Strategic Land Use Planning for Climate Change-Driven Water Shortages in El Alto, Bolivia

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Abstract

The highland city of El Alto, Bolivia, is vulnerable to climate change due to the region's declining water resources and its socio-economic, fiscal and governance constraints. El Alto could double in expanse by 2050 if past development patterns continue. National and international agencies are augmenting the water supply infrastructure, but the city and water utility's financial vulnerability in extending the distribution network is not being addressed. Peri-urban residents, including migrants displaced by rural drought, and urban residents solely reliant on piped water will be at risk to water shortages, water contamination and price spikes. While the link between drought and urban land use planning is not well studied, this case suggests that urban growth management should play a strong role in climate adaptation in arid zones. Besides supply-side infrastructure, adaptation efforts in the water sector should build El Alto's institutional capacity to manage urban growth and promote community drought resilience.

Keywords: climate change adaptation, vulnerability, urban, planning, water management, highland, Andes, Bolivia, water modeling, WEAP

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Linda Shi is an urban environmental planner who works to restore urban environmental services in developing countries, particularly regarding integrated water management. She is currently pursuing a doctorate in urban planning at the Massachusetts Institute of Technology. From 2010–2012, she was a research associate at the Institute for International Urban Development (I2UD), where she conducted environmental assessments and urban plans for cities and regions in Haiti and Tanzania, co-authored UN-Habitat's first *State of the Arab Cities Report*, and developed I2UD's work in climate adaptation. Prior to I2UD, she served as a regional program coordinator in Bangkok, Thailand, implementing USAID's Environmental Cooperation-Asia program on water and sanitation. There, she led a seven-country assessment on use and impacts of urban sanitation in South and Southeast Asia, and established peer-to-peer mentoring partnerships between water utilities in different countries to improve basic services delivery in Asian cities. She has also worked for the Rocky Mountain Institute in Colorado on the environmental regeneration of industrial river corridors. Linda has a B.A. from Yale University, a master in environmental management from the Yale School of Forestry and Environmental Studies, and a master's in urban planning from the Harvard Graduate School of Design, and is currently pursuing her doctorate in Urban Planning at MIT.

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Executive Summary

The City of El Alto, Bolivia is located at 4,080 meters above sea level on a semi-arid *altiplano* above La Paz. It relies on surface water for 80 percent of its water supply, much of which comes from glacial ice melt and precipitation, both of which are forecast to diminish significantly under climate change. At this critical juncture when international, national and local actors are developing major investment decisions to address current infrastructure backlogs and future needs, this research aimed to assess the relationship between land use planning, water access and water consumption. The relationship between current and worsening water scarcity on land use planning, both in low-lying arid environments and in mountainous communities affected by the disappearance of glacial ice, remains a critical gap in planning research, while the role of urban planning in flood risk mitigation is better understood. This research seeks to address this research gap by answering the following questions.

1. How will climate change affect water availability in El Alto?

Due to limited existing storage capacity, even without accounting for climate change, El Alto's water demand is expected to surpass supply by 2018. El Alto depends on glacial ice melt for 30 to 60 percent of its total water supply; glacial ice mass is already shrinking or disappeared and is projected to continue to decline as temperature are projected to rise by as much as 2°C by 2050. Surface runoff in the watersheds supplying El Alto with water is forecast in most models to decrease by as much as 20 to 40 percent, while other models show that total inflow into El Alto's reservoirs will decrease by 6 percent by 2050. Variations between seasons and between years can be much more erratic, in particular due to El Niño and La Niña events. While ongoing nationally and internationally supported infrastructure studies and projects will expand storage capacity and reduce physical exposure, climate change will also exacerbate the social and economic vulnerability of El Alto's residents and water utility. This has yet to be addressed through current and proposed water management projects.

2. How will climate change affect urbanization patterns in El Alto?

Past periods of accelerated population growth in El Alto coincide with El Niño and La Niña events that led to drought, floods and precipitous declines in agricultural productivity. For instance, from 1976 to 1992, a period of major agricultural instability in Bolivia, El Alto's population grew by over 9 percent per year. Rural drought, as well as intensifying storms causing landslides in La Paz, will continue to drive migration to El Alto, peaking in years of drought, when urban water supply will also be at its most limited. Additional studies of seasonal migration into El Alto are needed and worst-case scenarios compounding migration and drought need to be examined in ongoing models of regional water supply, as well as the sizing and siting of new storage and distribution systems.

El Alto's flat topography is conducive to extensive development and peri-urban dormitory settlements are fanning out from the older parts of the city. Past investments in major axial and circumferential arterials in El Alto, the influence of the airport at the center of the city, and escalating land prices in the city center and areas with services drive demand for land on the periphery for new migrants. The municipal government, under-staffed and under-funded, has been unable to develop plans and alternatives to developer-driven growth. From 2000 to 2010, the city's population grew by 54 percent, while the city's urbanized area grew by 144 percent. While El Alto could accommodate most new residents by 2050 within existing urbanization if it were built to zoned densities, a continuation of past trends would lead to a doubling of the city's land area by 2050. Growth is also spreading beyond El Alto's city limits to the neighboring *altiplano* Municipality of Viacha, requiring greater inter-municipal coordination on service delivery and growth management.

3. Who will be the most vulnerable to future water shortages?

El Alto's vulnerability and adaptive capacity to future water shortages also stem from its socio-economic and fiscal constraints. The majority of the population comprises recent rural migrants who are not accustomed to paying for water and property taxes. While the city's strong social associations have successfully allowed communities to agitate for services and pressure EPSAS to extend networks, El Alto is entirely dependent on donor funding for expansion and upgrading of the water network and on subsidies from the La Paz water system for operational expenses. Both of these conditions are susceptible to national policy changes and fluctuations in donor funding availability and allocation. Although EPSAS increased the number of water connections in El Alto by over 40 percent since it began operations in 2007, a doubling in service area would be financially daunting, particularly in the face of the proposed reorganization of the country's water utilities. The unmitigated urban expansion of the city poses a financial threat to EPSAS or any future water utility serving El Alto, which in the end will impact peri-urban communities seeking water connections.

The entire city is highly vulnerable to water shortages in times of drought and bottlenecks in the distribution network; water rationing has already begun in parts of the city. The distribution of risk is unevenly spread, with peri-urban households relying on standpipes, trucked water and communal wells at greater risk to contamination issues, falling water tables, service interruptions and price shocks. Rural migrants—some escaping climate-induced agricultural disasters—settling on peripheral areas where land is cheapest will be most physically and economically vulnerable to water shortages. Nevertheless, residents in the urban core who are entirely dependent on EPSAS and whose multi-story buildings make it difficult to use of rainwater collection systems, water storage tanks and communal wells are also less resilient in the face of water shortages.

4. How can water use efficiency strategies inform land use planning?

Demand-side management strategies such as water loss reduction and wastewater recycling for industrial use could help reduce future urban water demands. These strategies have clear implications for land use planning and development. Mapping water consumption in the city can be used to highlight areas that consume more on the whole and per customer. An ongoing industry mapping project by El Alto's Department of Environment should document characteristics of industrial water use and help to determine whether the national program on wastewater reuse could provide incentives such as revolving loans to industries and businesses to reduce their water consumption. Urban residential customers are also more likely to have water-flushed toilets and may be targeted for the new national toilet efficiency program.

5. What land use planning responses can improve water access equity and reduce vulnerability to future water shortages?

Based on our analysis and discussion with local stakeholders, this study identified potential top-down and bottom-up opportunities to reduce local vulnerability to water shortages under climate change. Given that ongoing projects are focused on large-scale infrastructural projects, these strategies highlight steps to more comprehensively reduce user risk under climate change in the context of El Alto. It is our hope that national and international agencies such as MMAyA, IADB, and the World Bank will consider these non-traditional strategies under climate adaptation and water funding. Core strategies include the following.

- Strengthen the technical capacity and funding of the Territorial Planning Office to plan and enforce land use development in order to reduce peri-urban sprawl and water distribution costs. Modify EPSAS' requirements for service extension to meet density and resilience goals, and leverage the incentives communities have to meet these standards.

- Integrate development, water and infrastructure planning through the creation of an inter-disciplinary, city-level taskforce and a community upgrading, densification and water resilience strategy that engages the city's strong community organizations. Although water is not the only logic of urban planning, the integrated consideration of water and other infrastructure in development planning is critical to targeting investments efficiently.

- As part of development upgrading and densification, promote water use efficiency, water loss reduction and wastewater reuse, as well as the creation of green networks to filter runoff, minimize pollution and promote aquifer recharge. Build in redundant infrastructure such as communal collection and storage systems to enhance community resilience to drought.

Objectives, Key Questions and Methodology

The relationship between current and growing water scarcity and land use planning, both in low-lying arid environments and in mountainous communities affected by the disappearance of glacial ice, remains a critical gap in planning research. The literature within the nascent adaptation field, at least, has not addressed the question of whether and how urban planning in practice can promote greater water resource efficiency and resilience to drought conditions (Agudelo-Vera et al., 2011). Using El Alto as a case study, this research considers the following questions:

1. How will climate change affect water demand and supply in El Alto?
2. How will climate change affect urbanization patterns in El Alto?
3. Who will be the most vulnerable to future water shortages?
4. How can water use efficiency strategies inform land use planning?
5. What land use planning responses can improve water access equity and reduce vulnerability to future water shortages?

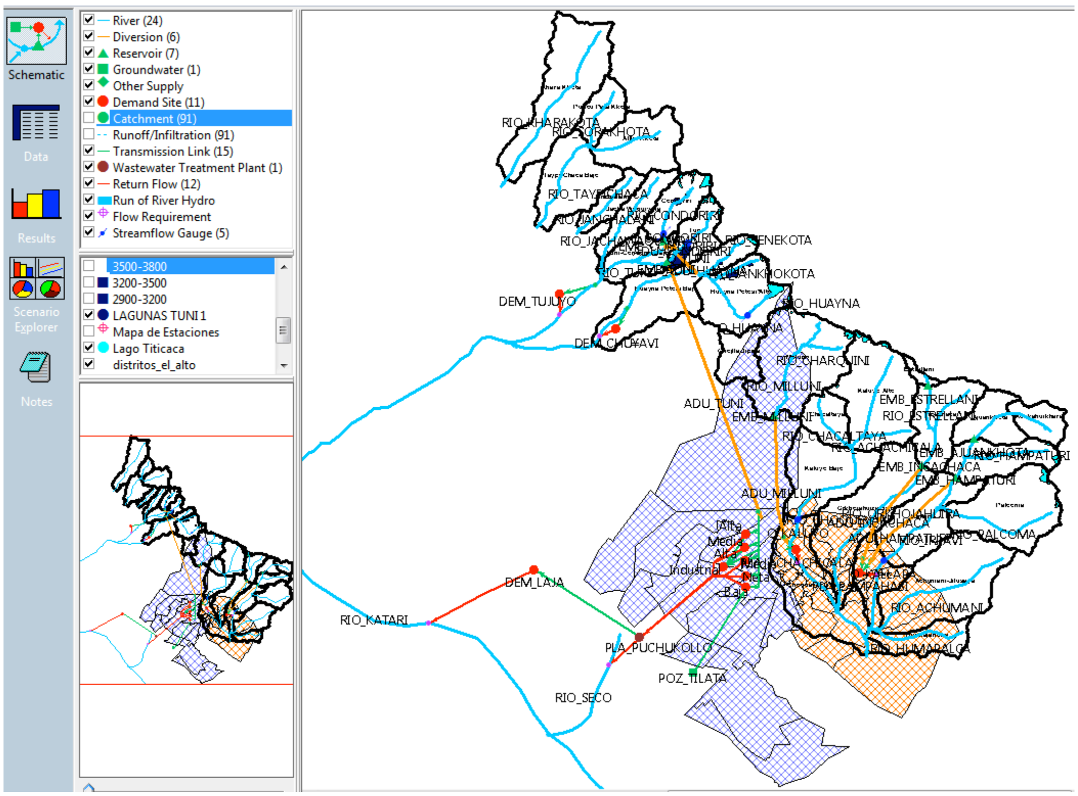
The research drew on desk reviews and an initial field visit in March 2012 that involved interviews and a local workshop that introduced the project to key stakeholders and sought their feedback through working groups. As part of the analysis, the team developed two land use scenarios (see table 1), and projected their impacts on water demands through the Water Evaluation and Planning (WEAP) modeling tool. On a second visit to Bolivia in October 2012, we presented these proposals and preliminary findings to local stakeholders, including the Empresa Pública Social de Água y Saneamiento (EPSAS) and the Bolivian Ministry of Environment and Water (MMAyA), who provided feedback on the viability of integrating land use planning with water infrastructure investments. We also consulted urban planning departments and agencies at different levels of government in El Alto and La Paz that are indirectly involved in water management and assessed local institutional capacity to implement the proposed recommendations.

Table 1. Proposed Scenarios

Trend Scenario	**Alternative Scenario**
• Constant rate of growth (3 million people by 2050) • Extensive development, with some densification of existing areas but mostly outward expansion of low-density growth. • Lack of capacity to manage and control urban growth	• Constant rate of growth (3 million people by 2050) • Significant densification of existing areas, focusing on expanding and improving water and other infrastructure; new areas of development have higher densities than the trend; significantly less outward expansion • The municipal government, in collaboration with the sub-mayors and community associations and organizations, supports and guides urban growth

WEAP is a water resources planning tool used to represent current water conditions; to assess the implications of changes in water supplies and demands; and to explore the effectiveness of different physical and/or policy interventions in balancing competing operational objectives. It has been widely used to support collaborative water resources planning by providing a common analytical and data management framework to engage stakeholders and decision-makers in an open planning process (de Condappa et al, 2009; Hoellermann et al, 2010; Sandoval-Solis and McKinney, 2010). Within the context of water planning for the cities of El Alto and La Paz, Bolivia, a focus group led by the MMAyA is using WEAP to assess the vulnerability of El Alto and La Paz to the effects of climate change and to identify strategies to improve climate resilience. The model simulates the main hydrologic processes of the watersheds (rainfall-runoff and snow and glacier accumulation/melt) and aggregated urban water usage (fig. 1). It has been developed as a tool to assess the geophysical changes within the source watersheds and evaluate structural interventions to mitigate anticipated adverse impacts of climate change. This study extends the tool to consider the water use implications of different development patterns in El Alto.

Figure 1. Schematic of El Alto/La Paz WEAP Model



Obtaining water consumption data was harder than expected for this project and posed a major challenge, as it does for many studies in low-income countries such as Bolivia. The last census took place in 2001, for which district level data could be mapped but was insufficiently disaggregated, and sub-district population numbers could not be accurately mapped. A new census is currently being planned with World Bank support. Given the highly sensitive and politicized nature of the research topic, limited water usage data from the local water utility EPSAS was available to the public. Total water usage data and the number of customers by *recorrido* was provided by EPSAS, but was not further disaggregated by user type (i.e. commercial, industrial, residential), which is critical to understanding urban demand. The Cadastral Department of El Alto was willing to share its maps and data, but lacked recent and updated population, land use and land value data. It is about to commence a 3D-Pictometry survey that will generate a complete database of built development in the city. Furthermore, in 2010, El Alto re-drew its district boundaries, which included subdividing the existing 10 districts into 14 districts. Data that existed for 10 or 14 districts had to be harmonized before they could be compared.

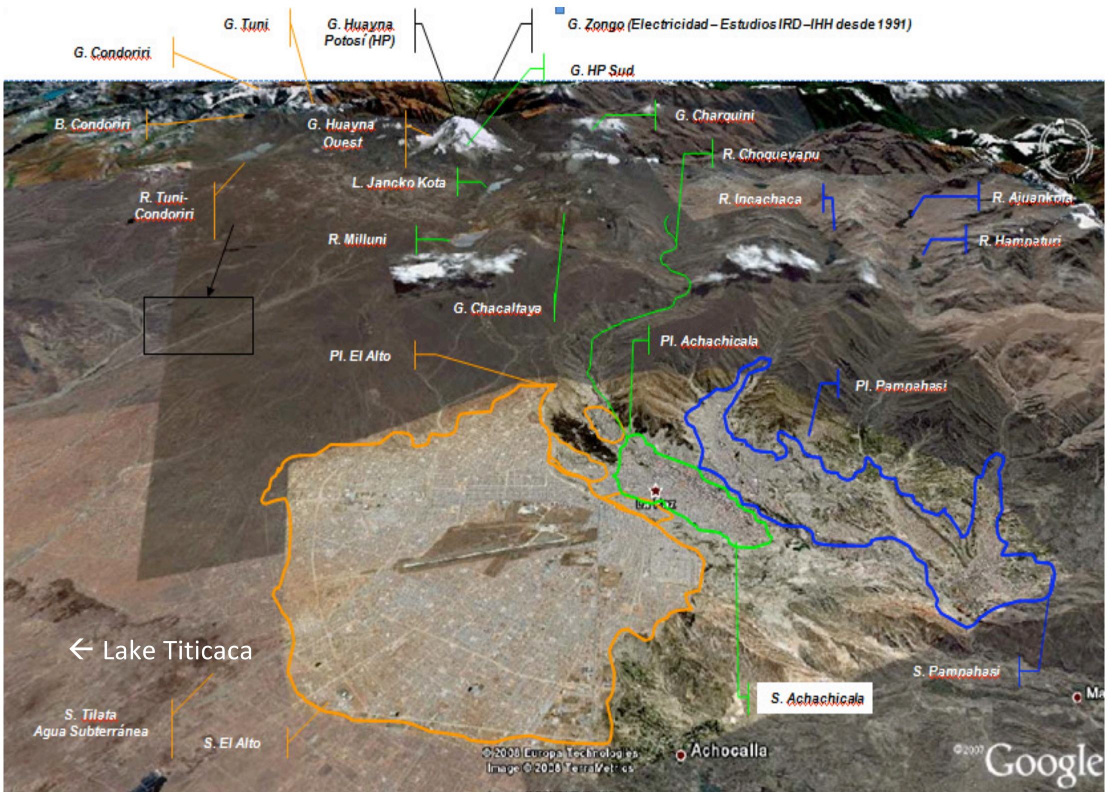
As a proxy for updated population estimates at the sub-district level, we drew on EPSAS data about their clients at the level of *recorridos* (see Annex 1 for additional information on data harmonization). In the absence of better data, our analysis conducted simpler computations and modified the scenarios to study urbanization impacts on water consumption. It endeavors to provide a methodology for how to consider the nexus of these two sectors, which can be applied when more updated data become available.

How Will Climate Change Affect Water Availability in El Alto?

The City of El Alto in Bolivia, the largest high-altitude city in the world, presents perhaps the most acute example of the crisis facing highland cities dependent on glaciers for water supply. Located at 4,080 meters above sea level on an *altiplano* (high plateau) 400 meters above La Paz Valley, El Alto has a semi-arid climate, with only 300–600 millimeters of rainfall per year. It lies within the Katari River watershed, which drains into Lake Titicaca, while La Paz drains into the Amazon River watershed. Due to limited water resources in the El Alto sub-watershed, the city relies on transfers from three other sub-watersheds—the Tuni, Condoriri and Huayna Potosí—for 80 percent of its water (fig. 2). This includes glacial ice melt, as well as surface runoff and groundwater movement. Due to the complex interactions between glaciers, evapo-transpiration and surface/sub-surface flows, estimates on how much of El Alto's water supply comes from glaciers varies from 30–60 percent (World Bank, 2008b; Painter, 2007). For the remaining 20 percent, El Alto draws on a battery of 27 wells 160 meters deep that pump water to southern parts of the city. Even without accounting for climate change, El Alto's water demand is expected to surpass supply by 2018 due to limited storage capacity and the city's explosive growth (fig. 3; IHH, 2012). In contrast, La Paz is growing more slowly—by the 1992–2001 period, its growth rate had fallen to 1.1 percent—and has larger supplies of available water.

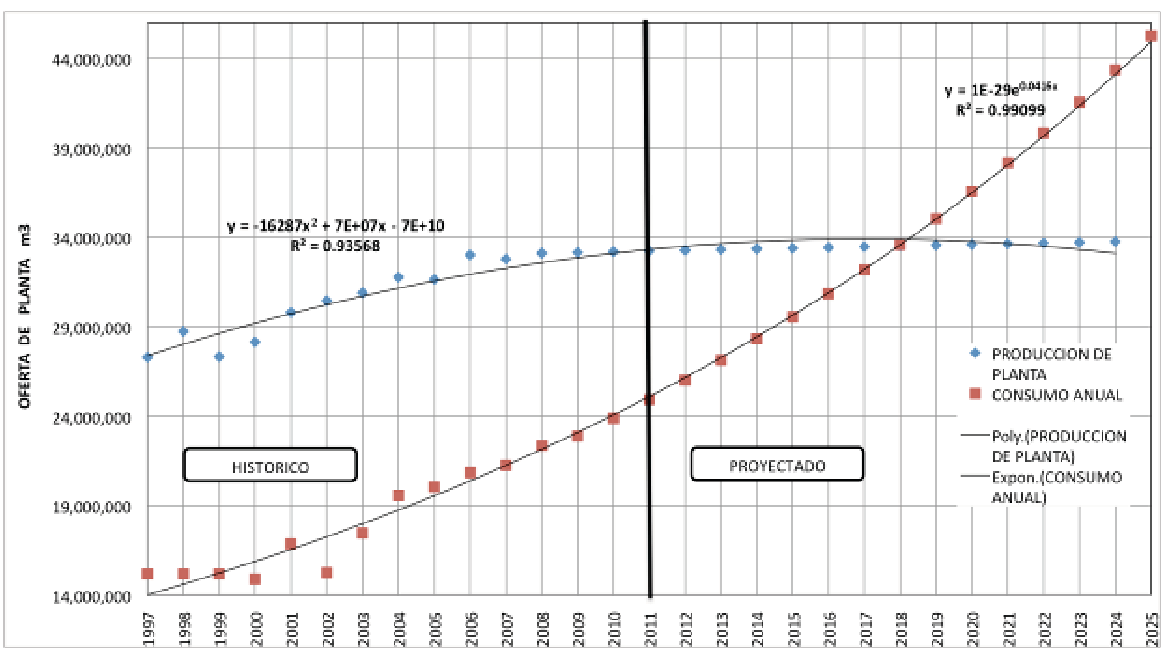
Climate change will exacerbate existing water scarcity. The PPCR/SPCR project (see below) developed detailed models of the watersheds, glaciers and operation system, and indicated important changes in glacier area (fig. 4) and water supply for six climate scenarios that range from optimistic to pessimistic (table 2). The IPCC's 2007 Al climate scenarios show reductions in glacier area, and most IPCC climate scenarios show a reduction in the stream-flow for the Tuni, Khara Khota and Taypichaca watersheds.

Figure 2. Glaciers and Rivers That Supply El Alto and La Paz with Water



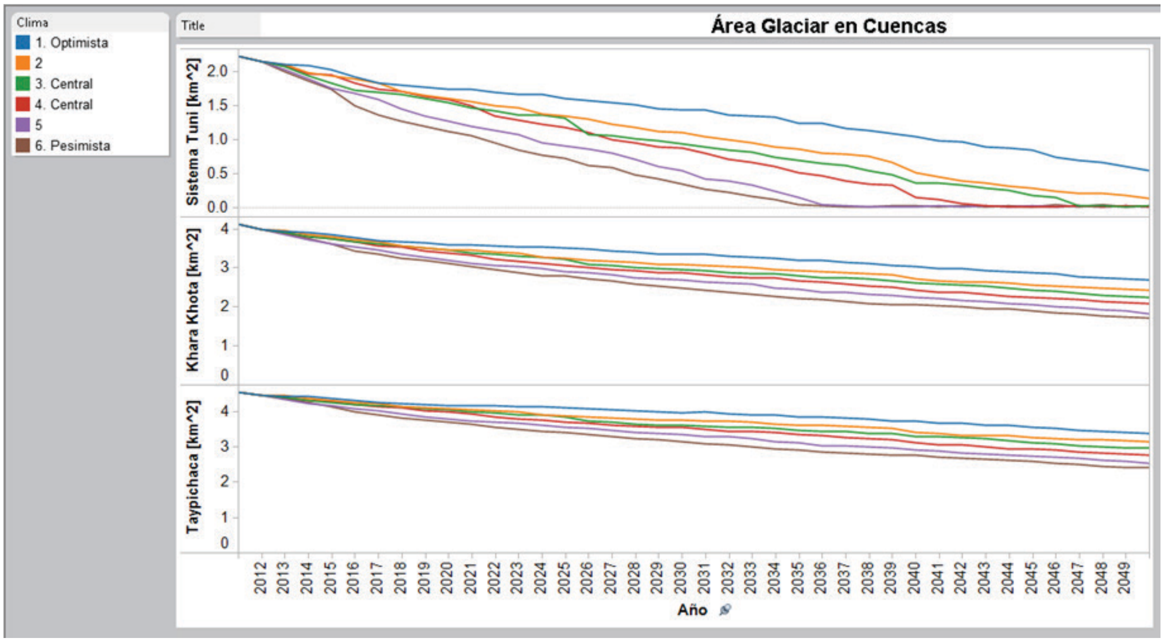
Source: IHH-UMSA 2012

Figure 3. Total Historic and Projected Annual Demand and Supply of Water In El Alto



Source: IHH, 2012

Figure 4. Glacier Area Recession for Climate Scenarios for 2011–2050



Source: PPCR/SPCR, 2012

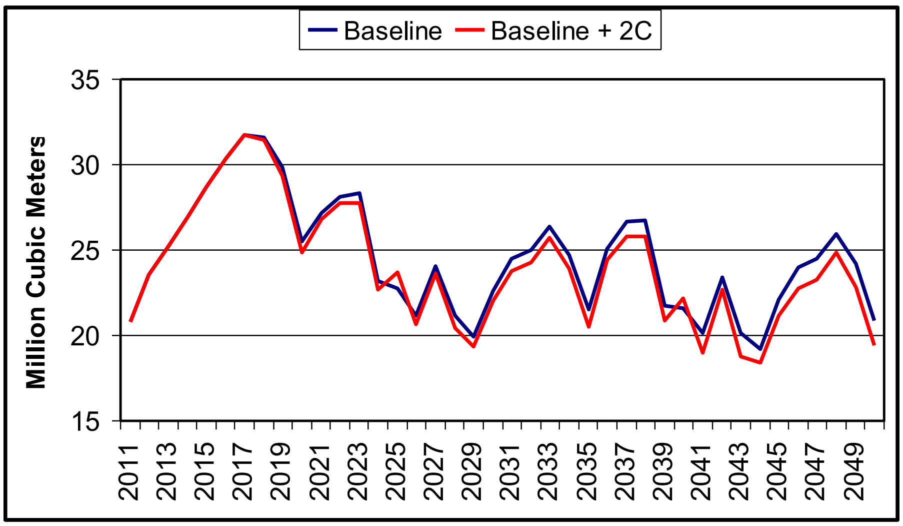
Table 2. Change in Precipitation, Temperature, and Average Annual Stream-Flow in 3 Systems for Historic Conditions (1995–2010) and 6 Climate Scenarios (2035–2050)

Climate Scenario	Precipitation (% change with respect to historic)	Temperature (°C change with respect to historic)	Fraction of Average Annual Stream-flow Relative to Historic Conditions		
			Sistema Tuni	Cuenca Khara Khota	Cuenca Taypichaca
Historic	NA	NA	0.95	1.05	1.32
Future-1 Optimist	+4.3	+0.5	1.04	0.72	1.08
Future-2	+3.5	+0.8	1.02	0.67	1.01
Future-3 Central	-0.8	+1.0	0.95	0.66	0.99
Future-4 Central	-3.0	+1.2	0.94	0.64	0.95
Future-5	-7.3	+1.5	0.79	0.59	0.89
Future-6 Pessimist	-10.3	+1.8	0.81	0.60	0.91

Source: PPCR/SPCR, 2012

To model El Alto's water system, our WEAP analysis used data from the Regional Climate-Change Projections from Multi-Model Ensembles (RCPM) project, provided by the National Center for Atmospheric Research (NCAR), to estimate future climate conditions. The RCPM uses statistical techniques to calculate the expected future climate change for a specified region based on observational data and the results of an ensemble of global climate models (UCAR, 2007).[1] These data suggest that the watersheds supplying water to El Alto and La Paz can expect an increase in temperature up to almost 2°C by 2050, while predictions of annual and monthly precipitation range from a ten percent decrease to a four percent increase as compared to recent historical records. In the WEAP model, applying a 2°C trend by 2050 alone resulted in a 6 percent decrease from 2011 levels in annual inflow to the main water supply reservoirs, although variations between seasons and between years can be much more erratic due to El Niño and La Niña events (fig. 5). This resulted in less filling of the reservoirs, which further constrained water deliveries to El Alto beyond a baseline simulation (without climate change) that was already pumping at near capacity to meet the growing water demand.

Figure 5. Water Supply Delivered to El Alto (in MCM/year)



Given the urgency of the situation, a number of national and international studies are working to identify immediate strategies for augmenting El Alto's water supply.[2] The MMAyA is exploring different levels of interventions with support from the Inter-American Development Bank (IADB) that could improve the supply side of the equation. Currently, the Project to Adapt to Glacial Retreat in the Tropical Andes (*Proyecto de Adaptación al Impacto del Retroceso Acelerado de Glaciares en los Andes Tropicales*, PRAA) funded by the Global Environment Facility is identifying short-term initiatives to improve water availability, though only to a limited extent. In the longer term, the IADB is funding an initiative to channel funds from the Climate Investment Fund under the Pilot Program for Climate Resilience /Strategic Plan for

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[1] RCPM data and analysis provided by the Institute for Mathematics Applied to Geosciences (IMAGe) at NCAR, based on model data from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (WCRP CMIP3) multi-model dataset. More can be found at rcpm.ucar.edu. © 2006, UCAR. All Rights Reserved.

[2] These include: MMAyA-funded Peñas project to identify alternative sources of water in the sub-watersheds around El Alto; JICA-funded Proyecto GRANDE study of glaciers that will be completed in 2015; HEC-HMS modeling work by IHH and research on alternative supplies for El Alto; CGIAR-funded COMPANDES project to develop WEAP models for the watersheds of El Alto and La Paz that was completed in 2012; and IADB-funded creation of WEAP models for watersheds surrounding El Alto and La Paz, including trainings for local users.

Climate Resilience (PPCR/SPCR) to obtain water from adjacent watersheds for El Alto (fig. 6). The designs and feasibility studies are anticipated to be completed by 2013, with construction to be completed by 2018. Finally, the El Alto/La Paz Metropolitan Master Plan for Water and Sanitation (*Plan Maestro Metropolitano de Agua y Saneamiento*) begun in 2012 by MMAyA with funding from IADB and the Government of Spain's international development agency (AECID) should provide additional scope and long term planning for additional water sources for the city. A number of other initiatives complement these efforts.[3]

Figure 6. Programs for Water Supply Improvement for the City of El Alto over Time

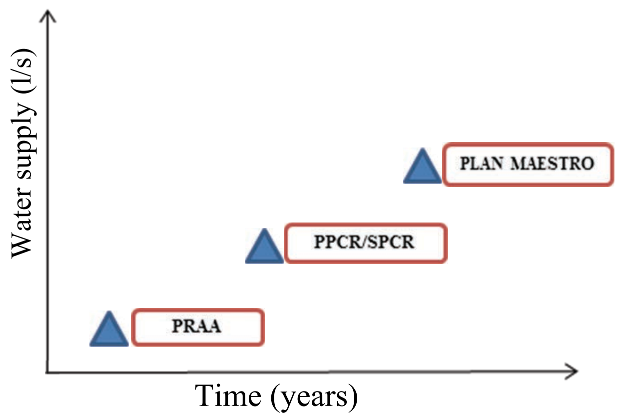
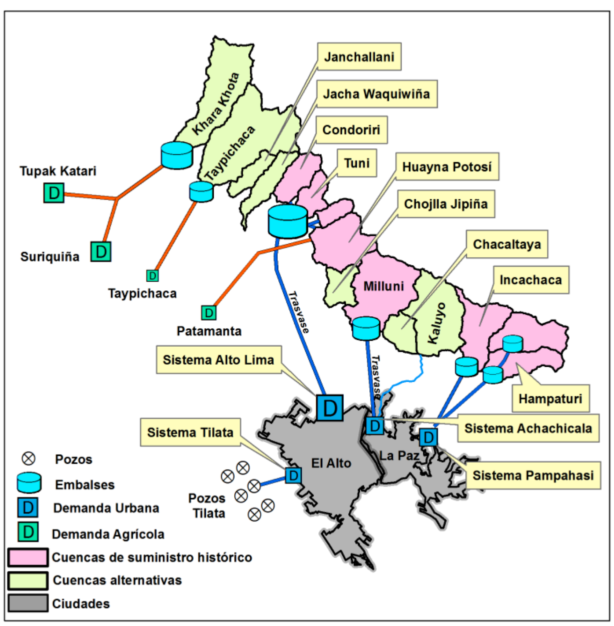


Figure 7. Current (in pink) and Potential Water Supply from Alternative Watersheds (in light green) for El Alto According to the PPCR/ SPCR



Source: PPCR/SPCR, 2012

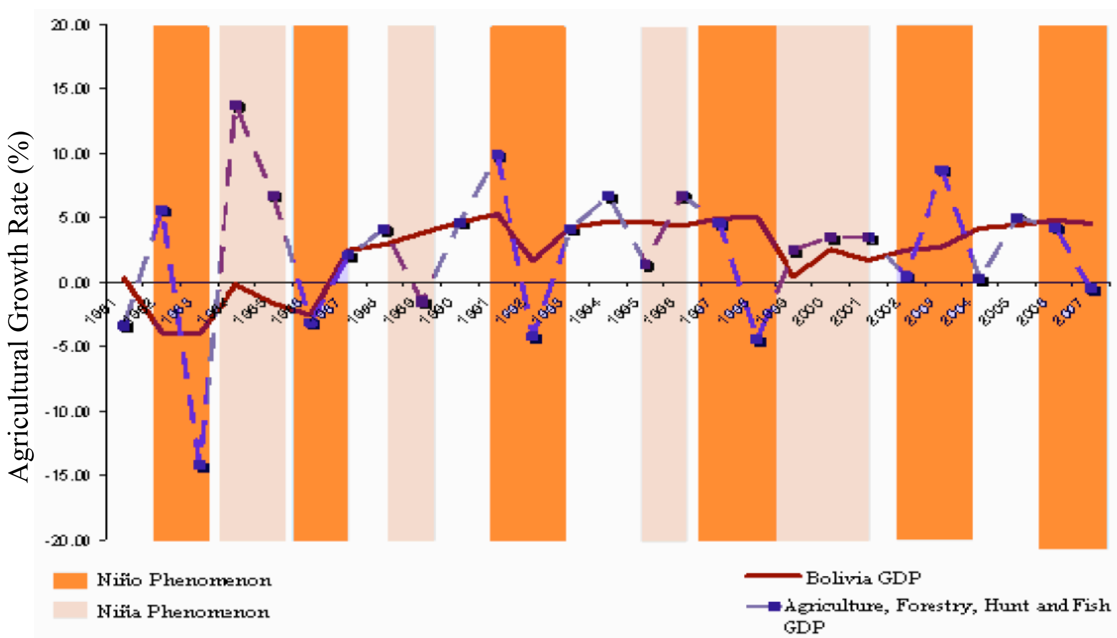
3 Although El Alto also has access to aquifers, the gravity-fed options from mountain reservoirs and intakes are the primary alternatives of interest, due to the expense of pumping groundwater.

How Will Climate Change Affect Urbanization Patterns in El Alto?

Climate Driven Migration and Urbanization

The metropolitan region of El Alto, La Paz and Viacha forms Bolivia's largest urban area and is the country's center of national government and main commercial hub. Due to the affordability and availability of property relative to La Paz, El Alto has become Bolivia's biggest growth pole, with one of the fastest growth rates in the western hemisphere. From 1976–92, El Alto grew at 9.2 percent a year, from 1992–2001 at 5.1 percent a year, and since 2001 to the present at around 3.7 percent a year (see table 3; INE, 2001; Calizaya et al., 2012). Historic patterns of population increase in El Alto suggest that crop loss from unstable weather has contributed to rapid urbanization in El Alto.

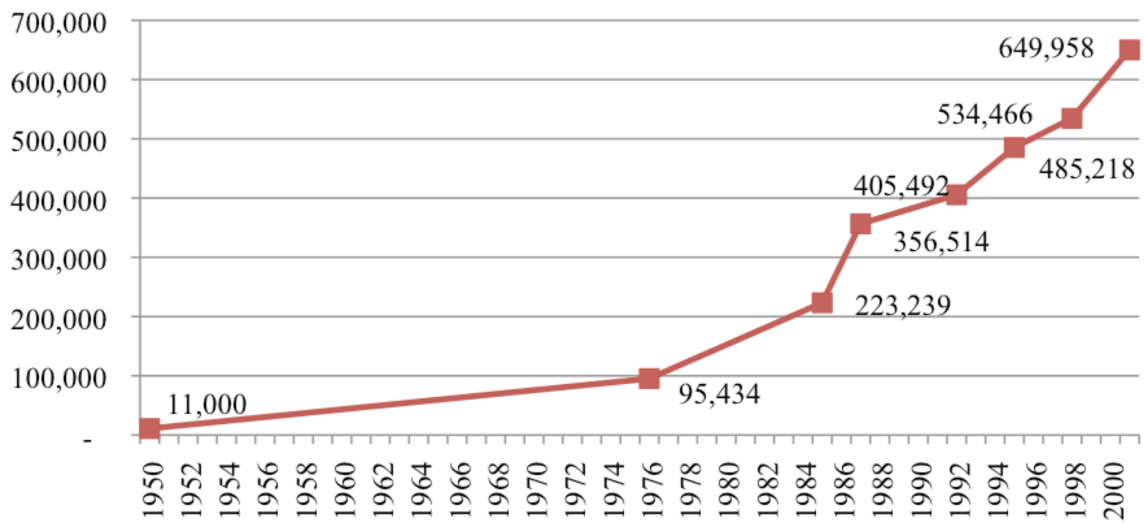
Figure 8. El Nino/La Nina Events Compared with Agricultural GDP Growth Rate 1991–2007



Source: Lordemann and Aguilar Salas, 2009

Starting in the 1980s to 1990s, El Niño events, which cause drought and frost, have intensified, with moderate to strong events taking place in 1982–83, 1986–87, 1991–92, 1994–95, 1997–98, 2002–03 and 2007 (fig. 8). Severe La Niña events took place in 1988–89 and 1999–2000, leading to heavy rainfall, flooding and landslides in the slopes around La Paz. These weather patterns, particularly El Niño events, lead to the loss of crops and negative agricultural growth, with the 1997/98 cycle resulting in a loss of 7 percent of GDP or US$530 million, 53 percent of which was caused by droughts in the *altiplano* (World Bank, 2008b). Given that the agricultural sector employs 40 percent of Bolivians, including 80 percent of the rural population, it is unsurprising that climatic shifts also coincide with periods of El Alto's highest population growth (Lordemann and Aguilar Salas, 2008). Over 1985–87, a period of precipitous crop loss, El Alto's growth rates were as high as 30 percent or 65,000 people per year (fig. 9). National mining reforms that displaced 30,000 miners in 1985–86, 25,000 of whom moved to El Alto, compounded climate-driven migration.

Figure 9. Population Growth in El Alto from 1950 to 2001



Source: INE, various

Table 3. Population in El Alto and La Paz—Historic and Projected Growth

	1950	1976	1992	2000	2010	2025	2050
Bolivia*		4.9M	7.0M	8.3M	9.9M	12.5M	-
La Paz		539,000	723,750	1.0M	877,363	-	-
El Alto	11,000	65,400	405,492	648,407	960,767	1.6M	Linear: 1.9M; Exponent.: 4.1M; Middle: 3.0 M**

Source: INE, unless otherwise noted; *World Bank; **Calizaya et al, 2012; +UN ESA

The historic climate-driven migration pattern suggests that El Alto's future population growth rates will be affected by reductions in rainfall resulting in *altiplano* droughts and intensifying storms leading to landslides in the La Paz valley. Migration is likely to peak in years of drought, when urban water supply will also be at its most limited. This pattern of urbanization is not well understood locally; for instance, the planning department cited growth in La Paz and the mining reforms as key drivers of El Alto's growth, and while all interviewees remarked on rapid urbanization in El Alto, no one mentioned crop loss. Additional studies of seasonal and disaster-driven migration into El Alto are needed, and worst-case scenarios compounding migration and drought need to be examined under the ongoing studies of regional water supply alternatives.[4]

4 A simplified WEAP urban water demand model has been created through this project, and can be linked with WEAP water supply models that account for climate change, which are still being developed by SEI under an ongoing IADB-funded initiative. The joining of these models, and further development of the urban demand model, which requires additional information, will more clearly indicate gaps in supply and demand.

The sizing and siting of new reservoirs should account for peak demand with migration patterns to ensure adequate supply in periods of natural disasters. Urban plans will need to accommodate and anticipate continued high rates of migration, particularly by vulnerable farmers that are migrating due to crop loss in bad years.

Urban Development Patterns in El Alto

The high plain around El Alto is by nature a relatively flat place that tends to have reduced water resources. Its flatness also allows for expansive urbanization and requires particular attention to the strategic investments in infrastructure and application of financial incentives to constrain or direct growth. The urban center of La Ceja contains El Alto's main commercial and governmental activities, with the main industrial zones extending to the south and west of La Ceja along main roads. The rest of the city serves as a dormitory to these areas and La Paz.

Figure 10. Growth of El Alto in the 2000s

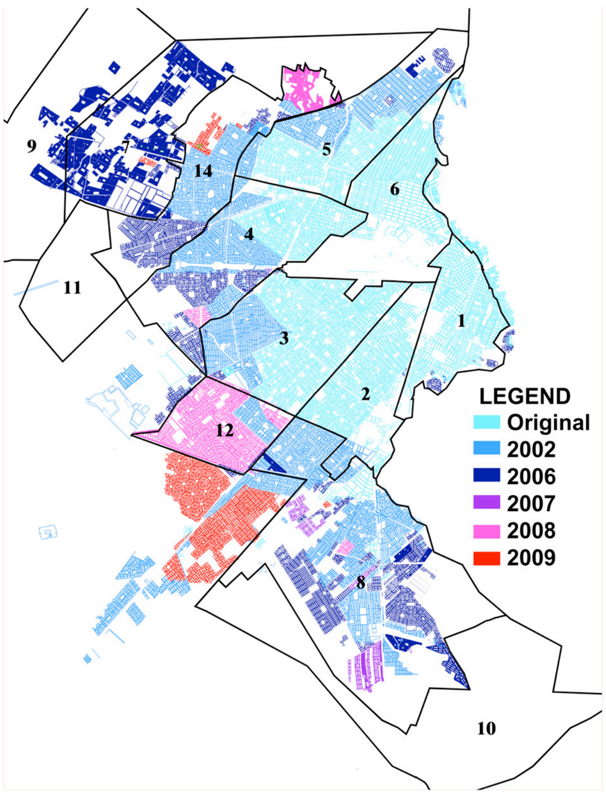
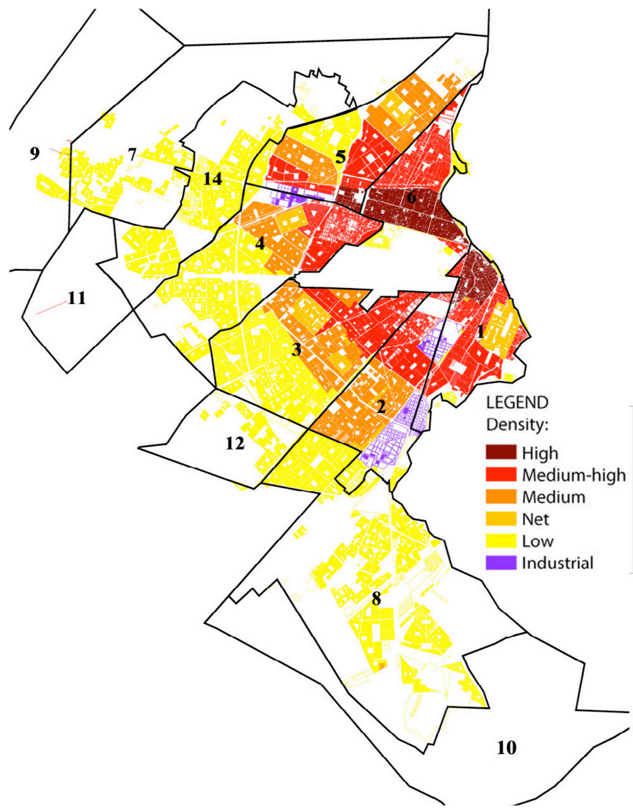


Figure 11. Zoned Densities in El Alto per USPA Guidelines



Sources: Cadastral Department, Municipal Government of El Alto

In compliance with national requirements, the Autonomous Municipal Government of El Alto (GAMEA) developed Land Use Guidelines (USPA), a *Plan Regulador* (1999), *Plan de Ordenamiento Urbano*, *Plan de Ordenamiento Urbano y Territorial* (2004), and two consecutive *Planes de Desarrollo Municipal* (2001–05, 2006–2010). These documents show that GAMEA is clearly aware of the high cost of sprawl, and the implications for delivering urban services such as water. Most of the above plans have not been legally endorsed by the City Council or implemented, and the city lacks a master plan or other physical planning document that indicates priorities and spatial strategies for future urban management. The Territorial Planning Office (*Oficina de Ordenamiento Territorial*), like much of the rest of GAMEA, is perpetually underfunded, under-staffed, and lacks the capacity to anticipate development or enforce plans, particularly in the face of the city's powerful social organizations. The Cadastral Department estimates that the city collects one-tenth of possible property tax revenue. In 2011, El Alto had a budget of Bs916 million (US$130 million), or US$1.30 per resident, of which 14 percent was allocated for public works in the city at large and 2.6 percent for district projects, which was not enough to complete any district projects that year.

Of the earliest plans for El Alto, the main components that have been implemented are the construction of four to five major arterials, such as the highway to Viacha, while other proposals to establish a green growth boundary and relocate the airport have been set aside (Zambrana, 2012). This has facilitated peripheral expansion, and growth over the past decade has primarily extended along these axial and circumferential roadways (fig. 10). As El Alto has urbanized, the municipality continually subdivided previously rural districts into new urban districts, growing from six urban districts and one rural district in 1996, to ten districts in 2005, to fourteen districts (ten urban and four rural) in 2010. Most recently, growth has spread beyond El Alto's borders to the neighboring city of Viacha, where El Alto has no planning jurisdiction and which lies entirely outside of the service limits of El Alto's water utility.

Urbanization has instead been driven by *loteadores*, or sub-dividers, who buy ten to twenty hectares of rural land, engage a professional to draft a plan meeting basic zoning requirements, initiate the legal consolidation of the area, and then sell the land to migrants. Migrants typically first build a rural style house out of basic materials, gradually add spaces and urban amenities as they adapt to urban practices and save more money, before eventually upgrading into brick or cement and multi-story housing. Most of this construction takes place without permits, which in theory are supposed to be obtained from the sub-mayoral offices. Along the way, communities work through social associations to ensure that the community's site plan is approved, which is a basic requirement for EPSAS to legally extend services, and that the municipality extends services. There is a pattern of households moving to La Paz and then Santa Cruz after receiving services, repeating the process each time (Zambrana, 2012). As services get extended, land values increase, forcing new migrants to settle in more peripheral areas.

One interviewee commented that urban planning in El Alto is essentially driven by the mobilization of communities on *ad hoc* fragmented basis—and not in accordance with any of the plans. Compliance with the USPA, in practice, is discretionary and subject to negotiation. Another noted that the local political culture in El Alto has not been conducive for pro-active urban planning, commenting that: "The citizens of El Alto don't accept norms or zoning regulations. They resist restrictions…they are very reactive." Yet, although the *loteadores* may not seek permits in advance, they cannot be said to contravene land use plans because no physical master plans exist for the city.
Furthermore, spatial analysis of community developments shows that they, by and large, comply with the USPA particularly in terms of setting aside 40 percent of land as public space and rights of way (see table 4).

This suggests that updating USPA standards and facilitating their implementation could serve as an entry point for the municipality to increase urbanization growth management. Certain features of the USPA tend to promote low-density development, such as the parking requirements and road provisions. Beyond general guidelines, the USPA does not further differentiate zoning and density by road scale or economic development zones, and it is much less detailed and prescriptive in its planning language than those for lot and building requirements. This has resulted in independently developed subdivisions that meet the code on paper but fail to deliver communities with identities, centers or cohesion. Even within low-rise development, it is possible to promote higher density by reducing lot size requirements, reduce standard street widths, and provide guidance on how to cluster spaces designated for public services, such as parks, schools and clinics to create local community centers.

Table 4. Zoning Specifications per USPA

Den-sity	Zoned Density	Min. lot size	FAR	Coverage		Parking	Height	Setbacks (in meters)		
	pp/ha	m^2		Zocalo	Tower		(max.)	Front	Side	Back
High	350-400	200	4	90%	70%	15 m^2 per 200m^2 built	5.43			3 (op)
Med High	300-350	200	2.8	70%	70%		4.00	3 (op)	2 (op)	4 (op)
Med	250-300	240	2.5	60%	60%		4.17	3	3 (op)	3 (op)
Net	200-250	250	2	70%	70%		2.86	3	2	3
Low	100-200	250	2	60%	60%		3.33	3	3	3

Source: GAMEA, USPA Guidelines; op = optional; FAR: floor area ratio, which states how much floor area can be built relative to the lot; Zocalo: building base/pedestal.

Table 5. Actual vs. Zoned Density in El Alto

Density Zone	Net Density (people / ha)	Total Land Area (ha) +	Land Area in Blocks (%)	Public Land Area (%)	Est. 2011 Pop*	Actual Density (people / ha)
High	350-400	554	68%	32%	87,603	158
Med High	300-350	2,140	63%	37%	264,925	124
Med	250-300	1,647	59%	41%	187,815	114
Net	200-250	350	51%	49%	58,408	167
Low	100-200	5,703	59%	41%	412,737**	72

+These areas are approximate based on USPA zoning guidelines; most additional development would fall into the low-density zone. *Population estimates based on the number of EPSAS clients, multiplied by their estimated number of residents per household (5.7); ** Given that EPSAS' network does not reach all peri-urban areas, this zone's population estimate is the least accurate.

The *Plan Ordenamiento* provides a zoned density map of El Alto corresponding with the USPA and calls for densities of 100 to 400 people per hectare throughout the city (fig. 11). However, by estimating population in each zone based on the number of water clients, it appears that the actual density of El Alto in each of these zoned areas is closer to 70 to 160 people per hectare (table 4). The densest areas of the first six districts are also the oldest areas in El Alto and roughly correspond to the areas that had received water services by 1997 (fig. 13). Future development and consolidation in the areas that received water services between 1997 and 2009 should be expected. However, since the city grew by 144 percent from 2000 to 2010, while the population increased by 54 percent, by far the greater tendency is for low-density settlements to expand along the periphery.

Conceptualizing Urban Growth in El Alto

As a conceptual exercise, to understand how projected population growth would translate to urban land demand, we developed two scenarios up to 2050 (tables 1 and 6). In both scenarios, population rises to 3 million by 2050, accounting for moderate levels of climate change and disaster-driven migration. In the first scenario, currently developed areas experience some densification, and house an additional 354,000 people, up from around one million people today. To accommodate the remaining 1.6 million people by 2050, new low-density developments would expand on the periphery. This would result in a physical expansion of over 12,300 hectares, or roughly doubling the city's current built area, in line with projections based on past trends.

Table 6. Possible Urban Growth and Land Use Scenarios for El Alto in 2050

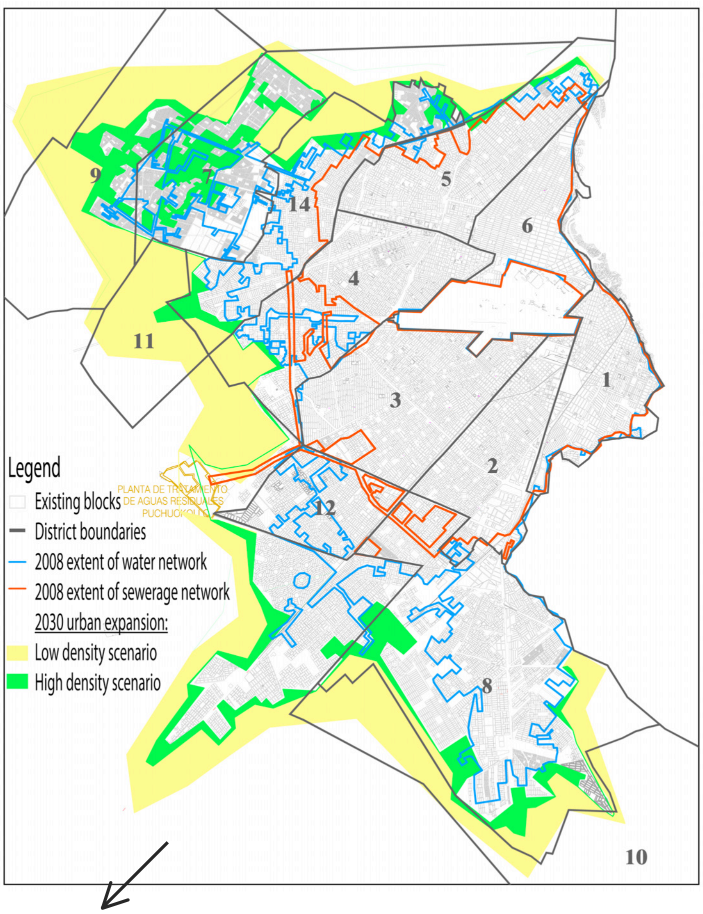
Land Use Scenario 1					Land Use Scenario 2				
Business as usual: some densification, but mostly peri-urban expansion					Significant efforts made to densify the city of El Alto				
Density	**Pop. growth per year**	**2050 Pop.**	**2050 Net Density (pp/ha)**	**2050 growth area (ha)**	**Density**	**Pop. growth per year**	**2050 Pop.**	**2050 Net Density (pp/ha)**	**2050 growth area (ha)**
High	0.8%	119,531	216		**High**	2.4%	220,912	399	
Med High	1.0%	390,531	183		**Med High**	2.7%	748,806	350	
Med	1.2%	299,068	182		**Medium**	2.5%	591,995	299	
Net	0.8%	79,695	228		**Net**	1.0%	186,100	246	
Low	1.4%	709,829	124		**Low**	2.6%	1,252,187	197	
Med (exp)		420,404	182	3,264	**Med (exp)**		100,000	299	472
Net (exp)		420,404	228	2,748	**Net (exp)**		100,000	246	605
Low (exp)		560,538	124	6,350	**Low (exp)**		131,632	197	924
Total		3,000,000		12,362	**Total**		3,000,000		1,529

Exp = Expansion area

In the second scenario, significant efforts are made to densify existing areas and to build denser communities in areas of expansion. Around 2.7 million people could be accommodated in existing areas, reaching the maximum limits established in the current zoned density map (fig. 11). The remaining 300,000 people would expand into new areas. This would result in a total land consumption of around 1,500 additional hectares by 2050, or roughly a 12 percent expansion in El Alto's current developed area. The scale of growth is shown conceptually in figure 12.

The results present very different potential choices in EPSAS' investment decisions to expand or upgrade the network and burdens for ongoing maintenance. The expansiveness of the city also has impacts on the provision of other services and burden on the city's tax collection. Furthermore, figure 12 suggests that continued growth will increasingly lie outside of El Alto's city limits and within the Municipality of Viacha. This carries important fiscal implications, given that the municipal government cannot control growth in Viacha nor benefit from taxes there, although community associations will likely nevertheless pressure EPSAS, rather than the Municipality of Viacha, the heart of which lies over 10 km south.

Figure 12. Conceptual Diagram Showing Amount of Land Required to Accommodate Additional Population in 2050 Given Density of Future Urbanization



Municipality of Viacha

Green zone: Potential 2050 expansion areas under high density scenario; Yellow zone: Potential 2050 expansion areas under low-density scenario; Blue line: 2009 water network extent; Red line: 2009 sewerage network extent.

Who Will Be the Most Vulnerable to Water Shortages?

El Alto is highly physically vulnerable to climate change due to water scarcity; ongoing infrastructural projects will go far to reduce physical exposure. A review of El Alto's socio-economic, political and fiscal conditions shows that these constraints are also important determinants of the city's vulnerability and adaptive capacity to climate-induced water shortages.

Fiscal Vulnerability of the Water Utility

In the late 1990s, the World Bank pressured the Government of Bolivia to privatize water services in the hopes of improving network extension and service quality. In El Alto and Cochabamba, a combination of insufficient concession regulations and government oversight, inadequate capitalization of the new concessions, and international managers inexperienced in Bolivian politics and social realities led to a "water war" in each of these cities. Efforts by the private companies to drastically raise tariffs—following years of excessively low tariffs under the previous public utility—led to widespread demonstrations and violent clashes. In El Alto, this eventually led to the dismantling of the private concession, *Aguas de la Ilimani*, and the creation of a transitional company serving La Paz and El Alto called EPSAS, or *Empresa Pública Social del Agua y Saneamiento*, that was to operate on a limited, six-month basis. During this interim period, the responsible ministries were to establish a public water company serving La Paz and El Alto based on a new model of public water and sewer services management. In actuality, EPSAS has continued operations for over six years because no public authority was ever created.

In 2007, the government also established a national "solidarity" tariff for basic consumption that applies to 89 percent of domestic users in El Alto, compared with 57 percent of domestic customers in La Paz (EPSAS, 2010; table 7). For a household with two income earners, this represented 0.6 to 1.2 percent of household income in 2001, possibly less in today's incomes. Industrial water tariffs are reputedly 10 times the base domestic rate, but many of the larger industries operate their own wells and do not pay EPSAS. While appeasing social movements, this tariff structure has once again returned the water utilities to unsustainable income streams. With the majority of users paying a subsidized rate and few commercial, cross-subsidizing customers, El Alto cannot generate enough water revenue to cover basic operations expenses. Of EPSAS' operating revenue, 75 percent comes from La Paz, where consumers use more water and pay higher unit costs, and 25 percent comes from El Alto, even though El Alto's population now exceeds that of La Paz. The operation of El Alto's water system is therefore dependent on the joint management of the two cities' water systems, and water consumers in La Paz essentially subsidize El Alto, a sore point in La Paz. There is also a mismatch in the interests of existing connected customers, who benefit from low water tariffs, and unconnected customers, for whom a better-capitalized water utility would improve their chances of new water connections.

Table 7. Bolivia's Domestic Water Tariffs

Water Use (m^3 per month)	Tariff (USD per m^3)
0-10	$0.17
10-30	$0.22
30-40	$0.44

Source: Project Workshop

Some discussants argued that EPSAS is in an untenable and precarious financial position leading to insolvency due to several factors. First, it is constrained politically from raising tariffs in El Alto to cover operational costs. International donor agencies finance EPSAS' capital investments largely on a discretionary, but not necessarily long-term programmatic, basis. Households are typically charged US$109 to connect to the water system, with a range of US$99 to $144 depending on community participation in excavation in unpaved areas, although the cost to EPSAS is US$284 to US$294 per connection (EPSAS website, *"Obras y Proyectos"*). For sewerage, households are charged US$148, with a range of US$128 to $178 to connect, compared to actual project costs of $312 to $1,332 per connection where trunk extensions are required.

Figure 13. Extent of Water Network in El Alto 1997, 2009

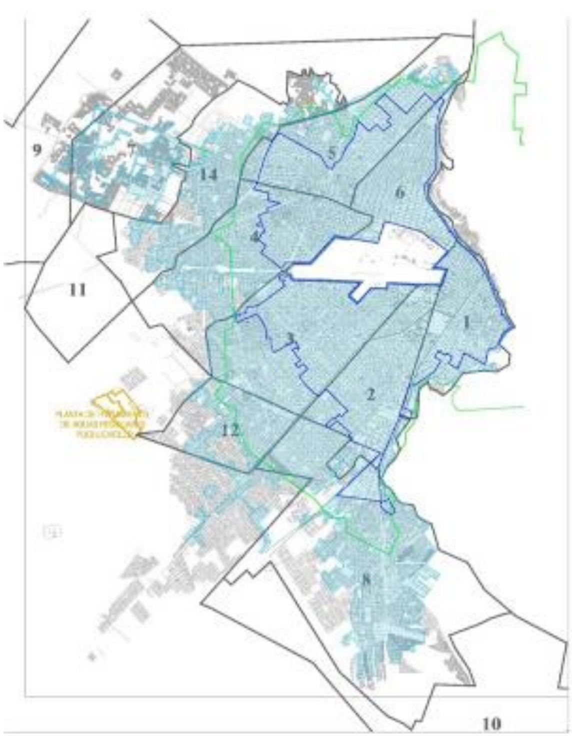
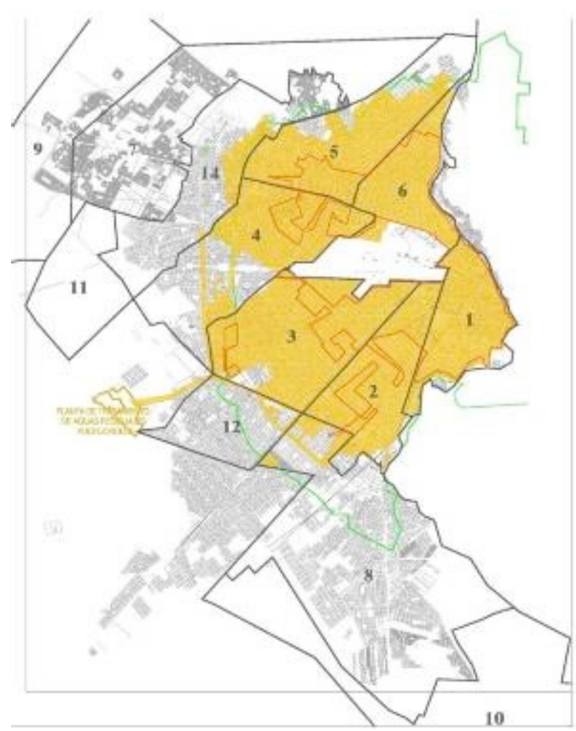


Figure 14. Extent of Sewerage Network in El Alto 1997, 2009



Source: Departamento del Catastro, GAMEA; Green line: EPSAS Service Concession Area; Blue line: 1997 water coverage; Blue shade: 2009 water coverage; Red line: 1997 sewerage coverage; Yellow shade: 2009 sewerage coverage.

Second, unions (COR) and community associations (FEJUVES) in El Alto wield formidable political power to pressure EPSAS to extend services beyond the legal boundaries set in EPSAS' contract, further taxing its fiscal solvency. From 2007 to 2010, EPSAS extended the water network in El Alto by 53,287 meters and installed 36,337 new connections (fig. 13–14). While this is an impressive achievement, the complete reliance on international capital funding is unsustainable given fluctuations in international aid, especially during this period of global economic crisis (Calizaya et al, 2012). With projected populations at least doubling by 2050 and urbanized area possibly doubling as well in the business-as-usual scenario, the need for infrastructure extension will almost certainly exceed international allocations. Finally, EPSAS does not have the benefit of a robust local planning department with the resources and capacity to control urbanization, or enforce plans and regulations that prescribe more concentrated patterns of development that reduce the cost of infrastructure provision.

EPSAS also faces political headwinds. The utility came under severe criticism in 2008 due to accounting errors, emergency tariff increases and poor disaster preparedness, including during drought that led to water shortages (*La Razón*, 2008). In November 2012, the oversight authority for water and basic sanitation, AAPS (*Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico*), under MMAyA issued a *Resolución Administrativa Regulatoria* that identified operational failures at EPSAS, criticized the management capacity and professional expertise within the organization and warned of insolvency. It demanded that EPSAS submit a development strategy by the end of 2012 (*La Razón*, 2012). In December 2012, the Public Management of Potable Water and Sewerage Bill (*Proyecto de Ley Gestión Pública de Agua Potable*) was introduced to the National Assembly. This would (i) dismantle EPSAS and create a metropolitan water authority responsible for managing supply and regional planning; and (ii) establish independent municipal water departments responsible for delivery of water and services, and which would buy water from this new metropolitan water authority. The sponsors of the bill contend that, "Only a strategic vision at the metropolitan scale can anticipate what future investments will be sufficient to guarantee an adequate system of production, supply and storage (reservoirs) to meet the growing demands in the region." (*Proyecto de Ley Gestión Pública de Agua Potable,* 2012). In place of EPSAS, the bill proposes the creation of a metropolitan water authority (*Empresa Metropolitana De Producción De Agua*) to manage the production and supply of water by means of reservoirs and storage systems and the exploitation of new sources. The bill gives each municipality the power to establish its own municipal water authority (*Empresa Municipal De Agua*) for the distribution of water and delivery of basic sanitary services to their respective jurisdictions.

This legislation is almost certainly motivated by the underlying resentment of government officials and citizens in La Paz to subsidizing El Alto's water, and who would rather invest in their own water network. If enacted by the national assembly, La Paz will no longer subsidize El Alto, and its municipal water authority, established under this bill, will use profits generated in La Paz to upgrade and manage infrastructure exclusively within the City's jurisdiction. This poses a major question for how El Alto would fund its operations, without changing the tariff structure. On the other hand, La Paz receives some water from a reservoir that lies in a sub-watershed within El Alto's jurisdiction (IHH, 2012). These conflicting interests and political tension conspire against inter-jurisdictional collaboration between La Paz and El Alto that could, otherwise, set the stage for more constructive solutions. Notwithstanding the political dynamics, a re-constituted EPSAS or newly-created, adequately capitalized public water authority explicitly charged with the management of water supply in the metropolitan region would be better-positioned to address the vulnerabilities to future water shortages.

The development of MMAyA's Metropolitan Master Plan for Water and Sanitation further demonstrates the complexity of water resource management on the ground. The objective of this plan is to produce a 20-year strategy for development and expansion of water and sanitation services in the La Paz and El Alto metro region. The plan will guide investments in the improvement and expansion of access to services, particularly in the peri-urban zones. A major intent is to develop an integrated plan for the entire La Paz / El Alto metro region that, in principle, will engender inter-jurisdictional cooperation between the municipal governments of La Paz, El Alto and the other municipalities that constitute the metro region. In fact, this has been a political challenge as collaboration between municipalities has stalled due to the competing interests of local governments. Municipal boundaries in many cases are in dispute and not clearly demarcated, and complicated by urban expansion into peri-urban areas. This has fiscal implications for each municipality because the size of transfers of funds from the national government to local governments is calculated on a per resident basis. It is in the interest of each municipal government to register and claim the largest population within its boundary—or, in the case of boundary disputes, to claim a boundary in the most expansive way that incorporates recent peri-urban settlements. GITEC, the consulting team responsible for the Master Plan, has attempted to frame the necessity for inter-jurisdictional collaboration by focusing on the aspects of water delivery management and infrastructure that supersede jurisdictional boundaries with mixed success. In a sense, national fiscal policy regarding funding transfers inadvertently creates a situation that conspires against the inter-jurisdictional cooperation required for water management.

Social Vulnerability

This fiscal and political context exacerbates the financial exposure of El Alto's residents. El Alto is considered to be the poorest city in Bolivia, which in turn is considered the poorest country in South America. As of the 2001 census, El Alto had an overall poverty incidence of 73 percent, with 43 percent of the total population identified as indigent (INE, 2001). In comparison, Latin America's overall rate of poverty in 2001 was 45 percent (GAMEA, 2002). This poverty is evident in many measures of development. The average per capita income in 2001 was US$ 488, roughly half the national average at the time (INE, 2001), and 63 percent of jobs are considered precarious (CEDLA as cited in *El Diario*, 2011). Among the poorest households, only 40 percent had some level of basic education. On average, residents had five years of education and 12 out of 100 people were illiterate. The cultural and economic dimensions of this poverty affect their ability to pay for water services, the amount of water they consume and their attitudes towards paying for water services.

The future uncertainty of the tariff structure in El Alto and operational and capital capacity of the water services provider impinges on the financial risk of households and the likelihood of their receiving upgrades. Peri-urban households may have to wait longer and longer for water services to reach them, and will be at higher risk during droughts when non-network water prices escalate. Residents in the urban core who are entirely dependent on piped services and whose multi-story buildings challenge the use of rainwater collection systems, water storage tanks and communal wells are also less resilient in the face of drought. If history repeats itself, tariffs may again surge at some critical point in the future, placing the poorest households at risk, leading to a socially volatile situation. In each case, it will be the poorest and the newest migrants to El Alto who are most vulnerable to inadequate and unsafe water and to shocks in water prices. Many of these settlers could themselves be environmental refugees, displaced by climate change induced-drought in rural areas.

How Can Water Use Efficiency Strategies Inform Land Use Planning?

Given the costliness of future investments to augment water supply for El Alto, it is timely to consider how water can be more efficiently used in the city and how land use planning can be informed by water shortage considerations. Most literature concerning water shortage management comes from the field of water engineering, where service providers have long been concerned with how to most efficiently supply customers with water. Demand-side management, or strategies to reduce total or unit water consumption, will be a key component of climate change adaptation. This commonly involves a) the reduction of water losses through leaky pipes and illegal connections; b) water use conservation; c) wastewater reuse; and d) water tariff reform. These strategies are all on the table in El Alto, and each has implications for urban planning and development upgrading. Reducing water loss and recycling wastewater could, if exercised in full, satisfy future demand for water in 2050, but the difficulty of their practical implementation suggests that these will play a mixed or minor role in relation to the expansion of water supply infrastructure.

Water Loss Reduction

According to EPSAS, water loss in El Alto is around 35 percent as of 2012, on par with the World Bank's estimate of average water loss in developing countries (World Bank, 2006). EPSAS does not know what percentage of this is due to physical (leakage) versus economic (illegal connections) losses. In the 1980s, when El Alto's water loss was as high as 50 percent, a project brought a U.S. company to train EPSAS engineers to identify and fix leaks. Since 2007, EPSAS, with international funding, has invested US$5 million in renovating the pipes, resulting in more moderate losses today (Berdeja, 2012). Given that water loss rates average 15 percent in developed countries (World Health Organization (WHO) as cited in World Bank, 2006), El Alto could expect, at best, to meet another 20 percent of future demand through additional water infrastructure loss reductions. Additional research is needed to map where these investments have taken place and future areas of investments. Such investment strategies could be integrated with broader urban upgrading priorities. For instance, water loss repairs may be coupled with pipe enlargements to accommodate greater densities in targeted urban areas.

Water Use Conservation

Highlighting the effects of water scarcity, population growth and climate change, MMAyA is developing a new policy on water use conservation, specifically low-flow toilets that would require all imported toilets—which comprise most of those in Bolivia—to meet efficiency standards. The government aims to reduce water consumption from as much as 250 liters per capita per day (lpcd) in some parts of the country, to European efficiency standards of 100 lpcd (Berdeja, 2012). The program, which would be piloted in La Paz and El Alto, would provide incentives and revolving loans to attract households and developers to replace old systems or use new technologies.

Despite good intentions, it is unclear whether this strategy would deliver the water savings desired, or whether it is the most cost-effective approach to boosting water use efficiency in El Alto. According to EPSAS, over 90 percent of residents in El Alto within the concession area have access to improved water services (EPSAS, 2011). As of 2007, of those with access, an estimated 72 percent have access to water in the home, 15 percent through public standpipes and 13 percent other pipe networks (GAMEA, 2007; EPSAS, 2011). An estimated 4 percent of households relied on wells, rivers, tankers (by EPSAS and other companies) and unimproved sources of water. It is unknown whether these figures include peri-urban areas outside of El Alto's municipal boundaries.

An estimated 89 percent of households in El Alto use less than $15m^3$ of water per month (EPSAS, 2010), which translates to an estimated municipal water use per capita of less than 143 liters per day. As a comparison, the WHO suggests that 100 liters per person per day is needed for healthful living, and water consumption per capita elsewhere in the country can be as high as 200 to 250 per person per day (Berdeja, 2012). Relative to the levels of in-house access, El Alto's domestic water use is quite low (WELL, 1998). This is likely due to a mix of low household incomes and a culture of low water use among the indigenous groups who comprise 80 percent of El Alto's population.

Given low per capita water use in El Alto households, it is unlikely that even a concerted effort in water use efficiency measures would have more than a marginal impact on overall water consumption. However, some opportunities for improving efficiency may exist within the urban core where EPSAS' water delivery records suggest that per capita water use is significantly higher than the city average. Among residential customers this is likely due to a higher incidence of flush toilets, which typically account for as much as one-third of indoor water use. Water-flushed toilets are used by 58 percent of households in El Alto (EPSAS, 2011). Other parts of the city, where water use is already low, may afford opportunities to implement alternative design features, such as dry toilets, which may not be feasible in high-density settings. Industrial and commercial water users should be the targets of water efficiency programs, as well as of other water efficiency upgrades besides toilets that may reap greater savings.

Wastewater Recycling and Reuse

As an industrial city, El Alto generates particularly high quantities of industrial wastewater with heavy metals, including from the textile, leather, dye and bottling companies and butcheries (GAMEA, 2002). The result has been that domestic and industrial wastewater has heavily polluted the city's three major rivers—the Seco, Seque and Hernani. These rivers are not only important for downstream farmers, but also feed into Lake Titicaca, an important source of freshwater for 2.5–3.0 million people in Peru and Bolivia (Cathcart and Bolonkin, 2007).

Pollution of Lake Titicaca, which has already begun, also threatens the lake's endemic fish species.

In 2010, EPSAS opened the Puchukollo wastewater treatment facility just outside of El Alto. It serves El Alto, Viacha and Laja, and has 12 stabilization ponds that can treat up to 446 liters per second. Current volumes at the facility are relatively low due to the lack of connections and sewerage lines leading to the facility. As of 2011, an estimated 68 percent of residences in the EPSAS service area are connected to the sewerage network. The limited reach of the network—relative to the water system—is due in part to the cost of extension and the difficulty of constructing piped sewers to the treatment plant in the southwest sector of El Alto given the lack of slope. Access to sewers is particularly low in the north and northwest districts, where households discharge directly into the rivers. Districts 7, 8 and 10 are prioritized for sewerage trunk line extension.

The second major thrust of MMAyA's water conservation policy is to reuse wastewater, citing Mexico's experience, where, following a water crisis, the government began to subsidize 50 percent of wastewater treatment plants' operational costs for agricultural reuse, aquifer recharge and industrial cooling (Berdeja, 2012). Although Bolivia as yet has no wastewater reuse standards, MMAyA believes the facility's reuse potential is tremendous (Berdeja, 2012). Downstream farmers are likely to most directly and cost-effectively benefit from the wastewater facility's treated water. While residents will not be using Puchukollo's water directly, aquifer recharge will also help counter the effect of EPSAS' and industries' groundwater extraction. While, there may be high potential for industrial reuse, an examination of the location of the city's major industrial areas and the location of primary water users by volume shows that industrial reuse would require 7 km of water pipes to bring treated water to the industrial areas. The expense of this strategy suggests it is likely secondary to other alternatives to reducing industrial water consumption. An alternative would be to develop smaller, industrial wastewater treatment and recycling facilities within existing industrial zones. As the costs of drilling and reservoir expansion increase, the option of wastewater reuse distribution infrastructure could become more attractive.

Tariff Reform

Studies of income suggest that it positively correlates with water consumption (Baumann et al., 1998; Dalhuisen, et al, 2003), with indoor water use remaining relatively stable across different income groups (Loh and Coghlan, 2003). Studies also suggest that water is price inelastic below a threshold for basic water needs, beyond which it tends to be price elastic, particularly under block rate pricing and when considered by income group (see review by Domene and Saurí, 2006). However, the income factor becomes weaker in explaining outdoor water consumption (Syme et al, 2004) and as the cost of water becomes a smaller proportion of income (Martinez-Espiñeira and Nauges, 2004). The low level of water consumption in El Alto suggests that it is approaching inelastic levels. Given Bolivia's history, this is one of the most controversial and contentious issues in the country, and specifically El Alto. Changes to the tariff structure could take place under the new water framework law, and the question of the costs of service extension will have a major impact on future adaptation efforts.

Land Use Impacts on Water Demand

Studies point to a combination of factors that influence household water consumption, key among them are household income, household size, housing typology, water prices, and consumer behavior or cultural practices (Domene and Saurí, 2006; Troy, et al, 2005). In El Alto, with clients using an average of 70 to 143 liters of water per day, and 80 percent sharing cultural and rural water use practices, housing typology, access to water and, to a lesser extent, income are likely to be an important factors.

The relationship between water consumption and housing typology and, by extension, land use density is highly context-specific. At the city scale, density appears to have no relationship with water use, although within cities, a number of studies have found housing type to be an important determinant, chiefly due to greater outdoor water use among single-family houses (Linaweaver, et al., 1967; Renwick and Green, 2000; Mukhopadhyay et al., 2001; Syme et al. 2004). In Barcelona, Domene and Sauri (2006) found that housing typology had a greater impact on water use than income. On the other hand, in Sydney, Australia, Troy, Holloway and Randolph (2005) found that while water consumption per household is higher for single-family houses than for denser dwellings, per capita consumption of water is essentially the same regardless of built form and density due to the fact that modernized urban multi-family buildings were more likely to have high water-consuming amenities such as gardens, pools and washing machines, while older houses were more likely to lack water-consuming appliances and more likely to use rainwater tanks and reuse greywater. In addition, per capita consumption of water tends to be greater in smaller households given diminishing economies of size; thus, the distribution of smaller households within a city also affects its water consumption (Domene and Sauri, 2006; Troy, et al., 2005).

As shown in figure 15, water consumption is highest within the urban core. Water use per EPSAS client (fig. 16) is highest in commercial and industrial centers and lowest in the peri-urban areas. Several factors may explain why urban density increases per capita water consumption in El Alto. Higher income households living in multi-story buildings are more likely to avail of water-flushed toilets. Although EPSAS' maps show that access has been extended to peri-urban areas, much of this is likely through community standpipes, and evidence shows that access to water outside of the house has a dramatic affect on reducing water consumption (WELL, 1998; Cairncross, 1987). Low-density houses may be more water efficient due to greater practices of rainwater collection, greywater reuse, and dry sanitation. These maps suggest that water efficiency efforts would do well to concentrate in certain *recorridos* where water use per client is highest, while water reuse, rainwater collection and improved sanitation promotion have greater potential in peri-urban areas. Water models should take into account this relationship between density and water consumption to accurately estimate water demand. Future investments can leverage the different water use patterns at each end of the building typology spectrum, promoting rainwater harvesting and household-level reuse and targeting dense communities for alleviating infrastructure bottlenecks, reducing water loss, and investing in water efficiency enhancements.

Figure 15. Total Water Use by *Recorrido* in El Alto per Year

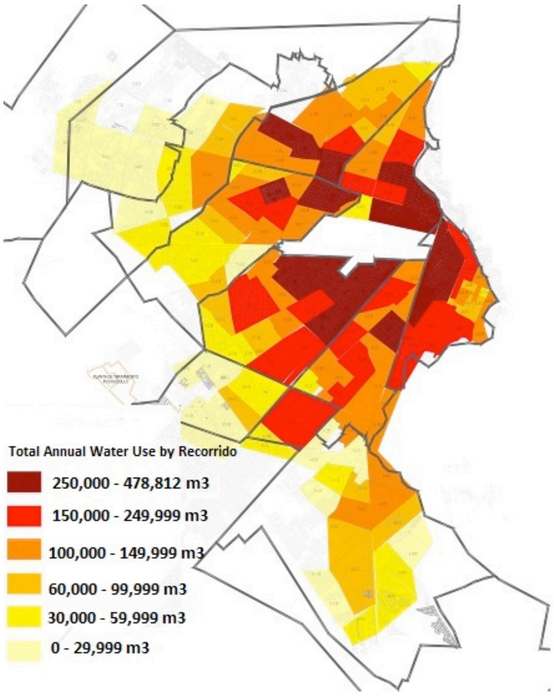
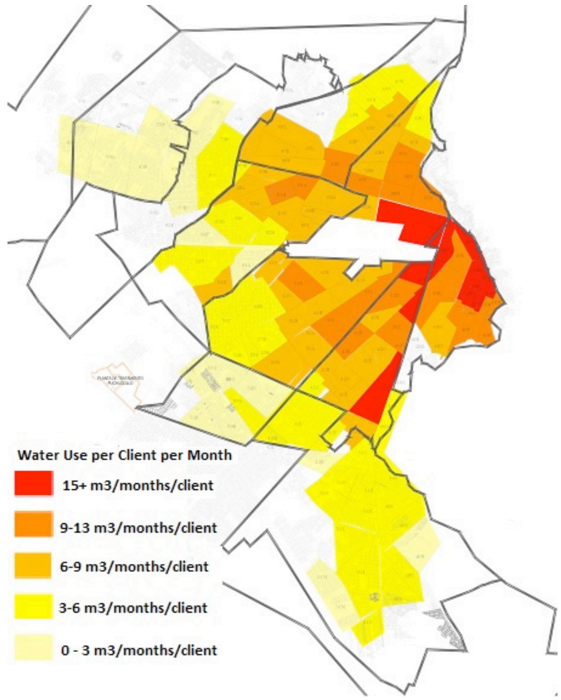


Figure 16. Water Use per Client by *Recorrido* in El Alto



Source: EPSAS 2012

What Land Use Planning Responses Can Improve Water Access Equity and Reduce Vulnerability to Future Water Shortages?

Strengthen Institutional Capacity for Integrated Management of Water and Land Use

No single strategy may be appropriate or easy to adopt given the complexity and sensitivity of local politics around water. In response to a number of our preliminary recommendations, local stakeholders concurred in principle, but repeatedly cautioned that there is insufficient municipal funding and capacity within the city of El Alto, and that complicated political competition challenges any efforts at coordination and management. For instance, although stakeholders acknowledged the benefits of a cross-sector taskforce, they worried that the institutional challenges involved in implementing this idea, as seen in the case of MMAyA's Metropolitan Water and Sanitation Master Plan, may reduce its efficacy or prevent its formation. We therefore propose a set of potential strategies that may be considered singly or in parallel with one another.

Build the Institutional Capacity of El Alto's Territorial Planning Office

The limited capacity of El Alto's Territorial Planning Office to control development and manage urban growth cannot be overstated. The municipal government, under-staffed and under-funded, is restricted, practically speaking, to reacting to developer-driven growth and approving development retroactively after the completion of construction. This is a major impediment to the coordination and alignment of urban planning and water infrastructure investment decisions, and was echoed in meetings with stakeholders, including officials from the Territorial Planning Office. A number of urban water management initiatives hinge upon the capacity of the Territorial Planning Office to coordinate, lead and implement. The national government and major international funders should consider allocating budget for this office as part of water and climate adaptation-oriented projects and funds.

Ongoing projects such as updating the property database of El Alto and the upcoming national census will provide a new set of baseline information on the city with which to improve management, revenue collection and service delivery. Complementing this, the Territorial Planning Office needs staff, technical assistance and funding to develop the capacity to undertake new spatial plans, engage community associations in participatory planning, apply new regulatory and entrepreneurial tools, and leverage capital assets, such as publicly owned land, to pro-actively guide growth and development.

Efforts undertaken during the PPCR/SPCR process are a step forward in this direction to improve water governance. It provided a setting to build and share information through the use of water supply and demands models within a focus group formed by the Vice Ministries of Water and Basic Sanitation and Irrigation under MMAyA, the Departmental and Municipal Governments of La Paz, the PRAA team, EPSAS, IHH and SENAMHI. Such a process could be replicated in El Alto and engage urban planning and management groups as appropriate.

Form an Inter-Disciplinary Water and Development Planning Taskforce

The City of La Paz is currently in the process of producing a *Plan La Paz 2040,* a comprehensive urban and economic development plan that will also include water management strategies and propose the development of new water sources. Several respondents in interviews noted that there had been no meaningful coordination between the drafters of the *Plan La Paz 2040* and the MMAyA's Metropolitan Water and Sanitation Master Plan for El Alto/La Paz. Some professional staff considered this a missed opportunity to capitalize on the inter-linkages between water management and urban planning at both the municipal and metropolitan scale. Within El Alto, although it is technically the responsibility of the mayor to tell EPSAS where to invest, EPSAS has taken the lead in the absence of direction from the municipal government. It is critical for the municipal government of El Alto to re-engage in this conversation and identify coherent infrastructure investment and urban development strategies. MMAyA, IADB and the World Bank might build incentives that encourage inter-jurisdictional collaboration into funding commitments.

There is a desire for an opportunity to launch an inter-jurisdictional taskforce that brings together sub-mayors, urban planners, water utility managers, funding agencies, research institutions and leaders of major community associations (e.g. COR and FEJUVE) to plan the urban and water investment strategies. This entity could either span both El Alto and La Paz, or at least El Alto. The taskforce can also jointly identify growth nodes where it makes sense to prioritize efforts to fix leaks and network bottlenecks, build a green drainage network, invest in more efficient water fixtures and water collection and recycling systems, upgrade additional public services, and create incentives for community densification and auto-investment. It could develop a package of urban infrastructure upgrades to support community development. A major goal would be to accommodate future residents within existing urbanized areas in order to increase economies of scale for service upgrading and extension. It will be important to engage the adjoining municipality of Viacha in these conversations to discuss collaboration and cooperation in land development controls and service extension.

Establish an Urban Planning Unit within EPSAS

EPSAS might be the *de facto* (and inadvertent) enforcer of zoning through its requirement that communities seeking service extension have a minimum density of 6 houses per block, 15 houses per cluster (2 blocks paired), or 50 people living within a cluster of 4 blocks. International donors who finance new infrastructure on behalf of EPSAS (such as JICA, EuropeAid, and the governments of Canada and the Netherlands) often require that 60 percent of the subdivided lots be occupied with houses. Although not within its mission or purpose, EPSAS may have the greatest regulatory power to manage urban development and hold communities to this minimum threshold. This leverage could function as a discretionary legal mechanism to implement urban planning.

An urban planning unit could be established within EPSAS with the explicit responsibility to engage in urban planning on a comprehensive basis and manage—or at least guide—urban management based on considerations that go beyond the narrower mission of EPSAS. Far from an EPSAS "takeover" of urban planning powers and responsibilities, this unit would work collaboratively with El Alto's municipal planners and strive to use their leverage to advance rational urban planning goals established by GAMEA. In a complicated political context in which various levels of government have conflicting interests, this would have to be skillfully negotiated.

Engage Community Associations in Developing an Integrated Community Upgrading Strategy

In interviews, local government staff and leaders expressed great frustration with the power of social associations to pressure or force the hand of government in "unreasonable" or "irrational" ways. However, given the limitations of top-down approaches and the fact that the associations are highly mobilized and powerful, the Territorial Planning Office and EPSAS could increase their engagement with community organizations in the development of integrated community upgrading strategies. In the first place, such efforts can identify priority interventions that advance local development needs, livelihood concerns, as well as urban water use efficiency and resilience. Secondly, communities can help design new multi-story housing that meets their needs, which often include space for commercial activity, urban agriculture/livestock and room for expansion for relatives. Third, community monitoring and enforcement of construction can provide an effective alternative or complement to municipal legal processes. Such efforts can also be built into the upcoming planning processes that will follow the completion of the census and property inventory efforts. Active community participation in the design of new growth nodes will be key to the implementation feasibility of any proposed plans. These nodes could provide places to target financial tools to support densification, as well as a chance to foster community focal points that begin to give identity and sense of place to what is currently a homogenous expanse of settlements with high resident turnover.

Promote Urban Resilience and Water Use Efficiency

Regardless of which organizational approach is selected, there are a set of planning design and upgrading strategies that can improve urban resilience to drought and water use efficiency.

Enhance Community Resilience to Drought Risks

Although adaptation is sometimes seen as a separate activity from development—a level of "development plus"—it can also be closely integrated into community development and livelihood considerations (Dodman, et al., 2009). While the large-scale infrastructure plans to expand El Alto's water supply will significantly reduce the city's exposure to drought, communities will also require stored water in case of water shortages, during which time water prices can escalate. Both in urban and peri-urban redevelopment and upgrading projects, there is an opportunity to promote locally appropriate strategies to increase water efficiency and reduce vulnerability. In urban areas this may include water loss reduction, pipe and drain expansion, roof-top storage tanks, green soakaways to enhance drainage and aquifer recharge as well as increased plantings for shade during heat spells that often accompany drought. In peri-urban areas, strategies may focus on rainwater water collection, improved dry sanitation, greywater reuse, and service expansion through a combination of well and piped water systems.

Policy changes to promote the adoption of these technologies may include modifications to USPA, which can provide guidelines on community-scale water collection and storage systems and urban green spaces. EPSAS, in addition to the minimum density thresholds, could also require that space be dedicated within blocks or site development plans for water collection, storage and drainage networks.

Create a Green Network to Reduce Water Pollution and Increase Aquifer Recharge

Although green spaces are dedicated in each development based on USPA regulations, in reality they are small, dispersed areas, many of which lack basic criteria for recreational use and are of poor condition due to the lack of maintenance. An integrated system of green spaces and a hierarchy of parks, plazas, sports fields and private areas, and green streets and avenues, explicitly designed as a water management strategy, would enhance the livability and quality of the built environment for residents and create a sense of coherence in an otherwise sprawling, fragmented urban fabric. These should complement the ongoing IADB-funded drainage master plan, and help to reduce flood risk impacts in the city. The reuse of wastewater to irrigate these spaces so that they can support usable community parks would help improve local quality of life and foster community cohesion.

Stakeholders endorsed the concept of green drainage networks but expressed skepticism about the capacity of the *Oficina de Ordenamiento Territorial*, *Alcaldía de El Alt*o to implement this strategy. Ideally, the municipal government would acquire and bank vacant, undeveloped land for an integrated system of green spaces and a hierarchy of parks, plazas, sports fields and private areas. The promotion of public green areas for urban agriculture, drainage and/or rainwater collection gardens that residents may use or lease could provide new incentives for communities to contribute to the greening of currently vacant land set aside for public use.

Following the updating of the property database, GAMEA anticipates increasing its tax revenue and could potentially create municipal loans to communities to establish these gardens and greenways.

Targeting Water Efficiency Projects at Both Puchukollo and Industrial Sites

Wastewater reuse from the Puchukollo is one important strategy that will benefit agricultural and downstream users and provide them with a buffer during droughts. However, it is too far to be reusable for industries, and too costly to adopt household wastewater reuse from the facility. In addition to ongoing wastewater reuse projects, MMAyA should consider providing technical assistance to help industrial facilities develop wastewater recycling systems. To address the lack of funding for such an initiative, MMAyA may consider tapping some of the funding planned for revolving loans for household toilet replacement and directing it towards revolving, low-interest loans to industries, as these offer greater water saving returns on investment. Additional research is needed to understand how much water industrial consumers use in El Alto. The Department of Environment is planning to undertake a survey of industries in El Alto, along with their hazardous waste streams. This could incorporate an assessment of their water consumption and wastewater generation, as well as opportunities for reuse. Household and commercial water reuse projects can be considered as part of a broader community upgrading strategy.

Reform Tariff Structure

Tariff reform is one of the most difficult aspects of water management to implement anywhere in the world, yet there is no question that the economics of water will, per force, eventually have to change in El Alto regardless of the passage of the new water management bill. One clear issue is that the current structure of the tariff, pegged to water consumption rather than income levels, may not be targeting the poorest of the poor. In a culture of low water consumption, low monthly water use may not be indicative of ability to pay. The upcoming national census will shed much light on the actual incomes, household sizes and household appliances in El Alto, and provide a new baseline for estimating household capacity to pay for water. An updated structure better targeting low rates for the poorest while raising rates for those who can afford to pay may improve the financial solvency of the water provider. Learning from the experience of *Aguas de la Ilimani*, such initiatives will clearly need to be accompanied by community consultations and public education.

Promote Tools to Advance Implementation of Urban Water Resilience

Foster Information Sharing and Complete the WEAP-Based Urban Demand Model

This research shows the potential to jointly analyze water and planning data to generate new understanding of future investment strategies. Given ongoing efforts to develop a full WEAP model of future water supply in El Alto/La Paz under climate change, decision-makers would benefit from a more fully developed urban demand model that links with the supply model. Future research would benefit from greater collaboration between EPSAS and GAMEA to develop the city's water demand model. There has been a generally positive reception to the use of the WEAP model in the IABD / MMAyA workshops and from the highly proficient cadre of hydrologists and engineers representing a range of government agencies and EPSAS trained to use WEAP. In addition, senior officials understand the potential of WEAP as a tool for decision-making. Workshops on a periodic basis organized around a more complete WEAP-Based Urban Demand Model could serve as a 'politically neutral' platform for inter-jurisdictional collaborative planning. As part of this, additional studies of seasonal and disaster-driven migration into El Alto are needed, and worst-case scenarios compounding migration and drought need to be examined under the ongoing studies of regional water supply alternatives. Peak demand should be accounted for in sizing and siting new reservoirs to ensure adequate supply in periods of natural disasters.

Develop New Financial Tools to Support Urban Housing Densification and Affordability

Public investments such as social housing through the *Fondo de Vivienda Social* (FONVIS), which primarily provides civil servants with discounts to buy or build homes, can showcase new USPA standards and models of dense, affordable, low-rise settlements. These approaches should be understood within the context of the housing market in El Alto. In El Alto and many Latin American cities, the formal economy has largely failed to provide housing for more than 40 percent of households, the remainder of which have an insufficient income to buy a finished house built by the formal sector. Some experts contend that the solution is an increase in the availability of serviced residential land to low-income households, which necessarily requires public sector intervention. As prior experience demonstrates, the lowest income households cannot afford land sold on the open market (Smolka, 2005). Other Latin American cities have experimented with projects and programs premised on modified urban planning regulations to allow for subdivisions with smaller lot sizes, fewer services, and lower costs—such as the Areas of Special Social Interest (AEIS, in its Portuguese acronym) allowed by Brazilian legislation. Concluding, however, that these measures are insufficient to solve the problem in these cities, Smolka and Larangeira (undated) argue for public sector interventions in urban land markets that induce the urban landowners and real estate developers to sell low-cost serviced land. These case studies might hold lessons for El Alto: interventions in the land market for the purpose of expanding the supply of low-cost serviced land might also be a vehicle through which to advance water demand management strategies.

Leverage Public Land as a Capital Asset

Land owned by public sector agencies at all levels of government is a significant capital asset that can be leveraged to meet important public purposes. These opportunities or 'leverage points' for public sector intervention are intrinsically bound up in the dynamics of the housing and land market. The sale or lease of land by local authorities to national government entities or private land developers allows local government to become active partners in projects within their boundaries that are financed by these parties. Local government can effectuate ground leases or sales with contingent terms that require adherence to architectural and site design standards, modeled on a 'high density / low-rise' cluster concept. This is the point in the process where local government can stipulate guidelines (either a modified USPA or other forms of guidelines) that enable land use goals and ensure a model of development that creates a platform to operationalize strategies that address water shortages. In the interviews, stakeholders acknowledged the possible benefit and utility of the transfer of national government land to local authorities as a capital asset that they could lease or leverage in beneficial public/private development partnerships. However, they also cited the difficult negotiations that this would entail between different levels of government and national agencies that often might not share the same interests.

Conclusion

The Intergovernmental Panel on Climate Change (IPCC) noted in its *Third Assessment Report* that the groups most vulnerable to climate change tend to be those with the greatest sensitivity to climate change and the least adaptability. It defines the vulnerability of any system to an external stress as a function of exposure, sensitivity and adaptive capacity (IPCC, 2001). The impact of warming temperatures and greater rainfall tends to be severest in areas that already face extreme climatic conditions and where livelihoods exist on the margin. The typical response, and the one seen in El Alto, has been to focus on infrastructural solutions that reduce physical exposure.

As this case study of El Alto demonstrates, climate change acts on existing conflicts over scarce natural resources and further stresses not only the resource base, but also political and financial adaptive capacity. The response must therefore more comprehensively address risk factors, integrating climate considerations and new initiatives into much needed development and governance improvements. The role of urban planning and spatial adaptation is better understood in areas susceptible to too much precipitation, while the study of its role in drought environments has been much more limited. This analysis suggests that urban planning and management does have a role to play in climate change-induced drought environments, which are often in flat and expansive places conducive to sprawling development. Drought will bring about two major effects: continued or higher rates of rural-to-urban migration, and reductions in water storage and supply. These tendencies will drive exurban development, as well as place significant new financial burdens on water service providers in terms of funding capital improvements for supply side expansion, extending water networks ever outwards, and maintaining this infrastructure. The vulnerability of the poor and peri-urban communities is linked to the financial vulnerability of the local water utility.

The implications of this analysis is that it is key for national and international implementers of climate change adaptation and water resource management projects in drought-prone environments to also technically and financially support improved governance capacity for urban growth management. At the same time, attention must be placed on end-user risk resilience, as the expansion of water capacity does not necessarily translate into the climate proofing of household water quality, health and financial vulnerability. Building on the important ongoing foundational investments in water infrastructure, greater horizontal and vertical coordination in water resource and land use management will contribute to more economically vibrant and climate resilient communities in high-altitude cities.

Annex 1: Methodology for Harmonizing the Water and Land Use Data

To develop a dataset that had water and land use data at comparable scales, we worked with EPSAS *recorrido* data, which largely followed the former district boundaries, before they were redrawn in 2010, as well as the zoning boundaries drawn in the USPA (see figures A1 and A2). For some calculations, *recorridos* that fell into multiple zoning designations were removed from the dataset.

Assessing actual density and urbanization requires grouping the *recorridos* into the USPA density zones, and applying multiples to the number of clients per *recorrido* to estimate actual population. On average, EPSAS estimates it serves 5.7 people per client, although the 2001 census established an average household size of 3.5, and the city's planning documents state 4.5. As seen in table A1, our projections establish an estimate of 4–5.5 members per family, slightly larger than the census estimate to account for temporary residents. EPSAS estimates that it reaches about 89 percent of households within its service area, and an estimated 50–60 percent of people beyond its service area; the multiplier accounts for these non-customers.

Unfortunately, EPSAS could not share their data on the percentage of clients or water used by residential, commercial and industrial customers. As a result, there are inaccuracies in this method given that customers include apartment complexes, commercial and industrial clients that do not necessarily translate into a residential population number. To verify the accuracy of such multipliers, we also grouped *recorridos* by pre-2010 district boundaries. As table A2 shows, these 2011 population estimates roughly correspond to the 2007 district population estimates cited in the *Plan de Desarrollo Municipal*.

Table A1. Estimated Population of Districts for 2011

District (2010 district #s)	EPSAS 2011 Clients	2011 Pop. Est. per pre-2010 Districts (EPSAS est.)	2007 Pop. Est. (per PDM)	Notes
1	17,106	104,432	116,132	Boundaries stayed same
2	17,411	106,294	93,521	Same
3 (3, 12)	34,505	236,135	189,382	Was divided in 2010
4	25,245	154,121	129,887	Mostly the same
5	21,212	129,499	128,721	Same
6	18,909	115,439	103,632	Same
7 + 9 (7, 9, 11, 13, 14)	6,107	111,728	34,212	Was divided in 2010
8	22,832	139,389	99,414	Same
10	-	7,904	6,587	2011 population estimate using 20% growth rate (PDM)
Total	**179,695**	**1,097,038**	**904,078**	

Table A2. Estimated Population per Zoning Area Based on Clients per Recorrido

Zoning	Zoned Density per ha	Estimated Density	# of Recorridos / zone	# EPSAS Clients	HH Size	% Access	Multiplier	Pop. estimate
High	350-400	158	8	2,912	4	0.95	1.05	12,261
Med High	300-350	124	22	43,413	5	0.95	1.05	228,489
Med	250-300	114	14	19,300	5.5	0.9	1.11	117,944
Net	200-250	167	8	20,820	5.5	0.9	1.11	127,233
Low	100-200	72	57	56,028	5.5	0.6	1.67	513,590

Figure A1. Map of EPSAS Recorridos Outlined on El Alto's Zoning Map

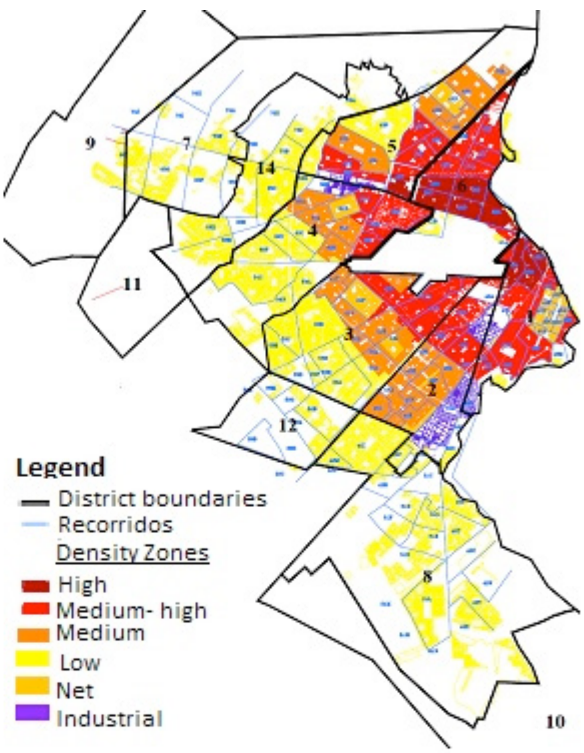
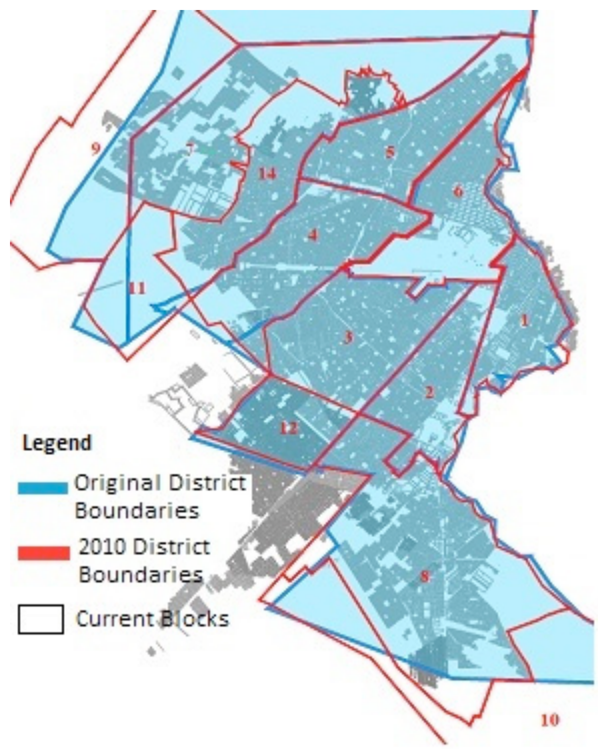


Figure A2. Map of Pre-2010 Borders (blue) and 2010 Redistricting (red)



Annex 2: Climate Change in the Andes

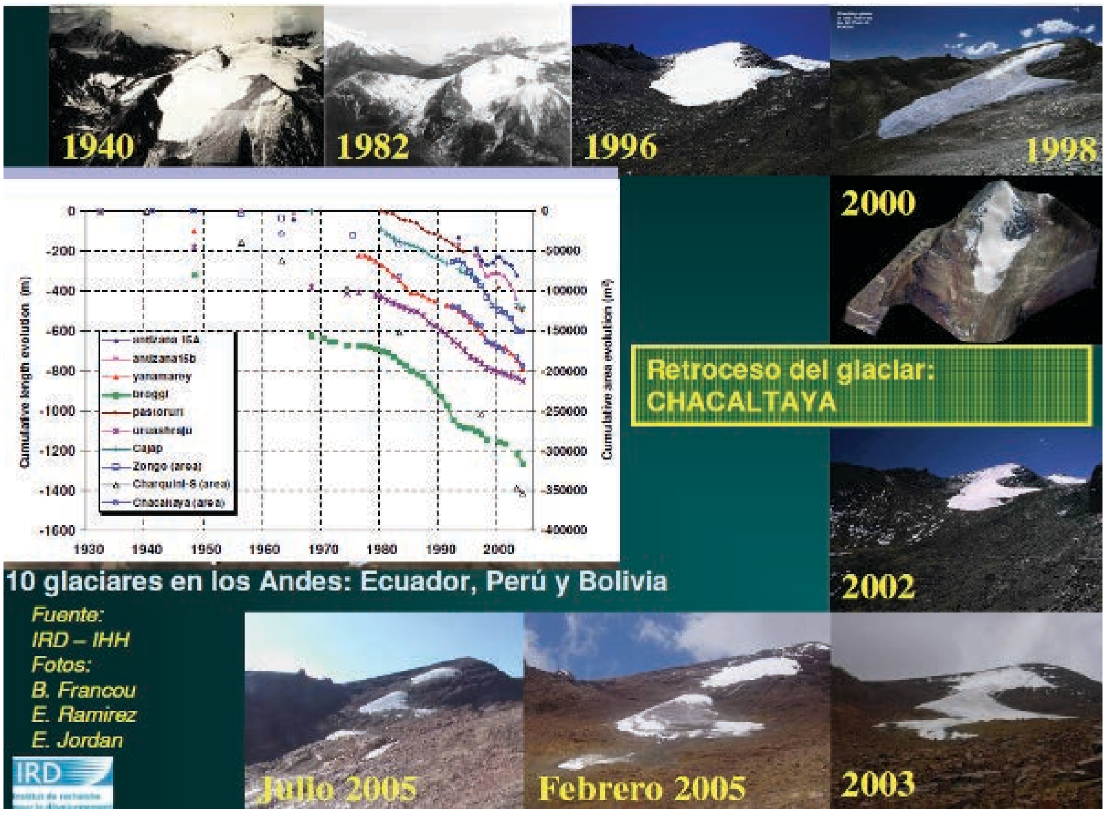
The Andean region contains approximately 95 percent of tropical glaciers in the world, usually found on isolated mountaintops that rise to over 5,000 meters above sea level (Lotze-Campen, 2009). Tropical glaciers tend to be smaller in size and are therefore more sensitive to environmental changes and less likely to accumulate long-lasting seasonal snow cover outside of glaciated areas ((Lotze-Campen, 2009; Vuille et al., 2008). In this region, climate change is already a reality, not a future threat. Over the last 50 to 70 years, the Andean region has experienced a temperature rise between 1°C and 2.2°C (Futuro Latinoamericano, 2008). This warming has coincided with accelerated glacial retreat throughout the Andes (Lotze-Campen, 2009).

Glaciers and mountain water systems also support agricultural activities, power generation and natural ecosystems (World Bank, 2008b). Notably, during the dry season, glaciers almost exclusively account for urban water stocks (Vuille et al., 2008). Given that estimates predict that temperatures will rise by another 3°C to 5°C this century in the region (IPCC, 2007; Vuille et al., 2008), glacial ice melt, as well as declining rainfall, surface runoff and increased evapo-transpiration pose serious concerns for the region's urban and rural water supply.

In the mountains above El Alto and La Paz, temperatures increased by 0.5°C from 1976 to 2006, with the result that from 1983 to 2006, the Tuni-Codoriri Glaciers lost 39 percent of their area, at a rate of 0.24 km^2 per year (PNCC, 2007). El Niño Southern Oscillation (ENSO) strongly affects cycles of drought, flooding and frost in Latin America, and contributes to glacial melting by decreasing rainfall, which leads to lower levels of ice formation, exposing new areas to solar rays and melting temperatures (Ramirez, 2009). The events of El Niño in the 1980s and 1990s are associated with severe drought and devastated crops in Bolivia, as well as rapid glacial melting (fig. A3).

More recently, La Niña has showered above average precipitation throughout Latin America, which particularly affects La Paz, which is drained by over 200 rivers and streams and has seen urbanization expanded onto sleep slopes without stabilization. In the spring of 2011, La Niña caused torrential rains and flooding, leading to severe landslides in La Paz. The landslides destroyed 7 communities, causing 60 deaths and leaving 11,000 people homeless. During the rainy season, El Alto suffers from serious floods due to its flat topography at the base of the mountains, and to the fact that roads were not required to include drainage systems prior to 2006. Drainage that does exist, mostly in the form of roadside ditches, is typically clogged with solid waste. As a result, the major roadways have become by default the channels for directing stormwater, resulting in erosion and flooding. Such events falsely contribute to a public perception that water scarcity is not an imminent threat.

Figure A3. Disappearance of the Chacaltaya Glacier (1940–2005)



Source: Ramirez, 2009

References

Agudelo-Vera, Claudia M., et al. (2011) "Resource Management as a Key Factor for Sustainable Urban Planning." *Journal of Environmental Management*, Vol. 92: 2295–2303.

Andersen, L.E. and R. Mamani P. (2009) "Cambio Climático en Bolivia hasta 2100: Síntesis de Costos y Oportunidades. Economía del Cambio Climático en Bolivia. La Paz.

Andrade, F.M. and B.L. Blacutt. (2010) "Evaluación del Modelo Climático Regional PRECIS para el Área de Bolivia: Comparación con Datos de Superficie." *Revista Boliviana de Física,* 16(16):1–12.

Baldivieso Farfan, Daniela. Personal Communication. Responsable de Bienes Municipales. March 26, 2012.

Barahona Parrado, Nelson. Personal Communication. Jefe de Unidad de Ordenamiento Territorial. March 26, 2012.

Baumann, D. D., J.J. Boland, and W.M. Hanemann. (1998) *Urban Water Demand Management and Planning*. New York: McGraw-Hill.

Berdeja Beltrán, Marcial. Personal Communication. Consultant to the Ministry of Environment on sanitary engineering and national water use efficiency strategies. March 23, 2012.

Burchell, Robert, et al. (1997) "Costs of Sprawl—Revisited." Transit Cooperative Research Program, Federal Transportation Administration.

Calizaya, Andres. Personal Communication. Research Professor at IHH. March 20, 2012.

Calizaya Terceros, A., et al. (2012). "Estrategia para la Concertación y Sostenibilidad del Abastecimiento de Agua para la Ciudad de El Alto." Paper presented at the XXV Latin American Congress on Hydraulics, September 2012.

Cairncross, S. (1987). "The Benefits of Water Supply" in Pickford, J., ed. *Developing World Water.* Grosvenor Press: London.

Cathcart, R.B. and A.A. Bolonkin. (2007) "Lake Titicaca—Physics of an Inherited Hydropower Macroproject Proposal." Available online at: http://arxiv.org/abs/physics/0703182v1.

Colque Tancara, Víctor.Personal Communication. Jefe de la Direccion del Medio Ambiente. March 23, 2012.

Dalhuisen, et al. (2003) "Price and Income Elasticities of Residential Water Demand: a Meta-Analysis." *Land Economics*, 79(2): 292–139.

de Condappa, D., Chaponniere, A., and Lemoalle, J. (2009) "A decision-support tool for water allocation in the Volta Basin". *Water International*, 34, 71–87.

Dodman, D.; Mitlin, D.; and Rayos Co, J.C. (2009) "Victims to Victors, Disasters to Opportunities: Community-Driven Responses to Climate Change in the Philippines." *International Development Planning Review*, 32(1).

Domene, Elena and David Saurí. (2006) "Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona." *Urban Studies*, Vol. 43 (9): 1605–1623.

Dziegielewski, B. and J.C. Kiefer. (2010) "Appropriate Design and Evaluation of Water Use and Conservation Metrics and Benchmarks." *The American Water Works Association Water Conservation Division Subcommittee Report*.

"El Alto registra desempleo critico comparado con ciudades troncales." *El Diario*, March 2011.

"Empresa de agua: En una resolución, la AAPS advierte de un riesgo de colapso y detalla 16 anomalías." *La Razón / La Paz*. December 14, 2012.

EPSAS. (2012) Data on water consumption by recorrido for El Alto and map of recorridos. La Paz.

______. (2012) "Obras y Proyectos." La Paz: EPSAS.

______. (2011) Summary data on annual water production, active connections, and population served. El Alto.

______. (2010) "Memoria Institucional 2010." La Paz: EPSAS.

"EPSAS recibe críticas a su labor y la transición agrava el problema." *La Razón*. February 11, 2008.

Fernandes, Edésio. (2011). "Regularization of Informal Settlements in Latin America." Lincoln Institute for Land Policy Focus Report, Cambridge, MA.

Futuro Latinoamericano. (2008) "Consultation to Assess Regional Priorities, Capabilities and Research Gaps on Climate Change and Poverty Reduction in Latin America and the Caribbean." Report Submitted by Fundación Futuro Latinoamericano to the International Development Research Centre (IDRC) and the Department for International Development of the United Kingdom. Quito.

Gobierno Municipal de El Alto (GAMEA), Bolivia. (2002) *Plan de Ordenamiento Urbano y Territorial—Un Esquema Estructural, Tomo I y II.* El Alto: GAMEA.

______. (2007) *Suma Qamaña: Plan de Desarrollo Municipal, El Alto 2007–2011, Diagnostico Municipal*. El Alto: Dirección de Planificación Coordinación y Seguimiento, Unidad de Planificación Estratégica.

______. (2006) *Plan de Desarrollo Municipal 2006–2010, Marco Estratégico*. El Alto: Gobierno Municipal de El Alto.

______. (1999) *Plan Regulador de la Ciudad de El Alto*. El Alto: Presidencia de la República Comisión Impulsora para Combatir la Pobreza en la Ciudad de El Alto.

______. *Ciudad de El Alto: Reglamento de Uso del Suelo y Patrones de Asentamiento (USPA)*. El Alto.

______. (2011) AutoCad Maps of El Alto. El Alto: Departamento de Catastro.

Gobierno Municipal de La Paz. (2007) *Plan de Desarrollo Municipal de La Paz, 2007–2011, Resumen Ejecutivo.* La Paz: Dirección de Planificación y Control.

Hoellermann, B., Giertz, S., and Diekkruger, B. (2010) "Benin 2025—Balancing future water availability and demand using WEAP System." *Water Resources Management*, doi:10.1007/s11269-010-9622-z.

Instituto de Hidrología y Hidráulica. (2011) "Oferta y Demanda de Agua en la Ciudad de El Alto." Excel Spreadsheet and Charts. La Paz: IHH.

Instituto Nacional de Estadísticas, Bolivia. El Alto Census Factsheet. (undated) La Paz: INE.

______. (2001) Censo Nacional 2001. La Paz: INE.

InterAmerican Development Bank. (2010) "Programa de Drenaje Pluvial en los Municipios La Paz y El Alto, Bolivia: Análisis Ambiental, Informe Final." Washington, DC: IADB.

______. (2007) "Estudio de Ingresos Municipales, País: Bolivia." Washington, DC: IADB.

International Monetary Fund. (2001) "Poverty Reduction Strategy Paper (PRSP) for Bolivia." La Paz: IMF.

Linaweaver, et al. (1967). "A Study of Residential Water Use." Baltimore: Johns Hopkins University for the Federal Housing Administration and Department of Housing and Urban Development.

Loh, M. and P. Coghlan. (2002) "Domestic Water Use Study: Perth, Western Australia 1998–2021." Perth, Western Australia: Water Corporations.

Lordemann, Javier Aliaga, and Tirza J. Aguilar Salas. "The Climate Change Effects on the Agricultural Sector of Bolivia." Instituto de Investigaciones Socio-económicas, Universidad Católica Boliviana San Pablo.

Lotze-Campen, H., et al. (2009) "Glacier Retreat in the Bolivian Andes as a Consequence of Global Climate Change." Potsdam: University of Potsdam.

Maquera, Antonio. Personal Communication. President of FESUCARUSU, union of per-urban workers. March 26, 2012.

Martinez-Espiñeira, R. and C. Nauges. (2004) "Is All Domestic Water Consumption Sensitive to Price Control?" *Applied Economics*, 36: 1679–1703.

Ministerio de Hacienda, Gobierno de Bolivia. (2003) "Ley 1178: Sistema Nacional de Planificación: Normas Básicas." La Paz: Ministerio de Hacienda.

Ministerio de Vivienda y Servicios Básicos, Gobierno de Bolivia. (2005) "Ordenamiento Espacial de los Asentamientos Humanos." La Paz.

______. (1998) "Planificación Urbana Participativa." La Paz: Programa de Apoyo a la Aplicación de Políticas en Asentamientos Humanos.

______. (1998) "Gestión en Obras y Servicios Municipales." La Paz: Programa de Apoyo a la Aplicación de Políticas en Asentamientos Humanos.

______. (1998) "Aspectos Ambientales en el Diseño Urbano." La Paz: Programa de Apoyo a la Aplicación de Políticas en Asentamientos Humanos.

Mukhopadhyay, et al. (2001) "Analysis of Freshwater Consumption Patterns in the Private Residences of Kuwait." *Urban Water*, 3: 53–62.

Painter, J. (2007) "Deglaciation in the Andean Region." In *Human Development Report 2007/2008: Fighting Climate Change: Human Solidarity in a Divided World*. New York: UNDP, Human Development Report Office.

Parry, M.L., et al, eds. (2007) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge, United Kingdom and New York: Cambridge University Press.

Programa Nacional de Cambios Climáticos. (2007). "Deshielo de la Cuenca del Tuni Condoriri y su impacto sobre los recursos hídricos de las ciudades de La Paz y El Alto." Final report of the project. La Paz, Bolivia.

Quezada, David. "La Metrópoli Andina, La Paz-El Alto; Cambio Climático y Justicia Caso Urbano." El Alto: Red Hábitat, 2010.

Ramirez, Edson. (2009) "Cambio Climático, Disponibilidad de Recursos Hídricos y Medidas de Adaptación en Bolivia." Presentation in Buenos Aires, Feb. 2009.

Renwick, M. and S. Archibald. (1998) "Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden?" *Land Economics,* 74(3): 343–359.

Rodriguez, G. Personal Communication. Head of EPSAS operations in El Alto. March 23, 2012.

Rojas, Eduardo. (2008) "Governing the Metropolis: Principles and Cases." Chapter in Rojas, Eduardo, Juan R. Cuadrado-Roura, Jos. Miguel, Fernandez Güell, eds, "The Metropolitan Regions of Latin America: Problems of Governance and Development." Washington DC and Cambridge: Inter-American Development Bank and David Rockefeller Center for Latin American Studies, Harvard University.

Sandoval-Solis S., McKinney D. (2010) "Evaluation of water conservation measures implemented in the Rio Grande/Bravo Basin." In Proceedings World Environmental & Water Resources Congress 2010, doi:10.1061/41114(371)212.

Shaban, Abdul. (2008) "Water Poverty in Urban India: a Study of Major Cities." UGC—Academic Staff College of Jamia Millia Islamia, New Delhi.

Sierra, Katherine. (2011) *Adaptation to Climate Change in Developing Country Urban Deltas: Issues and Approaches.* Cambridge: Lincoln Institute of Land Policy Working Paper.

Smolka, Martim and Larangeira. (Year) "Land: A Scarce Resource—Affordable Urban Land and the Prevention of Informal Settlements," Chapter in Building Cities, Inter-American Development Bank; Cities Alliance; David Rockefeller Center for Latin American Studies**,** Harvard University.

Smolka, Martim, and Ciro Biderman. (2011) "Housing Informality: an Economist's Perspective on Urban Planning." In *Oxford Handbook of Urban Economics and Planning,* Nancy Brooks, Kieran Donaghy, and Gerrit Knaap, eds. New York: Oxford University Press.

Syme, G.J., Q. Shao, M. Po, and E. Campbell. (2004) Predicting and Understanding Home Garden Water Use." *Landscape and Urban Planning,* 68: 121–128.

Thibeault, J. M., A. Seth, and M. Garcia. (2010). "Changing climate in the Bolivian Altiplano: CMIP3 projections for temperature and precipitation extremes." *Journal of Geophysical Research*, 115.

Troy, Patrick, Darren Holloway and Bill Randolph. (2005) "Water Use and the Built Environment: Patterns of Water Consumption in Sydney." City Futures Research Centre, Research Paper No. 1, University of New South Wales.

UCAR. (2007) "RCPM: Regional Climate-Change Projections from Multi-Model Ensembles." Available online at: http://rcpm.ucar.edu.

USAID. (2005) "Estudio sobre el Catastro en Bolivia." Washington DC: USAID.

______. (2004) "Evaluación de la Ciudad de El Alto." El Alto/La Paz: USAID.

Varis, Otto. (2006) "Megacities, Development and Water." *Water Resources Development*, Vol. 22(2): 199–225.

Vasquez, Martha. Personal Communication. Former Representative of Neighborhood FEJUVE. March 26, 2012.

Vuille, Mathias, et al. (2008) "Climate Change and Tropical Andean Glaciers: Past, Present and Future." *Earth-Science Reviews*, 89: 79–96.

WELL. (1998) "Guidance Manual on Water Supply and Sanitation Programmes." WEDC: Loughborough UK.

WHO. (2003) *Domestic Water Quantity, Service, Level and Health.* Geneva: World Health Organization.

World Bank. (2006) "The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries: How the Private Sector Can Help: a Look at Performance-Based Service Contracting." Water Supply and Sanitation Sector Board Discussion Paper Series, Paper No. 8.

World Bank. (2008a) "Climate Change Aspects in Agriculture: Bolivia Country Note." Washington, DC: World Bank.

______. (2008b) "Project Appraisal Document for an Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes Project." Washington, DC: 2008.

Zambrana, Salim Yapur. Personal Communication. IADB Coordinator embedded within the Government of El Also Planning Department. March 26, 2012.

Zotez Araoz, Jorge. Personal Communication. Gerente Tecnico de EPSAS. March 26, 2012.