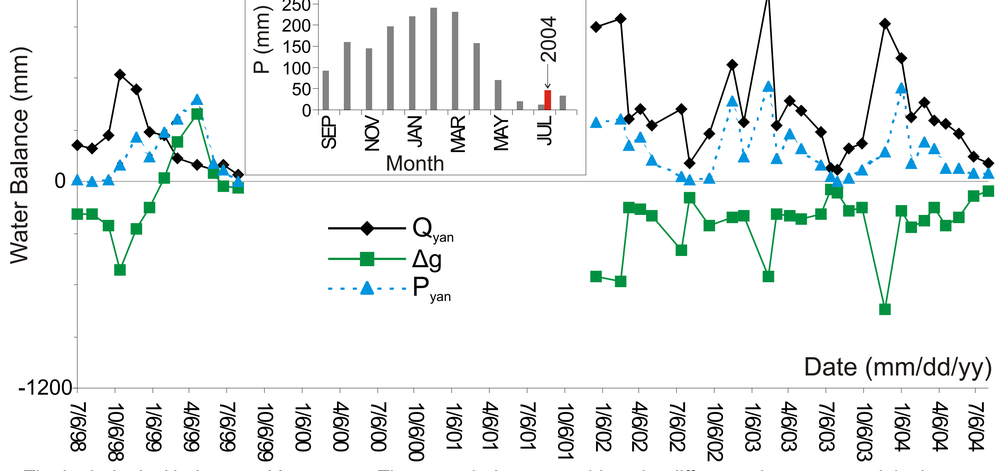
Glacial Storage Reduction

The Yanamarey glacier catchment (YAN) covers 1.3 km^2 between 4600 m and 5300 m in the southern Cordillera Blanca, and is representative of small glaciers in the Cordillera Blanca.

The recession in recent years has been very extensive (Gomez, 2004). Whereas the glacier experienced a positive mass gain during Jan - Apr 1999, the balance remained *negative over the entire measurement period* Dec 2001 to Jul 2004. Averaged storage changes in 1998-99 indicated that glacier melt from Yanamarey contributed 35% of the annual discharge. The glacier now appears to be in continual negative mass balance, and the average value is ~60% over the last 3 years. Seasonal stream runoff will likely become more variable in the future, as peak discharge coincides with highly seasonal peak precipitation.



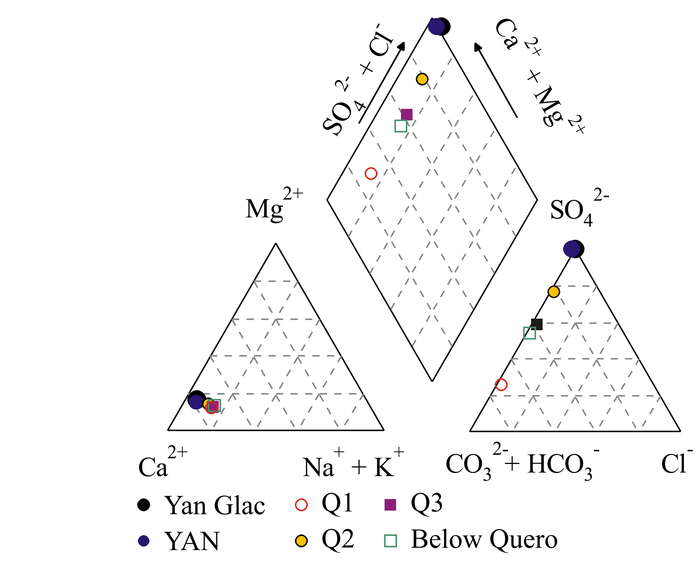


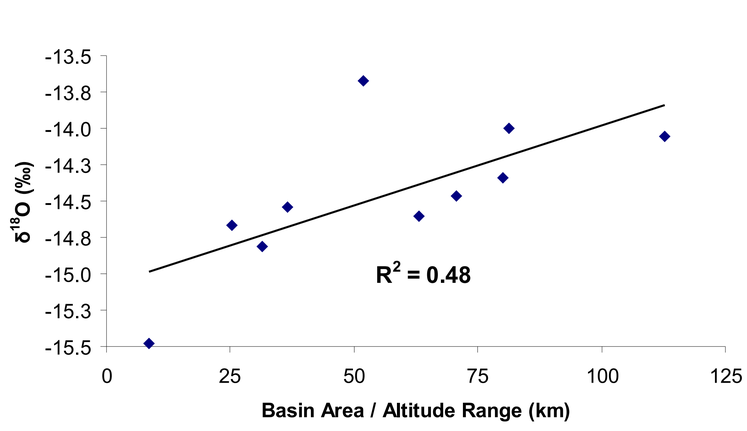


The hydrological balance at Yanamaray. The water-balance considers the difference between precipitation over the catchment (P) and the stream discharge leaving the catchment (Q) as the change in glacier storage term (Δg), where Δg = P - Q. A net loss (negative Δg) enhances stream discharge.

Glacierized Runoff

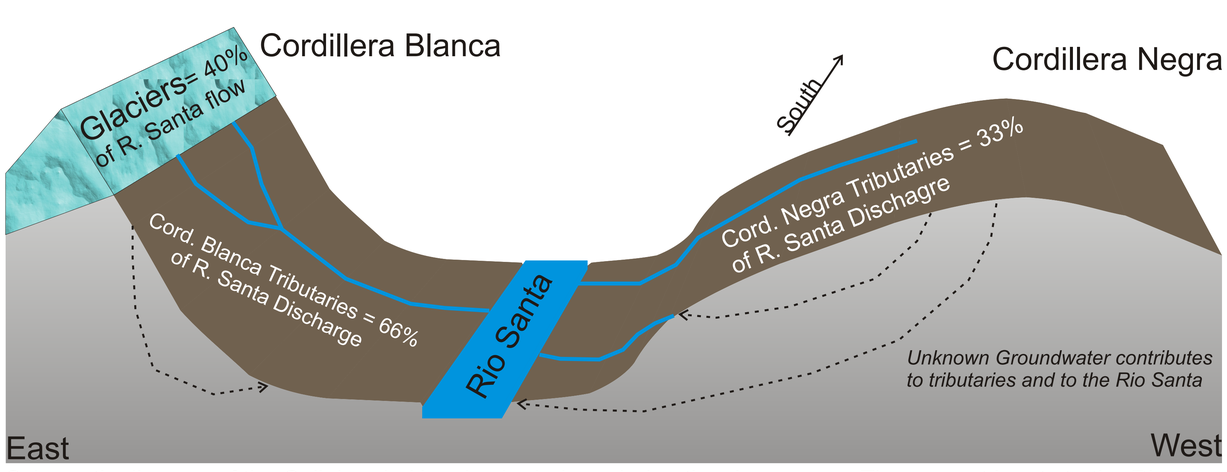
During 1998-1999, mixing models indicated Q3 was comprised of 30% of YAN annually; YAN, in turn, was estimated to be 35% glacier melt. Thus ~10.5% of the total annual discharge at Q3 was from melting glacier ice. In July 2004, ~50% of Q3 discharge is from YAN, which in turn is now ~60% glacier melt. Likewise, ~30% of the discharge volume at Q3 is estimated to be from melting ice. Q2 is estimated to be ~40% glacier melt by the same reasoning. These estimates represent one relatively dry month.



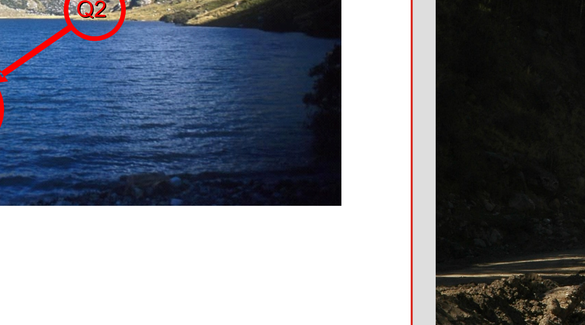


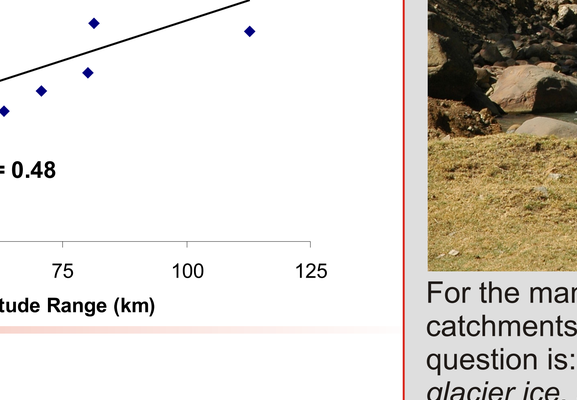
For the many streams that drain glacierized catchments, like Quebrada Honda at Marcara, a critical question is: *how much water is coming from melting glacier ice, and what will be the effect of glacial recession on this valuable water resource*?

Impact on the Callejon de Huaylas



Schematic diagram of the Callejon de Huaylas hydrology during the *dry season*. The percent inputs to the Rio Santa are based on geochemical and isotopic mixing models. An outstanding question is **"what is the groundwater contribution to the system?"** Ongoing analyses of end-members show consistent trends in isotopic composition controlled by basin geography and glacier coverage.





Conclusions

Despite the limitations and assumptions, our estimate of relative contributions to the Rio Santa provide a valuable and unprecedented quantification of glacier meltwater impact. Drawing on the analogue YAN-Querococha watershed, we can estimate the glacier meltwater contribution to the Rio Santa for 2004. Following the observation of hydrochemical mixing that two-thirds (66%) of averaged Rio Santa water in the Callejon de Huaylas (~8% glacierized) is comprised of Cordillera Blanca water, then we can **estimate ~40% of Rio Santa discharge is glacier melt.** Our dry season estimate comes from a season that was anomalously wet, and is thus conservative (Mark et al., 2005).

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