Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized

Adaptation to Climate Change — Vulnerability Assessment and Economic Aspects

PLURINATIONAL STATE OF

BOLIVIA

EACC Publications and Reports

1. Economics of Adaptation to Climate Change: Synthesis Report
2. Economics of Adaptation to Climate Change: Social Synthesis Report
3. The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates

Country Case Studies:

1. Bangladesh: Economics of Adaptation to Climate Change
2. Bolivia: Adaptation to Climate Change: Vulnerability Assessment and Economic Aspects
3. Ethiopia : Economics of Adaptation to Climate Change
4. Ghana: Economics of Adaptation to Climate Change
5. Mozambique: Economics of Adaptation to Climate Change
6. Samoa: Economics of Adaptation to Climate Change
7. Vietnam: Economics of Adaptation to Climate Change

Discussion Papers:

1. Economics of Adaptation to Extreme Weather Events in Developing Countries
2. The Costs of Adapting to Climate Change for Infrastructure
3. Adaptation of Forests to Climate Change
4. Costs of Agriculture Adaptation to Climate Change
5. Cost of Adapting Fisheries to Climate Change
6. Costs of Adaptation Related to Industrial and Municipal Water Supply and Riverine Flood Protection
7. Economics of Adaptation to Climate Change-Ecosystem Services
8. Modeling the Impact of Climate Change on Global Hydrology and Water Availability
9. Climate Change Scenarios and Climate Data
10. Economics of Coastal Zone Adaptation to Climate Change
11. Costs of Adapting to Climate Change for Human Health in Developing Countries
12. Social Dimensions of Adaptation to Climate Change in Bangladesh
13. Social Dimensions of Adaptation to Climate Change in Bolivia
14. Social Dimensions of Adaptation to Climate Change in Ethiopia
15. Social Dimensions of Adaptation to Climate Change in Ghana
16. Social Dimensions of Adaptation to Climate Change in Mozambique
17. Social Dimensions of Adaptation to Climate Change in Vietnam
18. Participatory Scenario Development Approaches for Identifying Pro-Poor Adaptation Options
19. Participatory Scenario Development Approaches for Pro-Poor Adaptation: Capacity Development Manual

A Pilot Study of the Economics of Adaptation to Climate Change

PLURINATIONAL STATE OF BOLIVIA

THE WORLD BANK

Ministry of Foreign Affairs
Government of the Netherlands

DFID Department for International Development
UNITED KINGDOM

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

1818 H Street, NW
Washington, DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org
E-mail: feedback@worldbank.org

Contents

Acronyms ix
Acknowledgments xi

Executive Summary *xiii*

1. Motivation and Context of the Study *1*
Background 1
Scope and Study Approach 2

2. Background on Bolivia's Economy *5*
The Socioeconomic Context 5
The Institutional Context 6

3. Vulnerability to Climate Variability and Climate Change *11*
Exposure to Extreme Events 12
Coping Strategies and Current Climate Variability 14
Assessment of Climate Change Impacts under Future Uncertainty 18

4. Sector Analysis: Agriculture *21*
Sector Description 21
Impact and Vulnerability to Climate Change of the Agriculture Sector 22
Adaptation Options for Crop Production 27

5. Sector Analysis: Water Resources *33*
Sector Description 33
Vulnerability of Water Resources Infrastructure to Climate Change 35
Adaptation Options: Rural Water Resources 36
Adaptation Options: Irrigation Infrastructure 40
Estimated Costs of Structural Adaptation Measures for Irrigation 42
Water Supply and Sanitation in Urban Areas 46

6. Local-level Perspectives on Adaptation to Climate Change 53
Past Adaptation and Coping Practices 54

7. Cost-benefit Analysis of Adaptation Investment Options 61

8. Methodology Investment Planning Tool (MIP)
for the Selection of Adaptation Options under Future Climate Uncertainty 65
Selection of Robust Strategies 65
Model Analysis 69
How Welfare is Lost 74
How Welfare is Restored 74
The Effect of Discounting 75

9. Overall Conclusions and Lessons Learned 81
Social Dimensions of Climate Change 81
Agriculture 82
Water Resources 84
Investment Planning Tool 87
How to Move Forward? 87

10. Works Cited 90

Annexes (available on line at www.worldbank.org/eacc)

Annexes
Annex 1: Assessment of Climate Change Impact and Adaptation Actions for the Water Resources of Bolivia
Annex 2: Climate Change Impacts and Adaptation Measures Regarding Production of Four Crops of High Importance for the Bolivian Economy (in Spanish)
Annex 3: National Irrigation Program, Mizque Basin, 2004–14-Viceminister of Water Management and Irrigation (in Spanish)
Annex 4: Adaptation to Climate Change for the Water Resources Infrastructure and Irrigation Management (in Spanish)
Annex 5: Social Perspectives of Climate Change and Adaptation in Bolivia (in Spanish)

Figures

1. Average Annual Precipitation in Bolivia 1951-2002 12
2: Most Vulnerable Municipalities Selected by Macro-region 13
3. Small and Poor Countries Financially Vulnerable to Extreme Weather Events 14
4. Annual Percentage Change of Agriculture GDP with the Effect of El Niño and La Niña Years 17
5. Projected Precipitation Changes to 2050 Under Different Climate Scenarios 19
6. Regional Distribution of Four Crop Cultivation 21
7. Estimated Changes in Annual Evapotranspiration Under Three Different Climate Conditions for Ten Weather Stations Up to 2050 24
8. Relative Yield of Quinoa for Three Climate Scenarios and a Scenario with No Precipitation in the Critical Phenological Period (Ratio of Simulated 2050 to Historical Yield) 25
9. Relative Yields of Three Potato Varieties for Three Climate Scenarios and a Scenario with No Precipitation During the Critical Phenological Period (Ratio Simulated 2050 to Historical) 26
10. Relative Soy Yield for Three Climate Scenarios and a Scenario with No Precipitation in the Critical Phenological Period (Ratio Simulated 2050 to Historical Yield) 27
11. Relative Maize Yield for Three Climate Scenarios (Ratio Simulated 2050 to Historical) 27
12. Projected Water Availability Index by 2050: Current, Wet, and Dry Scenarios 34
13. Water Demand by Sector at Year 2000 and 2050 36
14. Adaptation Strategies Aand Measures 43
15. Water Supply vs. Cost—Dams 44
16. Socioeconomic Strata of Local Communities 54
17. Past Responses to Climate Events 54
18. Distribution of Calculated Internal Rates of Return (IRR) on 74 Irrigation Pronar Projects 67
19. Tradeoff Between Social Benefits and Families Affected (Estimated Budget=$6 Million) 70
20. Tradeoff Between Social Benefits and Families Affected (Budget=$4 Million) 70
21. Tradeoff Between Social Benefits and Families Affected (Budget=$2 Million) 71
22. Baseline Scenario (Current Climate in 2090) 72
23. Future Climate in 2090 Under a Dry Scenario 72
24. How Social Welfare is Restored (Centralized Management, 0% Discount Rate) 73
25. Capacity Utilization of Projects 56 and 62 Under Dry Scenario 74
26. Cash Flow of Investment Programs Having Equal Social Benefits (Dry Scenario, 0% Discount Rate) 75
27. Restoring Welfare (Centralized Management, 6% Discount Rate) 76
28. Cash Flow of Investment Programs Having Equal Social Benefits 77
29. Strategic Components for Water Management 85

Tables

Es-1. Cost-Benefit Analysis of Adaptation Measures in the Agriculture and Water Sectors xviii
1. Direct and Indirect Effects of Drought on Local Populations 16
2. Economic Impact of the El Niño Events Since 1983 17
3. Summary of Main Climatic Characteristics of the Bolivia Wet and Dry Scenario 19
4. Vulnerability of Crops to the Main Climatic Stresses, Under Present and Future Conditions 23
5. Adaptation Strategy of the Contorno Calacoto Community 28
6. Economic, Social, and Environmental Costs for the Implementation of Adaptation Options in Four Crops 29
7. Economic, Social and Environmental Benefits for the Implementation of Adaptation Options in Four Crops 29
8. Social and Environmental Viability of Adaptation Options in Four Crops 30
9. Examples of Measures for Best Use of Existing Water Resources 39
10. Examples of Rainwater Harvesting 39
11. Examples of Improvement or Expansion of Existing Systems 40
12. Seasonality in Irrigation Systems (Hectares) 40
13. Summary of Infrastructure Costs 44
14. Changes in Water Supply for Dry and Wet Climate Scenarios of 2050 45
15. Projected Annual Irrigation Water Demand in 2050 45
16. Total Accumulated Deficit of Water for Irrigation 46
17. Total Estimated Costs for Water Infrastructure Needs to 2050 46
18. Adaptation Cost for Climate Change Scenarios 47
19. Key Climate Variables in Relation to the Urban Sector 48
20. Number of Municipalities Studied for the Social Component, by Macro-Region 53
21. Prioritized Adaptation Strategies (Planned and Autonomous) by Community in the Plains Region 56
22. Prioritized Adaptation Measures by Community in the Altiplano Region 57
23. Cost-Benefit Analysis of Adaptation Measures in the Agriculture and Water Resources Sectors 62
24. The Effect of Climate Change on Social Benefits of the Pronar Investment Program in the Mizque Watershed (6% Discount Rate, NPV in $ Millions) 69

Boxes

ES-1. The Mizque Watershed Mixed Integer Programming Investment Model xx
1. Access to International Funds for Adaptation: Pilot Program for Climate Resilience (PPCR) 8
2. Agriculture Insurance 31
3. Rio Los Negros, Bolivia –Beehives and Barbed Wire 38
4. Limitations of the Study 88


BAUTISTA

Acronyms

AAPS	Auditing and Social Control Authority of Water Supply and Sanitation
ANESAPA	National Association of Water Supply and Sanitation Utilities
CAF	Andean Development Corporation
CEPAL	Economic Commission for Latin America and the Caribbean
CRU	Climate Research Unit (University of East Anglia, U.K.)
CSIRO	Commonwealth Scientific and Industrial Research Organization
EACC	Economics of Adaptation to Climate Change
ENSO	El Niño Southern Oscillation
GCM	General Circulation Model
IHH	Institute of Hydraulics and Hydrology
INE	National Institute of Statistics
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
MNACC	National Mechanism for Adaptation to Climate Change
PNC	National Watershed Plan
PNCC	National Program for Climate Change
PNRR	National Rehabilitation and Reconstruction Plan
PNSB	National Basic Sanitation Plan
SENAMHI	National Meteorological and Hydraulics Service
SRES	Special Report on Emissions Scenarios
SWAT	Soil and Water Assessment Tool
UDAPE	Social and Economic Policy Analysis Unit
VIDECICODE	Vice Ministry of Civil Defense and Cooperation for Development
WFP	World Food Program

Note: Unless otherwise noted, all dollars are U.S. dollars.

Acknowledgments

This study was undertaken by a World Bank core team that included Ana Bucher (country coordinator), Carina Bachofen, Robert Schneider, Laurent Cretegny, David Corderi, Morten Blomqvist, and Ruth Llanos. This synthesis report was written and edited by Ana Bucher and Carina Bachofen. The overall EACC study was coordinated by Sergio Margulis (Task Team Leader).

The report draws on the work of many local partners and individuals who prepared separate sector chapters. The agriculture chapter was developed by a team including Dr. Magali García Cárdenas (team leader, Facultad de Agronomia, Universidad Mayor de San Andres (UMSA)), Ing. Jorge Cusicanqui (Facultad de Agronomía, UMSA), Dr. Bruno Condori Alí (Fundación PROINPA), Victoria Parra Goitia (UMSA), Ing. Gladys Tesoro Michel (UMSA), Ing. Claudia Saavedra (UMSA), Dr. Carmen Rosa Del Castillo Gutierrez (UMSA), Ing. Consuelo Luna (UMSA), Ing. Claudia Canedo (UMSA), and Ing. Carlos Cabrera (UMSA). The water resources chapter was prepared by Dr. Victor Vazquez and Ing. Alvaro Lambert. The social studies chapter was prepared by Lic. Miguel Morales. Cost-benefit analysis was written by Dr. Fernando Cossio and Lic. Valeria Sanchez (Institución Internacional de Economía y Empresa, IIDEE). The author of the modeling work for the planning investment tool was Erwin Kalvelagen.

The study team would also like to thank the government of the Plurinational State of Bolivia and in particular, the Vice Ministry of Environment, Biodiversity, and Climate Change, the National Program for Climate Change (PNCC-spanish acronyms), the Vice Ministry of Planning and External Finance (VIPFE), Vice Ministry of Development and Planning (VDP), and Unit for Socioeconomic Policy Analysis (UDAPE-spanish acronyms) for the provision of data, local information, guidance, and support in the development of the report.

The team is grateful to the following people for vital inputs, reviews, and criticisms of the project: Vice Minister of Environment, Biodiversity, and Climate Change Juan Pablo Ramos, Ing. Jaime Villanueva (Director PNCC), Lic. Ivy Beltran (PNCC), Ing. Jose Gutierrez (PNCC), Lic. Daniel Vargas (VDP), Harley Rodriguez (VIPFE), and Lic. Fernando Carrasco (VIPFE). In addition, strong support was provided by the local donor community, which is represented by Mr. Fernando Mendez (British Embassy-DFID), Mr. Eugster Sebastian (Swiss Cooperation-COSUDE), and Mr. Rob van den Boom (The Netherlands Embassy).

The EACC team is extremely grateful to all the members of the World Bank Latin America and Caribbean region and the Bolivia Office for its continued support in the development of the study. In particular, we would like to express our gratitude to Oscar Avalle (Country Manager), Maria Elena Soria, Ruth Llanos, and Morten Blomqvist, for their extensive contributions to the development and review of the report. We could not have completed this work without the continuous logistical support provided by Monica Torrelio, Rosario Monroy, and Monica Claros (Bolivia country office), Hawanty Page (ENV), and Grace Aguilar (ENV).

The report has benefited greatly from peer review comments and other feedback from World Bank staff, including Maximiliam Ashwill (LCSSO), Dilma Flores (ETWAN) Jorge Treviño (LCSAR), and Erwin de Nys (LCSEN), as well as from external peer reviewers, including Joel Smith (Stratus Consulting) and Gordon Hughes (consultant).

Executive Summary

CONTEXT

The Economics of Adaptation to Climate Change (EACC) study estimates that it will cost $75 – $100 billion each year for developing countries to adapt to climate change from 2010 to 2050 (World Bank 2009a). The study —funded by the governments of the Netherlands, United Kingdom, and Switzerland—has two specific objectives. The first is to develop a "global" estimate of adaptation costs to inform the international community's efforts on how to tailor adequate and sustainable support regarding new and additional resources to help vulnerable developing countries meet adaptation costs. The second objective is to support decision makers in developing countries to better evaluate and assess the risks posed by climate change and to better design strategies to adapt to climate change.

The EACC study includes a global track to meet the first study objective and a case study track to meet the second objective. The country track comprises seven countries: Ethiopia, Mozambique, Ghana, Bangladesh, Vietnam, The Plurinational State of Bolivia, and Samoa.

SCOPE AND BACKGROUND

Bolivia—known formally as the *Plurinational State of Bolivia*—faces a complex challenge in its efforts to adapt to climate variability and change. For example:

- The Bolivian population has always been exposed to hydrometeorological extremes and climate variability, particularly because of the influence of the El Niño Southern Oscillation (ENSO), which—regardless of climate change—occurs periodically in different areas across the country.
- Floods, landslides, and droughts, all of which have serious implications for food security and water supply, are common climate-related events.
- Its economic mainstays—mining and hydrocarbon extraction—suggest it is relatively insensitive to climate change, yet most of its people are engaged in small-scale agriculture and are quite vulnerable to changes in climate.
- Climate projections suggest changes in most precipitation patterns with a possible extended dry season, weakened early onset of rains, and more intense rainy seasons. However, variability in precipitation estimates across climate models is still very large and with limited validation with local data.

These characteristics were important factors in the design and development of the study, whose objective was to support existing efforts for the implementation of a national adaptation strategy in the country. For this purpose, the study evaluated a range of adaptation options for two of the most vulnerable sectors in Bolivia: agriculture (crop production of potato, quinoa, soy, and maize) and water (irrigation infrastructure and urban sanitation). In addition, a social component complemented the analysis and shed light on the distributional implications of different adaptation options on poor and vulnerable groups. A new development planning tool and climate change—based on a series of environmental, social and economic inputs— provides a new resource for decision makers to sequence and prioritize identified adaptation options. The study demonstrates the use of the tool by evaluating, at a watershed level, the feasibility and robustness of planned investments under projected climate change scenarios.

The study's authors have engaged and maintained a dialogue with the local government to assure alignment with the local needs and interests. This process meant an expansion of the social vulnerability study, a reduction of the evaluation of adaptation costs and a modification of the scale of analysis for the socioeconomic investment planning tool. Further, although national aggregated costs of adaptation actions were initially defined as one of the study's main objectives, the Bolivian government did not consider these estimates very useful at this time, in part because of existing data limitations and difficulties in capturing the ecological and cultural diversity of the country, thus resulting in too many uncertainties in the quality and aggregation of sector data. The Government's interest focused predominantly on the new knowledge the study generated about adaptation measures in the agriculture, social, and water sectors, as well as on the formulation of development planning tools that integrate adaptation options.

Based on the government's recommendation and adjustment to the Bolivian context, the study provides new insights on models and tools that can help estimate potential climate impacts and the cost of adaptation options. Further, new methodologies are tested and recommendations presented regarding areas where additional research, data, and capacity is needed to enhance adaptation action plans. Finally, the study highlights robust climate actions that could be implemented under any future scenarios despite uncertainties. Given the worldwide political importance of climate change, the findings of this study have great interest and relevance for policy making. The report, therefore, is aimed at a very broad audience, although it is primarily written having policy-makers in mind.

Key conclusions may contribute to the deployment of new methodologies and actions in relation to a climate resilient growth in Bolivia. However, the findings and results of the study do not necessarily reflect the opinion or views of the government of Bolivia and are solely based on scientific results.

BOLIVIA'S VULNERABILITY TO CLIMATE CHANGE

Insufficient national meteorological data and profound differences between different global hydrometeorological models make climate adaptation uncertain. At present, climate science does not provide sufficiently reliable ways of determining whether dry or wet scenarios are more likely, so the fundamental goal of adaptation must be to invest in building resilience to manage risk under a range of possible outcomes. Resilience to weather shocks is a high priority irrespective of climate change.

Within the last few decades, climate analysis from El Niño and La Niña events suggests increasing trends in the occurrence and intensity of these events. In Bolivia, the accumulation of these events within shorter time frames can easily threaten development-as-usual patterns, given the public sector's serious financial limitations. This vulnerability underscores the need for developing adaptation strategies that increase Bolivia's resilience against future climate disasters and promote sustainable development (World Development Report, World Bank 2010). The understanding of local vulnerability can present new information regarding additional costs of adaptation actions and the needs for adequate and sustainable support (from international as well as national sources) to facilitate implementation of robust adaptation interventions and increase climate resilience.

Though Bolivia's overall economy appears to be relatively climate resilient due to the high importance of hydrocarbon and mineral extraction in the economy, a relatively small percentage of the total population is engaged in this sector. A large portion of the country's population is extremely vulnerable to the effects of climate change, as it relies on subsistence agricultural production. Approximately 30 percent of Bolivia's rural population resides in the valleys and high plateau areas, where water availability is already problematic. In addition, these communities have limited means to cover the costs of adaptation. For the majority of the population, the impact of climate change on Bolivia's development and welfare is thus highly uncertain. Under most scenarios, subsistence farmers and other poor households are likely to be most affected by changes in weather variability and water availability associated with climate change. Uncertainty is greatest for the particularly vulnerable rural populations in the Altiplano.

The study considers two extreme climate scenarios in terms of water availability in order to simulate the range of worst-case scenarios, assuming that any possible changes in the Bolivian climate are likely to occur somewhere between these two. The wet scenario for Bolivia forecasts an average temperature increase of 1.55°C and an annual mean precipitation increase of +22 percent, whereas the dry scenario shows a temperature increase of 2.41°C and a decrease in precipitation of -19 percent averaged across the Bolivian territory. Higher temperatures and fewer frosts will probably stimulate agricultural production in the Altiplano and the valleys. The key uncertainties concern the total amount, timing, and intensity of precipitation. If the dry scenarios are correct, then the benefits of higher temperatures will be more than offset by more frequent and severe periods of low rainfall – especially in the southwest, together with an uncertain effect in the north. On the other hand, if the wet scenarios are correct, then agricultural yields should increase throughout much of the country, but this would require upgrades in infrastructure (flood control, water storage, and irrigation) together with improved agricultural practices.

Finally, climate change will not only affect rural areas. Several major cities located in the upper watersheds in the Altiplano and valley regions—such as La Paz-El Alto, Sucre, Potosí and Cochabamba—are significantly vulnerable to climate variability and water scarcity. These cities are highly exposed to decreasing rainfall trends, unexpected changes in seasonality, and prolonged droughts. The case of La Paz-El Alto is particularly alarming due to the melting of the Chacaltaya and Tuni-Condoriri glacier, which will reduce natural water supply, adding more stress to a system where demand has already matched supply. The water supply system of La Paz-El Alto suffered a scarcity alert in the wet season of 2008 that was repeated in the fall of 2009. Emergency measures, such as drilling wells were implemented to be able to meet demand levels in those periods. However, there is no information on groundwater resources and recharging capacity of the aquifers. Water shortages have already incited social conflicts in Cochabamba, Sucre, and Tarija.

POTENTIAL TO ADAPT – STRATEGIES FOR THE WATER AND AGRICULTURE SECTORS

The study in Bolivia primarily looked at the agricultural and water sectors. Even though the focus is mainly economic, political and institutional issues play a central role in understanding and identifying solutions to some of the major adaptation challenges. Without fundamental improvements in the policies and institutions that finance, maintain, and invest in the water and agriculture sectors, additional resources aimed at building resilience are not likely to be effective in the long run. Adaptation in Bolivia must go hand-in-hand with development.

Water management and irrigation

Investment in better water management will enhance the resilience of Bolivian farmers both to systematic changes associated with annual levels of rainfall, as well as greater year-to-year volatility in the rainfall patterns. Improved water management practices are conducive to smart development even in the absence of climate change; thus, this type of no-regrets investment will make sense given the prevailing uncertainty about future climate change. Yet the level and location of investment must take account of ongoing changes in agricultural productivity within the country, so investments are allocated to meet future patterns of production rather than based on historical patterns.

Water storage and harvesting is crucial to increase irrigation coverage in the agricultural sector. Irrigation is the major source of water consumption (84 percent of all water resources) and is supposed to increase in the future due to current agriculture expansion plans. However, the efficiency of traditional irrigation systems is relatively low. While water resources are abundant for the whole country, improving storage efficiency in wet periods to meet irrigation demand in deficit areas—such as the south of the Altiplano and El Chaco—is essential. Improvements in irrigation need to be accompanied by better overall management of water resources, including improved integrated watershed management in deficit watersheds, where resource competition between rural and urban populations is likely to increase.

Under the wet scenarios, there will be an increase in flooding, especially in the valleys and the eastern lowlands. Reforestation, development of systems for flood warnings, and disaster prevention can all reduce the economic and social costs of flooding in lowland areas.

The causes of current urban water shortages in Bolivia, a major social and economic problem, are complex, involving serious problems of institutional instability, under-financing, and poor demand management. Climate change exacerbates this scenario. As discussed in the urban water section, the main adaptation need for rural and peri-urban populations concerns their need for increased access to water and sanitation services.[1] A priority measure will be to extend existing urban networks to the peri-urban areas with no access to water and sanitation services. Rapid growth of these areas needs to be planned in advance to ensure adequate service (qualitative classification of each adaptation measure mentioned above is further described in Annex 1: Climate Change Impacts and Adaptation on Water Resources). The guiding principle to adaptation in the urban areas should be, as for rural areas, to develop at a faster rate and enhance proactive measures such as increased maintenance of infrastructure and less restoration needs. In addition, it would be advisable to consider the integration of "economics aspects of climate change" within new terms of reference for development plans (i.e. modification of the five master plans for urban sanitation in Bolivia). This calls not only for increased investments but also institutional capacity and governance in order to speed up investments based on solid data, investigation, and planning.

Agriculture

The crops analyzed were quinoa, potato, maize and soy. These crops are cultivated from the Altiplano to regions at lower elevations. All four crops, especially maize and potatoes are important sources of

1 See urban water section of Annex 1.

calories in the diet of an average family. Soy is, of course, a major export crop and consequently fundamental to the economy of Santa Cruz, as soy exports accounts for 30 percent of Bolivia's GDP. Analysis of the potential effect of climate change on crop yields revealed mixed results. The study estimates that Bolivia's agriculture sector under a wet climate scenario would benefit significantly from a warmer and wetter climate. Under such a scenario, yields for maize and soybeans, would increase 40 to 45 percent, and potatoes and quinoa yields would increase 60 to 90 percent. However, water availability at the early planting stages remains the key limiting factor. The expected crop yield losses from a drier climate are lower that the gains from a wetter and hotter climate.

On the other hand, the dry scenarios would lead to a reduction in agricultural yields in the Altiplano, the valleys, and the El Chaco regions. The effects of less rainfall and higher evaporation could only be offset by (a) a substantial investment in water storage and irrigation infrastructure, and (b) the adoption of more drought-resistant varieties and crops in the lowlands. Potential losses under a dry climate scenario are projected to be approximately 25 percent for maize and 10–15 percent for soybeans, potatoes, and quinoa. These results are driven by the agricultural benefits of a warmer, more frost-free climate. They suggest that rapid and timely implementation of irrigation (at least at the initial phases of crop development) would be even more attractive under a scenario of warmer climate. In both a wet and dry climate scenario, access to irrigation is a key adaptation intervention to reduce the vulnerability to the increased climate variability, including a shorter rainy season, droughts, and expected dry spells during the rainy season.

Another important area of adaptation concerns the combination of agricultural R&D and implementation and transfer of new technologies—particularly the development of new crops and varieties as well as the validation of improved methods of growing existing crops—with agricultural extension and education to disseminate and facilitate the adoption of new technologies. Again, a substantial commitment to agricultural R&D and extension would form an important component of any development strategy focusing on the needs of rural communities without any consideration of climate change. The key requirement may be to ensure that the focus of R&D and extension is on reinforcing the capacity of farmers to respond to climate variability in the short and longer term, as well as to be prepared for the requirements of climate conditions in 2050, rather than those of 2000.

ECONOMIC ASPECTS OF ADAPTING TO CLIMATE CHANGE

Based on the identified needs in the agricultural and water sector to improve access to irrigation and decrease water shortage as key adaptation interventions, three different economic assessments were made regarding the costs, benefits and sequencing of alternative adaptation measures at different levels.

The first exercise assessed the robustness of planning investments in the water sector by evaluating costs and benefits of Government selected projects that reflect types of adaptation measures for agriculture and water resources previously identified under the National Adaptation Plan for Bolivia. Projects were selected primarily based on the availability of data and regional distribution. Water projects included water supply and water management, and the agricultural consisted primarily of irrigation projects. The analysis was made in terms of financial (market) values and in socio-economic terms (shadow prices), and integrated climate change variables (temperature and precipitation) under a dry (worst case) and a no change climate scenario in 2050.[2] The objective was not to evaluate the projects themselves, but rather their

2 A wet scenario was not available at the time of the analysis

TABLE ES-1 COST-BENEFIT ANALYSIS OF ADAPTATION MEASURES IN THE AGRICULTURE AND WATER SECTORS

Project	*Investment Costs (000)*	*Beneficiaries*	*NPV[1] (000)*	*IRR (%)*	*NPV[1] (000)*	*IRR (%)*
			Baseline		*Dry scenario*	
WATER						
Distribution in Sapecho	3,440	2,199 persons	3,428	24	3,331	24
Potable water S.P. Cogotay	408	140 persons	8	13	3	13
Well drills Chapicollo	317	50 families	187	17	151	17
Flood Control Caranavi	4,052	528 houses	2,658	22	2,658	22
AGRICULTURE						
Irrigation dam S.P.Aiquile	11,476	147 ha	2,583	16	4,195	18
Dam restoration Tacagua	313,623	907 ha	(184,275)	3	(171,580)	3
Wall elevation Tacagua dam	120,457	907 ha	9,705	14	21,563	16
Irrigation B.Retiro S Paraisito	3,686	178 ha	17,260	71	14,874	63
Catchment Atajados/Aiquile	1,951	32 ha	115	14	347	16

1 NPV = Net present value
Note: parenthesis values indicate a negative NPV, suggesting that the dam restoration project is not economically feasible in this location.

economic feasibility and robustness as appropriate adaptation measures to climate variability in Bolivia (Table ES-1).

Under a dry scenario, the results suggest that the Altiplano will be favored by increased temperatures, while the oriental and Chaco zones will be negatively affected by increased temperatures and reduced precipitation. These results are in accordance with the spatial distribution of the projects where, depending on the area, the Internal Rate of Return (IRR) is reduced due to these regional impacts. The agriculture projects show a slight increase of the IRR under the climate change scenario in the highland zones (except the B.R. Paraisito project). This suggests that current planned investment in agriculture and water resources continue to be robust to climate change at least under extreme conditions. Thus, current adaptation measures in Bolivia represent primarily good development strategies under climate variability.

The cost benefit analysis illustrates the use of an economic tool for the evaluation of robustness of investment projects under a changing climate. However, the selection of projects is limited to rural areas due to data availability at the time of this analysis. It excludes the larger infrastructure projects in urban areas as these projects are usually excluded from national budgets and mostly financed by international cooperation.

The second exercise considered the possible effect of climate change on a planned long-term irrigation program at the watershed level (National Watershed Program—the Spanish acronym is PNC). The exercise evaluated the cost of providing the required level of additional water storage infrastructure to meet PNC's planned irrigation expansion to 2011 and estimated up to 2050. This was based on an analysis of water deficit and water surplus months, and therefore the necessity and potential to reallocate additional water through storage under a wet and a dry extreme climate scenario. **The estimated cost of the additional water storage required to match future monthly water deficits due to climate change, would be of additional $12 million to the projected baseline (no climate change) of irrigation needs by 2050 under the wet climate**

scenario, and an additional $60 million under the dry climate scenario.

The third exercise explored the effect of climate change on PNC's planned investment program for the Mizque watershed through the application of a mixed integer mathematical programming model (MIP). The Mizque watershed PNC study investigated climate change, climate uncertainty, and decentralization budget policy on the potential benefits of the PMIC-Mizque. This is a watershed that has been identified as being particularly susceptible to climate effects by impact analysis.

Within the assessment, allowing for climate change impacts appears to modify the original development plan and implies a significant reduction in the return on the program under at least one scenario. The investment model tool identified the most vulnerable population, and how to restore watershed-level benefits to their baseline levels through accelerated investment. However, ensuring that additional watershed benefits reach those suffering directly from water shortages is more difficult. This type of planning model permits a detailed comparison of investment alternatives and the potential effect of climate change on them—and it does so within a planning framework that is consistent over time. The approach also facilitates investigation of the robustness of alternative investment strategies to possible climate outcomes, something that is particularly important in view of the uncertainty over possible climate outcomes (Box ES-1).

Lastly, it is important to note that the original intent was to use the Bolivia study to do a much more ambitious exercise—to use the same mathematical modeling to identify the economically optimal timing of different adaptation projects, in different sectors, all competing for resources from a constrained budget. As this more ambitious exercise started, the team immediately was confronted with an immense requirement for data, including the costs of a range of projects, and this proved unfeasible. The challenge to use similar approaches to determine the optimal timing of adaptation projects in all sector remains.

LOCAL-LEVEL PERSPECTIVES ON ADAPTATION TO CLIMATE CHANGE

The populations most vulnerable to climate change are the poorest, who generally reside in dry zones (central and southern Altiplano, valleys and plains), and along riverbeds in lowland areas. Their livelihoods are based on rainfed agriculture, extensive livestock farming, forest harvesting, hunting, and fishing. The livelihood of these local communities depends on the climate. They have few alternatives to diversify their income, and no economic resources to invest in adaptation preventive actions and infrastructure. Results from the social component reveals that communities perceive the climate is getting hotter, the weather is more unpredictable, and almost everyone emphasizes that rainy seasons are shorter than previous decades. In other words, the communities did not see climate change as a future scenario but as already occurring.

Rural and indigenous communities have a long and rich history of systematic observation of the climate; indeed, their survival depends on this capacity. Climate change and increasing climate variability mean that many of the climatic indicators (i.e. shift in crop calendars) used by these communities are becoming less effective, so that people are in need of new indicators (access to historical climate trends and projections) to diagnose and predict future variability.

The social component of the EACC Bolivia study aimed to (a) identify how the impacts of climate change will affect the poorest and most vulnerable populations in Bolivia; (b) better understand how the most vulnerable communities perceive climate change and what, in their view, would be the most appropriate adaptation measures to strengthen the resilience of these populations; and (c) understand what types of public policies

BOX ES-1 THE MIZQUE WATERSHED MIXED INTEGER PROGRAMMING INVESTMENT MODEL

Through the application of a mixed integer mathematical programming model (MIP), the Mizque watershed study evaluates the effect of climate change on the government's potential investment program as identified by the PMIC-Mizque study. Seventy-four investment projects in 22 sub-basins were considered, each having an initial investment cost-- Operation & Maintenance assumed at 1 percent per year of initial investment-- and net farmer revenue based on sub-basin cropping patterns. New projects and rehabilitation of existing projects compete for budgetary resources, each requiring a quantity of irrigation water determined by the cropping pattern. Existing projects include competing needs between irrigation projects, potable water, and livestock. Available water is adjusted for climate change under three scenarios: a baseline scenario that maps out current climate and water availability, a "dry" scenario, and a "wet" scenario. In optimizing the sequencing of investment through time, projects can be built or rehabilitated any time up to 2050. Projects can also be built and not used to full capacity if, for example, water becomes constraining toward the end of the 40-year investment horizon.

This study is now available for government's use and adaptation to other circumstances. Importantly, the study methodology is completely transparent and is a straightforward extension of the work already undertaken by government and donors. The model permits analysis of the effect of (a) discount rates (or benefit/cost cut-off rates); (b) centralized vs decentralized budget management, and (c) climate change. In its current form, the model exercise can investigate either maximizing net social benefits or the number of families benefited. The main findings of the model are:

- **Effect of climate change effect on the investment plan.** Relative to the current climate, the effect of a "dry" future climate scenario would be to reduce the potential social benefits of the PMIC-Mizque irrigation program by 3–5 percent. The effect of the "wet" future scenario would be to increase benefits by 1–3 percent, as more water would be available for irrigation. These results vary somewhat at different levels of the budget constraint and between a decentralized versus a centralized management policy.

- **Effect of decentralized budget management effect on investment plan.** In the Mizque watershed, decentralized budgets to the sub-basin level could reduce potential benefits significantly if no overall coordination and planning is established at the watershed level. This is the case whether the objective of the model is to maximize national social benefits or to maximize the number of families benefiting. The MIP model estimates that decentralized budgeting reduces social benefits and/or the number of families directly benefiting from the projects by between 2 percent and 30 percent. Under a tight budget and a policy to maximize employment (instead of maximizing social benefits), decentralized management within sub-watersheds reduces the number of families receiving irrigation by nearly 20 percent. In the budgetary decentralized modeled scenarios, per capita investment was held constant across sub-watersheds and the model picked the best projects in each sub-watershed. In the centralized scenarios, the best projects were chosen regardless of where they were located in the watershed. Imposing a cost-benefit limit on projects significantly reduced the difference between the centralized and decentralized simulations. Coordination among decentralized and centralized budgetary policies is needed to ensure best use of resources and diminish potential competition for water resources.

- **Effect of uncertainty of climate change effect on investment plan.** This study found that most of the potential irrigation investment in the Mizque river watershed is robust to most climate outcomes, and that farther downstream in the watershed annual rainfall would remain sufficient for nearly all the irrigation projects identified in the PMIC-Mizque study, assuming sufficient storage was built as part of the program.

and political process would be best-suited to support preferred adaptation strategies.

Communities in the Altiplano and valleys gave priority to adaptation measures related to water management, followed by improved agricultural and livestock practices. They view drought as the principle threat to their livelihoods. In contrast, communities from the Chaco and plains regions asserted that improved agricultural practices were a priority, and considered water management measures to be of secondary importance.

Complementary investments in both hard (new infrastructure) and soft (safety nets, capacity building, knowledge sharing) adaptation options will be vital to meet the needs of the most vulnerable. Improving extension services and increasing access to markets, for example, will be needed to complement the development of hard adaptation measures such as the construction of infrastructure. Although soft adaptation measures require significant investments up front, they offer more socially and environmentally sustainable benefits in the longer term. Also, given Bolivia's rich cultural diversity it will be important to combine traditional adaptation knowledge with new methods to identify priorities. Local authorities tend to favor investment in discrete, hard measures, while community members tend to favor more comprehensive strategies that support more profound changes to livelihood systems threatened by climate change. Planning across scales of governance, respecting existing community decision-making structures, and aligning interests to ensure policy cohesion will be necessary for effective adaptation, particularly given Bolivia's unique system of decentralization.

RECOMMENDATIONS FOR AN ACTION AGENDA

The following recommendations are the outcome of a learning process during the development of the study, as well as part of the final conclusions from the specific models and sectoral research.

The study has emphasized the need to accelerate the development agenda, as in most cases, good development policies are the most robust adaptation policies.

- *Selected adaptation strategies and actions should be robust under both wet and dry conditions.* In particular, expanded water storage, watershed management in increasingly dry areas, and improved access to irrigation have been highlighted as key adaptation options that increase resilience to current and future climate variability and trends.

- *Strengthen integrated rural water management and improve water storage capacity.* Strong integrated management at the watershed level is needed to allow for increased water storage capacity (including building of new infrastructure) and avoid conflicts over competing needs. Current storage infrastructure needs to be revised, upgraded, and increased. Water storage and harvesting is necessary to increase irrigation coverage in the agricultural sector.

- *Improve urban water sanitation and water supply,* including fundamental improvements in the institutions that finance, maintains, and invest in water supply to effectively adapt to the fluctuating changes in supply and demand of resources due to climate variability.

- *Improve access to irrigation.* Under both wet and dry climate scenarios, improved access to irrigation is essential to manage shorter rainy seasons, droughts, and expected dry spells. Even in the more optimistic scenario of future wetter conditions, agricultural productivity can only increase if the capacity to store and use the needed additional water is available for farmers during critical growing periods. Increased research and use of new technology is crucial to ensure climate resilience in agricultural production for both subsistence farming and cash crop production. Higher temperatures can improve agricultural production if water concerns are addressed.

Strengthen people-centered development and carefully consider the distributional implications of policy actions.

- *Devote increased financial resources to promote resiliency and the fast implementation of selected soft and hard adaptation actions* that are carefully ordered, prioritized across time, and integrated into development planning.

- *Incorporate existing local perspectives and experience in dealing with climate issues and locally specific development practices.* Processes that underpin the development of adaptation policies should respect existing community practices, which guide the prioritization of investments. Combining traditional knowledge with new methods and technology is essential. Past coping strategies and adaptation practices to climate variability and extreme events hold valuable lessons for future adaptation planning.

- *Strengthen people-centered development.* The study identified that the most vulnerable groups are the poorest of the poor, who do not have reserves or production capital for investment in adaptation processes. These individuals generally reside in relatively dry zones—such as central and southern Altiplano, the valleys, and the Chaco,—where the poorest groups often depend on rainfed agriculture. Families that reside along riverbeds in lowland areas also are vulnerable to flooding.

Institutional capacity should be improved to accelerate implementation and clear identification of responsibilities.

- *Improve implementing capacity of key institutions.* In order to scale up implementation of climate-robust development activities—such as water storage, irrigation, research, and climate modeling—it will be important to improve the implementing capacity of identified government institutions.

- *Identify and divide clear responsibilities among institutions.* New legislation should identify clear responsibilities and roles among different institutions.

- *Improved coordination and dialogue among national, departmental, and municipal governments.* Improved coordination among different levels of government is crucial in order to optimize limited economic resources and make water storage investments sustainable.

Over the long term, protect the most vulnerable populations and strengthen disaster risk management practices.

- *In the period until 2050 and beyond, ensure that the most vulnerable populations are protected* from the current and (more extreme) future climate risks and water shortages, and that the needed institutional and infrastructure conditions are in place to support these people and to make the agricultural sector more climate resilient. By 2050, the country is expected to have a much higher level of infrastructure and physical assets increasing its potential vulnerability, but at the same time will likely have a much greater capacity to deal with climate shocks. Transfer and access to different technologies to improve resiliency to climate change is important for vulnerable populations.

- *Disaster risk management practices must be part of long-term development planning.* The focus should be on preventive actions. Disaster risk reduction needs to be part of long-term planning at all levels of government, across all industries, and particularly at the departmental and municipal level. This also includes improvements in disaster preparedness capacity.

New methodologies and improved data availability and analysis are important

to improve the basis for climate-robust decisions.

- *Considerable gaps in the hydrometeorological data increase uncertainties in climate models and lacks in the implementation of specific adaptation actions.* The study has identified many data gaps that should be improved, but also succeeded in collecting and systematizing hydrometeorological data that can be useful in future adaptation strategies and actions.

- *New flexible methodologies are needed to integrate climate change into national and regional planning.* The study has provided and tested several models and methodologies at different scales of analysis (i.e. macro and micro watershed level, department level, etc), which can serve as inspiration to integrate climate change in overall development strategies. The development of indicators of climate change vulnerability at the river basin level and for urban areas are examples of new components available to support further analysis as improved climate projections become available for Bolivia.

STUDY LIMITATIONS

This study should be valued for the contributions it makes from the methodological point of view, rather than the numerical results it offers under each specific sector. Data sources used are still limited and the level of accuracy is low within all sectors. The results in each sector analyzed should not be taken as absolute true, but rather as clues to deepen the level of analysis in the areas revealed as critical by this analysis.

The integration and flow of sector analysis data within different components was limited due to different timeframes allocated for the collection of baseline data and the analysis by local consultants. For example, the Social component originally intended to use inputs from the water and agriculture sector to inform workshop discussions and help draw links between different sectors. However, timing of the study resulted in the sector analyses to be conducted in parallel which led to difficulties for integrating the social study components overall.

The water resource analysis does not extend to all the water sub-sectors. That is, it does not analyze water for hydro-power generation, water for navigation purposes and neither water quality or transboundary issues. The analysis on future changes in water available, only takes into account the effect on climate change on the natural supply of water, assuming that future changes in the demand respond only to development and growth. Population and growth projections were estimated based on national statistics data (constant trend up to 2050).

All of these gaps may be closed as more reliable and accurate data is available, both from a temporal and geographic perspective. The report is by no means comprehensive and there are several limitations to the outcomes. The study should thus be considered a first step toward an integrated analysis that identifies areas and populations most vulnerable to climate change effects and evaluates robust adaptation practices to be implemented up to 2050.

ONE

Motivation and Context for Study

The Economics of Adaptation to Climate Change (EACC) study estimates that it will cost $75 — $100 billion each year for developing countries to adapt to climate change from 2010 to 2050 (World Bank 2009a). The study—funded by the governments of the Netherlands, United Kingdom, and Switzerland—has two specific objectives. The first is to develop a "global" estimate of adaptation costs to inform the international community's efforts on how to tailor adequate and sustainable support regarding new and additional resources to help vulnerable developing countries meet adaptation costs. The second objective is to support decision makers in developing countries to better evaluate and assess the risks posed by climate change and to better design strategies to adapt to climate change. This objective comprised the identification of adaptation options that incorporate strategies dealing with high uncertainty, potentially high future damages, and competing needs for investments in social and economic development up to 2050.

The EACC study includes a global track to meet the first study objective and a case study track to meet the second objective. The country track comprises seven countries: Ethiopia, Mozambique, Ghana, Bangladesh, Vietnam, Bolivia and Samoa. Under the global track, adaptation costs for all developing countries are estimated by major economic sectors using country-level data sets that have global coverage. Sectors covered are agriculture, forestry, fisheries, infrastructure, water resources, coastal zones, health, and ecosystem services. Cost implications of changes in the frequency of extreme weather events are also considered, including the implications for social protection programs. Under the country track, impacts of climate change and adaptation costs are being established by sector, but only for the major economic sectors in each case study country. In contrast to the global analysis, vulnerability assessments and participatory scenario workshops are being used to highlight the impact of climate change on vulnerable groups and to identify adaptation strategies that can benefit these groups from a bottom up and top-down approach.

Background

The purpose of this study was to assist the government of the Plurinational State of Bolivia (hereafter referred to as Bolivia) in their efforts to evaluate the potential economic impacts of climate change and to support their efforts to develop robust climate policies and investments in response to these potential impacts. The focus of the Bolivia case study was defined through an ongoing dialogue with the relevant government

institutions in Bolivia to ensure coverage of local priorities, needs and overall country buy-in. The government's interest resided predominantly in the *new knowledge* that would be generated about adaptation measures in the agriculture, social and water sectors, as well as in the formulation of *adaptation planning tools* to help evaluate, sequence, and prioritize adaptation options. Consequently, the Bolivian government did not consider the estimation of adaptation costs at a national or sector level useful at this time, due to the many uncertainties in the quality and aggregation of local data as well as the limitations inherent in a sector-specific approach. The dialogue process meant an expansion of the social vulnerability study, a reduction in the evaluation of adaptation costs and a modification in the scale of analysis for the socioeconomic investment planning tool. Consequently, the study approach for Bolivia differs substantially from other EACC pilot countries.

Scope and Study Approach

The study evaluated a range of adaptation options for two sectors: agriculture (production of crops) and water (irrigation infrastructure and urban sanitation). The agriculture component evaluated crop production under different climate scenarios and identified robust adaptation options for four major crop systems. The water sector focused in the evaluation of irrigation in rural areas and general aspects of urban needs under different climate scenarios. Identified options were contrasted with options previously identified by the National Program of Climate Change (PNCC).

The study was designed to improve knowledge on the economics of adaptation, presenting economic aspects of different adaptation options as potential development resources under a changing climate. The focus of the work was on government-led, or planned adaptation, including:

public infrastructure investments, agricultural research and extension services, community-based disaster preparedness, and implementation of regulations that enable private adaptation to help the vulnerable cope when planned adaptation measures are insufficient. A cost benefit analysis to assess robustness was performed on stylized adaptation options previously identified by the National Mechanism of Adaptation to Climate Change (PNCC, 2007) for the Agriculture and Water Resource sectors. The adaptation options identified in the National Adaptation Mechanism were validated and/or improved by each sector when contrasted with new climate change impact and vulnerability analysis for the agriculture (crop production) and the water infrastructure sectors (water storage and irrigation needs). As the great majority of adaptation options identified by the water, agriculture, and social components converged on the need of more efficient water management, most of the analysis were based on water infrastructure needs to meet new and additional demands.

A new development planning tool, based on socioeconomic analysis, was developed to improve development plans for water consumption at a vulnerable watershed level under projected climate change. The tool was developed to aid policymakers to sequence and prioritize identified adaptation options. Finally, a social component complemented the analysis and shed some light on the distributional implications of different adaptation options on poor and vulnerable groups.

The report is organized into eight sections. Section 1 provides a short context and motivation of the study. Section 2 provides selective background information on the Bolivian economy and its climate vulnerability. Sector 3 outlines country historical and current vulnerability to climate variability. Section 4 and 5 outline the sector modeling work in the agriculture and water resource sectors, respectively, and evaluate and identify robust adaptation options in relation to current and future vulnerabilities to climate change. Section 6 addresses the view and needs of the most vulnerable communities to climate change and contrast sector adaptation strategies to current climate variability and potential changes. Section 7 describes the development of a cost and benefit methodology for the evaluation of adaptation options by integrating climate change into its estimates. The analysis of stylized planned adaptation options identified by the government is used to exemplify the methodology. Section 8 details the application of a development modeling tool at a watershed level to characterize the sequencing and prioritization of adaptation options. Finally, section 9 draws tentative conclusions and recommended actions based on all preliminary findings. Main limitations of the study are summarized in Box 3.

TWO

Background on Bolivia's Economy

The Socioeconomic Context

Bolivia is a large country that encompasses several distinct climate zones. It has a modest population of approximately 10.4 million people and an annual growth rate of 3.4 percent (INE, 2007).[3] Within this vast territory, population density hovers at an average of 10 people per square kilometer – the lowest in the American continent – with around 40 percent of the population living in rural areas. By 2050, population is expected to grow to 15 million (EACC global report estimates).

According to the 2002 census, nearly two thirds of the population live in conditions of poverty and an estimated one third live in extreme poverty. Approximately 30 percent of Bolivia's rural population resides in the valleys and high plateau areas, where water availability is significantly less than the country average[4] and poverty levels are highest. The share of the population living in urban areas is expected to grow to 82 percent by 2050.[5] In addition, Bolivia has one of the largest indigenous population in South America; with 36 ethnic groups it is one of the few countries in the world where the majority of the population identify themselves as indigenous. Annual GDP is $1,363 per capita (INE, 2007) making Bolivia one of the poorest countries in South America. The share of agriculture in GDP was about 14 percent in 2005 (INE, 2005); based on historical development trends, this is likely to fall in the range 6-8 percent by 2050. According to the 2002 census about 65 percent of the population fell below the national poverty line including about 84 percent of the rural population. These high levels of poverty are associated with a very unequal distribution of income.

Bolivia's economy is relatively insensitive to changes in climate. The economy is based on mineral and hydrocarbon extraction and a strong soybean economy in the Eastern Lowland; according to most climate projections, this economy is expected to suffer relatively little from climate change. The industrial sector is small, and most internal demand is satisfied through imports. Nonetheless, *a large portion of Bolivia's population is extremely vulnerable to the effects of climate change as these people rely on agricultural production for subsistence.* For this segment of the population adaptation to climate change must be an essential component of any strategy for poverty alleviation and the enhancement of economic opportunities.

3 National Institute of Statistics (INE) and Ministry of Economy and Public Finance, Fiscal Analysis Framework (RAF).

4 See table 3, Water Resources Annex for data on water available per capita per sub-basin

5 EACC Global report , 2009

The Institutional Context

BOLIVIA'S DECENTRALIZED GOVERNANCE STRUCTURE

Recent changes to the Constitution establish indigenous and regional autonomy within departmental limits.[6] Indigenous autonomies will thus enjoy exclusive rights over territorial management and development of their farming and livestock sector; territorial autonomies will have rights over their territories. These structural changes aim to provide space for greater social and political inclusion for indigenous and peasant groups and establish a framework for a more decentralized government structure that is more responsive to Bolivia's cultural diversity. It is possible that once regional and indigenous autonomies are formed, they will follow the participatory planning structure already established at the municipal level, whereby investments are identified and prioritized in community and municipal workshops in which civil society directly makes decisions. However, according to the National Program for Climate Change, climate adaptation strategies will probably be implemented only at the local level when perceived relevant by local institutions and civil society. It is therefore important to also ensure coordination among different adaptation plans to improve implementation of actions at all levels (PNCC, 2002).

In 1994, the Bolivian Government passed a new decentralization law (Law 1551). The law is known as *Law of Popular Participation* and aims to: move decision-making process closer to the local population, enhance local participation, and ensure a more cost-efficient delivery of services by decentralization of financial resources to the municipalities. The decentralization policy should be able to enhance transparency and provide access to public finances by the local communities. However, lack of efficiency, technical capacity, and poor financial administration presents a challenge for many municipalities, which has resulted in low rates of implementation.

Enhanced coordination will be a key issue to implement coherent and efficient climate adaptation strategies and actions. This is also underscored in the results of the investment planning tool (section 8). The significant fiscal resources administrated autonomously by departmental and municipal governments might make it complex to implement regional projects across political boundaries and ensure financial contributions to such projects.

It will therefore be important in the development of national and regional climate adaption strategies to inform and capacity build local governments as well as ensure their participation in elaboration of strategies and actions.

CURRENT ADAPTATION AND DEVELOPMENT INITIATIVES

The formulation of national climate change policy currently falls under the realm of the Ministry of Environment and Water. Within this ministry, the institutions most closely related to climate change are the Vice Ministry of Water Resources and Irrigation and the Vice Ministry of Environment, Biodiversity, Climate Change and Forestry Management and Development. The National Program for Climate Change (PNCC–in Spanish), housed in the Vice Ministry of Environment, Biodiversity and Climate Change, is the body directly responsible for designing and implementing mitigation and adaptation actions across sectors.

In the past years, the PNCC has developed a *National Mechanism of Adaptation to Climate Change (2007)*. This mechanism is both a long-term strategy aimed at promoting national development

6 As such, indigenous autonomies will enjoy exclusive rights over territorial management and development of their farming and livestock sector; territorial autonomies will have rights over their territories.

as well as a tool to develop a cross-cutting structural response to climate change adaptation. The mechanism consists of a set of adaptation programs in five sectors: food security; sanitation; water resources; ecosystems; and human settlements and risk management. In addition, the mechanism addresses three cross-sectoral areas relevant to climate change adaptation: scientific investigation, education (research and capacity building), and anthropologic and ancestral knowledge as related to climate change. The mechanism links directly to the *National Development Program 2006-2010,* which aims to guarantee adequate and early response to the impacts of climate change across a range of sectors. More specifically, it proposes implementation strategies that generally promote inter-institutional activity consistent with the National Development Program's institutional framework. However, implementation of the National Mechanism has been quite slow.

A new *National Development Plan 2010-2015* is being developed that includes additional measures to protect the agricultural sector from climate-related damages. As part of incentive policies for production and food security and sovereignty, the Bolivian government proposes to implement a range of tools and mechanisms to improve access, achieve financial stabilization,

BOX 1 ACCESS TO INTERNATIONAL FUNDS FOR ADAPTATION: PILOT PROGRAM FOR CLIMATE RESILIENCE (PPCR)

Bolivia has recently confirmed participation in the Pilot Program for Climate Resilience, a program developed under the Climate Investment Funds. The PPCR is a country-led initiative that seeks to (a) strengthen capacities to integrate climate resilience into national and sectoral development plans; (b) foster development strategies that take into account climate resilience; (c) raise awareness among public, private, and civil society actors on the potential impacts and vulnerabilities posed by climate change; (d) help scale up climate-resilient investments; and (e) improve coordination between key actors in implementing climate-resilient programs. The EACC study, in collaboration with complementary ongoing World Bank initiatives, could be used to fill some of the knowledge gaps required for Phase 1 of the PPCR. Phase 2 of the PPCR may provide additional financial resources to help fund basic public and private sector investments—identified by the country in their climate-resilient development plans—developed during Phase 1 investments.

and support sustained agricultural productivity. Moreover, the plan aims to reduce risks associated with the production and marketing of agricultural products. The first climate change adaptation strategy at the municipal level (six municipalities in the Lake Titicaca) was also issued in 2007. The strategy identified the following priority action areas: territorial planning, water security, climate-proofing of productive systems, and capacity building and training as related to adaptation.

INSTITUTIONAL CHALLENGES TO INTEGRATING ADAPTATION INTO DEVELOPMENT PLANNING

Current adaptation practices disproportionately focus on post-event emergency action than on prevention. With limited human and financial resources, it may be inevitable that the pressure to respond to an immediate crisis overwhelms good intentions to prepare and implement longer term programs to limit the damage caused by future events. Nonetheless, a shift in focus is essential to enhance linkages between the National Mechanism's different sector programs. This includes the greater integration of the water resource management strategy and disaster risk prevention of meteorological events under sector programs for food security and human settlements. At a minimum, it should be possible to ensure that any reconstruction after current or future extreme events should be based on explicit assumptions about the frequency of recurrence of similar or worse events in the next 10, 20, or 50 years.

An improved understanding of climate change is needed to improve coordination and cooperation. Access to climate information, historical trends and potential future projections should be made more accessible to all vulnerable sectors. This should be accompanied by a better integration and interpretation of hydrometeorological information—that is, development of robust early warning systems— in decision-making processes and the formulation of strategies within all levels of society. At present, proper investment mechanisms rarely reach lower administrative levels, further weakening municipalities' planning and implementation capacity. Results from the social dimensions component reinforce this finding. In all municipalities studied, neither communities nor municipal governments prioritize short- or long-term multi-communal adaptation strategies. Notably, community representatives and local authorities only considered adaptation measures within a ten-to-fifteen-year time horizon. A long-term vision for dealing with the impacts of climate change is too abstract for many rural communities.

Several actions to address many of these issues and to implement the National Mechanism of Adaptation are already included in the formulation of the country proposal for the first phase of the Pilot Program for Climate Resiliency (Box 1). The Bolivia study hopes to contribute further to the PPCR initiative by filling local gaps on adaptation information and needs, as well as on the decision-making process under high uncertainty.

THREE

Vulnerability to Climate Variability and Climate Change

Bolivia is an extremely diverse territory stretching from the Andes to the Amazon. The country has been classified as one of the most important eco-regions in the world. The national territory varies considerably in elevation (from 6500 and 300 meters above sea level), vegetation (including forests, savannas, plains, semi-arid forests), and climate. Although Bolivia lies within tropical latitudes, temperatures are dependent on elevation and show little seasonal oscillation. In most cases, rainfall is most abundant during the southern summer, and tends to decrease from north to south (Figure 1). Bolivia is located in an area of intense climate variability, periodically disrupted by El Niño (ENSO).[7] The Andes Mountains, which cover much of Bolivia's territory, determines the occurrence of heavy convective processes that are inadequately captured by current general climate models (GCM). As a result, the regional or large-scale information provided by climate models requires local validation to improve possible scenarios. Based on Bolivia's socio-geographic characteristics, four macro-regions were used for this study:

Highlands (the Altiplano) have an altitude higher than 3500 meters above sea level (masl). The climate is dry and cold, with very sharp differences in daily temperature and precipitation amounts. The southern part of the region is more humid than the north. The diurnal amplitude is very high and in the evening temperatures are around 0° degree Centigrade. In the highlands, rainfall is generally low, but the mountains introduce very important variations.

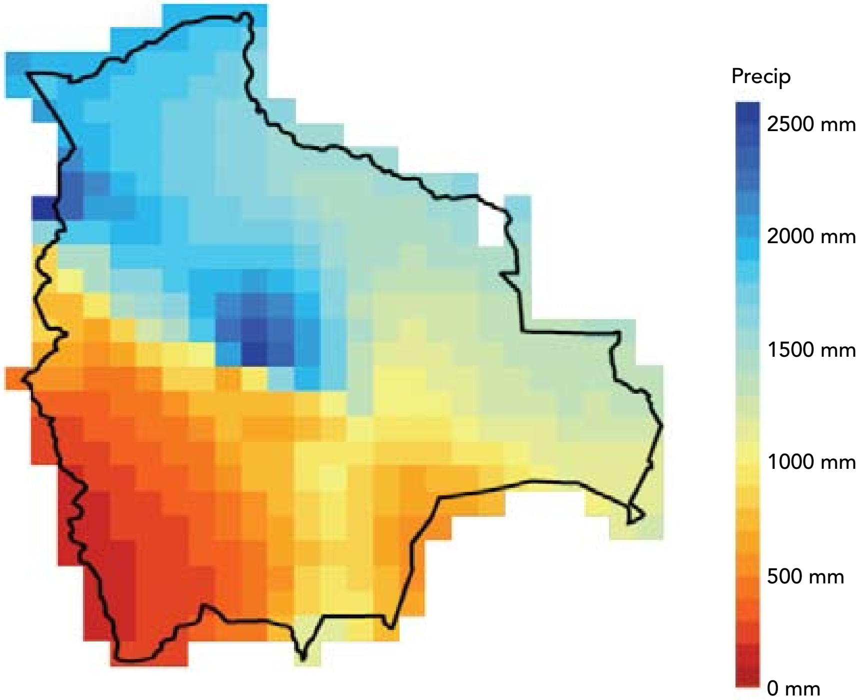
Valleys are found at the foothills of the oriental mountain range, with average altitude ranging from 1,000 to 3,500 masl. The climate is temperate and includes two sub-regions: dry valleys and the hot yungas region.

El Chaco is located in the south of Bolivia with an average altitude lower than 1000 masl. The climate is warm and dry. The departments of Tarija, Chuquisaca and Santa Cruz are found in this macro-region.

Plains are found in the northeastern region of Bolivia, with an average altitude lower than 1,000

7 The effects associated to both Niño and Niña years are quite unpredictable and impacts are similar meaning abnormal precipitation and positive or negative anomalies in the Altiplano and other regions, and higher incidence of other phenomena like hails and frosts in the Western arid areas. An increase in frequency and intensity of extreme events has been observed in Bolivia in the last decades (Impacts of ENSO phenomena. Beltrán and Gutiérrez, PNCC (forthcoming)). The strong or very strong ENSO events of 1997 and 1982 respectively, have caused major impacts due to the increase in population vulnerability to climate events. Despite the periodic recurrence of ENSO years, it is not easy to find clear patterns to help forecast their hydro-meteorological effects better. However, climate analysis from El Nino events suggests an increasing trend on the intensity of these events within the last decades.

FIGURE 1 **AVERAGE ANNUAL PRECIPITATION IN BOLIVIA 1951-2002**



Map produced by ClimateWizard © University of Washington and The Nature Conservancy , 2009.
Base climate data from the Climate Research Unit (TS2.1), University of East Anglia, UK, http://www.cru.uea.ac.uk

masl. The climate is warm and humid. The departments of Santa Cruz, Beni, Pando, La Paz, and Cochabamba are found in this macro-region.

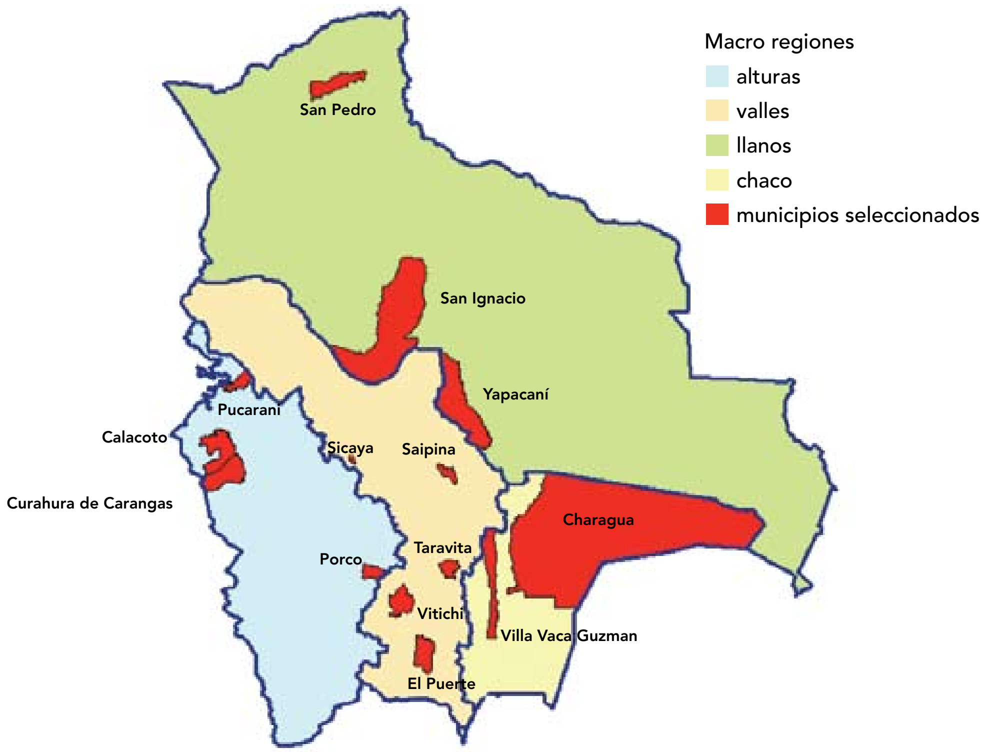
In addition to the macro-zone categorization, the country study undertook a social analysis which sought to identify and evaluate the vulnerability of different rural communities most threatened by climate variability. For this analysis, 14 rural municipalities[8] were chosen based on different macro-regions overlaid of data related to existing levels of population, current vulnerability (i.e. poverty levels and distribution of livelihoods) and agro-ecological zones. Figure 2 below shows the macro-zones of Bolivia and the location of the selected study sites.

8 Study limitations restricted the site selection to 14 municipalities.

Exposure to Extreme Events

As previously mentioned, the Bolivian population is particularly exposed to hydro-meteorological extremes, which - regardless of climate change- occur periodically in different areas across the country. In particular, Bolivia is very vulnerable to floods and droughts, both of which have serious implications for food security and water supply. According to estimates by Roche and Fernandez, (1986), more frequent and intensive floods in the northeastern part of Bolivia (Beni) spread around 10m/ha and are mainly localized in the Mamoré River watershed. In the western high plains and valleys, El Niño has caused droughts with consequent losses in crops and livestock, while producing floods in the East. These events have damaged crops and livestock and induced many residents to

FIGURE 2 **MOST VULNERABLE MUNICIPALITIES SELECTED BY MACRO-REGION**



migrate. During the last ENSO event, Beni and Santa Cruz departments suffered important losses in the soy, maize, yucca, sugar cane, and rice crops. Livestock is not only lost during the flood event, but also displaced to areas where it doesn´t adapt correctly and ends up producing less or dying. Farmers have to rent new land for pasture elsewhere, which affects their income (CEPAL, 2008).

Climate change is increasing the frequency with which extreme events occur and reducing the time to recover from a specific event. With less time to increase resilience and adaptive capacity before the next event occurs, Bolivia is more sensitive to climate variability. The CEPAL study has already reported that most of the damages caused by the 2008 ENSO-related events were influenced by a bad recovery from the impacts of 2007 extreme events. Hence, this increase in frequency and intensity has the dangerous potential to trigger a spiral of increasing vulnerability, which is important to bear in mind when designing adaptation strategies.

If the frequency of extreme weather events increases in countries such as Bolivia[9] (including the onset of El Niño and La Niña events), the accumulation of events within shorter time frames can threaten development as usual given the serious public sector financial limitations. This vulnerability of small economies underscores the need for financial contingency planning to increase the government's resilience against future disasters (Mechler et al. 2009) (Figure 3).

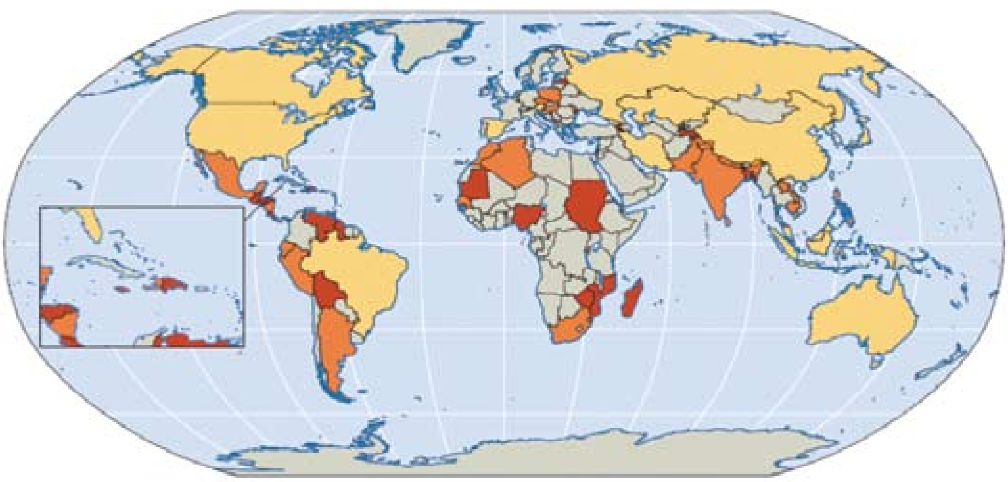
9 World Development Report 2010: Development and Climate Change. World Bank

Coping Strategies and Current Climate Variability

Due to historical climate variability in Bolivia, many indigenous groups have developed context specific adaptation strategies to survive on what can be considered to be marginal farming land whether it is located in the dry highlands or in the lowland plains. The indigenous population used different strategies to adapt and transform the landscape to cope with climate variability. These strategies can serve as inspiration in today's climate adaption, though a simple recovery of the past would be an over-simplification.

One way indigenous populations have adapted their livelihood to the climate variability in Bolivia is by diversifying their food security by producing different crops, breeding llamas and cattle as well as hunting and fishing depending on the local context. In the highlands or Altiplano, the indigenous population has used different elevations to produce different crops as well as sawing different varieties of the same crop. For instance, 21 different potato varieties were registered in one small community in the area of Cochabamba. The different varieties are resistant to drought, frost and pests. The families spread and reduce the risk to climate variability and change by cultivating different varieties resistant to the range of plausible climates.

FIGURE 3 SMALL AND POOR COUNTRIES FINANCIALLY VULNERABLE TO EXTREME WEATHER EVENTS



Financial Vulnerability	*Critical event return period (years)*
High	11 – 50
Medium	51 – 250
Low	> 250
	Not applicable

Source: Mechler and others, 2009.
Note: The map shows degree to which countries are financially vulnerable to floods and storms. For example, in countries shaded dark red, a severe weather event that would exceed the public sector's financial ability to restore damaged infrastructure and continue with development as planned is expected about once every 11 to 50 years (an annual probability of 2-10 percent). The high financial vulnerability of small economies underscores the need for financial contingency planning to increase governments' resilience against future disasters. Only the 74 most disaster-prone countries that experienced direct losses of at least 1 percent of GDP due to floods, storms, and droughts during the past 30 years were included in the analysis.

The indigenous population also transformed the landscape to reduce climate risk and improve the yields from marginal lands. In the Tiwanaku and Titicaca area, pre-hispanic cultures transformed the landscape with terraced fields, irrigation, canals and artificial ponds, which buffered against the extreme climate (such as drought, frost and hail), improved soil moisture and reduced loss of the topsoil. In the lowland Beni Plains, the Moxos population transformed wetlands in a highly sophisticated manner by establishing extensive systems of canals, raised fields, dikes and reservoirs, which allowed them to reduce the risks for flooding and control water flow while making the area highly productive. Ironically, these agricultural engineering systems are currently abandoned or underutilized and the large part of the indigenous knowledge has been lost.

These traditional strategies are in many ways a representation of robust measures that increase resilience to climate variability and should be re-evaluated in developing future climate resilient strategies in rural areas. However, this should be done in close dialogue with local population to evaluate the enabling conditions to promote the adoption of these "traditional" practices again, as the labor intensive construction of terraces and raised fields, for example, may not be attractive without the use of machinery. The traditional knowledge should therefore be complemented with latest technology and knowledge.

During the study, most of the communities emphasized the increasing difficulties to predict current weather, and that the traditional climatic indicators (i.e. cropping calendars) are no longer reliable. Thus, traditional knowledge could be complemented with the latest hydro-meteorological information of climate past and future trends, the creation of early warning systems, and the availability of climate information within rural areas.

The majority of communities studied for this report believe that over the past 20 to 30 years, the climate has been warming with implications for soil composition and crop cycles. In addition, animals, insects, plants and crops native to warmer zones have been appearing in traditionally cooler zones. Communities in the valleys and plains observed that winters are warmer and the overall, incidence of drought has increased. These observations coincide with results of the agriculture analysis which found that in years of projected drought, there will be significant declines in the yields of potato, corn and quinoa crops.

"The sun is stronger, the soil is drier and there are new illnesses in the plants."
Community workshop in La Sillada, Valleys macro-region

Representatives of ten of the fourteen communities studied confirmed that they have been affected by severe droughts in the past thirty years. Interviews reveal that livelihoods based on rain-fed potato farming and livestock farming are most threatened by increased incidence of drought. Table 1 presents community members' views on the direct and indirect effects of drought on their livelihoods.

During periods of drought, smallholder families are often forced to consume their food reserves, with severe implications for their long-term well-being. Given the likelihood of increased drought in Bolivia, past experience with the indirect effects of drought—such as rising commodity prices, forced migration, a decline in food availability, the introduction of new diseases, and the near extinction of native crops—inform the communities' vision of the types of adaptation measures that will be necessary in the future to cope with drought.

In 1983, the community of Qhawasiri (from the valleys macroregion) was so severely hit by drought that practically all potato seeds were destroyed. As a result, many men migrated in search of opportunities to earn money to buy new seeds. High demand and the low supply of seeds drove prices up and Bolivia was forced to import potato seeds. The arrival of these foreign seed varieties

TABLE 1 DIRECT AND INDIRECT EFFECTS OF DROUGHT ON LOCAL POPULATIONS

	Effect	*Percentage of assessed communities observing climate change trends (%)*
Direct effects	Decline or loss of productivity	100
	Loss of genetic material	86
	Decline in food	100
	Decreased availability of potable water	54
	Less hygiene	46
Indirect effects	Less monthly income/productive capital	100
	Adverse impact on children's education	62
	Increased incidence of illness	100

Source: Community workshops-Social Component

heralded the onset of new diseases and parasites never before seen in the region posing new development challenges for the long-term. In addition, livestock farming in some areas is ceasing to be a viable means of subsistence, hence many livestock farmers have had to find alternative livelihood opportunities.

Twelve of the fourteen communities in the highlands, valleys and plains reported that while there is less rainfall overall, rainfall has become more intense. They observed that the rivers carry less water or have dried up completely; there is less natural vegetation and agricultural yields have dropped. In contrast, community members from the Amazon region indicated that rains begin earlier and end later. For all populations, increasingly intense rainfall patterns have caused more flooding and erosion with devastating consequences for livelihoods dependent on the farming and livestock sector. Indirect effects of flooding and drought include increased malnutrition, propagation of illnesses and the potential to reverse past development gains.

Most of the post-event investments are allocated to rehabilitate infrastructure, which is vulnerable because it is poorly maintained, or has been built without taking flood risk sufficiently into account. Roads, irrigation infrastructure and precarious water and sanitation facilities in the rural and peri-urban areas are the most commonly affected infrastructures. The quality of construction of houses is not adequate in most of the rural and peri-urban areas throughout the national territory, and especially in Beni, Potosi, and Cochabamba departments (Oxfam-Fundepco, 2008).

During the first quarter of 2007, the impact of El Niño 2006-2007 in Bolivia cost approximately US$ 443.3 million in damages, half of which were direct damage to property and the remaining 45 percent were losses in cash flow, declines in production, reduced income and disruption of services. In 2003, a drought in Southern Santa Cruz destroyed almost all agricultural production and, at the same time, most of the country was affected by heavy rains and floods in different places, leading to landslides and extensive damage to infrastructure. In 2006, 64,000 ha of crops were damaged by floods. On average, the national government has spent around US $136 million per year to support the agriculture sector deal with climate-related losses. Notably, a comparison of current El Niño events and those in 1982/83 and 1997/98, which were of greater intensity and magnitude, show that although the affected population is today four times greater than in 1997/98, only a third of the population (in comparison to 1982/83) was injured. Table 2 shows the economic impacts by sectors from all Niño Events since 1983.

According to the National Statistical Institute (INE), major impacts occurred in the infrastructure sector (particularly on roads) as well as in the agriculture and livestock sectors (INE, 2008). Although damage and losses in housing infrastructure are somewhat less, this aspect has major implications for the most vulnerable groups — women, small traders, and indigenous peoples — as they lost valuable assets vital to pursuing their livelihood strategies. In addition, damage to roads greatly reduces access to markets — a consequence that can have serious long-term consequences.

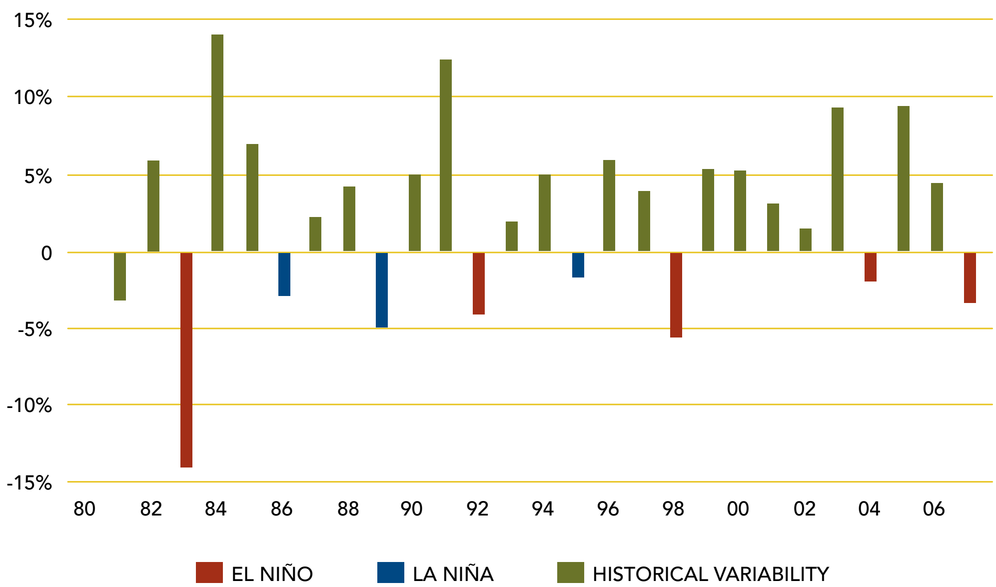
Figure 4 shows the influence of accumulating extreme events on agricultural GDP. The negative impact of strong El Niño events (red) is clear in the years 1982–83, 1991–92, and 2005–06. Also visible is the slight improvement of agriculture management in 2003–04. The effects of La Niña events, shown in blue, also are evident (although less severe) in the years 1985–86, 1988–89, and 1994–95.

TABLE 2 **ECONOMIC IMPACT OF THE EL NIÑO EVENTS SINCE 1983**

Date (El Niño)	People injured	Total Losses (millions of dollars in 2004)			
		Total Economic impacts	Direct damages	Loss (cash flow)	External effects *
1982-1983	1.600.000	2.821	1.759	1.062	101
1997-1998	135.000	649	262	387	32
2006-2007	562.594	443	242	200	18
2007 compared to 1982-1983 event (%)	35.2	52.9	46.5	63.6	7
2007 compared to 1997-1998 event (%)	416.7	84	113.8	63.8	12.8

* In terms of reduced imports, increased exports and capital flows altered by the event (INE, 2008)

FIGURE 4 **ANNUAL PERCENTAGE CHANGE OF AGRICULTURE GDP WITH THE EFFECT OF EL NIÑO AND LA NIÑA YEARS**



The effect from the phenomenon La Niña (blue) also show through (although less severe) in the years 1985-1986, 1988-1989 and 1994-1995.

Assessment of Climate Change Impacts Under Future Uncertainty

CLIMATE MODEL OUTPUTS

To account for uncertainty in climate predictions, the country study used three extreme climate change scenarios to project future ranges of climate change for the period of 2010 to 2050 under the SRES A2 scenario[10]. The study considered extreme scenarios in terms of water availability in order to simulate the worst-case scenarios, assuming that any possible changes in the Bolivian climate are likely to occur somewhere between these two.[11] The extreme scenarios used were Global Dry,[12] used as a dry model in the EACC global study (determined by CSIRO 3.0 global circulation model); Bolivia Wet, determined by the BCCR 2.0 global circulation model; and Bolivia Dry, determined by the GFDL 2.0 global circulation model**.** Climate projections for these models were created at a 0.5 by 0.5 spatial degree scale and a monthly time scale by applying model predictions through 2050 to a historical climate baseline obtained from the University of East Anglia Climate Research Unit's global climate database. These data sets were used mainly to determine impacts and adaptation options for the water resource sector.

The wet scenario for Bolivia forecasts an average temperature increase of 1.55°C and an annual mean precipitation increase of +22 percent, whereas the dry scenario shows a temperature increase of 2.41°C and a decrease in precipitation of -19 percent averaged across the Bolivian territory. The global dry scenario shows a temperature increase of 2.02°C and a decrease in rainfall of -10 percent. Table 3 and Figure 5 below show the main differences projected by the two scenarios in terms of geographical distribution obtained from GCM data aggregated at the subnational level. The trend over the period 2006 to 2050 indicates warming in all regions, with an increase in mean temperature of 2.3°C. Temperature increase is similar for the three models. No significant intra-annual variability was observed. In particular, the extremes of the different scenarios affect the Altiplano in the southwest—with large falls in rainfall in the dry scenarios and large increases in the wet scenario. As a consequence, uncertainty about the potential impacts of climate change is much greater for rural populations in the Altiplano.[13]

Most of the models do not agree with regard to rainfall projections by 2050 in terms of sign of the change, intensity, and geographical distribution in Bolivia. However, there is consensus that the current increasing trend of climate extremes will continue, causing longer and more frequent dry spells and more intense rainfall events (IPCC, 2007). The regional model PRECIS, implemented by Marengo et al. (2009), and also shows an expected increase in consecutive dry days for the North and a significant decrease for the Southwest under SRES A2. The same model forecasts an increase in extreme rainfall (maximum precipitation in five consecutive days) in the Chaco and valley regions (see Annex 1: Water Resources Impact Analysis, Figure 2).

10 SRES scenarios are *emission scenarios* developed by Nakicenovic and Swart (2000) and used, among others, as a basis for some of the *climate projections* used in the Fourth Assessment Report.

11 The climatic data resolution from current IPCC GCMs is quite low (on the order of 100–200 km). This implies an important loss of accuracy when the data is aggregated at smaller units (i.e. subbasin level). However, despite these uncertainties, the trends are sufficient to consider a changing climate toward more warmer and more erratic rainfall everywhere.

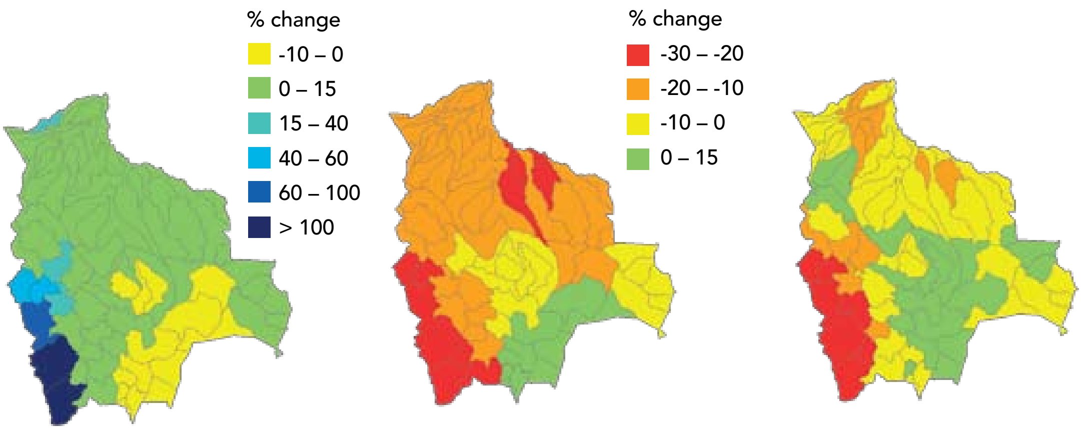
12 This particular model showed a less dry projection than the Bolivia dry, so the study focused on the Bolivia wet and dry to reflect possible extremes.

13 It is important to highlight the need to improve collection and access to hydrometeorological data to allow for enhanced calibration between low resolution global climate outputs and the local context.

TABLE 3 SUMMARY OF MAIN CLIMATIC CHARACTERISTICS OF THE BOLIVIA WET AND DRY SCENARIO

Wet Scenario	*Dry Scenario*
Small increase in rainfall throughout most of the territory; higher increase in western Altiplano; slight decrease in Chaco	Overall rainfall decreases, mostly in Altiplano and east of the Amazonian region; El Chaco shows a slight increase in annual rainfall
Slight increase in potential evapotranspiration due to increase in temperature; higher increase in Altiplano	Increase in potential evapotranspiration is higher in the Altiplano
High decrease in water availability in Chaco; highest increase in Altiplano and northern Amazonian region	Overall water availability decreases across the country, mostly in Altiplano and East Amazonas
Rainfall concentration diminishes for the Amazonian plains and increases in Altiplano, where the rainfall period starts sooner	Increase in rainfall concentration in the wet season in all the low lands

FIGURE 5 PROJECTED PRECIPITATION CHANGES TO 2050 UNDER DIFFERENT CLIMATE SCENARIOS



Bolivia Wet Scenario Global Dry Bolivia Dry Scenario

FOUR

Sector Analysis: Agriculture

Sector Description

The agricultural component attempts to understand climate change impacts and adaptation in the agriculture sector, which is one of the most vulnerable sectors to climate change in Bolivia. Food security is still a major concern in the country. The majority of the poorest population depends on agricultural production for subsistence. As a starting point to understand needed adaptation strategies in the agriculture sector, an effort has been made to evaluate major crops in the areas where they are currently grown (Figure 6).

FIGURE 6 REGIONAL DISTRIBUTION OF FOUR CROP CULTIVATION

Four crops—quinoa, potato, maize, and soy—were selected based on their importance for food security and the economy in Bolivia. This selection of crops seeks to capture the diversity of agriculture production systems in Bolivia. These crops are cultivated from the Altiplano to the lower areas. They also reflect the diversity between small-scale agriculture and local consumption (potato, maize, and quinoa), and commercial export crops (soya and the increasing export of quinoa). See Annex 2 for the complete agriculture background report, including further details on the crops selected.

QUINOA

Although the production of quinoa represents only 1.5 percent of agricultural GDP, it is very important for the food security of rural communities in the Altiplano. Annual production is around 25,200 metric tons, produced in approximately 45,000 ha of land by 70,000 agricultural producers. Almost 80 percent of these producers are small-scale subsistence farmers in the northern Altiplano. These farmers tend to rely solely on quinoa for nourishment and food security. The central and southern regions of the Altiplano contain less than 20 percent of the producers; however, production in these areas constitutes more than 55 percent of the total and is oriented toward international markets. Nonetheless, while Bolivia is a leading world exporter of this crop, the trade volume of quinoa is still relatively small compared to other agricultural export commodities in Bolivia. Three different study sites for this crop were selected reflecting differences in production and soils: Viacha (northern Altiplano), Patacamaya (central Altiplano), and Uyuni (south Altiplano).

POTATO

Potato is cultivated in seven out of the nine departments in Bolivia by approximately 200,000 family producers—almost a million people. More than 80 percent of the producers are small-scale farmers in the Altiplano and the valleys; the rest are located in sub-Andean zones. The cultivated area for potato is 6.5 percent of Bolivia's total cultivated land mass. Potato production is mostly geared toward internal consumption. The potato is an important component of the local population's diet and contributes greatly to the food security of local populations. Four study sites for this crop were selected: two in the department of La Paz (Belen and Patacamaya), and two in the department of Potosi (Puna and Mojo). Three different varieties of potato with significantly different phenological characteristics were studied: the Waycha variety, a commercial native potato; the Luki variety, a bitter potato; and the Alpha variety, a commercially imported potato.

SOYBEAN

Soybean cultivation constitutes more than 50 percent of total cultivated land in Bolivia. Total production has been around 1.3 million metric tons in recent years. Soybean represents more than 10 percent of agricultural GDP and is produced mainly for export and industrial processes. There are two main areas producing soy in Bolivia, the "expansion area" in the plains with an estimated of 380,000 ha under cultivation, and the "integrated area (valleys and plains)" with around 300,000 ha of cultivated area. The integrated area is composed of about 8,000 small farms. Two sites were chosen in the department of Santa Cruz (Trompillo and San Ignacio).

MAIZE

Maize is cultivated in all departments in Bolivia, yet most of the production takes place in the valleys/plains macroregion (Santa Cruz, Cochabamba, Chuquisaca and Tarija). The total cultivated area is 364,000 has. Santa Cruz is the largest producer of maize with 168,400 ha of land dedicated to the crop. Maize constitutes an important dietary component for rural populations and is also a vital input for the livestock sector in Bolivia. Three study sites were chosen: Trompillo and Camiri in the department of Santa Cruz, and Yacuiba in the department of Tarija.

Impact and Vulnerability to Climate Change of the Agriculture Sector

The agriculture sector is very sensitive to climate variability and climate change given that most of the productive systems are rainfed, soil conditions are poor, technological development is low, and there is low utilization of inputs. Global changes (both long-term change and changes in extremes) will have important implications for the economic productivity of the sector. The sector will be affected by two primary water-related climate risks:

- *Gradual changes in the magnitude and distribution of precipitation and temperature:* As an example, lowlands are going to face the highest increases in water deficit, while high and medium altitude crops might benefit from higher temperatures if accompanied by adaptation actions.

- *Changes in the frequency and magnitude of extreme events:* Climate events such as above average floods, prolonged droughts, and water scarcity will result in supply shocks to the agriculture sector.

A summary of most crop vulnerabilities to current and projected climate variability and change is shown in Table 4. According to projected climate impacts, vulnerability of crop yields to frost events is expected to decrease as temperatures rise, particularly in higher areas. Vulnerability to floods is also expected to decrease in areas where the water deficit is expected to increase. In contrast, vulnerability to droughts and plagues is expected to increase in these areas given that higher temperatures favor the development of crop diseases and plagues. Lower-lying regions, however, will continue to be vulnerable to droughts.

In general, both the potential effects of climate change and uncertainty about its impact on agriculture are likely to reinforce the shift of agricultural comparative advantage within Bolivia towards the eastern half of the country at the expense of the Altiplano and the valleys. This may not involve direct movement of population, but a process by which rural-urban migration is particularly rapid in the western departments together with the extension and intensification of agriculture in low zones below 1000 masl.

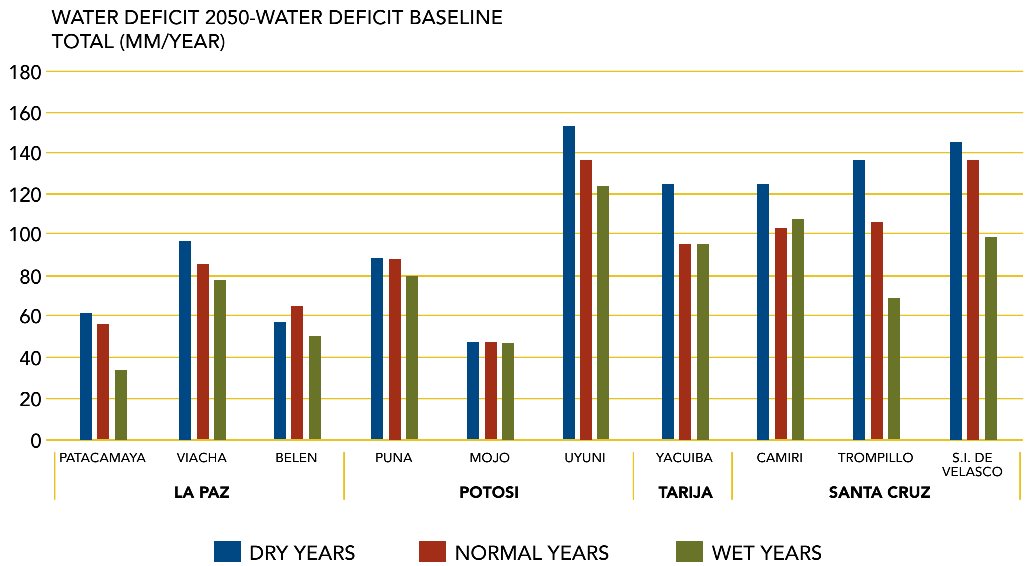
CLIMATE CHANGE SCENARIOS

Climate projections from general circulation models (GCMs) were used to assess the relative changes in temperature and precipitation in 2050 for the A2 emissions scenario produced by the IPCC. Seventeen GCMs forecast increase in temperature between 1.5 and 2.8 °C from current averages across the country. These models do not agree in rainfall projections by 2050 in terms of the sign of the change, intensity, and geographical distribution. However, it is agreed that the current increasing trend in intensity and frequency of climate extremes will continue (IPCC 2007). The projected precipitation changes reflect the possibility of an extended dry season, weakened early season rainfall, and more intense rainfall events during rainy season.

TABLE 4 VULNERABILITY OF CROPS TO THE MAIN CLIMATIC STRESSES, UNDER PRESENT AND FUTURE CONDITIONS

	Crop Vulnerability								
	Historical/Present					*Climate Change Scenario (2050)*			
Crop	*Drought*	*Frost*	*Floods*	*Plagues*	*Scenario*	*Drought*	*Frost*	*Floods*	*Plagues*
QUINOA	Medium	Medium	Low	Medium	*Dry*	High	Medium	Low	Medium
					Normal	Medium	Low	Low	High
					Wet	Low	Low	Medium	High
POTATO	High	High	Medium	Medium	*Dry*	High	Medium	Low	Medium
					Normal	Medium	Low	Low	High
					Wet	Low	Low	Medium	High
SOY	Low	Low	High	High	*Dry*	Medium	Low	Medium	High
					Normal	Low	Low	Medium	High
					Wet	Low	Low	High	Very High
MAIZE	High	Low	Medium	Medium	*Dry*	High	Low	Medium	Medium
					Normal	Low	Low	Medium	High
					Wet	Low	Low	High	High

FIGURE 7 ESTIMATED CHANGES IN ANNUAL EVAPOTRANSPIRATION UNDER THREE DIFFERENT CLIMATE CONDITIONS FOR TEN WEATHER STATIONS UP TO 2050



As low resolution GCM simulations did not adequately reflect historical seasonal climate change (maximum and minimum temperature change in the Altiplano, and intra-seasonal rainfall variability in Bolivia) climate data from national meteorological stations were included in the analysis to capture seasonal variability and complement GCM projections in the construction of future climate scenarios. Thus, 10 meteorological stations were selected in the production area of each crop[14] based on the availability of at least 30 years (up to 2008) of valid meteorological records. The long term records were statistically evaluated to determine monthly trends (for both minimum and maximum temperatures), and then used to project this identified trends up to 2050. Assumptions made are that trends would remain consistent for the locations, and within the upper (1 to 3°C) and lower (-1 to -3°C) temperatures range from the projected GCM results. The latter ranges were imposed due to the trends observed in some points to local reductions in the minimum temperatures that should not be ignored. With those variations, a set of temperature profiles were built for 2050, which was used later to apply the FAO-Penman-Monteith equation with missing parameters. The Reference Evapotranspiration (ETo) for 2050 was determined under these conditions.

Precipitation for a normal, dry and wet scenario was selected from the historic records of each station based on the general consensus that the rainfall regimes will not change in the totals but that the extreme years will be more frequent in the tropical areas, which was also an output coming from the GCM's. For the evaluation of the variation on the local climate conditions and expected water deficits for 2050, the differences between ETo and rainfall in dry, normal and wet[15] years at present and for 2050 were compared. The expected increases in water deficits are presented in Figure 7.

14 An analysis of the trends in the monthly changes of maximum and minimum temperatures was undertaken. Probability of extremes in historical precipitation (below 25 and above 75 percent likelihood of occurrence) helped generate the scenarios.

15 The study considers two extreme scenarios in terms of water availability in order to simulate the worst case scenarios, assuming that any possible changes in the Bolivian climate are likely to occur somewhere between these two.

Results showed that crop water deficits will increase given the increase in temperatures, especially in lower areas. The effects can be very severe in areas of the Altiplano, since its climate conditions are already characterized by low levels of precipitation and humidity.

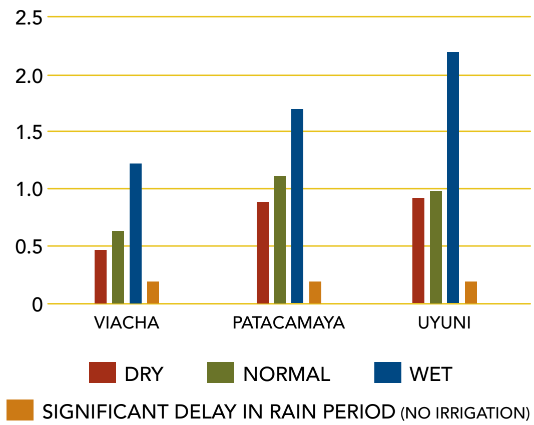
CROP YIELD MODEL OUTPUTS

Statistical crop growth models were used to simulate the response of crop yields to changes in temperature and precipitation as a result of climate change and adaptation options. The AQUACROP model was used for quinoa, maize, and soybean, and the SOLANUM-LINTUL agriculture model was used for potato. AQUACROP is a model developed by FAO to simulate crop yield response to different water availability conditions. SOLANUM-LINTUL is a model specifically developed for potato, calibrated to the existing crop varieties in Bolivia. It also simulates crop yield responses to temperature and water availability conditions. Limitations in the use of this model are fully described in the agriculture background report (Annex 2). The analysis suggests that climate change will lead to some reduction in crop yields under the normal and dry scenarios, primarily as a result of high levels of evapotranspiration due to higher temperatures. This could be offset by higher rainfall in the wet scenario, leading to higher yields. Crop yields are particularly sensitive to a reduction in rainfall during key growing periods as a result of a later onset of the rainy season. The implication is that there are substantial opportunities for shifts in cropping patterns within the country under any of the climate scenarios. Of course, this would not involve a direct relocation of production from the Altiplano to the plains, but shifts between neighboring subzones would certainly occur.

Quinoa

Climate change model simulation outputs show that quinoa crop yields will increase 35 percent under a wet scenario, 10 percent under a normal scenario, and moderately decrease under a dry scenario. The projected increase in crop yield stems from the increase in minimum temperatures and the consequent reduction in frost events—important limiting factors for quinoa productivity in the Altiplano. Figure 8 presents how the positive effect of increases in minimum temperatures is enhanced further in wet years.

FIGURE 8 RELATIVE YIELD OF QUINOA FOR THREE CLIMATE SCENARIOS AND A SCENARIO WITH NO PRECIPITATION IN THE CRITICAL PHENOLOGICAL PERIOD (RATIO OF SIMULATED 2050 TO HISTORICAL YIELD)

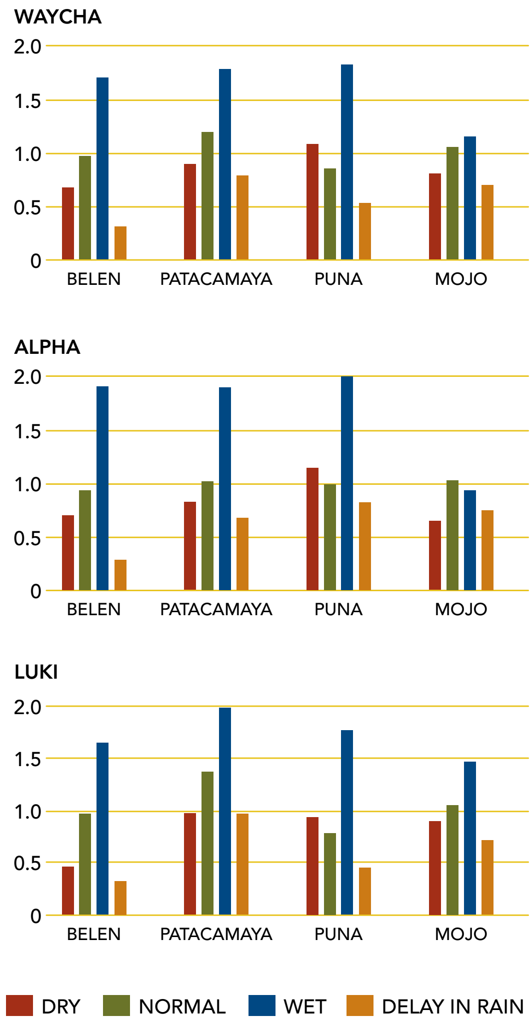


Even though these results may seem optimistic, a different conclusion is obtained when the possibility of a shift in the rainy season is analyzed. A delay of more than 20 days in the start of the raining season can have significant negative effects in quinoa given that this crop has a long-cycle, and farmers do not have much room for varying planting dates. The simulation of the effects of limited water availability on crop yields reveals that crop yields will be drastically reduced for any scenario attaining a minimum base yield that is in accordance with other studies of quinoa response to drought conditions in the critical phenological periods.

Potato

Results from the crop model simulation suggest that yields may increase between 1 and 16 percent for all varieties particularly for the Alpha variety, as a consequence of projected higher minimum temperatures. The Luki variety does not benefit as much from higher minimum temperatures given its natural resistance to frosts while. For the Waycha variety, relatively lower increases in yield are projected given that this variety has higher resistance to climatic stresses but lower overall productivity.

FIGURE 9 **RELATIVE YIELDS OF THREE POTATO VARIETIES FOR THREE CLIMATE SCENARIOS AND A SCENARIO WITH NO PRECIPITATION DURING THE CRITICAL PHENOLOGICAL PERIOD (RATIO SIMULATED 2050 TO HISTORICAL)**



Relative yield changes show important increases under a wet scenario, modest decreases under dry scenarios, and almost no change under a normal scenario. Figure 9 presents the results of four study sites. As with quinoa, adequate water supply is a crucial determinant of crop yields. Waycha and Alpha potato varieties in particular are highly sensitive to water deficits in the Mojo area. At the same time, short-cycle varieties such as Alpha are highly productive whenever crop water requirements are covered. These varieties have the potential to increase global productivity if managed properly. On the other hand, due to its vulnerability, climate change has the potential to eradicate the Luki variety. This variety has a long cycle and low but stable productivity due to its ability to resist frosts. For this reason, increases in minimum temperature can make Luki potato farming unattractive to farmers as it becomes more profitable to switch to more marketable and resistant varieties; that is, a delay in the rainy period will have an impact on the long-cycle varieties but not on the short-cycle varieties.

Soybean

Soybean yields are projected to increase under a wet scenario and decrease under a dry scenario. Figure 10 shows the relative yields for soybean. Yields increase only for a wet scenario that satisfies crop water requirements under climate change conditions. They decrease slightly under a no-climate-change scenario. Finally, yields decrease considerably under a dry a scenario and a scenario without water in the critical flourishing period. An additional simulated scenario included the possibility of a heat wave (20 dry days with high temperatures), which generated major reductions in yield. The possibility of having insufficient water during the critical phenological period causes a significant decrease in yields. This suggests that there will be a need to guarantee water availability during extreme situations to maintain productivity. While the study considered the summer crop season only, the results can also apply to the winter crop season, considering that dry years can significantly limit soybean production. While results suggest that soybean yields may increase in normal and wet years, this only applies to situations where precipitation is uniformly distributed across the cropping period. Long periods with excess rainfall or dry spells may imply a significant reduction in soybean productivity.

Maize

Simulation results show that maize yields can increase up to 20 percent under a wet scenario. This is not the case under dry and normal climate scenarios where yields are projected to decrease (see figure 11). This decrease is caused by an increase in temperature that results in higher crop water requirements.

Despite the results shown in the impact assessment section, a temperature increase can constitute an opportunity to increase crop productivity if crop water requirements are guaranteed at least during critical phenological periods.

FIGURE 10 RELATIVE SOY YIELD FOR THREE CLIMATE SCENARIOS AND A SCENARIO WITH NO PRECIPITATION IN THE CRITICAL PHENOLOGICAL PERIOD (RATIO SIMULATED 2050 TO HISTORICAL YIELD)

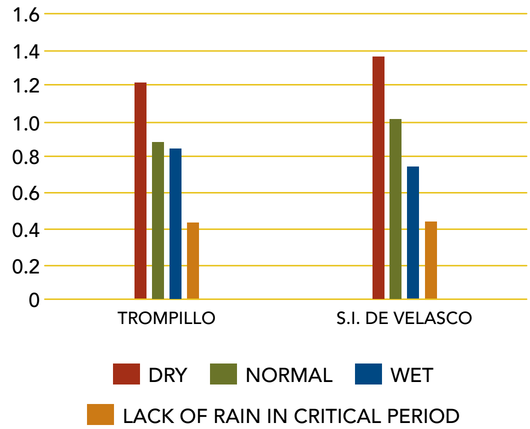
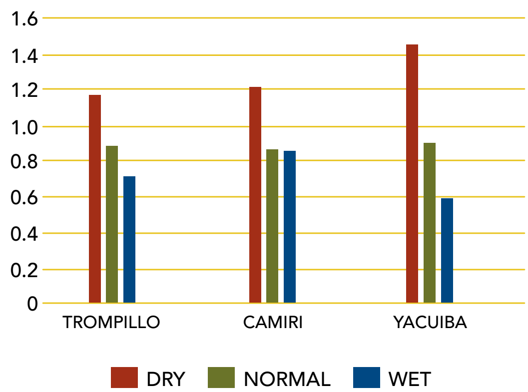


FIGURE 11 RELATIVE MAIZE YIELD FOR THREE CLIMATE SCENARIOS (RATIO SIMULATED 2050 TO HISTORICAL)



Adaptation Options for Crop Production

According to the estimated impact of climate change on the four studied crops, similar adaptation options were identified as crucial. Irrigation is clearly an important adaptation strategy for all four crops. For quinoa, irrigation is a suitable adaptation option considering that the frequency and probability of droughts during critical crop growth periods is projected to increase. Additional options include application of deficit irrigation, as well as changes in the sowing dates and crop varieties. For *potatoes*, improved irrigation is a vital adaptation strategy for areas where rainfall is irregular and temperatures are high. Additional options include better management of the different varieties, changes in sowing dates and application of irrigation in critical phenological periods. For *soybeans*, irrigation emerged again as the most important adaptation strategy, particularly in critical phonological periods. Additional adaptation options include investments in flood control measures as well as the introduction of input saving varieties. For *maize*, to enhance water retention and improve soil moisture conditions, specific adaptation measures include irrigation and flood control in wet periods, as well as improved soil management practices. Most adaptation strategies will require significant institutional support in order to avoid negative social and ecological impacts due to intensification of crop production; that is, maize requires intense water and soil management in order to maintain productivity.

In addition to improved irrigation measures, local populations engaged in rainfed agriculture put a high priority on better information and capacity building initiatives geared toward working with new and adapted seed varieties, as well as better infrastructure for conservation and storage of crops during warm periods. Complementary investments in both hard and soft adaptation options—extension services, crop insurance, and improved access and availability to hydrometeorological data—will be vital in order to improve agriculture adaptation policies and meet the needs of livelihoods based on rainfed agriculture. Additional efforts should be made to facilitate access, transfer and adoption of agriculture technologies that provide increased resiliency to vulnerable populations.

Table 5 below provides an example of the types of hard and soft adaptation measures which members of the Contorno Calacoto community prioritize for adapting to future climate variability and climate change. This community, located on the central Bolivian high plateau is characterized by its extreme poverty owing to very low agricultural production. Agricultural production has deteriorated significantly as a result of climate change, with water scarcity one of the community's major problems.

Some additional factors remain to be explored. This includes the potential role of investments in rural roads in providing the infrastructure required to facilitate shifts in the location of agricultural production linked to changes in comparative advantage.

QUALITATIVE ESTIMATION OF COSTS, BENEFITS, AND VIABILITY OF ADAPTATION OPTIONS UNDER CLIMATE CHANGE

Costs of prioritized adaptation options for the agriculture sector

Based on expert assessment of several local agriculture consultants, a qualitative matrix was constructed to provide some understanding of the economic, social, and environmental costs related to the implementation of adaptation measures

TABLE 5 ADAPTATION STRATEGY OF THE CONTORNO CALACOTO COMMUNITY

Priority	*Measure*
1	Construction of wells and water capture facilities
2	Construction of reservoirs (water capture)
3	Improvement of pasture and forage
4	Livestock infrastructure (pens, stables)
5	Support for agricultural activities (seeds, technical assistance and training)
6	Low interest financing management
7	Technical training in different activities
8	To organize a Producers ´Association
9	To improve productive infrastructure (soil management)
10	Handling and genetic improvement for cattle
11	Processing and marketing of local products

TABLE 6 ECONOMIC, SOCIAL, AND ENVIRONMENTAL COSTS FOR THE IMPLEMENTATION OF ADAPTATION OPTIONS IN FOUR CROPS

	ADAPTATION MEASURES																				
Crop	Irrigation and flood control			Management of varieties and crop changes			Changes in sowing dates and crop rotations			Use of insurance and agricultural subsidies			Climate forecasts and early warning systems			Market access			Agricultural research and extension services		
COST	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A
Quinoa	H	M	M	H	M	M	L	H	L	H	L	L	H	L	L	M	L	L	H	M	M
Potato	H	M	M	H	M	M	L	H	L	H	L	L	H	L	L	M	L	L	H	M	M
Maize	H	M	H	H	M	H	L	H	L	H	L	L	H	L	L	M	L	L	H	M	M
Soy	H	M	H	H	H	H	L	H	L	H	L	L	H	L	L	M	L	L	H	M	M

TABLE 7 ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS FOR THE IMPLEMENTATION OF ADAPTATION OPTIONS IN FOUR CROPS

	ADAPTATION MEASURES																				
Crop	Irrigation and flood control			Changes in varieties and crops			Changes in sowing dates and crop rotations			Use of insurance and agricultural subsidies			Climate forecasts and early warning systems			Market access			Agricultural research and extension services		
BENEFITS	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A
Quinoa	H	H	M	M	M	H	M	M	H	M	M	M	H	H	H	H	H	H	M	M	H
Potato	H	H	M	M	M	H	M	M	H	M	M	M	H	H	H	H	H	H	M	M	H
Maize	H	H	M	M	M	M	M	M	H	M	M	M	H	H	H	H	H	H	M	M	H
Soy	H	H	M	M	M	M	M	M	H	M	M	M	H	H	H	H	M	M	M	M	H

(Table 6). This oversimplified qualitative ranking—defined as high (H), medium (M), and low (L)—provides range estimates for economic costs (E), social costs (S), and environmental costs (A) based on the model crop yield simulation and socioeconomic analysis.[16]

Benefits of prioritized adaptation options for the agriculture sector

Table 7 presents the economic benefits (E), social benefits (S), and environmental benefits (A) for the implementation of adaptation measures to respond to climate change impacts based on the simulation and socioeconomic analysis of crop production. These benefits are further defined as high (H), medium (M), and low (L). Assessment of qualitative cost and benefits shows that despite producers having identified the most important adaptation measures (irrigation, for example), in some cases they do not represent the most attractive option in economic and environmental terms due to their high costs.

Viability of the implementation of selected adaptation options

The economic viability (E), social viability (S) and environmental viability (A) for the implementation of adaptation measures is presented below in response to climate change impacts. This is based on the simulation and socioeconomic analysis of crop production. Viability is defined as very high (VH), high (H), medium (M), or low (L). The viability analysis of adaptation measures is based on the difference between their costs and

16 The above rankings are merely an illustrative exercise to assess potential cost rankings and viability of implementation of adaptation measures and socioeconomic factors. A proper quantification of these parameters is needed before further interpretations can be made.

TABLE 8 SOCIAL AND ENVIRONMENTAL VIABILITY OF ADAPTATION OPTIONS IN FOUR CROPS

	ADAPTATION MEASURES																				
Crop	*Irrigation and flood control*			*Management of varieties and crop changes*			*Changes in sowing dates and crop rotations*			*Implementation of insurance and agricultural subsidies*			*Climate forecasts and early warning systems*			*Market access*			*Agricultural research and extension services*		
VIABILITY	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A	E	S	A
Quinoa	M	H	M	L	M	H	H	L	VH	L	H	H	M	VH	VH	H	VH	VH	L	M	H
Potato	M	H	M	L	M	H	H	L	VH	L	H	H	M	VH	VH	H	VH	VH	L	M	H
Maize	M	H	L	L	M	L	H	L	VH	L	H	H	M	VH	VH	H	VH	VH	L	M	H
Soy	M	H	L	L	L	L	H	L	VH	L	H	H	M	VH	VH	H	H	H	L	M	H

their benefits. Table 6 shows that a high cost is associated with both soft and hard planned adaptation needs including: a) construction/renovation of irrigation and flood control infrastructure; b) management of varieties and crop changes (including research and extension systems); c) creation of insurance and agricultural subsidies (see box 2); and d) access to climate forecasts and early warning systems. A low cost was assigned for the changes in cropping calendars and rotations –mainly considered an autonomous adaptation action done by farmers. Notably, the same actions are also considered to have the highest benefits in return (Table 7) making a case for the prioritization of these actions in the agriculture sector. Table 7 also shows that soft adaptation measures, such as improving extension services and increasing access to markets, also require significant investments up front, yet they also offer a high socially and environmentally sustainable benefits in the longer term.

Robust adaptation options are also viewed in terms of large co-benefits and interlinkages. For example, investments in rural roads can also be an important adaptation strategy because they increase access to markets for agricultural inputs and outputs. The implementation of policies that increase access to markets—bridging two vulnerable sectors, infrastructure and agriculture—could be implemented at a smaller scale for small-scale farmers, and complemented by additional macroeconomic measures for large-scale farmers. Table 8 suggests that planned adaptation actions—including increased irrigation resources and flood control measures, as well as the implementation of knowledge support for improved analysis of climate science—are highly costly and hard to implement in Bolivia.

Given the vast agroecological diversity and socioeconomic characteristics of agricultural producers in Bolivia, any adaptation measure will need to be evaluated in relation to its productive environment. Accordingly, decision makers should devise adaptation strategies that include medium- and long-term measures, even if they require larger up-front investments.

BOX 2 AGRICULTURE INSURANCE

Agriculture Insurance can also be considered a complementary measure for adaptation, yet its implementation might differ depending on the structure and size of the farming system. For example, the design and implementation plan for agricultural insurance schemes in the Altiplano for small-scale family producers would differ drastically from the type of approach that would be needed for areas like Santa Cruz, where most of the production is carried out by large-scale farmers. As a direct response to the need for agricultural insurance, the newly developed National Development Plan (2010–15) is considering a universal crop insurance scheme under the principle of universality of access (all farmers) and risk diversification. This insurance will cover the losses generated by climatic effects—floods, droughts, hailstorms, and frost—and will cover the 650,000 production units representing a total of 2,046,335 hectares. Of this total, 54 percent (1,094,257 ha) are dedicated to the cultivation of oilseeds, 38 percent to (772,389 ha) cereals, and almost 9 percent to quinoa, potatoes, and other crops.

FIVE

Sector Analysis: Water Resources

Sector Description

Water resources are abundant in Bolivia. Average rainfall is about 1,200 mm.[17] Despite high evaporation rates, average water allocation is high at approximately 45,000 m^3 per capita per year (Ministry of Environment and Water 2008). However, natural water supply presents both a marked geographical and seasonal variability: 45 percent of total rainfall falls within 3 months (December–February), with values from 600 to 100 mm in the cold Altiplano and less-cold central-southern valley regions, and values up to 2,000 mm in the warm lowlands, with maximum values of 5,000 mm in certain areas of the transition from the valley to the lowlands.

IMPACT AND VULNERABILITY TO CLIMATE CHANGE IN RURAL AREAS

According to most future climate projections, access to water resources in rural areas will be impacted by two major water-related climate risks: gradual changes in the magnitude and distribution of precipitation and temperature, and changes in the frequency and magnitude of extreme events; that is, above average occurrence of floods and prolonged droughts. In order to evaluate these impacts, two indicators were developed that can estimate the impact of climate variability on water access. The indicators can evaluate future estimates of water availability annually and changes inter-annually.

- ***Annual variability:*** Despite the three scenarios forecasting different changes in natural supply levels, the study shows a similar geographical annual distribution of water for all three. On an annual basis, most watersheds in the highlands (Altiplano), central/south valley, and Chaco regions would present a short gap between demand and supply levels.[18]

- ***Inter-annual water availability:*** Change in the monthly cumulative water deficit serves as a proxy indicator to measure how much more water would need to be stored in the future compared to the present, assuming that all the necessary storage capacity to meet demand during the dry season is met today.

17 1,146 mm reported by Aquastat, 1,459 mm from PNCC (2007), 1,189 mm estimated from CRU data

18 Problems of water scarcity are likely to worsen in the south of the valley region. The dry scenarios show a higher magnitude of scarcity problems in all the affected watersheds. The wet scenario, on the contrary, shows no problems in western watersheds of the highlands, since this scenario forecasts an important increase in rainfall there. Basins with high differences in upstream and downstream rainfall are expected to suffer high competition for water uses (for example, La Paz watershed).

FIGURE 12 **PROJECTED WATER AVAILABILITY INDEX BY 2050: CURRENT, WET, AND DRY SCENARIOS**

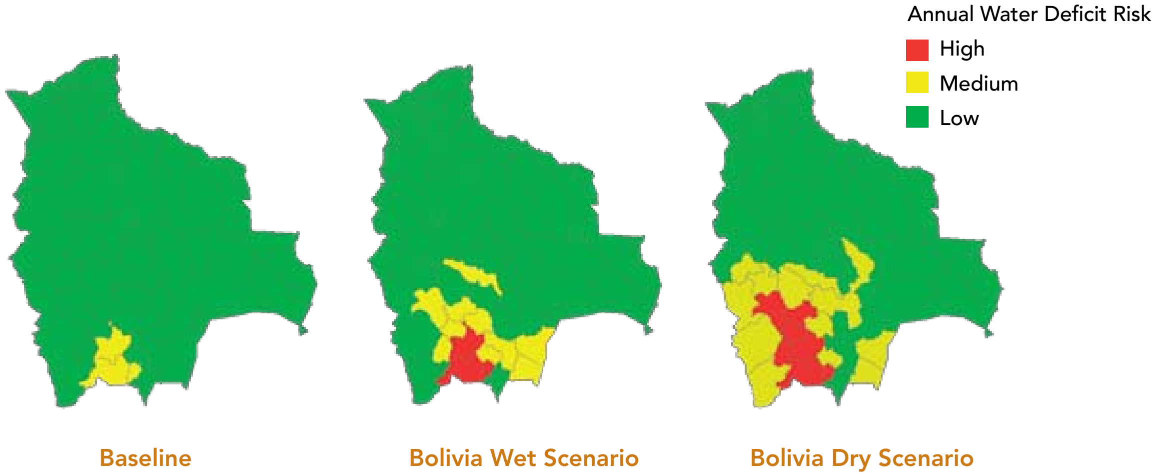


Figure 12 below shows the distribution of the expected water availability index by 2050 by the three modeled scenarios.[19] This indicator measures the relative difference (high, medium, low) between water supply and demand levels on an annual basis. Under the dry scenario, the entire highland area (Altiplano), mid-center valley regions, and Chaco region would need to increase their storage capacity significantly. In this case, the three scenarios show small differences among them because the differences in natural water supply during the dry season are small for the three models in the southwest. If the extra storage capacity is not satisfied, water stress during the dry season would increase, which would also reduce the possibility to expand irrigation in the area. These vulnerable basins are expected to suffer high competition for water usage, with strong potential to trigger social conflicts in particularly water-stressed areas during the dry seasons. Inadequate water management practices and lack of upstream-downstream regulation will reinforce these impacts.[20]

This study also undertook an assessment of water availability for crops.[21] Results show future impacts in rainfed agriculture caused by a reduction in dry season rainfalls and an increase in water deficit. Many areas that are currently rainfall abundant, and where more than one harvest per year today is feasible, might become more vulnerable if rainfall seasonality shortens and evapotranspiration increases. The Chaco, Altiplano, and plains watersheds (Low Grande basin in Santa Cruz) are the areas where the three

19 Detailed information on the parameters for the water availability index are described in the water resource background paper. See tables 22 and 23 in the annex for detailed values and evaluation criteria

20 Bolivia should upgrade its hydrometeorological information flows, improving the data sources, and current technical capacity to understand the hydrological responses of the watersheds to water cycle changes. This would be a key contribution to a solid IWRM strategy. Future steps could include a national network of early warning systems, starting with the critical watersheds mentioned in this study. These are very cost-effective measures if implemented adequately, meaning that the gains in the medium-to-long term can make really make a difference.

21 This measure takes into account future water stress (the difference between precipitation and potential evapotranspiration); changes in rainfall seasonality; and the extension of cropped land that is not irrigated. For further information on impacts on agriculture, please refer to the agricultural study.

scenarios reveal the need for more improved water availability for agricultural production. The dry scenarios show greater impact for these basins due to higher water stress values. The crop water availability indicator should be a good proxy to determine the most vulnerable watersheds, where expanding irrigation would be a key adaptation measure for coping with changing rainfall patterns as well as a reduction in water availability for crops (please see Annex 1).[22]

Two other vulnerability indicators were evaluated for rural areas: exposure to floods and droughts. Floods are the most recurrent extreme event (50 percent of events according to VIDECICODE in the period 2002–08, as reported by PNCC 2008). Almost every rainy season, rivers of the Iténez, Ichilo-Mamoré, or Beni basins overflow, inundating naturally floodable lowlands, but also affecting small towns and cities, crops, pastures, and livestock. Ten million hectares in the Beni plains are naturally floodable (CAF 2000). According to the analysis on water cycles and projected precipitation changes, flood events are likely to continue to occur in several Bolivian watersheds.[23]

Droughts are usually associated with El Niño events, but their frequency and distribution are not easy to predict. Basically, all the Altiplano, mid-south valley, and Chaco regions are exposed to long dry periods (see Annex 1, Water Resources and Impacts, maps 16 and 17). Apart from being naturally exposed to long dry periods and desertification, these events have an impact due to lack of preparedness, as indicated by poor water storage capacity and bad management of water resources at the watershed level; under-exploitation (and bad exploitation in some cases) of groundwater; poor forecasting and lack of anticipation of the event; inefficient application of water for irrigation; deforestation, which constrains aquifer recharge; overpopulation; and excessive consumption in some areas. All these factors contribute to the overall degradation of the watershed. Droughts have already caused major damages, mainly in the rural productive sectors of agriculture and livestock production.

Climate change and the rapid melting of glaciers are expected to exacerbate water shortages in the arid and semi-arid valleys and in the highlands. The highland areas are particularly sensitive to water shortages because these areas lack reservoirs necessary to ensure water availability during the dry seasons. An observed increase in runoff has only been temporary. In addition, glacial retreat represents an additional problem. In many places, glaciers act as a buffer for water availability during dry periods. Glaciers in Bolivia are shrinking at an alarming rate, which will reduce water supply for millions of people, particularly those living in urban centers. Farmers and the local biodiversity will be negatively affected. The present study does not include a detailed analysis of glacier retreat, as there are still large uncertainties associated with future surface water availability and dynamics of glaciers in the Altiplano. Luckily, there are several ongoing studies—such as the World Bank's *Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes Project*—that should help improve our understanding of glacier retreat and its impact on climate change and related adaptation options.

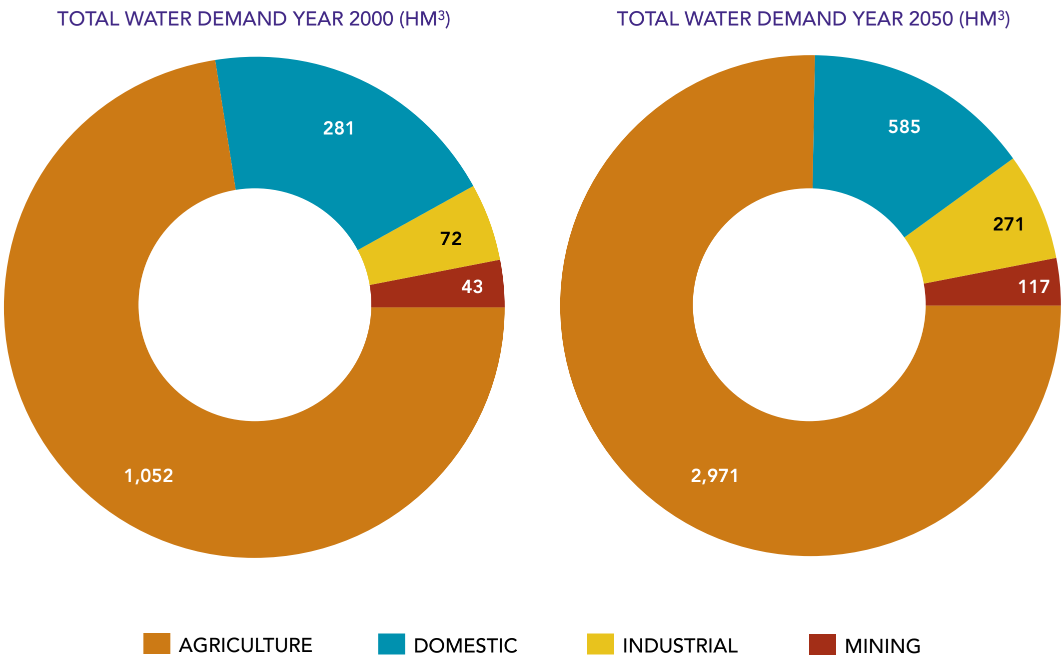
Vulnerability of Water Resources Infrastructure to Climate Change

Water infrastructure is underdeveloped in Bolivia. Despite presenting a high seasonality in water availability in the most populated and driest areas of the country, storage capacity is very low, with

22 For more information on the vulnerability and impact indicators, data assessment and data used for this analysis please see the water resources full report (Annex 1).

23 Maps of exposed watershed are presented in the water resources background paper. These maps were developed by combining information on the extension of floodable areas and the frequency with which floods occur.

FIGURE 13 WATER DEMAND BY SECTOR AT YEAR 2000 AND 2050



only 460 hm3 dedicated to storage (approximately equivalent to only 46 m3 per capita).[24, 25] Existing dams are mainly designed for hydropower generation and irrigation purposes. Water supply and sanitation coverage, despite recent improvements,[26] remains low, particularly in rural and peri-urban areas. In 2007, 74.5 percent of the population had access to water (87.5 percent in urban areas, and 50.3 percent in rural areas). With regard to sanitation, 53.7 percent of the urban population had access to sanitation while only 36.5 percent in rural areas.[27] The Altiplano and plains regions have a very unequal distribution of water resources and irrigation infrastructure. The efficiency of irrigation systems varies from 18 to 30 percent in traditional systems to 35 to 50 percent in improved systems. Irrigation for agricultural purposes accounts for 84 percent of water withdrawal in the country. However, in 2007,[28] the extracted water only irrigated less than 300,000 hectares (less than 11 percent) out of a total cropped area of 4 million has. Irrigation demand for agriculture purposes is expected to still increase in the future, as shown in Figure 13.

Adaptation Options: Rural Water Resources[29]

According to the impact and vulnerability assessment of water resources mentioned above, selected adaptation options were identified as

24 Data provided by GTZ-Proagro

25 This is low if compared with other neighboring countries such as Perú (100m3 pc) and Ecuador(540m3 pc)

26 From 2001 levels, the annual increase in access to water has been 0.3 percent, while access to sanitation has increased 0.85 percent, according to the National Sanitation Plan.

27 Data from National Sanitation Plan (updated version, August 2009)

28 Own estimates from PRONAR (2005) data and National Inventory of Irrigation (2000)

29 See table 7 in Water Resources- Annex 1-for further evaluation of adaptation measures developed in this section.

crucial in three main areas: (1) recurrent floods and droughts; (2) water access for agriculture; and (3) annual and intra-annual water scarcity. Specific options are also listed for each area.

(1) Adapting to recurring floods and droughts

Both soft and hard measures are necessary. Important actions would include:

- **An improved hydrometeorological disaster prevention strategy.** An improved disaster prevention strategy is needed to increase resilience and adaptive capacity toward extreme events is vital, especially if these events are expected to occur with increased frequency as projected by climate models. This strategy should involve the development of a sound hydrometeorological information system and an adequate risk management institutional framework that ensures efficient coordination among institutions. Disaster prevention plans should be implemented down to the local level with the necessary technology and infrastructure in place. Planning across scales of governance, aligning interests, and ensuring policy cohesion will be necessary to ensure the realization of an effective disaster prevention strategy. This is particularly true with regard to floods: development of a network of early warning systems at the national level is a major priority. According to results from the water resource impact study (Annex 1), this network should first address priority watersheds, including Niquisi, Chapare, Grande Bajo, Yapacani, Mapiri-Coroico, Mizque, and Bermejo.

- **Canalization.** Canalization of river channels, dykes, and upgrading drainage systems in population centers.

- **Reforestation.** Reforestation is a cost-effective option to combat severe erosion and can reduce watershed degradation in the valley region. Moreover, reforestation reduces the risk of landslides and sedimentation discharge.

- **Payment schemes for environmental services in specific areas.** Payments for environmental services, in particular where upstream activities may affect water uses downstream, should be considered. These measures can be applied in different contexts and attached to any of the previously mentioned adaptation measures. In Bolivia, while buying and selling environmental goods and services is a particularly sensitive political issue (Robertson and Wunder 2005), payments for watershed services schemes are being explored due to severe land use and water problems (Box 3).

(2) Adapting to improved water access for agriculture

Some adaptation actions include:

- **Expansion of Irrigation.** Under projected dry scenarios, drought-prone basins will require the transformation of currently rainfed areas into irrigated areas. This will involve improving water storage infrastructure[30] in the dry sub-basins of the Altiplano, mid-south valley regions, and Chaco.[31] The expansion of irrigated areas should be carefully analyzed due to the potentially high water constraints in these regions. Detailed supply and demand analysis at the watershed (or micro-basin) level (see Annex 3: National Irrigation Program, Mizque Basin, 2004–14) are required for projected critical areas where new irrigation projects are planned. Moreover, irrigation could also be expanded from surface diversion or groundwater exploitation—although additional analysis of groundwater

30 Refer to the irrigation section for further details on different storage options and their suitability in different contexts.

31 The Water Availability Index in 2050 and the Increase in Water Storage Indicator take into account a projected increase in demand for irrigation in all these basins, according to the irrigation demands determined by the National Irrigation Plan.

BOX 3 RIO LOS NEGROS, BOLIVIA –BEEHIVES AND BARBED WIRE

Within the Los Negros catchment in Bolivia, the NGO Fundación Natura is using external funding sources to facilitate payments between upstream and downstream farmers in the Santa Rosa community, covering some 250 km^2 within the catchment. Farmers who agree not to extend their area of cultivation into the cloud forest are provided with one beehive for every 10 hectares of forest conserved. In the second year of operation, the farmers requested and received barbed wire instead of beehives. The external funds used to buy the beehives and the barbed wire have been supplemented by two payments from the local municipality. One of the greatest challenges, but also one of the most important benefits of the program, has been to build trust between all the stakeholders in the Los Negros catchment.

Source: (Asquith and Vargas 2007)

availability and replenishment should also be considered, as discussed below—without further necessity to increase storage capacity basins with greater water availability. Irrigation would then guarantee protection against dry spells in the wet season and help expand cropping to the dry season.

- **Make irrigation practices more efficient and introduce new water saving technologies.** As water for irrigation accounts for more than 90 percent of total demand, these improved practices and efficient technologies should significantly reduce water demand.

(3) Adapting to (annual and seasonal) water scarcity

According to the vulnerability and risk assessment undertaken for this study, there are certain areas in the southwest where it is probable that annual water supply will not suffice to meet total demand at current development rates. It is therefore important to develop adaptation measures that promote water storage and allow for reduction in water demand. Such measures include the reallocation of water supply at the watershed level for different users, establishing clear property rights, and prioritizing certain uses with respect to others. This could be done by establishing quotas, or more effectively by price regulations, which can incorporate social equity criteria. In this case, a detailed supply-demand economic analysis of water uses is required in order to incorporate opportunity costs into water prices.

Where groundwater resources are still underexploited, increasing water availability is feasible. However, in Bolivia relatively little is known about the dynamics of groundwater resources and associated production capacity. Thus, while groundwater resources are exploited intensively in specific areas such as El Alto or Cochabamba, the possibility to increase supply by extracting groundwater in a sustainable way could be realized in other watersheds. This entails a whole range of physical measures, but also includes regulatory and policy options to evaluate the capacity and recharge potential of groundwater aquifers.

Additional measures include:

- **Storage infrastructure.** Current storage infrastructure needs to be revised, upgraded, and increased. The size and purposes of the new storage infrastructure should be determined as a function of each basin's

TABLE 9 EXAMPLES OF MEASURES FOR BEST USE OF EXISTING WATER RESOURCES

Macro-region	*Municipality*	*Community*	*Measure*
Chaco	Charagua	San Francisco	Micro-irrigation system construction and making use of river water
Altiplano	Carangas Curahuara	Uta Jila Manasaya	Drilling wells and installing hand pumps for drinking water
Valleys	Saipina	Oconi	Construction of a storage dam on the river Oconi
Valleys	Vitichi	Chapicollo	Underground storage tank*

* A very ancient traditional practice which consists of burying in the bed of the *quebradas* (small rivers which run only when it rains) a large tank for storing water. This resembles a swimming pool with a lid on it and is buried a few meters deep under the sand. The device has porous walls to capture water and has a small aperture where water can be extracted with the use of buckets. The people in the communities recount that their ancestors always used this method but younger generations are not familiar with it.

TABLE 10 EXAMPLES OF RAINWATER HARVESTING

Macro-region	*Municipality*	*Community*	*Measure*
Altiplano	Carangas Curahuara	Uta Jila Manasaya	Construction of *atajados* for the irrigation of *bofedales*
Valleys	Tarvita	La Silla	Construction of 50 earth *atajados* with capacity of 4000c.m.

characteristics. Tradeoffs should be considered among storage sizes, from small-scale infrastructure such as community-based "atajados" to large multipurpose dams such as the Misicuni project in Cochabamba. These tradeoffs need to consider overall economic and social benefits and costs in the long term. (See Annex 1, Water Resource Impacts, for a set of different typologies for this particular use.)

- **Water Transfers.** Although water transfers have high financial and social costs, this action can guarantee water access from basins that have a water surplus to those that are water-deficient. This measure is already under implementation at the micro-basin scale in the valley and Altiplano regions. The amount of transferred water should be carefully assessed.

- **Water reutilization.** Large-scale water reutilization is costly; however, water reutilization at the household level can be a very cost-effective measure to save water in urban areas.

- **Sanitation for peri-urban area.** The main adaptation need for rural and peri-urban populations is increased access to water and sanitation services.[32] The current access to water and sanitation services across the country must increase. A priority measure will be to extend existing urban networks to the peri-urban areas that currently lack access to water and sanitation services. Rapid growth of these areas needs to be planned in advance to ensure adequate service.[33]

Studied communities also provided examples of adaptation options for improved water management categorized into three areas: 1) improved use of existing water resources (Table 9); 2) construction of infrastructure for rainwater harvesting (Table 10); and 3) improvement and expansion of existing water systems (Table 11). The tables below provide examples of these types of measures prioritized in different communities.

1. *Use of existing water resources*: building infrastructure (construction of dams etc) to harness

32 See urban water section of this report

33 A qualitative classification of each adaptation measure mentioned above is in Annex 3, Water Resource Impacts. Additional information includes the regional and climate change scenario to which they are applicable, based on the climate change effects and impacts described in the previous sections.

TABLE 11 EXAMPLES OF IMPROVEMENT OR EXPANSION OF EXISTING SYSTEMS

Macro-region	*Municipality*	*Community*	*Measure*
Chaco	Charagua	San Francisco	Upgrading and expansion of drinking water system
Chaco	Villa Vaca Guzman	Aguayrenda	Repairs to tapping point, construction of holding tank and installation of pressurized irrigation
Plains	Yapacani	August 15	Emergency repairs to drinking water system and Education Center

TABLE 12 SEASONALITY IN IRRIGATION SYSTEMS (HECTARES)

Rivers		*Slopes*		*Wells*		*Reservoirs*		*Total*
Winter	*Summer*	*Winter*	*Summer*	*Winter*	*Summer*	*Winter*	*Summer*	*Annual*
40,346	114,185	3,044	10,826	6,788	7,372	21,428	22,043	226,032

Source: National Inventory of Irrigation Systems (PRONAR, 2000)

available water sources such as rivers, water catchment areas and underground aquifers.

2. *Rainwater harvesting*: building infrastructure to capture and store rainwater, involving the construction of artificial reservoirs and *atajados* (small dams) and providing facilities for harvesting roof water.

3. *Improvement and expansion of existing water systems:* infrastructure and equipment to expand water capture capacity and distribution systems with a view to avoiding future shortages. Improvement initiatives include training and the provision of facilities and equipment to make more efficient use of water such as pumping systems, improved piping layouts and other efforts to prevent irrigation water losses.

Adaptation Options: Irrigation Infrastructure

Irrigation is one of the most important climate change adaptation strategies in Bolivia. It will help ensure an adequate supply of water for food security and agricultural production. This study has analyzed different approaches for enhancing irrigation projects with the objective of increasing the resilience of the agriculture sector to climate change in 2050.

CURRENT IRRIGATION INFRASTRUCTURE

Where water is scarce, irrigation has made agriculture viable. Although limited, irrigated systems have developed most rapidly in the Altiplano, the valleys, the Chaco, and eastern plains, covering seven out of the nine departments in the country. More than 80 percent of regulated water flows are used for irrigation in the agriculture sector. According to the National Inventory of Irrigation, less than 300,000 hectares were irrigated in the year 2000. More than 4,000 irrigation systems were used and more than 200,000 families benefited. The construction of small-scale projects has been more intense, constituting 92 percent of all irrigation systems. In contrast, large-scale projects comprise 8 percent of irrigation systems, but supply 57 percent of irrigated water (see Annex 4, Irrigation Infrastructure report).

Most of these systems do not provide water to the entire irrigated area due to limitations in water supply. In general, these systems also supply free water during dry periods in the wet season. Seasonality in the application of irrigation is a very important aspect to consider, given that it defines crop market prices. Table 12 summarizes the irrigated areas by catchment type and season.

More than 60 percent of the area covered by irrigation systems is irrigated during summer (the rainy season) and only 32 percent of the area can use irrigation during winter (the season with the highest demand for water). At the same time, more than 60 percent of the irrigated area is covered by river catchments and 20 percent of the water comes from reservoirs. However, reservoir supply water for irrigation in 19 percent of the total irrigated area.

ADDITIONAL INFRASTRUCTURE NEEDS TO ADAPT TO CLIMATE CHANGE

Reservoirs guarantee complimentary irrigation during summer and store water for winter, a period when water is very much needed for agriculture. River catchments supply the highest amount of water in the country. This is because of the low investment costs needed for water river catchment projects. However, future projections indicate increased seasonal variability in the supply of water for irrigation. At present, due to limited infrastructure, most of the water is available during the wet season, while water scarcity occurs during winter.

Given that the projected tendency is for rainfall to be concentrated in fewer months during the year, it is clear that the construction of reservoirs will be an important strategy for irrigation to provide water to agriculture under new projected dry scenarios. Adaptation measures in irrigation will need to follow three strategic pillars:

1. **Ensure an adequate supply of water for crops** through the construction of infrastructure for regulating and storing water. This will help address seasonal variation in water supply and increased requirements for crop water.

2. **Increase efficiency in water use and management** through improvements in water distribution infrastructure, improvements in irrigation application techniques, and technical assistance for a more efficient management of irrigation systems.

3. **Exploit residual urban water supplies for irrigation** through appropriate treatment before its application to crops.

Integration of climate change into national irrigation projects will not only imply reassessing projects that take into account additional crop water requirements, but also designing hydraulic infrastructure so that (a) the system has enough operational flexibility to assure an efficient use of water, taking into account seasonal variations in water supply; (b) infrastructure has the capacity to withstand extreme climatic events of greater magnitude than historically observed; and (c) infrastructure is designed with a longer lifetime and increased volume in mind.

Although it is an ambitious target to plan and implement additional irrigation infrastructure, it is important to pursue an integrated water management strategy. Drought-prone watersheds should emphasize the exploitation of surface resources in wet periods, allowing aquifer recharge and exploitation of available groundwater sources during dry season.

COMPARATIVE ANALYSIS OF STRUCTURAL ADAPTATION STRATEGIES IN IRRIGATION

Figure 14 represents the adaptation strategies and measures in irrigation that were considered and evaluated as important adaptation options: water storage and regulation, water harvesting, surface water catchments, sub-surface water catchments, and groundwater catchments.

Detailed analysis of each one is described in Annex 4. Specific attention was devoted to the analysis of large structures to estimate costs and feasibility.

Estimated Costs of Structural Adaptation Measures for Irrigation

A review of projects executed between 1995 and 2008 was used to construct a range of infrastructure costs[34] as a function of volume of water regulated for the main adaptation measures discussed in this study.[35] Figure 15 represents a distribution of the type of dams and associated costs to date. The green area represents dams with a high cost-benefit ratio. These are dams that have already been built in places with the highest potential; thus, rehabilitation would be the only option to climate-proof these structures. The pink area represents the majority of the dams built in the valley area and the Altiplano. The construction of these dams has followed certain eligibility criteria that limit the amount of investment per irrigated hectare and household.

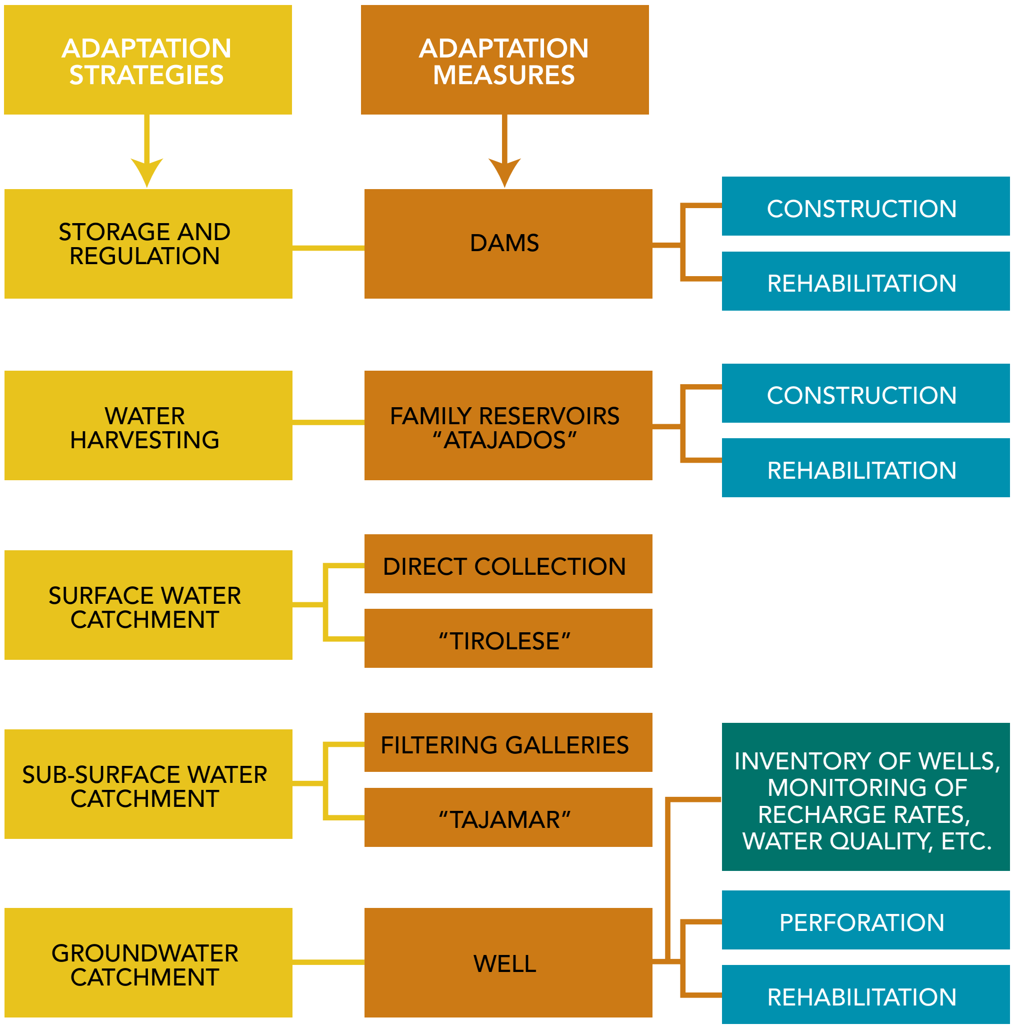
The current outlook for new construction of dams is outside of the eligibility criteria established at the sector level, meaning that there are not many eligible areas left for new dams that would represent a high benefit/cost ratio for investors. Therefore, in order to integrate climate change impacts, these criteria should be made flexible enough to allow for a greater number of households to benefit under the future climate change challenges. The blue area in the graph represents the current situation where there is a lower benefit-cost ratio under new initiatives. A summary of the water infrastructure project costs is presented in Table 13.

"Atajados" is another relevant infrastructure for water collection at the local level. These water catchments are normally implemented as water harvesting projects that include several atajados for a community. This type of measure has been very popular in local communities due to its lost cost and maintenance needs. An atajado is constructed for every family; the typical cost is \$3,500 to \$5,500, with a storage capacity between 1,000 and 2,500 m^3.

34 Costs have been standardized to 2009 bolivianos based on a index of construction costs available at the National Statistical Institute.

35 This range of costs is based on a relatively small sample of projects and should not be interpreted as the true values. Furthermore, it should be noted that the country has very diverse physio-geographic characteristics, which implies that projects with similar volumes have significant differences in costs.

FIGURE 14 **ADAPTATION STRATEGIES AND MEASURES**



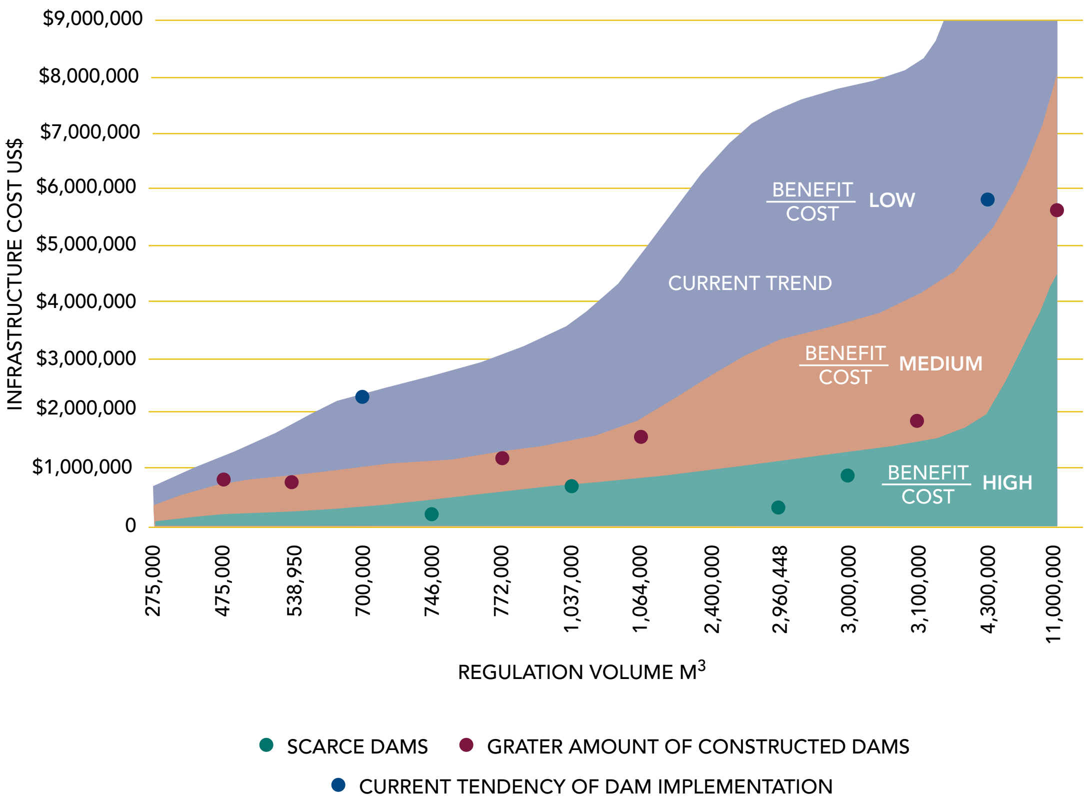
In the case of high-technology irrigation systems, the cost is between $2,800 and $3,600 per hectare,[36] depending on the area where it is installed. In addition to this cost there are operation and maintenance costs, as well as training costs. The benefit of these systems is the possibility of doubling the efficiency of applied irrigated water.

36 Manual de Riego Tecnificado - PIEN - 2008 (P. Hoogendam – C. Ríos)

ESTIMATION OF ADDITIONAL STORAGE CAPACITY FOR IRRIGATION AND ESTIMATED POTENTIAL COSTS

This section presents a theoretical framework to estimate adaptation requirements for additional storage capacity needed to provide water for irrigation in periods of water deficits. The underlying objective is to compensate for the new variation in water supply due to climate change for a given

FIGURE 15 WATER SUPPLY VS. COST—DAMS



agriculture water demand. Projections of agriculture water demand were based on assumptions about the future expansion of irrigation in the country (see Annex 4).[37]

The estimation of adaptation needs and stylized cost of storage capacity follows a four-step approach: (1) estimation of water supply in 2050; (2) estimation of water demand in 2050; (3) estimation of monthly accumulated deficit (supply and demand balance); and (4) estimation of the total cost of adaptation, defined in terms of the cost of building additional storage capacity (see Annex 4).

37 Due to time and data constraints, additional crop water requirements due to higher temperatures were not considered in the estimation of agriculture water demands. Furthermore, the amount of infrastructure for storage capacity is assumed to be constant with respect to the present; in other words, there is no growth of storage capacity in the no-climate-change baseline.

TABLE 13 SUMMARY OF INFRASTRUCTURE COSTS

Regulated Volume m3	*Infrastructure Costs $US*
DAMS	
275,000–600,000	300,000–825,000
600,000–1,000,000	220,000–1,700,000
1,000,000–3,000,000	340,000 –1,600,000
3,000,000–4,300,000	900,000–5,900,000
4,300,000–11,000,000	5,600,000–5,900,000
SURFACE CATCHMENTS	
70,000–200,000	39,000–140,000
200,000–325,000	110,000–278,000
325,000–560,000	184,000–280,000
560,000–1,300,000	280,000–505,000
SUB-SURFACE CATCHMENTS	
70,000–200,000	50,000–135,000
200,000–300,000	93,000–187,000
300,000–400,000	147,000–325,000

TABLE 14 CHANGES IN WATER SUPPLY FOR DRY AND WET CLIMATE SCENARIOS OF 2050

Percentage Variation with respect to the baseline								
SCENARIO	Santa Cruz	Cocha-bamba	La Paz	Oruro	Potosí	Tarija	Chuqui-saca	National Average
DRY	+0.60%	-6.79%	-10.45%	-15.08%	-10.99%	-3.29%	+1.63%	-6.34%
WET	-7.33%	+8.19%	+17.72%	+14.40%	+14.38%	+9.16%	+3.08%	+8.51%

TABLE 15 PROJECTED ANNUAL IRRIGATION WATER DEMAND IN 2050

Measured in millions m3							
Santa Cruz	Cocha-bamba	La Paz	Oruro	Potosí	Tarija	Chuquisaca	Country total
456.28	443.70	261.96	169.21	654.08	426.87	402.15	2,814.25

Estimation of Water Supply for 2050

Estimating changes in water supply is described in detail in Annex 1. For comparison purposes, monthly water supply was aggregated from the river basin to the department level for the seven departments that apply irrigation in the country. Table 14 contains the variation of monthly water supply for the two climate scenarios studied. The variation is measured in percentage terms compared to the present situation.

The national average of changes in water supply shows an increase in water supply of 8.51 percent for the wet scenario and a decrease of 6.34 percent for the dry scenario. Santa Cruz (plains) exhibits a reversal in trends for the dry and wet scenarios, which can mean that more rain will occur in the dry season.

Estimation of Water Demand for 2050

The estimation of future irrigation water demand (up to 2050) was based on existing calculations to 2015 by the Vice-Ministry of Irrigation, taking into account the projected expansion of irrigation and the trend for increasing water regulation to accommodate irrigation in the dry season. According to the National Inventory of Irrigation Systems, almost 70 percent of irrigation systems provide water in the wet season, while 30 percent provide water in the dry season. In order to identify future storage needs, it was assumed in these new calculations that there will be a need to use 70 percent of irrigation water during the dry season (from April to November) by 2050. Table 15 presents annual irrigation water demand in 2050 by department.

Water Supply and Demand Balance in 2050

A monthly water supply and demand balance was done to estimate a shortage of water in the dry season or an excess of water in the wet season. By comparing both figures, it is possible to obtain estimates of the additional water needs to alleviate the monthly deficits that could potentially be obtained from water storage of monthly surpluses. The monthly deficit for the dry periods was aggregated for the entire year to obtain the annual storage capacity needs at the department level by 2050 (Table 18).[38]

As shown in Table 16 for Santa Cruz, the GCM project changes of rainfall precipitations will also be erratic even under the wet scenarios. This suggests that rainfall could be concentrated in shorter periods during the wet season, which means that monthly water deficits can also occur

38 It should be noted that this monthly balance cannot take into account additional irrigation needs during periods of drought occurring in the wet season; therefore these estimations may have a downward bias.

TABLE 16 **TOTAL ACCUMULATED DEFICIT OF WATER FOR IRRIGATION**

Measured in millions m3								
SCENARIO	Santa Cruz	Cocha-bamba	La Paz	Oruro	Potosí	Tarija	Chuqui-saca	National Average
NO CLIMATE CHANGE	9.62	39.16	2.62	29.69	220.82	68.79	77.33	448.03
DRY	11.37	51.11	11.88	35.34	240.74	72.46	81.06	503.95
WET	11.76	42.54	3.72	31.84	220.06	67.03	80.01	456.96

TABLE 17 **TOTAL ESTIMATED COSTS FOR WATER INFRASTRUCTURE NEEDS TO 2050**

	Estimated Investment cost US$		
Department	No Climate Change	Dry Climate Scenario	Wet Climate Scenario
Santa Cruz	10,311,396	12,179,669	12,598,115
Cochabamba	41,959,327	54,758,218	45,573,934
La Paz	2,805,019	12,725,095	3,983,341
Oruro	31,806,015	37,866,677	34,119,795
Potosí	236,592,155	257,931,679	235,780,328
Tarija	73,705,418	77,634,335	71,823,380
Chuquisaca	82,849,966	86,854,946	85,720,325
TOTAL	**480,029,296**	539,950,620	489,599,217

in the wet season (see Annex 4, Figure 13 for further details).

Estimation of the cost of implementing irrigation actions as adaptation measures

The cost of building or restoring water storage to adapt to new irrigation is defined by the cost of building additional storage capacity to compensate for the increase in the annual water deficit due to climate change. This cost was obtained for the two extreme hydrological scenarios in order to obtain a possible range of costs in addition to a baseline cost with no climate change (Table 17). The estimated additional storage capacity does not take into consideration additional water needs during the wet season due to data limitations.

The estimated cost of increased adaptation measures for irrigation is around \$60 million for the dry climate scenario, and \$12 million for the wet scenario to 2050. These costs are in addition to the baseline estimated cost to meet water storage needs without climate change (Table 18).

It should be noted, however, that the definition of adaptation actions and its costs for the irrigation component is a narrow one. Additional costs stemming from the optimization of water uses—such as improvements in existing infrastructure or technical assistance to improve the application of irrigation—should also be considered.

Water Supply and Sanitation in Urban Areas

VULNERABILITY TO CLIMATE CHANGE

Cities relying on a single water source are more exposed than those relying on different sources. Almost all urban areas within the plains region

TABLE 18 ADAPTATION COST FOR CLIMATE CHANGE SCENARIOS

	DRY CLIMATE SCENARIO		WET CLIMATE SCENARIO	
DEPARTMENT	Additional Storage Needs (m^3)	Estimated Investment US$ **	Additional Storage Needs (m^3)	Estimated Investment US$ **
Santa Cruz	1,743,721	1,868,273	2,134,271	2,286,719
Cochabamba	11,945,632	12,798,891	3,373,634	3,614,607
La Paz	9,258,737	9,920,076	1,099,767	1,178,321
Oruro	5,656,619	6,060,663	2,159,528	2,313,780
Potosí	19,916,889	21,339,524	0	0
Tarija	3,666,989	3,928,917	0	0
Chuquisaca	3,737,981	4,004,980	2,679,002	2,870,359
COUNTRY TOTAL	55,926,569	**59,921,324**	11,446,202	**12,263,787**

* It is assumed and average consumption of 7,000 m^3 per irrigated hectare
** It is assumed an investment cost of 7,500 $us per hectare irrigated by a water storage infrastructure

rely exclusively on groundwater. Other cities—such as Sucre or Bermejo—rely exclusively on surface water. In areas where supply is already below demand levels, critical situations can be exacerbated by a potential drought, bringing additional water restrictions on the population.[39] Such cities are especially vulnerable because surface resources tend to be more susceptible to changes in precipitation and therefore their capacity is reduced before groundwater sources. The cities of La Paz/El Alto, Potosí, Yacuiba, Tarija, and Cochabamba rely on sources without enough capacity to satisfy demand (see Annex 1). Yet, there are also cities like Camiri, which is completely reliant on groundwater sources that have suffered severe restrictions during dry periods. Water quality in the raw source also can be affected by biological contamination or other activities like mining. The lack of adequate protection of the sources increases their level of exposure.

In many cases—such as Cochabamba, Sucre, or Tarija—the competition for water resources is high, and social conflicts are frequent between the urban utility and different user communities. These conflicts are likely to increase if the resource becomes scarcer. This is an important point to consider in all the areas that have already reached the capacity of their source, since any decrease in natural supply caused by climate change will reduce per capita consumption and bring it down to dangerous levels. The problem of relying on a weak water source can also reinforce other types of social vulnerabilities. For instance, during the drought of 1997 in Cochabamba, tariff collection rates dropped abruptly since consumers did not pay for a service they were not receiving (CAF, 2000). Moreover, in critical situations, utilities have to purchase water from other sources.

Climate change will affect the capacity of the urban utilities to deliver water and sanitation services and also the capacity to control floods, since they will become more frequent and intense, especially in the plains areas. A summary of potential climate impacts on the urban water sector is shown in Table 19. The principal urban areas of the country are exposed to different climate change effects that threaten their capacity to provide safe water and sanitation. Cities placed in the head of watersheds in the Altiplano and valley regions—such as La Paz-El Alto (Titicaca and Beni basins), Sucre,

39 During the drought of 1997 there were severe water restrictions in the urban areas of Cochabamba, Sucre, Potosí, Bermejo, and Tarija (all of them using surface resources).

TABLE 19 KEY CLIMATE VARIABLES IN RELATION TO THE URBAN SECTOR

Climate Change Effect	*Impact*
Temperature increase/ higher evapotranspiration/ decrease in natural supply	Increase in water demand due to temperature increase/Problems of food security/Impacts in agriculture in the rural sector may trigger important increase in rural to urban migration, creating strong/unexpected increases in water demand/utility is not able to satisfy demand levels
	People without safe access may suffer important health impacts since unprotected sources might disappear or present poorer quality
Greater precipitation variability/ longer dry periods	Storage capacity might not be enough to supply water during the dry season
Floods	Damage in urban infrastructure
	Water quality worsened

Potosí (Parapeti-Pilcomayo), and Cochabamba (Grande)—are more prone to be exposed to threats affecting their water source, since water availability in those areas is significantly less than downstream of their corresponding basins. These cities are highly exposed to decreasing rainfall trends, unexpected changes in seasonality, and prolonged droughts.

The case of La Paz-El Alto is particularly worrying due to the disappearance of the glacial contribution to the superficial runoff, which, though not properly quantified, will provoke a reduction in the amount of natural water supply and pose an extra threat on this metropolitan area where demand has already matched supply[40]. A detailed description of each of the vulnerability indicators, measuring both climate change effects and vulnerability of the water utilities, is presented in Annex 1.

For Cochabamba or Santa Cruz basins, the changes shown by the wet and dry scenarios are similar. In Santa Cruz, studies have predicted that current supply[41] levels, without taking into any climate change effect into consideration, would satisfy demand up to 2022. Graphs show, with both wet and dry scenarios projecting a decrease in natural water supply, that the gap between supply and demand will close earlier than what is currently expected. A similar situation exists for Cochabamba, which is currently not meeting the demand by a gap of almost 50 percent. Both climate change scenarios forecast a decrease in natural supply aggravating the problem.

ADAPTATION OPTIONS FOR THE URBAN WATER INFRASTRUCTURE

The guiding principle to adaptation in urban areas should be, as for rural areas, to develop faster.[42] The strategy consists of increasing the capacity of water utilities to supply safe water and sanitation services for the entire population. This

40 The water supply system of La Paz-El Alto suffered a scarcity alert in the wet season of 2008, which was repeated in the fall of 2009. Emergency measures—such as drilling emergency wells—were implemented to meet demand levels in those periods.

41 These studies were mentioned in the Strategic Development Plans.

42 The separation of adaptation from development costs often refers to the concept of the "adaptation deficit," which captures the notion that countries are underprepared for current climate conditions, much less for future climate change. Presumably, these shortfalls occur because people are underinformed about climate uncertainty and therefore do not rationally allocate resources to adapt to current climate events. The shortfall is not the result of low levels of development but of less than optimal allocations of limited resources, resulting in, say, an insufficient urban drainage infrastructure. The cost of closing this shortfall and bringing countries up to an "acceptable" standard for dealing with current climate conditions—given their level of development—is one definition of the adaptation deficit. The second use of the term captures the notion that poor countries have less capacity to adapt to change, whether induced by climate change or other factors, because of their lower stage of development. A country's adaptive capacity is thus expected to increase with development. This meaning is perhaps better captured by the term "development deficit."

should be done by addressing the vulnerabilities indicated in this analysis. Water supply and sanitation utilities need to take climate change into account when developing their strategic plans in the long term. In this sense, a major concern of urban planners or utility managers will be how to manage the uncertainty associated with climate change. A reasonable approach would be to estimate the minimum threshold level of natural supply of water (or the threshold in rainfall seasonality) at which the utility would have problems in delivering a safe service. Next, we estimated the probability for that threshold to occur given the different predictions from the climate models. The problem with this approach is that, on one side many utilities are already under or have already reached that threshold without having to deal with climate change; on the other, the current climatic data available still does not allow for estimation of that probability with sufficient accuracy.

Adaptation options for urban development can be divided into three categories, supply-side adaptation options, demand-side options, and integral measures and flood control.

Supply-side adaptation options

Reinforce, improve, protect, and diversify water sources. This is necessary in order to strengthen the production capacity of the urban utilities, especially in cities of the arid regions like

La Paz, Cochabamba, or Sucre, but also others, including Bermejo or Guayamerin. Taking climate change into consideration in the utilities' development plans implies determining the point at which it would be necessary to strengthen the production capacity of the utility, not only to deal with expected increase in demand, but also to be able to supply water safely during drier periods.

In addition, it will be necessary to ensure protection against extreme rainfall events. This is particularly important for urban centers located in areas with strong rainfall seasonality.

Protect water sources to guarantee quality. Hydrogeological studies are being developed in the area of El Alto in order to determine the dynamics of the source. Similar studies would be required for areas with high pressure on water resources such as Cochabamba. In some cases, analyses have begun but have not been completed.

Extend water supply infrastructure to the entire population, including peri-urban areas. This is a development target already acknowledged in the National Sanitation Plan. If the target is met, nearly all of the main urban centers would boast universal coverage for water and sanitation by 2050.

Review storage capacity. A review of storage capacity is necessary to ensure that the existing capacity would consider additional losses due to an increase in evaporation rates and changes in rainfall variability, as well as to climate-proof these storage facilities for floods. In addition, urban planners would be able to anticipate future growth rates of different cities.

Improve sanitation infrastructure. It is important to increase the number of houses connected to the sewerage network and to treat and discharge effluent safely. Moreover, since increasing the number of houses connected to the sewerage network will take time, it would be necessary to reinforce the existing on-site sanitation options in nonconsolidated urban land, making them flood-resistant, only as a temporary measure before those areas are incorporated into the network.

Demand –side adaptation options

Ensure that tariff structures are progressive. Demand-side options would be particularly necessary for all the urban areas of the arid zone in the Altiplano, valleys, and Chaco regions, and more specifically for those presenting high population growth rates. However, given the current situation of the urban water sector, supply-side adaptation options still are the first priority. Utilities should ensure that tariff structures are progressive, guaranteeing access for basic consumption and increasing pressure for high nonproductive uses. In case consumption rates increase in the future, supporting the implementation of reutilization measures at the household level should be also considered, like simple small bio-filters to reuse water from the basin to flush toilets.

Integral measures and flood control

Incorporate utilities' development plans into watershed development plans. This strategy promotes the inclusion of cities as an important element of watershed management so they are integrated into the water management strategies planned for the entire basin. Water use can then be quantified and compared to natural supply in that watershed in order to plan a sustainable coexistence among all rural/urban users. Moreover, integrating the city as one element of the watershed facilitates assimilation of the "hydrometeorological risk" concept as a key characteristic of urban planning instruments. City planners might be able then to determine risky areas where, for instance, construction should not be permitted, or to detect crucial zones where infrastructure is at risk during floods or extreme rainfall events. In many cases, it is more cost-effective to implement an early warning system than to review, rebuild, or overbuild a drainage system in consolidated urban land. However, as mentioned above, these warning systems only make sense if they are framed in the physical context of the watershed.

SIX

Local-level Perspectives on Adaptation to Climate Change

The livelihoods of the poorest families in Bolivia are based on rainfed agriculture, small-scale livestock farming, and seasonal labor. Better-off families engage in livelihood activities based on a combination of rainfed and irrigated agriculture, livestock farming, nonagricultural work, and temporary migration. Those households most resilient to climate change have livelihood strategies based on irrigated agriculture with less of a rainfed component, semi-free-range livestock farming or large-scale livestock farming, dairy, and occupations in the services sector. The most vulnerable families are those that have elderly, handicapped, and young members, as well as female-headed households.

For the purpose of this study, focus group discussions, community workshops, expert interviews and household interviews were conducted in fourteen municipalities[43],[44] (see table 20).

TABLE 20 NUMBER OF MUNICIPALITIES STUDIED FOR THE SOCIAL COMPONENT, BY MACRO-REGION

Macro-region	*Number of municipalities*
Altiplano	4
Valleys	5
Chaco	2
Plains	3
Total	14

The poverty levels of 70 interviewed households were classified based on indicators such as land tenure, livestock holdings, family prestige, children's occupation, and type of housing[45]. Figure 16 presents the socio-economic stratification of the interviewed families. This was a relative classification, constructed by comparing one family with another, recognizing that what constitutes poor families in one community may be very different in other communities. Nonetheless, this classification allowed for an approximation of the assets holdings of each level. Those families

43 The methodology consisted of a literature review, sampling to identify the municipalities most vulnerable to climate change today and fieldwork. For the fieldwork, a total of 42 key informants and seventy households (five households per community) were interviewed; forty-five focus group discussions on livelihood strategies were conducted; one national workshop took place with experts of each region under study; and fourteen workshops that used participatory scenario development techniques were held with community representatives of each selected municipality. Fieldwork was conducted by nine private institutions selected for long-standing experience in the municipalities.

44 A general methodology for the social component was developed by the central EACC team in Washington. Local consultants tailored this methodology to fit the Bolivian context and best characterize vulnerability to climate change within the local context. See Annex 5 for more information on methodology of the social component

45 In the study areas, all of the families are considered to be poor according to the definition of poverty from the National Institute of Statistics.

considered least poor have assets that are five to ten times superior to those of the poorest families. Salient differences in socioeconomic status are mostly explained by ownership of livestock and arable land. The region with the greatest inequality is the Plains macro-region, where indigenous and peasant communities live side-by-side with the agro-industry, large-scale cattle breeders and timber industries.

Past Adaptation and Coping Practices

We interviewed 70 households about past coping strategies in the event of a flood, drought, hailstorm, and/or frost. Fifty percent of those interviewed did not engage in new activities to manage the extreme event. These families were either unaffected by the climate event and had relatively strong adaptive capacity, meaning a diversified livelihood strategy with income-generating activities not sensitive to climate, or had too few resources to invest in new adaptation measures and in some cases survived by consuming less food or resorting to reserves. In the latter group, households that continued their traditional livelihood strategies did so despite the fact that after many years of adapting to climate change, their coping strategies were no longer sufficient. Those mostly consisted of elderly, children, handicapped people, and single women with few resources who generally relied on assistance from families or neighbors.

> *…I dedicate myself to milk production; I have a few cows and in addition, I go from house to house to pick up milk and I sell everything to a business. When there was drought, milk production fell by half due to lack of forage for the animals. I had to survive on this. I don't have a husband and my children are too young to go work and I cannot abandon my household….*
> *(Case of Juana Mamani, 37 years old, Municipality Pucarani, Highlands)*

The remaining 50 percent of households interviewed engaged in a diverse range of adaptations. Some integrated new activities to their livelihood strategies—for example, temporary

FIGURE 16 SOCIOECONOMIC STRATA OF LOCAL COMMUNITIES

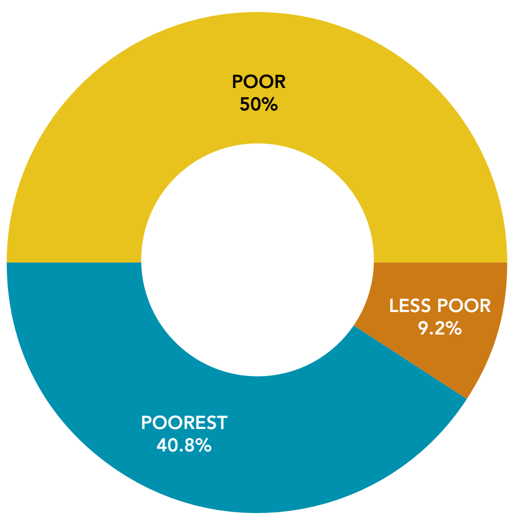
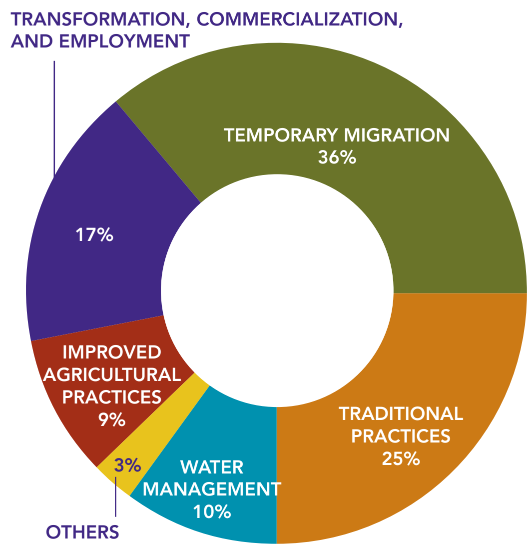


FIGURE 17 PAST RESPONSES TO CLIMATE EVENTS



migration—and others pursued the same activities but experimented with ways to improve their traditional practices. Figure 17 summarizes the adaptation activities of these families.

Of the 70 households interviewed, 25 households resorted to temporary migration. These families had not previously engaged in migration but felt it necessary in order to compensate for economic losses (see also Annex 5 for the complete Social Component Report).

Results reveal that in order to adapt to changes in climate, 17 percent of households interviewed developed new livelihood activities such as the production of artisan goods or engaging in trade or local work. This analysis further shows that the majority of households who did adapt to climate events resorted to an average of one new adaptation measure per event in an attempt to compensate for losses. Twenty-five percent of families reverted to ancient indigenous practices, including rituals to call for rain, creating smoke to combat frosts, and lighting fireworks to combat hailstorms.

During the local community workshops, participants discussed the autonomous changes they have pursued in the past with a view to later discussing the types of adaptation measures that will be necessary in the future. In the past, production systems have gradually changed with little external support from the state or local institutions. The majority of these changes are undertaken autonomously and at their own cost, without prior planning. As with all innovations in farming, the process takes many years and is conducted on a "trial and error" basis. Once local strategies are deemed successful, municipal governments and local institutions—at the solicitation of communities—have taken some of these innovations and translated them into large-scale projects. Irrigation and protective infrastructure projects have been introduced in such a manner in five of the studied communities.

USING SCENARIO DEVELOPMENT EXERCISES TO ENVISION FUTURE ADAPTATION PRIORITIES

Based on their climate observations over the past 20 to 30 years, all community members that participated in the study believe that future climate will be characterized by higher temperatures, water scarcity, more irregular rainfall, and a shorter but more intense rainy season. Only in the Amazon region do community members expect that rain will fall more frequently than before, causing increased incidence of flooding. The adaptation measures prioritized by the communities were specific in terms of their needs, the number of beneficiaries at stake, types of past experiences dealing with climate hazards, their own cultural criteria, and considered economic values. With the objective of finding tendencies emerging from this diverse and complex set of adaptation strategies, the measures have been classified into eight types:

- Water management
- Infrastructure
- Improved livestock farming
- Improved agricultural practices
- Better environmental management
- Training and capacity building
- Credit and finance
- Transformation and employment

Table 21 and 22 below presents a very wide variety of community livelihood strategies in the Plains and Altiplano regions of Bolivia, respectively. This diversity of options can be explained by the following factors: first, each strategy tends to reflect the specific concerns of an individual community, especially regarding the extent to which the community is exposed and sensitive to climate change. Adaptation measures identified by communities and the order of priority assigned to each also mirror the kind of measures or investments that have been pursued (or not) in the community in the past. In effect, this shows how preferred

TABLE 21 PRIORITIZED ADAPTATION STRATEGIES (PLANNED AND AUTONOMOUS) BY COMMUNITY IN THE PLAINS REGION

San Isidro (Yapacani Municipality)	*Puerto San Borja (San Ignacio Municipality)*	*Agosto 15 (Yapacani Municipality)*	*Valparaiso (San Pedro Municipality)*
Water supply system for cattle	Construction of water hole (*aguada*)	Emergency water recovery and Educational Center	Community flat boat to transport produce to market
Construction of social housing	Family plots to be fenced off	Construction of defenses on the River Yapacaní	To plant fast-growing vegetables
Improved dual-purpose cattle	Grain storage system	Repair of 5 km of main road in the Agosto 15 community	Domestic irrigation using waterwheels in orchards
Construction of the Condorito Bridge	Irrigation pumps to be installed	Installing windbreaks in rice paddies	30 irrigation pumps for irrigating family orchards in the Valparaiso community (with river water)
Pilot centre for apiculture improvement	Construction of artificial terracing	Restarting rice production in the Agosto 15 community	10 irrigation pumps for lifting river water to irrigate family vegetable plots
Controlling high incidence of weeds in pastures and orchards	Construction of furrow terracing (*camellones*)	To diversify agricultural production by planting citrus and cocoa	
Joint production of citrus and coffee			
Diagnostic study on flowering times of local plants			

Source: community workshops

adaptation strategies depend on the recent history of a particular community. For example, communities that have benefitted from investments in water management schemes that have resulted in safer drinking water do not consider water management for improved drinking water to be necessary for their future livelihood strategy as they do not view the current system as inadequate.

The presence or lack of institutions is a second determinant for identifying, prioritizing and sequencing adaptation strategies in Bolivia. Where local authorities and privatized institutions have a history of supporting development, community members will count on their continued support and prioritize measures that require external support. Where institutions do not have a strong presence, prioritized adaptation options will not be based on major external support.

With regards to migration, rural communities' consideration of migration as a viable and preferred adaptation strategy was strongly influenced by social preferences. Temporary migration was not prioritized as an adaptation measure in the studied communities. Rather, the logic of the communities in the identification of adaptation measures was, "What should we do to adapt so that we do not have to abandon the community?" A woman from the municipality of Beni in the Plains region argued:

> *"We do not want to move the community; for the authorities this is the easy way out. We want to stay in the community, even if floods occur. It cost us dearly to move our community to this place and it is now in a strategic location, everybody passes by our port. Assistance should focus on helping us to stay in our own place, not to help move us."*

Thus, social preferences may be more influential determinants of adaptation preferences than economic rationale. From the above example, one can see that populations will not always opt for

TABLE 22 PRIORITIZED ADAPTATION MEASURES BY COMMUNITY IN THE ALTIPLANO REGION

Chaquilla (Porco)	Contorno Calacoto (Calacoto)	Pampajasi (Pucarani)	Jila Manasaya Uta (Curawara Carangas)
Improved water irrigation management systems to streamline water use and reduce silting	Construction of wells and water catchment facilities	Construction of a dam	Construction of multifamily water system
Construction of new irrigation channels to include water tapping facilities and water flow chambers for efficient irrigation.	Construction of reservoirs	Construction of reservoirs	Drilling wells and installing hand pumps for drinking water
Measures to recover degraded wetlands (fencing, fertilization, irrigation and replanting)	Improvement of pastures and fodder	Build infrastructure for dairy herd management	Improving family wells and installing hand pumps
Training and user awareness to enable sustainable use of available resources.	Livestock Infrastructure	Management and improvement of agricultural production	Improvement of native grasslands with the construction of infiltration trenches and planting native grass seeds
Construction of roofed livestock shelters and other necessary infrastructure to upgrade production	Support for farming activities	Management and conservation of fodder	Construction of atajados for irrigating wetlands (bofedales)
Comprehensive animal health program	Management of low-interest loan finance	Improvement of dairy herds	
To improve reproductive and genetic management.	Technical training in various activities	To support the establishment of a body to produce and sell aggregates	
Training and awareness among livestock raisers for the sustainable production and handling of animals.	To organize a Producers Association	Vegetable production in solar-heated enclosures	
Construction and / or repair of defenses and retaining walls in cultivated terraced plots.	Improvement of productive infrastructure	Handling and production of potato crops	
Improvement of irrigation canals and water tapping facilities for efficient use of irrigation water.	Management and livestock genetic improvement		
Opening and / or construction of drainage ditches to prevent moisture damage to crops.	Processing and marketing of local products		
Organic farming using selected native species and varieties tolerant to adverse weather conditions.			
Training and awareness-raising of community residents to protect and preserve soils used for growing crops			

Source: Community Workshops

wealth maximizing options. In Bolivia, where land is closely linked not only with subsistence but also with culture and identity, indigenous populations may view remaining on ancestral land as more important than the pursuit of more lucrative endeavors elsewhere.

Notably, key informant and household interviews revealed that major discrepancies exist between the ways that local authorities and communities perceive adaptation to climate change now and in the future. Most local authorities interviewed consider climate change a problem that will arrive in the future and maintain that investment in infrastructure projects is the best form of adaptation. In contrast, communities consider climate change to be a reality today and discussed the need to define strategies that support fundamental transformations in livelihood activities, rather than individual "hard" adaptation measures.

SYNTHESIS OF FINDINGS ON LOCAL LEVEL PERSPECTIVES ON ADAPTATION

Rural and indigenous communities have a long and rich history of systematic observation of the climate; indeed, their survival depends on this capacity. Climate change and increasing climate variability mean that many of the climatic indicators used by these communities are becoming less effective. Community workshops revealed that due to an increasing inability to predict weather patterns, people are in need of new indicators to diagnose and predict future variability. Based on their climate observations over the past 20 to 30 years, all community members that participated in the study believe that future climate scenarios will be characterized by higher temperatures, water scarcity, more irregular rainfall, and a shorter but more intense rainy season. Only in the Amazon region is rainfall expected to fall more frequently than before, causing increased incidence of flooding.

Communities in the valleys and highlands prioritized adaptation measures related to water management, followed by improved agricultural and livestock practices. They view drought as the principle threat to their livelihoods. In contrast, communities from the Chaco and plains regions asserted that improved agricultural practices were a priority and considered water management measures to be of secondary importance.

The results also demonstrate that communities view adaptation strategies not as isolated measures or as single projects, but rather as a complex set of complementary measures that are comprised of both hard and soft measures. Infrastructure investments will be insufficient if complementary efforts are not made to promote capacity building, institutional development, and in many cases, fundamental transformation to underlying logic and livelihood strategies. In particular, adaptation strategies may imply major changes to production systems that will need appropriate technological and organizational adjustments as well. For this reason, understanding these adaptation measures as a hierarchy with a specific order of execution is essential, as some strategies will depend on the sustainable implementation of others.

SEVEN

Cost-benefit Analysis of Adaptation Investment Options

The cost-benefit analysis tool was designed to allow the integration of climate change variables into the development of cash flows with costs and benefits for climate resilient options. The analysis also tries to answer the question of how cost-benefit analysis for regular development projects can be affected by climate change. Such information can be useful for the distribution of national budgets and the prioritization and sequencing of adaptation options in future public expenditures. Detailed cost-benefit analysis was done on stylized adaptation options from two sectors—agriculture and water—based on selected adaptation options from the : National Mechanism of Adaptation to Climate Change (PNCC 2007, 1997) and also validated with the local agriculture and water resources sector experts. The empirical analysis allowed for the derivation of estimated costs of eight adaptation measures in the long term (30 years[46]). The water projects were aggregated in two components: provision of water supply and flood control. For this analysis, the infrastructure adaptation options that were analyzed included:

Water resources sector

- Irrigation (dam, derivation, harvesting, and undersurface)
- Treated water supply (dam, wells, and superficial water catchment)
- Flood control (hydraulic control and territorial management)

Agriculture

- Public research (ie: new crop varieties resistant to drought)
- Extension services (ie: introduction of new farming techniques)
- Rural roads
- Irrigation techniques (on cultivated land area)

The cost-benefit analysis was applied to a set of adaptation option in terms of financial values (market values) and in socioeconomic terms (shadow price). The analysis integrated climate change variables (temperature and precipitation) under dry (worst case scenario) and no-change climate scenarios[47]. Results were interpreted for these two climate scenarios.

46 The analysis evaluates primarily the useful life of projects without major investments for operations and maintenance. Thus it was not feasible to predict future reinvestments and cash flows of a project after 30 years.

47 At the moment of this analysis data from the wet scenario was not available. The dry scenario was considered the worst case scenario as "drought " as it remains one of the biggest challenges for Bolivia to be resolved in the high altitudes.

The cost-benefit analysis consisted of the following steps:

1. Estimation of investment cost at the project level

- Itemization of the physical, engineering, and/or biological components of each project
- Quantification of the physical amounts of materials for each item that will be used in the course of implementing the investment project
- Estimation of the market value for each component (both in financial and economic terms)

2. Estimation of avoided damages for each investment project

- Identification of all possible outcomes (avoided damages or benefits) from the implementation of the investment alternative
- Quantification of each outcome in physical units
- Valuation of each outcome both in financial and economic monetary terms (that is, at market and shadow prices)

All evaluated projects had positive socioeconomic analysis results (Table 23 below). This suggests that the projects are robust for any climate scenario and public investment in these areas is quite justified for the region. Similarly, all water projects (for irrigation use and flood control) also were positive as crop production on the particular irrigation area is expected to increase significantly if water provision is available, at least during the most critical phenological stages. These results are in agreement with the agriculture and water resources analysis presented before.

TABLE 23 COST-BENEFIT ANALYSIS OF ADAPTATION MEASURES IN THE AGRICULTURE AND WATER RESOURCES SECTORS

	Economic Analysis		Economic Analysis Baseline		Economic Analysis with Climate Change (dry scenario)	
Project Name	Investment Costs	Beneficiaries	Net actual value	IRR	Net actual value	IRR
WATER ADAPTATION PROJECTS						
Potable Water distribution Sapecho	3,440,553	2,199 Persons	3,428,089	24.0%	3,331,530	23.95%
Potable Water System San Pedro de Cogotay	408,345	140 Persons	8,105	12.91%	2,916	12.76%
Wells drilling Chapicollo	317,136	50 Families	187,383	17.35%	151,686	16.83%
Flood Control Caranavi	4,052,215	528 Houses	2,658,043	21.5%	2,658,043	21.5%
AGRICULTURE ADAPTATION PROJECTS						
Irrigation Dam San Pedro Aiquile	11,476,499	147 Ha.	2,583,295	15.74%	4,195,411	17.61%
Dam restoration Tacagua	313,623,524	907 Ha. (incremental)	(184,275,594)	2.65%	(171,580,897)	3.46%
Elevation of dam wall Tacagua Dam	120,457,550	907 Has. incremental	9,705,456	14.02%	21,563,503	15.66%
Irrigation by Derivation Buen Retiro Sur Paraisito	3, 686,740	178 Has.	17,260,185	71.02%	14,874,454	63.01%
Small water catchment "Atajados" Aiquile	1,951,407	32 Has.	115,778	13.94%	347,000	16.41%

In the agriculture and water resources studies, results suggest that the Altiplano will be favored by increased temperatures, while the oriental and Chaco zones will be negatively affected by increased temperatures and a reduction in precipitation. These results are in accordance with the spatial distribution of the selected projects, where depending on the area, the IRR is reduced due to these regional impacts. The agriculture projects show an increase of the IRR under climate change in the highland zones. This suggests that current planned investment in agriculture and water resources continue to be robust to climate change, at least under extreme condition. Thus, adaptation measures in Bolivia represent primarily good development strategies under climate variability.

The cost-benefit analysis presented above represents an example of the use of an improved economic tool for the evaluation of investment projects under a changing climate. However, the selection of projects is limited due to the availability of a narrow selection of projects (mostly water projects in the rural area), which do not include large infrastructure projects and urban areas. A detailed cost-benefit analysis is an important input to be used in the process of sequencing and prioritization of different investment adaptation options.

EIGHT

Methodology Investment Planning Tool (MIP)

for the Selection of Adaptation Options under Future Climate Uncertainty

Selection of Robust Strategies

The development of the Investments Planning Tool (Mixed Integer Mathematical Programming Model - MIP) is an example of investigation into the possible effect of climate change on irrigation development in Bolivia, identified as a major adaptation need in the agriculture, water resources, and social components of the study. The development of the case study intends to evaluate the effect of a changing climate on decisions to make durable investments. In particular, the model developed for this study permits the investigation of the effect on investment of (1) a budget constraint, (2) a decision to centralize or decentralize the investment decisions, and (3) the impacts of climate change. The results of this study are illustrative of the major issues. The watershed planning model developed for this investigation is also intended to become a practical, useful planning tool for the Bolivian authorities, to be refined and updated as additional climate and watershed data become available.

THE WATERSHED

The Mizque watershed is a sub-watershed of the Rio Grande macro-watershed, which has been identified as one of Bolivia's watersheds most vulnerable to climate change. This vulnerability is due both to the existing level of poverty in the watershed (Cedeagro 2005, Pronar 2005) and to higher expected impacts from droughts. The study results on water resources (Annex1) identifies the larger Mizque Basin (as defined in the National Watershed Plan) as being one of the more vulnerable in the country. However, its vulnerability is mainly due to a high proportion of people without access to water and sanitation, and its vulnerability to floods and droughts. It is a particular hot-spot when analyzing the urban sector due to high competition for water with irrigation. As part of the National Water Basin Promotion Program (PPPNC), the Ministry of Sustainable Development and Planning prepared the Integrated Management Plan for the Rio Mizque Watershed (Annex 3). The Rio Mizque watershed of the PMIC-Mizque is the downstream part of the larger Mizque watershed. The PMIC-Mizque study, published in 2005 (Annex 3), provided the background data for this study. These data include an inventory of potential irrigation projects along with their costs and principle characteristics, as well as a water balance by sub-basin.

In order to explore the effect of climate change on the economic and physical viability of the irrigation projects identified in the PMIC-Mizque study, the data were projected forward to 2090 (to allow model to readjust beyond 2050) and combined with 2090 climate projections to generate a mixed integer programming model. This model simulates the decision process of a planner who invests in irrigation programs through time to maximize the benefits they provide to the residents of the watershed. His/her investment choice is constrained by financial resources and water resources. Three different annual budget constraints are explored; $2 million, $4 million, and $6 million. Any money not spent can be saved (at the social discount rate) and accumulated for the future. As irrigation must compete with potable water and water for animals, two policies are explored: (1) decentralization of budgets to the sub-basin level vs centralized Mizque watershed-level watershed planning, and (2) maximizing the number of families receiving irrigation vs maximizing the economic benefits from irrigation.[48] The model was run under three climate scenarios, "wet," "dry," and the current climate.[49] These rainfall regimes correspond to those discussed in section 5 above.

Exploring the effect of budgetary decentralization was considered a high priority in the face of the potential conflict between the well-known benefits of watershed-level management and Bolivia's new policies to support budgetary decentralization. One of the objectives, therefore, was to see how important the possible tradeoff between maximizing overall watershed benefits and decentralized management might be, and how it might be minimized.

48 Benefits are maximized at a 0% discount rate and 6% discount rate.

49 Present supply levels were reported by the PRONAR study. In order to determine CC scenarios and changes in water availability, present and future annual runoff values for the Mizque basin were determined using CLIRUN-2 software. Data from 17 GCMs were analyzed and dry and wet scenarios were chosen as a function of the highest decrease and increase in runoff respectively. Those turned out to be the GFDL 2.1 model as the wet scenario with an expected increase in annual runoff of 16 percent; and the CCCMA model for the dry scenario with a 24 percent decrease in annual runoff for 2050. These two percentages were applied to the present supply reported by sub-basin in order to obtain future annual runoff.

DATA

The data for this study were provided by the PMIC-Mizque study. This study provides the following, which were used by the current adaptation study: (a) a water balance for the 22 sub-basins in the watershed; (b) projections of future water demand up to 2014; (c) identification of 74 potential irrigation projects in the watershed; (d) investment cost, number of families benefited, and additional irrigated hectares for each project; (e) cropping patterns and water demand by cropping pattern in each sub-basin; and (f) cash-flow by cropping pattern in each sub-basin.[50]

METHODOLOGY

The methodology for the Investment Planning Tool was designed using development plans for the Mizque Watershed by the National Watershed Plan (Plan Nacional de Cuencas, PNC). The use of the official data provides an opportunity to validate and evaluate identified potential projects under the new climate change constraints. This represents a plausible way of integrating adaptation to climate change into development plans in regard to the prioritization and sequencing of projects within a planned portfolio, but taking a changing climate into consideration.

As described above, a mixed integer mathematical programming model (MIP) was constructed to extend the PMIC-Mizque study to a 50-year future time horizon and to put it into an optimizing framework.[51] This framework permits the model to choose the optimal investment program

50 For several crops in the water balance table, net revenue was not available. For these (minor) crops, net revenue was estimated based on closely related crops for which information was available, following consultation with Bolivian agricultural experts.

51 The study's time horizon was 90 years. This was considered necessary to adequately consider investments that would be made over the next 50 years. This is the case because projects were considered to have a 20-year life with the option to reform them at half the cost for an additional 20 years. Thus any project built in 2050, for example, would be considering possible benefits up to 2090.

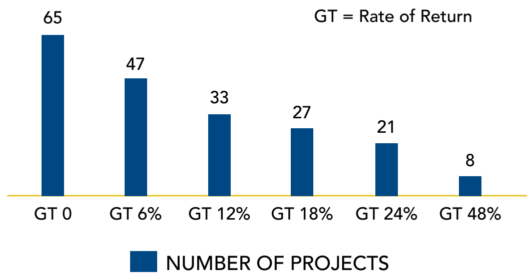
over the 50 years under (1) varying budgets, (2) two different decentralization policies, and (3) different objectives to be maximized—overall social benefits and number of participating families. Through the application of the model, the study evaluates the effect of climate change on the government's future investment program as identified by the PMIC-Mizque study. This required assembling the PMIC-Mizque data to create 74 investment projects. Each investment project has an initial investment cost, future operations and maintenance (assumed at 1 percent per year of initial investment) and net farmer revenue. Each project also requires a quantity of irrigation water as determined by the cropping pattern in the sub-basin. New irrigation projects in each sub-basin must compete for water with existing irrigation projects, potable water, and livestock. Available water is adjusted for climate change. UN projections are used as the basis for projected urban and rural population growth rates to 2050. Three climate scenarios are investigated; a baseline scenario that projects current climate and water availability forward, and a wet and dry scenario. Combing the project investment costs, cropping (net) revenue, and an assumed O&M cost of 1 percent, the 74 potential irrigation projects yield the distribution of internal rates of return (IRR) shown in Figure 18.

As shown in Figure 18, of the 74 projects, 65 have a social rate of return[52] greater than 0 percent and 47 have a social rate of return greater than 6 percent. Investment in an irrigation project may be made in any year between 2010 and 2050[53]. Projects are assumed to have a 20 year life after which they may (optionally) be refurbished at a cost of 40 percent of the initial investment. Investing in a project creates the option to irrigate. If

52 "Social rate of return" means the return on all costs and benefits, to whomever they may accrue.

53 To permit investment in the end of the period, which will only benefit following 2050, the model was optimized with a planning horizon to 2090. For the climate scenarios the transition from the current to the2090 climate was assumed linear based on the 2050 projection.

FIGURE 18 DISTRIBUTION OF CALCULATED INTERNAL RATES OF RETURN (IRR) ON 74 IRRIGATION PRONAR PROJECTS



sufficient water is not available the irrigation system may be operated below capacity. However, the economic decision to construct the irrigation project takes this under-use into account at the time of the investment decision.

Simulations explore the effect of climate change within the context of (1) the tradeoff between the number of families directly benefited and the national social benefits, (2) different budget constraints ($2, $4, and $6 million per year), and (3) differing social discount rates (0 percent and 6 percent), and (4), a decentralized and a centralized budgetary policy. As illustrated in Figure 18, at a 0 percent discount rate, 65 of the 74 projects are economically viable. At a 6 percent discount rate, the number of viable projects reduces to 47. The budget constraint serves to ration the number of projects that can be built in any given year. Savings are permitted (at the discount rate) to permit the accumulation of resources to afford large projects. In all, the runs reported the budget constraint permits implementing all the projects over the 40 years. A tighter budget constraint simply slows the rate of implementation.

IDENTIFICATION OF CLIMATE-RESILIENT INVESTMENT ALTERNATIVES: EXAMPLE OF THE MIZQUE WATERSHED AND IRRIGATION CASE STUDY

These include an inventory of potential irrigation projects along with their costs and principle characteristics, as well as a water balance by sub-basin. In order to explore the effect of climate change on the economic and physical viability of this potential investment program, the data were projected forward to 2090 and combined with 2090 climate projections to generate a mixed integer programming model. This model was then used to explore the effect of climate under various climate, policy, and budget scenarios.

Effect of climate change. Relative to the current climate, the effect of the "dry" climate scenario is to reduce potential social benefits of the PMIC-Mizque irrigation program by 3–5 percent. The effect of the "wet" scenario is to increase benefits by 1–3 percent. The effect on the number of families benefited is very similar. These results vary somewhat at different levels of the budget constraint and between the two watershed management policies (decentralized and centralized).

Effect of decentralized management. A policy of decentralized investment was simulated by imposing budget restrictions at each subwatershed rather than at the level of the Mizque watershed as whole. These subwatershed budgets were calculated to keep per capita investment equal across all subwatersheds. A policy to decentralize budgets to the sub-basin level reduces potential benefits significantly more than climate change. This is true whether the objective is to maximize national social benefits[54] or to maximize the number of families benefiting.[55] The effect of decentralizing the budget to the subwatershed level is to reduce social benefits and/or number of families directly benefiting from the projects by between 2 percent and 30 percent. This effect is least when the budget constraint is loose (there is more money to invest) and where projects must pass a stricter cost-benefit test. It grows as the budget constraint tightens and the cost-benefit criteria are loosened. With a tight budget and loose criteria for the quality of projects, decentralized budgetary management permits poor projects in one sub-basin to be built, even though much better projects cannot be built due to lack of resources in other sub-basins. This effect diminishes as the budget constraint is loosened, because both the good and poor projects get built. It also diminishes with a more demanding cost-benefit test, because poor projects get screened out of all sub-basins. Imposing a cost-benefit test equivalent to a 6 percent rate of return (using a 6 percent discount rate) keeps the social benefits of the decentralized policy within 5 percent of the centralized policy. However, under a tight budget and a policy to maximize employment (instead of maximizing social benefits), decentralized management reduces the number of families receiving irrigation by nearly 20 percent.

There are two important qualifications to the generality of these results. First, the decentralized policy simulated was one where sub-basins population could only spend their budget on the PMIC-Mizque projects. Had a wider range of projects been available, including projects other than irrigation, the results could have been very different. Second, in the Mizque basin no inter-basin water conflict emerged under any of the scenarios. Had upstream-downstream water conflict emerged the need for basin-wide planning would have been greater. In the Mizque basin, conflict existed over financial resources only. Had conflict emerged over water also the difficulty in identifying tradeoffs between centralized and decentralized policies becomes much greater. Optimization models of the type illustrated in this study can be extremely useful tools for exploring the relative benefits of alternative constrained

54 Net social benefits are equal to the net present value over the 50-year horizon of the net farmer revenue from new crops brought into production through irrigation, minus investment and maintenance costs of new irrigation structures.

55 The objective of maximizing the number of families benefiting does not look at the economic cost and benefit of the projects. It simply maximizes the number of families that can get irrigation at each budget constraint and decentralization regime.

TABLE 24 THE EFFECT OF CLIMATE CHANGE ON SOCIAL BENEFITS OF THE PRONAR INVESTMENT PROGRAM IN THE MIZQUE WATERSHED (6% DISCOUNT RATE, NPV IN $ MILLIONS)

	Budget constraint ($ million/yr)					
	6	4	2	6	4	2
Climate Scenarios	Centralized budget and management			Decentralized budget and management		
wet	15.7	15.6	15.3	14.6	14.0	12.6
baseline	15.5	15.4	15.1	14.4	13.8	12.4
dry	15.0	14.9	14.6	13.9	13.3	11.9

decentralization policies; that is policies which permit decentralized decision-making, but within the context of rules established by basin-wide management principles.

Effect of climate uncertainty. Despite the Mizque river watershed being in a macro watershed considered vulnerable to climate change, this study found that most of the potential irrigation investment in the Mizque river watershed is robust to climate outcomes. This is the case because major vulnerability problems are upstream and relate to urban water supply, santitation, and threats of floods and droughts. This analysis suggests that farther downstream in the Mizque River watershed of the PMIC-Mizque study, annual rainfall would remain sufficient for nearly all the irrigation projects identified in the PMIC-Mizque study, assuming sufficient storage was built as part of the program.[56] Seventy-four potential projects were identified by PMIC-Mizque in sixteen of the twenty-two sub-basins of the Mizque river watershed. Of these sixteen sub-basins, only three experience water scarcity prior to 2050—even under the "dry" scenario. Two of the water-constrained sub-basins contain a total of three potential projects—all of which are viable and robust under all three climate scenarios. This leaves eight projects in the third water-constrained sub-basin (Tipajara) that are sensitive to climate uncertainty. Of these, only one project is robust to all three climate scenarios (at a discount rate of 6 percent), with three projects robust to two out of the three climate outcomes.

56 It was not possible to make this assessment as part of this study. This issue should be investigated in subsequent work. The model framework of this study provides an ideal tool for this investigation.

Lastly, it is important to note that the original intent was to use the Bolivia study to do a much more ambitious exercise—to use the same mathematical modeling to identify the economically optimal timing of different adaptation projects, in different sectors, all competing for resources from a constrained budget. As this more ambitious exercise started, the team immediately was confronted with an immense requirement for data, including the costs of projects, and this proved unfeasible. The challenge to use similar approaches to determine the optimal timing of adaptation projects remains.

Model Analysis

THE EFFECT OF CLIMATE ON THE WATERSHED INVESTMENT PROGRAM

The effect of climate change on the social benefits of the PMIC-Mizque watershed investment program are shown in Table 24 below.

Table 24 shows the effect of optimizing the social benefits of Mizque irrigation assuming a

FIGURE 19 TRADEOFF BETWEEN SOCIAL BENEFITS AND FAMILIES AFFECTED (ESTIMATED BUDGET=$6 MILLION)

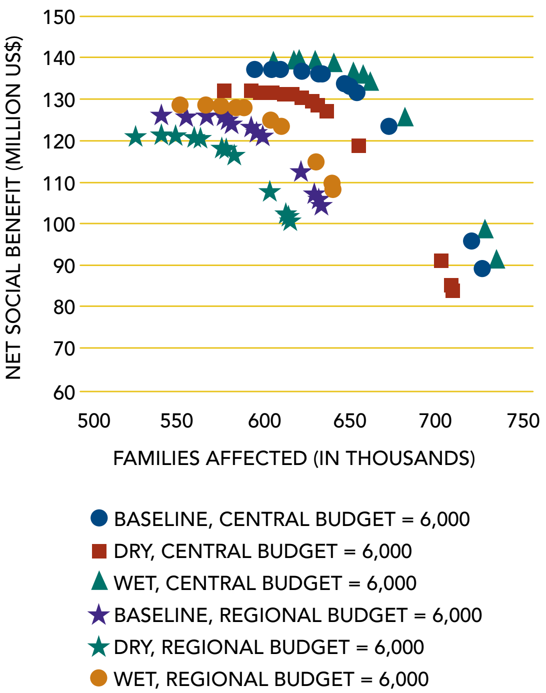
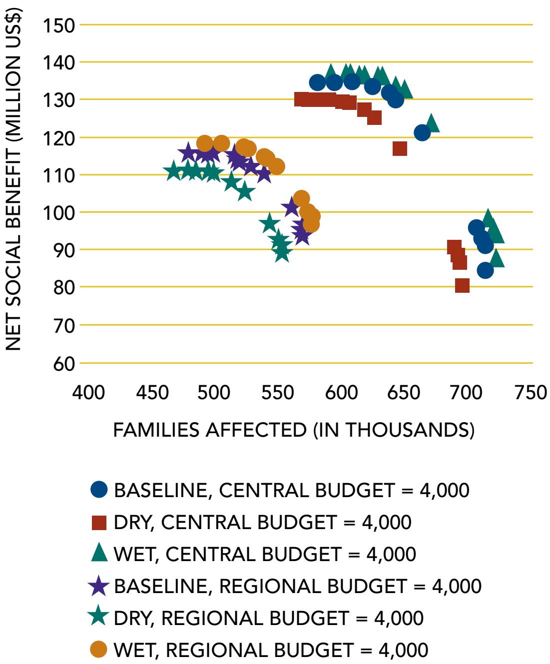


FIGURE 20 TRADEOFF BETWEEN SOCIAL BENEFITS AND FAMILIES AFFECTED (BUDGET=$4 MILLION)



6 percent social discount rate.[57] The effect of the dry climate scenario is to reduce the value of the investment program by 3 to 4 percent in all the budget scenarios, while the effect of the wet scenario is to increase the benefits by 1 percent. The difference in the benefits due to climate change is due to the difference in water availability in the Tipajara sub-basin, as discussed in the section below entitled *"How welfare is lost."* The effect of a policy of decentralized management and budgeting is considerably more important than of climate change. With a $2 million budget constraint, its effect is to reduce watershed benefits by 7 percent. This loss in benefits grows as the budget constraint is loosened. At a constraint of $6 million annually, the differences between scenarios under a centralized and decentralized policy reach approximately 18 percent. Similar results obtain optimizing at a 0 percent discount, except the effect of decentralized management is more pronounced.

THE IMPACT OF BUDGET, CLIMATE, AND DECENTRALIZATION POLICY.

Figures 19 trough 21 illustrates the relative importance of budget, climate, and decentralization policy. For each scenario the curve (traced by the symbols) represents the best possible combination of social benefits and families served.[58] Thus for example, the curve traced by the green diamonds in Figure 18 represents the best combination of social benefits and number of families employed that can be achieved under the wet climate scenario with a centralized budgetary policy and with a budget of US$ 6 million

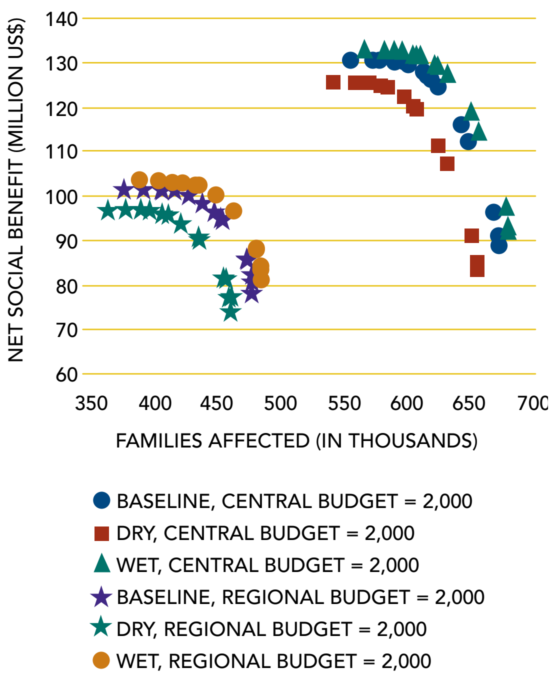
57 The Net Present Value (NPV) of the investment program is equal to the sum of all the net benefits in each year over the 50-year planning horizon discounted back to the present: NPV= $\sum_{t=1}^{50} \frac{(Bt - Ct)}{(1+r)^t}$
where Bt and Ct represent the benefits and costs of investing and operating the irrigation systems in each year, t is the year (1–50), and r is the social discount rate applied.

58 It is important to note that these graphs are shown in undiscounted terms. That is, the Net Present Values shown are the simple sum over the 50 years of the cost and benefits of all projects included in the solution.

per year. The upper leftmost triangle represents the highest social benefits achievable under this scenario, giving no weight to number of families reached. This is slightly under $140 million in social benefits and approximately 62,000 families reached. The lower rightmost triangle on the other hand represents the combination of social benefits and families reached that would be achieved giving no weight to social benefits—focusing exclusively on number of families reached. Thus as shown by the figure if one maximized only the number of families reached and gave no weight to the social economic benefits, the number of families reached with new PMIC-Mizque irrigation projects would be approximately 74,000 families at social benefits of slightly over $90 million. Between the point that maximizes social benefits on the upper left and that which maximizes families reached on the lower right lie the other points on the curve generating the "possibilities frontier" of the best combinations of families reached and social benefits (in this wet climate, centralized budgetary policy and $6 million budget scenario).

Figures 19, 20 and 21 similarly trace the possibilities frontier for a dry, wet, and baseline scenario for both a centralized and a decentralized budgetary policy—yielding a total of 6 scenarios in each figure. Figure 19 shows the "possibilities frontiers" for a budget allocation of $ 6 million per year, while Figures 20 and 21 do the same for budgets of $4 million and $ 2 million, respectively. Looking at the three figures two major points stand out. First, regardless of the climate regime, centralized watershed management yields higher national social benefits and a larger number of direct beneficiaries than does a decentralized regime. Note for example, that in each figure the possibilities frontiers for all three climate scenarios for the centralized regime are always above and to the right (higher social benefits and more families benefiting) of the possibilities frontiers for the decentralized regime. In other words whether one wants to maximize social benefits or the

FIGURE 21 TRADEOFF BETWEEN SOCIAL BENEFITS AND FAMILIES AFFECTED (BUDGET=$2 MILLION)



number of families receiving irrigation benefits, watershed-wide planning will always yield higher benefits than decentralized budgeting, and this policy effect is more important in magnitude than the effect of climate change.

Second, this effect becomes more pronounced as resources become more limited. This can be seen by comparing figure 19 (based on a budget of $ 6 million per year) with Figure 21 (illustrating a budget of $2 billion per year). With a $6 million annual budget, the difference in the maximum social benefits between the centralized and the decentralized regime (for a given climate regime) are typically around $10 million; for the $2 million budget, the difference becomes $30 million.[59]

59 This compares the vertical distance between the upper left most points on each climate scenario.

FIGURE 22 BASELINE SCENARIO (CURRENT CLIMATE IN 2090)

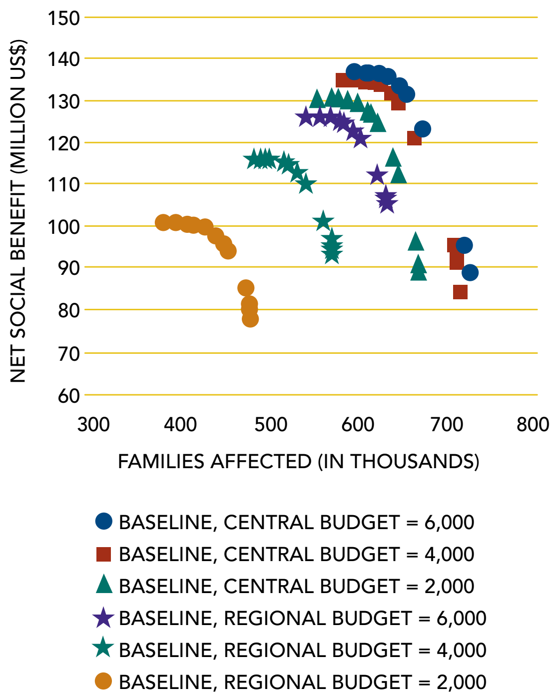
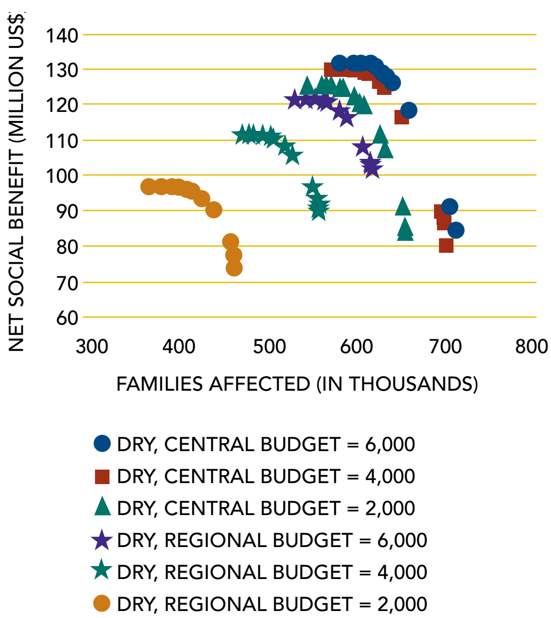


FIGURE 23 FUTURE CLIMATE IN 2090 UNDER A DRY SCENARIO



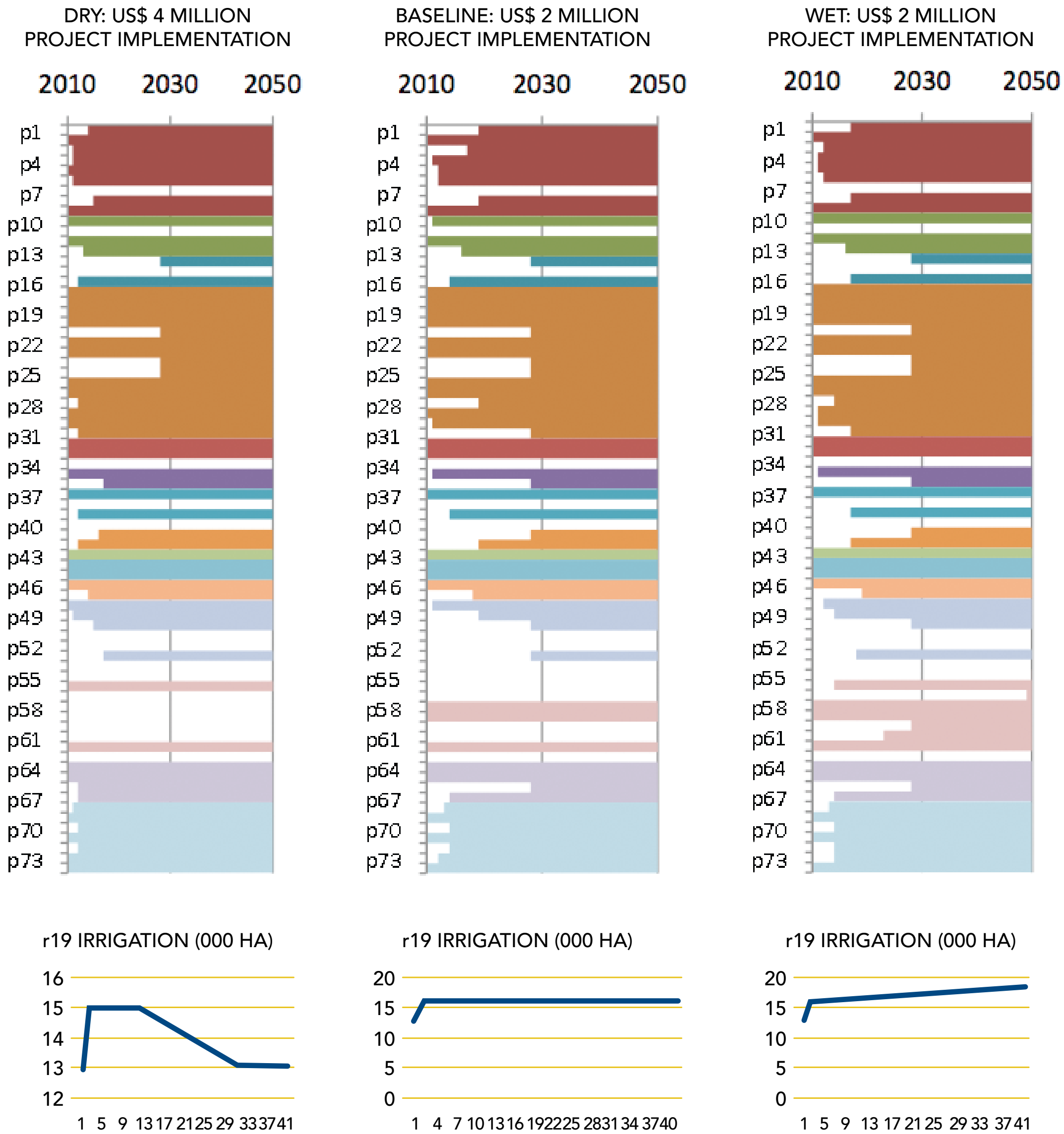
Similarly for the number of families potentially affected, the difference in beneficiaries between the two policy regimes grows from some 100,000 families with a $6 million budget to some 150,000 families with a $2 million budget.[60]

Figures 22 and 23 illustrate the relative importance of policy, budgetary resources, and climate for the baseline and dry climate scenarios. For both scenarios all centralized budget choices produce higher benefits than do the decentralized budget choices. That is, even the $2 million/yr budget administered through centralized budget watershed management would produce higher benefits than the $6 million/yr budget administered at the sub-basin level. Comparing the two figures permits an idea of the effect of the budget constraint. For example, to maintain the $130 million social benefits achievable under the current climate (Figure 22) with a $2 million/yr budget constraint would require US$ 4 million/yr under the "dry" climate regime (Figure 23).

It should be noted, however that this does not mean that the cost of maintaining US$4 million of social benefits under the "dry" scenario would be twice the cost of that under the baseline scenario. The budget constrains the annual budget allocation (which can be saved or spent), not the total that can be spent over the 40-year investment time horizon. In fact, the undiscounted total investment in constructing and refurbishing irrigation projects was essentially equal for the optimal program under the two climate scenarios. The difference is that to equate benefits under the two scenarios requires the dry scenario to produce significant additional irrigation at the beginning of the period. This additional irrigation early in the period compensates for lost irrigation at the end of the period, thereby permitting benefits to be

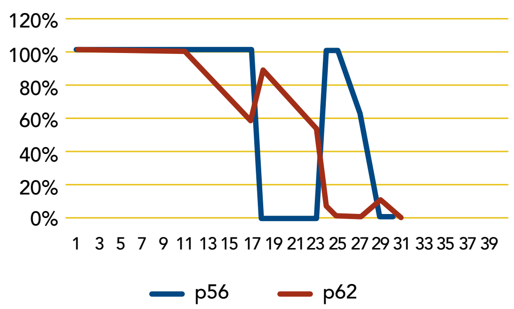
60 This compares the horizontal distance between the lower rightmost points on each climate scenario.

FIGURE 24 HOW SOCIAL WELFARE IS RESTORED (CENTRALIZED MANAGEMENT, 0% DISCOUNT)



TOTAL PROGRAM BENEFITS			
Social Benefits (number of projects)	130	130	133
Families (number of people)	568,566	552,475	569,466
Irrigated Area (has)	1,134,821	1,105,123	1,122,771

FIGURE 25. CAPACITY UTILIZATION OF PROJECTS 56 AND 62 UNDER DRY SCENARIO



equated between the baseline and dry scenarios. In order to make this additional irrigation early, the budget constraint must be relaxed for the "dry" scenario.

How Welfare is Lost

Note that all welfare loss under the dry climate scenario (as captured in this study) is due to reduced irrigation potential in the Tipajara sub-basin. Figure 24 illustrates the path of irrigation development in the sub-basin (under the three climate scenarios).

Under the "baseline" and "wet" scenarios with a US$ 2 million (annual) budget the authorities would construct immediately 3 projects, Montecillos (p58), Puca pila (p59), and Tipa Tipa (p62) (note projects p55-p62 are in sub-basin 19) raising irrigated area from 13,000ha to 16,000ha. Under the wet climate scenario additional projects are built throughout the 50 year period as made possible by additional water availability. Under the dry climate regime on the other hand, two projects are built-- Tipa Tipa (p62) and Kurumayu (p56).

While these projects initially increase irrigated area to 14,000 ha, starting in 2021 water shortages begin to prevent both projects from operating at full capacity, as shown in Figure 25.

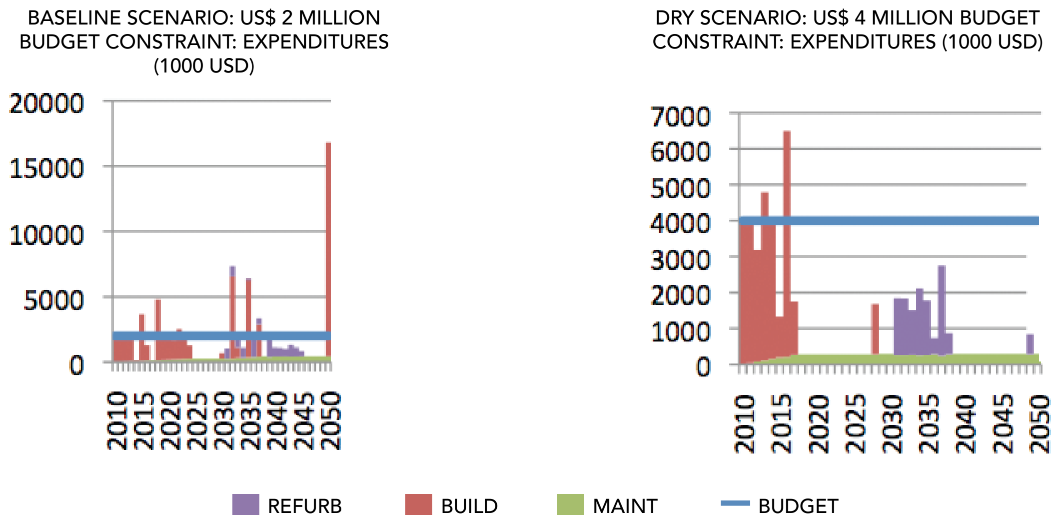
Figure 25 shows the evolution of projects 56 and 62 under the dry scenario. While current water availability permits both projects to operation at full capacity, shortages begin to emerge in year 11 (2021) when at least one of the projects is forced to reduce irrigated area. The "boom-bust" capacity utilization produced by the model illustrates dramatically the potential for serious water conflict. Good institutions could ensure a more equitable division of the remaining water—and a smooth transition to other employment. Note that in year 31 the projects built by the program have run out of water.

How Welfare is Restored

It is important to understand in detail how welfare is restored by increasing the budget for irrigation projects. As will be shown, the sense in which "welfare is restored" is quite narrow. In Figures 26, the Mizque watershed level benefits are restored through relaxing the budget constraint (from US$ 2 million to $4 million) for the dry scenario. A relaxed budget permits more rapid irrigation development in sub-basins not experiencing water shortages. By implementing projects earlier project benefits are available for more years, compensating (in numerical terms) for the losses to accrue in the Tipajara sub-basin from 2021 onwards. Comparing the implementation of projects across the three climate regimes (Figure 26) reveals that, in order to compensate, the projects in the dry watershed are implemented prior to the projects in the baseline watershed.

For these benefits to actually translate into restoration of benefits for the inhabitants of the Tipajara sub-basin however, it would require significant institutional innovations.

FIGURE 26 CASH FLOW OF INVESTMENT PROGRAMS HAVING EQUAL SOCIAL BENEFITS (DRY SCENARIO, 0% DISCOUNTS)



The Effect of Discounting

The analysis above was done in undiscounted terms. This means that future benefits and costs receive weights equal to current benefits and costs. The most important effect of imposing a discount rate greater than 0 discounting is to exclude all projects for which the IRR is below the discount rate. This concept is especially important for evaluating if resources would be better spent on irrigation development in the Mizque basin or spent elsewhere in Bolivian society. For the purpose of this study, we have assumed that this social opportunity cost of capital is equal to 6 percent.

HOW DOES DISCOUNTING CHANGE THE ABOVE ANALYSIS?

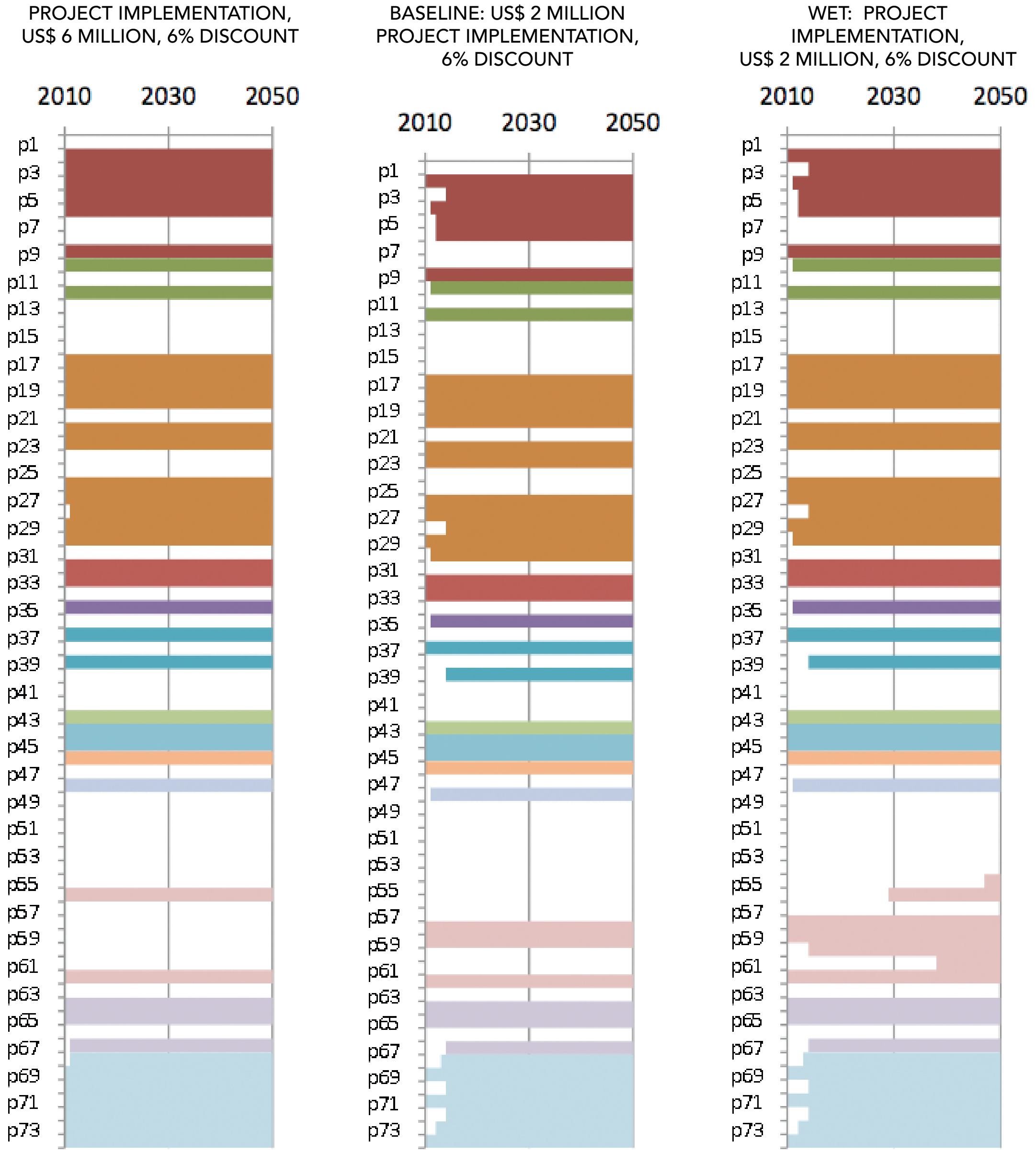
As shown in Figure 18, requiring a 6 percent rate of return on projects reduces the number of eligible projects to 47. This can be seen by comparing the number of projects implemented in Figures 24 and 27.[61] Eliminating projects with an IRR less than 6 percent nearly halves both the number of families served by additional irrigation and the number of additional acres brought under irrigation. Despite the reduced number of eligible projects, it now takes a more rapid cash flow (Figure 28) in the beginning of the period to build the projects necessary to compensate for losses as climate change reduces water availability—$6 million compared to $2 million in the 0 percent discount case above.[62] This (probably unrealistically) requires that 37 projects be built in the first year and the remainder in the second year.

The primary purpose of this analysis is to demonstrate the usefulness of an intertemporal optimization approach to investment analysis under

61 As stated above, the logic of using this discount would be that at a rate of return below 6 percent the investment resources would generate more social benefits if invested outside of irrigation in the Mizque watershed.

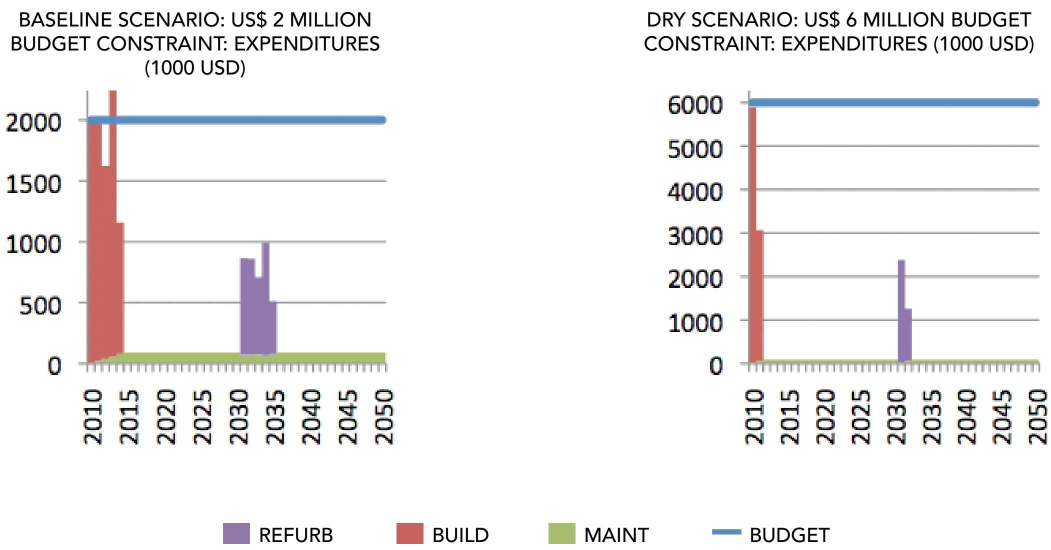
62 As shown in Figure 27 with a 6 percent discount rate a $6 million budget in the dry scenario produces roughly the same social benefits as a $2 million budget in the baseline scenario (an NPV of 15.0 vs 15.1)

FIGURE 27 **RESTORING WELFARE (CENTRALIZED MANAGEMENT, 6% DISCOUNT)**



TOTAL PROGRAM BENEFITS			
Social Benefits (number of projects)	15.0	15.1	15.3
Families (number of people)	277,618	287,387	298,479
Irrigated Area (has)	644,324	659,195	674,777

FIGURE 28 CASH FLOW OF INVESTMENT PROGRAMS HAVING EQUAL SOCIAL BENEFITS.



climate change. Clearly, further modification would be required before this model could actually be employed by the planning authorities. First, for many of the projects further analysis would be necessary. The Mizque Hydrological Plan study (Annex 3) documents the current status of project preparation for these projects. Most are currently project ideas, with neither final project designs nor feasibility studies completed. In addition, as mentioned above, it is not clear whether additional storage would be required for these irrigation projects, or whether there is sufficient storage included in their current design. Second, the treatment of climate could be improved. Due to time limitations, climate change was incorporated in the model by linearly extrapolating the 2010–50 climate projection to 2090. More sophisticated treatment of the 2050–90 period would be warranted in further work. Finally, additional investigation of the budget constraint would be interesting. The budget constraints employed ($2, $4, and $6 million annually) probably permit an unrealistic number of projects to be built in any given year, failing to take into account implementation capacity. Further analysis should explore implementation as well as financial constraints.

Limitation inherent to economic analysis of climate change

Other limitations, inherent to any economic analysis of climate change, are highlighted by this case study. Most importantly is the notion of compensation. This study has taken the welfare in the Mizque watershed over the period 2010–20 as the unit of analysis. It has restored welfare losses caused by climate change by providing additional financing to construct additional irrigation. While this additional irrigation was constructed in the Mizque watershed, it was constructed prior to the water shortages emerging, and in areas other than those suffering from water shortages. For this compensation to actually reach the families directly affected by water shortages, it requires that mechanisms be put in place to either move these families to the benefiting areas or to move the benefits to the affected families. What this study has been able to do is to identify the vulnerable population

(those residing in the Tipajara sub-basin) and to identify how, though building additional irrigation projects, the Mizque watershed can maintain its potential productivity over the time horizon. What the study cannot do is identify the mechanisms though which the Mizque watershed compensates the populations directly affected.

It is noteworthy, for example, that (in order to maximize social benefits from irrigation) the model invests in two projects in Tipajara sub-basin in 2011 only to start to phase them out as shortages emerge in 2021. Having identified that the population in the Tipajara sub-basin is vulnerable to water shortages, a more farsighted policy might be to seek alternatives to irrigation for this population rather than to make short-term gains from unsustainable (even if profitable) new projects.

CONCLUSIONS FOR THE INVESTMENT PLANNING TOOL

Specifically, the study investigated the effect on climate change on a program of irrigation development in Bolivia's Mizque watershed. Several conclusions emerge. First, the effect of climate change on irrigation development appears to modify the original development plan, in particular for the Tipajara sub-basin. This investment should be considered due to a water deficit estimated in 2021. Second, under the worst-case scenario (dry) the effect of climate change in this sub-basin reduces the return on PRONAR's potential investment program by approximately 3 percent. And third, this reduction is less than that which would occur should investment decisions be decentralized to the sub-basin level rather than maintained at the overall watershed level.

The study has identified the most vulnerable population, and how to restore watershed-level benefits to their baseline (without climate change) levels through accelerated investment. While highlighting the problem of the vulnerable population, this study has not identified mechanisms to ensure that additional watershed benefits reach those suffering directly from water shortages. This problem is inherent to, and an important limitation of, economic studies that aggregate across space and over time. The higher the level of aggregation the more important the problem becomes.

The study has illustrated the advantages and disadvantages of this type of planning model for climate change analysis. The major advantages are that it permits a detailed comparison of investment alternatives and the potential effect of climate change upon them—and does so within an intertemporally optimal (planning) framework. While not fully exploited in this study due to the relatively simple nature of the water constraint that emerged from the study (effectively restricted to a single sub-basin), the method also permits exploring the robustness of alternative investment strategies to possible climate outcomes. For many applications this ability to explore robustness is critical, especially in view of the uncertainty over possible climate outcomes. Optimization models of the type illustrated in this study can also be extremely useful tools for exploring the relative benefits of alternative constrained decentralization policies; that is policies which permit decentralized decision-making, but within the context of rules established by basin-wide management principles. The major disadvantage is that they require good project level data and a good characterization of the effect of climate change on projects, which are not generally available. We doubt that there is any serious way to improve the quality of long-term investment planning under uncertainty without the quality of data that were available for this study, however. This is an argument for many more preliminary investment studies of the type done by Pronar and Cedeagro in the PMIC-Mizque study, which formed the basis for the current work.

NINE

Overall Conclusions and Lessons Learned

Social Dimensions of Climate Change

Rural and indigenous communities have a long and rich history of systematic observation of the climate; indeed their survival depends on this capacity. Climate change and increasing climate variability mean that many of the climatic indicators used by these communities are becoming less effective. However, community workshops revealed that due to an increasing inability to predict weather patterns, people are in need of new indicators to diagnose and predict future variability. Based on their climate observations over the past twenty to thirty years, all community members that participated in the study believe that future climate scenarios will be characterized by higher temperatures; water scarcity; more irregular rainfall; and a shorter but more intense rainy season.

Communities in the valleys and highlands put the highest priority on adaptation measures related to water management, followed by improved agricultural and livestock practices. They view drought as the principle threat to their livelihoods. In contrast, communities from the Chaco and plains regions asserted that improved agricultural practices were most important and considered water management measures to be of secondary significance. Annex 5, an analysis of social dimensions, provides more detail on the adaptation measures prioritized by type and community. In addition, results demonstrate that communities view adaptation strategies not as isolated measures nor as single projects but rather as a complex set of complementary measures that are comprised of both hard and soft measures. Infrastructure investments will be insufficient if complementary efforts are not made to promote capacity building, institutional development, and in many cases, fundamental transformation to underlying logic and livelihood strategies. In particular, adaptation strategies may imply major changes to production systems that will need appropriate technological and organizational adjustments as well. For this reason, understanding these adaptation measures as a hierarchy with a specific order of execution is essential as some strategies will depend on the sustainable implementation of others.

The following lessons for crafting adaptation policies can be extracted from the results of community-level investigation:

Past coping strategies and adaptation practices to climate variability and extreme events hold valuable lessons for future adaptation planning and should form the basis for adaptation policy formulation. Combining traditional knowledge with new methods appears to be essential. Adaptation to climate change is not something new for indigenous communities; they have developed livelihood systems in line with a changing, dynamic environment. At the same time, local authorities and communities may lack the technical knowledge needed to build resilience to climate change. Greater information provision and capacity building initiatives on the impacts of climate change and adaptation policies hold significant promise to increase the adaptive capacity of local authorities, technical experts, and community members alike.

Planning across scales of governance, aligning interests, and ensuring policy cohesion will be necessary to ensure effective adaptation, particularly given Bolivia's unique system of decentralization. Identification and prioritization of adaptation measures is a complex and delicate process that depends on various sources of information, oftentimes based on a fragile negotiation process at the local level. Consequently, adaptation policies should be defined in a participatory manner respectful of the existing processes at the local level that define investment priorities. It will be essential to effectively engage relevant community members, as well as local authorities, in the development and adaptation planning process. For example, planning across scales of governance is necessary for the formulation of a clear and efficient normative framework to support community efforts for regulating access to forests and pastureland—a key adaptation measure for building resilience. Collaboration and coordination with local institutions, private organizations, and producer organizations will increase the effectiveness of adaptation policies.

Municipal investments are identified and prioritized in community and municipal workshops in which civil society directly makes decisions. Prioritization of public investments at the community level is complex and shaped by local power dynamics, which results in a fragile negotiation process that can be easily destabilized by external interventions. **Respecting existing community practices, which guide the prioritization of investments, may help facilitate the development of adaptation policies.**

Agriculture

Although crop and climate models represent an oversimplification of natural systems—and hence, should be interpreted with caution—they are the most current tools used to help evaluate trends and potential effects due to a changing climate. Under the specific assumptions of this study, the effects of climate change—an increase in the variability of rainfall and in the occurrence of drought periods—could have important implications in the productive systems of quinoa, maize, soybean, and potatoes. These expected changes can have important implications for the future sustainability of agriculture in Bolivia.

Investment in better water management will enhance the resilience of Bolivian agriculture both to systematic changes in annual levels of rainfall and to greater year-to-year volatility in the rainfall patterns. Such investment would be desirable under most development strategies for a stable climate, so that climate change is likely to reinforce the benefits of such investments. Similar observations apply to other investments in rural infrastructure, particularly for rural roads that can improve market access in existing and new areas of cultivation. In both cases, the level and location of investment must take account of changes in agricultural comparative advantage within the country, so investments are allocated to meet future patterns of production rather than being based on historical patterns.

Analysis of the potential effect of climate change on crop yields revealed mixed results. Under a dry scenario, crop yields are expected to decline if the additional crop water requirements resulting from temperature increases are not covered. Study results suggest that low-altitude crops (mainly maize and soybean) will face yield declines of up to 40 percent, mostly due to water shortages and hot spells during critical crop stages. Under a wet scenario with increased temperatures, the impact and vulnerability analysis of climate change in the four crops suggests that crop productivity can be significantly increased; however, this result does not take into account the possibility of events such as an increased incidence of plagues, long periods of dry spells, and flooding of soils.

The projected increase in temperature can also be an opportunity to improve crop productivity if water is available in the critical phenological periods of the crops. Improved irrigation can provide the appropriate amount of water needed in periods of increased crop water deficits and can be considered a suitable adaptation strategy to changes in climate conditions. This suggests that Bolivia's agriculture sector would significantly benefit from a warmer and wetter climate. Under such a scenario, yields for maize and soybeans would increase 40 to 45 percent, and potatoes and quinoa yields would increase 60 to 90 percent. The expected crop yield losses from a drier climate are lower than the gains from a wetter and hotter climate. Potential losses from a drier climate are projected to be approximately 25 percent for maize and 10 to 15 percent for soybeans, potatoes, and quinoa. These results are driven by the agricultural benefits of a warmer, more frost-free climate. They suggest that rapid and timely implementation of irrigation (at least at the initial phases of crop development) would be even more attractive under a scenario of climate change. These actions, along with crop insurance schemes, are starting to be considered within the new National Development Plan (2010–15).

The diversity of ecosystems and socio-economic characteristics of agricultural producers in Bolivia implies that any adaptation measure needs to be evaluated in relation to its productive environment. In the past, farmers with livelihoods based on rainfed agriculture have adapted autonomously in a variety of ways including building micro-scale irrigation and defense infrastructure to cope with floods; changing to new crop varieties; converting land used for livestock farming to land for cultivation; resorting to temporary labor migration; and engaging in the services sector. Subsistence farmers with low adaptive capacity have fewer possibilities to adapt due to lack of resources.

Decision-makers need to devise adaptation strategies that include medium and long-term measures even if they require larger investments up front. The introduction of new crop varieties and improved management of the existing varieties is important to increase the resilience of the agriculture sector to climate change. The sustainability of this strategy will depend on the successful implementation of a national agricultural research and extension service, and improving farmers' access to markets for agricultural inputs, agricultural outputs, credit, and crop insurance, etc. There is also a need to improve entrepreneurial skills to generate off farm income (alternative livelihoods) and to improve access to loans and microcredit. Focus group discussions and community workshops reveal that community members believe that adaptation is not only about investing in infrastructure; in addition, adaptation requires capacity building, organizational development and uses of technology. Support for substantial changes to livelihood systems and practices—such as shifting from rainfed to irrigated systems and from free-range livestock to controlled livestock farming—will be crucial.

Accordingly, agricultural extension services and measures to increase access to markets require significant investments, yet they can offer longer term, socially and environmentally sustainable benefits. The implementation of adaptation options such as agriculture insurance or actions to increase market access will differ depending on the structure and size of the farming systems. The approach to implement these in areas such as the Altiplano, where small-scale family producers are the majority, will be different from appropriate approaches for areas such as Santa Cruz where most of the production is done by large scale farmers. The agricultural models for the different crops all suggest that availability of water is crucial to increase the resilience to climate change in the sector. Increased evaporation (due to higher temperature), more irregular precipitation (shorter and intensified rainy season as well as hot spells), and higher frequency of extreme weather events (droughts and flooding) emphasize the need for investment in water storage and irrigation, which would be climate robust scenarios in both a dry and wet climate scenario by reducing the climate vulnerability of rainfed agriculture.

Water Resources

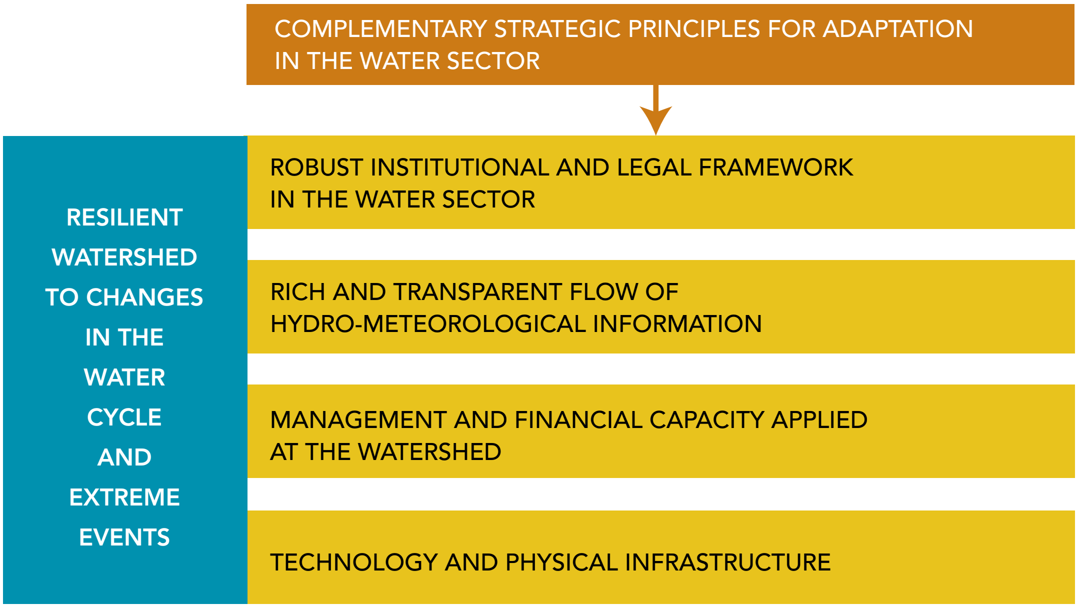
Water is considered one of the most vulnerable sectors that will require additional investments (to mitigate floods and droughts) through hard (dam and irrigation infrastructure) and soft measures (capacity building and education, extension services). Investments in water resources should be tailored to improve planning and management at the watershed level, as there is a great need for improvement in water storage capacity to utilize excess water in wet months and years. Improved water access and irrigation increases resiliency to droughts in the planting season, is robust across climate scenarios, and more than doubles the average yield of the major crops in the region. Cost-benefit analysis of irrigation projects in the region suggests that most types of irrigation are economically viable investment opportunities in both "with and without" climate change scenarios. Clearly, adaptation in Bolivia must go hand in hand with development. Even though the focus is mainly economic, political and institutional issues play a central role in understanding and in identifying solutions to some of the major adaptation challenges. Without fundamental improvements in the policies and institutions that finance, maintain, and invest in the water and agriculture sectors, additional resources aimed at building resilience are not likely to be effective in the long run.

RURAL WATER RESOURCES

It is imperative to find equilibrium between developing faster than business as usual and integrating robust adaptation measures that minimize uncertainty within a reasonable timeframe. In order to reduce dependency on the water cycle and therefore on variability in natural water supply, it will be necessary to develop a solid integrated water management strategy that functions across scales, and in particular, at the watershed level. For better and more effective water resources planning, the principles of integrated water resources management, acknowledged in the National Watershed Plan, should be transformed into practical and effective measures. This is important not only from an adaptation to climate change perspective, but also to protect water resources and guarantee present and future needs for all water uses, including for environmental services. However, needed basin-wide management, departing from the current situation of small-scale community investments, will require significant institutional strengthening. Many of the adaptation investments require multi-communal agreements; and thus, the state should create the appropriate space to generate such agreements.

Strategies for better water management should rely on four strategic components, including (1) an adequate institutional and legal framework to ensure a correct and coordinated engagement of the different actors in the water sector, including frameworks that ensure alignment with the needs and interests of local populations and make space for engagement of the most vulnerable members of society; (2) a good flow of technical information on the water cycle and water demands by basin;

FIGURE 29 **STRATEGIC COMPONENTS FOR WATER MANAGEMENT**



(3) a solid financial, managerial, and technical capacity to ensure water resources management is implemented under sustainability criteria; and (4) provision of and access to the necessary physical infrastructure and technology (see Figure 29).

With these strategic principles in place, long-term trends of reduced water availability could be addressed. This would also facilitate development of a disaster prevention strategy to improve control over water systems and increase their resilience. In addition, an effective strategy should reduce dependence on natural water variability and provide increased resilience of water systems. Specific measures should include:

- Definition of basin boundaries and basic information about the basin
- Specification of water uses in the basin and establishment of cost recovery measures from the different water sub-sectors to protect water resources
- Prioritization of water uses in the basin
- Elaboration of necessary regulations based on Integrated Water Resource Management principles and the specifications of the basin, such as the determination of environmental flows and vulnerable locations based on information on hydrologic information
- Determination of the different actors involved in the water sector in that basin and definition of the rules under which they should interact for decision making and investment planning purposes.
- Prioritization of measures to protect water resources and guarantee water uses Elaboration of an investment plan for the basin.
- Elaboration of an investment plan for the Basin.

IMPROVING IRRIGATION INFRASTRUCTURE

Irrigation can ensure an adequate supply of water for agriculture and compensate for increased crop water requirements. The irrigation potential of the country implies that this can be considered as a suitable adaptation strategy to changes in climate conditions. Building infrastructure to store water and regulate seasonal water flows will need to be part of a future irrigation strategy to increase the climate resilience of the agriculture sector in Bolivia. Irrigation systems based on reservoirs have been identified as a cost-efficient adaptation measure. These systems equilibrate seasonal water supply and have a high return per implemented unit. Reservoirs currently constitute 2 percent of irrigation projects, yet they represent 19 percent of total irrigated water supply. However, rehabilitation of existing reservoirs and building of new ones will come at an additional cost to the sector.

Mainstreaming climate change considerations in hydraulic infrastructure projects will imply ensuring the flexibility of operation in the system, revisiting the designed volume capacity and structure lifetime, and increasing the resilience to extreme events of higher magnitude. Irrigation strategies that promote a more efficient use of water constitute a win-win option. Optimizing water use in irrigation relies on measures such as improving water distribution systems and increasing irrigation efficiency. For example, it has been found that increasing the efficiency of gravity irrigation systems by almost 50 percent is a relatively simple measure to implement. The sustainability of any irrigation strategy, measure, or project can be reinforced by using an integrated river basin planning and management approach. In addition to this, complementary investments in the agriculture sector—such as extension services or education—will also contribute to the sustainability of irrigation investments.

URBAN WATER RESOURCES

The urban sector is already highly exposed to climate variability, due the different vulnerability dimensions (resource, infrastructure, and operative management capacity) it presents. Climate change impacts—including reductions in water availability and the increased frequency and intensity of floods and droughts—would generate additional stress on the current capacity of utilities to safely deliver water and sanitation services and to control floods. Urban areas in the arid zones have more difficulty in increasing production capacity due to natural water availability constraints, particularly when these areas are located in basin heads. Peri-urban areas of Cochabamba and La Paz/El Alto are particular hotspots due to the high competition for water, poor infrastructure, and exposure to climate change effects. Groups living in the peri-urban areas of rapidly growing cities are especially vulnerable to the effects of climate change, because they are often not connected to the water and sanitation networks; they rely on unstable resources; and they live in risky areas such as steep slopes or flood-prone areas. While a more detailed analysis of these trends is needed, in a country that is rapidly urbanizing, city planners should anticipate future urban growth rates in order to be able to provide for safe settlements.

Most of the adaptation measures described in the study are "supply-driven." In order to increase resilience to changes in climate, urban utilities need to reinforce and diversify their water sources, increase coverage, properly manage effluents, and guarantee adequate storage capacity in anticipation of changes in rainfall variability and increasing evapotranspiration rates (especially under dry scenarios). These measures imply that water utilities in Bolivia need to improve their operations, management and financial performance, for which they would certainly need additional external support. In the case of floods, tradeoffs and complementarities between hard and soft measures need to be carefully evaluated. Hard measures include reviewing and upgrading current drainage systems; canalizing river channels when crossing urban soil; construction of dykes, river deviations, and gates; or even larger measures such as as building upstream dams for flood control. Soft adaptation measures consist of early warning systems, upstream reforestation, or ensuring clean river beds and safe wards. The most effective adaptation strategy will combine both hard and soft measures.

The National Watershed Plan may provide guidance on implementing IWRM at the watershed level, so utility planners could incorporate in their master development plans a broader watershed management that considers the city as very important. In this context, the generation of valuable and long-term hydrometeorological information at the watershed level would allow urban planners to incorporate risk management measures in their land planning instruments. This would enable them to identify risky areas and to develop and implement the consequent urban regulations increasing the long-term resilience to extreme events.

Investment Planning Tool

The investment model tool identified the most vulnerable population, and how to restore watershed-level benefits to their baseline levels through accelerated investment, but ensuring that additional watershed benefits reach those suffering directly from water shortages is more difficult. This type of planning model permits a detailed comparison of investment alternatives and the potential effect of climate change upon them—and it does so within a planning framework that is consistent over time. The approach also facilitates investigation of the robustness of alternative investment strategies to possible climate outcomes, something that is particularly important in view of the uncertainty over possible climate outcomes.

Results from the investment planning tool showed that sequencing and prioritization of irrigation projects depends mostly on decentralized management rather than on climate change impacts (regardless whether the objective is to maximize national social benefits or to maximize the number of families directly benefitting from the projects) in the evaluation of water development projects at a watershed level. The effect is least where the budget constraint is loose and where projects must pass stricter cost-benefit tests.

The study has illustrated the advantages and disadvantages of this type of planning model for climate change analysis. The major advantages are that it permits a detailed comparison of investment alternatives and the potential effect of climate change upon them—and does so within an inter-temporally optimal (planning) framework. While not fully exploited in this study due to the relatively simple nature of the water constraint (effectively restricted to a single sub-basin), the method also permits exploring the robustness of alternative investment strategies to possible climate outcomes. For many applications, this ability to explore robustness is critical, especially in view of the uncertainty over possible climate outcomes. The major disadvantage is that it requires good project-level data and a good characterization of the effect of climate change on projects. Currently, most of the needed data for this type of analysis is limited and/or expensive to generate and synthesize. Unfortunately, there is no serious way to improve the quality of investment planning under uncertainty without this detailed project and climate-level analysis. Additional limitations are described in Box 4.

How to Move Forward?

The Bolivian government has made an important and serious start in understanding and responding to climate change effects. However, Bolivia, like most other countries in the world, still needs

BOX 4 LIMITATIONS OF THE STUDY

A key limitation in the context of the EACC is that all models used channel researchers to ask and answer questions that can be answered by the models. Yet the most important questions may be institutional or cultural, or more likely a combination of these plus political factors. For example: How to influence the location of people away from high-risk or increasingly unproductive areas? How to improve the allocation of water and land? How to improve the quality of education? The tools used in this analysis help to define the importance of doing these things, but they cannot tell us how to get them done. For that, however, economics is clearly not sufficient, but the study by definition was not set to understand all aspects of adaptation to climate change.

To make calculations tractable, the study limits both the breadth of economic analysis and the length of the time horizon. It investigates public sector adaptation only, and the investment horizon of the study is to 2050 only. Although climate science tells us that adaptation costs and damages will increase over time, and that major effects such as melting of ice sheets are more likely to occur well beyond this horizon, uncertainty with regard to both climate and growth make unproductive efforts to analyze adaptation beyond this period.

Most of the results of this study are based on biophysical, engineering, and economic models. As discussed above, these models use mathematical techniques to represent physical and economic processes. The more the real world phenomena being simulated are generated by deterministic physical processes, the better the performance of the models. As phenomena become increasingly influenced by uncertainty (with unknown underlying probability distributions), or by human behavior and institutional change, the ability to simulate weakens.

In addition to the sectoral and temporal efficiency problem, the overall approach of the models excluded other critically important elements: ecosystem services (forest and biodiversity), health, and further integration of the social and economic analyses. With regard to biodiversity, in particular, it is still not clear how to quantify the impact of climate change and what adaptation measures are effective for preserving it, but the information needed to estimate adaptation costs is largely unavailable.

The study is also limited by the lack of information in important sectors relevant for the development of the country. A specific example is the analysis of the infrastructure sector. Data from the global EACC study is presented below aggregated at the country level as a reference in terms of adaptation costs. The validation of data at the local level remains to be done.

to develop and implement effective and complementary policies, institutions and practices to adapt to the reality of severe climate risks. According to a recent report by Oxfam, an overarching institutional and public policy framework for national policy on climate change adaptation and mitigation needs to be developed through a twin strategy: "First, by integrating climate change measures into the new legislative framework that will implement Bolivia's new Constitution and thereby embed climate change policy at the highest level. Second, the government should further develop and implement a national adaptation strategy that is properly mainstreamed across the government's programs for eradicating poverty, and adopted by and coordinated across all the key ministries. Such plans should also identify the most urgent adaptation activities and the cost of these, and secure international financing for their implementation." (Oxfam, 2009)

Dealing with current climate risk should be a priority in order to increase future resilience. In particular, disaster risk reduction needs to be part of long-term planning at all levels of government, across all industries, and particularly at the departmental and municipal level. This also includes improvement of capacity in regard to disaster preparedness. Given the increased climatic risk and severe vulnerability of small agricultural producers, the development of an agricultural insurance scheme should be a priority in addition to water storage and management. Improved water management should also focus on urban areas where increased demand is generating water shortage problems. Given the high rate of water loss through poor infrastructure, which in cities like El Alto leads to loss rates of up to 40 per cent, the government should place a high priority on building new infrastructure for water storage. At the community level, existing rainfall must be captured, stored, and used to its maximum capacity.

The EACC study could be used to fulfill some of the knowledge gaps required for the advancement of the adaptation agenda in the country. Additional ongoing initiatives by the Word Bank will also complement the initial information provided by the EACC study. An example of such initiatives is the detailed modeling of surface water availability using a hydrological (SWAT) model that is being developed by the World Bank-Latin America and Caribbean Region. The SWAT tool will be able to improve climatic data for the baseline at the watershed level, and therefore to improve the accuracy of the vulnerability indicators (mainly for the water sector). The improvement in the resolution of climate projections, however, still needs further work from the climatology cluster. Both studies, as well as others previously mentioned in the report, will provide support to the initial phases of the PPCR.

Works Cited

ANESAPA. 2009. Strategic plans of 12 EPSAS. Bolivia

Asquith, N.M. & M.T. Vargas. 2007. Fair Deals for Watershed Services in Bolivia. Natural Resource Issues.International Institute for Environmental and Development. London, UK.

Roche M.A, and Fernandez C. 1986. Los balances hídricos de Bolivia. Premier Symposium de la Recherche Française en Bolivie, LaPaz, Septembre 1986 : 44-47.

Beltrán, I., and J.L. Gutiérre. 2008. " Impact of ENSO phenomena" PHICAB. "Balance Hídrico Superficial de Bolivia" (1990).

Centro de Desarrollo Agropecuario (CEDEAGRO) 2005. Planificación hídrica de la Cuenca del Mizque. GTZ. PRONAR.

CEPAL 2008 Evaluación de los eventos ENSO 2007 and 2008 en la Region Andina.

Climate Change National Program (PNCC). 2006. "Evaluation of trends of climate change in Arid and Semi-Arid areas of Bolivia".

Climate Change National Program (PNCC). 2006. "Climate Change in Bolivia" .

Climate Change National Program (PNCC). 2007. "Climate Change National Adaptation Mechanism" Climate Change National Program. 1998. "Vulnerability and Adaptation of the Water Resources in Bolivia".

Climate Change National Program (PNCC). 2007 "Flood events in the Beni basin in 2007" Ministry of Environment and Water.

Corporación Andina de Fomento (CAF).2000. Lecciones del Nino en Bolivia en 1997-1998 (2000)

Fundepco. Oxfam. 2008. "Threats, vulnerabilities and risks of Bolivia Atlas"

Government of Bolivia.2010. National Development Program 2010 -2015.

Institute of Hydrology and Hydraulics. 2005. "Hydrologic Balance of the Pilcomayo Basin".

Intergovernmental Panel for Climate Change (IPCC). 2007. "Climate Change and Water Technical Report"

I Intergovernmental Panel for Climate Change (IPCC).2007. Fourth Assessment Report

Killeen,T. J. et al. 2007. "Thirty Years of Land-cover Change in Bolivia." *Ambio* 36 (7): *600-606.*

Marengo, J.A., et al.2009."Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system". International Journal of Climatology.

Mechler R. et al. 2009, A Risk Management Approach for Assessing Adaptation to Changing Flood and Drought Risks in Europe, Chapter 8, In: M. Hulme, H. Neufeldt (eds.). Making Climate Change Work for Us: European Perspectives on Adaptation and Mitigation Strategies. Cambridge University

Ministry of Agriculture. (2005) "National Irrigation Plan". Manual de Riego Tecnificado - PIEN - 2008 (P. Hoogendam – C. Ríos)

Ministry of Agriculture. National Irrigation Program. "Inventario Nacional de Sistemas de Riego" (2000)

Ministry of Environment and Water. "National Watershed Plan. (Strategic and conceptual framework)" (2006).

National Institute of Statistics (INE). 2001. Population census 2001 and Population projections by department up to 2030 (2001).

National Institute of Statistics (INE) and Ministry of Economy and Public Finance, Fiscal Analysis Framework (RAF).

Orellana, R. 1995. Aproximaciones a un marco teórico para la comprensión y el manejo de conflictos socio-ambientales. CERES – FTPP. Cochabamba, Bolivia.

Oxfam Fundepco. 2008. "Threaths, vulnerabilities and risks of Bolivia Atlas"

Oxfam. 2009. Bolivia: Climate Change, poverty and adaptation.

Robertson, N. and S. Wunder. 2005. *Fresh Tracks in the Forest Assessing Incipient Payments for Environmental Services Initiatives in Bolivia.* Bogor, Indonesia: CIFOR.

San Andres University, Institut de Recherche pour le Developpement. “Deshielo de la Cuenca del Tuni Condoriri y du impacto sobre los recursos hídricos de las ciudades de la Paz y El Alto” (2007).

UNESCO. “Water in Bolivia” (2008).

UNISDR. “National Report on Institutional Vulnerability in Disaster Risk Management” (2004).

Vice-ministry of Natural Resources and Environment. “Diagnostico y priorización de Cuencas Hidrográficas en Bolivia” (1997).

World Bank. “Water and Climate Change: Understanding the Risks and Making Climate-Smart Investment Decisions” (2009).

World Bank 2009a. *The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates.* Consultation draft. Washington, DC: The World Bank.

World Bank.2010. *World Development Report: Development and Climate Change.* Washington, DC: World Bank.

World Food Program, SINSAT, UDAPE. 2003 “Municipal Atlas of Food Security”

World Food Program, SINSAT, UDAPE. 2007 “Municipal Atlas of Food Security”

Water and Sanitation Program. 2009“Peri-urban strategy for water and sanitation” (Working Paper) (2009)

THE WORLD BANK

Ministry of Foreign Affairs
Government of the Netherlands

DFID Department for International Development
UNITED KINGDOM

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

The World Bank Group
1818 H Street, NW
Washington, D.C. 20433 USA

Tel: 202 473 1000
Fax: 202 477 6391

www.worldbank.org/eacc