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ADAPTATION TO CLIMATE CHANGE:

CASE STUDY – GLACIAL RETREAT AND ADAPTATION OPTIONS IN PERU'S RIO SANTA BASIN
(DRAFT FINAL)

January 2011

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COVER PHOTO: Pastoruri Glacier, Cordillera Blanca, Peru

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DISCLAIMER

This report was prepared by Daene C. McKinney, the University of Texas at Austin, Glen Anderson, International Resources Group, and Alton Byers, The Mountain Institute. The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government

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ACRONYMS

ANA	Autoridad Nacional del Agua
ATDR	Technical Administration of Irrigation District
CAR	Regional Environmental Commission
CCSM	Community Climate System Model
CEDEP	Ecumenical Centre for Promotion and Social Action
DIGESA	Directorate General Environmental Health
ENSO	El Niño/La Niña-Southern Oscillation
GLOF	Glacial Lake Outburst Floods
GTH	The Huascaran Working Group
HNP	Huascaran National Park
INRENA	National Institute of Natural Resources
IPCC	Intergovernmental Panel on Climate Change
IRH	Administration in Water Resources
ITCZ	Inter-tropical Convergence Zone
LRH	Ley de Recursos Hídricos (Water Resources Law)
MINAM	Ministry of Environment
NCAR	National Center for Atmospheric Research
O&M	Operations and Maintenance
PRONAMACHCS	National Watershed Management and Soil Conservation
RBH	Huascaran Biosphere Reserve
UGEL	Regional Section of the Ministry of Education
UNFCCC	United Nations Framework Convention on Climate Change
V&A	Vulnerability and Adaptation
WRM	Water Resources Management

I. INTRODUCTION

1.1. BACKGROUND

1.1.1. PERU

Peru is the third largest country by area in South America (1,285,000 km^2), after Brazil and Argentina. There are three main regions of the country: the Pacific coast, the mountainous Andes, and the Amazon rainforest to the east. The Andes control the climate of Peru; Atlantic air masses, blocked by the mountains, provide a warm, humid climate in the east, and the cold Humboldt Current creates a dry climate along the Pacific coast. The annual oscillation of the inter-tropical convergence zone (ITCZ) causes annual dry (May to October) and wet (November to April) seasons, with the length of the rainy season diminishing from north to south, and precipitation from east to west (Chevalliar et al., 2004). Water resources and population are very unevenly spread across Peru, with the majority of the population (about 70%) living near the coast, a region that receives less than 2% of the country's available water (Consejo Nacional del Ambiente, 2001; Price and Recharte, 2008). Nearly all the water that is available in the coastal region comes from rivers of glacier origin on the western slopes of the Andes (Chevalliar et al., 2004).

1.1.2. RIO SANTA BASIN

The Rio Santa Basin is located in the Ancash "department"[1] of Peru about 400 km north of Lima (Fig. 1). The river runs north from the headwaters in the Callejón de Huaylas valley between the Cordilleras Negra and Blanca mountain ranges. The Cordillera Blanca is the most extensively glaciated tropical region in the world (Kaser *et al.*, 2003). The highland areas of the basin feature extensive small, rural subsistence farming and grazing. The middle basin supports some small, irrigated farming and is home to the Cañon del Pato hydroelectric facility, one of the largest in Peru. The river outlet at the Pacific Ocean is near the city of Chimbote, an area with major commercial agricultural development in the Chavimochic and Chinecas Irrigation Project areas.

The Rio Santa Basin from the high mountains to the coastal areas is projected to experience increased vulnerability to changes in water resources availability, mostly due to changing climate and the impact on the region's glaciers. This is projected to result in, among other things, decreased glacier area, decreased glacier melt water in the dry season, increased glacier lake and avalanche risk, decreased dry season water availability for municipal and irrigation use, and reduced dry season flows for hydropower generation (Kaser et al., 2003; Mark and Seltzer, 2003; Francou and Coudrain, 2005); Juen et al., 2007; Mark et al., 2010). The middle basin, Callejón de Huaylas, is one of the hardest hit regions of the world in terms of floods from glacial lakes and large ice avalanches. Basin water users have been adapting to this changing glacial and water resource situation in various ways, many of which will be illustrated below.

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[1] A regional administrative area of Peru

1.2. CASE STUDY OBJECTIVES

The case study is designed to facilitate dialogue in the Rio Santa Basin on options for improving water resources management, accounting for non-climate stresses, and mainstreaming climate concerns into management plans and practices. The case study is structured to apply USAID's Vulnerability and Adaptation (V&A) approach for assessing vulnerability and identifying and assessing adaptations that would reduce exposure and/or sensitivity to climate change and variability and/or increase adaptive capacity. The overall goal of the V&A assessments is to promote climate-resilient development in the Basin.

1.3. ROADMAP

The remainder of the case study is organized into five chapters. Chapter 2 provides a detailed description of the Rio Santa Basin, its topography, geology, climate, people, and water resources. There has been considerable research on the high mountain ecosystems and the impact of glacial retreat and climate change. However, for the purposes of the case study, more attention is given to water resources and to economic activities that depend on water resources. Chapter 3 examines non-climate and climate stresses and their implications for water resources, economic sectors, and livelihoods.

Chapter 4 provides an overview of adaptation options that can reduce vulnerability to climate variability and change. The list of adaptation options is drawn from three sources: (1) Peru's National Adaptation Plan; (2) Workshops and stakeholder meetings in the Rio Santa Basin; and (3) Case study team's review of literature and site visits to the upper and lower basins. The list of adaptation options resulting from these sources is screened and developed into five categories: (1) water management; (2) agriculture; (3) disaster risk management; (4) ecosystems; and (5) capacity building.

The final chapters include an assessment of adaptation options enumerated in Chapter 4 and recommendations for short- and medium-term priorities to promote climate-resilient development in the Rio Santa Basin.

2. CHARACTERISTICS OF THE RIO SANTA BASIN

This chapter presents a brief overview of water resources in the Rio Santa Basin. Background information is presented on the topography, demographics, geology, climate, water resources and current water infrastructure.

2.1. TOPOGRAPHY AND DEMOGRAPHICS

The Rio Santa Basin runs from the Chuquicara Basin in the north to the area south of Lake Conococha (> 4,000 m) to the coast near Chimbote (Exhibit 1 on the next page). The headwaters of the Rio Santa are in the Cordillera Blanca, the world's most extensive tropical high mountain range with more than 30 peaks in excess of 6,000 m above sea level and about one-quarter of all tropical glaciers (~ 600 km^2) (Kaser *et al.*, 2003). The Rio Santa, with 28 sub-basins, has a length of 316 km, an area of 12,200 km^2 (Mark et al., 2010), and an average annual flow of 5,994 million cubic meters (m^3) (Technical Assessors Associates, 2002). The Rio Santa has an average slope of 1.4%, which becomes more pronounced in the area between the confluence of the Cedros and Quitaracsa rivers, forming the so-called "Cañon del Pato", where it reaches a slope of 4% (Quesquen-Rumiche, 2007). The basin can be separated into three zones by elevation: the high mountain areas (> 2000 m), the Callejón de Huaylas valley region (1000–2000 m), and the coastal region (< 1000 m). Each of these regions has distinct socio-economic activities and climate characteristics.

Lake Conocoche at the headwaters of the Rio Santa

The source of the Rio Santa is Lake Conococha (4080 m), which is fed by small streams of the Cordillera Negra and Lake Macar in the Tuco River originating in the glaciers of the Nevado de Tuco in the Cordillera Blanca (Technical Assessor Associates, 2002; Price and Recharte, 2008). The Rio Santa runs north from Lake Conococha between Cordillera Blanca and Cordillera Negra, forming the Callejón de Huaylas. Further downstream, after passing the Cañon del Pato, at the confluence with the Rio Manta, the river turns west and finally arrives at the coast near the city of Chimbote. (Price and Recharte, 2008)

The high mountain areas (upper basin) and Callejón de Huaylas regions are populated by indigenous, Quechua-speaking farmers (campesinos) living in mountain villages, mixed with monolingual Spanish speakers and bilingual Quechua-Spanish speakers in small towns and cities along the Rio Santa. The urban-based groups are politically and economically dominant. The upper basin residents are engaged in livelihood strategies of subsistence and market-based agro-pastoralism, and tourism (Young and Lipton, 2006).

Within the Rio Santa Basin there are 60 municipalities (eight of which are located only partially in the basin) with a population from the 2005 census of approximately 1,697,221 people, of which 806,749 are in the mountainous Ancash Department and 890,472 are in the coastal La Libertad Department, including the city of Trujillo a major water consumer in the basin. There are 187,749 inhabitants in the upper basin, 244,878 in the middle basin and 1,264,595 in the lower basin (Hendriks, 2008). Bury et al. (2010) note that 267,000 people inhabit the upper Rio Santa Basin with more than half of the population concentrated in major urban and peri-urban clusters along the Rio Santa, including the cities of Caraz, Yungay, Carhuaz, Recuay, Catac, and Huaraz.

Exhibit 1. Location of the Rio Santa Basin.

Source: TMI, 2010

The social and economic characteristics of the Callejón de Huaylas are representative of other Peruvian highland regions. The rural population, comprised mostly of traditional Quechua peasant families, is engaged in mostly subsistence agriculture in the high valleys and cattle pastures. Callejón de Huaylas cities are intermediate in size and characterized by rapid growth. The mining and quarrying industry is the largest economic sector and there are two major mines in the region. Tourism is also a major economic sector in the region and is one of the few non-traditional income sources for rural families living in the Cordillera Blanca (Price and Recharte, 2008).

2.2. GEOLOGY AND GLACIERS

2.2.1. GEOLOGY AND GLACIERS OF THE CORDILLERA BLANCA

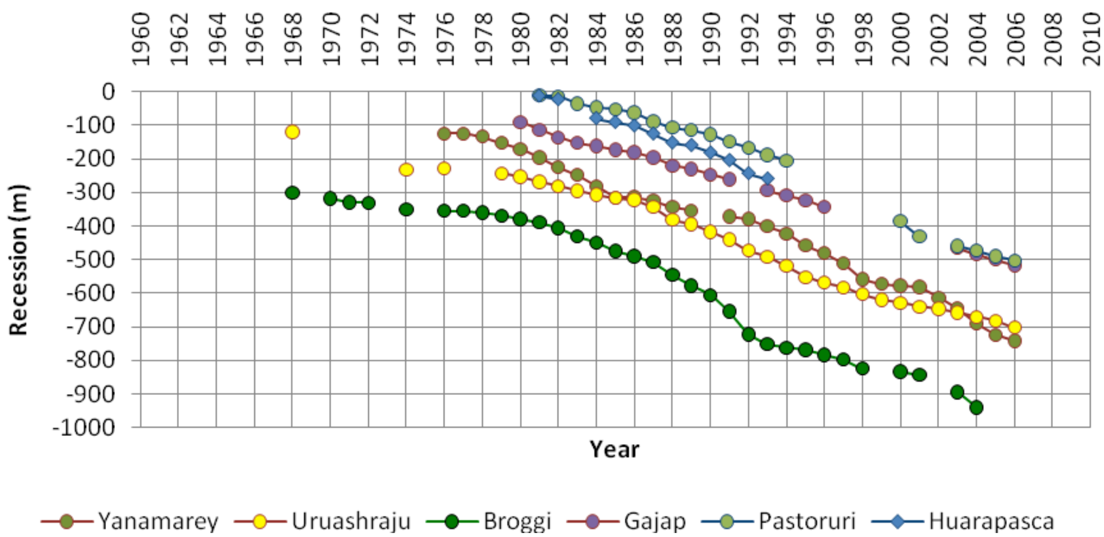
The Cordillera Blanca, located approximately 180 kilometers (km) from the Peruvian coast where the Nazca plate dips below the South American continental plate, is a relatively recent granodioritic batholithic intrusion into folded and faulted Mesozoic marine sediments (Young and Lipton, 2006; Mark, 2008; Sevinc, 2009). Large-scale uplift has produced the current Cordillera Blanca and Cordillera Negra ranges with the Callejón de Huaylas in between them forming the Rio Santa Basin. The uplift of the high peaks, over 200 surpassing 5000 m elevation, has been driven to a great degree by glacial erosion (Mark, 2008). Mt. Huascaran has a height of 6780 m rising 2500 m above the Rio Santa valley in less than 15 km (Ricker, 1977). This great height, plus global cooling periods, has led to major and repeated glaciation of the region.

Glaciers and ice caps (excluding the large ice sheets of Greenland and Antarctica) cover about 530,000 km^2 of the Earth and have a volume of approximately 92,000 km^3 (Lemke *et al.*, 2007). Variations in climate affect glacial advance and recession (ablation) and the length of the seasons associated with each process. Estimates of glacier volume tend to be highly uncertain due to the unknown nature of the topography of the underlying bedrock. Glacier extent is controlled by energy fluxes and snowfall and it is negatively correlated with air temperature "air temperature; that is, glaciers grow when snow and ice accumulate, and they recede as temperatures rise (Lemke et al., 2007).. Glaciers worldwide have shrunk by varying amounts from their recent maximum in the mid-19th century, but the recession has become very pronounced since the 1980s.

In the tropics, the annual variation of air temperature is smaller than its diurnal variation, so glacier ablation (melting, evaporation, sublimation, calving, or erosion) occurs year-round and accumulation is controlled by the seasonality of precipitation (Kaser and Osmaston, 2002). Glacial variations (ablation and accumulation) are mainly a function of humidity and the consequent effects of various components of the glacier energy and mass balance (precipitation, cloud cover, and global radiation) (Kaser and Georges, 1997; Kaser and Osmaston, 2002). Changes in glacier extent tend to lag behind climate changes by a few years in tropical mountains (Kaser *et al.*, 2003). About one-quarter of the world's tropical glaciers are found in the Cordillera Blanca. In 1970 there were about 722 glaciers with

Pastoruri Glacier has retreated significantly over the past decades elevations ranging from 3000 to 6800 m covering about 723 km² (Kaser and Osmaston, 2002). This estimate was revised downward to 658 km² by reinterpretation of the 1970 data in 2004 (Georges, 2004). Tropical glaciers, like the ones dominating the Cordillera Blanca in the Rio Santa Basin, have shrunk by varying amounts from their recent maximum in Little Ice Age (LIA - maximum glacial advance around AD 1630±27 (Vuille *et al.*, 2008). Racoviteanu *et al.* (2008) found 571 glaciers covering an area of 569 km² and experiencing a decrease in glacier area of -0.68% per year over the thirty-three year period 1970 - 2003. This represents a 22.4% decrease in area from 1970 to 2003. Glacial retreat has continued and Exhibit 2 (adapted from Portocarrero, 2008) shows the cumulative annual retreat (in meters) of several Cordillera Blanca glaciers up to 2006 (Broggi disappeared in 2004).

Exhibit 2. Glacier retreat in the Cordillera Blanca to 2006



Source: Portocarrero *et al.* (2008)

2.2.2. GLACIAL RISKS IN THE RIO SANTA BASIN

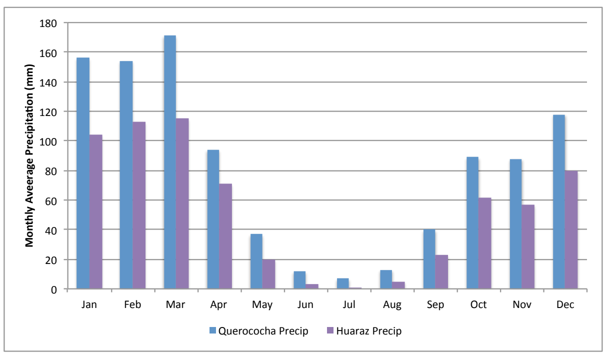
The glacially-dominated Rio Santa Basin faces unique challenges in adapting to recent and continuing global climate change, including projected reduced dry season flows and increased threats of glacial lake floods, both of which have strong impacts on regional social, environmental and economic systems. As glaciers have melted in the Andes, new glacier lakes have been created or enlarged. Usually contained by dams of loose boulders and soil, these lakes present a risk of glacial lake outburst floods (GLOF). GLOFs unleash stored lake water, often causing enormous devastation downstream that can include high death tolls as well as the destruction of valuable farmland and costly infrastructure (e.g., hydroelectric facilities, roads, and bridges). The Cordillera Blanca in Peru has a long history of glacier-related catastrophes that has been recorded since 1725 (Carey 2010). A notable example is the 1941 Lake Palcacocha GLOF disaster in Huaraz, Peru that killed nearly 6,000 people within minutes (Hambrey and Alean 2004; Carey 2005; Carey, 2010). Events such as the 1941 GLOF prompted the creation the Glaciological Unit in Huaraz that has developed methods to successfully drain and control 35 lakes throughout the range (Carey 2010). Nevertheless, these precautions have not fully addressed the threat of GLOFs; on April 12, 2010 following an extremely warm year, an ice avalanche the size of several football fields, fell into Lake 513a and caused extensive flooding downstream, destroyed at least 50 homes, but resulted in loss of life (La Republica 2010).

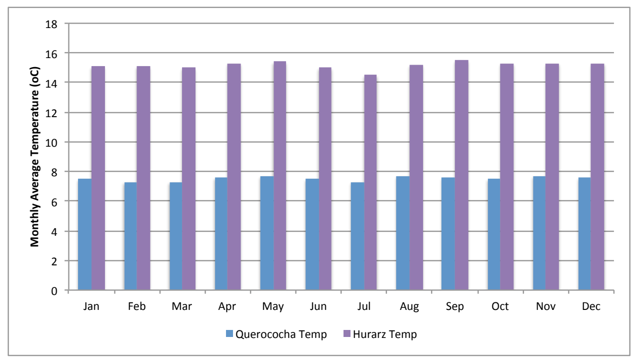
2.3. CLIMATE

2.3.1. TEMPERATURE

The climate in the tropics is mainly characterized by the oscillation of the ITCZ and the trade winds resulting in a minor annual air temperature seasonality but remarkable atmospheric moisture content seasonality (Maurer, 2009). Few climate records exist in the Rio Santa Basin (Maurer, 2009). Average annual temperatures in the mountains of the Cordillera Blanca range from 0^{o}C to 9^{o}C with slightly higher temperatures during the wet season (see Exhibit 3 below) and an annual temperature range that is much smaller than the diurnal variation (Kaser *et al.,* 1990). Air temperature fluctuation in the central portion of the Callejón de Huaylas over a year is also less variable than the daily temperature range (Baraer et al., 2009). Both the Querococha station (3980 m) in the Cordillera Blanca and Huaraz station (3063m) in the Callejón de Huaylas show small variations (Mark and Seltzer, 2003).

Exhibit 3. Average monthly precipitation and temperature at Huaraz station (3063m, H-Precip, H-Temp) in the Callejón de Huaylas and Querococha station (4012m, Q-Precip, Q-Temp) in the Cordillera Blanca





Source: Tarazona-Santos (2005)

2.3.2. PRECIPITATION

In the Cordillera Blanca, the wet season is from October to April, when about 70 – 80% of annual precipitation falls and the Inter Tropical Convergence Zone (ITCZ) is over the region (Kaser *et al.*, 2003). During the dry season from May to September, the ITCZ moves north of the region. The Cordillera Blanca creates a high barrier (~ 180 km long and almost 7000 m high) between the humid Amazon basin and the extremely dry Peruvian coastal region (Kaser and Georges, 1999). The Amazonian side of the cordillera is two to three times wetter than the Pacific side (Racoviteanu *et al.*, 2008). Mean annual precipitation varies from 1520 mm at Safuna (4275 m) on the eastern side to 165 mm at Hidroelectra (1386 m) on the western side (Kaser *et al.*, 2003). Precipitation is highest along the Cordillera Blanca and lower in the Callejón de Huaylas valley. The wettest months are from January to March, accounting for more than 50% of annual precipitation, and the driest months are from June to August, accounting for less than 2% (Georges, 2005; Juen, 2006; Vuille *et al.*, 2008).

2.4. WATER RESOURCES

2.4.1. WATER RESOURCES IN PERU

Peru has three very distinct climatic regions: a very arid western coastal zone, a central high mountainous zone (Andean region), and a humid tropical jungle zone (dense Amazonian rainforest) to the east. With its population concentrated in the dry coastal zone, Peru is considered a "water-scarce" country. The availability of water in the western watersheds, critical to the local population as well as the national economy of Peru, is becoming a critical issue as glacier retreat has become extensive and impacts on dry season river runoff are projected to increase. The total water availability in the main regions of Peru is shown in Exhibit 4 (below) and the use of the water in different sectors is described in Exhibit 5 (below). Total consumptive water use was 20,072 million m^3/year in 2009, including: 80% in agriculture; 18% for municipal and industrial; and 2% in mining, while non-consumptive use (hydroelectric energy production) is about 11,139 million m^3/year (ANA, 2009).

Exhibit 4. Annual Availability of Surface Water in Peru (2009)

				Water Availability			
	Area	Population		Surface Water	Groundwater	Total	
Region	(km^2)	(persons)	(%)	(million m^3)	(million m^3)	(million m^3)	(%)
Pacific	278 482	18 620 070	66	35 632	2 849	38 481	2.2
Atlantic	957 822	8 680 616	30.8	1 719 814	-	1 719 814	97.3
L. Titicaca	48 911	920 078	3.3	9 877	-	9 877	0.6
Total	1 285 216	28 220 764	100	1 765 323	2 849	1 768 172	100

Source: ANA - DCPRH 2008 (http://www.ana.gob.pe/snirh/dsp_disphidrica.aspx)

Exhibit 5. Annual Level of Water Use in Peru (2009)

	Consumptive Use					Non-consumptive Use	
	Municipal	Agricultural	Mining	Industrial	Total	Energy	Total
Region	(million m^3)	(million m^3)	(million m^3)	(million m^3)	(million m^3)	(million m^3)	(million m^3)
Pacific	2 086	14 051	302	1 103	17 542	4 245	4 245
Atlantic	345	1 946	97	49	2 437	6 881	6 881
L. Titicaca	27	61	2	3	93	13	13
Total	2 458	16 058	401	1 155	20 072	11 139	11 139

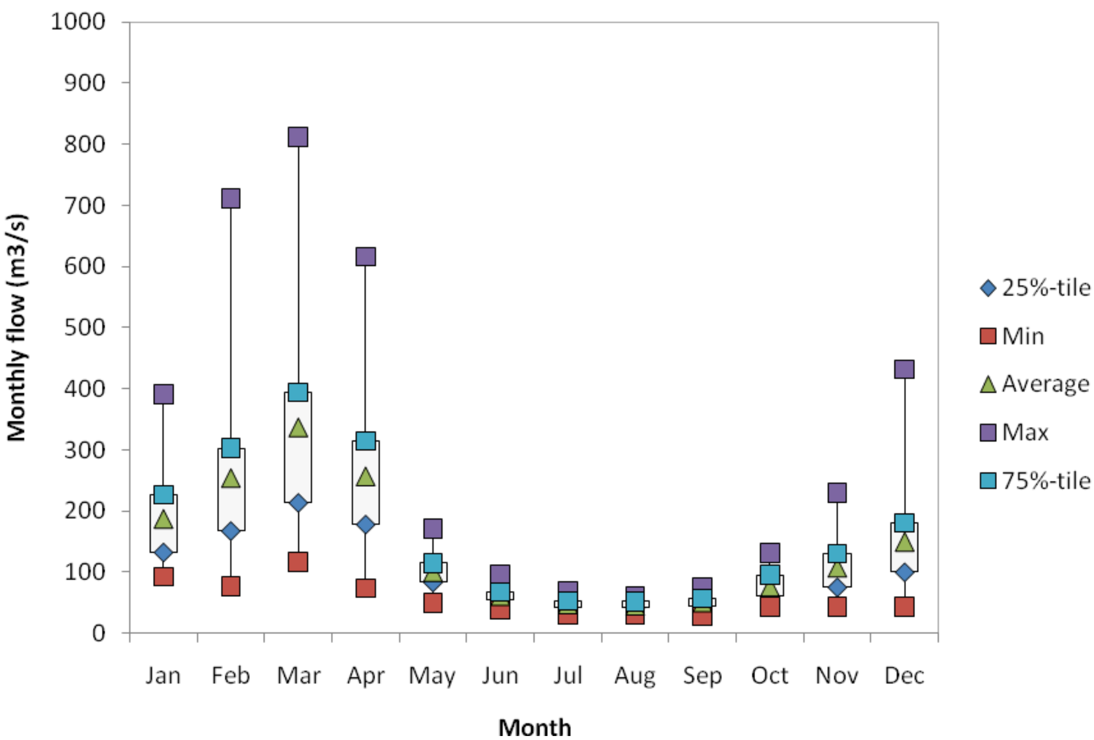
Source: ANA, (2009)

The Rio Santa, which drains the western slopes of the Cordillera Blanca, has the second largest flow of the Peruvian coastal rivers, with an average annual flow of approximately 5,591 million m^3/year (177 m^3/year) (ANA, 2009). Twenty of the 23 tributary streams of the Rio Santa arise from the glaciers of the Cordillera Blanca.

Community and Rio Yanamito (on left) and Rio Santa (at middle right)

Condorcerro station is the main station that records flows arriving at the coast and available to the major coastal irrigation projects at Chavimochic and Chinecas. Exhibit 6 shows that the flows in the lower basin have significant variability and are somewhat skewed toward the lower flows, but do experience significant high flows in the wet period. During the dry season (May to September) runoff in the Rio Santa is dominated by glacier melt and the continual glacial melt buffers variations in annual and long-term runoff (Kaser *et al.*, 2003; Juen, *et al.*, 2007). As a result of the region's two distinct seasons, the flow of the Rio Santa fluctuates significantly over the year, with a maximum flow of approximately 400 cubic meters per second (m3/sec) in March and a minimum flow of about 55 m3/sec in August-September. The outer tropical climatic environment and the high altitude of the Cordillera Blanca provide a large reservoir of frozen water that acts as seasonal storage.

Exhibit 6. Average monthly flows (m3/sec) for the Condorcerro station in the Rio Santa Santa Basin (1956 – 2008)



Source: Chavimochic Special Irrigation Project, 2010

The proportion of glacier melt contributing to stream discharge varies by catchment according to percent of glaciated surface area and seasonally in high-elevation tropical regions with glacier melt accounting for a larger proportion of discharges in the dry season (Kaser and others, 1990; Kaser, 1995; Kaser and Georges, 1997; Mark and Seltzer, 200). Precipitation and streamflow are correlated in most of the sub-catchments of the Cordillera Blanca entering the Callejón de Huaylas with higher flow during October – April (Mark and Seltzer, 2003). A significant amount of annual stream discharge to the Rio Santa is supplied by melting glacier ice. At least one-third of the water discharged hydrologically each year comes from glacier melt. The relative melt proportion of stream discharge is greatest during the dry season, and also diminishes downstream from the glacier as precipitation runoff and ground-water discharge are mixed into the streams (Mark and Seltzer, 2003). Mark *et al.* (2005) provide a conservative estimate that two-thirds (66%) of dry season Rio Santa water in the Callejón de Huaylas reach is Cordillera Blanca water, and 40% is from glacier melt.

2.4.2. WATER USE IN THE RIO SANTA

Detail of viaduct from Lake Llanganuco to Yungay

Water uses in the basin include withdrawals from rivers and lakes for households and small-scale irrigation to towns and cities in the Callejón de Huaylas for domestic, municipal, and industrial purposes, including agriculture and mining. The water from this river supplies all of the following: a large area of mostly small-scale, intense agricultural activity between 2,000 and 4,000 m elevation; a hydroelectric plant representing 5 per cent of Peru's total energy production capacity; large-scale intensive commercial agriculture in the coastal area with two large irrigation projects for export crops (Chavimochic and Chinecas); and a large part of the drinking water to two major urban areas on the coast with a combined population of more than one million people (Chimbote and Trujillo) (Painter, 2007). The Rio Santa flow in the dry season (June-September) is, on average, below 47 m^3/sec (see Exhibit 6 above), a threshold flow rate that indicates an emergency situation for the agricultural and hydropower sectors (Hendriks, 2008). In the wet season, flow rates are adequate to meet agricultural and hydropower requirements.

AGRICULTURE

Subsistence farming, in the upper basin, as well as large-scale commercial farming, in the coastal area, can be found in the Rio Santa Basin. The total irrigated area that receives water from the Rio Santa is about 252,500 hectares (ha) (Rojas and Pagador, 2000) of which 54,000 ha is located in the upper, Callejón de Huaylas part of the basin, and 198,500 ha are in the Chavimochic and Chinecas irrigation areas on the coast.

- Chinecas Project2 with about 52,000 ha irrigated in the provinces of Santa and Casma. This irrigation district also uses water from the ephemeral rivers Santa, Lacramarca, Nepeña and Sechin.
- Chavimochic Project3 which irrigates about 144,500 ha of agricultural land, produces 2,500 kW of electricity, and supplies 20 million m3 of drinking water for metropolitan Trujillo.

DOMESTIC USE

Municipal water demand in the upper basin is approximately 300 liters per capita per day on average for urban and rural populations (Condom *et al.*, 2009). This includes the upper basin cities of Recuay, Huaraz, Carhuaz, Caraz, and Yungay, supplied by drinking water from the tributaries of the Cordillera Blanca. The Rio Santa also supplies drinking water to the coastal cities of Trujillo (1000 liters per sec average) and Chimbote (500 liters per sec average).

HYDROPOWER

Ancash generates about 5.2% of electricity in Peru, with the Río Santa playing a significant role in supplying water to the Cañon del Pato and Santa Rita hydropower plants (Galewski, 2010).

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[2] www.pechinecas.gob.pe

[3] www.chavimochic.gob.pe

The hydroelectric power plant at Cañon del Pato began operation in 1958 with 50 megawatts (MW) installed capacity (extended to 263 MW between 1967 and 1999) (Duke Energy, 2010). The Cañon del Pato hydroelectric facility uses the uncontrolled (run-of-the-river) flow of the Rio Santa and the releases from four Cordillera Blanca lakes (Paron, Cullicocha, Aguascocha, Rajucolta,) to generate electricity. The four glacial lakes are anticipated to provide 70 million m^3 of flow in the dry season (Exhibit 7). This is about one-half of the maximum flow based on permitted release rates from the four lakes.

Exhibit 7. Lakes Providing Storage for Cañon Del Pato Hydroelectric Facility

Lake	Date of Operation	Maximum Storage Volume (million m3)	Permitted Release Rate (m3/sec)	Maximum Flow for 120 day dry season (million m3)
Cullicocha	1992	8	4	41.5
Aquascocha	2002	8.5	2	20.7
Rajucocha	2005	10	2.5	25.9
Paron	1992	35	5.5	57.0
Total		61.5	14	144.1

Source: Duke Energy staff, Cañon del Pato Hydroelectric Facility, Peru

Lake Paron, the largest lake in the Cordillera Blanca (4190 m) and the key lake in hydropower production at the Cañon del Pato facility, has been the source of recent conflict between the hydroelectric facility operator (currently Duke Energy) and the local community. On 29 July 2008, farmers from the Huaylas Province occupied the Cañon del Pato facility in protest for excessive releases from Lake Paron, which had resulted in a 50% drop in the lake levels. Originally, Duke Energy was licensed to release 1 m^3/sec from the lake for power generation purposes, but this was subsequently increased to 5.5 m^3/sec. Duke progressively increased releases beyond that level, surpassing the maximum safe release is 4 m^3/sec, the licensed release rate of 5.5 m^3/sec and as much as 10 m^3/sec (NACL, 2009). The excessive flow rates resulted in erosion of the basin, destruction of the irrigation system inlet and negatively impacted municipal water quality downstream. The protest led to the creation of a multi-sector commission to oversee the National Water Authority's development of a water use plan for Huaylas Province and find a resolution to the conflict.

WATER QUALITY INCLUDING SEDIMENT

The water quality of the Rio Santa is degraded from municipal and industrial waste. The basin suffers from basic problems of water pollution, as none of their cities have wastewater treatment systems, so all sewerage systems are dumping human wastes directly into the river and as a result studies show high levels of total coliform (Spang, 2006). Only three municipalities have operational programs for wastewater treatment. In addition, 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 (Price and Recharte, 2008).

According to local Ministry of Agriculture representatives in Huaraz, the Rio Santa is "pretty much lost due to contamination" (Villavicencio, personal communication, March 1, 2010). The tributaries are relatively clean, but the main stem of the river below Catac is so contaminated that the government has prohibited all diversions from the river. Mining wastes are the main source of the contamination. The diversions from the river have been reduced by 20% so far compared to the 1990s and the Ministry of Agriculture is planning further reductions. There is a remediation project under way for the mine waste, but it is not known how long it will last and what the outcome will be. The irrigation projects near Chimbote and Trujillo divert and use the water anyway. Trujillo has to treat the water before using it as a municipal supply, but Chimbote does not treat the water. The irrigation projects, Chinecas and Chavimochic, incur additional operating costs because they must treat the water to reduce sediment before distributing it to structures and drip irrigation systems. There have been several studies on water quality in the basin that have identified problematic parameters – phenol, sulfur, arsenic, cadmium, mercury, nickel, lead, zinc, nitrate, and coliform – which have exceeded maximum allowable limits for domestic water supply (Price and Recharte, 2008).

2.4.4. WATER RESOURCES MANAGEMENT IN THE RIO SANTA BASIN

NATIONAL LEVEL INSTITUTIONS AND POLICY

The 1993 Constitution declares that natural resources are the renewable and nonrenewable heritage of the nation and the state is sovereign in their use. That is, in the case of water, the state is the owner of the asset even if the same rights are granted to others. The newly created National Water Authority (Autoridad Nacional del Agua – ANA, established in December 2008), the newly approved Water Resources Law (Ley de Recursos Hídricos – LRH, published March 31, 2009) and the draft National water resources management (WRM) Strategy (Estrategia Nacional para la Gestion de los Recursos Hidricos Continentales del Peru) aim at creating a cohesive institutional and legal framework, financial sustainability for infrastructure operations and maintenance (O&M) and development, protection of aquatic ecosystems, and resilience to climate change impacts (Cardenas and Price, 2009). Authorities responsible for water management at the national level include the Administration of Water Resources (IRH) of the National Institute of Natural Resources (INRENA) and the National Watershed Management and Soil Conservation (PRONAMACHCS).

Villagers meet to discuss water supply system issues in Yanomito

In Peru, effective and sustainable management of high-Andean watersheds is a major area of concern among coastal water users and communities. These watersheds are the major water source for the Coastal Plain, which is the most important production area for Peruvian agricultural exports and where much of the Peruvian population is concentrated. The predominant approaches to watershed management have been policy and infrastructure development, without a sense of connection with local societies, the culture of water, or with the ecosystem processes that affect the water cycle (Price and Recharte, 2008).

BASIN LEVEL INSTITUTIONS AND POLICY

Basin level water management institutions and policy in the Santa River Basin involves a multitude of dispersed actors – ranging from traditional water users in the Andean communities of the basin, to urban users and businesses – in a complex geography and mechanisms to explore and develop shared interests are lacking (Price and Recharte, 2008).

The water management institutional setting that preceded the creation of the National Water Authority ANA in December 2008 and the current water law of 2009 is undergoing profound transformation. Although there are key regulations still to be enacted, the country has been divided into several water administration authorities (AAA - Autorida Administrativa del Agua) comprised of local water authorities. The law calls for the establishment of Watershed Management Councils which are expected to represent the broad spectrum of water users. Annex 2 in Price and Recharte (2010) lists the major institutions operating in the basin.

The 2009 water law recognizes social, cultural, economic, and environmental value of water, and calls for integrated management and equilibrium between the different values (Article 1) (Galewski, 2010). The law also calls for the creation of mechanisms that allow participation by water users in the decision-making process and the assistance to organizations of water users and support for education and knowledge sharing. The objectives of the new water management system are to coordinate and ensure integrated and multi-sectoral management, sustainable and efficient use, and conservation of the resource. Changes were also made in the way the legal system treats water: it is now recognized as a renewable resource and water quality is now included in the law. The 2009 law prioritizes water uses (see Exhibit 8).

Exhibit 8. Prioritization of Water Uses under the 2009 Law on Water

<table>
<tr><th>Priority</th><th colspan="2">Use</th></tr>
<tr><td>1st</td><td colspan="2">Primary use: Satisfy basic human needs such as cooking, direct consumption, personal hygiene, ceremonial, cultural, religious, and ritual use.</td></tr>
<tr><td>2nd</td><td colspan="2">Public Use:
Capture of water for a public water source or for public infrastructure that should be treated and serve basic human needs.</td></tr>
<tr><td rowspan="2">3rd</td><td colspan="2">Productive use (used in the process of production in any capacity) includes (in rank order, highest first):</td></tr>
<tr><td>a. Agriculture
b. Fishing
c. Energy
d. Industrial
e. Medicinal</td><td>f. Mining
g. Recreation
h. Tourism
i. Transportation</td></tr>
</table>

Source: Adapted from Galewski, 2010

LOCAL LEVEL AGRICULTURAL WATER MANAGEMENT: CALLEJÓN DE HUAYLAS

There are three Irrigation Districts within the upper Rio Santa Basin: Santa-Lacramarca-Nepeña, Huari and Huaraz. The Huaraz Irrigation District includes the middle and upper Santa watershed, a highland area with altitudes varying from 3100m to 6800m. The Upper Rio Santa Basin within the Callejón de Huaylas, is in jurisdiction of the Huaraz Irrigation District, within the provinces of Recuay, Huaraz, Carhuaz, Yungay, Huaylas and Corongo. It has a total area of 6742.12 km^2, (INRENA, March 2001), ranging between 3100m and 6800m with a very rugged topography. The Huaraz Irrigation District is organized in four Irrigation Sectors: Huaraz, Huascaran, Caraz and Corongo, seven Irrigation Sub-sectors, and twenty-eight Irrigation Commissions.

Water users in the Huaraz Irrigation District are organized into the Callejon de Huaylas Board of Users (registered in 2002). This organization is made up of user committees that engage Irrigation Commissions and Board Members. Its main role is the management of irrigation water. Irrigation Committees are made up of irrigation users, individual property owners and peasant communities representing properties that are within communal areas. The distribution of irrigation water is the responsibility of the Irrigation Committees, which are directly responsible for water management. Water delivery to irrigators registered with their respective committees in the Callejón de Huaylas Board of Users is done according to committee approval,. Water delivery to users is done empirically (without meetings), since none of the water committees have metering infrastructure and/or regulation of flows, allowing them to know how the flows are distributed.

The distribution of irrigation water occurs in two forms: the first is free-demand distribution and the second shift distribution (with strict rules) where the irrigation organization plays an important role in maintaining order within the system. Some of the irrigation channels cross the territory of several peasant communities; the communities provide for the maintenance and operation of the infrastructure within their area.

BUSINESSES AND EMPLOYERS

Agricultural export companies, water utilities, and hydropower and mining companies also have influence over the management of water in the basin, although there is no cooperative network to coordinate their perspective on the water resource sector (Price and Recharte, 2008).

Mining companies are numerous in the basin and have different ways of working and monitoring the environmental impact of their activities depending on their size. The main public concern is the negative impact of mining on water quality and most companies do not have comprehensive programs to support sustainable water use or management.

Hydropower companies are also a major non-consumptive user of water in the basin. There are three companies in the basin: (1) Duke Energy International SA operating the Cañon del Pato facility, (2) Cahua Company SA in the Pariac River basin, downstream from Lake Rajucolta, and (3) Pampa Blanca operated by Chavimochic Irrigation District.

3. PROBLEM DIAGNOSIS

This chapter provides an assessment of problems related to the sustainable provision of water resources in the Rio Santa Basin. Some attention is also given to natural resources impacted by climate change that may contribute in positive and negative ways to the challenges of managing water in the Rio Santa. The chapter is divided into three parts focusing on an overview of non-climatic and climatic stressors and assessment of the vulnerability of water and natural resources to climate change and variability.

3.1. NON-CLIMATIC STRESSORS ON WATER RESOURCES

There are a number of stressors (factors) that can affect the availability and quality of freshwater resources in the Rio Santa Basin. Non-climatic stressors refer to those factors that would impact freshwater resources in the absence of climatic factors. Three groups of factors are described in this section: 1) population pressure; 2) economic growth; 3) water pollution; and 4) weaknesses in water management; and 5) land cover and erosion.

3.1.1. POPULATION GROWTH

As the population of the Rio Santa Basin grows, there will be increased demand for freshwater supplies. Population increases over the last thirty years have placed greater stress on the existing sources of freshwater. As noted in Table 1, the 2007 population in the basin was a little less than 1.8 million. In 1993, the population was just over 1.4 million, so there has been an increase of almost 400,000 people over the 14 years, or about a 22% (1.6% per year) increase. This growth has been primarily in the lower basin and coastal areas and there is no indication that this trend should change in the coming decades. This will place increasing pressure to supply municipal water to the coastal cities (Trujillo, Santa and perhaps Chimbote). Urban growth is projected to increase at a rate of 1.6% and rural areas at 1.2% in the basin (Escobar et al., 2008).

3.1.2. ECONOMIC GROWTH

ECONOMY, POVERTY AND DEVELOPMENT IN PERU

The Peruvian economy has been very strong for the past decade, with Gross Domestic Product (GDP) growing by more than 4% per year from 2002 to 2006 and up to 9% per year in 2007 and 2008 (CIA, 2010). National poverty has been reduced by about 15% since 2002 (CIA, 2010). Increased GDP generates increased demand for water but also greater capacity for improving water infrastructure and promting improved utilization of water.

Not all Peruvians have shared in the benefits of growth, and 44.5% of the population was below the poverty line in 2006 (CIA, 2010). In 2004, Ancash had a higher percentage of people in poverty (55.3%) and extreme poverty (23.4%) than the national average (51.6% and 19.2%, respectively) (World Bank 2005). High levels of rural poverty often increase stress on natural resources due to overgrazing and fuelwood harvesting, and degradation of land cover.

RIO SANTA BASIN WATER DEMAND

The Río Santa has a finite and changing capacity to meet water demands for agriculture, hydropower and municipal uses. Agricultural water demand is high throughout the basin. Farmland is irrigated in the upper part of the basin and in coastal areas (see Sec. 2.4.3). While the irrigated area is larger in the coastal irrigation districts than in the Callejón de Huaylas, the highland sections of the watershed also have significant irrigated lands and the number of registered water user units is larger in the upper basins (47,000 users) than in the lowland areas (20,300 users) (Hendriks, 2008).

Demand for Andean water in coastal areas is growing due to population increases (natural increase and migration) and expansion of high valued crops for export markets. The two important coastal cities of Chimbote and Trujillo have increasing domestic water needs, along with industrial demands. Huaraz and Carhuaz in the upper basin have experienced high rates of urban population increase 47.5% and 36.7%, respectively, between 1993 and 2007 (INEI, 1993, 2007). To meet the Millennium Development Goals for water and sanitation, Peru will need to allocate water to these purposes. In 2008, 82% of Peruvian households had access to improved drinking water sources (90% of urban and 61% of rural) and 68% have access to improved sanitary facilities (81% of urban and 36% of rural) (UN, 2010).

3.1.3. WATER POLLUTION

There are several water quality concerns in the Rio Santa Basin, including mine tailing pollution, agricultural runoff, discharge of untreated sewage, natural mineralization of the tributary flows, and sedimentation. The problems are complex and require long-term government and community development programs to solve. Some of these aspects are discussed below.

DOMESTIC AND MUNICIPAL WASTERWATER POLLUTION

Sanitation issues are a major concern in the Callejón de Huaylas. The campesino communities lack wastewater treatment service, and cities like Huaraz, which do offer some wastewater treatment, have inconsistent service and many individual discharges into the Río Santa (Galewski, 2010).

MINE TAILING POLLUTION

Mining is important to the Callejón de Huaylas economy, as the region is a major producer of copper, lead, zinc, gold, and silver (Galewski, 2010). Mining operations use water for some mining practices, road maintenance and employee residences. Acid drainage, illegal dumping, and mine tailings contaminate water with lead, arsenic, and other metals. Large and medium mines are regulated by the Ministry of Energy and Mining and are subject to environmental regulation, but small mines are not regulated. Tailings from abandoned mines, such as the Ticapampa Mine, located near Catac south of Huaraz are environmentally hazardous and generate acidic runoff as well as heavy metal contamination (Sevinc, 2009). The government has instituted a program to reduce diversions from the main stem of the river in the Callejón de Huaylas and further reductions are planned. There is a remediation project underway for the mine waste near Catac, but the likely success and timing of the project is unknown.

AGRICULTURAL POLLUTION

Highland campesinos are involved in subsistence farming and grow potatoes, corn, quinoa, barley, wheat, oca, and olluco (typical Andean crops) for household consumption and for sale in local and regional markets. The use of pesticides and fertilizers for crop production is another source of water pollution (Galewski, 2010).

3.1.4. WEAKNESS IN WATER MANAGEMENT

As noted in Sec. 2.4.4, the water management institutions in the basin are undergoing reform and do not apply integrated water resources management principles and tools due to the fragmentation and lack of consultative mechanisms. Although the creation of the advisory council described earlier in the report calls for the participation of campesino communities and indigenous groups when they are part of watershed territory, no mechanisms have been created to ensure representation. This suggests future dissonance between watershed management and local management (Galewski, 2010). One of the main concerns among NGOs and local groups is that communities will not actually have an opportunity to participate in the decision-making body despite the participatory process. This lack of representation needs to be addressed and campesino communities will need support to overcome their lack of experience and limited technical vocabulary required to effectively voice their positions within this new decision-making body (Galewski, 2010).

3.1.5. LAND COVER AND EROSION

In the Huascaran National Park, there are many areas forested by *polylepis sp*., a member of the rose family found at high altitude in the Andes. It is a threatened tree that is frequently harvested for firewood. It previously covered almost the entire area above the normal treeline but it has been reduced to small remaining pockets. Intensive cattle grazing has inhibited the regeneration of trees within historically deforested landscapes (remnant forests are located primarily on ancient boulder fields inaccessible to cattle)(see: Byers 2004 for a discussion). A general lack of stakeholder input in the design of the conservation effort has resulted in unsustainable reforestation efforts in the area. There appears to be a lot of potential for ecosystem restoration projects in this area, but the relationship with cattle ranchers may inhibit this success. Ranchers were operating in the area prior to the creation of the National Park and their grazing rights were protected as part of the establishment of the park.

Typical undamaged mature polylepis forest

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3.2. CLIMATE AND CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Current climate and anticipated climate change impact water resources in a variety of ways. In combination with the non-climate stressors discussed in the previous section, climate presents a formidable challenge to the Rio Santa Basin in meeting the water needs of its people.

3.2.1. RECENT AND CURRENT CLIMATE

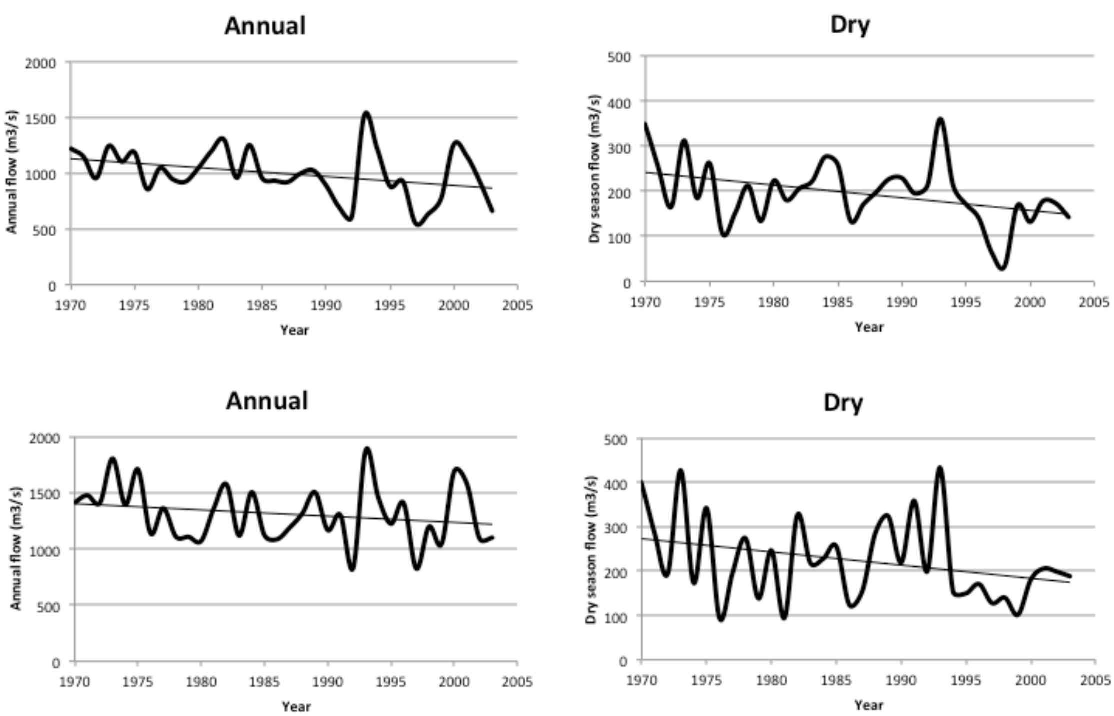
TEMPERATURE

Temperature records in the Rio Santa Basin are relatively scarce and difficult to obtain. Average annual temperature in the Cordillera Blanca has been increasing 0.35 to 0.39^{o}C/decade between 1951 and 1999 (Bury *et al*., 2010). Querococha station in the Cordillera Blanca (3980m) has records of monthly temperatures varying between 5.6 to 9^{o}C (Juen, 2006). From 1965 to 1994, the data show that there has been a slight warming and a reduction in the variability of temperature at the Querococha station with minimum temperature increasing about 0.25^{o}C/decade, average temperature increasing 0.012^{o}C/decade, and the maximum temperature decreasing 0.108 ^{o}C/decade (Technical Assessors Associates, 2002). Racoviteanu *et al.* (2008) analyzed annual air temperature records from 1970-1999 at three stations (including Huaraz and Recuay in the Callejón de Huaylas) and found an upward trend at these stations with air temperature increasing faster at lower elevations.

PRECIPITATION

Precipitation records for many Rio Santa Basin stations are available, although the period of record tends to be only up to about the year 2000 for most stations. The precipitation trend is steady or downward at many stations in the Cordillera Blanca. Racoviteanu *et al.* (2008) analyzed annual precipitation records for the period 1970-1999 at three stations (including Lake Paron and Llanganuco stations in the Cordillera Blanca) and found an insignificant negative trend at two out of the three stations. Monthly precipitation records from 1970 to 2003 for these stations also indicated weak downward precipitation trends. Records from 1970 to 2003 at Cordillera Blanca stations in Querococha (in the south of the range) and Cullicocha (in the north) were also analyzed for trends, and both stations appear to have a downward trend (see Exhibit 9), and when analyzed statistically (Mann-Kendall test, Helsel and Hirsch, 1991), the trends are significant at each station ($\alpha = 0.1$) Increasing temperature has a slight effect on glacier recession, but atmospheric humidity probably has a larger effect on the outer tropical, high altitude glaciers of the region (Cuffey and Paterson, 2010). Vuille et al. (2003) also analyzed precipitation between 1950 and 1994 using information from 42 monitoring stations in the Andes and concluded that there was no clear regional trend.

Exhibit 9. Annual and dry season flow at Querococha (top) and Cullicocha (bottom) stations Rio Santa Basin (1970 – 2003)



Source: Egenor, 2004

3.2.2. CLIMATE CHANGE PROJECTIONS

TEMPERATURE

The recent generation of Global Circulation Model (GCM) projections of future climate change in the tropical Andes indicates a continued warming of the tropical troposphere throughout the 21st century, with a temperature increase that is enhanced at higher elevations (Vuille et al., 2008). By 2100, based on the "A2" intensive greenhouse gas emission scenario, the tropical Andes may experience warming on the order of 4.5–5°C. The recent (2007) generation of GCMs have poor resolution of the topography of the Andes and projected temperature changes for the Andes may be too low (Vuille et al., 2008).

PRECIPITATION

Most of the recent GCMs predict an increase in precipitation in the inner tropical Andes during the wet season and a decrease during the dry season, which would effectively enhance the seasonal hydrological cycle (Vera et al., 2006). The spatial pattern of change is similar for all emission scenarios and is less evident in the outer tropics (e.g., the Cordillera Blanca region), but the amplitude of the change is much stronger in the A2 scenario than in the less emission intensive scenarios, A1B and B1 (Boulanger et al., 2007). Differences between GCM projections are much larger for precipitation than for temperature. In the case of temperature projections, all GCMs indicate increasing values but they do not agree on the sign or magnitude of changes in precipitation.

GLACIER RECESSION

Simulations of tropical Andean glaciers under the projected climate changes indicate that glaciers will continue to retreat during this century (Vuille et al., 2008). Many smaller, low-lying glaciers will disappear within a few decades, and in catchments with larger glaciers, changes in streamflow seasonality will affect downstream water availability. In the short-term, as glaciers retreat and lose mass, there may be a temporary increase in runoff, but this increase will not last very long, as the frozen water stored in glaciers diminishes (Mark, 2008; Vuille et al., 2008). An eventual decline in glacier melt and streamflow may significantly affect the availability of drinking water, water for hydropower production, mining and irrigation (e.g. Barry and Seimon, 2000; Barnett et al., 2005; Francou and Coudrain, 2005; Bradley et al., 2006; Vuille, 2006; Vergara et al., 2007).

RUNOFF

The simulations show that dry season runoff will be significantly decreased and wet season flows will be increased due to larger glacier-free areas and therefore enhanced direct runoff (Vuille *et al.*, 2008). The overall discharge may not change very much, but the seasonality of discharges intensifies significantly depending on the percentage of glaciated area and other catchment-dependent factors with runoff seasonality changes being larger in catchments with a greater degree of glaciation.

3.3. VULNERABILITY TO CLIMATE VARIABILITY AND CHANGE: WATER RESOURCES

3.3.1. SECOND NATIONAL COMMUNICATION TO UNFCCC

The Second National Communication of the Government of Peru to the UNFCCC (MINAM, 2010) notes that the vulnerability to climate change in the basin is focused on:

- Increased rainfall during El Niño events is likely to be a major factor in the vulnerability of infrastructure. Approximately 24% of the catchment area has low vulnerability level, and almost half the area of the basin (49%) has a medium vulnerability level, due to erosion and damage to infrastructure.

- Transportation routes exposed to increased precipitation during the El Niño events will increase vulnerability for 4% of paved roads, 17% of roads and 15% of trails in the basin.
- Decline in rainfall during the La Niña events will be a factor affecting the vulnerability of agriculture in the basin. Rain-fed agricultural areas located in the Cordillera Negra and the Tablachaca River with important subsistence agriculture will be highly vulnerable. Irrigated agriculture will also suffer negative impacts if these phenomena become more recurrent.
- Tourist activity is important for the area and is sensitive to extreme events during El Niño events (e.g., the torrential rains and mudslides that occurred early in 2010 near Macchu Picchu south of the Rio Santa Basin) and deglaciation, which could alter the quality of and access to hiking and viewing sites.
- In the future, agriculture in areas that were considered at risk of frost could be negatively affected with temperatures below 6°C. Areas in the upper basin, where this phenomenon is likely, are expected to experience minimum temperature increase on the order of 0.5 to 0.7°C, indicating a slight reduction in vulnerability from frost.

3.3.2. WATER SHORTAGES AND LACK OF STORAGE

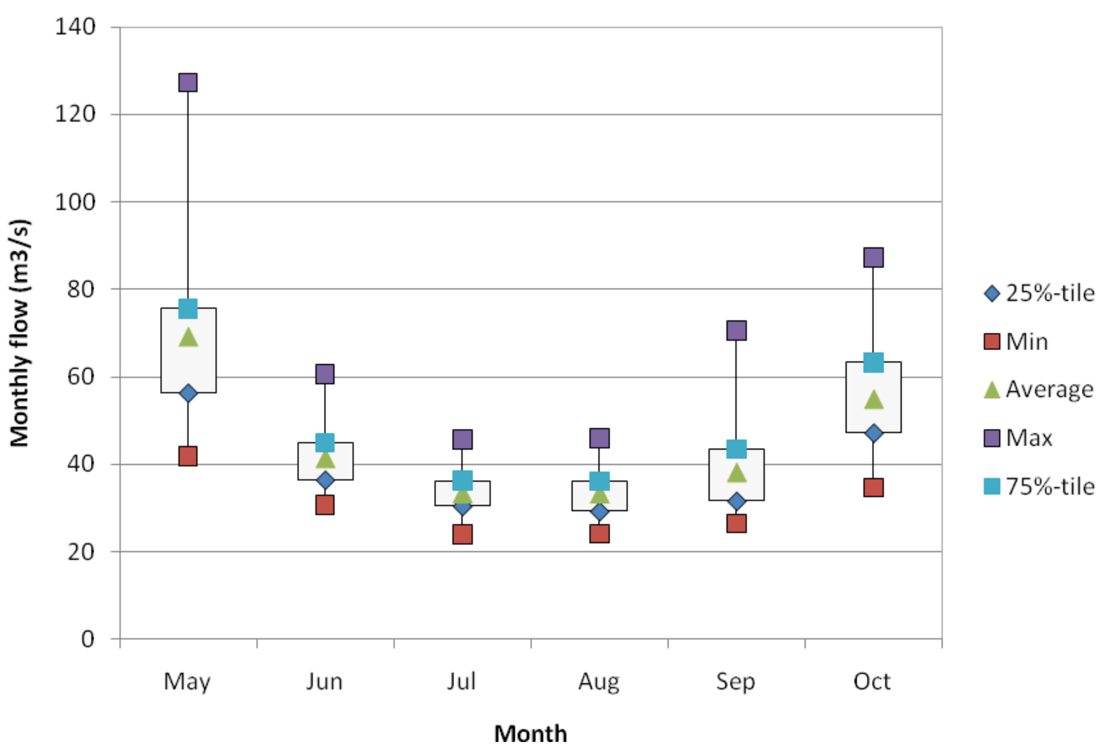
Bury *et al.* (2010) note that in 2008, PRONAMACH (Programa de Desarrollo Productivo Agrario Rural, the Agricultural Productivity and Rural Development Program of Peru) began to construct new downstream water diversions from Lake Querococha in response to new water rights claims by several downstream communities. Several case study respondents indicated that conflicts within the community and around the region over access to irrigation water have been increasing and that they expect them to become more prevalent as water resources continue to decline. As the glaciers shrink, the difference between wet- and dry-season stream flow will become greater, since there will be less glacier volume to store the wet season precipitation, and less ice melt to buffer the low flows in the dry season (Mark and Seltzer, 2003). If glacier recession continues, the buffering impact on runoff will decrease and runoff variation will be dominated increasingly by precipitation (Kaser *et al.*, 2003).

Water storage tank above Yanomito village (about 3800 m)

Recent analysis of global climate model results has predicted warming of about +2.5 °C by the end of the century over the Andes, with the largest increases concentrated at the tropical glaciers (Bradley et al., 2004). Mark and Seltzer (2005, citing Barry and Seimon, 2000), note that if these glaciers disappear, there could be water supply crises. Glacier melt contribution to annual streamflow in the Rio Santa Basin may be about 20% (Racoviteanu, 2009) and groundwater may be the largest contributor to basin outflow, contributing as much as 20% in the dry season (Baraer *et al.* 2009). Juen et al. (2007) predicted that in the future dry season runoff from glaciated Cordillera Blanca basins may decrease by more than 20% (with respect to 1961-1990 flows), and wet season flows may increase as much as 20%. Continued glacial recession will result in increased variability of annual runoff, which is increasingly dominated by precipitation (Bury *et al.*, 2010; Coudrain *et al.*, 2005; Juen et al. 2007). Thus water managers and stakeholders in the basin must anticipate a change in the availability of water over the long term.

Given the shift in water supply from glacier melt dominant to precipitation dominant, existing lakes in the Cordillera Blanca and their ability to be used as seasonal regulation storage to move the water availability (runoff) from the wet season to the dry season as the glaciers used to do may become very important adaptation measures to reduce vulnerability. This may serve to reduce vulnerability only for the smaller, local users in the upper to middle basin and not address concerns of the large irrigation users in the lower and coastal region. One recent study calculated that the dry season flow of the river was already insufficient to satisfy the needs of the Chavimochic and Chinecas Irrigation Projects and that the annual cost of reduced glacial melting for the Cañon del Pato hydroelectric plant in the Rio Santa valley was significant (Vergaraet al., 2006). The plant's design minimum flow rate is 80 m3/sec, but this is not always available, especially in the dry season (see Exhibit 10).

Exhibit 10. Rio Santa flow through Cañon del Pato hydroelectric facility (average monthly flow at La Balsa plus Los Cedros stations 1954-2003). Design flow is 80 m³/sec.



Source: Chavimochic Special Irrigation Project, 2010

The four lakes providing storage for Cañon del Pato hydroelectric facility (Exhibit 8 in Chapter 2) fill each year from glacial melt or precipitation. As temperatures increase from global warming, and there is rainfall at higher elevations, the Duke Energy operators expect that the operation of the lakes will not change, since the lakes will still capture the same amount of water as long as the precipitation does not decrease. They are very committed to the idea that precipitation will stay the same or increase slightly over the coming decades. However, this may not actually be the case. The Peruvian Andean region gets about 80% of its power from hydropower in glacier dominated basins (Vergara 2007), especially in the Rio Santa Basin where glacier contribution to runoff is nearly 60% at La Balsa station (Mark et al., 2005) and could be reduced by as much as 60% due to glacier recession. Vergara (2007) predicts that the Cañon del Pato hydropower plant output would drop by 20% with a 50% reduction in glacier melt contribution and as much as 40% if the glaciers disappear completely. The economic cost of a 50% reduction in glacier melt contribution is estimated to cost $5.7 million per year to the power plant owners or $10.1 million per year to the consumers.

3.3.2. FLOOD RISK AND GLACIER LAKE MANAGEMENT

The problems of Glacial Lake Outburst Floods (GLOFs) have not been entirely solved in the Cordillera Blanca: the continued and accelerated melting of glacial ice is once again filling many "controlled" lakes to dangerous levels, such as Lake Palcacocha, now containing over 17 million m^3 of water compared to less than 1 million m^3 when first lowered in the 1950s (Portocarrero, personal communication, 2010). The outburst of this lake would not only have severe consequences to local populations, but would have serious impacts on Huaraz's freshwater supply, hydroelectric power generation, irrigation infrastructure, and water quality (Huggel et al. 2003; Duke Energy, personal communication, 2010).

The moraine dam at the outlet of Lake Paron has a debris-covered glacier with an ice core that is melting and weakening the dam and increasing the risk of failure (Cesar Portocarrero, personal communication, March 2010). The lake overflow is located at 4,200 m and it is recommended that a 10 m minimum freeboard (height of water below the top of the dam) be maintained, so the maximum safe operational limit is 4190 m. Recently an emergency was declared because the water level was too high and draining of the lake commenced. The maximum rate of drainage is 8 cm/day) and draining will continue until the level reaches 4190 m. The Glaciology Unit is in charge of the operations and they are training the local campesinos to operate the system, since control was turned over to them in 2010. The lake control system was designed to release 3.8 m3/sec and was built over a period between the 1960s to the 1990s for a total cost of US$3 million.

Glacial lakes that form at the base of glaciers or their tongues as the glacier recedes can provide water storage, but they also represent major risks since the outlets are often natural formations (terminal and lateral moraines) that may not be geotechnically sound and are prone to failure as water levels rise often resulting in glacial lake outburst floods (GLOF). The number of glacial lakes in the Cordillera Blanca has increased from 223 in 1953 to 452 in 2009 (Carey 2005; Zapata, 2009). Most of the Callejón de Huaylas' residents (less than one half million people) live directly below Cordillera Blanca glaciers and glacial lakes (Bury et al., 2010). The Peruvian government has undertaken 35 "lake security projects" to ensure the safety of the Cordillera Blanca glacial lakes. This has involved lowering lake levels through channels and tunnels to reduce pressure on moraine dams and constructing artificial dams to strengthen moraine dams and prevent their failure from waves caused by icefalls (Carey, 2005). New lakes continue to form as glacier tongues recede, creating potentially dangerous conditions that the Glaciology and Hydrological Resources Unit need to monitor and maintain continually.

3.3.3. WATER QUALITY DEGRADATION

Water quality in the Rio Santa Basin is one of the factors certain to become worse over time and with climate change impacts. Higher concentrations of many harmful chemicals are expected as flow volumes in the river decline in summer.

3.3.4. DEFORESTATION

As mentioned above, severe deforestation has been a major impact in the basin for some time. Mostly, this is a result of overgrazing due to the lack of development of an understanding among the local livestock herders regarding the impacts of grazing on the land and the loss of benefits resulting from this practice.

3.3.5. TOURISM AND RECREATION

The glaciers of the Cordillera Blanca and Lake Llanganuco in Huascaran National Park are major tourism attraction in the region. Severe flooding can impact access to Huascaran National Park and reductions in the glaciated area and area closures in glaciated areas (such as the Pastoruri Glacier) may require reorientation of tourism and/or shifts to less attractive destinations.

4. ADAPTATION OPTIONS

As discussed in previous chapters, concerns about climate change in Peru are not new. The Peruvian Government has developed a National Adaptation Plan (Section 4.1) and adaptation responses to climate change have been the focus of recent international workshops and stakeholder meetings (Section 4.2). The objective of this chapter is to develop a list of adaptation options that can be considered in addressing climate change and variability in the Rio Santa Basin. In compiling this list of adaptation options (Section 4.3), we have reviewed the National Adaptation Plan, results of recent workshops, drawn from a field assessment in February-March 2010, and reflected recommendations from other Peruvian documents and international experience.

4.1. NATIONAL ADAPTATION PLAN

The Government of Peru has developed a National Adaptation Plan for climate change built on five pillars (MINAM, 2010): information, skills, policies and tools, technology, and financing. Under this program, the Government of Peru has initiated some adaptation measures in the region of the Rio Santa Basin (MINAM, 2010). Most of these have focused on information gathering, research, and capacity building.

- Numerous projects on capacity building for disaster reduction (ITDG-Practical Solutions, MINAM, MINEDU, SENAMHI, INDECI, Municipalities of Huaraz, Yungay, Carhuaz, Municipality of Independencia, Acopampa and Ranrahirca. Association of Municipalities of the San Martin Region, Local Government Awajun, Yuracyacu, Dorado, Regional Governments and San Martín Ancash, Local Education Management Unit Yungay, Universidad Nacional Santiago Antúnez de Mayolo, World Vision, European Commission, Save the Children, OXFAM America, and the World Bank's project, Comunidad Andina de Naciones)
- Several research investigations on glaciers and water resources (IRD)
- Technologies for adaptation to and mitigation of climate change (Practical Action-ITDG, CEPES IPROGA, Ecumenical Centre for Promotion and Social Action (CEDEP), Radio Marañón, Capirona, European Commission)
- Research on the availability of water in different basins (SENAMHI)
- Determination of water availability in basins with glaciers (SENAMHI)
- PROCLIM Future Climate Scenarios and Water Resource Availability in the Rio Santa Basin (MINAM, regional natural resource management and environmental management of the regional government of Ancash, and IRD SENAMHI)
- Implementation of adaptation measures (2010-2012) (MINAM, BID)

4.2. WORKSHOP RESULTS

Several workshops and training sessions on vulnerability and adaptation to climate change have been held in the region. Three of these are described in this section:

1. July 2009 – International Conference-Workshop titled "Adapting to a World without Glaciers: Realities, Challenges, and Actions", convened July 7-15, 2009, in Lima and Huaraz, Peru.

2. February 2010 – One-day stakeholder workshop in the upper basin (Marcara) of the Rio Santa, convened by The Mountain Institute

3. February 2010 – One-day stakeholder workshop in the lower basin (Chimbote) of the Rio Santa, convened by The Mountain Institute

4.2.1. JULY 2009 INTERNATIONAL CONFERENCE-WORKSHOP

This workshop brought together international and Peruvian researchers and Peruvian national and local policymakers to discuss the current research on the impacts of climate change on glaciers, water and natural resources, and the populations that rely on these resources for their livelihoods. Participants developed a slate of recommendations for research and policy in three areas: water and risks; ecosystems and biodiversity; and agriculture. The workshop report provides details on the activities and results of the workshop (TMI, 2009). Following is a short summary of the most important observations and recommendations.

- Current responses to increased climate variability are mainly found at the local level. They are based on the knowledge and traditions of local cultures and are expressed in their agricultural, water management, and biodiversity conservation practices.

- Non-governmental organizations are working with local populations to compile and systematize traditional knowledge on climate change with a view to promoting the continued use of proven best practices.

- In Peru there is a strong need to develop and strengthen institutions at different levels of government, which in turn will help build their capacities for enhanced climate change research and action.

Recommendations and pilot activities for adapting to climate change in Peru and the Rio Santa Basin resulting from the workshop have been incorporated into the list of adaptation options in Section 4.3.

4.2.2. FEBRUARY 2010 STAKEHOLDER WORKSHOPS

A stakeholder workshop focused on climate change and variability in the upper basin of the Rio Santa was held in Marcara on February 20, 2010. The highland workshop combined training on climate vulnerability and adaptation with stakeholder discussions of climate concerns and solutions to elicit the level of interest of local participants to engage in specific measures, and institutional arrangements to enhance sustainability of adaptation measures. This workshop gathered farmers coming from rural communities and their corresponding municipal government authorities who discussed practical ways to cooperate in adaptation. All this information was important to the more detailed design of activities of the USAID/Peru-funded project, Peaks to Coast implemented by The Mountain Institute and local partners in the Rio Santa Basin and Piura-paramo region of Northern Peru.

The specific objectives of the workshop were:

1. To make available to the key stakeholders in the basin knowledge, tools and methodologies for adaptation to climate change

2. To strengthen the capacities of the key stakeholders to adapt to climate change, so that this knowledge can be replicated locally

3. To reinforce a network of people and institutions with knowledge, tools and methodologies for adaptation to climate change in order to create a platform and drivers for concrete actions in the basin

For this workshop, stakeholders included: municipalities, communities, forest committees, Huascaran National Park staff, regional government representatives, NGOs, university researchers, journalists, and other actors.

Projects currently being implemented or planned in the Ancash Department were discussed:

1. Lake control infrastructure projects
2. Reforestation of 12,000 hectares (Chiquián, Aquia, Huasta, Pacllón, Bolognesi province, i.e. the areas located in the headwater areas of Ancash)
3. Forestry project in the headwaters of Fortaleza River and in Huallanca District
4. Inventory of surface and ground water resources in campesino communities
5. Milk production, construction of dams and canals, drip irrigation, and improved pasture lands
6. Reforestation of the headwater area of Conococha Lake

Assets and resources that should be protected were identified and adaption options were recommended. This workshop provided information to design an adaptation training program for rural communities affected by glacier recession and jump-started a process with five municipalities located in the headwaters of the Rio Santa Basin. This evolved into a commonwealth of local governments established to cooperate in climate change adaptation measures.

The second stakeholder workshop was held in Chimbote on February 22, 2010, and focused on climate impacts on the lower basin of the Rio Santa and the two irrigation networks that are supplied by the river. The coastal zone workshop provided introductory training on climate change and vulnerability as well as valuable information on stakeholder perceptions of climate change related problems and interest in cooperating with highland stakeholders of the watershed in adaptation measures.

Farmers participating in the workshop perceived that the main assets affected by changes in climate were (1) irrigation infrastructures and (2) crops. Irrigation is affected by extreme events: flooding of the river affecting canals, intake gates, and the canals themselves; and extended periods of drought and lower flow levels in the Rio Santa available than normally expected during the dry season. Impacts on crops seemed to be less clearly defined but concerns including perceived increases in plant infestations, combined with a lack of technical assistance, crop insurance and poor farmer organization.

Recognizing the important role of water management in the upper basin, water user groups in the lowland areas and the Chavimochic and Chinecas irrigation projects were particularly interested in fostering linkages with counterparts in the altiplano. Further training to develop adaptation strategies was agreed with these stakeholders with the expectation that cooperation with the emerging organization in the headwaters of the basin will develop.

4.3. ADAPTATION MEASURES ADDRESSING IDENTIFIED ISSUES

The three workshops described in the previous section generated extensive lists of adaptation measures that participants proposed to address climate variability and change concerns in the Rio Santa Basin. The *World without Glaciers* International Conference-Workshop also resulted in more general recommendations on climate change and adaptation that could be implemented in other basins and at the national and sub-national levels. In addition, the case study draws from other sources for recommendations on adaptation (plans, literature) as well as the authors' proposals, based on international experience. These proposals and recommendations are organized below into five topic areas: 1) water management; 2) agriculture; 3) risk management; 4) ecosystems; and 5) capacity building.

4.3.1. WATER MANAGEMENT

RESEARCH AND INFORMATION MANAGEMENT

- *Data and information needs* – Government agencies and stakeholders have consistently pointed out the need to identify, upgrade, collect and analyze data on water users, uses, and availability. This includes identifying current and future water uses and users, including agricultural, industrial, urban, and informal water uses (TMI, 2009).
- *Water sources and future availability* – There is a definite lack of credible water availability assessments in the basin and tributaries. These could be carried out to identify the contributions of different water sources, e.g., glacial melt, precipitation, and groundwater, and the future availability from them under future climate projections (TMI, 2009; MINAM, 2010).
- *Groundwater* – Groundwater resources in the basin are relatively unknown and unmonitored. Groundwater levels need to be monitored frequently and the resource assessed to understand the response to changing climate conditions, and make decision about its use as complement in drought conditions (Price and Recharte, 2008).

INTEGRATED WATER RESOURCES MANAGEMENT

- *Stakeholder Capacity* – Stakeholder capacity and participation in watershed management needs to be strengthened (TMI, 2010). Stakeholder participation in decision-making for watershed management should be developed and strengthened by convening stakeholders groups to analyze their interests and interactions (TMI, 2009).
- *Past and Present Practices* – Greater knowledge of past and current water management practices should be developed, including policies, institutions, scales, actors, and laws (TMI, 2009).
- *Decision Making* – Adaptation to changing climate should be integrated into water management decision-making processes using scenarios and through appropriate project design and public policy (MINAM, 2010).
- *Public Awareness* – Increase education, communication, and information to raise public awareness on water resources and good water management practices (TMI, 2009).
- *Water Quality* – Water pollution from many sources, e.g., municipal, industrial, and agricultural sources, is a major problem and needs to be addressed in the basin. Fees for mining pollution should be considered as a means of reducing pollution. Environment regulations should be enforced. Mining waste, in particular, must be monitored and regulated in a responsible manner. (Price and Recharte, 2008).

INFRASTRUCTURE

- *Storage and Distribution* – A likely outcome of climate change in this region is a much more variable and unreliable dry season flow. In order to handle this, household-scale water storage and distribution systems will need to be developed or improved, including small reservoirs or modified lakes in strategic zones and modernization of distribution systems (Price and Recharte, 2008).

4.3.2. AGRICULTURE

RESEARCH AND INFORMATION MANAGEMENT

- *Traditional Practices* – Collect and analyze traditional knowledge on farming and irrigation practices and adaptation to climate change. Local cultures have adapted to climatic events in the past, accumulating ancestral knowledge that should be recovered and incorporated into modern adaptation strategies (TMI, 2009).

GOOD PRACTICES

- *Livelihoods* – Promote diversified livelihoods for farmers, including diversification of cultivation, animal husbandry, and non-farm activities (e.g., agricultural tourism and ecotourism)
- *Crop Selection and Patterns* – Change cropping patterns and varieties to reduce water requirements. For instance, in the lower part of the basin, specifically in the Peruvian coast, the typical crop is rice which consumes a lot of water at low efficiency causing negative effects on drainage and degrading soils by increasing salinity. There are serious conflicts and competition for water resources in the Peruvian coast, and higher value crops with less water consumption and will be needed in the next few decades (Price and Recharte, 2008). Conservation of crops diversity and "vertical" land use systems through the simultaneous use of vertical gradient for crops and animal production (TMI, 2010).

INFRASTRUCTURE

- *Storage and Distribution* – Water storage and irrigation systems need to be improved, including small reservoirs or modified lakes in strategic zones and modernization of distribution systems. Improvements may be achieved by rehabilitating and/or modifying existing systems or by constructing new systems to replace existing systems or expand availability and access to addition water resources for agricultural purposes.
- *New Irrigation Technologies* – Most irrigation systems in Peru are comprised of aggregations of small farms with gravity-fed flood and furrow irrigation systems. Income from agriculture is inadequate to finance new irrigation technologies. Fragmentation of property and hydraulic infrastructure conditions make it difficult to adapt to climate change effects (Price and Recharte, 2008).

4.3.3. RISK MANAGEMENT

- *Early Warning Systems* – While avalanches move at tremendous speeds of up to 200 km/hour (e.g., avalanche and mudslide that destroyed Yungay in 1970), glacial lake outburst floods travel at speeds that would enable early warning systems to facilitate evacuation measures in all but the closest villages to the GLOFs. Assessment of potential lead times and likely areas of exposure are needed to inform the design and installation of GLOF monitoring and alarm systems.
- *Glacial Lake Infrastructure* – The Cordillera Blanca region has experienced numerous glacial lake accidents in the past. With increasing temperatures and glacial retreat, the number, distribution, and risks posed by glacial lakes will need to be monitored and assessed to determine if current glacial lake infrastructure needs to be maintained and what measures might be required for newly formed lakes.
- *Disaster Risk Management* – Climate change adaptation must be integrated into the decision making process for disaster risk management. Climate-related disasters can result in significant economic costs that are disproportionately borne by vulnerable populations which lack the adaptive capacity to recover from damages to farms and homes due to floods) or absorb drought-related crop losses. Disaster prevention is particularly important as a priority for development and as part of poverty reduction, since disasters have devastating effects on the population and economy of Peru (MINAM, 2010).

4.3.4. ECOSYSTEMS

RESEARCH AND INFORMATION MANAGEMENT

- *Identify and Evaluate Vulnerable Communities, Ecosystems, and Biological Zones* – Stakeholders have identified the need to evaluate vulnerabilities to changes in water use, vegetation cover and productive systems as a result of climate change. This can be accomplished through the use of remote sensing and social science methods, with an emphasis on watershed headwaters and diversity of climate zones, especially in economic corridors._Water related impacts on ecosystems and critical habitats should be identified to assess the fragility of these ecosystems to climate change and to identify mechanisms or strategies for maintaining these services in a sustainable manner. Ecosystem maps and catalogs should be developed that prioritize restoration, and conservation activities. Major wetlands should be identified and threats to their conservation evaluated. Land use models should be developed with a focus on ecosystems and governance. Develop/expand monitoring of biodiversity (richness, changes in species range, invasive species) (Price and Recharte, 2008; and TMI, 2010).

- *Vulnerability and Adaptation* – Assess how individuals value biodiversity and interact with ecosystems from a cultural and economic perspective (TMI, 2009).

NATURAL RESOURCES MANAGEMENT

- *Environmental Policy* – Improve existing environmental policies and norms and design new ones on biodiversity conservation and environmental services tailored to each ecosystem (TMI, 2009). Evaluate current and potential capacities of sub-watersheds as environmental service providers: Identify capacities of a sub-watershed, with an emphasis on grasslands & forests, as environmental service providers (TMI, 2009)._Develop and implement mandatory payment mechanisms for environmental services: Strengthen existing legal framework on payment for environmental services (TMI, 2009). Develop legislation to require payment for environmental services provided by headwaters to agricultural irrigation projects in the coast (e.g. Chinecas) (TMI, 2010).
- *Critical Area Management* – Prioritize, protect, and manage critical areas for conservation of biodiversity and agro-biodiversity. Conservation and management of biodiversity and ecosystems, through prioritizing, protecting, and managing critical areas (TMI, 2009). A good example of this is the Huascaran Biosphere Reserve (RBH), which is a promising mechanism for integrated water management and adaptation to climate change impacts. Huascaran National Park (HNP) is the core of the Huascaran Biosphere Reserve. The RBH offers a unique setting to coordinate actions to adapt to climate change and sustainable water management, beginning with educational activities (Price and Recharte, 2008). More support from the Huascaran National Park to establish community private conservation areas (TMI, 2010).
- *Reforestation of degraded forest ecosystems* – Promote conservation areas and sustainable use and management of native forests: sustain their role in regulating water (TMI, 2010). The peasant community of Canrey Chico proposes reforestation actions and training in climate change (TMI, 2010). The peasant community of Aquia proposes the promotion of reforestation projects that create benefits for households (TMI, 2010).
- *Sustainable management of native pastures* – native pastures play an important role in regulating water (TMI, 2010).
- *Expand wetlands area and apply good management practices* (TMI, 2010) – Well-managed and protected coastal wetlands serve as buffers against the upwelling of water (TMI, 2010). Puna wetlands ("bofedales") provide a range of ecosystem services including a role in the water cycle (TMI, 2010).

4.3.5. CAPACITY BUILDING

TRAINING AND KNOWLEDGE MANAGEMENT

- *National intercultural education program on climate change* – Design and implement education and awareness programs that integrate traditional knowledge and cultural diversity with scientific knowledge on climate change (TMI, 2009). Raise public awareness of the impact of climate change on water resources, agriculture, the economy, and biodiversity and ecosystems (TMI, 2009). In support of public awareness campaigns, information on climate change, climate impacts, and vulnerability should be compiled, synthesized, and tailored to range of audiences and disseminated through variety of delivery mechanisms (print and visual media, internet, radio, information booths as festivals and public events).

- ***Climate change curriculum*** – Development of curricula on climate change for primary and secondary education and other impacted topics.
- ***Investigate interactions between lowland and highland regions*** – Explore social, cultural, economic, and environmental ties between lowlands and highlands on the eastern and western slopes (TMI, 2009).
- ***Increase information, research and monitoring*** – The availability of information is an urgent issue for decision making in Peru. This requires having a reliable and detailed database. The roles of local and regional factors that determine climate trends need to be to better identified and observed deepen understanding about exposure, sensitivity and preferred options (MINAM, 2010).
- ***V&A training*** – Design/tailor vulnerability and adaptation training for decision-makers and stakeholders. Training should be tailored to local climate variability and change, utilize tools appropriate to the types of decisions that are taken by businesses, communities, and sectors. In support of V&A training, the following are needed
  - Develop of training-of-trainers programs, including training and reference materials, certification of training programs and trainers
  - Training needs assessments to enhance targeting of training to range of audiences

DECISION-MAKING AND IMPLEMENTATION

- ***Strengthen government assessment and adaptation capacity*** – Support government agencies to implement more effective responses to climate change: Improve the capacities of different government agencies in resource management, strengthening synergies to address climate change and creating databases that can be shared across sectors (TMI, 2009). Strengthen capacity of policymakers and stakeholders to design and implement adaptation strategies and climate-resilient sector strategies. The National Water Authority (ANA) of Ancash [Local Water Agency (ALA)/Geology unit] should be reinforced and supported (TMI, 2010).
- ***Enhance coordination among organizations*** – There is a need to improve coordination between governmental, non-governmental, and civil society organizations. Specific needs include:
  - Working Group Huascaran (GTH) should be strengthened as cooperative public and private actors as a mechanism that can promote dialogue with communities on water management (Price and Recharte, 2008).
  - Huascaran National Park and the Regional Government of Ancash should promote a joint agenda, and the NGOs should have a supporting role (TMI, 2010).
  - Strengthen a network of municipalities that are recognized for their innovative work on climate change (TMI, 2010). Connect all the different groups that are working on the climate change initiative (GTH), Regional Section of the Ministry of Education (UGEL), etc. All these groups should agree on a common agenda (for example through the regional Movement of Concerned Citizens on Climate Change (MOCICC)) (TMI, 2010).
  - In the municipalities it is important to work with key technical committees. At the same time it is necessary to improve cooperation on climate change adaptation between districts and provinces.
  - In the regional government level it is necessary to establish a consultative group of [scientists] experts in climate change (TMI, 2010).
  - The former Management Committee for the Headwater Area which is currently deactivated should be reestablished; existing land use planning projects for the Ancash region should be funded by the regional government (ecological and economic zoning (ZEE) projects). Existing portfolios of projects in reforestation, restoration of native grasslands, clean up of mining passives should receive green light from the regional government (TMI, 2010).
- ***Linkages between climate research and policy*** – Strengthen linkages between climate research and policy at the national and local levels. Increase multidisciplinary work of engineers, economists, and

glaciologists (Price and Recharte, 2008). Partnerships of researchers: Promote partnerships with networks of researchers specializing in different aspects of watershed management, ecological anthropology, problems of climate change and other relevant to the interests of the basin. Develop a proactive relationship with the scientific community by positioning the social issues in research agendas (Price and Recharte, 2008).

- *Stakeholder mapping* – Map in detail the interests of different groups of users in the basin of Santa and the opportunities for cooperation, from the coast to the highlands. Identify cooperative action among actors that can be implemented without much cost (Price and Recharte, 2008).
- *Local collaborative actions* – Identify specific actions for collaboration on a small scale but symbolic of the cooperation between high and low areas and institutional actors in the basin. Examples of actions include restoration of native grasslands and forests by measuring water flow with local participation, information and forums for dialogue between stakeholders in the basin, communities with high cooperative research on adaptation strategies to climate change (Price and Recharte, 2008).
- *Climate change funding* – Funding enables the implementation of adaptation measures and it should be integrated into policies and government programs, in addition to being aligned with the logistical and technical needs of the state to optimize the use of scarce resources (MINAM, 2010). Sensitize municipalities and the Ministry of Education on the importance of investing public funds on training and capacity building on climate change (TMI, 2010).

5. ASSESSMENT OF ADAPTATION OPTIONS

In the previous chapter, we provided an initial list of adaptation options. The purpose of this chapter is to provide a preliminary, rough assessment of adaptation options to facilitate further discussions and actions by decision-makers and stakeholders in the Rio Santa Basin. The chapter is divided into two parts. Section 5.1 describes criteria selected for assessing adaptation options. Section 5.2 provides a summary of the assessments conducted for adaptation options in the five categories presented in Section 4. For each category, a summary table and notes are provided on the adaptation assessments.

5.1. ASSESSMENT CRITERIA AND PROCESS

In selecting assessment criteria, the major consideration is to apply criteria that can be evaluated in terms of the information that is readily available on adaptations. As detailed elaboration of adaptation options was beyond the scope of the case study, simple, qualitative criteria that are designed only to indicate relative magnitudes have been selected. These include:

- ***Time Period*** – the time period refers to the amount of time it would take to design and implement the adaptation. Short term time periods include less than one year, less than 2 years, and 2 years. The medium time period is specified as 3 to 5 years. However, many of the adaptation options that might be implemented in 3 to 5 years would likely require a longer period for implementation, especially if costly infrastructure is required. The value of differentiating timeframes for adaptation is to facilitate dialogue and planning on adaptation actions.

- ***Ease of implementation*** – three levels of difficulty in implementing adaptations were specified: less difficult, difficult, and very difficult. Ease of implementation focuses mainly on non-economic constraints such as requirements for high level decisions, staff capacity to design and implement, or availability of information and required skills to design and implement. In general, studies, capacity building, and awareness campaigns are less difficult to implement, whereas adaptations such as new policies requiring legislative action or much stronger enforcement, planning efforts for which supporting information and analysis is lacking, and infrastructure that requires considerable design work will be difficult or very difficult to implement.

- ***Cost*** – three levels of costs are specified: low costs of less than $100,000, medium costs of up to $1 million, and high costs of more than $1 million. Evaluation of adaptation costs is based largely on international experience adjusted and tailored to the scale of measures in the Rio Santa Basin.

- ***Effectiveness*** – the effectiveness of adaptations was assessed as low, medium, and high in terms of two different scales. The first scale is in terms of the contribution of the adaptation in reducing or mitigating vulnerability to climate change. The effectiveness of adaptations on this scale is designated in capital letters "LOW," "MEDIUM," and "HIGH" in the tables in Section 5.2. The second scale in terms of effectiveness focuses on the effectiveness of the option in advancing adaptation planning. The effectiveness of adaptations on this scale is designated in lower case italic letters "*low*," "*medium*," and "*high*" in the tables, recognizing that most studies and analytical efforts will not directly reduce climate vulnerability.

5.2. ADAPTATION ASSESSMENTS

Following the format of Section 4.3, adaptation assessments were conducted for the five categories of adaptation options: water management, agriculture, disaster risks, ecosystems, and capacity building.

5.2.1. WATER MANAGEMENT

Table 5-1 Assessment of Adaptation Measures: Water Management

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Identify, upgrade, collect, and analyze data on water users, uses, and availability	< 1 year	LD	H	*high*
Conduct assessment of water availability in basin and tributaries from different sources (glacial melt, precipitation, groundwater) under different climate scenarios	2 years	D	M	*medium*
Implement groundwater monitoring and evaluation program in the basin[1]	> 2 years	VD	L	*high*
Strengthen stakeholder capacity to participate in IWRM decision-making in the basin and sub-basins	2 years	D[2]	M	*high*
Conduct study of historical and current perspective on water policies, institutions, scales, actors, and laws	1 year	LD	H	*medium*
Mainstream climate concerns into water management decision-making processes	2 years	D	H	HIGH
Increase education and information to increase public awareness on water resources and good management practices	2 years	LD	H	high
Address water pollution issues in the basin	3 to 5 years	D	L	MEDIUM
Invest in water storage infrastructure and water distribution networks	3 to 5 years	D[3]	L [4]	HIGH

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

Notes:

1 The difficulty in implementing this option arises from the fact that there are few monitoring wells in place that would facilitate characterization of the groundwater resource. A hydro-geologic study and testing program would have to be implemented before the adaptation option could be operationalized.

2 This will take time because there are a number of related activities that need to be achieved: access to the decision-making process must be articulated in policy, roles and responsibilities articulated, and the skill set of various stakeholders strengthened so that they can play a productive role. There also needs to be assurances of transparency and unimpeded flow of information.

3 In addition to the usual hurdles of developing the design documents, tendering construction, and securing financing for infrastructure, it will be necessary to develop public support, particularly for new storage lakes and reservoirs.

4 Costs are assessed as high, although it will depend on the number, scale, and timing of new infrastructure.

5.2.2. AGRICULTURE

Table 5-2 Assessment of Adaptation Measures: Agriculture

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Collect and analyze traditional knowledge on farming and irrigation practices	1 year	LD	H	*medium*
Promote diversified livelihoods for farmers including agricultural diversification and non-farm activities	2 years	D[1]	M	MEDIUM
Promote changes in cropping patterns and varieties to reduce water requirements	1 to 2 years	D[2]	M	HIGH
Rehabilitate existing water storage infrastructure and irrigation systems	2 years	D	L	MEDIUM
Develop new water storage infrastructure and irrigation systems	3 to 5 years	D	L	MEDIUM
Implement new irrigation technologies	2 years	D	L	HIGH

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

Notes:

1 Given the diversity of communities and large differences in opportunities for alternative livelihoods, the assessment of these opportunities will take some time as will the design of incentives to diversify livelihoods and find financing for such opportunities.

2 Full implementation would first require "in situ" piloting to ensure that alternatives are suitable for local soil conditions and microclimate

5.2.3. DISASTER RISKS

Table 5-3 Assessment of Adaptation Measures: Disaster Risks

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Design and implement flood and GLOF early warning systems	2 years	D	M[1]	HIGH
Assess existing glacial lake safety and risks[2]	2 years	D	M	*high*
Design and construct new glacial lake outflow infrastructure	3 to 5 years	VD	L	HIGH[3]
Integrate climate risks and responses into disaster risk management plans	1 to 2 years	LD	M	HIGH

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

Notes:

1 The costs are specified as medium but could be higher depending on how the geographic scope of the early warning system. However the system could be phased with highest GLOF risks address first.

2 This option would be implemented in parallel with the early warning system and support the design of new GLOF infrastructure.

3 The high assessment assumes new infrastructure is prioritized for the most critical lakes.

5.2.4. ECOSYSTEMS

Table 5-4 Assessment of Adaptation Measures: Ecosystems

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Identify and evaluate vulnerable communities, ecosystems, and biological zones	1 to 2 years	LD	M	*high*
Improve environmental policies and norms to promote biodiversity conservation and protect environmental services	2 years	D[1]	M	HIGH
Prioritize, protect, and manage critical areas for conservation of bio-diversity and agro-biodiversity	3 to 5 years	D	M	HIGH
Implement program to reforest degraded forest ecosystems	2+ years	LD	L[2]	MEDIUM
Implement sustainable management practices for native pastures	2+ years	LD	M	MEDIUM
Expand wetlands areas and apply good management practices	2+ years	LD	M	MEDIUM

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

Notes:

1 The challenge will be not only in reforming policies but also developing a consensus among landowners and managers, without which enforcement of management practices will be very difficult.

2 These costs could be high or medium depending on the extent of degraded forest areas and the cost of trees and plants to reforest degraded areas.

3 The case study team did not have an opportunity to visit wetland areas or determine the area that would be expanded. An assessment of wetland areas for potential expansion should precede implementation, at which time ease of implementation, costs and effectiveness could be reassessed.

5.2.5. CAPACITY BUILDING

Table 5-5a Assessment of Adaptation Measures: Capacity Building: Training and Knowledge Management

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Design and implement educational and awareness programs that integrate traditional knowledge and cultural diversity with climate change knowledge	1 to 2 years	LD	H	*high*
Develop and implement climate change curricula for primary and secondary education	2 years	LD	H	*medium*
Investigate social, cultural, economic, and environmental ties between lowlands and highlands	1 to 2 years	D	M	*medium*

Improve quality and accessibility of climate data and analysis	1 to 2 years	D	M	*high*
Design/tailor V&A training for decision-makers and stakeholders	< 1 year	LD	M	*high*

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

Table 5-5b Assessment of Adaptation Measures: Capacity Building: Decision-making and Implementation

Option	Time Period	Ease of Implementation	Affordability	Effectiveness
Enhance coordination among organizations on climate change	1 to 2 years	D	H	*medium*
Strengthen linkages between climate research and policy	1 to 2 years	D	H	*medium*
Stakeholder mapping	1 year	LD	H	*medium*
Implement collaborative actions between higher and lower basin stakeholders	1 to 2 years	D	M	MEDIUM
Identify and facilitate access to climate change funding	1 to 2 years	LD	H	*high*

- Ease of Implementation – LD = less difficult, D=difficult, VD=very difficult
- Affordability – H=high affordability/low cost (<$100,000), M=medium affordability ($100,000 to $1,000,000), L= low affordability/high cost (>$1,000,000)

6. RECOMMENDATIONS

This case study provides a snapshot of recent trends in weather and the current situation in the Rio Santa Basin. As we have observed, the combination of non-climate stressors, weak institutional capacity for decision-making and management, and recent and expected future climate change poses significant challenges for the Rio Santa Basin, its inhabitants, businesses, and natural resources. In the previous chapters, we have described the climate and non-climate stressors and provided a menu of potential measures that can contribute to adaptation planning and the reduction of vulnerability to climate change and variability.

While the challenges of promoting climate-resilient management of the Rio Santa Basin seem daunting, given the aggregate costs of needed measures, the task of mobilizing financing, and timeframe for designing, approving, and implementing the suite of policy reforms to support management, there are a number of actions that can be taken in the next few years. Adaptation is a continuous process of assessment, action, monitoring, and adjustment to changes in development objectives, political, economic, social, and cultural context, and climate information. Initial steps can be taken now and as capacity to understand and manage climate impacts increases in the Basin, additional measures can be implemented.

Recommendations provided in this chapter are organized around three themes: 1) building the foundation for adaptation planning; 2) improving management of water and natural resources in the Basin; and 3) moving from planning to action.

6.1. BUILDING A FOUNDATION FOR ADAPTATION PLANNING

Effective adaptation planning requires appropriate information and analysis, skilled decision-makers, an informed public, and a transparent process for taking decisions. Priorities for building this foundation in the Rio Santa Basin include the following:

- *Improved data collection and monitoring of water and natural resources.* Baseline values need to be established to facilitate monitoring and assessment of changes due to climate and also, as adaptations are implemented, to evaluate their effectiveness in reducing climate vulnerability.
- *Compilation of traditional knowledge.* There appears to be a wealth of traditional knowledge about crops, farming methods, and water management that should be considered in adaptation planning.
- *Climate impact analysis.* Research is needed to understand changes in mountain ecosystems due to temperature increases and changes in glaciated areas and understand how glacial retreat will affect surface water storage and flows, groundwater recharge, and evaporation rates. Such information, combined with precipitation information, is vital to understanding how the annual water cycle will change for the Basin.
- *Capacity building for decision-makers, stakeholders, and civil society.* In order to assess, design, and implement adaptations, decision-makers will require new skills that can best be gained through V&A training and mentoring in the planning process. Exchanges and opportunities to compare experiences with other regions of Peru and other countries can contribute to decision-makers' capacity. Stakeholders and civil society also need to become more

aware of climate change and impacts and how their lives and livelihoods may be affected. Education and public awareness campaigns targeted to stakeholders, citizens, and students at all levels will foster a better informed public. In addition, stakeholders would benefit from training targeted at developing skills to participate effectively in adaptation planning processes.

- *Strengthening the adaptation planning process.* Adaptation planning must be carried out at appropriate scales. While much of adaptation planning, internationally, has been conducted on a national scale, donors and practitioners have encouraged adaptation planning at sub-national scales such as ecosystems, river basins, and watersheds. For the Rio Santa Basin, regional and local government representatives, water users and other stakeholders, and civil society organizations should be involved in the planning process. The process should be designed to facilitate the flow of information from communities and businesses to ensure regional initiatives are responsive to local concerns. The regional planning process should also maintain an open dialogue with national-level authorities, recognizing that many of the policy reforms that promote climate-resilient management will need to be adopted at the national level. In addition, national agencies can play a role as a facilitator or conduit for technical assistance and financing provided by Peru, donors, and multilateral development banks.

6.2. IMPROVED MANAGEMENT OF WATER AND ECOSYTEMS

Independent of climate change, there are opportunities to improve the management of water resources and ecosystems, particularly the high mountain areas. As noted previously, these resources have been degraded because of water pollution and unsustainable land management practices in the mountains. When climate stressors are factored into the management challenges, the importance of improving resource management to address non-climate stressors cannot be overemphasized. Priorities for improving resource management include the following:

- *Data collection and monitoring*. Improvement in the collection and monitoring of water flows, water quality, and groundwater is a major gap in water resources management in the Basin. As noted in Chapter 4, few resources have been invested in understanding groundwater storage, infiltration to surface water, and quality of groundwater, or potential to augment surface water flows. As noted above, baselines need to be established for mountain ecosystems to facilitate monitoring of ecosystem health if measures are implemented to address degraded areas and promote ecosystem services.

- *Decision support tools*. A more systematic management regime is needed in the Basin. Decision support tools can facilitate management of water allocation, but they are only as good as the quality of historical data used to calibrate them and the real time data used to take decisions. Decision support tools should be developed concurrently with efforts to improve data quality.

- *Evolving an integrated management approach*. Integrated management of the Rio Santa Basin will require better data and analysis as well as an improved process for reflecting and responding to water user and civil society concerns. Climate concerns should be mainstreamed into modeling and planning. Water allocation models already have the capacity to simulate climate scenarios and assess their potential implications on management. Close coordination should be stressed between disaster risk management (GLOFs and floods) and water management as well as with the various economic sectors that rely on water as an input.

- *Planning for improved management of critical ecosystems*. It is generally asserted that healthy ecosystems are more resilient to climate change than damaged or unhealthy ecosystems, largely because they can respond to changes or variability more effectively. As discussed earlier, improved management of mountain ecosystems will require additional analysis of areas (to facilitate critical areas designation), and policy reforms and resources to implement effective management measures. In justifying such improved management, the contributions of these areas to ecosystem services, including role in regulating water, reducing sediment loadings, and supporting local livelihoods should be taken into account.

6.3. FROM PLANNING TO IMPLEMENTATION

While the recommendations above stress improved planning, there are opportunities to implement near-term adaptation measures. Not only will these measures yield benefits and help to reduce vulnerability to climate change but they also will reinforce the need for a sustained and continuous commitment to adaptation planning, implementation, and monitoring. Furthermore, with the prospect for significant donor support for adaptation resulting from UNFCCC negotiations, decision-makers and stakeholders are encouraged to develop project designs and apply for financial support. Such applications will be more attractive to donors if they represent priority actions that have been identified in regional adaptation planning exercises. The recommendations provided below can be characterized as "no regrets" options that can be justified on economic and social grounds on the basis of current climate. They focus mainly on improved water utilization and piloting activities.

- *Improved water utilization.* One of the best strategies for increasing adaptive capacity (and reducing climate vulnerability) to droughts is to use water more efficiently. For example:
  - In agriculture, the key opportunities focus on rehabilitation of irrigation systems, better irrigation practices and adoption of more efficient irrigation technologies. Drought-resistant plant varieties and alternative crops and improved soil management
  - In the municipal sector, this can include efforts to reduce leaks in distribution networks, adoption of water-saving devices and appliances in households and businesses, and changes in behavior leading to water conservation.
  - In the industrial and mining sectors, there are water efficiency measures that can be promoted but the major challenge in these sectors is to address water quality concerns and promote improved quality for downstream users.
- *Small-scale water storage and irrigation systems.* In the high mountain sub-basins of the Rio Santa Basin, small-scale infrastructure projects may be appropriate to meet local water needs for drinking water, irrigation, and livestock.
- *Design and pilot testing of early warning systems.* Given the potential for flash floods and GLOFs, a project with potential benefits and replication would focus on the design and testing of an early warning system at the community level.
- *Restoration of degraded mountain ecosystems.* On a pilot basis, a degraded area could be assessed and a suite of measures related to restoration, replanting, and management measures designed and implemented.
- *Diversifying livelihoods.* To increase adaptive capacity and enable campesinos to respond to climate changes more effectively, a pilot program could be implemented at the community level to strengthen existing livelihoods (improving profitability of farms) and assess opportunities for alternative livelihoods, including diversified agriculture and tourism services.

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