Unclassified **ENV/EPOC/GF/SD/RD(2004)7/FINAL**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

07-Feb-2005

English - Or. English

ENVIRONMENT DIRECTORATE
Environment Policy Committee

ENV/EPOC/GF/SD/RD(2004)7/FINAL
Unclassified

Global Forum on Sustainable Development

CLIMATE CHANGE IMPACT ON THE WATER RESOURCES FROM THE MOUNTAINS IN PERU

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Paris, 11-12 November 2004

English - Or. English

JT00178090

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CLIMATE CHANGE IMPACT ON THE WATER RESOURCES FROM THE MOUNTAINS IN PERU[1]

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Introduction

Located in a tropical zone (between the Equator and 18^0 south) (Fig. 1), Peru, with 1 285 000 km^2, is the third largest country in South America, after Brazil and Argentina. There are basically three main regions: the Pacific coast (*costa*), the mountainous region (*sierra*) Cordillera of the Andes which runs the length of the country from north to south, and the Amazonian forest (*selva*) to the east.

Figure 1. **The three regions of Peru**

1. *Suggested citation:* Chevallier, Pierre, Bernard Pouyaud, and Wilson Suarez (2004), *Climate Change Impact on the Water Resources from the Mountains in Peru*, paper presented at the OECD Global Forum on Sustainable Development: Development and Climate Change, ENV/EPOC/GF/SD(2004)7/FINAL, OECD, Paris.

   The opinions expressed in this paper are those of the individual authors and do not necessarily reflect the views of their organisations or of the OECD.

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Source: www.andix.com.

Peru's climate is strongly marked by the mountain barrier of the Andes. To the east, the Atlantic air masses are responsible for the warm and humid climate of the Amazonian forest. To the west, along the whole coastal strip, the proximity of the South Pacific anti-cyclone and its accompanying subsidence, reinforced by the cold Humboldt current which flows parallel to the Pacific coast, generate a climate which becomes increasingly dry the further south one goes. The average precipitation in Lima is only of some 25 mm a year.

In the mountains, the annual oscillation of the inter-tropical convergence zone (ITCZ) gives rise to alternate dry and wet seasons, the latter occurring over the southern hemisphere summer (December to April), which vary depending on altitude and the orientation of the mountain slopes. Broadly speaking, it can be said that the length of the rainy season diminishes from north to south, and precipitation from east to west.

Given the climate, water resources are very unevenly spread. Roughly half of the country's 27.1 million inhabitants (INED, 2004) live on the coastal strip, one-third in the mountainous regions of the Cordillera of the Andes, and one-sixth in the vast Amazonian plain (Consejo Nacional del Ambiente, 2001), with the end result that these populations have extremely different levels of access to water resources.

In the barren coastal region, nearly all the water available today comes from rivers flowing down the western slopes on the Cordillera of the Andes and therefore, in the dry season, is of glacier origin. Nevertheless, it is in this region that most of the large cities are located -- including the capital Lima, with more than 8 million inhabitants in total -- and that the large majority of economic activity is also concentrated.

Tropical glaciers and climate change

In the rainy season, the rivers flowing into the Pacific Ocean are fed by the rainfall in the mountains, as well as glacier melt. In the dry season, the rivers are fed exclusively by melt waters from the glaciers which cover the mountain tops higher than 5 000 m.

Peru possesses some 70% of the planet's inter-tropical glaciers. Records, kept for the last fifty years or so, show that these glaciers are in general retreat, a trend which has been accelerating since the mid 1970s. For the 18 main Peruvian ranges of the Cordillera of the Andes with glaciers, it is estimated that between the 1960s and the end of the 1990s, there has been a loss of more than 20% in surface area, as in volume (Leavell and Portocarrero, 2003).

In partnership with the National Meteorology and Hydrology Service (Senamhi) and the National Natural Resources Institute (INRENA) of Peru, and in particular its Glaciology and Water Resources Unit (UGRH) in Huaraz, the IRD's Great Ice Research Unit has, since the end of the 1990s, been carrying out a research programme aimed precisely at evaluating the impact of climate change on water resources, and the resulting consequences for human activity (Pouyaud *et al*., 2003). In a first phase, the study focused on the Rio Santa valley which drains the Cordillera Blanca, the highest and most ice-bound cordillera in the country (Fig. 2).

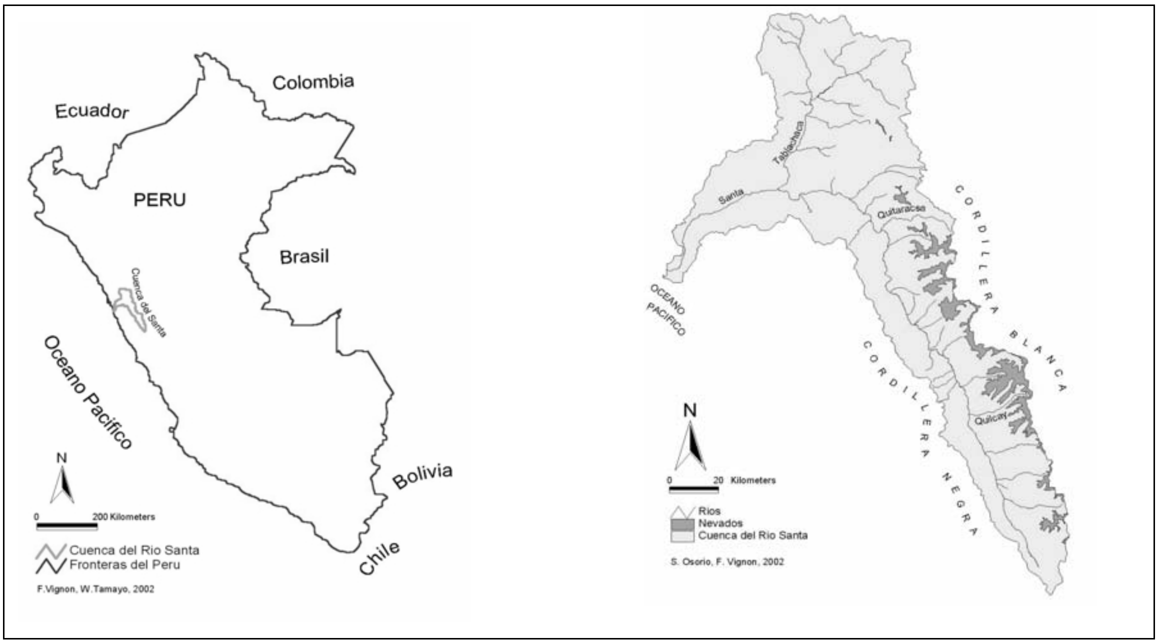
How do tropical glaciers work and how are they responding to global warming?

Compared to glaciers in temperate or polar regions, tropical glaciers have two special features:

- They are subjected to considerably higher levels of radiation since they are located in low tropical latitudes, but higher altitudes.
- The period of maximum precipitation, feeding their upper zones in the form of snowfall, coincides with the summer period when temperatures are highest, melting the ice in their lower zones.

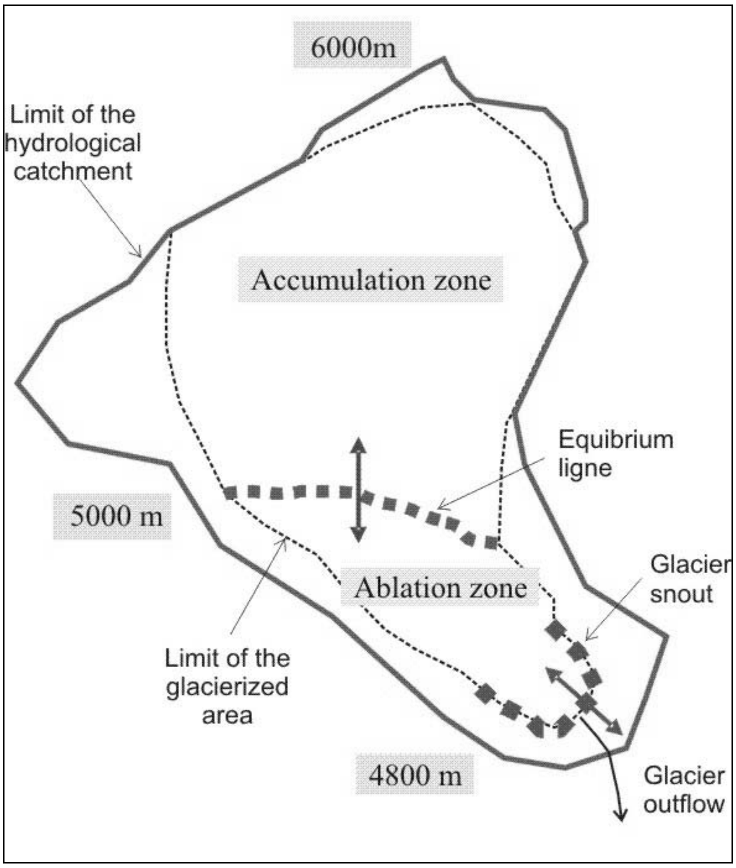
The combination of the two means that tropical glaciers are particularly sensitive to variations in climate, of which they constitute an excellent indicator.

Figure 2. **Location of the Rio Santa Basin within Peru and of the glaciers, which are supplying it**



Source: Suarez (2003).

Figure 3. **Working scheme of a tropical glacial hydrological catchment**



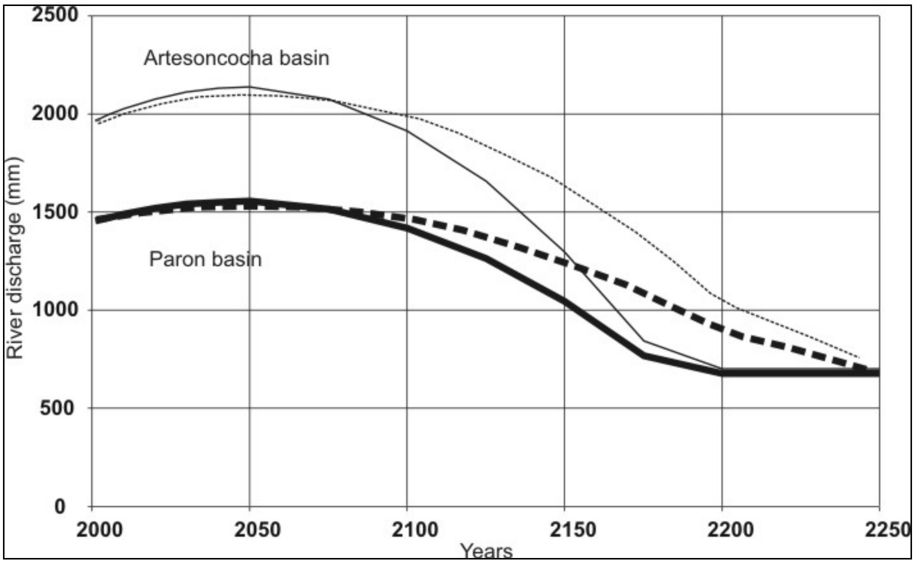
More precisely (Fig. 3), tropical glaciers lie in hydrological basins which catch precipitation. Part of the basin is not covered by ice. There are two zones on the glacier itself: (1) the higher, or “accumulation” zone where the snow accumulates before being turned under pressure into firn, then into ice, the major source of glacier build-up; (2) the lower, or “ablation” zone which is the major source of melt waters at the “glacier snout”. These two zones are separated by the “equilibrium line” where the net balance equals zero, accumulation offsetting ablation. If precipitation remains equal, a variation in temperature leads to an advance or retreat of the glacier snout and equilibrium line as a result of a variation in the accumulation/ablation ratio. Consequently, the limits of glacierised and non-glacierised areas gradually change in response to climate variation. The outcome is a significant change in the volume and pattern of runoff. The result of the global warming already under way is: (1) the glacier snout retreats as does the equilibrium line, (2) the accumulation zone shrinks and ablation increases in relation to accumulation, (3) the total surface area of the glacier shrinks while the proportion of non-glacierised area increases in relation to the glacierised area in the drainage basin.

What are the consequences for river discharges?

The glacier scenario described above in time changes the pattern of water volume in the rivers it feeds, in accordance with the initial glacierisation rate.

In a first phase, in the most glacierised drainage basins (Fig. 4), the acceleration of glacier melt will increase the average volume of glacier outflows by accelerating the water imbalance: the volume discharged will be higher than the volume precipitated in the form of snow or rain. Then in a second stage, with the gradual emptying of the reservoir represented by the glacier, and the increase in the non-glacierised area of drainage basins, the contribution from melt water will fall and will not be offset by that provided by rain: discharges from the whole drainage basin will decrease.

Figure 4. **Tentative forecast for water resources flowing from glaciers in the Rio Santa Basin**



The Artesoncocha Basin (thin lines) contains a 75% glacierised area, and the Paron Basin (thick lines) a 45% one. The dotted lines illustrate the forecast using the 1950-2000 time series data, the continuous lines reflecting the 1980-2000 time series.

Source: adapted from B.Pouyaud, unpublished document (2004).

There are two immediate main questions which then arise for all water users: (1) when will maximum discharge occur, (2) what is the minimum resource level which will be attained subsequently and when will this occur?

An excellent correlation has been found between the runoff from highly glacierised drainage basins (more than one-third glacierisation) and the air temperatures obtained from climatic reanalysis models, based on field and satellite measurements coupled with mathematical simulations. On the basis of future temperature forecasts, it has been possible to construct a first model for forecasting the future trend of glacier water resources in coming centuries. Although still approximate, this model is sufficiently robust to be used as a basis for Fig. 4 (Pouyaud, 2004, to be published in the proceedings of the Huaraz symposium). Without relying too much on the time-scales forecast, the accuracy of which remains highly approximate given the model used, the following points may be noted:

- The scale of runoff variation depends on the initial proportion of the glacierised area of the drainage basin, but tends towards an identical value corresponding to the nivopluvial runoff alone after the total disappearance of the glacierised part of the drainage basin.

- If records for the last 20 years are used for the model calibration, the decrease is considerably faster than if the last 50 years are used. This is because of the acceleration over the period 1976-2000 of the warming trend, which is probably still less than that used by most models for the future.

What are the consequential risks for the population?

Looking at a map or satellite picture, it can be seen that the cordilleras of Peru are dotted with innumberable glacial lakes, some of which were formed recently (Ames, 1998).

These lakes constitute a major hazard for people living in the valleys, since they could burst their banks at any time, and their waters, surging down the slopes, would lay waste everything in their path. Such catastrophes can be caused by three types of phenomena, which may or may not occur simultaneously:

- With the increase in runoff, the volume of water retained in the lakes increases along with the hydrostatic pressure on the retaining barrier, usually morainal in nature. Excess volume is likely to produce overflow and the breaking of the morainal dam which will release the lake waters. In some places, new lakes have appeared, the banks of which are not consolidated and are particularly unstable.

- Global warming increases the instability of the ice, and serac avalanches are more frequent. These avalanches project heavy materials into the lakes which create a shock wave which can also provoke a sudden overflow and the breaking of the lake’s banks.

- Glacier retreat liberates, in the rocky sides of the slopes, tensions built up when the glaciers were weighing down on them, and this can give rise to major rock-slides.

To all this must be added the fact that the Cordilleras of the Andes is a region of intense seismic activity. Any earthquake is likely to amplify the processes described above. This is what happened in Yungay at the foot of Huascaran in the Cordillera Blanca in May 1970, leading to the destruction of the town and 20 000 victims all in a few minutes.

To prevent accidents, the Peruvian authorities introduced, as early as the 1940s, an important surveillance programme for mountain lakes, for some of which an overflow tunnel has been created, making it possible to drain the lake to some extent and keep it at a level significantly below overflow. This approach was extremely useful in 2002, for example, when an avalanche of several million m3 of rocks fell into the *Laguna Safuna* (north-east of the Cordillera Blanca). Although this caused a wave estimated at nearly 70 m high, it did not give rise to any human victims, merely sweeping away a few cows and llamas from a mountain pasture (Reynolds *et al*, 2003).

Mountain water resource and use for human activities

In the Rio Santa valley, the focus of the study by IRD and its Peruvian partners, the harnessing and use of glacier water is of vital social and economic importance, not only for the region but for the country as a whole. From top to bottom:

- Above 5 000 m, the glaciers themselves and the mountain tops above them are a tourist asset which have for several decades attracted mountaineers from the world over;

- Between 2 000 and 4 000 m, irrigated slope agriculture has been practised for centuries by the Quechua peasants with the help of complex systems of small channels in the sides of the mountains, the *acequias*.

- Below 2 000 m, taking advantage of the extraordinary natural site of the Canõn del Pato and its differences in level, turbines are used to convert the waters of the Rio Santa into electrical energy.
- Below 800 m, at the foot of the Andes, water from the Rio Santa is used to irrigate huge agricultural areas recently created in the barren coastal zone, thus considerably increasing the traditional irrigation areas of the main deltas of small coastal rivers.

In the context of both the current climate change and sustained economic and social development, each of these "uses" gives rise to comments and questions. An illustration "following the water flow" of these uses was the subject of a recent television film "*Cordillère Blanche, les rivières de glace"*, co-produced by Europimages, France 5 and the IRD (Desenne, 2003).

Tourist attraction of the high mountains

For some 30 years already, the cordilleras of Peru have proved particularly attractive to mountain climbers and walkers of all levels, and more recently for other mountain sports such as mountain bikes, canoeing and rafting, the last two of which are directly dependent on the state of water courses. This influx of foreigners has led to the development of an important local tourism and recreation industry (hotels, agencies providing guides, services and transport, the sale and renting of equipment, supplies, etc.). The fragility of this economic system confronted by sudden changes to the glacier environment can be illustrated by an event which occurred in 2003 in the region of Huaraz (Kaser and Georges, 2003). On 2 April 2003, NASA announced, on the basis of a picture taken by the ASTER satellite, the imminent fall of a large ice-cap into a lake above the town of Huaraz (100 000 inhabitants), the heart of high-mountain tourism in Peru. The anxiety provoked by this announcement ruined the tourist season which was just beginning, causing damage estimated in millions of dollars. It later transpired that the picture had been wrongly interpreted, and that there was no particular new risk.

Hydropower

The Huallanca hydroelectric plant (270 MW, some 5% of Peru's energy production capacity) harnesses the waters of the Rio Santa. At full capacity, it needs a water flow of some 60 m3/s, a volume which the Rio Santa cannot provide when it is at minimum flow. The plant operator, Egenor, has constructed small side dams immediately upstream from where the water is taken, where water is stored during the day to be released, each evening, at the time of peak consumption. But in order to regulate the water resources of the Rio Santa, Egenor relies above all on managing natural lakes, the main one of which is Lake Paron, with a regulation capacity of 60 million m3. If done properly, managing these lakes can offer advantages in terms of security: this is the case for Lake Paron, which now constitutes a lower level of risk for the valley below, but the planned raising of the water level in other lakes may be dangerous given the fragility of their morainal barrier.

Traditional agriculture and stock-breeding

In any event, damming water for hydroelectric purposes can prejudice traditional irrigation on the high mountain slopes if the period over which such irrigation is needed does not "suit". The increase in the peasant population in the Andes area and the fact that, with global warming, it will become possible to cultivate, therefore irrigate, at ever higher altitudes, means that the resources required by traditional irrigation are set to grow and will increasingly be in competition with hydroelectric needs. Thus, even in the highest regions, there will be greater and more intense conflict between different users.

Large-scale irrigated agriculture

The *proyecto especial Chavimochic*, north of the Rio Santa mouth in the Pacific Ocean, covers 135 000 ha of various crops destined mainly for export (fruit, asparagus, etc.), and attracts agricultural workers who migrate from mountain areas to settle in the infertile coastal plain. The economy of the city of Trujillo (one million inhabitants) depends to a considerable extent on these facilities which also provide its drinking water. Other hydro-agricultural projects are being studied, such as the one at Chineca, south of the Rio Santa. It is already obvious that at the driest period of the year, the 20 or so m3/s to which the Rio Santa has been known to fall will not be enough to satisfy projects which need, at the same period, more than 100 m3/s. With the predicted disappearance of the glaciers, these minimum flows will inevitably be reduced further, while the topography of the valley does not allow for an increase in the number of reservoirs which would nonetheless be essential.

Conclusion

Tropical glaciers are particularly sensitive to variations in climate. Furthermore, the use of glacial water resource is of vital social and economic importance in Peru. In the mountains glacial water sustains economic activities ranging from traditional stock-breeding and mountain crops to hydropower, and as an international tourist attraction and associated local development. The fragility of this economic system is threatened by sudden changes to the glacier environment and climate change.

In the coastal region, nearly all of the water available today originates in the mountains and during the dry season it is of glacier origin. It is home to about half of Peru’s population and the centre of economic activity. The huge investment of public and/or private initiatives for a large scale irrigated agriculture and for the fast industrialization drains a large number of people who leave their roots and traditional activities and migrate to an inhospitable place where development projects are built on an unbalanced water resource. Climate change increases the risks related to water balance and availability in these coastal economic and social systems.

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