Waning Water in the Andes:

Physical changes in the climate and glacial systems, social constraints, and possible adaptation strategies

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Contents

1. Introduction

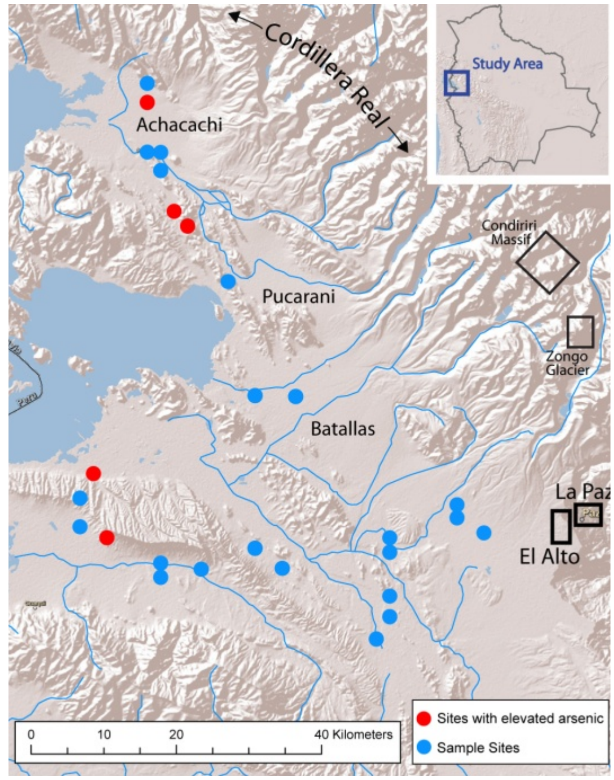

Figure 1. The focus of this paper is on the northern extension of the Bolivian Altiplano. Colored circles mark locations of water samples collected by Terra Resource Development International.

Air currents push the moist Amazonian air west during the austral summer months, stacking clouds against the Bolivian Andes. As the air ascends, it condenses and drapes the mountain peaks in snow. In the high elevations, glaciers grow and ooze down valleys, their lower half penetrates warmer climes that melt the ice. Streams begin at the toes of the glaciers. Water flows past clusters of small, mud houses that blend seamlessly into the landscape on the western flanks of the Cordillera Real. Small herds of llamas and sheep drink from the rivers, and make-shift canals divert the water to irrigate potato and quinoa fields that support the meager economies of most rural communities. People dip buckets in the rivers or lower them down hand-dug wells that are recharged by the streams and rain, carrying the water to their houses for domestic uses. Not far from the Condiriri and Huayna Potosi glaciers, water flows into reservoirs and is diverted to the swelling urban populations of La Paz and El Alto. In the Bolivian Andes a large fraction of the water supply for approximately two million people comes from the mountains.

Glaciers are a vital component of the surface water supply in many glaciated mountain ranges around the world, including Bolivia. However, threatened by climate change most alpine glaciers are retreating, and glaciers in Bolivia are particularly sensitive to these changes. News stories, policy briefs, and scientific papers have repeatedly warned that receding glaciers forebode reductions in water supply in the Andes. But, the impacts of climate change are not simply created by warming temperatures or melting glaciers. The impacts are embedded in a dynamically linked social and physical context that often work in concert to amplify the impacts and consequences.

Bolivia is Latin America's second poorest country (Bolivia, 2001) and the ability to adapt depends on wealth. The Intergovernmental Panel on Climate Changes (IPCC) and the World Bank have stated that poor countries are most susceptible to climate change (IPCC, 2007; Vergara, 2005), while other studies have suggested that the most hard hit regions will be in arid areas (e.g Eakin, 2007). In the Andes, climate change, waning glaciers, water resource management, and a poor population meet in a critical nexus, creating a perfect storm for dire consequences.

Melting glaciers present challenges for managing water resources in the Andes (Byg and Salick, 2009). But even without the added complexity of climate change, humanitarian efforts in developing countries often fail without scientifically sound planning and the participation of local people (Terra Resource Development International, NGO). This implies that climate change adaptation strategies must combine scientific research and local insight for success (Kloprogge and Van Der Sluijs, 2006), ensuring the minimization of societal risks while also improving the livelihoods of people.

Characterizing the problem with physical and social vulnerability studies is a logical first step. Devising solutions is the next stage. Adaptation and mitigation solutions require an integrated approach that meshes the understanding of the physical system, in which glaciers and climate operate, with the capabilities and constraints within the human system.

In the scientific literature, however, climate change impact studies in Bolivia heavily lean toward the physical dimension with scant information that sheds light on the social context. For example, more time and money has been directed to the glaciologists who have erected sophisticated weather stations on a few glaciers to measure the energy balance and build models of the physical processes that control melting. Fewer resources have been applied to social scientists who meet with communities and city officials to inquire how changes will impact communities and the obstacles and opportunities the people possess to cope with those changes. Both the physical and social contexts are needed to construct a more complete view of the pressures and variables acting within the human-climate-resource system. Ultimately, this integrated picture will better inform the actors involved in development and policy making, such as non-governmental organizations, international development banks, and state agencies.

This paper is an attempt to summarize the state-of-the-knowledge concerning the threat climate changes poses on glaciers in the Andes (and therefore a component of water supply) and on the communities that rely on water trickling from the glaciers. . The central focus is the populated area in the northern extensions of the Bolivia Altiplano (Figure 1), but limited information on this region requires gleaning knowledge from nearby and more studied areas, such as Peru. The World Bank echoed this sentiment when it stated: “Better understanding of regional climate trends [for Bolivia] and projected impacts is essential for the work on adaptation” (Vergara, 2005).

This paper first highlights the current observations in the glacial and climate systems, followed by a summary of the social context and the perceptions of climate change of the people living in the Bolivian Altiplano. The final part—“finding solutions”—draws in part on the author’s own experience in the country.

2. Methodology: A brief note

In this paper the Altiplano refers to the physiographic region at base and to the west of the Andes Mountains. It is an elevated plateau with average elevation around 13,000 feet above sea-level (asl). The word “Andes” refers to the glaciated mountains, many of which crest 20,000 feet asl.

Information in this report is taken from studies published in scientific journals, reports published by development banks and international aid groups, and from the author’s personal experiences living in working in the Bolivian Altiplano since 2000. However, many non-governmental agencies work in the Andes, and results from their work are often not published in journals. These organizations focus more on development and less on physical science, which contributes to the skewed availability of information for the physical sciences. Larger development organizations, like the World Bank and the International Development Bank, have produced valuable reports, but information on projects from smaller organizations, such as Save the Children and Plane Altiplano, only make it into annual reports that provide insufficient detail to be useful. The physical science literature is also incomplete. There are likely unpublished studies and additional data sources housed within Bolivian agencies that are not publically accessible—data from several weather stations in the Altiplano, for example, are for purchase only, and there is no on-line form to make the transaction. A clear picture is painted, however, even with an incomplete understanding of the Bolivian social context and the current and projected climate-glacier-water supply changes: adapting to waning water supplies is essential but challenging.

3. Observations of Ice and Climate: Laying the foundation for concern

*More effective management "must be based on a sound understanding of what determines a basin's… vulnerability." -Claudia Pahl-*Wostl, 2007

Alpine glaciers are natural reservoirs that store precipitation during the wet season and release it throughout the year, helping to regulate the streamflows. In arid regions and in climates with a pronounced dry season, glacial-melt water enables water courses to have constant minimum baseflows that buffer the effects of the long dry season. In addition to regulating streamflows, large portions of the water stored in glaciers make it to spigots and irrigation ditches, becoming integral to sustaining domestic and agriculture activities. Glaciers are, therefore, an important part of the water balance in regions where they are extensive. In Peru, for example, the

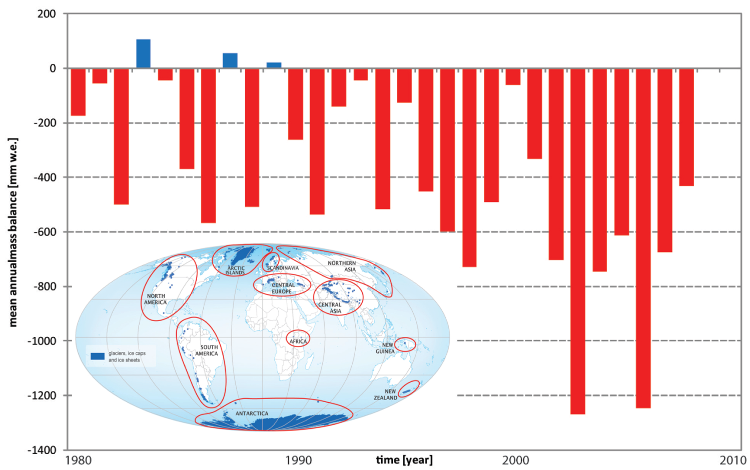

Figure 2. Changes in the average annual mass balance of 30 glaciers in 9 mountain ranges between 1980 and 2008. Inset shows locations of the ranges. Source: World Glacier Monitoring Service.

Yanamarey watershed receives about 30 percent of its annual surface water from melting ice (Mark and Seltzer, 2003). While it is unknown exactly how much water is consumed globally by humans and the total number of people who rely on glacier water, one-fourth of the world's population lives within the glacial-drained Himalayan basins. Millions more live in watersheds in South America that drain the Andes. And in Bolivia, more than two million people live in watersheds that tap the glaciated terrains of the Cordillera Real (Figure 1).

Mountain glaciers in many of ranges around the globe, however, are retreating. The trend in the average annual mass balance for 30 reference glaciers—glaciers that have been keenly monitored and that are good indicators of regional patterns—has been negative since 1980 (Figure 2; World Glacier Monitoring Service, 2008). These glaciers span nine different mountain chains, including the Andes (Figure 2, inset). In only three of the last 30 years has the average mass balance been positive (blue bars in Figure 2); this same pattern is likely occurring in unmonitored glacial systems as well.

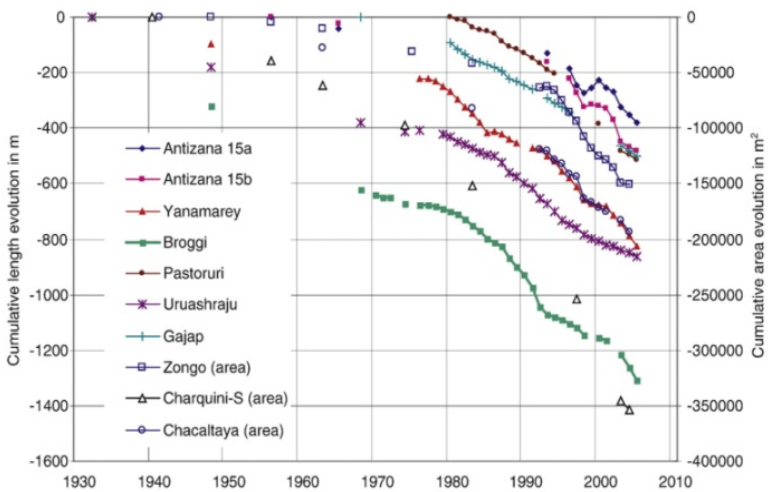

Figure 3. Changes in the cumulative length and area of 10 glaciers in Equator, Peru, and Bolivia. Zongo, Charquini-S, and chacaltaya are located in the Cordillera Real, Bolivia. Figure from Vuille et al., 2008.

Since alpine glaciers are highly sensitive to changes in temperature and precipitation, they are good independent records of climate change.

Based on glacial changes, tree rings and other climate proxies, and direct measurements, the IPCC has stated that climate change is unequivocal (Schneider et al., 2007). Since 1900, global average temperatures have increased by about 1.3 degrees Fahrenheit, with an acceleration in warming becoming pronounced around 1970 (IPCC, 2007).

In the Andes temperature change mimics the global pattern. An analysis of temperature trends based on 279 station records between the latitudes 1°N and 23°S show that near-surface air temperature has significantly increased by about 0.18 °F per decade during the last 70 years; the overall temperature increase has been approximately 1.2 degrees F since 1939 (Vuille and Bradley, 2000; Vuille et al., 2003). In addition, in the Andes, the elevation in which temperatures drop below freezing has increased by 174 feet between 1958 and 2000 (Diaz et al., 2003).

Bolivian glaciers are especially susceptible to changes in climate for two main reasons. First, most of the alpine glaciers are small. About 80 percent of them have an aerial extent of less than 0.5 km^2 (Francou et al., 2000).The smaller the area the greater the fraction of glacial loss per unit increase in temperature. On longer timescales, temperature serves as a good proxy for all the climate effects that cause glacial mass wasting. Second, mountain glaciers are at high elevations which are experiencing more rapid warming than lower elevations (Bradley et al., 2006).

The sensitivity of Bolivian glaciers to climate change and regional warming are causing retreat (Figure 3). Vuille and others (2008) summarized changes in glacier lengths and volumes for ten glaciers located in Equator, Peru, and Bolivia and found that every one of them has displayed negative trends. Three of those glaciers correspond to Bolivia—Zongo, Charquini, and Chacaltaya. In another study, Soruco and others (2009) found that Bolivia's mountain glaciers have lost nearly 50 percent of their 1975 mass. The IPCC has stated that many of these glaciers may disappear entirely between 2020–2030 (Magrin et al., 2007). The Bolivian and South American glacial story mimics the global pattern: glaciers are in near uniform and continuous retreat.

In addition to the longer-term trends of mass declines (e.g. Figure 3), recent observations have shown that glaciers in Bolivia are rapidly melting (Francou et al., 2003; Vuille et al., 2008) with accelerating rates. The Charquini glacier, for example, has experienced a fourfold increase in recession rates between 1983 and 1997 (Vuille et al., 2008). The small Chacaltaya glacier completely disappeared in 2009, a few years earlier than expected. Furthermore, during the last 25 years, the decadal warming trends have been more than triple the decadal trend during

1939–1998 (Vuille and Bradley, 2000).

While there is a strong correlation between increasing temperatures and glacial mass wasting, on annual timescales melting is controlled principally by humidity (Vuille and Bradley, 2000; Vuille et al., 2003). Humidity controls the partitioning of the available energy into melt and sublimation (the process of converting solid phase water into a gas phase). When humidity is relatively high, more melting occurs. Although no long-term and continuous in-situ records exist to document changes in humidity in the Andes, Vuille and others (2003a) analyzed interpolated and gridded data (CRU05 dataset) and discovered significant increases in relative humidity in western Bolivia of 0.5–1.0 percent per decade between 1950 and 1995.

While the mean state of climate and glacier changes is important, many studies suggest that the greatest threat to people will be felt in extreme events such as prolonged droughts, hurricanes, and heat waves (e.g. Easterling et al., 2000), which will also likely influence the behavior of glaciers. In Latin America there is ample evidence of increases in extreme episodes that include positive trends in warm nights and a positive tendency for intense rainfall events and consecutive dry days (Magrin et al., 2007). However, since climate and weather monitoring stations in Bolivia are sparse, poorly quality controlled, and not publically available, assessing changes in the distribution of extreme events is problematic (Vuille et al. (2008) describes the monitoring network as inadequate).

4. Social Context: Climate change impacts influenced by social pressures

Solutions "are embedded in a network of social routines… negligence [of social context] can lead to failures in the introduction of new technologies…." -Claudia Pahl-Wostl, 2007

The IPCC, development banks, and a host of other sources state that poverty exacerbates the negative effects of climate change. Implicit in this concern is that climate changes can perpetuate poverty because poor and therefore less resilient communities have fewer resources to bounce back after climate shocks or gradual degeneration. The climate-welfare connections are numerous (Figure 3). If a household, for example, lives hand-to-mouth and a prolonged drought decimates a crop, there is often insufficient money available to purchase needed materials to cope with the drought. Similarly, if a prolonged drought or reductions in streamflow cause water tables to lower, shallow wells may become high and dry which, in turn, threaten human health. Some suggest this will cause an increasing number of displaced people, or a climate diaspora.

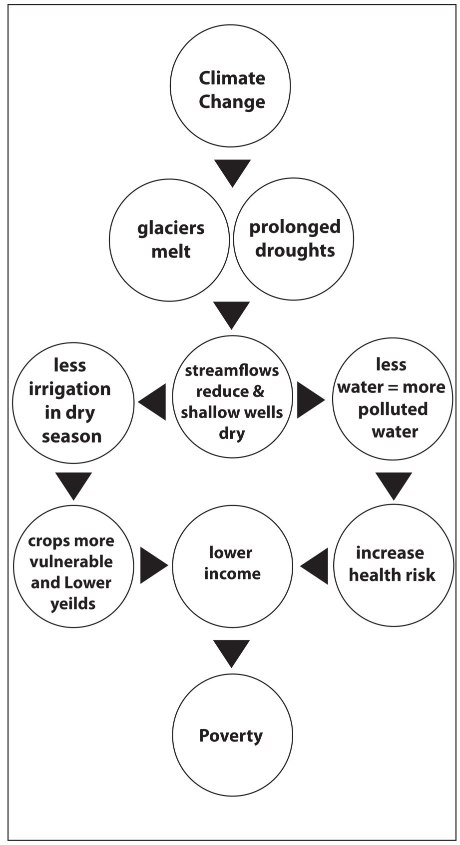

Figure 3. Conceptual diagram of links between climate and social livelihoods.

A lack of resources and the inability to obtain them is a central tenet of poverty and is part of a feedback cycle that can perpetuate the impoverished condition. This is evident in the water sector in Latin America and other countries around the world. Limited financial resources prevent the construction of dams and irrigation canals, investments in local water development that would reduce poverty, and basic education (e.g. UNICEF, 2005). On a global scale, drinking unsanitary water contributes to the deaths of nearly 1.4 million children who die each year (UNICEF, 2005). In Latin America, the IPCC summarized in the 2007 assessment report the state of water access. The report highlighted that 13.9 percent of the population, or 71.5 million people, have no access to a safe water supply, and 63 percent of these (45 million people) live in rural areas (Magrin et al., 2007). The report also stated that many rural communities rely on limited fresh water resources (surface or underground) and that many others rely on rainwater, using water cropping methods which are extremely vulnerable to drought and other weather events (Magrin et al., 2007).

Bolivia is a microcosm of the aforementioned statistics. Poverty is widespread. In 2001, the country ranked as the second poorest nation in Latin America (Bolivia, 2001). In 2001, most Bolivians were chronically sick with dysentery and 70 percent of rural families earned less than two dollars USD a day (Bolivia, 2001), an amount deemed by the World Bank to be insufficient to provide the basic necessities of life. Furthermore, 78 percent of poverty-stricken families did not have access to clean drinking water (Bolivia, 2001). This implies that the majority of the poor population obtains its water from either surface water or shallow wells. In the nine ensuring years since those figures were published, the story has likely not significantly improved.

These numbers imply that reductions in surface water supply will likely place greater stress on those communities relying on streams for domestic and irrigation water, potentially causing residents of rural villages to migrate to the cities of El Alto or La Paz where welfare likely does not improve their situation (Vergara, 2005). Although it is beyond the scope of this paper to characterize the impact of migration on welfare, moving to the urban centers of La Paz and El Alto is likely, at best, a zero-sum game—improving access to water will be offset by having less economic food security and by becoming more exposed to crime. In a recent survey of six rural communities in the Bolivian Altiplano, 76 percent of the people interviewed stated that there are sufficient water resources (Gonzales et al., 2006).

Since climate change is reducing the water stored and released in glaciers, surface water flows are being affected. Unfortunately, there is no data on the shifts in the timing or seasonality of streamflows in Bolivia and few records of climatological changes in extreme events. This is an important knowledge gap since many studies have concluded that the greatest impact of climate change will be felt through extreme events and that poor communities will be the hardest hit by these episodes (Easterling et al., 2000; Magrin et al., 2007). Additionally, there is evidence in Latin America that extreme events are becoming more common (Magrin et al., 2007). This trend is corroborated in the perceptions and anecdotes of Bolivians who are living in rural communities. Gonzales and others (2006) recently surveyed 180 people in six rural Bolivian Aliplano communities. More than 75 percent of the respondents believed that droughts in recent years are more frequent and intense than in the past; half the respondents stated that drought has the greatest impact on livelihoods. The people also perceive a later start to the rainy season, causing the sowing date to be delayed which can make the growing season shorter and reduce crop yields. With respect to precipitation, nearly 90 percent of the respondents suggested that the total amount of rain per year is declining. Finally, about 75 percent of the people interviewed stated that less water is available now than ten years ago.

5. Projected Climate and Water Supply Changes

Perceptions that water is less available now than in the past and long-term observations of glacial retreat beg the question: what effect will climate change have on water resources in the future?

Nearly all state-of-the-art general circulation climate models (GCM) project a warmer future (IPCC, 2007). The model spread in global average temperature increase by the end of the century is large, ranging between 2 and 12 degrees F depending on global greenhouse gas emissions (GHG; USGCRP, 2009). The best estimate for doubling GHG concentrations in the atmosphere to 560 parts per million (ppm) is about 6 degrees F—a concentration that would be reached with steady increases in emissions at current rates (~2 ppm/year) in about 80 years. However, accelerations in current trends in GHG emissions suggest that future temperature changes will fall in the higher end of the range if emissions are

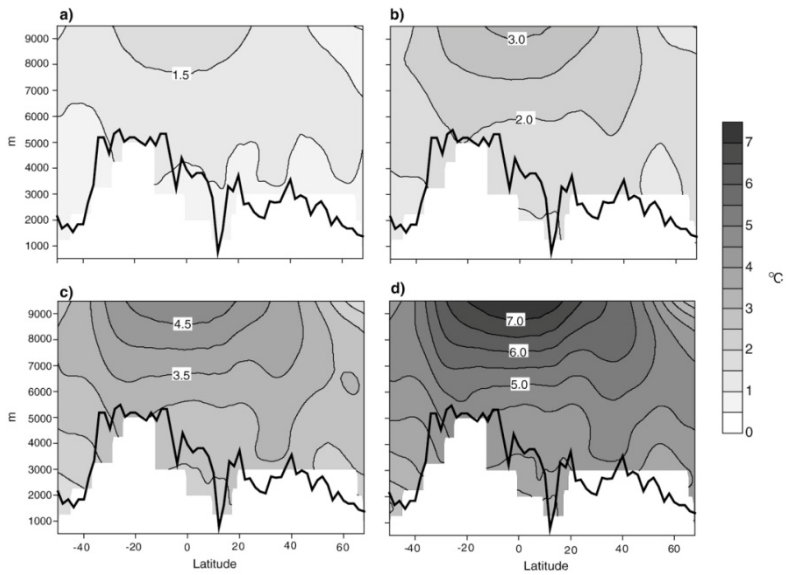

Figure 5. Projected changes in mean annual near-surface temperature for a) 2026–2035, b) 2046–2055, c) 2066–2075 and d) 2090–2099. All Panels show departure from 1990–1999 average along the axis of the American Cordillera from Alaska to Patagonia. Results show the mean of eight different GCMs used in the IPCC 4th assessment report using the A2 GHG emissions scenario. Black line denotes mean elevation along transect. Altiplano region is found around -20 degrees S latitude. Figure and caption taken from Vuille et al. (2008) but plots reflect analysis completed by Bradley et al., 2006.

not drastically and rapidly reduced (USGCRP, 2009). Bradley et al. (2006) investigated the annual near-surface temperature change along the axis of the American Cordillera from Alaska to Patagonia. They analyzed results from eight different GCMs that are driven by the A2 GHG emission scenario, a higher-end trajectory. Results indicate a continued warming of the tropical t roposphere throughout the 21^{st} century, with a temperature increase enhanced at higher elevations (Figure 5). By the end of the 21st century, the tropical Andes may experience intense warming on the order of 8–9 degrees F (Figure 5d).

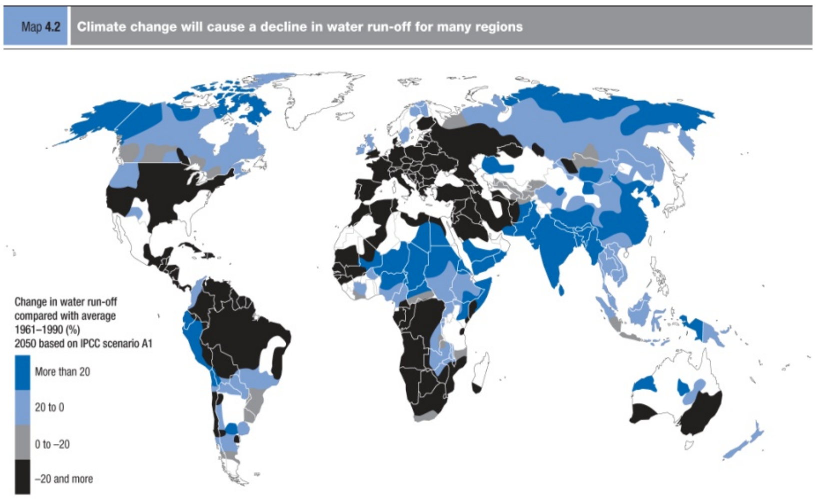

Figure 6. Projections of changes in surface water run-off resulting from GCM simulations of the A1 emission scenario. Source: UN Development Program Human Development Report 2006, using data produced by Arnell, 2004

However, GCM results provide insight at the global scale, but their coarse spatial resolution makes them inappropriate for impact studies and regional analysis. In perhaps the only study to use a regional climate model to address Andean climate change, Urrutia and Vuille (2009) assessed changes caused by a high and low IPCC emission scenario and found that temperatures would increase between about 4 and 11 degrees F by 2100, with higher elevations warming at a greater rate.

Projected changes in global precipitation are less certain, but most models used for the IPCC 4^{th}

assessment report project an increase in precipitation in the tropical Andes during the wet season and a decrease during the dry season, effectively enhancing the seasonal hydrological cycle (Magrin et al., 2007). Even if precipitation does not change, warmer temperatures alone will increase evaporation and transpiration which will reduce surface water runoff. As a result, projections of changes in surface water suggest future declines. According to a global study by Arnell (2004), many regions will likely experience a major reduction in surface water, including the Bolivia Altiplano which is projected to experience surface water runoff declines of 20 percent or more by 2050, assuming GHG emissions follow the higher emissions trajectories (Figure 6). Some estimates suggest that by the 2020s, between 53 and 206 million people worldwide will experience water stress for the first time, while another 374 to 1,661 million people are projected to experience an increase in water stress (Arnell, 2004). In Latin America, the IPCC assessment report published in 2007 stated that the number of people experiencing water stress could increase, reaching between 7 and 77 million people by 2050 (Magrin et al., 2007). By the end of the second half of the century, that number could balloon to be between 60 and 150 million. This is, in part, caused by the combined negative effects of the growing water demand for domestic use and irrigation due to an increasing population and the expected climate changes.

Numerous studies also conclude that global warming will cause more extreme climate events, such as droughts and heat waves (e.g. Easterling et al., 2000;) which may actually be more devastating to Bolivian communities than gradual declines in seasonal water supply. In an economic analysis, Ahmed and others (2009) investigated the impact of climate volatility on poverty and found that extremes under present climate volatility increase poverty in many parts of the developing world and that global warming exacerbates poverty vulnerability in many nations.

There are several major limitations to global climate models. First, the spatial resolution is, at best, approximately 5000 square miles, which is clearly too large to simulate alpine glaciers hundreds of times smaller. Second, when future water shortages will become acute depends on the actual GHG emission trajectory and the resulting climate response and on the site-specific response of glaciated catchments to climate change. To get a better picture of climate change impacts, physically-based glacier models that simulate the waxing and waning of ice volume in response to climate fluctuations are needed. Unfortunately, no glacier model has been applied to Bolivian glaciers. Several studies, however, have developed and applied physically based, although simplified, glacier models in Peru. Pouyaud et al. (2005) applied a uniform and conservative steady warming rate of approximately 2 degrees F per century to simulate the runoff coefficient for several catchments in the Cordillera Blanca until the year 2300. The results show that runoff will increase for 25–50 years before decreases begin. Using a more sophisticated glacier model, Juen et al. (2007) assess how the seasonality of runoff in the Cordillera Blanca changes in response to four different GHG emission scenarios which span the high to low emissions range. As expected, glacier volume is significantly reduced in all scenarios; however, the glaciers do not disappear completely. In the Llanganuco catchment, for example, in 2050 the watershed contains between 38 percent (B1, ‘best case’ scenario) and 60 percent (A2, ‘worst case’ scenario) less ice when compared to 1990 areas. As a result, dry season runoff is significantly reduced (Juen et al, 2007).

While the timing and percent declines should not be transferred to alpine glaciers in Bolivia, it is likely that Bolivia will see similar patterns in seasonal runoff changes. It is important to recognize that if glaciers continue to retreat but total precipitation increases, there may be only seasonal changes in streamflow volume and no change in total water volume passing through the river. But this alone will have negative impacts. According to Bradley et al., (2006), "Although an increase in glacier melting initially increases runoff, the disappearance of glaciers will cause very abrupt changes in streamflow because of the lack of a glacial buffer during the dry season and this will affect the availability of drinking water, and of water for agriculture and hydropower production."

In general, many climate modeling studies and research that has chronicled changes in glaciers in the last 50 years agree that future changes are likely to threaten water supply in the Andes (e.g. Arnell, 2004; Bradley et al., 2006; IPCC, 2007; Vuille et al., 2008). Moving forward, it is prudent to investigate different adaptation strategies.

6. Finding Solutions

"Beyond tracing the physical dimensions and hydrochemistry of glacier recession, there is an outstanding need to situate glaciers within specific social and cultural contexts where future management decisions must be made." -Mark, 2008

Adaptation is local, embedded in a socio-economic, political, and physical context unique to scales as small as the community level. It also requires top-down strategies that can inject needed financial resources and technical expertise and bottom-up approaches that empower local citizens in the solutions. The international community has recognized that a large limitation to effective adaption is capital. To address this, an accord (not binding) was struck in December, 2009 at the United National Climate Change Conference that lays the foundation for the allocation of US$ 30 billion between 2010–2012 for adaptation projects in developing countries, ramping up to US$ 100 billion per year by 2020 (Kintisch, 2010). It is likely that a large portion of this money will go to projects outlined in the recent IPCC assessment report, which includes projects that develop groundwater, restore and broaden water storage systems, develop public awareness campaigns, and improve participation of vulnerable groups in adaptation and mitigation programs (Magrin et al., 2007). In the same report, the IPCC also stated that water management in Latin America should be the central point of climate change adaptation in order to strengthen the countries' capacities to manage the availability and demand of water resource, and ensure the safety of people and protection of property under changing climatic conditions (Magrin et al., 2007).

There remains, however, critical knowledge gaps that if not addressed threaten to undermine any adaptation project. In the Bolivian Altiplano effective adaption will likely include securing additional water resources to compensate for the diminished contribution of glacial meltwater to streamflows. Groundwater will therefore likely play a greater role in future water resource development. However, few studies have been published documenting the quality of groundwater around the cities of El Alto and La Paz and the rural communities near Lake Titicaca. In a preliminary study conducted by Terra Resource Development International (Terra), 30 groundwater samples collected from shallow wells (predominantly < 250 feet) were analyzed. In five locations, the water had dangerous concentrations of arsenic—a cancer-causing heavy metal that naturally occurs in volcanic geologic settings—that exceeded the World Health Organizations (WHO) guidelines (Figure 1). In three of the samples, concentrations exceeded 70 parts per billion, or greater than 700 percent of the acceptable limits. The communities for which these contaminated wells provided water are unaware of the potential health effects. This is common throughout the region. According to a local Bolivian water development company, it is rare to comprehensively test the quality of water from wells (personal communication, AguaSubT). Unfortunately, there are numerous examples where water resource development strategies have led to exposure to unsafe drinking water when improving access to drinking water exists (e.g. Howard, 2003), including widespread arsenic poisoning in Bangladesh that some have labeled the worst poisoning tragedy in history (Pearce, 2001; see Case Study).

The Bangladesh catastrophe is an example of how implementing development and adaptation strategies based solely on an understanding of the physical problem can generate more harm than benefit. It is critical to look beyond the physical context. Adaptation to climate change can follow a similar path if characterizations of the physical problem are not balanced by the vulnerabilities and strengths of the communities. Unfortunately, there have been many examples of latrine projects, green houses, and small-scale community water projects that are unused or derelict in the Altiplano. Many of these projects were constructed in the 1980s, and the common perception is that external aid organizations neglected community involvement.

There was little emphasis on sustained education of the benefits of the new project and when the organization moved on, the community returned to what it had been doing.

In water projects infrastructure was erected, but community organization was not strengthened. Often, there was no form of water governance that collected user fees which provided financial resources to perform maintenance or purchase new parts. As a result, many projects functioned only until the pump needed replacement. Today, wells in the region sit idle while villagers collect water from contaminated streams.

In more recent projects the community has become an integral component in both the project's design and management which has fostered some success. For example, a World Bank sponsored water development program has promoted using low-cost technologies, requiring communities to contribute a portion of the cost of the system and after completion

7. Case Study: Adaption / development gone awry

The following summary is based on an article written by Fred Pearce in 2001 for the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

In the 1970s most rural residents of Bangladesh relied on surface ponds and rivers for their drinking water. But each year, bacteria-infested surface waters in Bangladesh and other countries was unleashing an assault of water-borne diseases, killing about quarter of a million children each year, according to the World Bank. To solve the problem, United Nations Children's Fund (UNICEF) spearheaded a massive well drilling campaign to tap groundwater sources and provide "clean water".

Millions of dollars flooded into the country in the 1970s. Thousands of wells were drilled, distribution networks laid, and spigots installed. The quality of the water, however, was not tested—most people assumed groundwater was safe to drink. The end result was one of the largest outbreaks of mass poisoning in history, according to the World Health Organization (WHO). Up to half the country's groundwater wells—estimated in 2001 to be around 10 million—have been poisoned. In September, 2001, the WHO released a report estimating that between 35 and 77 million Bangladeshis may have been and still be drinking water with arsenic concentrations that exceed the WHO safety limit of 10 parts per billion. Twenty thousand people could die each year, according to the UN Development Program.

of the project, handing over control of the system to the local community. A recent study surveyed 99 communities who were recipients of new or improved water systems from this program. In all but four of the communities, the water systems were functioning 5–8 years later (Davis et al, 2008). This model appears to be working, although not enough time has elapsed to judge its sustainability.

8. Final Thoughts

Bolivia is an extreme example of the clash between poverty, climate change, and limited water resources. In the region and in the Andes in general, the observations are clear—glaciers are retreating. Even without certain projections on the time evolution of glacier retreat, the understanding of the climate system is robust enough to imply that current glacial trends will continue. Observations have spurred repeated statements that climate change threatens the water supply principally because by some estimates 80 percent of the water used by Bolivians living in the Altiplano originates in the higher elevations of the watersheds. Without proper adaptation plans, climate change impacts on water supply could instigate future conflict and deepen poverty.

Although adaptation will be costly, it will likely be less expensive than mitigation. According to the IPCC, if no action is taken to slow down climate change in Latin America in the next several decades, climate-related disasters could carry a price tag around US$300 billion per year (Magrin et al., 2007). To put this in perspective, it will cost around US$18 billion to extend access to safe water to 121 million people in Latin America, which would meet the Millennium

Development Goals of Safe Water (Magrin et al., 2007).

The silver lining in climate change adaptation is that it has the potential to improve water access and water quality. If financial resources for water development are made availability and adaptation/development projects are based on sound physical and social science, communities can avoid using contaminated surface water, particularly near urban populations many people currently use streams grossly polluted with industrial, agricultural, and human pollution (Chunnoff, 2009).

There are many knowledge gaps that need to be filled in order to foster improved welfare now and under future climate uncertainty. On the physical side, the contribution of streamflow to aquifer recharge is unknown. This is important because if the contribution of precipitation to streamflow swamps the contribution of glacial ice melt then retreating glaciers may not be that important. Conversely, if glacial meltwater significantly contributes to aquifer recharge then diminishing glaciers will reduce the amount of water that can be sustainably extracted from the aquifers.

On the social side, important unanswered questions relate to how communities will be affected by changing surface water supplies and whether changing seasonality is important. Climate change has the ability to create a climate diaspora. Prolonged droughts or other events, including gradual decreases in water supply, can cause rural people to migrate to urban areas in search of work. In Bolivia, El Alto and La Paz do not offer employment opportunities. Moreover, a recent economic analysis concluded poor urban laborers in developing countries are the most vulnerable to climate change (Ahmed et al., 2009). Without effective adaptation, it is likely that waning water will deepen poverty in Bolivia, and in other, similar regions as well.

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