# Melting in the Andes: Goodbye glaciers

Researchers are racing to determine how shrinking glaciers in the Andes will affect the water supply of millions of people.

- Barbara Fraser[1]

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## Image Slideshow

1.

Peru's Cordillera Blanca contain the most dense concentration of glaciers in the tropics, but the ice is rapidly melting. An international research team is assessing how the retreat of the glaciers is affecting the region's rivers and people.
Barbara Fraser

2.

In the high-elevation valleys of the Cordillera Blanca, Jeffrey McKenzie of McGill University in Montreal, Canada, is trying to assess how much glacial melt and precipitation enters streams and groundwater.
Barbara Fraser

3.

McKenzie drills a hole so he can study the soil composition and install a device to measure groundwater flow.
Barbara Fraser

4.

Graduate student Ryan Gordon from Syracuse University in New York pours dye into a river to measure the flow rate.
Barbara Fraser

5.

Downstream, Gordon and Daniel Chávez (left), a graduate student at McGill University, measure the dye concentration to calculate how much water is flowing through the stream.
Barbara Fraser

6.

Wearing gloves to avoid contaminating his results, graduate student Alfonso Fernández of Ohio State University in Columbus takes a water sample that will be analysed for heavy metals.
Barbara Fraser

From the shade of an adobe house overlooking Peru's Santa River, Jimmy Melgarejo squints at the dual peaks of Mount Huascarán looming against a cloudless sky. “The snow keeps getting farther away,” says Melgarejo, a farmer worried about his livelihood. “It's moving up, little by little. When the snow disappears, there will be no water.”

Throughout the Andes, millions of people voice the same concern as they watch climate change eat away at the mountain chain's icy mantle. But although everyone fears a water shortage, they do not know how quickly it will come or how severe it will be.

An interdisciplinary team of scientists is now trying to provide some answers through a US$1-million project funded by the US National Science Foundation. The crew, which pulls together hydrologists, geochemists, geographers and historians, mainly from the United States and Canada, is tracking the fate of glacial meltwater as it runs from the mountains down to the ocean. Their goal is to develop models to forecast water flow and its effects on residents downstream. The rapid changes in the Andes “warrant a new kind of interdisciplinary, integrated study”, says geographer Bryan Mark of Ohio State University in Columbus, who is one of the principal investigators of the project. “We're trying to cross traditional boundaries, so

we're not studying water separately from people."

Peru has the largest mass of tropical glaciers in the world, and most are in the Cordillera Blanca, or White Mountains (see 'Going with the flow'). The snow-capped range towering over the Santa River, which winds 347 kilometres to the desert coast, is "the most densely glaciated mountain range in the tropics", says Mathias Vuille, a climate scientist at the State University of New York in Albany. With so much melting ice, and hundreds of thousands of people dependent on the glaciers, the Santa River valley — also known as the Callejón de Huaylas — has become a prime place to assess the changes caused by global warming.

# Nature Podcast

Barbara Fraser spends some time in the Peruvian highlands with scientists monitoring the water supply.

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As the most comprehensive study so far to examine melting glaciers and their impacts, the project will arm policy-makers with crucial information about how to adapt to climate change in the region, says Mark. The project could also contribute to models for other watersheds in the Andes and for ones as far away as the Himalayas.

The results so far present a mixed forecast. Despite the fears of Melgarejo and other residents, the river will not dry up completely during the dry season. But increasing demands on river water for drinking, irrigation and electricity generation will lead to conflicts over the dwindling — and increasingly expensive — resource. And there is not much time to plan for the changes. "This is a reality now," says Michel Baraer, a project member and hydrologist at the University of Quebec, Canada. "We don't have 50 years to adapt."

# The heat is on

On a crisp morning in July, Mark, Baraer and some colleagues with the project climb a lupin-fringed path to Lake Cuchillacocha, which sits at 4,600 metres above sea level, just below a glacier on Mount Pucaranra. There, they work in shifts through the day and frigid night, taking infrared images every half hour of the glacier and surrounding rock. Other instruments on and around the glacier's tongue record solar radiation, wind speed and direction, temperature and humidity.

The researchers are studying how quickly the ice, rock and lake warm up during the day and cool at night. By correlating these detailed data with measurements of ice thickness and extent made remotely by satellite and planes, the team hopes to develop models for forecasting how quickly glaciers will retreat across the Cordillera Blanca and what the impacts will be.


Earlier studies have shown that glaciers in the mountain range have shrunk by 20–30% since 1970 (ref. 1), and the rate seems to be accelerating. Researchers at the French Research Institute for Development (IRD) in Marseilles have found that the glaciated area in the tropical Andes is now decreasing by 3% a year (ref. 1).

Because the amount of precipitation has not changed much over the past few decades, researchers blame rising temperatures for the glacial retreat; the region has warmed an average of about 0.1 °C per decade since the 1970s, said Antoine Rabatel, a glaciologist at France's University of Grenoble and a member of the IRD study, at a conference at Santiago Antúnez de Mayolo National University in Huaraz in early July.

According to Rabatel, glaciers above 5,400 metres — such as those on Huascarán, Peru's highest peak — will shrink but survive because temperatures there will remain relatively cool. But those at lower elevations are doomed to disappear. In the past few decades, those glaciers have lost twice as much mass as ones at higher elevations1.

That is bad news for residents because the glaciers serve as a buffer, locking up precipitation during the rainy season and releasing water slowly during the dry season, between June and September, when almost no rain falls.

“You can think of glaciers as hydrological Prozac — they smooth out the highs and lows,” says Jeffrey McKenzie, a hydrogeologist at McGill University in Montreal, Canada. Without the glaciers, downstream water users will have to adapt to greater variability between the wet

and dry seasons.

From Lake Cuchillacocha, the Quilcayhuanca River tumbles down a broad, glacially carved valley. At a site about 7 kilometres downstream, McKenzie dips a probe into the river and measures a pH of 3.4. The lake is even worse, with a pH of 2.8. McKenzie, who is studying the interaction between surface water and groundwater, explains that many lakes and rivers in the Cordillera Blanca are naturally acidic because glaciers grind over rocks rich in sulphate, which gets dissolved into the meltwater.

McKenzie also collects samples to identify the water's geochemical 'fingerprint' — its concentrations of stable isotopes of oxygen and hydrogen as well as several types of dissolved ions, which meltwater picks up as it flows through rocks near the leading edge of the glacier. Those data have allowed McKenzie and his colleagues to calculate that glaciers contribute about 30% of the water in the Santa River during the dry season[2]; the rest comes from wet-season precipitation that slowly flows through groundwater and eventually reaches the river.

The finding suggests that after the glaciers melt away, substantial amounts of water from rain and snow will still flow through the Santa River during the dry season. Yet with the population and agriculture expanding in the region, losing even 30% of the river flow during that season could still cause severe distress, particularly during a drought, says Baraer. And residents may not have much time to prepare because Baraer calculates that the Santa River valley has already passed a critical point known as 'peak water'.

When glaciers first begin to recede, the rivers downstream initially swell with the added meltwater until the glacial supply starts to ebb. After that peak water point, the amount of discharge drops off sharply. Baraer and his colleagues studied discharge records for nine tributaries of the Santa River, with data going back to the 1950s. The records suggest that seven of the nine catchments passed the peak water point between the 1960s and the 1980s (ref. [2]).

Georg Kaser, co-chair of the Climate and Cryospheric Research Center at the University of Innsbruck in Austria, cautions that without data from all catchments, it is difficult to know whether peak water has passed for the entire Santa River watershed. The ice caps on the higher mountains in the centre of the Cordillera Blanca remain largely intact, he notes. Nonetheless, the results should prompt Peruvians, especially policy-makers, to finally deal with the threat of declining water supplies, says Kaser. “We have been telling them for more than 20 years that this peak flow will come soon, but we just spoke into the wind,” he says.


A researcher launches a doppler device to measure stream discharge.

B. FRASER

Peru currently has no comprehensive plan for addressing future water shortages in the Santa River catchment, according to Gabriel Quijandría, vice-minister for strategic development of natural resources in the environment ministry. “There needs to be a substantial improvement in the way water is used,” he says.

Construction of small reservoirs that could be tapped in the dry season could be “part of the answer, but not all of it”, Quijandría says. Some researchers, however, question the feasibility of building artificial reservoirs within the steep topography of the Cordillera Blanca, where earthquakes are a constant threat.

For McKenzie, peak water is only part of the story. To forecast discharge rates more accurately, he is studying how the glacial meltwater and precipitation eventually reach the Santa River. The valley floor below Lake Cuchillacocha is a boggy wetland that acts as a sponge, storing meltwater and water from precipitation and releasing it gradually into the river. McKenzie has found that it takes groundwater an average of 18 months to work its way through the wetland and into the river.

This year, McKenzie spent two weeks drilling narrow bore holes up to 6 metres deep in the Quilcayhuanca Valley and another one farther north. Material from the holes provided clues about the composition of the soil, and in some of the holes McKenzie installed piezometers — devices that use pressure to gauge water levels. By next year, he expects to have data that will help to answer questions about the direction, levels and fluctuations of groundwater movement. From there, the researchers intend to model how the flow of groundwater into the river system will change as the meltwater decreases. They are also concerned about the threat of human activities in the upper valleys; livestock grazing and extraction of peat for potting soil could dry out the wetlands and diminish their capacity to store water, warn the researchers.

# Extreme floods

Although residents of the Santa River valley fret over forecasts of declining flows, they also worry about the opposite problem: too much water. The lakes at the feet of glaciers are often

contained by unstable natural dams that give way in outburst floods, caused, for example, by a large chunk of ice dropping into the water. And the glaciers can steepen as they melt, making them more prone to avalanches. Outburst floods and avalanches have killed more than 25,000 people in the Callejón de Huaylas since the 1940s, says Mark Carey, an environmental historian at the University of Oregon in Eugene who is one of the leaders of the glacier project. The largest city in the Santa River valley, Huaraz, and many smaller towns are built on the deposits of former floods and landslides, he says. An outburst flood could kill tens of thousands of people, he estimates.

The National Water Authority in Peru currently monitors more than 35 lakes, according to Jesús Gómez of the agency's glaciology unit. He says that the agency has prepared for the risk by lowering water levels when they reach a dangerous point, but an unusually large ice fall could still cause a flood, and the unit's $300,000 annual budget is not sufficient to install automated systems that could warn of an advancing flood.

The shrinking glaciers could also amplify other hazards, notably water pollution. Downstream from Huaraz, Mark gingerly steps past a stream of raw sewage pouring into the Santa River from the tiny community of Mancos. Nearby, Alfonso Fernández, a Chilean doctoral candidate studying with Mark, lays out an array of small plastic bottles on a rock and uses a syringe to sample the water. Back in the lab, a team will analyse them for isotopic signatures to pinpoint the source of the water and will measure concentrations of pollutants such as heavy metals.

Sewage is not the only problem. Some tributaries of the Santa River contain naturally high levels of heavy metals, whereas others leach arsenic, cadmium and lead from tailings at old mine sites. The water quality in the river will probably fall as decreasing discharge concentrates the pollution, says Mark.

That could intensify competition for clean water, says Adán Pajuelo, president of a local irrigation committee, as he deftly cuts carnations in a field in Cruz de Mayo, a farming community near glacier-fed Lake Parón. In 2008, local farmers accused Duke Energy, a US power company, of overdrawing water from Lake Parón for its hydroelectric dam downstream. The farmers padlocked the lake's sluice gates, which limited the amount of water the company could draw from the lake.

The stand-off lasted nearly two years, until national government officials brokered a truce. Tensions have subsided, but Pajuelo worries that a drought year combined with impacts from a gold mine slated to be built near the lake could leave the farmers with only a small flow of polluted water to irrigate their crops.

Competition gets even stiffer downstream, where the river plunges through a narrow canyon past the hydroelectric plant towards the Pacific Ocean. In the coastal desert, asparagus, artichokes, fruit trees and sugar cane — mostly bound for export markets — sprout from land that was barren just over a decade ago. The Chavimochic irrigation project, which diverts water from the Santa River to irrigate 75,000 hectares of land, will cover more than twice that area when it is complete.

“Export agriculture is transforming the region,” says Jeffrey Bury, a geographer at the University of California, Santa Cruz, who is a principal investigator on the Santa River project. If the peak water scenario holds true, he says, “that will put inevitable tension on what the water is supposed to be used for and who is supposed to get it”.

All the issues affecting the Santa River come together at its mouth on the Peruvian coast. In the dry days of July, the once mighty river has shrivelled into a narrow stream trickling among cobbles and rubbish. If demands for water continue to grow, says Carey, then within a few years, it is possible that in the dry months no water from the Cordillera Blanca will reach the sea.

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