Alpine Lakes and Glaciers in Peru: Managing Sources of Water & Destruction

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Problem Statement:

One quarter of the world's tropical glaciers are found in the appropriately named *Cordillera Blanca* of Peru (see Map 1).[1] These glaciers play a crucial role in the local water cycle as the majority of the runoff from these glaciers flows into the heavily populated Rio Santa watershed.[2] As the water runs to the Pacific, it is used by local households, industry, agriculture and hydroelectric power plants located in the Rio Santa river valley (see Map 2). During the dry season, the flow of the Rio Santa is made up almost entirely of glacial runoff, demonstrating the importance of the water storage and release capacity of the tropical glaciers for the populations living in the Rio Santa valley, also known as the *Callejon de Huaylas*.[3]

There is a dual management issue with the melting of the glaciers and the formation of glacial lakes. While the lakes can act as storage for the river system (and the bigger the lake the greater the storage capacity), they also represent a major avalanche/mudslide risk to the populations living in the stream valleys below (the bigger the lake the greater the risk.) In fact, 30 glacier-related disasters have occurred since 1941, killing approximately 30,000 people.[4] Therefore, the effective management of the water levels and stabilization of the system of glacial lakes in the region is critical to maintain the existing water supply, as well as prevent natural catastrophes from devastating local populations.

Physical Description of the Region

Peru has three unique hydrologic zones: an arid coastal zone, the mountainous Andean region and the dense rainforest to the East. Meanwhile, the vast majority of the population lives along the dry coast, while the water-rich Amazon region remains relatively uninhabited. Because of this geographical mismatch between national water resources and the human population, Peru is estimated to be a "water-scarce" country by 2025 if population growth trends remain high.[5] For this reason the management of existing watersheds that empty into the Pacific Ocean is currently a critical issue and will only become more essential in the context of increasing demand for water resources.

The Rio Santa drains a 14,954 km^2 basin as it flows 316 km from its origin in Laguna Aguash (4,000 meters above sea level) down to the coast.[6] The region is marked by two distinct seasons: a wet season, with 70-80% of annual precipitation occurring between October and April, and a dry season from May to September (See Figure 1).[7] As a result of this fluctuation in precipitation, the flow of the Rio Santa fluctuates significantly over the course of the year, with a maximum flow of approximately 400 cubic meters per second in March and an estimated minimum flow of about 55 m^3/s in September and August (see Figure 2 for the monthly hydrograph of the Rio Santa.)

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1 Kaser and Osmaston 2001, as cited in Kaser et al. 2003

2 Kaser et al. 2003

3 Ibid.

4 Carey 2005

5 PAI, http://popenvironment.org/pai/water-14.html

6 Ministry of Agriculture, http://www.minag.gob.pe/hidro_cuenca_princ.shtml

7 Kaser et al. 2003

Currently, the quality of the Rio Santa is declining from municipal and industrial waste. No wastewater treatment plants exist in the Rio Santa valley, so all sewerage systems are dumping human wastes directly into the river[8] and as a result studies show high levels of total coliforms.[9] Meanwhile, mining in the valley has led to increased levels of heavy metals and toxics, including copper, lead and cyanide; and, application of agricultural fertilizers has led to increased levels of nitrates in the water.[10]

The *Cordillera Blanca* region is covered by nearly 600 square kilometers of glacial ice, even though it is located only 8-10 degrees latitude South of the Equator.[11] The total glaciated area of the *Cordillera Blanca* is 724 km^2 representing a volume of approximately 22,600 MMC of water.[12] Meanwhile, these glaciers are rapidly retreating as a result climate change,. In fact, a 1997 study of satellite images estimated that the total glacial area in the *Cordillera Blanca* has decreased by 15% in the last 50 years.[13]

As mentioned previously, the tropical glaciers of the *Cordillera Blanca* have an integral impact on the runoff levels supplying downstream rivers by capturing and storing water as snow in the rainy season and releasing water as melted snow in the dry season (See Figure 3).[14] As a glacier decreases in size, its ability to provide this service decreases.[15] Therefore, the loss of glacial mass has the potential to cause significant water shortages in the future.

In addition to the concern about decreasing water storage services, deglaciation can lead to massive avalanches as ice chunks cleave from the existing glacial mass. Furthermore, the melting and retreating ice leads to the formation of glacial lakes in loose sediment formations that can rupture as result of tectonic activity or falling ice from the melting glaciers.[16] Indeed the number of glacial lakes in the region has increased from 223 in 1953[17] to 374 in 1997.[18] Many devastating avalanches and outburst floods have already occurred as a result of unstable glaciers and lakes, and the potential for further damage remains (see Table 1 below).

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[8] Discussion with Nelson Santillán, 5/28/05

[9] Ministry of Agriculture: http://www.minag.gob.pe/hidro_cuenca_prob.shtml

[10] Ibid.

[11] Kaser et al. 2003

[12] http://www.minag.gob.pe/hidro_cuenca_princ.shtml

[13] Ibid.

[14] Kaser et al., 2003

[15] Ibid.

[16] Mark, 2000

[17] Fernandez, Concha and Hoempler 1953 by Carey 2005

[18] Electroperu 1997 by Carey 2005

Table 1. Five most deadly 20th century glacier-related disasters in Peru's *Cordillera Blanca*[19]

Date	Principal area affected	Disaster type	Number deaths
13 December 1941	Huaraz	Outburst flood	5000
17 January 1945	Chavín	Outburst flood	500
20 October 1950	Los Cedros Canyon	Outburst flood	200
10 January 1962	Ranrahirca	Avalanche	4000
31 May 1970	Yungay	Avalanche	18,000

Currently, the Peruvian federal government has funded projects for the stabilization of 35 lakes that were considered to be the greatest threats to the populations inhabiting the valley below. The construction of tunnels prevents the increase in lake size above the tunnel outlet and dams are used to reinforce the existing, and potentially unstable, moraine walls. An interesting phenomenon has developed in some cases where the lakes are growing substantially in size despite the installation of tunnels. Local experts have founds that as glacial mass retreats from below the lake surface, the lake reservoirs can become both deeper and longer, thereby increasing the potential for disaster despite the existence of drainage tunnels.[20] This phenomenon illustrates the necessity for on-going management of existing lake projects, while continuing to assess potential damage from lakes that have not yet been stabilized. See example of existing stabilization dam (Figure 6.)

National Development Indicators

Using per capita GDP as an economic indicator of development, Peru is distinctly underdeveloped (at per capita income of $2,368 in 2000 at 1995 dollars) as compared to the rest of South America ($4,218 per capita in 2000, 1995 dollars) and the rest of the world ($5,632 per capita in 2000, 1995 dollars.)[21] Figure 4 demonstrates how Peru's per capita GDP has historically remained well below the regional and world averages. The national poverty indicators suggest the high levels of economic inequality in the country. It is estimated that 18.1% of the population lives on less than one dollar a day, and 37.7% of the population lives on less than two dollars per day.[22]

As an alternative, and potentially more robust indicator of development (combining GDP, life expectancy and literacy into an aggregated indicator), the Human Development Indicator (HDI) ranking for Peru is 79, indicating a medium level of development (countries ranked between 58 and 145.)[23] Additionally while progress ahs not been rapid in improving the HDI indicator, there has been progress nonetheless, as

[19] Carey 2005
[20] Discussion with Marco Zapata Luyo, 5/27/05
[21] World Resources Institute (WRI) 2002, earthtrends.wri.org/text/economics-business/country-profile-144
[22] UNDP 2005, Human Development Report (HDR), hdr.undp.org/statistics/data/countries.cfm?c=PER
[23] Ibid.

Peru increased its HDI from a value of 0.643 in 1975 to their current (2005) value of 0.762.[24]

In this context of underdevelopment and high poverty rates, malnutrition remains a significant obstacle, although significant progress has been achieved in the last decade. Estimates show that the percent of the population considered undernourished between 1990 and 1992 was as high as 42% and current estimates show that the percent undernourished has decreased to about 13%.[25] Additional indicators relating to malnutrition include: 7% of children under five are underweight for age and 25% of children under five are under height for age.[26] These indictors suggest the system of food production and distribution within the country is currently insufficient.

Peru continues to suffer from incomplete coverage of water and sanitation infrastructure. Approximately 81% (2002) of people have access to an improved water source (up from 52% in 1990) and 62% (2002) have access to improved sanitation (up from 52% in 1990).[27] The effects of inadequate sanitation and water supplies was evidenced by the 1993 cholera outbreak that spread rapidly across Peru, and eventually spread across South America and up through Central America to Mexico.

The World Health Organization estimates that health expenditures in Peru are approximately 4.4% of annual GDP.[28] National life expectancy at birth is 68 years for men and 73 years for women and average child mortality is 36 male deaths and 32 female deaths per 1000 live births.[29] According to the United Nations Development Programme (UNDP), this child mortality is not evenly distributed across income quintiles, with poor children (bottom quintile) are over 5 times more likely to die before the age of five than wealthy children (top quintile).[30]

In the political realm, Peru suffered through decades of military dictatorship until 1980 when democracy was restored to the nation. However, like many South American countries the democratic governments have been plagued with scandals and corruption, first under the economically-focused and strict authority of Alberto Fujimori, and currently under the leadership of Alejandro Toledo.[31] Meanwhile, Peru has suffered for over two decades under the domestic Maoist insurgent guerilla group, the Shining Path, estimated to have killed nearly 70,000 people.[32] While the activities of the Shining Path have decreased in recent years, the country remains plagued by additional domestic instability based on the large exports of cocaine from the country.

Socioeconomic Description of the Region

The Rio Santa watershed is almost entirely within the boundaries of the department (equivalent to state or province) of Ancash. Ancash department is inhabited

[24] UNDP 2005, Human Development Report (HDR), hdr.undp.org/statistics/data/countries.cfm?c=PER
[25] Ibid.
[26] Ibid.
[27] Ibid.
[28] Ibid.
[29] WHO 2002, Country Profile, www.who.int/countries/per/en/
[30] UNDP 2005, Human Development Report (HDR), hdr.undp.org/statistics/data/countries.cfm?c=PER
[31] CIA World Fact Book 2006, www.cia.gov/cia/publications/factbook/geos/pe
[32] Commission for Truth and Reconciliation 2003, www.derechos.org/nizkor/peru/libros/cv/

by 1,139,083 people. The two largest cities in the Department are Chimbote (approximately 270,000 people) on the coast and Huaraz (app. 60,000 people) in the mountains. The results of inadequate water supplies and sanitation are evident in Ancash, where intestinal infections were the leading cause of morbidity in 2002 (956 cases, 3.6% of total morbidity) and the 4th leading cause of morbidity in 2003 (769 cases, 3.1% total morbidity).

As you trace the passage of water from the glaciers and mountain lakes, it provides a variety of services to the people. In the high mountain areas water from local tributaries is used for by households and for small-scale irrigation. In the towns and cities in the *Callejon de Huaylas*, the tributary and Rio Santa water is used for domestic, industrial and municipal purposes. Along the Rio Santa, the water is used for medium and small-scale agriculture, mining, and domestic use. At the narrow valley of the Canon del Pato, a hydroelectric dam produces a significant portion of electricity for the region. Finally, as the water makes its way toward the Pacific it is diverted at a variety of locations for small- to industrial-scale agriculture in the arid regions closer to the coast and finally, used by the city of Chimbote.[33]

Demographic data show a significant growth in the populations inhabiting this valley, and while the number of people requiring water resources is growing (over 1 million people), so is the amount of water used per person as the region modernizes.[34] Meanwhile, as described above, the potential of water scarcity in the dry season as a result of deglaciation is evident.[35] Some possible effects of this water scarcity might include: local water conflicts, human health effects, loss of biodiversity, economic decline and decreased production of hydroelectric power (currently producing 250MW, see Figure 5.) Furthermore, decreased water levels in the river will only lead to increased concentrations of pollutants in the river (described previously), so the regions will not only have less water, but water of lower quality if current trends continue.

Glacier-related disasters can be mitigated in two ways: 1) Managing natural risk: stabilize glacial lakes to prevent outburst floods and 2) Managing planned risk: move people out of the way of potential avalanche and flood trajectories, so that should a disaster occur, the human impacts is minimized. In regards to Option 2, it is important to note that most of the towns in the watershed have been built directly in stream valleys, which also serve as avalanche paths. In the past, government agencies have encouraged the local people to move to safer areas, but the residents have shown great resistance to any rezoning initiatives. Carey notes:

> [P]eople often complained about the nonexistent or contradictory government-distributed information, locals sometimes rejected or ignored the safety measures the State did enact. When engineers and planners tried to resettle inhabitants outside potential hazard zones, for example, many people protested angrily, calling it “State intervention” instead of disaster mitigation or safety precautions.[36]

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[33] Discussion with Nelson Santillán, 5/28/05
[34] Kaser et al., 2003
[35] Ibid.
[36] Carey 2005, p.130

This quote not only illustrates that the risk of glacial disasters continues to be a prescient issues as many people knowingly inhabit disaster-prone areas, but also shows that there is a significant level of mistrust and a lack of communication between state agencies and local residents.

Finally, tourism revenue in the region is estimated at approximately $3.6 million, a significant source of revenue to the region. The awe-inspiring mountains in the region including Mt. Huascaran (the tallest mountain in Peru at 6,768 meters above sea level) and the well-known Mt. Artesonraju (the inspiration behind the Paramount Pictures logo) draw visitors and adventurers from all over Peru and the globe. Furthermore, the glaciers and lakes specifically are of principal interests to tourists. However, glacial retreat and systems for lake stabilization may be negatively influencing tourism. According to Marco Zapata Luyo of the Unidad Glaciologia y Recursos Hidricos (UGRH), the reduced level of Laguna Paron has decreased trekking and tourism to the area.[37]

Water Supply System

Given the physical and socioeconomic dynamics in the region, it is clear that the management of water resources is inextricably linked to a complex variety of other issues. Looking to the future, it is evident that the melting of the tropical glaciers may lead to significant water shortages in the region. The question remains: how should planners in the region respond to this potential water shortage?

In the book *Small-Scale Water Supplies: A Review of Technologies,* the author, Brian Skinner, provides an elaborate decision tree of appropriate water sources for communities. It is worth noting that the decision tree starts with the following question: "Is it feasible to protect/improve existing water sources?"[38] In the case of the glacial lakes of the *Cordillera Blanca* region of Peru, the answer is "yes", as evidenced by existing projects to protect the glacial lakes. The subsequent question asks, "Can existing/improved sources provide enough water?"[39] Again, in this region there is currently sufficient water in the Santa watershed to meet household, agricultural, industrial and hydroelectric demand, but shortages do occur occasionally in the dry season.[40] A "yes" answer to this follow-up question generates the following option for water supply planning: "Consider protecting and improving existing sources."[41]

While this decision path seems relatively straightforward, it is crucial for water planners to, first and foremost, work with existing natural systems for sustainable provision of water resources. What is so unique to the case of the Rio Santa, is that the exogenous force of climate change is rapidly and dynamically altering the characteristics of the watershed. Therefore, it is imperative that water management in the region is similarly dynamic, with planning strategies that do not just "protect and improve the *existing* sources," but also the *evolving* sources of freshwater in the region.

To accomplish this task, water planners in the region will need to continue developing infrastructure projects to stabilize the lakes (reinforced dam walls and/or

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37 Discussion with Marco Zapata Luyo, 5/27/05

38 Skinner 2003

39 Ibid.

40 Angeles 2003

41 Skinner 2003

managed water levels). However, the most critical response (and most complex) will be to create an improved water management structure to address the changing physical hydrology as well as the evolving social and economic demands for water resources. Currently, there is no integrated plan for the management of water resources in terms of withdrawals across sectors (e.g. hydroelectric centers, human consumption, mining, industry, agriculture, among others) or effluent pollution (e.g. sewerage, mining, industry, agrochemicals and solid wastes).[42] See Table 2 for an attempted summary of all the uses and potential abuses of water resources in the region.

Table 2. Water Use Categories for Catchment Planning[43]

Water Use Categories	Uses in Rio Santa Watershed
Potable (Drinking) Water Supply	• Municipal Water Supply • Residential Water Supply (Rural)
Industrial Water Supply	• Process Water Supply o Mining • Aquaculture
Agriculture	• Irrigation Waters • Livestock Watering
Flood Control	• Impoundment of high flows for delayed release • Construction of dams, tunnels and weirs?
Hydroelectric Power Generation	• Impoundment of water for power generation • Construction of dams • Pumping and drawdown of reservoirs
Navigation	• Recreational Boating
Water-based Recreation	• Fishing • Boating • Swimming • Hiking
Fish and Wildlife Habitat	• Aquatic and riparian habitats • Protection of community structure • Protection of rare and endangered species
Water Quality Management	• Protection of minimum flows for water quality preservation • Low-flow augmentation from reservoirs • Assimilation of waste discharges from municipalities and industries • Assimilation of storm- and combined-sewer discharge

The existing institutional structure is insufficient for the effective management of the Rio Santa watershed. Communication and cooperation between agencies and with stakeholders is lacking, and institutions that are managing aspects of the water resource

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[42] http://www.minag.gob.pe/hidro_cuenca_princ.shtml
[43] Adapted from Heathcote 1998

regime in the region are substantially compartmentalized. For instance, in Huaraz, there are four Departments under the supervision of the Ministry of Agriculture: URGH (Unidad de Recursos Glaciologia y Hidrologia – responsible for monitoring glaciers, glacial lakes and glacier-related risk), Aguas Tecnicas ("Technical Waters" – responsible for municipal distribution of water), the Forestry Department and the Huascaran National Park. While all these departments are operating under a single institution (Ministry of Agriculture) and they are all working on water-related issues, there is little communication between the agencies.[44] Meanwhile outside agencies are also managing aspects of the water system in the region (e.g. Egenor manages specific lakes to maintain sufficient flows to operate the hydroelectric dam at Canon del Pato.) Clearly, these groups need to come together to create an optimal, integrated basin management plan.

While there is currently much discussion about the definition and application of Integrated Water Resources Management (IWRM), it is widely recognized as a potentially powerful tool for optimizing the allocation and use of water resources within a watershed. Ideally, the process allows for the maximization of benefits across the social, industrial and environmental spheres of water resources. An early definition of IWRM, then referred to as "Comprehensive management", came from a Canadian study and is outlined as follows:

- A watershed plan sufficiently comprehensive to take into account all uses of the water system and other activities that affect water flow and quality.
- Information about the watershed's full hydrological regime
- An analytical system, or model, capable of revealing the full range of impacts that would be produced by particular uses and developments in the watershed.
- Specified management objectives for the watershed, with criteria for assessing management alternatives in an objective and unbiased way
- Participation of all relevant regulatory agencies
- Provisions for public participation in determining objectives and in management decisions[45]

It is interesting to that the above definition of "comprehensive management" addresses many management qualities that are currently major issues in the Rio Santa Basin. Indeed, the *Master Plan for the Huascaran National Park 2003-2007* explicitly lists a set of water resource problems in the region:

- Electrical companies' lack of knowledge of environmental regulations.
- Poor understanding that water resources are becoming scarce.
- The water deficit is increasing over time.
- Lack of data on flows and discharge.
- Demand for water is in excess of supply.
- Lack of an updated inventory of glaciers.
- Lack of studies on the available supply of water for better allocation across uses.
- Conflicts between users over the provision of water (in the dry season.)
- Lack of a protocol for the exchange of information between everyone involved.
- Water tariffs paid by Egenor (energy company) do not cover the costs of conservation in National Protected Areas.
- Lack of organizational consolidation of water users.

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44 Discussion with Marco Zapata Luyo, 5/27/05

45 Pearse et al. 1985 by Heathcote 1998

- Absence of prevention, management and control measures for the short-, medium- and long-term.
- Absence of the appropriate policies and strategies for the integrated managemnt of water.
- Institutional relations are not fluid between irrigation districts, users and NGOs.
- Sectoral interference in the use of water.
- Absence of quantitative and qualitative studies of the impacts of the use of lakes by Egenor (hydroelectric company) on biodiversity in the region.
- High pressure above some of the new dams.
- Use of water in existing dams happens in the absence of management.
- Water pollution from tourism, livestock activities and mining.[46]

It is important to note that managing water-related risk is distinctly absent from the list of challenges besides the brief mention of "high pressure above some new dams." The fact that this list is missing potentially important items such as the disaster risk only reinforces the need for broad and open communication between regulators, managers and users. It might turn out that the concerns of the Huascaran National Park researchers are quite different than those of the residents of Huaraz, or agriculturalists outside Chimbote or local agencies working with limited budgets. Ideally, improved participation and coordination in the management process could provide a more complete picture of the resources, challenges and goals for water management in the region.

Currently there is watershed-based management, with an appointed director operating under the Commission for Water Resources, charged with "Proposing and formulating policies, development plans and prioritization plans for the use and protection natural water resources in the watersheds, and finally promoting its rational use."[47] However, the watershed–based management approach has yet to permeate the daily water management structures in the region. Additionally, user groups currently exist for irrigation allocation, but not for household and municipal use.[48] In other words, there are components of IWRM currently in place in the region, but an overarching, comprehensive approach/strategy is seriously lacking.

The implementation and coordination of an IWRM system is not "simple" because all the competing users (outlined in Table 2 above) need to come together and negotiate appropriate allocation and management strategies. However, in comparison to the less management-intensive "business as usual" strategy, the immediate transition to IWRM (with all its required mediation and negotiation) will be a simpler process in the long-run by avoiding future water scarcity through current improvements of management. In other words, the current management system is somewhat of a free-for-all with fragmented management, increasing withdrawals, increasing pollution and little overall understanding of the watershed system. Subsequently, while IWRM is not inherently simple, the simplicity of the current system is unsustainable and requires and upgrade.

The IWRM process requires heavy investments in human capital, but improved management of the watershed might avoid future financial and material investments associated with large infrastructure projects to augment and manipulate water resources as they become scarce. The reliance on human capital makes the IWRM more reliable because users and policymakers of a watershed can become an informed, autonomous

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[46] Translated by the author from Angeles et al. 2003

[47] Author's translation from INRENA website,http://www.inrena.gob.pe/irh/irh_estru_di_gestcuencas.htm

[48] http://www.inrena.gob.pe/irh/irh_infointeres_jusuarios.htm

unit that is less reliant on the dictates of central government. This decentralization becomes even more critical in the context of political instability at the national level as mentioned above. Additionally, management decisions will revolve around the direct perspectives of the users through participatory round table sessions and conferences, rather than based on the educated guesses (or politically motivated decisions) of faraway policymakers. Finally, as evidenced by the list of water problems identified by the Huascaran National Park Master Plan, the need for improved management is currently acknowledged in the region, which hints that the current landscape is fertile for a management transition to IWRM.

If the need for a comprehensive management approach seems to be accepted across agencies and users, how come it has not been implemented in the region? I would argue that there are three main obstacles preventing the development of an integrated approach: 1) lack of financial resources 2) vested interests in the *status quo* and 3) lack of an updated water policy at the national level.

The implementation of an IWRM plan is expensive for two main reasons: collection of information for decision-making (e.g. inventory of water use by sector, impacts of various uses, collection of hydrologic data, and application of computer models, all on-going) and the capital required to improve communication (e.g. updated communication infrastructure, increased jobs for data management and transfer, and conferences and meetings, all on-going). However, these funds for water management are currently scarce in the region.

This was not always the case. In the wake of the Yungay disaster in 1970, money flowed from the capital, Lima, to the *Callejon de Huaylas* for disaster relief as well as for the implementation of constructed works for glacial lake stabilization to prevent future disasters.[49] However, funding has steadily decreased with time as the horrible memories of the Yungay disaster slowly fade. Carey writes:

> Peruvian glaciologists and geologists working in Huaraz are…frustrated. The national government keeps slashing their budget, making it nearly impossible to monitor the Cordillera Blanca's ~ 600 glaciers and 374 glacial lakes or to maintain the region's 35 'lakes security projects' that have been completed since 1941.[50]

In other words, the regional experts rely on national level financing to perform their duties. If tourism in the region (~$3.6 million) by a mere 3%, then annual revenue for water management in the region could be increased by approximately $108,000. This would be an important injection of capital into the management of resource critical to maintain the influx of tourists. Furthermore, it certainly seems possible that the financing loop could be entirely closed within the watershed if the tourism tax was combined with additional taxes on large-scale agriculture and hydroelectric power production that more appropriately reflect the real costs of water use by these sectors. However, apart from a brief mention of inadequate tariffs paid by Egenor (hydroelectric company), I found no other information related to restructuring water finances. In fact, a roundtable of NGOs

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[49] Discussion with Nelson Santillán, 5/28/05

[50] Carey 2005 p. 123

put together a report on the integrated management of the Santa and proposed a many good ideas, but completely neglected to mention any ideas for cost recovery or economic sustainability.[51]

However, discussion can be cheap and it seems that gains could be made from preliminary discussions between users, decision-makers and researchers. After all, there is a significant amount of information readily available that could be discussed in the context of some basic characteristics of effective water management, as outlined by Heathcote:

1. Allows an adequate supply of water that is sustainable over many years.
2. Maintains water quality at levels that meet government standards and other societal water quality objectives.
3. Allows sustainable economic development over the short and long term.[52]

These preliminary discussions could even be focused on establishing a coordinated effort to request more funding from the national government or donor agencies. Regardless of the particular goal, increased communication will be an important first step towards an integrated management approach, and certainly possible in spite of little funding.

The second obstacle to IWRM was resistance by groups gaining from the current (mis)management. One candidate for this camp might be the hydroelectric company, Egenor, which seems to be operating relatively autonomously, unfettered by environmental regulation or inter-agency cooperation. In this case, they might not see any advantage to cooperating with other groups as a part of a basin-wide management program. However, it is always possible that synergies could be gained through coordination. As an example of potential gains through cooperation, Polak wirtes:

> More than a billion people in the world's poor rural areas do not have access to clean drinking water, and another billion peopler lack access to affordable small-plot irrigation. Yet, the world's experts in water and sanitation on the one hand, and irrigation on the other hand, rarely talk to each other, much less collaborate. This is unconscionable, because integrating access to drinking water and irrigation water at the village level provides an unparalleled opportunity to provide clean drinking water for the rural poor and at the same time expand the access of smallholders to the irrigation water they need to increase and stabilize their income from agriculture.[53]

In terms of Egenor, basin-wide cooperation may lead to an increased lifespan for the hydroelectric dam at Canon del Pato if water shortages are able to be avoided in the future through properly managed allocations.

The third obstacle I mentioned was the lack national water legislation that promotes integrated and participatory water management. The current National Water Law of Peru, focuses almost completely on distribution of water and hardly addresses conservation of water sources for future use.[54] This is an incomplete policy. If the national government does not promote the comprehensive management of water resources, then it is unlikely that regional departments will be able to single-handedly

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[51] Baes et al. 1999

[52] Heathcote 1998

[53] Polak 2002

[54] Discussion with Nelson Santillán, 5/28/05

implement IWRM regimes, especially in the context of limited funding. Finally, this narrow view of water resources is especially egregious considering that Peru is currently pegged to be a water-scarce country in 2025.

I would like to specifically note that human resources *is not* a limiting factor for effective management in the region. Throughout my time in Peru, I met many dedicated professionals completely committed to improving the management of water resources in the region. In fact, in one discussion, a colleague mentioned that he sometimes has trouble sleeping at night because he is so concerned about the proper management of the glacial lakes.[55] Finally, I was fortunate enough to sit in on an engineering class at the Universidad de San Pedro in Huaraz for a lecture by Marco Zapata Luyo (UGRH) and was pleased to see the enthusiasm and intelligence demonstrated by the class of future water managers in the region.

In addition to human resources, the region is rich in natural resources, which bring in tourists (and their dollars) from all over the world. A portion of tourism revenue should be directed towards the creation and implementation of an integrated water management strategy, so that all livelihoods can be sustained by a reliable water supply into the future.

Finally, the political will of the people is ripe for mobilization and participation in the management of the region's water. The public has shown its collective power vividly in the past. After the disasters in the region had wiped away an entire town, many townspeople hiked all the way up the mountain valleys to be sure that the "lakes stabilization projects" were underway and effective.[56] If the community was willing to go to such great lengths to protect themselves from immediate danger, then it is likely they will be willing to participate in planning that will prevent the dangers of future water scarcity.

Conclusion

The Rio Santa watershed is a region blessed and cursed with water resources. On the one hand, the massive glaciers and multitude of glacial lakes represent a major resource for clean water as well as tourism and hydroelectric power generation; and on the other hand, climate change is transforming these water storage systems into potential sources for devastating natural disasters. The complex nature of the watershed requires a complex management approach to ensure that overall social, economic and environmental benefits are maximized and costs are minimized. These management efforts will need to be fundamentally participatory, or will be doomed to failure. Schramm writes:

> Planning is done for people and people have different and often competing wants, desires and hopes; political institutions should be designed to meet those wants. One of the best ways to condemn planning efforts to oblivion or failure is to turn the task over to a self-contained, isolated team of experts who fail to communicate with one another, the people their plans are to serve, and those with political, decision-making authority. Within this dynamic, competing world of human wants and values there is no ultimate reality or single-dimensioned optimum that can be determined by scientific methods alone.[57]

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[55] Ibid.

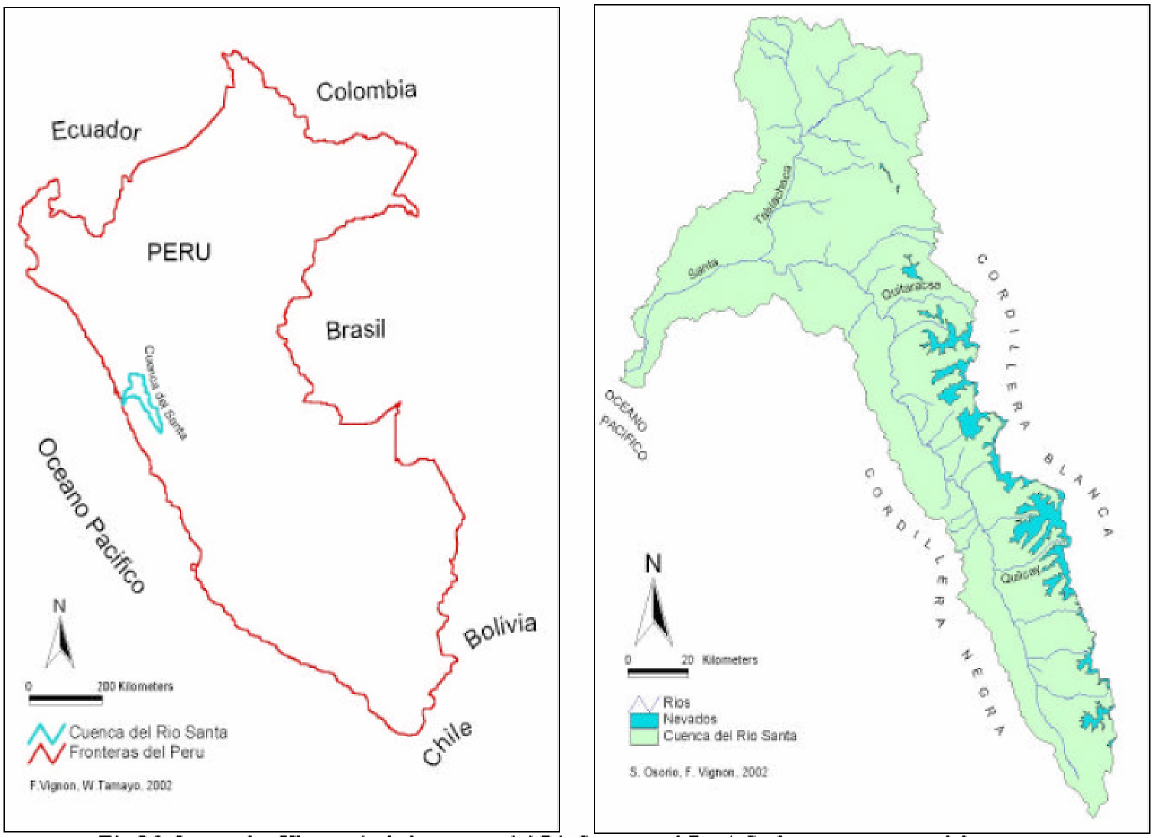
[56] Carey 2005

[57] Schramm 1980 by Heathcote 1998

Perhaps inspiration for improved interactions with water resources in the region can be found within the nearby ruins of ancient civilizations. A quick survey of the Inca geography reveals that all lasting structures were built above river valleys (not in potential avalanche paths) and in locations with carefully cultivated water distribution networks. In fact, the stone aqueducts of the Incas, constructed over 500 years ago, still carry water to the Macchu Picchu and other Inca ruins to this day – undeniable evidence of integrated water planning of long ago.

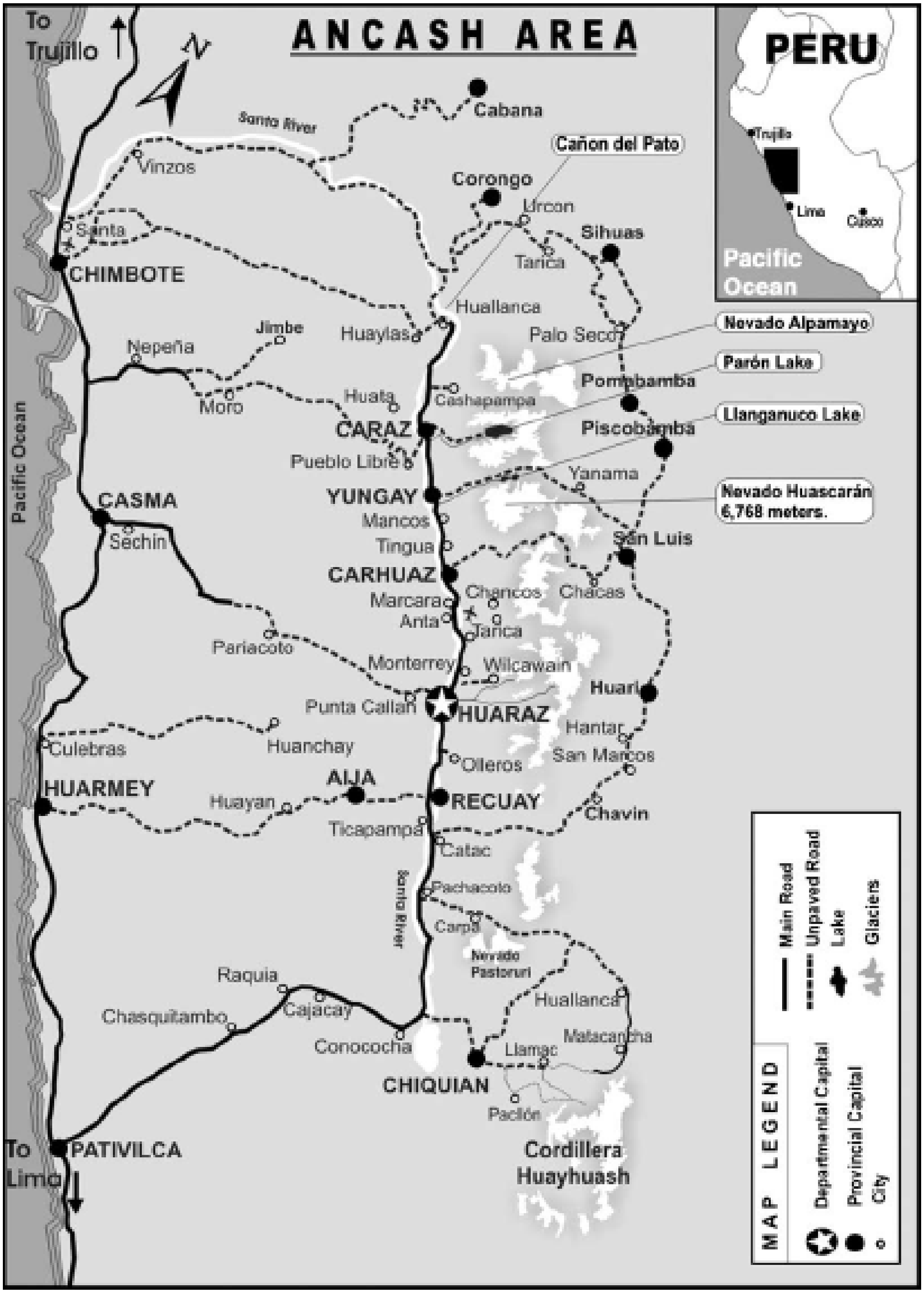
Appendix of All Maps and Figures

Map 1 – Map and Location of the Rio Santa Watershed[58]



58 Yerren, et al., 2003

Map 2. Department of Ancash and Cordillera Blanca, Peru.[59]



59 Map by Tito Olaza as referenced by Carey 2005

Figure 1. Precipitation and Humidity for the town of Huaraz[60]

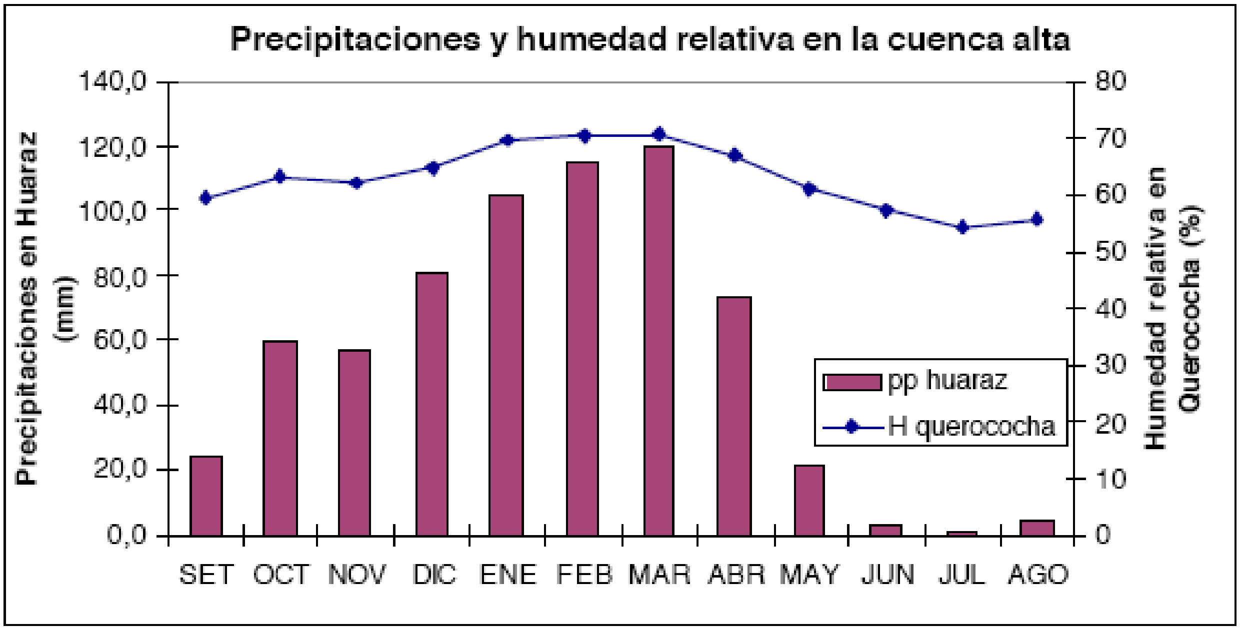
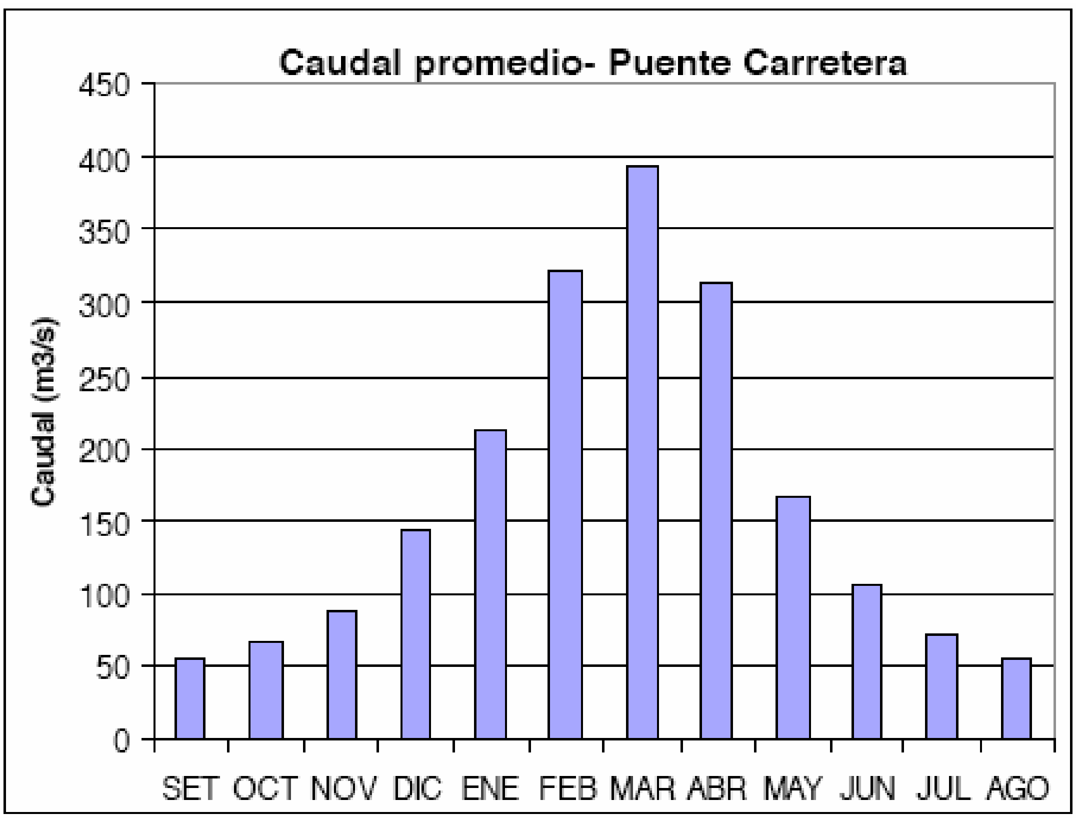


Figure 2. Monthly Flow at the Outlet (*Puente Carretera*) of the Rio Santa watershed[61]



[60] Yerren, et al., 2003
[61] Yerren, et al., 2003

Figure 3. Accumulation and Melting of Cordillera Blanca Glaciers in Wet Season and Dry Season[62]

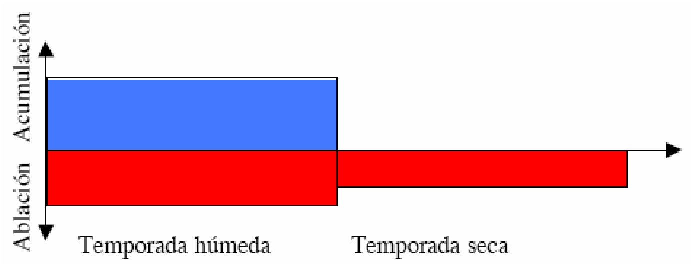


Figure 4.

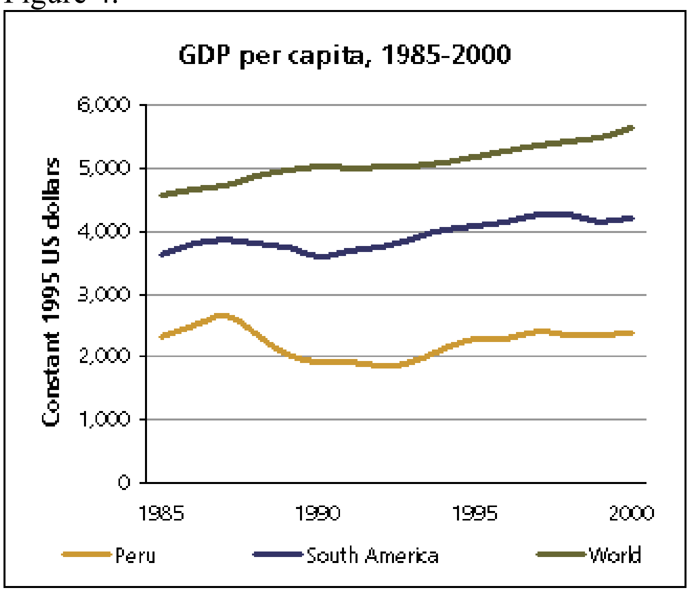
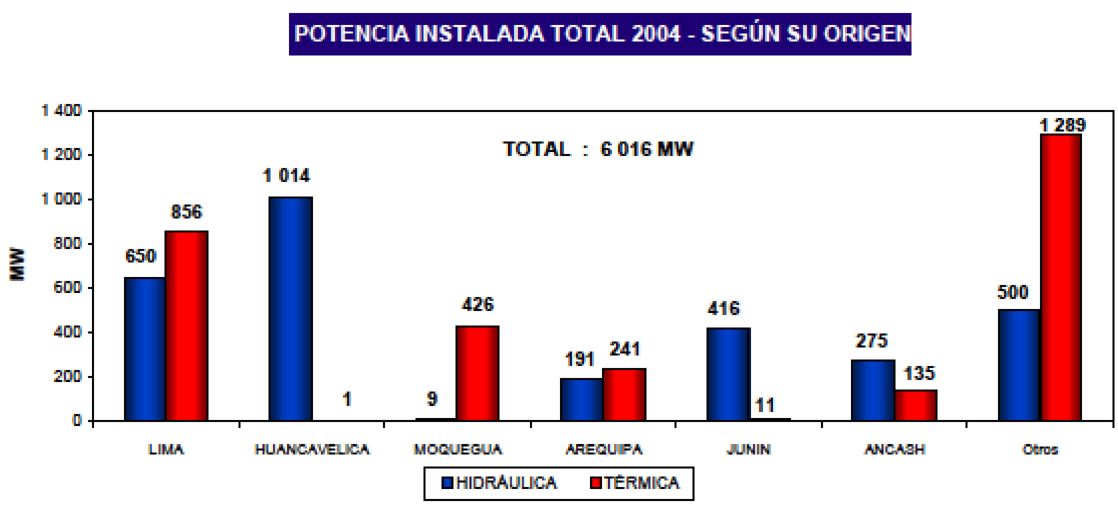


Figure 5. Power Generation by Department[63]



[62] Yerren, et al., 2003
[63] http://www.minem.gob.pe/archivos/dge/publicaciones/anuario2004/generacion.pdf

Figure 6. Example of a Lake Stabilization Project[64]

[64] Zapata Luyo, M. 2005

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