The Consequences of Climate Change for the Water Resources of Perú

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Abstract

The tropical nations of the Andes are beginning to experience the consequences of global climate change. Perú, which has the greatest concentration of glaciers in all of the tropics, is dependent on runoff from its cordilleras for water for hydroelectric generation, irrigation and drinking water supply. Rapid recession of the mountain glaciers will lead to reduced meltwater contribution to stream flow, and diminished water availability in the near future. Many of these glaciers will disappear entirely within the next 50 years. Huge infrastructural investments are being made to obtain water for the arid Pacific coastal plain; home to nearly 70% of Perú's 28 million people. At the current rate of growth, Lima will have a population of 15 million within 25-30 years. Water supply, which is barely adequate for the population today, will need to be doubled

Introduction

Perú is a nation of physical extremes, with highly varied topographic regions and diverse ecological zones that result from these extremes of topography and precipitation. Located along the west coast of South America, from 3 degrees to 18 degrees south latitude; Perú's climate ranges from desert areas along the coast, to tropical rain forest of the Amazon basin in the eastern interior. Between these extremes lie a number of narrow north-trending cordilleras, which rise to elevations well above 6000 meters (Figure 1).

Although located in tropical latitudes, Perú's mountains contain the largest volume of glaciers in any tropical region of the world. Melting of these ice masses results in significant fresh water flow in the nation's rivers, even during the extended dry season from April through October. Most of the rivers draining the Perúvian Andes are tributary to the Amazon River. Rivers flowing down the steep western slope of the range to the Pacific Ocean have limited drainage basins and only those which drain glaciated ranges have sufficient water for irrigation agriculture year-round.

Today the population of Perú is more than 28 million, and more than 70% are living along the western coast. These coastal cities rely on water flowing to the Pacific from the mountain regions; and on ground water well systems to provide fresh water resources. Lima, with nearly one-third of Perú's population, has grown beyond its water supply capabilities. In recent years the Lima water utility, SEDAPAL, has begun importation of water from reservoirs in the mountainous basin to the east; with the expectation that glacial meltwaters will recharge the lakes and reservoirs of these regions.

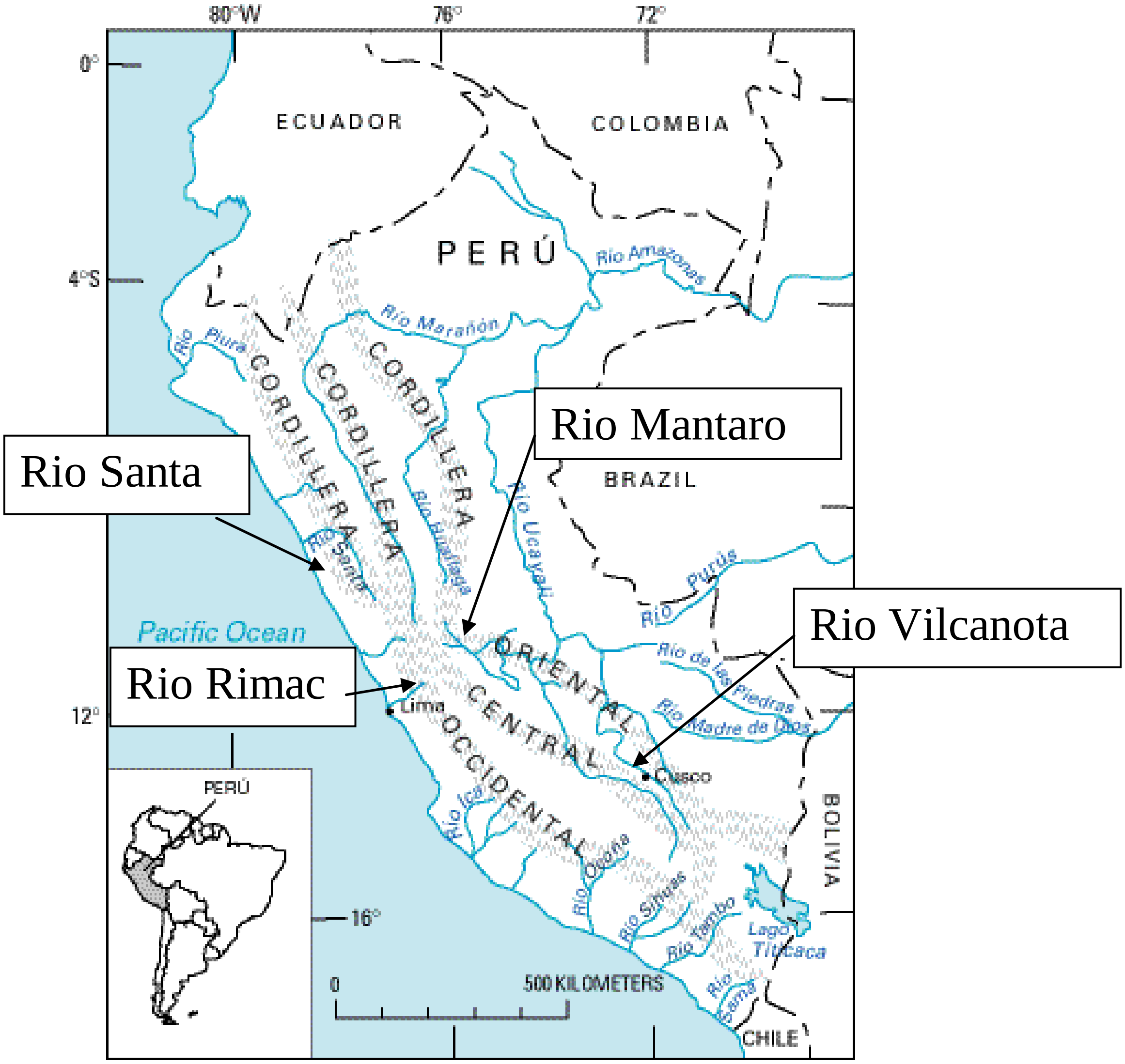

Figure 1. Location map of Perú, and the major cordilleras and rivers. Locations of the river basins of study are highlighted (USGS PP 1386 I-4).

Much of the agricultural production of Perú is in the dry coastal regions where year-round climate is consistent and water is supplied by massive irrigation works. Electric generating capacity in the country (6.2 GW) is about 50% from hydropower (3.24 GW), mostly from small generators of less than 100 MW (Ministerio de Energia y Minas, 2006). Due to the higher cost of thermal generation, about 70% of the energy produced annually is from hydro generation.

Even without a changing climate and disappearing glaciers, Perú will face a monumental challenge to meet the water and energy needs of the country's rapidly growing population

Climate of Perú

Perú is located on the western margin of South America, and normal weather patterns travel from the Atlantic Ocean and across the Amazon Basin, dropping most of their moisture as rainfall over the Amazon. The Andes provide a high barrier to migration of moisture further west, and most precipitation falls on the easternmost cordillera with little moisture reaching the western ranges. The continental divide between the Atlantic drainages and those flowing to the Pacific is located less than 200 km from the Pacific and consequently most runoff is to the east into the Amazon Basin.

The cold Humboldt Current flows north along the west coast of South America from Antarctica, effectively inhibiting rainfall along the coast. Cold water rising along the Perúvian coast has spawned one of the most productive fisheries in the world due to the nutrient-rich waters, and coastal societies in this part of the world have long obtained much of their food sources from the sea. Rainfall is highly seasonal throughout Perú with most of the annual precipitation coming during the austral summer (November-April). In northeastern Perú annual rainfall typically exceeds 2000 mm, but for much of Perú annual precipitation is well below 500 mm. Along parts of the southwest coast, rain may only fall once every 10 years.

For thousands of years a frequent but irregular climate phenomenon known as El Niño has interrupted the Humboldt Current; greatly changing the sea temperature, as well as precipitation patterns in Perú and worldwide. During an El Niño event Pacific Ocean currents reverse their normal westerly flow, bringing abnormally warm waters to the coast of Perú and causing a collapse of the anchovy-based fishery. El Niño events may last for more than a year, and cause significant change in rainfall patterns, with heavy rains and floods along the normally arid western slope of the Andes. At the same time that El Niño causes severe flooding in northwestern Perú, the southeastern highlands and altiplano may experience drought.

La Niña is another climate aberration during which abnormally cold waters accumulate offshore of Perú, and in much of northern Perú drier than normal conditions occur. Ice core records from SW Perú have shown higher than normal snowfall accumulations during La Niña years (Cole, 2001).

Both phenomena are part of a global ocean water-atmospheric pattern known as ENSO. This El Nino-Southern Oscillation has a profound effect on global climate conditions, influencing the intensity of Asian monsoons and Atlantic hurricanes, as well as periods of prolonged drought in regions from Australia to western North America (Thompson et al., 1984).

Hydrologic Regions

To assess the present hydrologic conditions, and to evaluate future sustainability issues, several river basins have been studied (Figure 1). Two of the rivers drain the westernmost cordillera, one drains the central highlands flowing toward the Amazon, and the fourth drains the southeastern mountains of the Altiplano. The waters of all four rivers are used for potable supply, irrigation and power generation, but each illustrates aspects of the changes that diminished flow will bring to the rivers of Perú.

The Rio Santa in northwestern Perú drains portions of the Cordilleras Negra and Blanca, flowing north through the Callejon de Huaylas to the Pacific. Before reaching the ocean, much of the discharge is diverted into the Chavimochic irrigation project and transferred to large factory farms in La Libertad Department. Ultimately the Chavimochic water supply is delivered to Trujillo, Perú's third largest city. It was in these coastal river valleys that the early Perúvian civilizations of the Moche and Chimor developed.

Rio Mantaro drains the Cordillera Central and the relatively wet altiplano of Junin and Huancavelica Departments, flowing to the Apurimac and ultimately adding to the flow of the Amazon. The headwater region is dominated by mining, and suffers from the pollution of more than 150 years of exploitation. Downstream, near Jauja and Huancayo, is a major agricultural region and in its lower reaches is the Mantaro hydropower project, which supplies nearly one-sixth of the electricity produced in Perú. The central highland was the center of the Huari civilization, which predated the Inca.

The Rio Vilcanota in southeastern Perú drains much of the area north of the Lake Titicaca basin, including the Cordillera Vilcanota, which contains Perú's second largest concentration of glaciers; and is also a major tributary to the Rio Amazon. The high altitude valley of the Vilcanota flows through Cusco Department and has traditionally been the breadbasket of Perú's mountain civilizations. Cusco city was the capital of the Incan empire, and today is home to more than 300 000 people. Nearly half of Cusco's water supply is derived from wells in the Vilcanota valley, and downstream, another regional hydropower station is located within sight of the famous ruins of Machu Picchu.

Rio Rimac is a relatively small river in comparison to the first three, but is certainly the most important river in Perú because its waters supply Lima; the nation's capital and home to nearly one-third of its people. The Rimac flows westward from the Cordillera Central and in its short, steep fall to the Pacific Ocean, numerous hydro projects generate 565 MW, almost 10% of Perú's electricity. These stations supply major mining districts, and the industrial and urban demands of Lima Department. Efforts have been made in recent years to develop storage reservoirs high in the drainage basins in order to provide adequate flow for hydropower and water supplies during prolonged dry periods.

Climate Change and Glacier Resources

Perú has more glaciers in its mountains than any other tropical country, but the area covered by ice is rapidly decreasing. Estimates from aerial photography of the area of glaciers, made by Hidrandina in the 1960s was 2596 km^2, but a second estimate in 1997 showed a reduction in area of nearly 22 percent in less than 30 years (Ames et al., 1989).

The greatest concentrations of glaciers are in the Cordillera Blanca (approx. 564 km^2) in Ancash, Cordillera Vilcanota (approx. 420 km^2) in Cusco, and in the Cordillera Central (approx. 138

km^2) in Junin (Morales Arnao, 1999). The glaciers of the Cordillera Blanca drain into the Rio Santa in the west and into Rio Marañon in the east. Numerous high altitude lakes provide storage of the glacial meltwaters and their contributions sustain the flow of Rio Santa during the dry season. This year-round flow has fostered hydropower generation and significant irrigation projects along the Pacific coast both south and north of the river's mouth at Chimbote.

Cordillera Vilcanota is located in southeastern Perú and is the headwaters of Rio Vilcanota, a major tributary of Rio Ucayali, and source of water for irrigation, potable supply and power for much of Cusco Department. The Quelccaya ice cap, largest glacier in Perú, is located at the southern end of the Cordillera Vilcanota. Several ice cores have been recovered from Quelccaya, yielding a 160 m long climate record of the last 1500 years. One of the best documented glaciers in the Andes is the Qory Kalis outlet glacier from the Quelccaya ice cap. This glacier has been measured by photogrammetric methods regularly since 1963 and has retreated steadily, with a greatly increased rate of retreat in recent years. Qory Kalis glacier may disappear completely within the next decade (Thompson et al., 2006).

Glaciers of the Cordillera Central (Figure 2) and the Cordillera Viuda just to the north are all small but provide meltwater to recharge numerous alpine lakes and wetlands which sustain the flow in Rio Mantaro and Rio Rimac. These two rivers systems account for 41.6% of Perú's available hydroelectric generating potential.

Figure 2. Glaciers of the Cordillera Central. Nevado Carhuachuco and the headwaters of the Rio Yauli, Junin, Perú.

Climate Change and the Rise and Fall of Perúvian Civilization

Ice cores recovered from Perúvian ice caps have yielded some of the best climate records of tropical South America during the Holocene Epoch, and indicate significant extended periods of drought; which have been correlated with major changes in the well-being of early civilizations and empires of the pre-colonial Americas (Moseley, 2001). Cores have been obtained from Nevado Huascaran near Huaraz in the Cordillera Blanca, Nevado Coropuna near Arequipa in the Cordillera Ampato, and from the Quelccaya ice cap south of Cusco (Thompson et al., 2006). These ice cores, preserved at the Byrd Polar Research Center at The Ohio State University, provide an archive of Holocene climate, precipitation and temperature variation. Together with lacustrine sediment cores recovered from Lake Titicaca and Lake Junin, these climate proxies provide a detailed history of drought and periods of abundant precipitation, as well as a record of El Niño and La Niña events for the last 1500 years (Thompson et al., 1984; Binford et al., 1997).

Of particular note are periods of lengthy drought which spanned decades during the years 540-610, 650-760, and 1100-1500 AD (Thompson et al., 1985). These years mark significant cultural changes in the Andean region. The prolonged droughts of the first Millennium coincide with the demise of the Moche culture in northern coastal Perú and the return to wet conditions in 760 AD may well have led to the success of the Huari culture in the central Andes (Moseley, 2001). The Huari may have successfully developed irrigation and agricultural practices in the moister Cordillera Central which allowed them to make it through mega-drought. They emerged from this dry time as a successful empire which spanned much of central Perú, rivaling that of the contemporaneous Tiwanaku culture, centered around Lake Titicaca (Figure 1).

Both the Huari and the Tiwanaku cultures were extremely successful during the extended wet period of 760-1100 AD, but the longer mega-drought period beginning in 1100 appears to have ended both cultures' dominance in their respective regions. Entering this drought, populations of the central and eastern cordilleras, and the Altiplano from Titicaca north, supported a population greater than that which exists today (Binford et al., 1997). With the severe drought, precipitation in the Altiplano and the surrounding mountains decreased and the level of Lake Titicaca declined sharply. The agricultural system developed around this lake collapsed and as the Tiwanakan civilization declined, the Aymaran people migrated north into the mountains to farm at higher altitudes, where rainfall agriculture could still be practiced on terraced hillsides.

The Incan empire arose in the earliest 15th century on the foundations of the Huari and Aymaran cultures in the mountains and Altiplano of the Cordillera Occidental. Much of their imperial strength was founded upon solid agricultural practices which were able to provide food supplies to a large and growing population, even as the region began to emerge from prolonged drought. With the return of adequate rainfall in the region during the mid 15th century, farmers migrated to lower elevations and once again were able to sustain agriculture in the high mountain river valleys. The Incan practices of collective agriculture, regional supply and transport supported the rapid growth of their empire. By the early 16th century, the Inca were in control of nearly all the land and peoples between central Ecuador and northern Chile (Moseley, 2001).

In 1532, the Spanish conquest of Perú began and in spite of the power and extent of the Incan empire, within a year the Inca capital of Cusco was captured. Although Inca resistance continued for another 50 years, the colonial era of South America had begun.

Impacts of Climate Change and Deglaciation on Modern Perú

Deglaciation of the Andes will result in decreased discharge in the rivers of Perú, over the long term. Although the glacier retreat has been recognized for nearly a half century, it is only now being taken seriously. Impacts will be felt throughout the country, but will be greatest along the arid Pacific coast, where nearly three-fourths of the people live and work. In a nation where 70% of the electricity generated is from hydropower, reduced discharge can only mean less generation. Most are run-of-river power plants and lack significant reservoir storage. Agriculture on the arid coastal plain is quite productive, but only because large irrigation schemes have been developed. Potable water supply will diminish, as population continues to grow. Examples from the Rios Santa and Rimac basins are presented below.

Rio Santa

Rio Santa, in Ancash Department, north of Lima, is the longest river flowing to the Pacific Ocean (316 km) and drains much of the glaciated Cordillera Blanca (14 954 km^2) and the arid Cordillera Negra. The Cordillera Blanca has the highest mountains and the most glacial ice (564 km^2) of any cordillera in Perú. Rio Santa is one of the few west-flowing rivers to reach the sea during the dry season, and its flow is sustained by meltwaters from these glaciers. The glacial meltwater contribution to the discharge of Rio Santa has been estimated at approximately 40% (Mark et al., 2005).

Rio Santa is the largest river on the populous western slope of the Andes, and supplies water to the interior valley of the Callejon de Huaylas as well as irrigation water for agricultural developments in the lower valley and three river valleys north of the Santa.
Huaraz, the capital of Ancash, and the Callejon de Huaylas are important tourist destinations, and the home to more than 300 000 people who are dependent upon the river and its tributaries for water supply for domestic and agricultural use.

At the north end of the Callejon de Huaylas is the Cañon de Pato hydroelectric station at Huallanca. This is one of the older power plants in Perú, and has a generating capacity of 264.4 MW. Like most hydro plants in Perú, Cañon de Pato is a run-of-river generator and can only operate at full capacity for a portion of the year. Today, during the months of June-September, the entire flow of the Santa has to be diverted to power the turbines at Huallanca. To ensure power availability during peak demand hours, two off-stream reservoirs have been constructed to store water for daily release during the hours of high demand each evening. Several of the high altitude glacial lakes of the Cordillera Blanca have been dammed and are used as regulating reservoirs to enhance flow of the Santa during the dry season. These lakes are fed largely by meltwater from the glaciers.

A new large hydroelectric generating station is currently proposed for a location about 70 km downstream of Huallanca. The new Santa Rita plant will have a generating capacity of 220 MW and has been proposed as a CDM investment to offset global CO_2 emissions. A recent study of the consequences of decreased meltwater contribution on hydroelectric power productivity at Cañon de Pato suggests that a 50% reduction in meltwater would result in approximately 20% less power productivity (Vergara et al., 2007).

Although the current installed hydroelectric generating capacity in all of Perú is only 3240 MW, the Ministry of Energy and Mines has recently suggested that the hydroelectric potential for all of Perú is 58 937 MW. The greatest potential for new generation is from the large rivers flowing east from the Andes. Decreased contribution to the discharge of the Santa and other west-flowing rivers will limit the output of Cañon de Pato and most other important hydropower plants of the western slope of the Andes.

The greatest potential economic and social impact of climate change to those dependent upon the sustained flow of Rio Santa will be felt outside of its drainage basin in the Department of La Libertad, well north of the Callejon de Huaylas. About 70 km before the Santa reaches the Pacific Ocean; much of its discharge is diverted into the Chavimochic irrigation project (Figure 3).

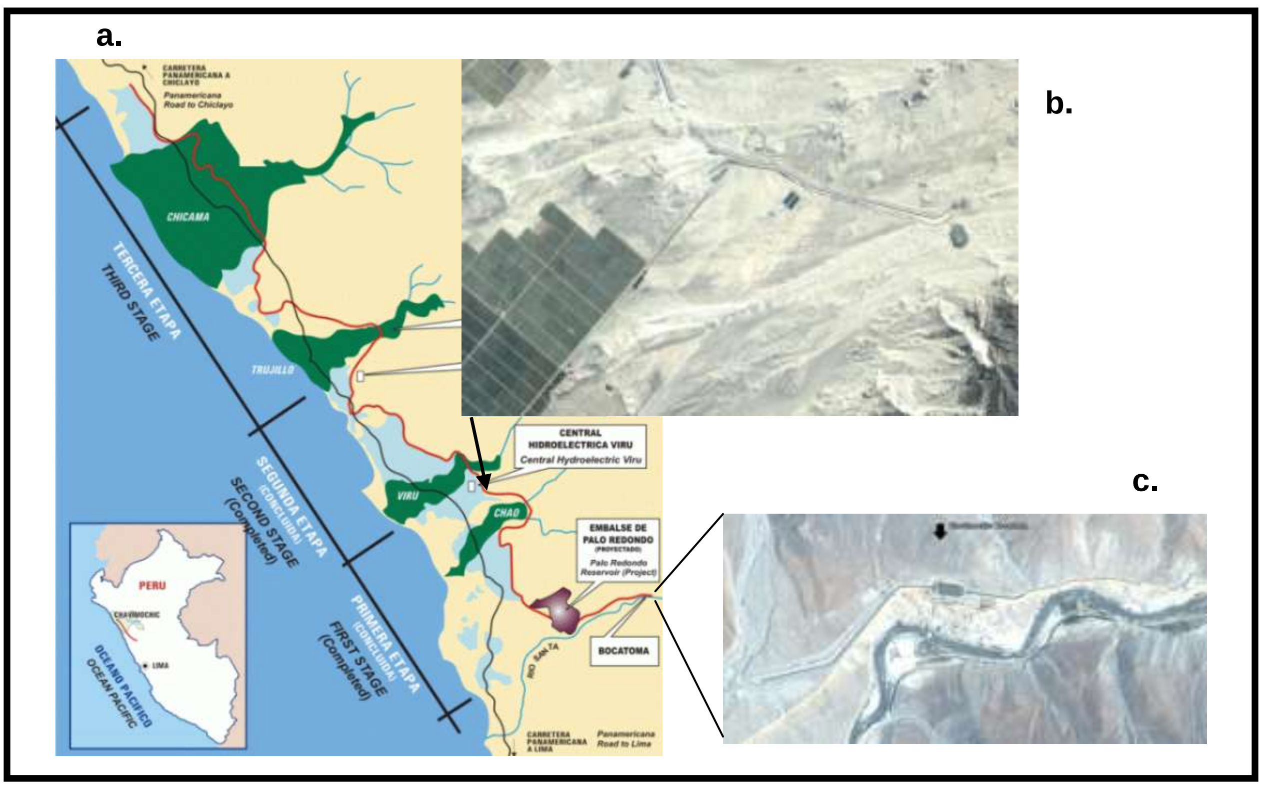

Figure 3. Chavimochic Irrigation Project located in La Libertad Department.

a. Map of stages 1-3, only stages 1 and 2 are complete. Shaded areas are irrigated farmland.
b. Newly irrigated farmland near Viru, Perú. Canal flows right to left from tunnel.
c. Diversion of the Rio Santa into Chavimochic canal

This system, designed for a maximum discharge of approximately 100 m^3s^{-1}, transfers water to four perennially dry river valleys north of the Santa; to irrigate nearly 150 000 hectares of agricultural land. Large factory farms have been developed in the last decade in the *Cha*o, *Vi*ru, *Mo*che valleys. Stage three of the project, to begin in 2007, will extend the canal to the *Chic*ama valley. As of 2005 the value of asparagus and other export crops grown in these irrigated farms exceeded US $180 million (Chanduvi, 2006). These factory farms grow year-round, support more than 30 000 full-time jobs, and have become the largest industry of the region.

Additionally, the Chavimochic canal will power three small hydroelectric plants for 68 MW of power generation; and deliver 1 m^3s^{-1} of potable water for the City of Trujillo (population 736 000). When the canal is extended to the Chicama valley, it will provide potable water for the city of Chiclayo as well. Sustainability of the Chavimochic project and the economic prosperity it has brought to La Libertad, depends upon continued diversion of a substantial portion of the Rio Santa's discharge. As glaciers disappear from the highlands of the Cordillera Blanca, flow in the river will decrease, prohibiting full flow to the Chavimochic canal.

Rio Rimac

Colonial Lima is located on the narrow coastal plain of the Pacific, and is one of the oldest cities of the Americas; founded in 1535, shortly after the conquest of the Incan Empire by the Spanish. It has a European look and bustles with activity and a rapidly growing population. In the 1930's the population was only 300 000, but today is greater than 8 million people. Nearly half of those have arrived from the country during the last 30 years, and the city struggles with infrastructure to support this rapid growth. The original small colonial town is located along the south bank of the Rio Rimac and public water supply from the river was initiated in the late 1500's.

The Pacific coast of Perú is tectonically active, with frequent earthquakes, and mountains more than 6000 meters in elevation just 120 km inland. The average gradient of the Rio Rimac is more than 3%; and it flows from the wetlands, lagunas and glacial meltwaters of the Cordillera Central through steep narrow valleys onto a clastic wedge of coarse alluvial sediments between the mountains and the coast.

Today Lima has sprawled across three coastal basins (Figure 4), and the city continues to grow with the addition of Pueblos Jovenes (Young Towns). These additions begin with minimal infrastructure planning and the hope that utilities will follow their settlement. Most of this expansion has been to the north into the Rio Chillon basin; and a ground water and surface water treatment plant has been added at the northernmost part of the distribution system. The city has also expanded to the south and southeast into the Rio Lurin basin, and plans are in place for a new distribution system to be developed there also. The potential supply from these marginal basins is limited due to their small size and lack of significant recharge areas high in the Andes.

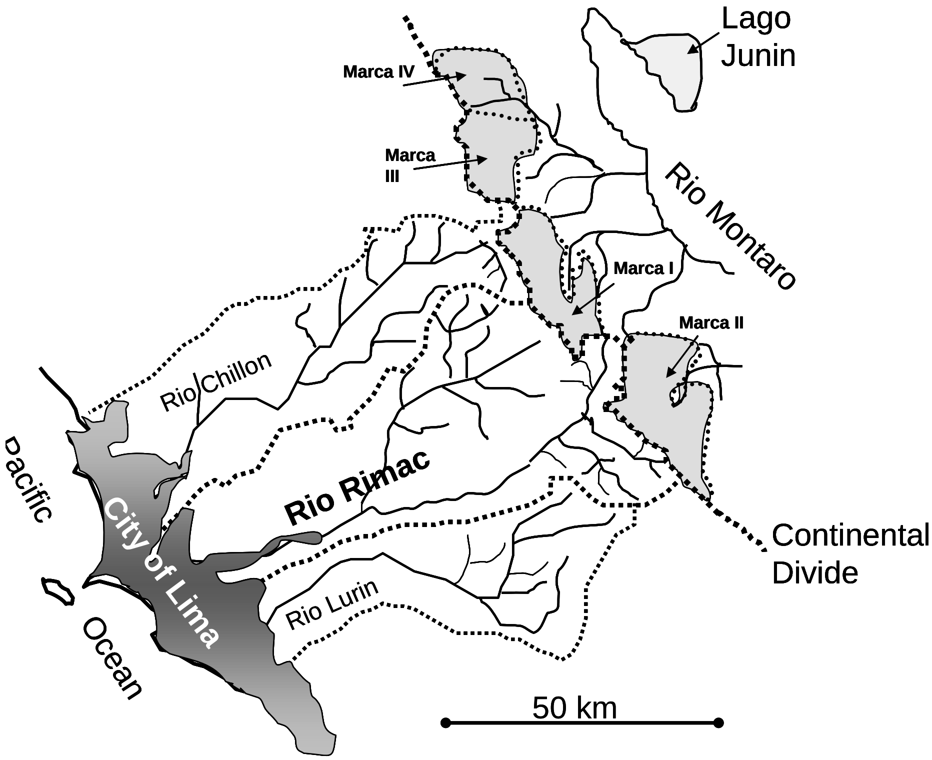

Figure 4. Lima area and the Marca I-IV water system enhancements

Nearly 75 percent of the water supply of Lima today (32 m^3s^{-1}) is from the discharge of the Rio Rimac, which is diverted nearly in its entirety and treated for distribution at La Atarjea, several kilometers upstream of Lima central. Additionally 454 wells are connected to the distribution system throughout the network, however only about 232 are in service at this time (Lopez, 2004). These wells supplement the surface supply of the Rimac with nearly 8.5 m^3s^{-1} of water, but the aquifers vary in quality; and have been overexploited, resulting in rapidly falling water levels. Local contamination issues result both from land usage, wastewater infiltration and saltwater intrusion in many areas, and have forced abandonment of numerous wells. In addition to SEDAPAL's wells, nearly 2270 large private wells supply industry and several municipalities, resulting in an unsustainable exploitation of the aquifer.

Total supply of the Lima water system averages 42.5 m^3s^{-1} today. The population served in 2005 was estimated to be 7.3 million, with service averaging 23 hours per day. More than one million people in Lima are not served by SEDAPAL and are forced to buy water from haulers at highly inflated rates. Plans to expand water supply to the Lima distribution network are focused on supplementing flow of the Rio Rimac. Precipitation in the highlands where the river has its origin is significant, and during the wet season more than 12 m^3s^{-1} bypasses La Atarjea and flows to the sea. Reservoirs to retard this discharge have been developed in the upper basins of Rio Santa Eulalia and Rio Blanca, the two rivers which contribute the bulk of Rio Rimac's discharge.

In the mid 1990's a set of projects was conceived to augment the supply to each of these two sub basins by constructing aqueducts to bring water across the continental divide from the headwaters of the Rio Montaro, in the Department of Junin. This staged project (Marca I-V) would modify existing lagunas into storage reservoirs and gather the resources of the headwaters of the Montaro and its tributaries with canal systems (Figure 4). Water would then be transferred by tunnels across the divide into the basin of the Rimac. The first portion of this system (Marca I) was completed in 1997 when the Marcapomacocha reservoirs were connected to the headwaters of the Rio Santa Eulalia. Marca III consists of a series of gathering canals and tunnels to bring water from additional lagunas south to Marcapomacocha to enhance the available water for transfer across the divide and into the Rimac basin, and was completed several years ago. At present, another enhancement (Marca IV) is to be added to connect the large Laguna Huascacocha to Marcapomacocha. Work on this project began in late 2007, with completion expected in 2009.

Enhancements to the Rio Blanca flow are to come from an ambitious project (Marca II), which will redirect the drainage from a portion of the glaciated Cordillera Central, southeast of the Rimac basin, which today is tributary to the Rio Mantaro. This will be done by collecting most of the flow of the Rio Yauli and directing it up basin to Laguna Pomacocha, and then into a new 10-km tunnel for transfer beneath the continental divide and into Rio Blanca. Marca II has been delayed since the late 1990's, but may be carried out concurrently with Marca IV. Together the new projects are expected to cost nearly US $150 million, and will add 7.2 m^3s^{-1} to the discharge of the Rimac.

In order to utilize the enhanced flow of the Rio Rimac at Lima, a new treatment plant is planned above the existing La Atarjea plant, which operates at capacity. The new plant at Huachipa is to have a capacity of 10 m^3s^{-1}, and will distribute water to the rapidly growing portions of the city to the north and south of Lima central. Huachipa is expected to cost US $130 million, with an additional US $140 needed for water distribution lines.

President Alan Garcia, newly elected in 2006, has pledged to provide water for all of Lima's residents, and an aggressive campaign of improvements, "Agua para Todos (Water for All)", has begun. However, without the enhanced supply from the Marca projects (7.2 m^3s^{-1}) anticipated in 2011, Sedapal will not have enough water to meet the demand. Supply security beyond 2011 is dependent upon factors both within and beyond SEDAPAL's control. It has been estimated that the aging water distribution infrastructure loses as much as 40% of its water; and the enhanced reservoirs of the Cordillera Central, on both sides of the continental divide, are dependent today on continued heavy rainfall during the wet season and on glacial meltwaters to supplement recharge of the reservoirs during the dry months. As recently as 2005, water supply in the city was impacted due to inadequate wet season recharge of the Marcapomacocha lagunas. Prolonged drought, and reduced glacial ice due to climate change, could severely restrict the water supply in the future.

Hydroelectric generation in the Rio Rimac basin accounts for 565 MW of capacity, close to the area of greatest demand. Water transferred from the Mantaro basin enhances the discharge of Rio Santa Eulalia and the Rimac, and the hydroelectric plants benefit from this as well. Present development of the Marca IV project is in large part due to its enhancement of available water from Marcapomacocha; and the ability to make additional electric power along the Rio Rimac. Marca II has been in and out of favor with SEDAPAL, due to its higher cost, and development is currently on hold. The water which could be supplied from Marca II is likely to be needed in the near future.

As in many coastal cities with water resource issues, many grasp at the promise of desalination. This is the case in Lima today, with hopes that abundant natural gas from the Camisea project of eastern Cusco will provide energy for the power-hungry desalination process. Another suggestion is that nuclear power generation could provide cheap energy for making fresh water from the sea. Neither nuclear power nor fresh water from desalination is a low cost option; however these may be the options of last resort.

Conclusions

The concentration of Perú's population, industry and commercial agriculture along the narrow Pacific coastal plain poses sustainability issues for a future which promises warmer temperatures and limited glacial storage of water. Less meltwater contributions to the rivers will result in lower flow to the coast, and ultimately will impact irrigation, power generation and most importantly, drinking water supplies. SEDAPAL is in a race to increase supply from the mountains, to try to catch up to the city's rapid population growth. These costly projects are designed for the needs of today, but may not be adequate for the demands of tomorrow. Recharge of the mountain reservoirs is dependent on summer rainfall, and winter meltwaters from the glaciated peaks of the Cordillera Central. These glaciers are shrinking fast and many will likely disappear within 50 years.

Hydroelectric generating capacity is likely to decrease for the near term and the tendency will be to replace that capacity with thermal plants which can use natural gas for reliable production, independent of the vagaries of drought or meltwater contribution to stream flow. Electricity production from hydrocarbons will be more expensive than hydropower and will add CO_2 to the atmosphere as well. Investment in renewable energy sources, such as wind and solar may be viable alternatives, and is just beginning to be discussed.

Extended droughts have been recurrent in the Andes and have severely impacted Inca and pre-Inca cultures. Return of severe drought conditions would certainly place serious restrictions on the ability of SEDAPAL to fulfill the promise of "Water for All" called for by President Garcia. This is not likely to be just a short-term concern. SEDAPAL must improve the efficiencies of their distribution system and press forward with the costly expansion plans of Marca I-V. Future presidents will struggle with water supply problems as well; and Lima, the largest city in the Americas to be sited in a desert, may have to turn to the sea for water supply. Where the nation will get the money or energy for desalination is a looming question.

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