

CPWF Project Report

Andes Basin Focal Project (Andes BFP)

Project Number PN63

Mark Mulligan¹, Jorge Rubiano¹, Glenn Hyman⁴, Juan Gabriel Leon³, Miguel Saravia⁵, Douglas White⁴, Viviana Vargas³, John Selvaraj³, Chereen Ball⁴, Andrew Farrow⁴, John Alexander Marín³, Olga Lucía Pulido³, Alexa Ramírez³, Tatiana Gutierrez², Leonardo Sáenz Cruz¹, Augusto Castro⁵, Meike Andersson⁴

¹ King's College London (KCL), UK

² Universidad Autónoma de Occidente (UNAO)

³ National University of Colombia (UNAL), Sede Palmira, Colombia

⁴ International Center for Tropical Agriculture (CIAT), Cali, Colombia

⁵ Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN), Lima, Peru

for submission to the



CGIAR Challenge Program on
WATER & FOOD

December 18, 2009



Acknowledgements

We are indebted to all who have contributed in one way or the other to the work of the Andes BFP and the writing of this report, in particular:

To the Commission of the European Community (EC) and the International Fund for Agricultural Development (IFAD) for the grant provided to the CPWF for this project.

To Simon Cook (BFP Leader) for his guidance and insights on the 'big picture'. Also to Elizabeth Barona (CIAT), Augusto Castro (CONDESAN), James García (CIAT), Tatiana Halland (KCL, London), Tatiana Rebecca McIntosh (KCL, London), Margarita Ortiz (CIAT), Jessica Santacruz (UNAL), Simone Staiger-Rivas (CIAT), Bibiana Duarte (Wageningen University, Netherlands) and all the members of organizations linked with us at different stages in the project, in particular to Sylvia Benitez (TNC), Edwin Pajares (CEDEPAS), Jaqueline Armas (Coordinadora del Jequetepeque) and Teresa Ore (IPROGRA). Finally we thank the CPWF and its donors and the basin focal projects team for funding, support and guidance throughout the process. We hope that these efforts bore fruit in the outcomes and products of the BFP-ANDES.



Program Preface

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

The CPWF Basin Focal Project for the Andes system of basins worked with a range of local stakeholders to develop a better understanding of the mechanisms for improving the productivity of water in the Andes. We considered productivity in broad terms as the productivity of energy (HEP), food and fiber (agriculture) and livelihoods (industry, transport and benefit sharing such as Payments for Environmental Services schemes (PES)).

In addition to the compiled data bases and analyses on poverty and institutions, one of the key deliverables of the project was the development and deployment of the AguaAndes policy support system (PSS). This integrates analyses of water availability and productivity within the local environmental and policy context. It is a web-based policy support system combining an extensive spatial database with process-based models for hydrology, crop production and socio-economic processes. It is intended to allow analysts and decision makers to test the potential onsite and offsite impacts of land and water management decisions in terms of their ability to sustain environmental services and human wellbeing. Interventions and recommendations for future actions on water and food in the region are presented.

CPWF Project Report Series

Each report in the CPWF Project Report series is reviewed internally by CPWF staff and researchers. The reports are published and distributed both in hard copy and electronically at www.waterandfood.org. Reports may be copied freely and cited with due acknowledgment. Before taking any action based on the information in this publication, readers are advised to seek expert professional, scientific and technical advice.

Citation

Mulligan, M., J. Rubiano, G. Hyman, J. G. Leon, M. Saravia, D. White, V. Vargas, J. Selvaraj, C. Ball, A. Farrow, J. A. Marín, O. L. Pulido, A. Ramírez, T. Gutierrez, L. Sáenz Cruz, A. Castro, M. Andersson (2009) The Andes Basin Focal Project. Final Report to the CGIAR Challenge Program on Water and Food. <http://www.bfpandes.org>

Table of Contents

Acronyms and Abbreviations	10
Acknowledgements	Error! Bookmark not defined.
Executive Summary	11
OBJECTIVES OF THE CPWF	13
ROLE AND OBJECTIVES OF THE ANDES BFP	13
INTRODUCTION.....	14
1. Water availability and access	21
2. Water productivity.....	34
3. Institutions.....	43
4. Poverty.....	57
5. Interventions.....	66
References.....	78
Appendix A
Appendix B
Appendix C
Appendix D.....	.
Appendix E
Appendix F

Table of Contents (detailed)

Acronyms and Abbreviations	10
Acknowledgements	Error! Bookmark not defined.
Executive Summary	11
OBJECTIVES OF THE CPWF	13
ROLE AND OBJECTIVES OF THE ANDES BFP	13
INTRODUCTION	14
Demographic and socio-economic context	15
Biophysical, climatic, and land use context	17
Agricultural trends.....	17
Gender issues	19
The influence of policies and markets.....	20
Urbanization	20
1. Water availability and access	21
1.1. Water availability	22
1.1.1. Regional scale inputs (rainfall, fog and snowmelt).....	22
1.1.2. Regional scale outputs (evapo-transpiration)	23
1.1.3. Regional scale balance (water balance and runoff)	23
1.1.4. Regional scale stores (dams, wetlands, groundwater)	23
1.1.5. Per capita water resources and dry-spots	23
1.1.6. Water deficits.....	24
1.2. Water access and quality	26
1.2.1. Factors related to water scarcity in the focus sub-basins	26
1.2.2. Water use magnitude and distribution by sector	28
1.2.3. Water use magnitude and distribution by source	29
1.3. Threats to water provision and upstream-downstream linkages	30
1.3.1. Natural hazards.....	30
1.3.2. Modelling threats to water provision.....	31
1.4. Conclusions.....	33
2. Water productivity.....	34
2.1. Water productivity in the Andes	34
2.1.1. Agricultural water productivity and crop/drop	34
2.1.2. Water for fisheries	36
2.1.3. Water for hydropower	36
2.1.4. Water for nature: Environmental flows	38
2.1.5. Water for urban populations.....	38
2.2. Threats to productivity.....	39
2.2.1. Agricultural productivity	41
2.2.2. Hydropower production	41
2.2.3. Urban and industrial uses	41
2.2.4. Environmental flows.....	42
2.3. Conclusions.....	42
3. Institutions.....	43
3.1. Definitions and concepts	43
3.1.1. Institutions versus organizations	43
3.1.2. Formal and informal.....	44
3.1.3. Issues of scale	44
3.2. Institutions in the Andean region	45
3.2.1. Policy instruments and the role of land tenure.....	45
3.2.2. Formal and informal mechanisms of public participation	46
3.2.3. Organizational structures at different levels	47
3.2.4. Organizational roles at local scale	48
3.3. Institutional performance	48
3.3.1. Literature review	48
3.3.2. The Institutional Environmental Index (IEI)	49
3.4. Institutional perceptions and needs	51

3.4.1.	Organizational analysis (institutional perceptions).....	51
3.4.2.	The AguAAndes Policy Support System.....	52
3.4.3.	Key strategic institutional recommendations	55
3.5.	Conclusions	57
4.	Poverty	57
4.1.	Levels of poverty in the Andes compared with other CPWF basins	58
4.2.	The levels and distribution of poverty in the Andes	58
4.3.	The nature of poverty in the Andes	60
4.3.1.	Factors influencing poverty at country level	60
4.3.2.	Factors influencing poverty at the watershed scale	62
4.3.3.	The effect of natural hazards.....	64
4.4.	Conclusions	65
5.	Interventions.....	66
5.1	Previous interventions in the region.....	67
5.1.1.	Intervention context	67
5.1.2.	Intervention strategies	67
5.1.3.	Intervention impacts.....	68
5.2	Potential strategic interventions in the region	69
5.2.1.	Technical interventions.....	69
5.2.2.	Institutional interventions	70
5.3	Conclusions and recommendations: Key interventions by activity sector	73
5.3.1.	Broad-scale interventions	73
5.3.2.	High-value and low-productivity smallholder farming	74
5.3.3.	Large-scale (irrigated) commercial agriculture.....	76
5.3.4.	Urban centers, industry and mining	76
References.....		78

List of Figures

Figure 1.	The Andes 'basin' is defined as the area of all catchments above 500 m.a.s.l. (blue).....	15
Figure 2.	Urban and rural poverty in four Andean countries, 2005 (Source: CEPAL, PSE 2007, Statistical Annex	16
Figure 3.	Geographical distribution of indigenous and African descendent population in 2000.....	17
Figure 4.	Some of the water related issues in key Andean sub-basins. Abbreviations: Bio=Biodiversity loss, Def=Deforestation, Deg=Ecosystem degradation, Ero=Erosion, Ins=poor institutions, Pol=Pollution, Pov=Poverty, Sed=Sedimentation, WSc=Water scarcity	18
Figure 5.	Evolution of agricultural area (left) and fertilizer consumption (right) between 1961 and 2002	18
Figure 6.	Major cities in the Andes region (source: ESRI data and maps, 2002) ..	21
Figure 7.	Water balance for the Andes (mm/yr) (left) and difference between WorldClim and TRMM water balance (mm/yr) (right).....	25
Figure 8.	Population density (persons/km ² , 2005) (left), mean per capita water balance (mm/person or 1000's m ³ /person) (center) and mean per capita water balance on a pixel basis (mm/person or 1000's m ³ /person) by Municipality (right). Log scale from green to red. Pink and purple colors are below minimum shown on legend.....	25
Figure 9.	Domestic water demand (m ³) (left), water supply (m ³) (water balance) (center), and water surplus/deficit (m ³) for the Andes (right).....	26
Figure 10	Water use distribution in the Andes sub-basins by sector.....	30
Figure 11.	Change in forest cover (fraction) (left) and water balance (mm/yr) (center) due to land use change between pre-agricultural scenario and current; and future change in water balance per capita with climate change to 2050 (m ³ /person) (right)	32
Figure 12.	Percentage of runoff originating in mines and quarries (Jequetepeque area, N Peru)	32
Figure 13.	Mean water productivity (g/ha./mm) (crop per drop) for WorldClim rainfall (left) and TRMM rainfall (right)	35
Figure 14.	Dry matter productivity (kg/ha/yr) for pasture (left) , irrigated cropland (center), and all cropland (right)	35
Figure 15.	Aquaculture site suitability in the Andes	36
Figure 16.	Hydrological response to climate change in the Andes (mean of 17 models) for 2050s). Left: mean annual temperature change to 2050s(°C), center left: mean annual precipitation change to 2050s (mm), center right: mean annual evapo-transpiration change to 2050s (mm), right: mean annual water balance change to 2050s (mm)	40
Figure 17.	Sensitivity of the Andes to land use and climate change: What will happen by 2050 as we continue to push? Left: Runoff sensitivity to tree cover change (% change in runoff per % change in tree cover), center: Runoff sensitivity to precipitation change (% change in runoff per % change in precipitation), right: Runoff sensitivity to temperature change (% change in runoff per % change in precipitation). Red circles indicate areas of particularly high sensitivity.	41
Figure 18.	Land tenure in Ecuador (top), Colombia (center), and Peru (bottom) in terms of % of total area and % agricultural productive unit (APU).	46
Figure 19.	Preference for potential interventions in Fúquene sub-basin to solve water-related problems (Source: Fúquene Workshop WP4)	49
Figure 20.	The Institutional Environment Index (IEI) for the four focus countries in the Andean region	51
Figure 21.	Example of presentation of results for AguAAndes in map form	54
Figure 22.	Example of presentation of results of AguAAndes in a geobrowser	54
Figure 23.	Example of presentation of results of AguAAndes as time series charts	55

Figure 24. Spatial distribution of poverty in the Andes basin using the 'choropleth' approach (left) and Local Indicators of Spatial Autocorrelation (LISA) (right).....	61
Figure 25. Local Indicators of Spatial Autocorrelation (LISA) for national poverty indicators of the four BFP Andes countries (top left: Colombia, top right: Ecuador, bottom left: Peru, bottom right: Bolivia).....	62
Figure 26. People affected by floods, landslides and droughts in the Latin American region from 1990 to 2003.....	65

List of Tables

Table 1.	Improved water supply and sanitation in the Andean Region, 2006 (WHO, 2008)	27
Table 2.	Improved water supply and sanitation in the Fúquene sub-basin (MAVDT, 2006).....	28
Table 3.	Water use by sector in the four Andes BFP countries in 2000 (FAO, 2003a)	29
Table 4.	Irrigated area in four Andean countries (Source: Aquastat, FAO)	29
Table 5.	Hydroelectric installed capacities, annual energy production and energy sales in the four Andes BFP countries	37
Table 6.	Direct democracy mechanism at national level in the four Andes BFP countries	47
Table 7.	Comparison of usability characteristics of SWAT and AguAAndes for tropical montane environments	52
Table 8.	Key factors related to poverty and poverty-water linkages in the three Andes BFP sub-basins	63
Table 9.	Different intervention strategies identified in the three Andes BFP focus basins	68

Acronyms and Abbreviations

BFP	Basin Focal Projects, www.waterandfood.org/research/basin-focal-projects.html
CAPRADE	Comité Andino para la Prevención y Atención de Desastres (= Andean Committee for Disaster Prevention and Care)
CCF	Community Capitals Framework
CGIAR	Consultative Group on International Agricultural Research, www.cgiar.org
CIESIN	Center for International Earth Science Information Network, Columbia University
CONDESAN	Consortium for Sustainable Development of the Andean Ecoregion, www.condesan.org
CPWF	Challenge Program for Water and Food, www.waterandfood.org
CWS	Compensation for Watershed Services
DMP	Dry Matter Production
DRM	Disaster Risk Management
FIESTA	Fog Interception for the Enhancement of Streamflow in Tropical Areas, www.ambiotek.com/fiesta
GCM	General Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPW	Gridded Population of the World, http://sedac.ciesin.columbia.edu/gpw
HEP	Hydro-electric power
IPCC	United Nations Intergovernmental Panel on Climate Change
IPCC SRES AR4	Fourth Assessment Report (AR4) of the IPCC Special Report on Emissions Scenarios (SRES), www.ipcc.ch/
ITCZ	Intertropical Convergence Zone
IWRM	Integrated water resources management
MODIS	MODerate resolution Imaging Spectroradiometer, http://modis.gsfc.nasa.gov/
MODIS VCF	MODIS Vegetation Continuous Fields, www.landcover.org/data/vcf/
NGO	Non-Governmental Organization
PA	Protected Area
PES	Payments for Environmental Services
PSS	Policy Support System
PWS	Payments for Watershed Services
SD	Standard Deviation
SPOT	Satellite Pour l'Observation de la Terre, www.spotimage.com
SPOT-VGT	SPOT Vegetation (database), www.spot-vegetation.com/
SWAT	Soil and Water Assessment Tool, www.brc.tamus.edu/swat/
TRMM	Tropical Rainfall Measuring Mission, http://trmm.gsfc.nasa.gov/
UNEP-GEMS	United Nations Global Environment Monitoring System, www.gemstat.org/datasrc.aspx

Executive Summary

The Andes system of basins in Latin America – as defined for this project – reaches from Colombia, through Ecuador, and Peru to Bolivia, and includes several large and small river basins from 500 m.a.s.l. elevation and higher. The system is different from other CPWF focus basins in two main ways. First, in biophysical terms it is the most mountainous of the CPWF basins, has the greatest rainfall extremes, and the greatest spatial heterogeneity in climate, geology and soils. Also, the Andes region has greater inequality between the upper reaches of watersheds and the lower valley areas compared to CPWF basins with less relief in other parts of the world. Secondly, in contrast to most CPWF basins in Africa and Asia, the Andes basin countries are considered highly urbanized on account of overall levels of rural poverty and the contribution of agriculture to GDP. Crop production is mainly for income generation (cash cropping), and subsistence agriculture is not a dominant feature. Still about half of the population in Colombia, Ecuador, and Peru, and almost two thirds in Bolivia are considered poor, based on their position relative to national poverty lines. Of these 47 million poor people, 26 million depend on rural livelihoods.

We identified three main drivers (or constraints) of development in the Andean system of basins:

Biophysical features limit water productivity and development in various respects. Generally, water scarcity is much less a problem than in other CPWF basins, especially in the northern Andes. The most important water-related hazards that affect livelihoods in the Andes are droughts and floods related to the El Niño phenomena, but the severity of droughts in the Andes is probably less than in CPWF basins in Africa and Asia.

The most significant constraints are to do with terrain and its impact on soil water storage and soil quality. Soil erosion and sedimentation are key water-related problems in the Andes influencing both agricultural productivity and downstream water quality. In the other basins water quality issues are more often related to urban and industrial contamination and associated health impacts from bacterial, parasitic or viral infection. Water quality issues in the Andes are mainly due to steep slopes with marginal agriculture carried out with little emphasis on erosion control coupled with intense rainfall leading to soil erosion and landsliding. In the highly urbanised northern countries there are also significant inputs from urban wastewater, industrial and mining sources.

Markets and **policies** are two important and related drivers that play a key role in enhancing or constraining development in the Andes region, particularly in rural areas. Global market forces, supported by favorable national economic policies and free trade agreements, are encouraging the spread of commercial and high-value agriculture. This, in combination with a lack of investment in rural areas (*e.g.*, low provision of education) and political unrest and violence (*e.g.*, Colombia), has led to the increased marginalization and isolation of smallholder agriculture. This is true particularly in the Andean uplands and has led to continued rural-urban migration. These drivers are negatively affecting rural development in the Andes system of basins, and have led to demographic shift and a trend towards increasing urbanization. As a consequence, natural resource degradation is becoming a critical issue for sustainability, always affecting the most vulnerable (the urban and rural poor) most strongly. This is particularly clear in the four main water use sectors: rural use, lowland commercial agriculture, urban areas and industry. For rural use: land degradation with soil erosion and loss of productivity (especially in the

uplands) and often leading to downstream impacts is a key issue. Downstream commercial agriculture: gives rise to conflict between irrigation vs. supply to major cities, sedimentation and other water quality losses, increased susceptibility to natural hazards such as landslides, floods, and droughts. For urban and industrial use the main issues are of water quality and distribution (sanitation) and use conflicts (between for example, irrigation, domestic and mining uses).

Risks: A number of new and continued risks confront the sustainability of water productivity in the Andes. Scenario analyses clearly indicate that much of the Andes will experience increases in precipitation. The overall water balance is also expected to increase, which will likely bring water productivity benefits throughout the central and southern Andes. Though these benefits may come with dis-benefits including increasing frequency of higher magnitude rainfall events, increased soil erosion, and changes in patterns of suitability for particular crops, there will be an overall benefit of greater water availability for total crop growth in the currently-water-limited southern Andes. The extent to which this increased productivity in the south will be matched by increased crop failure through extreme events such as floods and landslides in the hyper-humid and populous northern Andes remains unknown. Outside (and on occasion even inside) of currently protected areas, the need for greater food supplies for internal and external markets will tend to push landscapes along the same trajectory they have taken historically towards greater agriculturalization. This land use change will also have impacts on water availability, water regulation and water quality though the nature of these impacts will be highly locale-specific and will generally be less – at least in terms of water quantity impacts – than those expected from climate change.

Opportunities: A number of new opportunities with potential to provide water productivity benefits have recently arisen. Amongst these hydropower generation, compensation for ecosystem service provision (PES schemes), niche-production (dairy and high-value), and increasing income from tourism stand out as providing sustainable pathways out of poverty for marginalized agricultural communities.

OBJECTIVES OF THE CPWF

The Challenge Program for Water and Food (CPWF) represents one of the most comprehensive assessments of the relationship between water, food production and poverty (www.waterandfood.org/about-cpwf.html). Through the paradigm of water productivity – developing ways to produce more food with less water – the CPWF offers a new approach to natural resources management research within the CGIAR. The CPWF works together with governmental institutions, NGOs, research, industry and community groups in partnerships which seek meaningful impact through innovation derived from scientific research.

The Challenge Program is working towards achieving:

- Food security for all at the household level.
- Poverty alleviation through increased sustainable livelihoods in rural and peri-urban areas.
- Environmental security through improved water quality as well as maintenance of water-related ecosystems, biodiversity and ecosystem services

ROLE AND OBJECTIVES OF THE ANDES BFP

Within the CPWF, the Basin Focal Projects (BFP) provide strategic insight of the links between water, food, and poverty in globally important river basins (<http://cpwfbfp.pbworks.com/>). Based on robust scientific analysis within ten river basins these projects address the following key questions :

- a. How much water is there?
- b. Who uses the water and how much flow remains?
- c. How well is water used? What is its water productivity?
- d. What is known about the institutions that manage food and water systems?
- e. What are the impacts of water use patterns on poverty and livelihoods?

By addressing these questions for the Andes region, the Andes BFP aims to "*enable and promote the use of the best available science in the formulation and testing of land and water policies for better livelihoods, in cases where currently science is little used*". This report presents the diagnosis of the current status of water productivity, water poverty, environmental security, and the social and institutional context in the Andes basin including gender issues; and makes recommendations for interventions to address Andean water poverty. The research and development work carried out for this purpose in addition helps to address a series of more specific client needs, including:

- a. Provision of accessible baseline data and information
- b. Provision of accessible tools for testing effects of alternative policy options (interventions) and their intended and unintended consequences
- c. Provision of accessible knowledge on impacts of climate change
- d. Provision of accessible knowledge of (seasonal) downstream impacts of land use change on water supply to cities/dams
- e. Simplification of the complex problems around food and water for better engagement in evidence based solutions
- f. Provision of accessible spatial planning tools for optimization in a highly heterogeneous and connected environment
- g. Facilitation of an institutional framework for evidence-based policy implementation

INTRODUCTION

Compared with the other basins of the CPWF (Volta, Nile, Limpopo, Yellow, Mekong, Karkeh, and Indogangetic), the surface area of the Andes basin in Latin America (as defined here: 2.89 million km²) is second only to the Nile (3.09 million km²). Unlike the other CPWF basins, the Andes 'basin' is not a true basin that flows into a single outlet, but rather a series of neighboring basins flowing independently to the Pacific, Amazon/Atlantic and Caribbean. They stretch over 63 degrees of latitude (11°N to 52°S) and reach from Colombia, through Ecuador and Peru to Bolivia, and further south into Chile and Argentina (Figure 1). This latitudinal extent means that the basins (most of which run east-west or west-east) cover a wide range of climate regimes from equatorial through tropical, temperate, and near polar.

The Andes system is different from other CPWF focus basins in several aspects. First, due to its biophysical heterogeneity – it is the most mountainous of the CPWF basins (covering elevations from sea level to almost 7000 m.a.s.l.), has the greatest rainfall extremes, and the greatest spatial heterogeneity in climate, geology, soils, and vegetation. Second, the countries of the Andes basin are considered urbanized and industrialized (on account of overall levels of rural poverty and low contribution of agriculture to GDP), whereas most countries of the BFP basins in Africa and Asia have more agricultural economies (e.g., Volta) or transforming economies (e.g., Karkeh and Mekong) (World Bank, 2007). The Andes basin is extensively covered by cropland and pastures, but subsistence agriculture is not a dominant feature and crop production is mainly for income generation through markets. Nevertheless, considerable numbers of people remain in deep poverty.

This report considers several groups of activities, linked within a complex environment in which flows of water, food, and other resources influence well-being of specific groups and development of the region as a whole. Firstly we consider **smallholder farmers**. Approximately 26 million of these people from rural areas are considered poor. While many smallholder farmers depend on rural livelihoods, many more have migrated to swell the ranks of the urban poor who live in rapidly expanding cities. Urban dwellers constitute the second group – about 21 million of whom are increasing local demands on food and water in the Andes. These first two groups comprise about half of the population of the four focus countries of the BFP Andes (Bolivia, Colombia, Ecuador, and Peru).

A third group is **commercial agriculture** – much of it irrigated – that occupies a relatively small proportion of the total area, but a high proportion of the more agriculturally favored areas, producing sugarcane, bananas, rice, palm, and high-value crops such as coffee, fruits, and more recently biofuels. **Mining and other industrial uses** (e.g., dams and hydroelectric plants, oil and gas pipelines) complete the picture. They occupy a very small area but have a disproportionate and expanding impact on rural income (employment), environmental resources (degradation), and land tenure issues (conflict between tenure and increasing concessions).



Figure 1. The Andes 'basin' is defined as the area of all catchments above 500 m.a.s.l. (blue)

Demographic and socio-economic context

In 2005, the four Andean countries in the study region had a population of about 95 million, that is 17% of the total Latin American population (560 million). The average growth rate in the last 25 five years (1980-2005) was 2%/yr, ranging from 1.9%/yr in Colombia and Peru to 2.3%/yr in Bolivia (UN, 2007).

Forty-seven million people in the four study countries are considered poor, based on their position relative to national poverty lines (Figure 2). This corresponds to about half of the population in Colombia, Ecuador and Peru, and almost two-thirds in Bolivia. Of these total poor, 26 million depend on rural livelihoods. Poverty is sometimes related to lack of water, in other cases to excess water, and is affected by hazards to productivity such as landslides, soil erosion/degradation, nutrient losses, and downstream impacts (including sedimentation, water quality losses, flooding, lack of supply to major cities) of upstream land and water related interventions. Both land and water related interventions have impacts on health and poverty; sometimes directly through water supply, sometimes mediated through food production.

In terms of ethnic distribution, several clusters of indigenous and African descendants can be found in the Andes region. While indigenous communities are more concentrated in southern Peru and most of Bolivia, African descendants are

found mainly along the Pacific coast in Colombia, northern Ecuador and northern Peru (Figure 3). In many indigenous communities in the highland villages, native languages such as Quechua are the main form of communication, with Spanish being spoken only by younger educated men. This has traditionally led to a lack of opportunities to participate in civil and political spheres at a regional and national level. Traditional forms of land use and specific agricultural systems are dominant in these communities, and local organizations play a strong role in the management of natural resources.

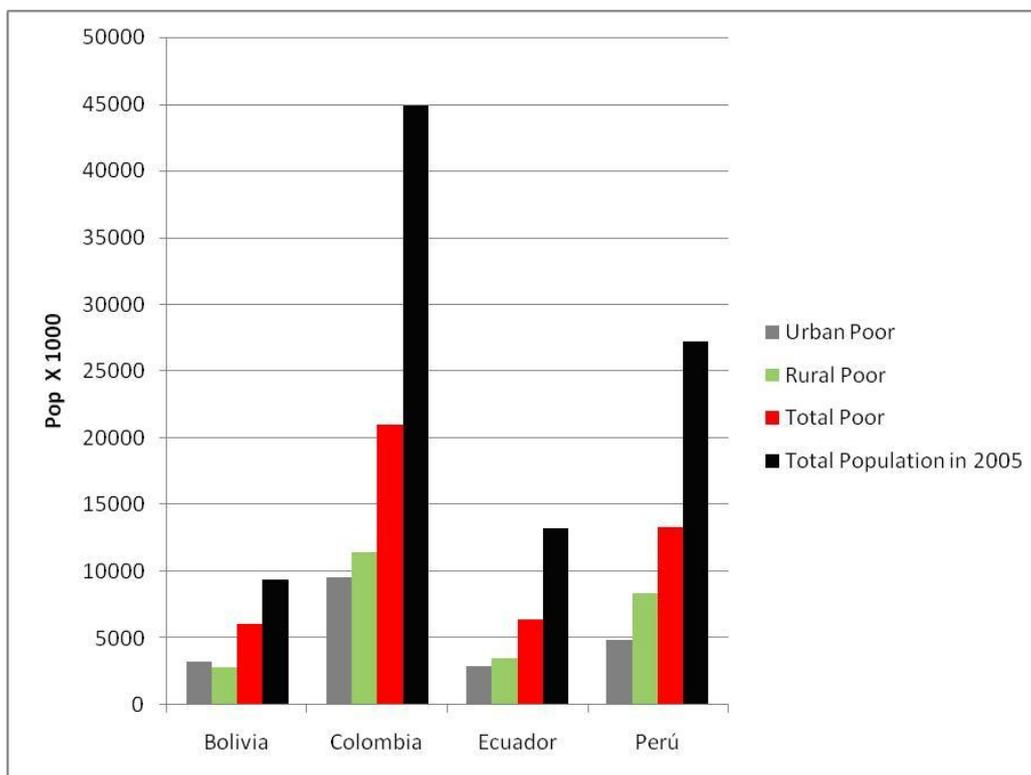


Figure 2. Urban and rural poverty in four Andean countries, 2005 (Source: CEPAL, PSE 2007, Statistical Annex)

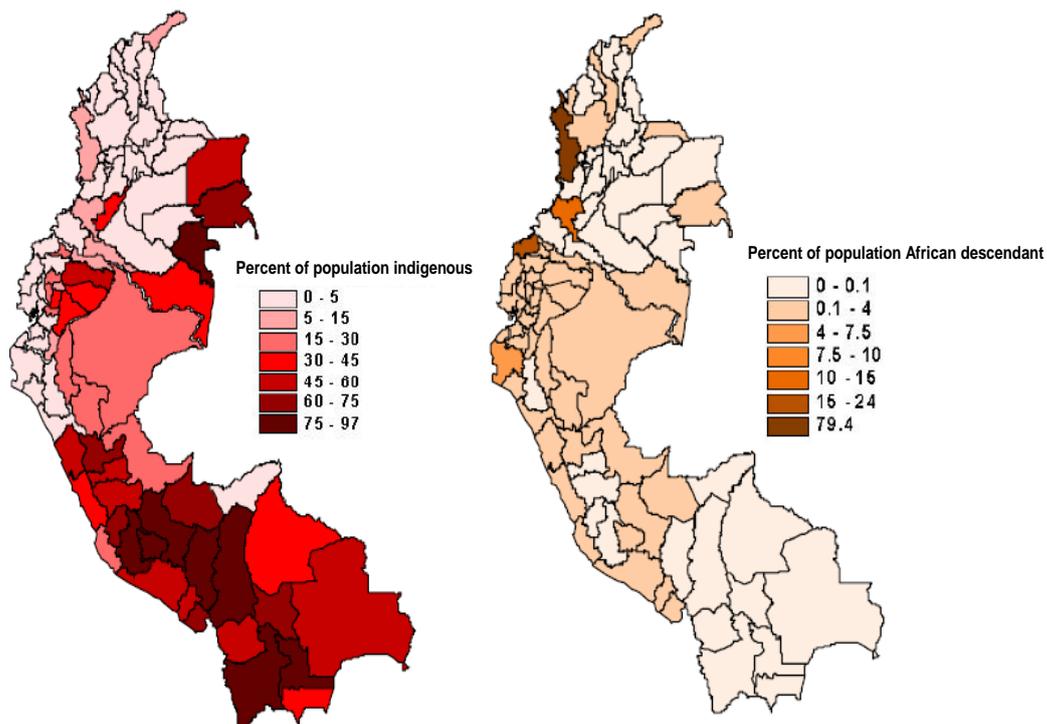


Figure 3. Geographical distribution of indigenous and African descendant population in 2000

Biophysical, climatic, and land use context

As mentioned above, the dominant characteristic of the Andean landscape is ***spatial variability*** in climate, geology, soils, and vegetation, combined with temporal variability as a consequence of the passage of the Inter-tropical Convergence Zone (ITCZ). Rainfall is highly variable both spatially and seasonally. Conditions range from hyper-humid (>10,000 mm/yr) in parts of Colombia to hyper-arid (that is, a few hundred mm/year) in parts of Chile and Bolivia. Detailed information and maps of rainfall distribution, landscape features, and land use are provided in Appendices A.1.1 and A.1.2.

The Andes are host to competing land use demands on very steep lands, including different types of agricultural production systems (see following section), water management projects such as existing and proposed major dam projects, inter-basin transfers, and mining. Moreover, the Andes are environmentally sensitive, and the provision of watershed services by ecosystems – highly prized for their biological diversity – provides important new livelihood options in the form of payments for environmental services (PES) and other non-agricultural livelihood options. A number of specific issues and interactions of water and well-being exist in Andean catchments, which are summarised in Figure 4.

Agricultural trends

Agriculture is the dominant user of water resources in the Andes, and the area dedicated to agriculture in Latin America has increased steadily (Figure 5, left). By the end of 2001 it accounted for about 770 millions ha, almost twice as much as by the end of the 50's. For three of the four Andes BFP countries (Colombia, Ecuador and Peru), the agricultural area has remained more or less stable since the mid 70's whereas the consumption of fertilizers has increased several-fold (Figure 5, right), indicating increasing intensification of agricultural land use. In Bolivia in contrast, fertilizer consumption remained the same whereas the country expanded its agricultural area by about 7 million ha.

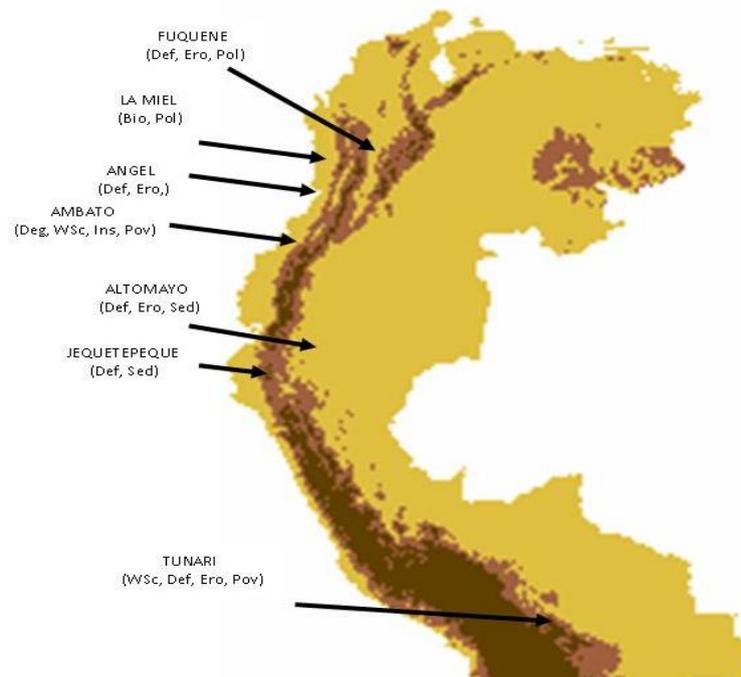


Figure 4. Some of the water related issues in key Andean sub-basins. Abbreviations: Bio=Biodiversity loss, Def=Deforestation, Deg=Ecosystem degradation, Ero=Erosion, Ins=poor institutions, Pol=Pollution, Pov=Poverty, Sed=Sedimentation, WSc=Water scarcity

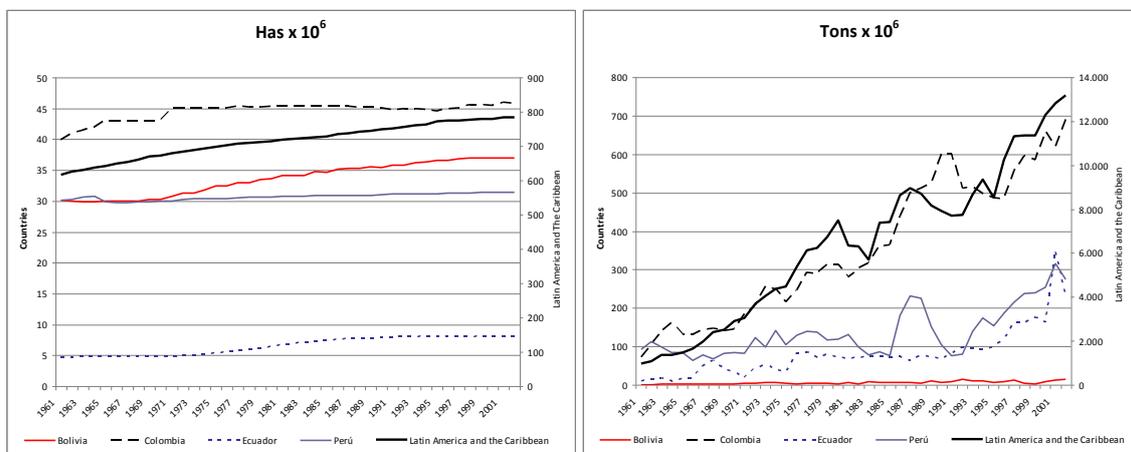


Figure 5. Evolution of agricultural area (left) and fertilizer consumption (right) between 1961 and 2002

Three broad categories of agricultural production systems can be distinguished in the Andes region:

In the highlands, agricultural production is generally characterized by **low productivity smallholder farming** which has traditionally been the main source of regional and local food supply. Maize, potatoes, beans, wheat, and livestock are the major crops produced in these areas. Although these smallholder farming systems traditionally pose low demands on natural and external resources and potentially are a provider of ecosystem services, they have become increasingly eco-inefficient due to distorted market trends and neo-liberal economic policies that do not internalize environmental externalities. In spite of the generally fertile and rich soils in the humid highlands, the rural upland population is largely excluded

from secure markets for their produce – not only due to geographical isolation and lack of infrastructure/roads to reach markets quickly, but also due to national policies of food importation and price controls that have negatively influenced the terms of trade between urban and rural centers. Andean upland communities have seen a marked decrease in the profitability and demand for domestically-grown basic staple crops along with most other global regions. Increasingly households engaged in smallholder agriculture are seeing basic grains such as maize and potatoes change from cash-generating status to truly subsistence crops. This has a negative impact on various key environmental, economic, and social factors resulting in rapid urbanization (Katz, 2003).

In contrast, agricultural production in the lowlands and inter-Andean valleys is mostly dominated by **large-scale production systems dedicated to commercial agriculture** such as sugarcane, oil palm, soy, and rice. These production systems are an important contributor to rural livelihoods and are currently expanding in response to demand. However, they are a heavy user of environmental resources and can be environmentally degrading (especially through soil erosion and pollution).

A third agricultural sector is that of **high-value smallholder farming**, targeted within the diverse environments yet to be connected with markets. Coffee is the classic example of such a high value produce. These production systems generally have a low resource demand and are relatively eco-efficient where values can be assured. In the Andean highlands, the most important potential high-value agricultural sector is probably dairy production, however cut flowers, fish farming, and wool/textiles have also been important sources of wage employment. Increasing urbanization has led to a strong growth in urban demand for industrially processed dairy products. At present there has been a rapid increase in milk production along the coast but not so much growth in the Andean highlands, where, in fact, an increase in milk production would create the greatest benefits for the poor (Bernet et al., 2001).

Gender issues

Women play an important role in the productive, labor, and migratory dynamics in the Andean region, particularly in the rural areas and the highlands. With the fore-mentioned conversion of many staple crops (such as maize and potatoes) from cash-generating status to subsistence crops, men have increasingly left farms to search more profitable, off-farm (often migratory) employment. Many rural women, - especially those in communities with limited access to reliable off-farm employment – are thus left with cultivation of subsistence crops and control over important production and use decisions, meaning that their (generally unpaid) participation in agricultural tasks is the main source of food security at a household level (Radcliffe, 1990).

At the same time men have come to represent a large source of labor for non-local labor markets in agricultural production systems dedicated to both commercial and more high-value export crops such as coffee, fruits, tea, and more recently flowers, as well as in the domestic and industrial sectors (mining, fish processing). This has led to a general increase in household reliance on non-farm sources of labor including off-farm wage work in agriculture, wage work in non-farm activities, rural non-farm self employment (trading), and remittances from urban areas (Jokisch, 2002).

It is important to consider the effects that this rural-urban migration has had on agricultural production and land use practices. While migration has not led to total agricultural abandonment and semi-subsistence agriculture remains an important risk averse economic and cultural activity, it has undoubtedly led to increased

environmental degradation caused by labor shortages. Even where men are not physically absent for extended periods of time, trade and price liberalization affecting important food crops have produced the same effect with widespread reallocation of household labor to accommodate higher input and lower output prices for basic grains that still form the foundation of the diet of rural poor.

The influence of policies and markets

Prices of food crops in the Andean region are driven to a large extent by main producers overseas where subsidies distort the real cost of production, and reduce competitiveness of farmers in developing nations. A focus on primary non-processed crops, minerals, fuels, and raw material for biofuels limits the potential benefits that are later obtained by nations with more industrial capacity. Workers in such systems require less training, which is also reflected in reduced investments in education – which are very limited throughout the region. The current radicalization of some governmental positions is a reflection of the reaction against a system that has for years divided the region politically and economically. The gap between the poor and the non-poor is growing and this provokes violence and social unrest.

Urbanization

As laid out above, political and economic insecurity have led to a depopulation of rural areas in Andean countries, particularly in the upland regions. Land tenure concentration amongst the rich and the loss in profitability of smallholding agriculture have been the main driving factors for this (Rodriguez and Busso, 2009). As a consequence, urban populations have expanded rapidly in several regional cities (Figure 6), but these cities capacity to cope with the ensuing social and economic problems of rapid growth is in question. In the last 25 years, the population in urban areas has increased steadily throughout Latin America while the rural population has remained more or less stable in absolute terms (resulting in a relative decrease of rural inhabitants as a proportion of total population). According to a recent revision of “rurality” in Latin America (Chomitz et al., 2005), almost half of the population lives more than an hour away¹ from large cities (100,000 inhabitants or more), and in areas with densities below 150 people/km². A quarter of these live in areas with extremely low densities, and about a third of them (18% of LAC total) are more than four hours distant from large cities. The increase in urban population means more pollution and higher water and food demand from a non-farming community, stretching the demand for goods and services from rural areas.

The imperfection of this development process in Andean countries means deterioration of quality of life of the remaining rural population. Rural areas are left behind in investment policies, and local and national administrations cannot cope with the demand in services from increasing urban populations that are augmenting slums and poverty. It is widely accepted that the main source of water pollution in the region is the lack of proper management of waste water and disposals from urban and industrial centers. The region faces the duality of promoting migration to cities while not having adequate response to the needs of the newcomers.

¹ Authors arbitrarily assigned travel speeds of 10 to 60 km/hr to roads of increasing quality, and 4 km/hr to off-road travel.

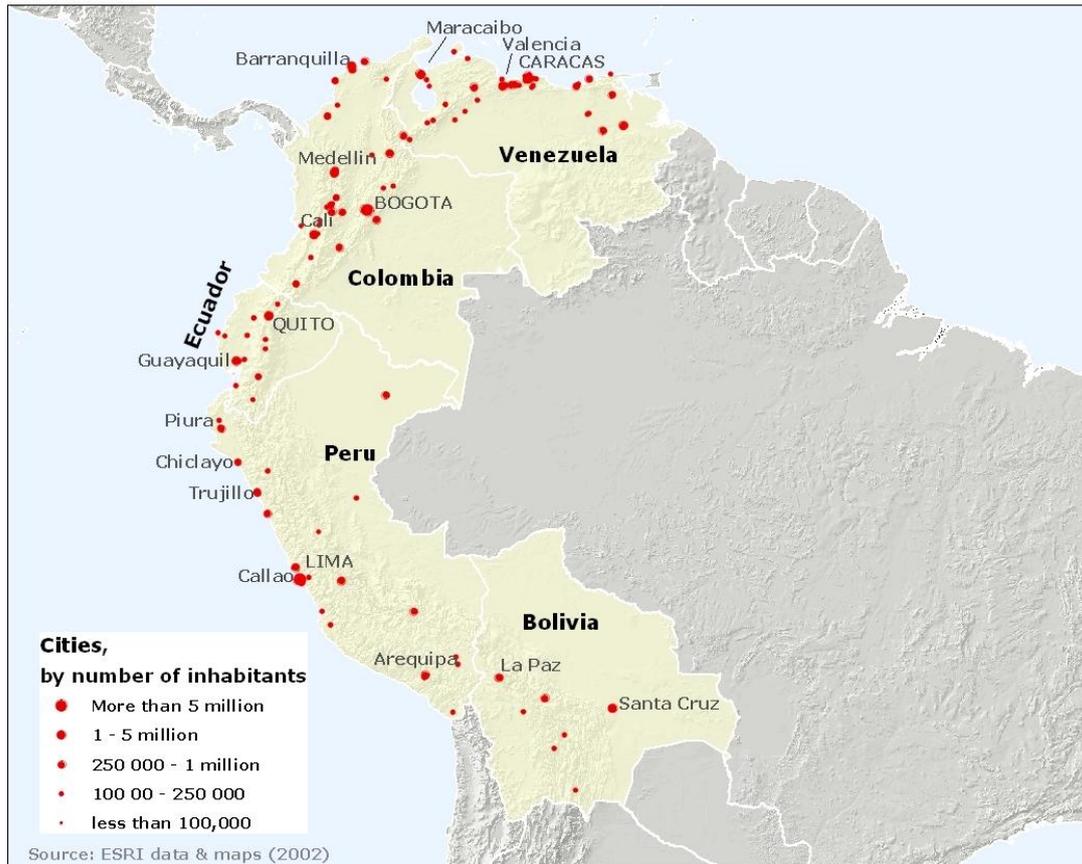


Figure 6. Major cities in the Andes region (source: ESRI data and maps, 2002)

1. Water availability and access

To avoid the inclusion of large lowland areas, the Andes BFP 'basin' focuses on the mountainous catchments and is defined as the area of all catchments above 500 m.a.s.l. (Figure 1). A subset of this area incorporating four focus countries (Colombia, Ecuador, Peru, and Bolivia) was chosen for more broad-scale regional socio-economic analyses. Within these countries, particular emphasis was placed upon three sub-basins. The sub-basins selected were Fúquene in Colombia, Ambato in Ecuador, and Jequetepeque in Peru, since these are of particular stakeholder interest, have significant data resources, and relevant water related issues.

To address the wide range of stakeholders and potential users of information, from international to local level, we carried out a) coarse Andes-wide regional analyses to identify areas inside and beyond the four focus countries where particular issues are important (1 km or lower resolution), as well as b) finer-scale basin studies in three key sub-basins with detailed analyses of issues of particular site-specific interest (resolution up to 1 ha).

In the following section on water availability and access, we address the first two key questions posed to all Basin Focal Projects:

- How much water is there?
- Who uses the water and how much flow remains?

1.1. Water availability

To assess water availability in the Andes, the best available ground measured and remotely sensed datasets were used to parameterise a 1 km spatial resolution application of the data-intensive FIESTA delivery model (www.ambiotek.com/fiesta; Mulligan and Burke, 2005), which provides monthly and annual water balance calculations for the period 1950-2006 when parameterised with the WorldClim climatology (Hijmans et al., 2005), and for 1998-2006 when parameterised with the TRMM climatology (Mulligan, 2006a). The FIESTA model requires more than 140 input maps for the region, all of which were derived from various sources available in the SimTerra database (Mulligan, 2009). The results of this analysis were used to define water availability and then combined with information on water access to better understand access to water for different purposes. See Appendix A.2 for detailed methodological information and maps on regional water inputs, outputs and water balance.

1.1.1. Regional scale inputs (rainfall, fog and snowmelt)

Two different precipitation climatologies were used to characterise inputs from precipitation. They showed a similar pattern, with the highest values recorded in the Chocó region of Colombia, the Caribbean lowlands and the eastern slopes of the Andes from Colombia, through Ecuador to Peru and Bolivia. The driest areas include the Bolivian Altiplano, Chile and Argentina. There is no simple pattern of rainfall with elevation, though the maximum rainfall tends to decline with elevation. In spite of the broad agreement between the two climatologies, discrepancies can be of the order of thousands of mm in some spatially restricted areas. This uncertainty in basic inputs because of high spatial variability makes the quantification of absolute magnitudes of water input extremely difficult, and thus substantially reduces the precision with which water accounts can be calculated. It is likely that the real incident rainfall is somewhere between the remotely sensed but highly spatially-detailed TRMM estimate and the ground-measured but highly interpolated WorldClim estimate.

The Andes are characterised by frequent and persistent cloud cover, which can often be at ground level. Cloudiness is associated with both high rainfall but also reduced evapo-transpiration because of reduced solar radiation inputs. In addition where clouds are at ground level and pass through tall vegetation such as forest, cloud- or fog- interception can be significant. Cloud frequency partly determines rainfall and the intensity of solar radiation, and follows a similar pattern as rainfall. It is therefore potentially a good measure of water availability or aridity. Cloud frequency is greatest in the Amazonian and Pacific flanks of the northern Andes and very rare in parts of the Bolivian Altiplano. These levels of cloud frequency can lead to fog inputs contributing up to 10% of annual water flows, even in wet areas, and up to 50% in areas with high fog frequency and very low rainfall inputs such as the Chilean coast.

Inputs of water from snow are difficult to assess analytically, given that the precipitation that forms snow is captured in some of the remotely sensed and ground station records but is then stored seasonally until conditions are appropriate for melting, at which point the inputs contribute to the hydrological regime. Rather than a distinct input *per se*, snow is a transient storage affecting seasonal water yields. Its significance on spring flows is likely to be much greater in the highly seasonal thermal environments of the southern Andes. In long term climate analyses like these snow is captured in the precipitation inputs and does not significantly affect long term mean water availability at the annual and Andes scale, its effects being largely seasonal and localized.

1.1.2. Regional scale outputs (evapo-transpiration)

At the Andean scale 'losses' of water to soil infiltration and even groundwater recharge are likely to re-surface downstream in the short or long term and are thus not true losses. The only true water loss is due to evapo-transpiration, though even evapo-transpiration may be recycled as sun-blocking cloud cover or rainfall within the basin, thus contributing to gains elsewhere. The dominant controls on potential and actual evapo-transpiration are (a) the available energy in the form of solar radiation (determined by latitude, elevation, topography and cloud frequency), (b) the vegetation cover of the surface, and for actual evapo-transpiration (c) the available water. Potential evapo-transpiration is greatest in the clear, high-altitude southern Andes and parts of the northern Andean foothills and Pacific coastal zone, with maximum values of 1500 mm/yr down to 300 mm/yr in the high, cold, cloudy peaks of Colombia and Ecuador. Actual evapo-transpiration follows broadly the same pattern, but with somewhat lower values as it is constrained by the available water.

1.1.3. Regional scale balance (water balance and runoff)

Precipitation inputs minus actual evapo-transpiration determine the water balance at a particular location. Because the spatial variability of rainfall in the Andes is much greater in magnitude than the spatial variability of evapo-transpiration, the pattern of water balance tends to be dominated by spatial variability in rainfall. Figure 7 (left) shows water balances for the Andes indicating highly positive values around 4500 mm for much of the northern Andean slopes throughout Colombia and in the Eastern Andes of Ecuador, Peru and Bolivia. Water balance values are much lower (500-1000 mm/yr) throughout the rest of the Andes, and some negative balances occur in the high southern Andes, especially in the south-west, indicating an excess of evapo-transpiration over local rainfall, the actual evapo-transpiration being fed by water from upstream. Figure 7 (right) shows the differences in water balance between the two rainfall climatologies used. In most parts of the Andes these differences vary between 0 and ± 1000 mm/yr, but in a few places they can be as high as ± 5000 mm/yr.

1.1.4. Regional scale stores (dams, wetlands, groundwater)

Because of its mountainous nature, groundwater is not a strong feature of Andean water resources. Though subsurface flows do contribute to groundwater reserves on the Pacific coastal plain, the most significant water resources are rivers, lakes, and dam projects. According to the tropics-wide database of dams (Sáenz and Mulligan, 2009), there are about 174 dams in the Andean. Of these, 58 are found in Argentina, 46 in Colombia, 35 in Peru, 15 in Venezuela, 8 in Chile, 6 in Ecuador, and 6 in Bolivia. The area draining into these dams covers approximately 389,190 km² (about 11% of the surface area of the Andean system of basins). Eighty-one per cent of this area is found in Argentina, around 10% in Colombia, 10% in Chile, 6.5% in Venezuela, 5% in Peru, 4% in Ecuador, and less than 1% in Bolivia. The storage capacity of Andean dams is of at least 100 million m³, of which just below 50% is found in Argentina, 17% in Colombia, 16% in Venezuela, close to 8% in Ecuador, around 6% in Chile, 5% in Peru, and less than 1% (0.3%) in Bolivia. Water from dams assures the provision of potable water to around 50 million people in the region (Sáenz and Mulligan, 2009).

1.1.5. Per capita water resources and dry-spots

Per-capita water balances (Figure 8, center) are very low in the southern Andes and some areas of the northern Andes with high population densities, but for much of the northern Andes the per-capita water balances are high. The per capita runoff (Figure 8, right) indicates very high values in the northern and eastern Andes, but very low values especially in the southwest. When averaging the per-capita water

balance by municipality in order to understand the likely location of dry-spots, a number of municipalities in Chile, Argentina, and Bolivia present the least water balance per-capita. The very least water balance per-capita is found in Antofagasta De La Sierra in the Department of Catamarca (Argentina).

1.1.6. Water deficits

A range of 20 to 40 liters of freshwater per person per day is considered the minimum to meet needs for drinking and sanitation (Gleick, 1996). If water for bathing and cooking is included as well, this figure varies between 27 and 200 liters per-capita per day. An average of 100 liters of freshwater per-capita per day is suggested as a rough estimate of the amount needed for a minimally acceptable standard of living in developing countries, not including uses for agriculture and industry (Falkenmark and Widstrand, 1992). Furthermore, urbanization increases water use dramatically.

With an average annual per capita water withdrawal of about 600 m³, the Andean region is not normally considered water scarce (FAO, 2003a). However, this average masks a very wide variation in availability (see above). When assuming a Per-capita water need of 150 liters per person per day, then we can calculate the water demand (Figure 9). This excludes agricultural demands that are already accounted for in the evapo-transpiration component of the water balance and industrial demands that are rather specific and focused on individual sites. By multiplying 150 liters/person/day by the population surface we obtain a water demand map (Figure 9, left), which shows demand hotspots in the urban areas. The annual water supply is given by the modeled water balance (incorporating evapo-transpiration demands of agriculture and all other land uses) (Figure 9, center). The difference between these two represents the water surplus/deficit (Figure 9, right). The demand figures are an order of magnitude less than supply, indicating that the contribution of is insignificant when compared to the demand posed on water supply from agriculture and other land uses.

Clearly the Andes are in surplus north and east of the Peruvian coastal strip, and in deficit south and west of the same. Though water demands can be greater in the urban areas because of population concentration, when one considers that urban areas have better developed supply infrastructures, individual water deficits (in quality as well as quantity) can sometimes be higher in rural areas due to the low coverage of water treatment plants and aqueducts, and competing water use for irrigation. This analysis does not account for water quality, so the picture may change a little for urban areas with significant upstream land use or mining impacts.

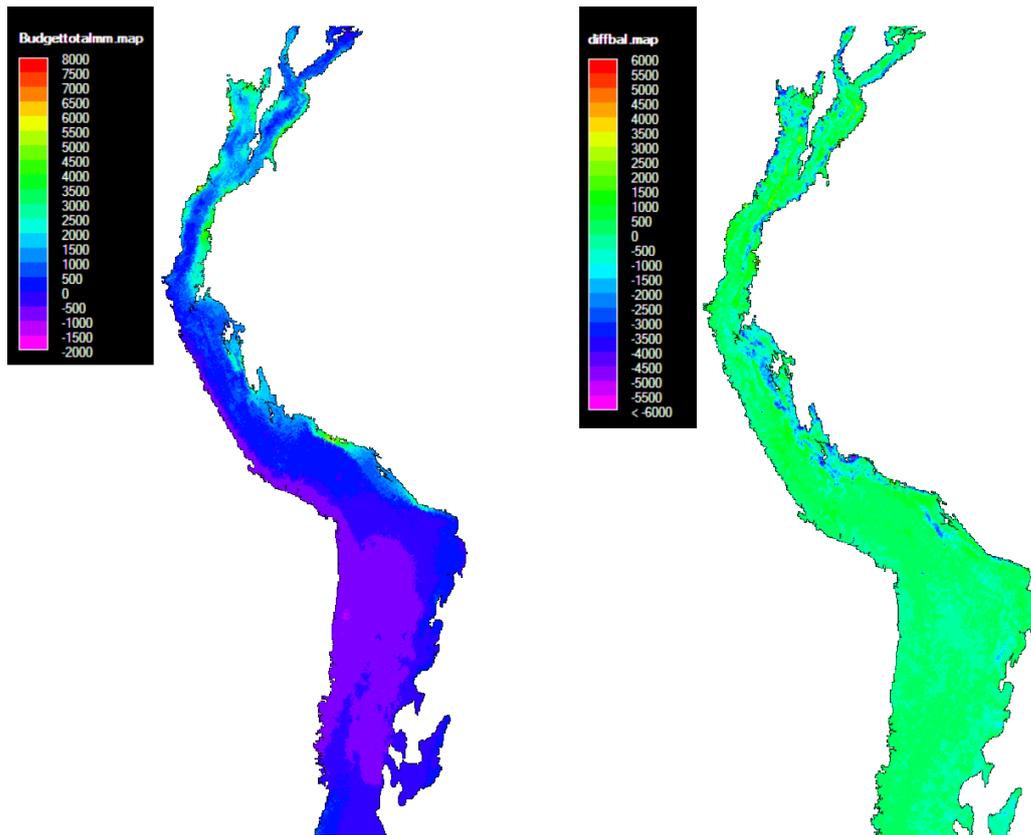


Figure 7. Water balance for the Andes (mm/yr) (left) and difference between WorldClim and TRMM water balance (mm/yr) (right)

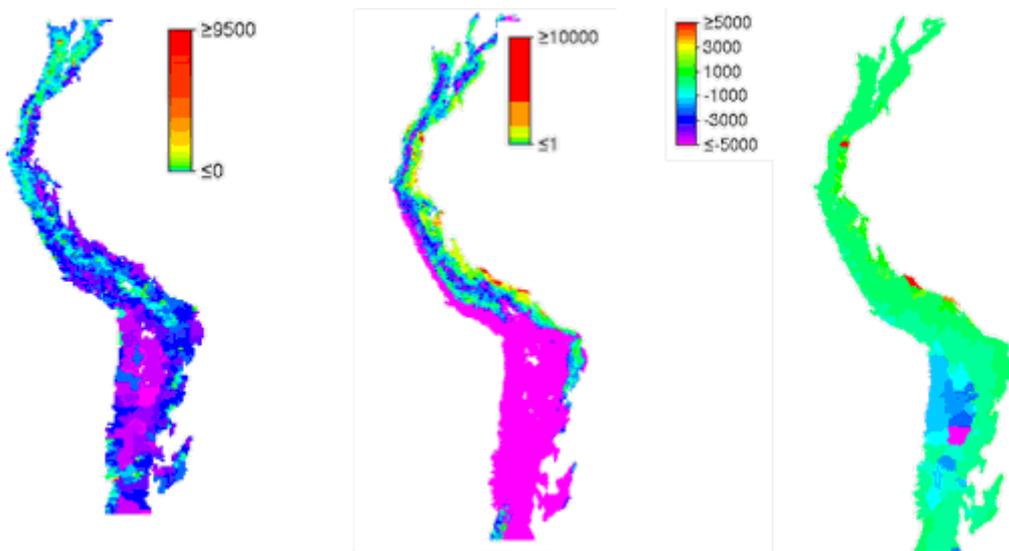


Figure 8. Population density (persons/km², 2005) (left), mean per capita water balance (mm/person or 1000's m³/person) (center) and mean per capita water balance on a pixel basis (mm/person or 1000's m³/person) by Municipality (right). Log scale from green to red. Pink and purple colors are below minimum shown on legend.

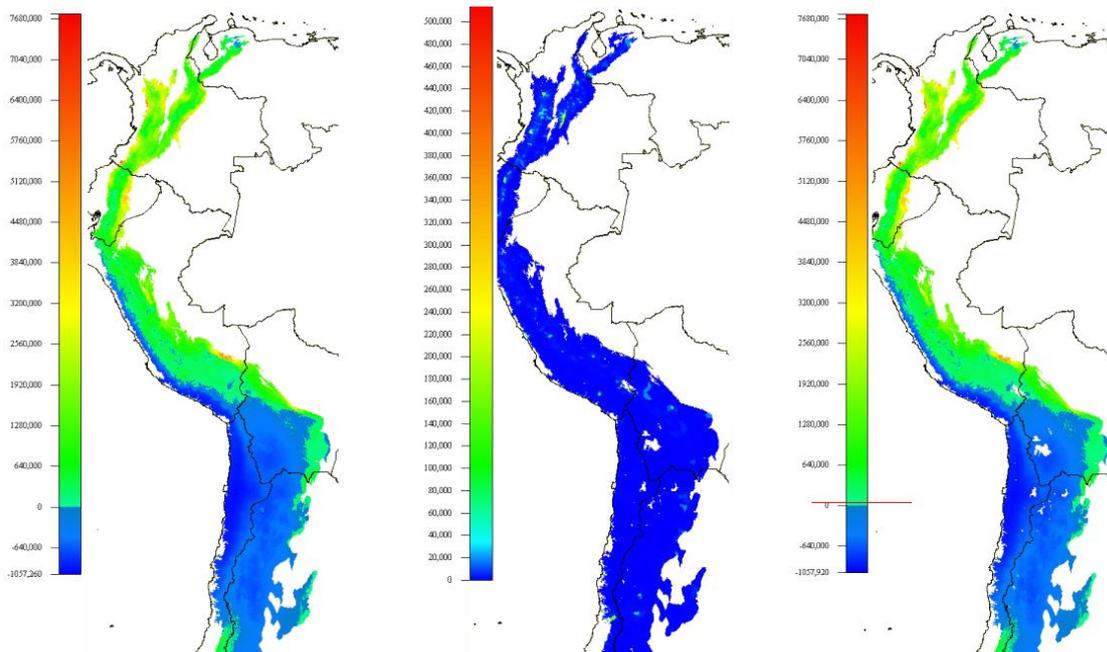


Figure 9. Domestic water demand (m^3) (left), water supply (m^3) (water balance) (center), and water surplus/deficit (m^3) for the Andes (right)

1.2. Water access and quality

The most common factors that limit water access (quality) in the Andes basin are anthropogenic interventions in the water-producing cloud forest and páramo zones (although these are usually protected areas such as National Parks and Nature Reserves), deforestation, unequal distribution of water, high water demand from the agricultural sector, and contamination from agriculture, urban, mining or industrial uses. Factors that lead to local conflict include upstream pressure from multiple users, increasing threats to environmental flows, and lack of enforceable regulation.

An approximation of the current status of water access can be obtained from national census data on piped water to households and sanitation facilities (WHO, 2008). Data shows that a quarter of the rural population does not have adequate water access and more than half have insufficient sanitation facilities (Table 1).

Water quality in the Andes basin is affected mainly by contamination from point sources – domestic and industrial wastewater. Non-point sources also contribute - from livestock and agriculture, and other anthropogenic interventions such as deforestation and human activities in the water-producing páramo zones. Especially in the densely populated northern Andes, the issue of water quality and human footprint on water quality may be more significant than water quantity (which is generally plentiful in the northern Andes).

1.2.1. Factors related to water scarcity in the focus sub-basins

A detailed analysis was carried out to identify the limitations that affect water access on the sub-basin level, focusing on the three Andes BFP sub-basins Ambato (Ecuador), Fúquene (Colombia), and Jequetepeque (Peru). Based on these specific cases, a model was developed that allows the estimation of extent of water scarcity in the region and water accessibility costs in terms of water access and transport infrastructure costs. The Microsoft Excel-based **Water Scarcity Model for the Andean System of Basins** (Appendix A.4a) provides information that can be used

to guide the integrated management of water resources, especially in rural areas where access is poor. The user manual to this model (Pulido and Leon, 2009) is attached as Appendix A.4b.

Ambato sub-basin (Ecuador)

The Ambato sub-basin in Ecuador is seriously affected by problems of water scarcity and quality that are mainly related to expansion of the agricultural frontier and over-exploitation of the páramo (through burning and grazing), deforestation of cloud forests, high water demands from the agricultural sector, unequal water distribution, water contamination, and low levels of precipitation in some areas. Annual rainfall levels do not exceed 200 to 400 mm/yr and are concentrated during a period of 7 to 9 months, during which the basin is classified as “prone to desertification” (Lugo, 1995; in Guaman et al., 2005). Water demand in the basin exceeds supply by 40%, causing a water deficit of 903 million m³/yr, which in turn threatens ecosystem functionality (water regulation) and the maintenance and sustainability of the hydric resources (Maldonado and Kosmus, 2003; Arias et al., 2005).

Table 1. Improved water supply and sanitation in the Andean Region, 2006 (WHO, 2008)

	Piped water supply (%)		Sanitation facilities(%)	
	Urban	Rural	Urban	Rural
Bolivia	96	69	54	22
Colombia	99	77	85	58
Ecuador	98	91	81	72
Peru	92	63	85	36
<i>Average</i>	96	75	76	47

Fúquene sub-basin (Colombia)

The Fúquene sub-basin in Colombia is experiencing a great pressure on its water resources and water scarcity is increasingly observed due to the unsustainable productive activities in the basin, including inadequate soil management (frequent tillage and high use of agrochemicals and machinery on fragile soils, cultivation on steep slopes), high water demand from the agricultural sector, deforestation, and deterioration of the páramo ecosystem. These unsustainable land use practices have led to the loss of soil fertility, decreased productivity, and increased soil erosion, which in turn has caused the eutrophication and excessive growth of aquatic plants in Lake Fúquene (JICA, 2000, in Otero and Quintero, 2006). Furthermore, the water volumes of the rivers discharging into Lake Fúquene have decreased by 50% on average over the past 25 years (CAR, 2006). This, together with systematic drainage activities carried out during the 1970’s resulted in the loss of 75% of the lake’s surface area in the past 60 years (PUJ, 2004; Otero and Quintero, 2006). Today, the water demand in the basin (127 million m³/yr) is equal to the supply (Cantillo and Gonzales, 2008).

In the urban areas, the vast majority (93%) of the population has access to piped water of acceptable quality – but not so in the sparsely-populated rural areas (CAR, 2006), where only 30% of the municipalities have piped water coverage of more than 70%. Many rural families obtain water from small springs and wells, or divert water from the closest river. However, there are also 24 village water supply systems with communal tanks and distribution system. With respect to the sanitation facilities in urban areas, 86% of the municipalities have sanitation coverage of more than 80% whereas in the rural areas the situation is the opposite, with 86% of the municipalities having no or less than 15% coverage of sanitation facilities (Table 2). The majority of households in rural areas therefore use septic tanks. The development and implementation of a water supply and sanitation plans – as projected in the Strategic Action Plan for Environmental Management in the Ubaté watershed – is urgently needed. An irrigation and drainage bureau exists at sub-basin level, however its coverage is limited and in practice the main functions carried out relate to drainage rather than regulating access to irrigation water.

Table 2. Improved water supply and sanitation in the Fúquene sub-basin (MAVDT, 2006)

Piped water supply (%)				Sanitation facilities (%)			
Urban		Rural		Urban		Rural	
coverage %	Municipalities %	coverage %	Municipalities %	coverage %	Municipalities %	coverage %	Municipalities %
100	43	71 - 92	29	96 - 100	43	15 - 30	14
91 - 99	50	41 - 70	36	81 - 95	43	1 - 15	50
70 - 90	7	18 - 40	36	50 - 80	14	0	36

Jequetepeque sub-basin (Peru)

In the Jequetepeque sub-basin in Peru, the total water demand amounts to 727 million m³/yr, with localized water deficits in both dry and rainy seasons (CIP, 2007). Agriculture is the principal economic activity in the basin, ignoring the fact that the majority of the soils are not suitable for productive activities. For example, in the upstream region of the basin there are 13,000 to 18,000 ha. under crop cultivation, exceeding by far the 2,830 ha. considered as suitable for agriculture (Universidad Nacional de Ingeniería, 2000). The following socio-economic and environmental factors were found to affect water scarcity and quality: overexploitation and excessive water demand for irrigated agriculture, deforestation, and an irregular water regime (65% of the river discharges occur during three months, February to April, and in the dry season river discharges can reach volumes of less than 1 m³/s).

Water access for irrigation in the Jequetepeque basin is regulated by two types of water rights: water licenses provide permanent and secure water access, whereas water permits allow water access only if the amount of available water during a given year exceeds the quantity of water granted to license holders. Water access is not only un-equal in terms of the types of water right, but also in terms of the quantity associated with these, since the quantities per unit area assigned to water license holders can be two- or three-fold those of water permit holders.

1.2.2. Water use magnitude and distribution by sector

The dominant water use in the four Andean countries is agriculture, followed by domestic and industrial uses, except in Colombia where domestic water use

exceeds that for agriculture. The localized situation in the three Andes BFP focus sub-basins is very similar to these national-level patterns (Figure 10).

Ambato sub-basin (Ecuador)

The sources of water inputs in the Ambato sub-basin are from cloud and fog interception by páramo vegetation, snowmelt of glaciers, and precipitation. The water coming from the páramos ($11 \text{ m}^3/\text{s}$) is collected by more than 120 irrigation channels, and then distributed to the principal cities and urban and rural communities in Tungurahua province (Jadán, 1999). However, many smaller communities in the rural areas are not covered by this system and depend exclusively on rain-fed agriculture and precipitation water for domestic uses. The channeled water is used principally for irrigation (94%), with only 6% being used to cover basic domestic needs. The agricultural sector consumes approximately 320 million m^3/yr , whereas domestic uses correspond to less than 2 million m^3/yr (Girard, 2005 en CPWF, 2007).

Fúquene sub-basin (Colombia)

In the Fúquene sub-basin in Colombia, more than 80% of the available (surface) water is used for irrigated agriculture, and relatively small amounts are for domestic (9%) and industrial (6%) uses (Figure 10, center). The total water demand is estimated at 127 million m^3/yr (MAVDT et al., 2006), of which approximately 107 million m^3/yr correspond to the agricultural sector. Water demand for domestic uses amounts to almost 11 million m^3/yr , 7.5 million m^3/yr for industrial uses, and less than two million m^3/yr for livestock.

Jequetepeque sub-basin (Peru)

Of the 727 million m^3/yr total water demand in the Jequetepeque basin in Peru, 719 million (99%) are consumed by agriculture (Girón, 2003; López and Girón, 2007). Domestic uses consume less than 1% (6 million m^3/yr) of the water resources, and demands for other uses such as industrial and livestock are almost negligible (Figure 10, right).

Piped water access ranges from 40% to 70% in the San Miguel, Contumazá, Cajamarca, Chepén, and Pacasmayo provinces, whereas in San Pablo province only 34% of the population has piped water access (INEI, 2007). The remaining households have water access through the public distribution system outside of households, through wells, or diversion of water from rivers and springs.

1.2.3. Water use magnitude and distribution by source

Sources of water in the Andean region include glacier, rainfall, surface, natural and artificial reservoirs, groundwater, and desalination plants. Data regarding use by source is fragmented and incomplete. For example, groundwater studies in Colombia cover less than 15% of the national area. Similarly, most artificial reservoirs have multiple uses and water accounting is not always available for public consultation, though some information is available related to irrigated areas by country (FAO, 2003a).

Table 3. Water use by sector in the four Andes BFP countries in 2000 (FAO, 2003a)

Country	Total freshwater withdrawal		Domestic Use		Industrial Use		Agricultural Use	
	(km ³ /yr)	(m ³ /p/yr)	(m ³ /p/yr)	(%)	(m ³ /p/yr)	(%)	(m ³ /p/yr)	(%)
Bolivia	1,4	157	21	13	11	7	127	81
Colombia	10,7	235	118	50	9	4	108	46
Ecuador	17,0	1283	160	12	68	5	1055	82
Peru	20,1	720	60	8	73	10	587	82

Table 4. Irrigated area in four Andean countries (Source: Aquastat, FAO)

Country	Irrigated area (in 1000 ha)	% of cultivated area
Bolivia	128	3.9
Colombia	900	21.1
Ecuador	863	28.7
Peru	1195	28.1

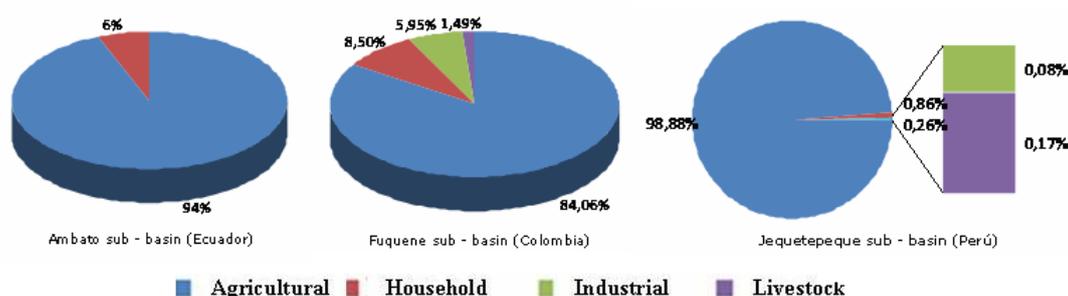


Figure 10 Water use distribution in the Andes sub-basins by sector

1.3. Threats to water provision and upstream-downstream linkages

1.3.1. Natural hazards

The Andean region is highly prone to natural hazards such as earthquakes, landslides, tsunamis, and volcanic eruptions because its territory rests on three active tectonic plates and is situated within the Pacific “Ring of Fire” where 80% of the world’s seismic and volcanic activity takes place. It is naturally a site of extreme climates, which take the form of successive and lengthy droughts, floods and strong winds (Comunidad Andina, 2004). The most important water-related natural hazards that affect livelihoods in the Andes are droughts and floods related to the El Niño and La Niña phenomena. On-going climate change has potentially contributed to increased magnitude and frequency of these climatic extremes in the recent past, and their occurrences are predicted to become even more frequent and stronger in the future. Communities in Andean river basins are highly vulnerable to disasters because to economic and geographic reasons such as the occupation of unsafe sites and environmentally inadequate or non-resilient livelihood options.

1.3.2. Modelling threats to water provision

In order to better understand the threats to current provision of water resources in the Andes, the FIESTA model was used with three scenarios for change: (a) a land use change scenario based on continued agriculturalisation of pre-human montane forest dominated cover, (b) a climate change scenario based on the IPCC SRES AR4 scenarios (IPCC, 2007), (c) an analysis of the contribution of protected versus non-protected lands to downstream flows of water to urban areas (in order to better understand the potential impact of contamination from non-protected lands through mining and agricultural impacts).

The scenario for **land use change** (Figure 11, left and center) took the tree cover for pre-agricultural times (the climatic potential tree cover) as a baseline for hydrological simulation and compared this with a simulation based on tree cover as measured by the MODIS sensor for 2005.

The difference in forest cover (Figure 11; left) indicates hotspots of forest loss in the eastern Andes/western Amazon as well as the Pacific regions of Colombia, Ecuador and Peru. The resulting change in water balance between the historic and current land use change scenario is shown in Figure 11 (center). The consequences have been an increase in water balance (up to 12.5 mm/yr) and runoff (<1%), resulting from decreased evapo-transpiration of around the same magnitude in places where forest has been replaced by other vegetation covers. At the Andes-scale a flow increase is the dominant effect of this deforestation. Though the annual flow has increased its seasonal variability may also have changed in a positive or negative manner.

In order to evaluate the Andean-scale impact of **climate change** on water availability, the FIESTA model was run with a multiple-model scenario for climate change based on IPCC SRES AR4 (mean of 17 models; IPCC, 2007). Since the Andean-scale analysis has no snow component, any effects on glacial melting are not included in the analysis. However, since glacial melting is not an extra input but rather a transient storage of existing inputs, it affects the seasonality of available water but not the amount of total available water. Figure 11 (right) shows the difference in water availability per person between the baseline (current) scenario and the climate change scenario by 2050, indicating increases in available water per person ($\text{m}^3/\text{yr}/\text{person}$) throughout the northern and eastern Andes.

Results from analyzing - at Andean-scale - the mean proportion of runoff in rivers used for urban supply derived from mining operations, showed that between 0 and 10% of the runoff that reaches most Andean cities comes from areas influenced by upstream mining operations (for example, 13% for Quito, 5% for Bogota, 8% for Lima). See Appendix A.3 for further methodological detail and Andean-scale maps.

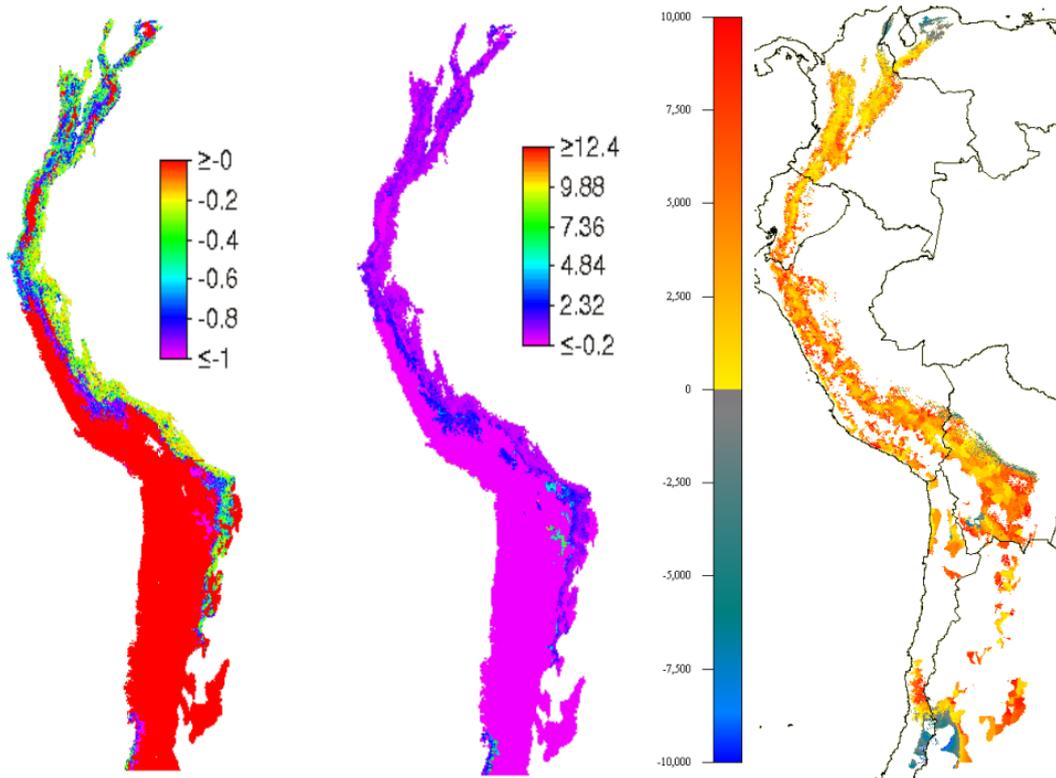


Figure 11. Change in forest cover (fraction) (left) and water balance (mm/yr) (center) due to land use change between pre-agricultural scenario and current; and future change in water balance per capita with climate change to 2050 (m^3 /person) (right)

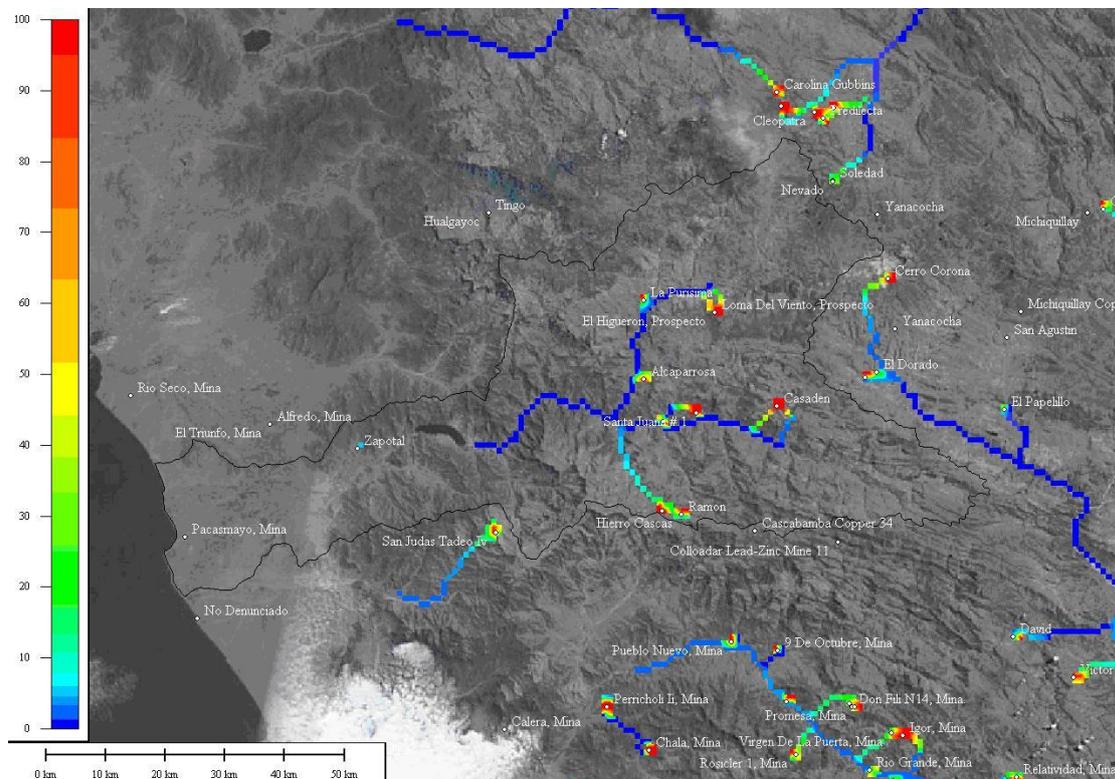


Figure 12. Percentage of runoff originating in mines and quarries (Jequetepeque area, N Peru)

Data on the locations and **outputs from industry, mining and urban centers** and their potential impacts on water quality and its downstream effects are mostly

lacking for the Andes. Whilst the UNEP-GEMS database² contains many stations for the Amazon, it has very few stations in the Andes. In order to better understand the potential quality of water and impacts upon it, we therefore looked more broadly at the origins of water arriving at major cities. There are 24,454 known mines and quarries in the Andes basin (Hearn et al., 2003). By analysing the runoff generated in the areas of these mines and its contribution to the total runoff of the basin we can better understand the likely impact of these mines on water quality.

If we assume that the quality of runoff water from mines is less than that from other areas, then any presence of a runoff signal from mines which represents more than say 0.0001% of the runoff (equivalent 1 part per million – a representative threshold for toxin concentrations) could be considered an impact. For particular contaminants, specific threshold concentrations will be necessary. Figure 12 shows an example from the Jequetepeque Basin, Peru where the proportion of runoff derived from mining operations is illustrated (down to 0.0001% - 1 part per million). Clearly, mine and quarry waters are soon swamped by runoff

1.4. Conclusions

Water availability in the Andes system of basins is provided in the form of rainfall, fog (i.e., ground-level cloud cover), and snowmelt. Contributions from fog 10% on average but can be up to 50% in areas with high cloud frequency and very low rainfall inputs (such as the Chilean coast). Groundwater sources play only a minor role, except in large inter-andean valleys, due to steep slopes and deep aquifers. About 11% of the Andean surface area drains into dams, which play an important role in regulating seasonal water availability (mainly for irrigation, urban supply or hydropower generation downstream). The main water 'losses' in the Andes are due to evapo-transpiration that varies depending on local conditions of vegetation cover (including agriculture and all other land uses) and solar radiation. Solar radiation in turn is determined by latitude, elevation, topography, and cloud frequency. Climate change will likely increase water availability throughout the Andes and this will be particularly significant in the drier southern Andes.

Water access and quality are limited mainly by anthropogenic interventions, in particular deforestation, high water demand from agriculture, contamination from agriculture, urban, or industrial uses, and unequal distribution of water due to pressure from several uses. Agriculture is the dominant water user in the four Andes BFP countries (Colombia, Ecuador, Peru and Bolivia), followed by domestic and industrial uses – with the exception of Colombia where domestic water use more or less equals that of agriculture.

Two broad trends can be distinguished in the Andes: water availability is generally not a limiting factor in the northern parts of the Andes (for example the Chocó region of Colombia and Caribbean lowlands) and along the Amazonian flank of the Andes from Colombia, through Ecuador to Peru and Bolivia. In these areas water inputs from rain, fog, and locally, snowmelt, are abundant and evapo-transpiration is rather low, resulting in water balances of up to 4500 mm/yr for much of the northern Andean region. Per-capita water resources reveal a surplus and sufficient water is available for much of the northern Andes, with somewhat lower resources in areas with high population densities (around the capital cities of Bogotá and Quito, and other large urban centers).

In contrast, in the southern Andes water inputs are lower and potential evapo-transpiration is considerably higher. Water balances for this region are much lower (500-1000 mm/yr), and a lack of water supply relative to demand is apparent in the driest areas. Consequently, per capita water balances in this part of the Andes

² www.gemstat.org/datasrc.aspx

are also very low, and water deficits are found south and west of a Peruvian coastal strip, particularly in the clear, high-altitude south-west of the Bolivian Altiplano, Chile, and Argentina.

2. Water productivity

In this section, we ask

- What is water productivity?
- How well is water used?
- What is known about the efficiency of water use in the Andes region?

2.1. Water productivity in the Andes

Water productivity can be narrowly defined as: *the crop production per unit of water used*. However, this is not the best representation of the total value of water for the Andes, nor does it reflect the role of water in the alleviation of poverty. In the Andes, we have to consider the importance of water not only for food production, but also for a significant generation of hydroelectric power (HEP), for use by large urban populations and important industrial/extractive processes in the region (e.g., mining), and for the maintenance of environmental flows.

The Andes BFP therefore uses a more broadly-defined view of water productivity than the measured *crop per drop* productivity as defined by the CPWF. We define water productivity for BFP Andes as: *the contribution of water to human well-being through production of food, energy and other goods and services*. While the Andes-scale analysis will look at the CPWF agricultural productivity of water (i.e. *crop per drop*), we will also take a broader view at water productivity for other uses.

2.1.1. Agricultural water productivity and crop/drop

Here water productivity at the Andean scale is calculated as the mean crop production per unit of mean rainfall (the *crop per drop of rainfall*) calculated from analyses of dry matter production every ten days over the last ten years from 1km resolution SPOT-VGT data. Once again we use two different assessments of mean rainfall, the TRMM and the WorldClim (see Appendix B.1 for further detail). Results indicate that the greatest *crop per drop* productivity is measured in parts of Peru, Ecuador, and Chile where rainfall is very low (Figure 13). The patterns are broadly similar between the two rainfall climatologies, though the absolute values are sometimes different because of differences in measured rainfall. Averaging by elevation and catchment indicates that the lowest elevations and small, lowland-dominated Pacific and Eastern foothill catchments have the greatest *crop per drop* productivity.

Figure 14 shows the calculated dry matter productivity for different agricultural land uses in the Andes (with agriculture defined according to Ramankutty et al., 2008 and Siebert et al., 2007). The highest productivity for all agricultural types is found in the northern countries – especially Colombia and Ecuador – and in Argentina. Given the high precipitation inputs in the north of the basin, the greatest *crop per drop* productivity is again found in Argentina and parts of Ecuador. Water productivity in the Andes is rather low in comparison with the lowlands especially of Colombia, Ecuador, Peru and Bolivia.

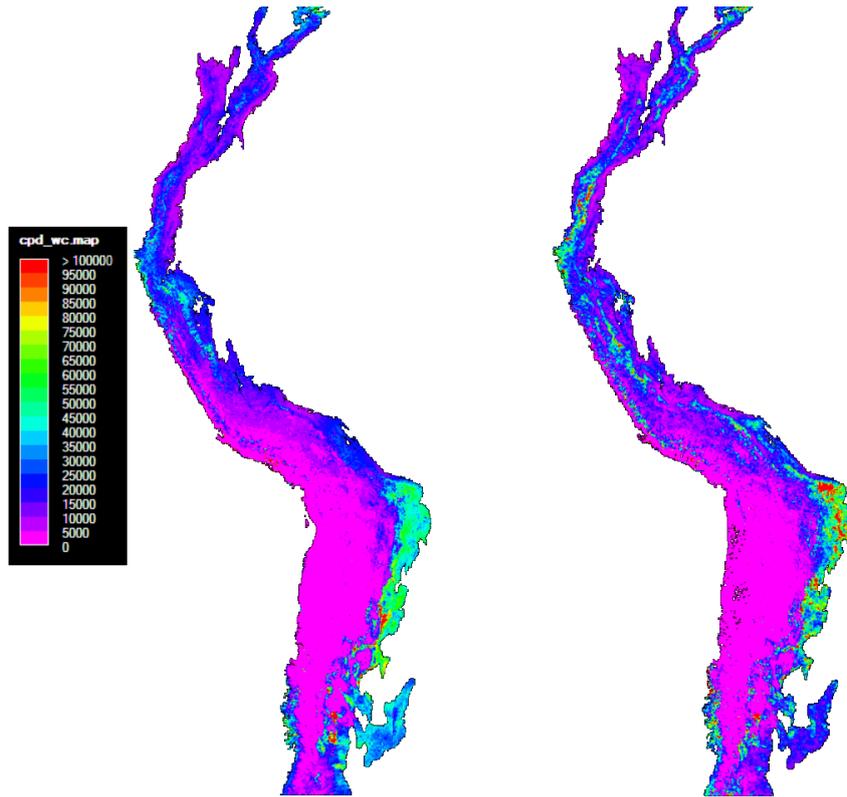


Figure 13. Mean water productivity (g/ha./mm) (crop per drop) for WorldClim rainfall (left) and TRMM rainfall (right)

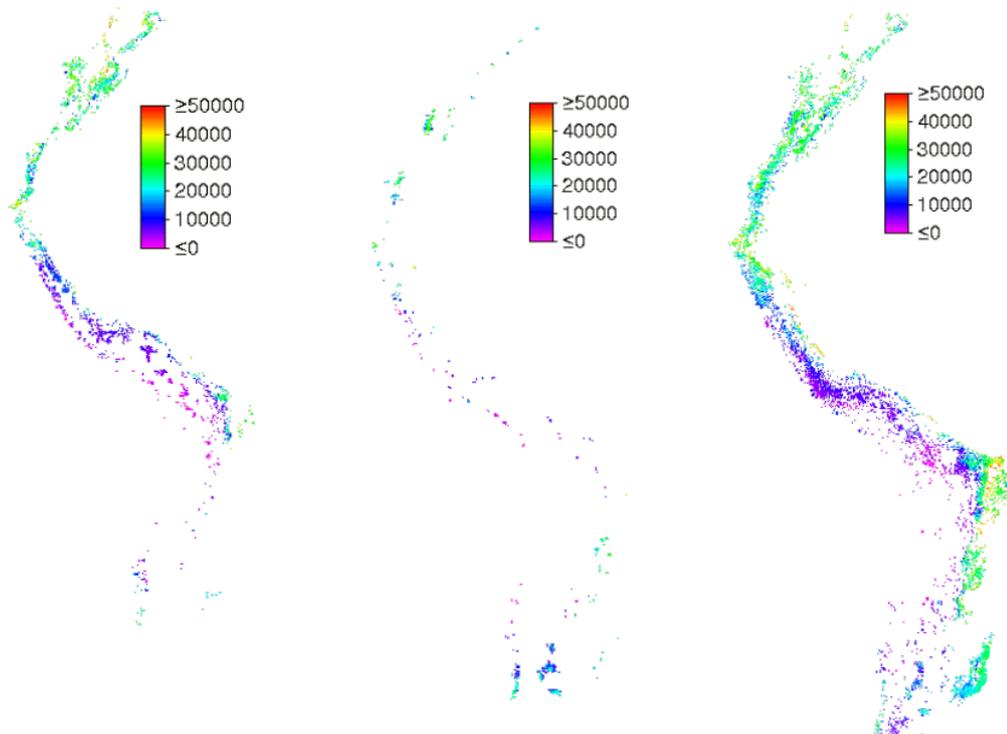


Figure 14. Dry matter productivity (kg/ha/yr) for pasture (left) , irrigated cropland (center), and all cropland (right)

2.1.2. Water for fisheries

Capture fisheries and aquaculture are other important economic activities in the Andean region that depend on water resources. Their contribution to total food production is 1.3% in Colombia, 3.6% in Ecuador, and 0.2% in Bolivia, with a per-capita consumption of 4 and 6 kg/yr in Colombia and Ecuador. In Peru, the fisheries sector is particularly important, and almost 50% of the total food production comes from aquatic resources. At 21 kg/yr the per-capita fish consumption in Peru is among the highest worldwide (NMFS, 2002).

A model was developed to (a) identify the factors that influence aquaculture water productivity (production per unit of water used including feed) in the Andes, (b) identify areas with the greatest potential for the construction of aquaculture systems in the region, and (c) estimate the total investment required for setting up a semi-intensive aquaculture system at a given site (Appendix B.2). The **Fisheries Model** uses data such as slope, distance to water source, distance to urban areas (for commercialization through access to markets), soil texture, land cover and land use and population density. The model illustrates the site suitability at different levels for aquaculture in the Andes region (Figure 15). Using three scenarios where different weights were given to each environmental factor, it could be concluded that slope, distance to water source, and distance to urban areas are the factors that most influence aquaculture suitability. Results indicate around 56% of area in the Andes are within the range of moderate to highly suitable regions for fish farming.

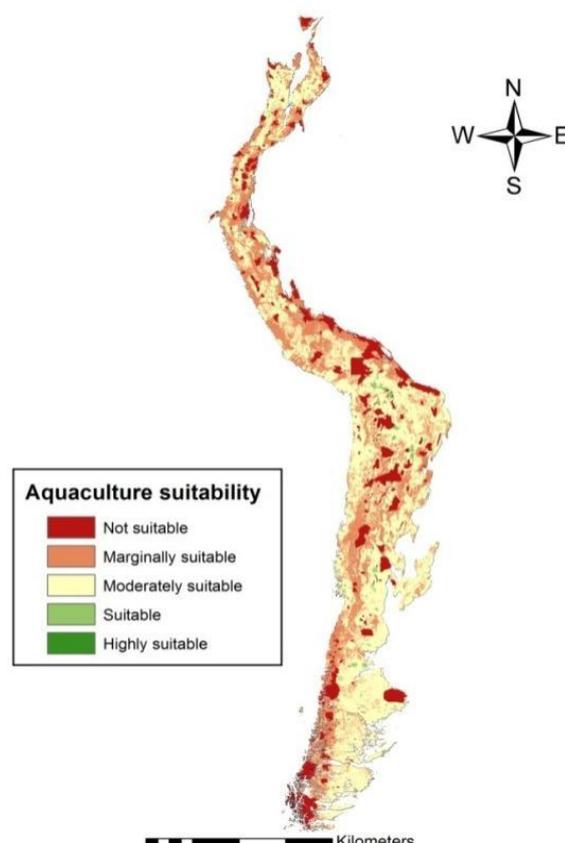


Figure 15. Aquaculture site suitability in the Andes

2.1.3. Water for hydropower

The Andean countries possess a large hydroelectric capacity. Taking into consideration the national energy sectors in the seven countries that have areas in the Andean region (Argentina, Bolivia, Chile, Colombia, Ecuador, Perú, and

Venezuela), the reported installed hydroelectric capacity amounts to at least 46,000 MW. For the Andean system of basins the capacity is estimated to be at least 20,000 MW (Sáenz and Mulligan, 2009).

Reliable country-level figures of hydroelectric installed capacity are available from national statistical systems such as the SIEL (Sistema de Información Eléctrico Colombiano) in Colombia or CONELEC (Consejo Nacional de Electricidad) in Ecuador, as well as from the energy ministries in Peru, Argentina, Venezuela, and Chile. However, estimates for the Andean system of basins are difficult to obtain, since national-level data do not distinguish hydroelectric capacities for dams in the Andean highlands. The estimate of 20,000 MW provided by Sáenz and Mulligan (2009) is based on an inventory of dams reported in global registers such as the World Register of Dams (ICOLD, 2003) and national inventories such as INGETEC (2004) in Colombia. The installed capacities reported by ICOLD (2003) are relatively comprehensive for dams with hydroelectric plants in Colombia, however this is not the case for other Andean countries such as Peru, Ecuador or Bolivia.

Improving the Andean dam census and the collection of information on relevant dam features such as hydroelectric installed capacities is therefore key to fully recognizing the contribution of the Andean system of basins to the energy industry in the region. This aspect should be included in future regional projects tackling these issues. For the purpose of this report, we present energy related figures for the region at national-levels and not only within the Andean system of basins, due to the above mentioned data limitations. The hydroelectric installed capacity for the four focus countries of the Andean system of basins is at least 16,500 MW (Table 5). Energy production and energy sales from hydroelectric plants in these four countries are significant. The energy generation amounts to over 60,000 GWh/yr, which underpins an economic sector with annual sales amounting to close to 5 billion USD (Table 5). The energy sector is very well-developed, and strong actors are present in the region. The most prominent example is the Spanish Endesa Energy Group (www.endesa.es), which accounts for around five million customers in the region and controls the majority of energy generation and commercialization businesses in Colombia (Emgesa), Peru (Edegel, Eepsa), Chile (Engesa Chile), and Argentina (Endesa 2009).

Table 5. Hydroelectric installed capacities, annual energy production and energy sales in the four Andes BFP countries

Country	Installed capacity (MW)	Production (GWh/yr) (2007+)	Energy sales (million USD)	Source
Bolivia	487	1116	95	MHE (2007)
Colombia	10,800	30,000	2747	SIEL (2009)
Ecuador	2056	11,293	960	CONELEC (2009)
Peru	3242	18,187	1081	MEM (2008)

In summary, water productivity in the form of hydropower energy is significant in the Andean region. Hydroelectricity generation is a strong economic sector, which is already contributing significantly to the economic development of the countries in the region and will probably play an even more important role in the future, due to its potential for providing energy with a low carbon footprint.

The operation of dam reservoirs can certainly be optimized and understood as an important intervention (WCD, 2000; Sáenz, 2009). But, to ensure that the current productivity of water in the form of hydroelectricity is maintained and improved in

the region, more efficient and financially viable Integrated Watershed Management (IWM) (including PES Schemes) is required. In order to achieve this, the active participation of dam companies, in collaboration with other relevant regional stakeholders involved in the water management process is necessary. Such schemes are particularly promising in the Andean basins as most dam-feeding watersheds already face land use degradation especially in their upper parts, with negative consequences for water quality and watershed sedimentation rates reaching dam reservoirs (see also sections [4.3.2](#) and [5.3.2](#)). Improved watershed management approaches and PES could not only mitigate these impacts, but also help in the adaptation of dam watersheds to the projected effects of climate change (see section [1.3](#)).

2.1.4. Water for nature: Environmental flows

Environmental flows are often considered as the water 'left over' once all other uses have been accounted for. Since water is fundamental to sustain ecosystems from páramos through to mangroves, environmental flows are critical to the continued provision of ecosystem services and should thus be considered as *the* flows that ensure that other water uses are possible rather than the flows left over after all other water uses. The role of environmental flows, and the importance of land management to protect these, can be illustrated by using the example of protected areas (PAs). The impact of different land covers on watershed services is a highly debated topic. On the basis of the literature the following rules-of-thumb can be identified:

- *Water quantity services:* Protected ecosystems do not necessarily generate more rainfall than agricultural land uses. Protected ecosystems may even have higher evapo-transpiration and thus lower water yields. *Thus quantity benefits are difficult to prove.*
- *Water regulation services:* Protected ecosystems do not protect against the most destructive floods. For 'normal' events they do encourage more subsurface flow and thus more seasonally regular flow regimes. *Benefits are therefore likely especially in highly seasonal environments.*
- *Water quality services (where quality is quantity for a purpose):* Protected ecosystems encourage infiltration leading to lower soil erosion and sedimentation. Unprotected land tends to have higher inputs of pesticides, herbicides, fertilizers, etc. *Thus, there are clear quality benefits of PA's in the generation of higher quality water than from non-protected areas.*

Assuming that protected areas have a positive impact on water (especially water quality) the proportion of streamflow at a point that is derived from protected areas upstream is thus an indicator of the potential quality of water received and lack of impacts from agriculture, industry and mining as well as urban waste-water. Our analyses of this process indicate that the influence of protected areas declines significantly downstream of their locations as flows are dominated by the much more ubiquitous unprotected landscapes (see Appendix B.1 for methodological details).

2.1.5. Water for urban populations

The Andean population is highly urbanized with a concentration of large urban areas in Colombia and, to a lesser extent, throughout the southern Andes. These urban areas are associated with significant areas of irrigated agriculture, and the highest recorded GDP. Water supply is critical to the operation of these large urban centers and we can estimate the fraction of water originating from protected areas

within the boundaries of urban areas, multiplying this by the total urban population consuming water to derive the number of persons consuming or benefiting from water which fell as rain on a protected area (see Appendix B.1). Large cities with significant protected areas immediately upstream clearly benefit greatly from water filtered through these protected areas, which – all things considered – is likely to be lower in pesticides, herbicides and other contaminants than water derived from non-protected lands.

2.2. Threats to productivity

As we have seen, land use change in the Andes has tended to replace forests with agricultural land uses and as such has tended to lead to increases in runoff (1.3.1). This has disadvantages (runoff will tend to carry more sediment, soil erosion will be significant, runoff may be more seasonal and dry season flows may be lower) but in general will very likely not have the same impact on agriculture as that of climate change (1.3.2). The spatial coincidence of pasture, cropland, urban areas and protected areas in the Andes (Appendix B.1) indicates a highly impacted system in terms of human land use but also one in which protected areas play a key part in the maintenance of ecosystem functions and the supply of water to end users. On the basis of the analyses carried out, the continued conversion of the remaining natural landscape – especially Andean forests – to pasture and cropland will lead to continued increases in water yield, soil erosion, sediment yield and water quality deteriorations which will impact upon these highly urbanized populations.

Climate change is much more difficult to define but for land use change the future seems very clear. Outside (and perhaps even inside) of currently protected areas, the need for greater food supplies for internal and external markets will tend to push landscapes along the same trajectory they have taken historically towards further agriculturalisation. As a result of climate change we expect global temperature and rainfall to increase, but the projected impact at the regional scale on the Andes varies between climate models. Here we present the results of 17 GCMs forced by the SRES A2a scenario and presented as differences between the present and the 2050s (see Appendix B.1 for methodological details).

In terms of their hydrological impact, Figure 16 shows the mean change in temperature and precipitation for these 17 models followed by the results from the FIESTA delivery model applied to this climate scenario. The impact on evapotranspiration is generally a small increase as a result of the higher temperatures increasing atmospheric demand. The impact on water balance is, however, much more affected by the higher rainfall receipt, such that water balance is generally 100 mm higher under the climate change scenario, despite the higher evapotranspiration.

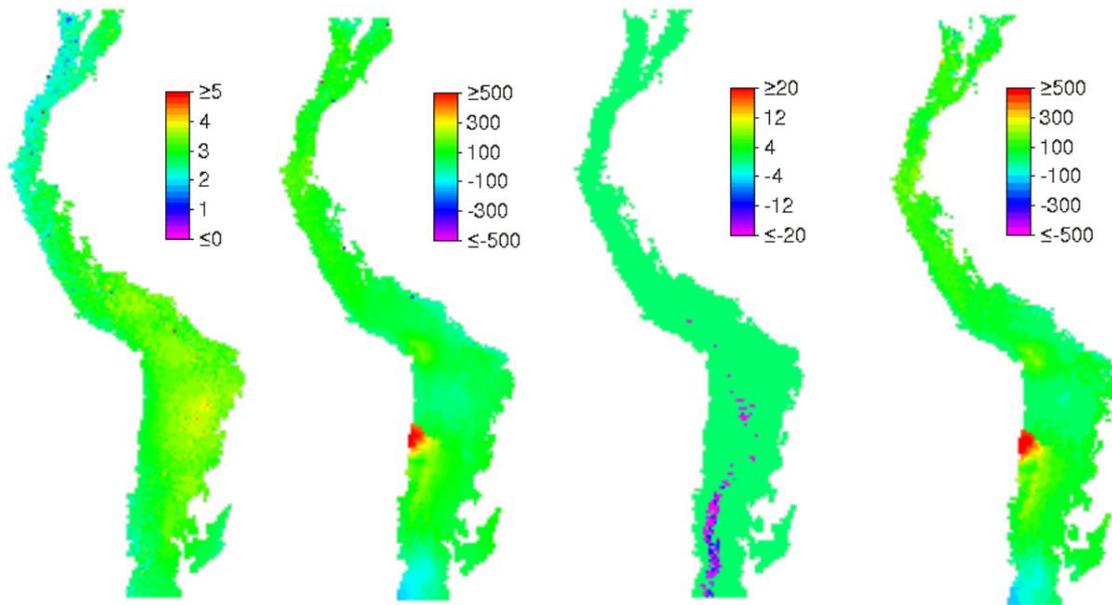


Figure 16. Hydrological response to climate change in the Andes (mean of 17 models) for 2050s). Left: mean annual temperature change to 2050s(°C), center left: mean annual precipitation change to 2050s (mm), center right: mean annual evapo-transpiration change to 2050s (mm), right: mean annual water balance change to 2050s (mm)

Hence, whilst we can expect continued impacts of land use change on all aspects of water availability for all water use purposes (Appendix B.1), the big unknown is climate change. The regional picture for climate change suggests further wetting on top of that produced by reduced evapo-transpiration as a result of continued land use change, but local details are highly uncertain. This suggests that the best approach from a policy point of view is not to rely on projections of change at all, but rather to better understand the sensitivity of water and production systems to change and pay particular attention to careful management where those sensitivities are high, irrespective of the highly uncertain projections for change. If we consider the sensitivity of the Andes to land use and climate change (measured as % change in runoff per % change in tree cover, % change in runoff per % change in temperature and % change in runoff per % change in precipitation), we can identify parts of the Andes that are particularly sensitive to change, however that change may be manifested (Figure 17). These areas need to be carefully managed, especially if important ecosystems and human populations rely on them for water. Parts of the higher western and central Andes appear more sensitive to land use change than the slopes closer to the 500 m.a.s.l. catchment boundary. In terms of sensitivity to precipitation change, the lower slopes show the greatest change in runoff per unit change in precipitation. For temperature change, coastal Peru and Chile show the greatest change in runoff per unit change in temperature. These are already some of the driest areas in the region.

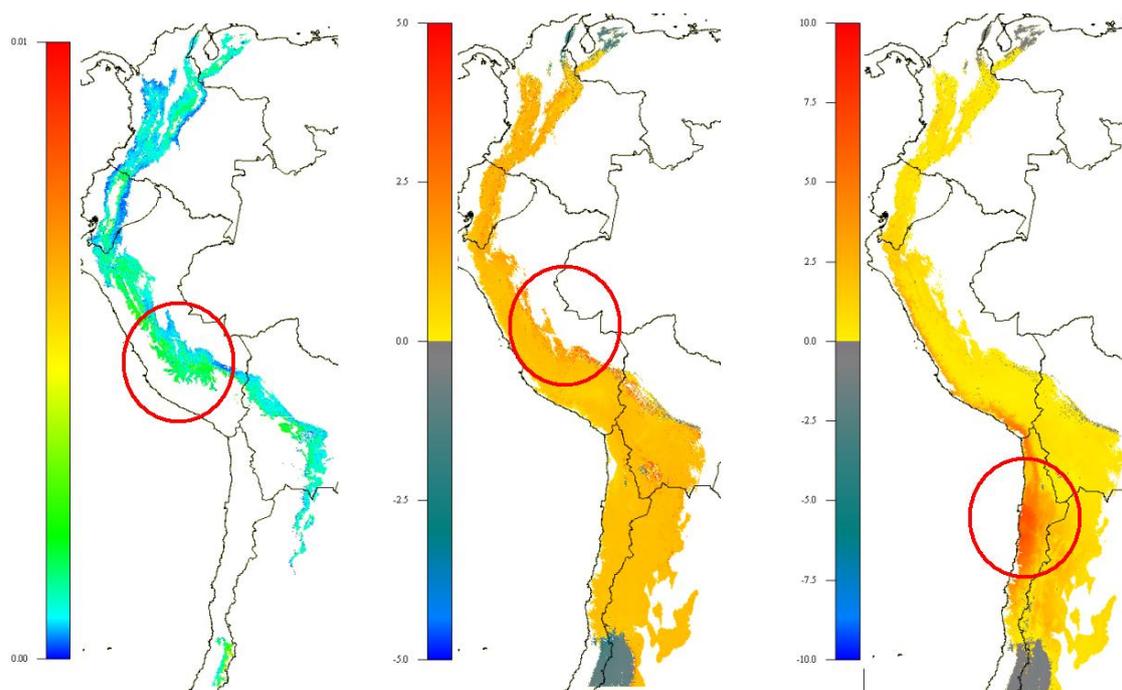


Figure 17. Sensitivity of the Andes to land use and climate change: What will happen by 2050 as we continue to push? Left: Runoff sensitivity to tree cover change (% change in runoff per % change in tree cover), center: Runoff sensitivity to precipitation change (% change in runoff per % change in precipitation), right: Runoff sensitivity to temperature change (% change in runoff per % change in precipitation). Red circles indicate areas of particularly high sensitivity.

2.2.1. Agricultural productivity

The heterogeneous nature of the Andes means that crops are focused in tight altitudinal bands throughout, and climate change will thus bring spatial shifts in agricultural suitability for particular crops with implications for water demands and conflict with other uses. It is not possible to understand the likely dynamics of agricultural production for the entire Andes in the face of climate and land use change using this type of global analysis. But the AguAAndes online Policy Support System (PSS), developed in the course of this project, makes it possible to look into these dynamics on a crop by crop basis in any part of the Andes, and thus readers requiring locally specific analyses should use the policy support system at <http://www.policysupport.org/links/aguaandes> for their specific case.

2.2.2. Hydropower production

Understanding the impact of climate change and land use change on the operation of hydropower dams is beyond the scope of this study. Projects are ongoing to better understand the likely impact of these scenarios on water productivity at dams. Clearly land use change has the potential to both increase peak flows and to contribute (capacity-reducing and turbine-damaging) sediment to reservoirs thus affecting their function. Moreover, climate change may also increase mean annual flows with positive impacts, if not offset by increased flow seasonality and/or sediment concentrations. Improved hydrological knowledge on the way these threats affect the operation of dams but also a more adequate communication of these findings, and integration with dam operation and optimization models are increasingly required to prepare, mitigate, or adapt to these impacts.

2.2.3. Urban and industrial uses

Population growth, damage to ecosystems through land use change and mining impacts are the main threats to urban populations. Since the general climatic trend

may be for an increase in available water, it will be the quality of that water which determines its usability for urban and industrial functions. We have already indicated the importance of careful land protection and management to maintaining water flow quantity and quality into urban areas. The Andes already have significant mining activities, and this is set to increase with the opening up of new concessions to international markets. Careful regulation of waste from these mines combined with significantly enhanced water treatment capacity will be required to reduce negative impacts on populations, their health and their livelihoods.

2.2.4. Environmental flows

The greatest threat to sustaining environmental flows in the Andes will be continued growth in the hydropower, irrigation and mining sectors as well as population growth and urban demands. The region is expected to continue growing in terms of population, but this growth will be highly concentrated in urban areas with negative growth in some rural areas as rural-urban migration continues (Appendix B.1). Pressures will continue to be greatest in the large urban centers of Bogota, Cali, Medellin, Quito, Lima, La Paz, and Santiago, and will continue to demand more water from the surrounding catchments. This requires careful water pricing and regulation, regulatory reform especially for contamination limitation, adoption of multiple use and increased use-efficiency and water-friendly land management measures .

2.3. Conclusions

To assess water productivity in the Andes in a comprehensive way, it is necessary to use a more holistic approach that goes beyond the traditional concept of *crop per drop* (i.e., agricultural) water productivity. Water in the Andes is not only important for food production, but also for the generation of hydroelectricity, for use by large urban populations, for important industrial/extractive processes (e.g., mining), and for the maintenance of environmental flows.

Crop per drop of rainfall from agriculture and aquaculture is rather low in the Andean region in comparison with the lowlands of the same countries. Crop per drop of rainfall is greatest in areas with low rainfall, that is, in the southern basin and particularly in drier regions of Peru, Ecuador, and Chile. However this is only one measure of water productivity. Crop per drop of rainfall is a coarse measure of productive efficiency since in wetter areas large volumes of water are diverted to runoff and have little impact on local productivity. Better measures include crop per drop of evaporation (a measure of the land use system water efficiency) and crop per drop of transpiration (a measure of the crop physiological production efficiency).

Aquaculture productivity in the Andes is mostly of local relevance, although in Peru almost 50% of the total food production comes from aquatic resources. Hydropower generation is another important form of water productivity in the Andes, which can contribute up to 50% to national energy supply (e.g., in Peru) and is an important economic sector in the region. Water supply is also critical to the operation of the large urban centers that are scattered throughout the Andes and are often associated with significant areas of irrigated agriculture. Last but not least, water as an environmental flow is essential for other ecosystem services and functions, such as water quantity, quality, and regulation. The protection of water-producing zones (such as the cloud forests páramos) is key for maintaining the provision of these ecosystem services and functions, and for the sustained supply of water to end users.

Water productivity is limited and threatened by human interventions, in particular from continued deforestation and land use change in protected areas and key

water-producing zones, but also from growth in the industrial sector (mining and hydropower) and the increasing demands of urban centers. The result of these activities are increased water yield and regime flashiness (flooding), soil erosion, sediment yield, and water quality deteriorations all of which may affect downstream populations.

Climate change is likely to result in increased water availability and runoff throughout the Andean region, and will affect agriculture as well as urban centers. Threats to water productivity will be greatest in regions that are already most exposed to land use change and thus more sensitive to further impacts from climate change, such as parts of the higher elevation western and central Andes. The most southern Andean slopes are some of the driest areas in the region (coastal Peru and Chile) and will experience the significant changes in runoff due to climate change. Throughout the Andean region, agriculture will need to adapt to climate change, and the likely response includes altitudinal and spatial shifts of different agricultural production systems. This will bring about implications for water demand from other uses and may lead to conflicts over water access and distribution.

3. Institutions

Institutions are the consequence of a dynamic and complex setting in which people socially organize and debate the way in which they relate with each other and with nature. The following key questions guided the work of the Andes BFP in addressing water and institutions in the region:

- What are the relevant institutions in the context of the Andean region?
- What is known about the key institutions related to water issues at different spatial levels in the Andes?
- How do institutions perform, and are they using and sharing the best available information (and if not why not)?
- What is needed for institutions to use and share the best available information and achieve more effective and more development-focused water management and use?

3.1. Definitions and concepts

Institutions can be defined as the “humanly-devised constraints for coordinating human interactions”. In other words, institutions are a society’s rules of the game that provide a structure within which members of a society – individually or collectively – cooperate or compete (North, 1990). For water management, which often includes many actors, institutions guide and limit decisions and actions. Institutions can also promote inaction, thereby preserving the *status quo*. Existing rules and customs (i.e., institutions) on water ownership and use are not only a pathway but also a target for change.

3.1.1. Institutions versus organizations

Institutions consist of both social mechanisms and social organizations. Social mechanisms include formal regulations, laws, and policies, and informal customs and traditions. With regard to the management of water resources, property rights play a determinant role when it comes to the power of decision-making about the use of water resources and organizations can be classified according to the quality of ownership over the resource base (private property, common property (state-owned), collectively-owned).

Social organizations are public or private. They can be grouped by administrative scale and thematic sector (development, conservation, religious etc.), and may also reflect the objectives and interests of distinct stakeholders. Public organizations

that affect water use can be governmental or non-governmental. Government organizations function at different scales ranging from municipal, to departmental and national level. They typically have a social or environmental objective. Non-governmental organizations can be classified in a similar manner (including local-level community-based organizations). Private organizations comprise for example privately-held multinational businesses.

Historically, regulatory and legislative models from Northern countries assume that the private sector consists of formally registered companies, and that the public sector has the administrative efficiency and enforcement capacity to implement incentives, fines, and demands for compliance with environmental legislation. Unsurprisingly, this cannot be successful in Andean watersheds as it would overlook the vast majority of water users.

3.1.2. Formal and informal

Institutions include both formal and informal structures, especially with respect to water management. Formal institutions are typically laws and rules with national and international scope, including property rights (collective and individual) of water access and use. They are usually supported by legal documents. Formal institutions on water resources are becoming a central issue in nations' constitutions, due to internal and external forces such as international agreements as well as social movements calling for an integrated approach to the management of water resources.

Informal institutions are typically not documented and can include traditions and customs, which often started decades ago and determine the use and access to water. Informal institutions evolve through spontaneous interaction and are usually not purposively designed (Hardin, 1968; North, 1990). They can be considered local-level translations of (usually national or international-level) formal institutions, and often they slowly become part of their formal counterparts (Saleth and Dinar, 2004). Influences occur in both directions however, and formal institutions are also derived from and dependent on informal institutions. The operational strength and stability of formal institutions is often rooted in informal institutions (Eggertsson, 1996).

So far, formal institutional reforms have usually focused on direct state interventions favoring privatization and the reduction of central power (Garcia, 1998). Meanwhile, local mechanism and informal institutions promote development objectives that are often opposed to neo-liberal policies of market efficiency and accumulation of power. In this context, limited (or lacking) dialogue between formal and informal institutions often gave rise to conflicts over water use and distribution.

3.1.3. Issues of scale

Formal institutions of water use and access often act at national and supra-national levels, while informal institutions usually operate in local settings, and may not be known at higher scales and *vice versa*. In situations where relevant formal and informal institutions are not compatible with each other, overlaps between institutions at different scales can therefore cause confusion and conflict – a common characteristic in the Andes. For example, indigenous and peasants communities have a long tradition of rules and customs that are not always recognized by official authorities and formal institutions, and in some cases are contradictory to current legislations. Additionally, where government policies have sought to provide technical assistance in peasant and indigenous communities to improve water supply, irrigation and small hydropower systems, policies that support powerful private sector entities usually take precedence (see section [3.3](#) on institutional performance for more detail).

Inconsistencies, overlaps and conflicts may also arise due to a lack of coordination among formal organizations with distinct objectives within the same level, for example among different national-level ministries (e.g. energy, agriculture, health/social, and environment). Moreover, insufficient financial and human resources often limit the enforcement of formal regulations. Consequently, informal institutions affect how water resources are used.

3.2. Institutions in the Andean region

For the Andes region, secondary data and literature review were the main source of information to produce a rapid assessment of the status and trends of policy and institutional changes, and their influence on water development, allocation, use, and productivity in different parts of the basin. The literature review covered different administrative levels of the system and focused on documentation related to the national perspectives of the four Andes BFP countries Bolivia, Colombia, Ecuador, and Peru (see sections [3.2.1](#) to [3.2.3](#)). The three focus sub-basins Ambato (Ecuador), Fuquene (Colombia), and Jequetepeque (Peru) were used to provide detailed examples of institutional arrangements that reflect the diversity present in the wider Andean context. In addition, the research team took advantage of the contacts established with water users and local organizations in the Fúquene focus sub-basin to get a better sense of issues and take a closer look at the legitimacy of current organizations involved in water use and management ([3.2.4](#)). A field visit to the Jequetepeque sub-basin provided direct information on the actions taken by different stakeholders in their attempt for improving water use and access. Furthermore, direct and electronic stakeholder consultations were carried out to inquire about potential strategic interventions and the use of information for the improvement of water management and planning.

3.2.1. Policy instruments and the role of land tenure

Andean national governments have generated, and continue to produce, large amounts of legislation concerning water. These policies address many aspects of water use, often reflecting the needs of specific sectors, and sometimes creating confusion and conflict among different sector interests. Such water laws usually dictate water management according to specific quantities and flow rates of the resource (e.g., cubic meters of water per month or per year).

Furthermore, water use and rights are closely linked with land tenure. Land property in itself reflects historical and institutional arrangements between community members. Land tenure has evolved relatively slowly through time, with the exception of land reforms occurring in selected and usually reduced areas. Land tenure in three of the four Andes BFP countries (Figure 18) shows that the pressure on smallholder agriculture – and consequently land concentration – is rising. Although data for Bolivia are not available with the same level of detail, land concentration is also extremely unequal. This land tenure pattern in the region is considered a source of social unrest and civil conflict (Ibañez and Querubin, 2004), and Gini coefficients for Andean countries are among the highest in the world (USAID and ARD Inc., 2008). Even areas that were previously subjected to land reforms with food production as the main objective (e.g., in the Roldanillo, La Union, Toro (RUT) area, one of Colombia’s main irrigation districts), are now experiencing land concentration processes due to a combination of factors, including the expansion of biofuels and loss of productivity of smallholder agriculture. Land use changes in these areas are also changing local power relationships and affect the way water is being distributed and used (see Appendix C.1).

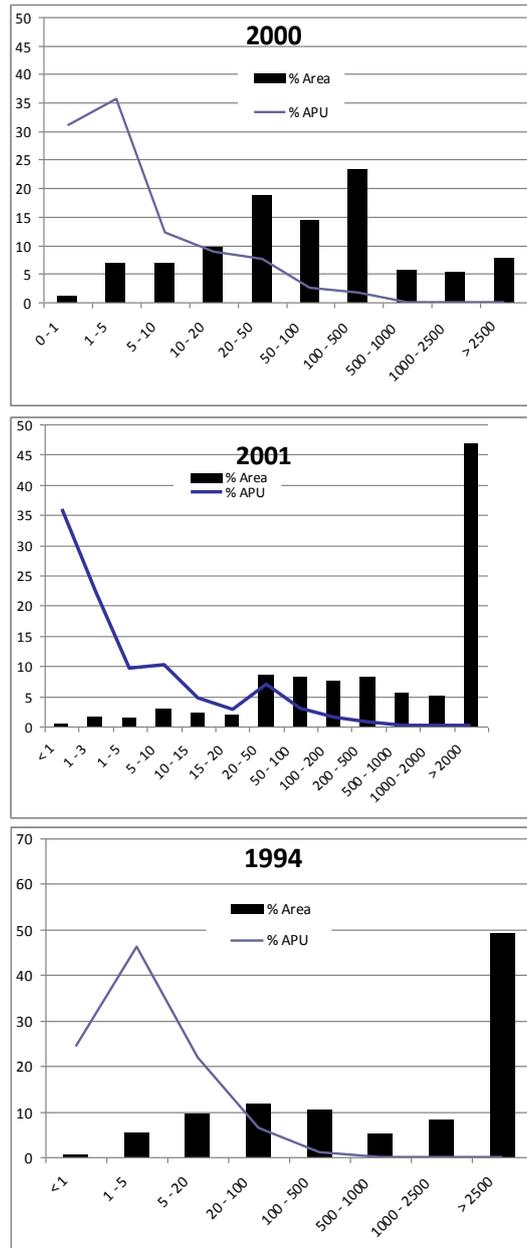


Figure 18. Land tenure in Ecuador (top), Colombia (center), and Peru (bottom) in terms of % of total area and % agricultural productive unit (APU).

3.2.2. Formal and informal mechanisms of public participation

Formal mechanisms of public participation in the region are an integral part of the democratic character of Andean countries and their constitutions (Table 6). In spite of the potential usefulness of these mechanisms for better and more participative water resource management in the region, there is hardly any evidence for actual impacts in terms of participation and representation (Payne et al., 2007). Instead, it rather seems that low levels of education and the political power of the established sectors limit the use and functioning of these mechanisms. Throughout the Andes region, this has resulted in a situation where lawsuits demanding better access to water are common, mobilizations for public protest against the mismanagement of water resources are frequent, and public pressure is growing to reduce the impacts of water contamination from industry and urban settlements. Processes vary from country to country and are stronger in areas where indigenous or otherwise organized communities are affected.

However, water use and allocation can also be influenced by other, informal approaches such as market-based instruments. For example, compensation for the provision of environmental services (such as water resources) is becoming an attractive and feasible alternative to quantity-based command-and-control allocations of water. In several Andean countries, upland farmers are receiving economic benefits for the adoption of land management practices that favor the provision of cleaner water (Pérez, 2000; Echavarría, 2002; FONAFIFO, 2004).

To avoid the costs of removing sediments from water, water consumers in urban areas are willing to invest in improved land management of upstream water catchments. Investments typically cover the establishment and maintenance costs of soil conservation structures (e.g., terraces, infiltration ditches, and wells). Current experiences have a very localized focus, but attempts are made to expand in coverage. To meet conservation goals, a variety of NGOs are initiating and supporting these pioneer projects. Both public and private sector interests are also often involved in such projects.

3.2.3. Organizational structures at different levels

In the following, we present the general organizational structure in the region with particular emphasis on official organizations. Institutional arrangements and expressions are relatively similar across the four Andes BFP countries with respect to customs and legislations, as well as with respect to the presence and effectiveness of official (governmental) and social (civil) actors influencing water use and management (see Andes BFP institutions database at <http://webpc.ciat.cgiar.org/impacto/Datos/Institucional.htm>). Unlike other CPWF basins, the Andes basin has few water flows that cross national boundaries. Therefore, government organizations at national and sub-national levels are endowed with the management of water resources in the region. National government organizations are defined by sector according to water use, e.g. agriculture, urban development, electricity and energy, etc. In Colombia, sub-national organizations are defined geographically (by watershed) and politically (by administrative department). The involvement of numerous government ministries at multiple levels creates confusion regarding roles, responsibilities, and ultimately rights to water use and access. Water management details in the four Andes BFP countries are documented in Appendix C.4.

Table 6. Direct democracy mechanism at national level in the four Andes BFP countries

Country	Popular legislative initiative		Plebiscite/Referendum		Recall	
	Exists	Used	Exists	Used	Exists	Used
Bolivia	Yes	No	Yes	Yes	No	No
Colombia	Yes	Yes	Yes	Yes	Yes	No
Ecuador	Yes	No	Yes	Yes	No	No
Peru	Yes	No	Yes	Yes	No	No

Although water is not yet considered a strategic resource in any of the Andean countries, significant changes with respect to water management were taking place at national level at the time of this revision. Constitutional changes were made and new entities for the administration of water resources were created. In Bolivia, after a long internal debate the Water Ministry Office was created in 2009. In Peru, the National Authority for Water (Spanish: Autoridad Nacional del Agua, ANA) was

established as part of the Environmental Ministry. A new law derogates the private property of water and proposes the use of watersheds as the biophysical unit for management. At the end of 2009, Ecuador modified the terms of reference of the Consejo Nacional del Agua, which also belongs to the Ministry of Environment, Rural and Marine Areas (MARM). From now on, the body will be the advisory group for all decisions related to the management of water resources in the country. In Colombia, the congress is debating a new Water Law which would include the management of watersheds by environmental authorities.

Furthermore, throughout the region, important grassroots activities are taking place and water user associations are growing and gaining more influence. Water Forums are becoming more common, which often question the role of national authorities and the concessions given to transnational companies for water use and administration. Relevant examples include the establishment of a "water defense coordinator" in Bolivia and the "Committee for the Promotion of a Water Referendum" in Colombia.

3.2.4. Organizational roles at local scale

In the Fúquene focus sub-basin in Colombia, we focused on analysing the performance of organizations that develop, influence or manage water use institutions, using seven criteria commonly used to measure the performance of private sector firms (see Appendix C.3.1). Results of the perception analysis of organizational performance were diverse, not only across organizations but also amongst the performance criteria within organizations. NGOs and research / education organizations scored highest, while private enterprises such as fishing, agribusiness and mining organizations scored lowest in their perception about the particular indicators for each organization. Of the seven criteria examined, *representativity of interests* received the highest scores, whereas *following laws and rules* and *group cohesion* obtained the lowest scores. This information can be used to better understand the strengths and weaknesses of organizations and help identify priority areas for change.

Responses to a prioritization of water management interventions produced surprising results (Figure 19). Indirect interventions to water management were preferred over direct ones. *Participation and community organization* were considered of highest priority along with *environmental and civic culture education* and *ecosystem and conservation area protection*. Direct interventions such as *payments for environmental services* and *control and implementation of regulations* were least favored. These results point to a need to better understand local preferences and the underlying reasons for priority interventions (Rodriguez et al., 2009).

3.3. Institutional performance

3.3.1. Literature review

Several authors highlight the fact that the four countries hold a similar history and by consequence a similar current institutional and political status (e.g., Oré and Castillo, 2009). For example, a common problem of institutional performance is that the economic and planning instruments available for water use and control are often disarticulated. Typically the legislation on water resources is not fully compiled or unified, often incomplete and in some cases contradictory (Gutierrez, 2005). Furthermore, the jurisdictions of environmental authorities often do not coincide with administrative units, which makes exerting proper management complicated if not impossible (Dourojeanni, 2002). Policies and control mechanisms are weak and the participation of civil society and water users is not fully incorporated. Moreover, water is often managed by sectors impeding an integrated

approach or even the implementation of watershed plans. Where these are present, lack of resources and trained people is a limitation for implementation. This is reflected in the over-use and over-allocation of water resources by authorities.

One example for an issue of scale, where relevant formal and informal institutions are not compatible with each other (see section 3.1.3), is the Indigenous Law in Chile, which was enforced in 1993 to support the development of indigenous water resources, management systems and territories. However in practice, the more powerful Water Code and Mining Code held more weight where a clash of interests occurred. This holds also true in Peru, Ecuador, and Bolivia where mining laws and investment policies support mining and petrol companies who are continually responsible for the deterioration of numerous catchments and watershed areas, and for damaging peasant and indigenous water use systems in these areas. Inequalities in land tenure and lack of formal tenancy facilitate the intervention of powerful external actors (Boelens et al., 2005).

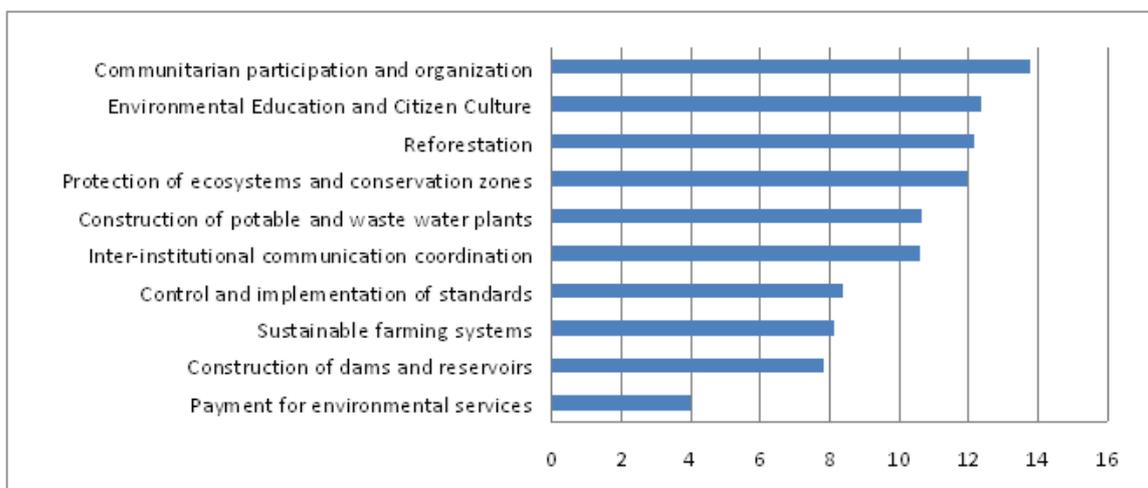


Figure 19. Preference for potential interventions in Fúquene sub-basin to solve water-related problems (Source: Fúquene Workshop WP4)

Generally, conflicts over water use (and quality) are more frequent in rural than in urban areas (see for example section 1.1.6 on water deficits). Local scarcity has already led to serious conflicts over water in Bolivia and Peru (Olivera, 2004; Fraser, 2009). Water shortages are emerging in several other places, as a consequence of over-allocation or failure to anticipate rapid expansion of urban centers and commercial agriculture (Anonymous, 2000).

3.3.2. The Institutional Environmental Index (IEI)

To assess the performance of organizations and institutions in the region, we used the Institutional Environmental Index (IEI) as an indication of the manifest behavior of the performance of organizations and institutions useful for the society (Hodgson, 2006). The section ends with a set of key recommendations pointing towards institutional reforms and changes.

The institutional environment plays a crucial role at the moment of identifying strategic interventions to promote the development and conservation of water resources. Due to time and resource limitations of this study it was not possible to conduct an exhaustive evaluation of all institutions in the Andean region. Instead we calculated the *Institutional Environmental Index (IEI)*, which uses the apparent

behavior of institutions as approximation for overall institutional performance, based on municipal-level data for the four Andes BFP countries.

The *Institutional Environmental Index* reflects to a certain extent the quality of life in each municipality, in terms of service provision such as education, health, potable water, security, and investments in infrastructure, among others. When the quality and quantity of any of these services is high, it is assumed that this indicates the presence and functioning of institutions, and effective government or communal actions providing for local development. In contrast, when low values are scored it is assumed that the conditions for these indicators are inadequate, and hence the desired institutional support is lacking. The model has been integrated into the Policy Support System developed by the Andes BFP, as a filter to evaluate the viability or not of external interventions. For a detailed description of the methodology and underlying assumptions see Appendix C.5.

As expected, results show that the IEI is considerably higher around urban centers for the Andes region, in contrast to a more heterogeneous situation in rural areas (Figure 20). When urban centers are excluded from the analysis, the conditions in rural areas can be differentiated with greater precision. Such information is of particular importance for organizations that are considering development investments in multiple thematic areas, including water, health, education and infrastructure.

The methodology allows one to obtain an integral vision of different social, economic and political components, all of which are determinant factors for implementing research and development activities in the Andean region. A more detailed study of the factors associated with a high or low IEI score allows one to identify potential variables that may be responsible for limiting development at municipal level. The spatial configuration of these variables can help targeting specific efforts to improve local development conditions. Analysis of the four Andean countries showed that variables associated with education and nutritional status were the most determinant for the performance of IEI.

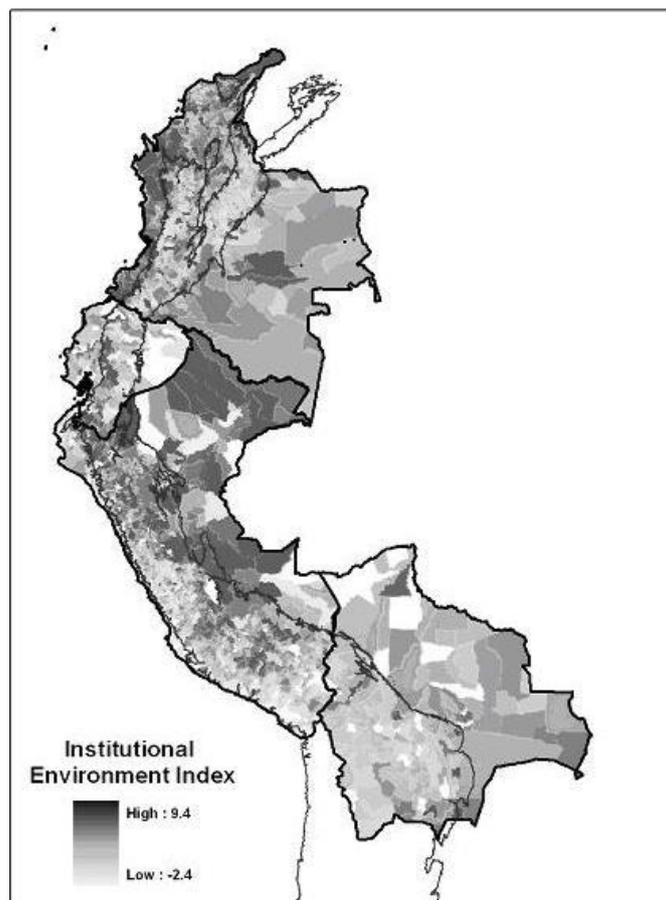


Figure 20. The Institutional Environment Index (IEI) for the four focus countries in the Andean region

3.4. Institutional perceptions and needs

3.4.1. Organizational analysis (institutional perceptions)

A questionnaire was developed and sent to 80 regional stakeholders to (a) provide a clearer picture of the current needs and perspectives of actors working in and researching key sectors related to development processes within the Andes, (b) inform about the scope and content of our Policy Support System (PSS), and (c) ensure the relevance of policy options within the system (Annex C.3.2). The questionnaire also provided key information on the level of importance given to various issues such as the effects of soil erosion and access to water resources in watershed management by policy makers. Respondents included 46% development workers, 26% scientists, 21% students, and 9% public sector employees from seven countries in the Andean region.

Much to our surprise, water and water productivity were not top of the agenda for these end-users, who indicated that:

- a. The highest priority in Andean watersheds is soil erosion (71%),
- b. 44% said that the effects of soil erosion on agricultural livelihoods should be considered more in the policy making process,
- c. 48% said reform in the institutional approach regarding the management of water resources is important,
- d. 66% of respondents observed that equality of access to water is important,
- e. 58% said the implementation of Payment for Environmental Services is a priority.

Moreover, in response to questions on how the Andes BFP can help lift knowledge barriers to better water management for food, 46% of the respondents indicated that knowledge barriers were not an issue since scientific data were routinely not used to support water policy. The reasons for the low uptake of policy support tools like SWAT (the Soil and Water Assessment Tool) in the Andes included lack of knowledge of them, lack of or expensive data, and lack of training and local capacity in their use. Respondents agreed that the most important factor in the successful use of such systems is the availability of reliable data with a sufficient level of detail for both regional and local application, followed by spatial analysis and modeling tools to trigger the generation and use of reliable data.

Respondents also called for a more participatory and integrative policy making process, including the consideration of Payments for Environmental Services as an effective way to improve institutional water management and increase co-operation between different water users and institutions. The watershed up to the national scale was considered the most important levels of detail and geographic resolution required for a range of potential users. National public sector development agencies and local municipal planning offices were seen as the sectors most likely to benefit from such a PSS. This signals the need for an effective strategy of knowledge sharing that takes into consideration the technical capacities of all potential users, to ensure accessibility to all levels of users. The issue of low technical capacity within governance institutions can be approached by collaboration of other sectors likely to benefit from the systems use, such as NGOs engaged with rural development and the academic sector.

3.4.2. The AguAAndes Policy Support System

The AguAAndes policy support system (PSS) is a web-based policy support tool that aims to overcome many of the barriers to the use of traditional knowledge and contemporary policy support systems by organizations implementing water policies. It ties together the detailed data presented here (and much more) in order to tackle the complex issues around water management in a spatially detailed and locally relevant way. It allows users to examine the impacts of particular interventions on either alleviating or worsening the long-term water-production-poverty situation under different land use and climate change scenarios.

The first barrier to use of scientific knowledge in policy formulation is issues around the availability of data. AguAAndes is based on the simTerra policy support framework (www.ambiotek.com/simterra) and thus has direct access to substantial global and regional databases presented in a consistent and usable form at no cost. Table 7 shows a comparison of the usability constraints for of SWAT (a popular hydrological modeling tool) and AguAAndes for tropical montane environments and indicates the main advantages of AguAAndes over other types of policy support tools. As a web-based system AguAAndes users do not need to install or manage local software or databases, since all applications are run on the online-server and thus the technical, computing and GIS capacity required is minimal. This removes a further constraint to use (the availability of local technical capacity).

The PSS can be accessed at www.policysupport.org/links/aguaandes. It comprises a series of models and submodels such as those for hydrology with associated full online documentation. Users define an area for policy support, the system then prepares the available datasets, and can then be run for particular parameters, policy options and scenarios for climate and land use.

Results are presented to the user in map form (Figure 21 and Figure 22), and as charts (Figure 23). This enables rapid assessment of the hydrological knowledge base for an area and rapid testing of the potential impacts of scenarios or policy interventions using consistent data and models. It removes the delays and costs of

developing GIS and spatial analysis projects to answer these questions and helps build local capacity through access to data and tools. AguAAndes is no silver bullet, since its results are – as with any science – highly dependent on the quality of available data and the (social)-scientific knowledge of the systems being simulated. It does, however, provide a common platform for discussion of what is and what is not known in an area, democratizes knowledge and acts as a platform for knowledge development for any area within the Andes. In partnership with key stakeholders who have been engaged in the development of the PSS since the beginning of Andes BFP, a series of policy exercises have been developed to provide examples of application.

Policy exercises

The AguAAndes PSS comes with a series of policy exercises but only the key two are described here. The first policy exercise allows users to define a baseline simulation of climate and hydrology for any part of the Andes at 1 km spatial resolution. This is a hot-spotting tool which provides a consistent hydrological dataset for the Andes but also allows the identification of areas with specific hydrological conditions (e.g., aridity, seasonal drought) and hazards (e.g., soil erosion). The second policy exercise defines the impact of climate change. Both exercises are described in greater detail within the AguAAndes system, and are summarised in Appendix F.1.

Table 7. Comparison of usability characteristics of SWAT and AguAAndes for tropical montane environments

Soil Water Assessment Tool (SWAT)	AguAAndes
Complex, requires training	Simple policy analyst interface (more detail provided – if required - in a scientific interface to the same system)
Data not available, not detailed or expensive to obtain	All data provided for entire model domain at two levels of detail (1ha and 1km)
Require significant local data handling (GIS) capacity	No GIS capacity required
Not applicable in data scarce environments	Applicable in any data environment
Not developed for mountain environments	Developed specifically for tropical mountain environments

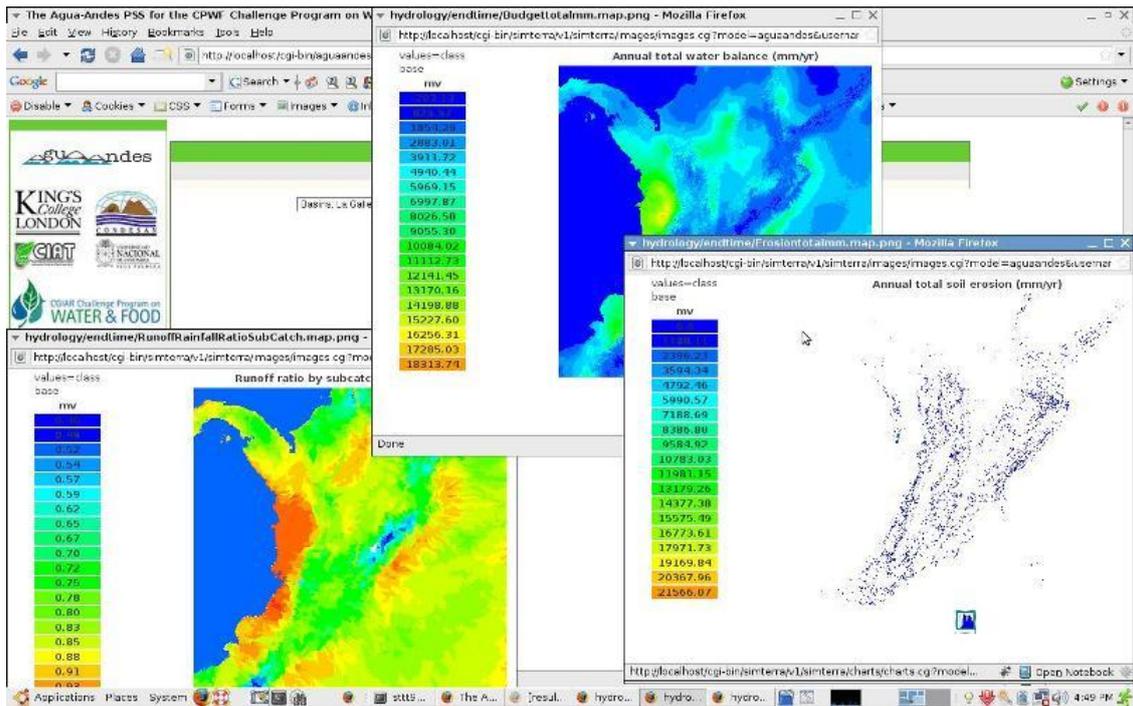


Figure 21. Example of presentation of results for AguAAndes in map form

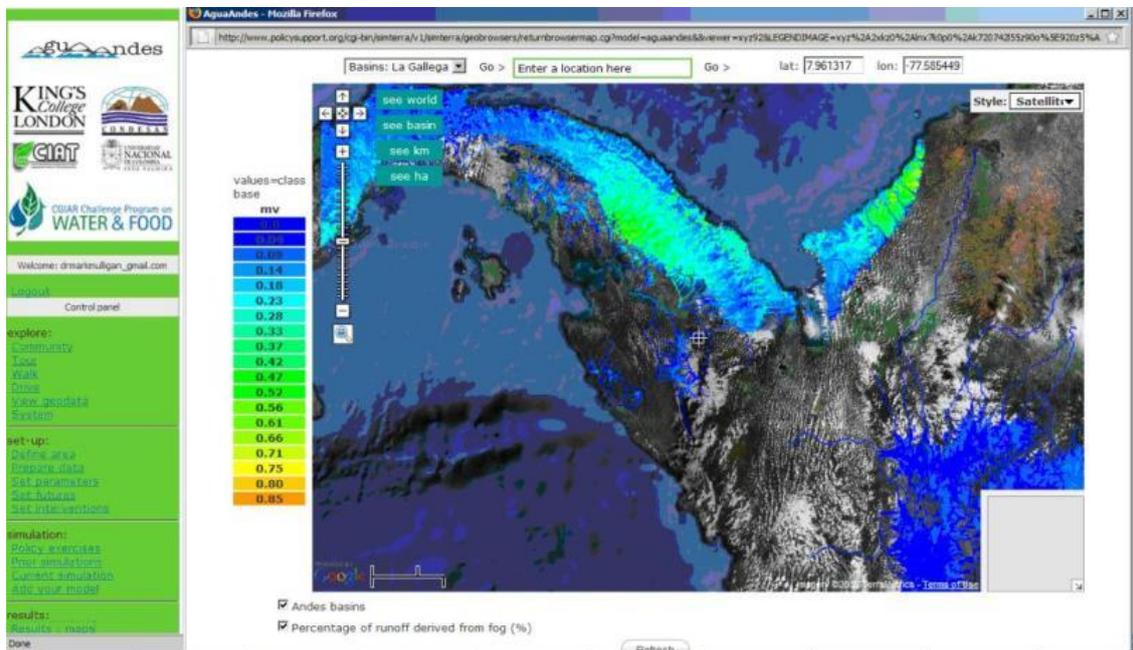


Figure 22. Example of presentation of results of AguAAndes in a geobrowser

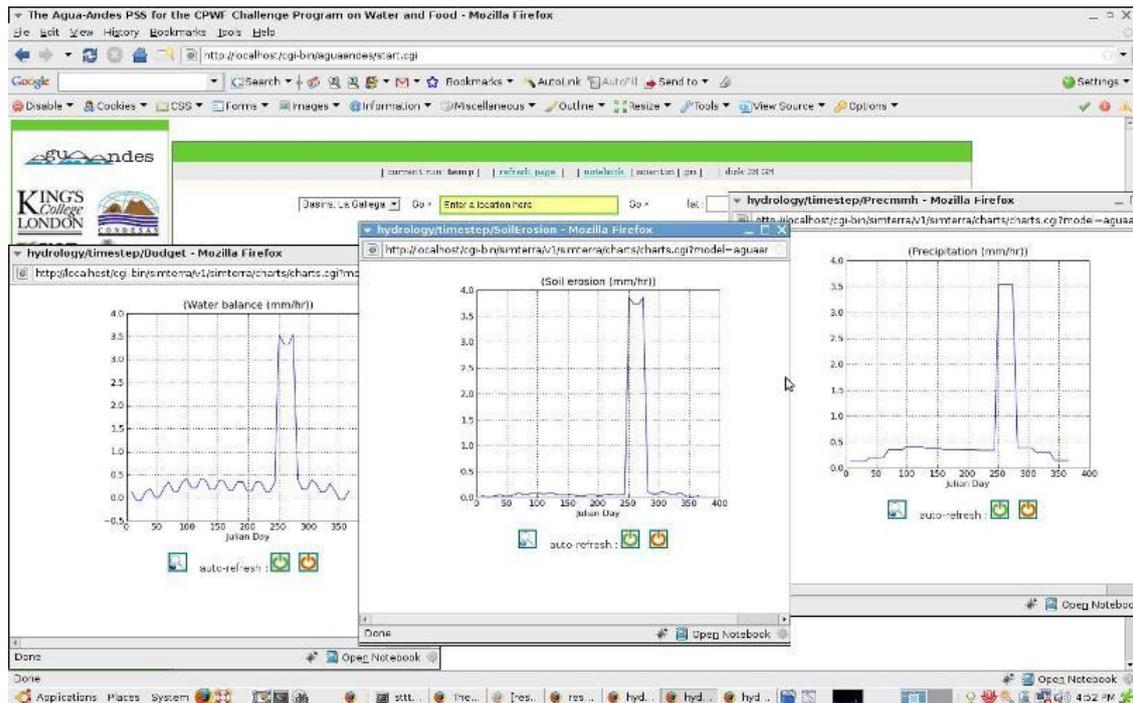


Figure 23. Example of presentation of results of AguAAndes as time series charts

3.4.3. Key strategic institutional recommendations

The co-existence of both formal and informal types of institutions in the Andes region makes it necessary to develop a better understanding of the conflicting issues and synergies derived from such coexistence. In some cases, the legal implications of this coexistence are unclear or even contradictory. In others, a lack of coordination among institutions from different thematic sectors leads to inconsistencies, overlaps and even conflicts of policies, regulations, and sectoral development plans due to distinct objectives (e.g., energy, agriculture, health/social, conservation). Moreover, insufficient financial and human resources often limit the enforcement of formal regulations. Consequently, informal institutions affect how water resources are used.

General institutional trends in Andean countries regarding agricultural water management have increasingly leaned towards the rhetoric of participation, decentralization and transfer of management to local governments. This requires reforms to ensure more accountability and better integration with civil society and government structures. State intervention generally neglects the democratic involvement of user organizations questioning the rights gained in the new country Constitutions. In Ecuador for example, peasant and indigenous farmers with less than 1 hectare represent 60% of all farmers and account for the major part of national food production. However, they receive only 13% of the benefits of state spending in irrigation. At the same time, large landowners represent only 6% of all farmers (by land area) and they receive 41% of the benefits of state spending on irrigation (Whitaker, 1992; Boelens et al., 2005).

The developmental impacts of improving participatory mechanisms are significant. This has to be accompanied with appropriate education and skills training and a common information base for dialogue. In terms of improving human development indicators affected by water access and water quality, local governments take action to solve the problems only if there is a group of well-organized people to exert political pressure. Since petitions backed by an organization stand a better

chance of being heard by the local authorities, well-informed water user associations are crucial to solving problems of this nature (Bastidas, 1999). In this context, providing more and better data and technology in an appropriate and accessible manner can contribute to increasing the capacity of local institutions to take better-informed decisions. Hydrological analysis should therefore be integrated more closely with integrated water resource management assessments in order to support policy making processes (e.g., a more systemic analysis of water resources at the local level so that all existing water interventions, such as water diversions, point pollution sources *etc.* are accounted for in analysis).

As stated earlier, urbanization is a process implemented with the support of national and macro-economic (trade) policies. Given the imperfection of this process in Andean countries, this has caused the deterioration of quality of life of the remaining rural population and a lack of response to the services demanded by pressures in urban centers, leading to increasing poverty and unsustainable management of natural resources (Rigg, 2006). There is a strong argument to suggest that the most effective rural poverty alleviation strategy is to facilitate and encourage this process by providing rural populations with the skills and education needed to equalise the benefits of new labour markets be they off-farm wage work in agriculture (involving the further intensification and industrialization of high-value commodities such as dairy products, fish and flowers) or wage work in non-farm activities (fish processing, domestic and factory work and artisanal weaving).

Due to the diverse physical and social contexts of Andean communities, the task of implementing water management legislation at a local level has historically faced problems. This is apparent in the disparity between official legislation formulated by official state agencies and the reality facing water users in basins. A general characteristic of legislation surrounding water resource management in Andean countries is both its minimal influence in the Andean highlands and the level of resistance that it provokes. Often official regulations define precisely the finest details of water use such as how water users must organize, how water must be distributed, how they must contribute to the maintenance of their irrigation systems, and how water must be distributed. However, legislation and norms designed to generate integrated water resource management are in practice adjusted by a variety of intermediary stakeholders, each with their own ideologies, rules and interests. Informal water management institutions are generally associated with the cultural water practices of marginalized indigenous communities, which include rights to establish authority for sanctioning and the rights to access, and use of infrastructure. Approaches to resolving the gap between the two include:

- *Provision of a common baseline* of high quality information and tools for policy negotiation which are accessible and open to all in a transparent manner
- *A consensus-based management approach*. This entails negotiation and collaboration among different water users. The generation or strengthening of platforms (communication spaces) is considered central to this approach.
- *An empowerment approach*. This is centered around providing groups with less advocacy and voting power the capacity and space in which to join with other similar interest groups (Candelo, 2005). Successful alliance building between grassroots groups and assistant institutions such as NGOs have produced positive results in some cases, a good example being where environmental groups, peasant organizations, and NGOs, sometimes with local government actors, join and manage to force other actors to practice "responsible water management".

3.5. Conclusions

The institutional picture obtained illustrates a very dynamic and changing landscape in the Andes. Large corporations for drinking water administration are present in the region, government and international funds for dams and irrigation infrastructure are increasingly becoming available, mineral and fuel concessions are being granted in important hydrological areas across the region, and water user associations are growing and gaining more influence. Although water is not yet considered a strategic resource in any of the Andean countries, significant changes with respect to water management were taking place at the national level at the time of this revision. Constitutional changes were made and new entities for the administration of water resources were created with new legislations, new central water agencies, and active debates about new water laws.

In spite of these positive developments, the diversity of interest groups – reflected in the organizational structure behind water resources management – apparently makes it difficult to reach a consensus about truly integrated approaches. A variety of actors and interest groups are reflected in a wide range of institutional arrangements that govern the functioning of these organizations, including international agreements, bi-lateral treaties, national legislations, and policies, responsibilities assigned to minor entities at territorial level, and local practices. Thus, the management and administration of water resources in the Andes region varies according to the usage priorities (e.g., domestic, industry, irrigation) and objectives (e.g., water access, basic sanitation, hydroelectric power generation) of the respective actors in each region.

A common call to improve water resources management, is that for more decisive, participative efforts of discussion and analysis of existing rules and regulations to identify those that are most convenient for society as a whole, without disregarding local particularities. However, in this context it is necessary to evaluate the operability of the “integrated approach” that has been widely promoted for the management of water resources. Unfortunately, the concept of “integrated water resource management” as promoted in the different countries’ regulations is very difficult to put into practice, and its benefits are still limited by problems of implementation, in particular those related to the transformation of current institutional structures in favor of sectorial integration.

Formal regulations and informal practices associated with water resource management are well documented for the Andean region. However, formal mechanisms of public participation for resource management decisions warrant a careful revision to better understand the reasons for their limited use. In particular the (non-)adoption of these mechanisms by marginal sectors of the society needs to be evaluated in the light of other social and political conditions that may limit their effectiveness. The spatially and culturally highly diverse context of the Andean region warrants that the priorities defined at national levels consider local particularities more decisively.

4. Poverty

Poverty in the Andean region persists. Forty-seven million people in the four study countries are considered poor (Figure 2). This corresponds to about half of the population in Colombia, Ecuador and Peru, and almost two thirds in Bolivia. Of these total poor, 26 million are rural poor.

As most of the region is dependent on agriculture and water resources, understanding interactions between poverty and water is needed to support policies and development interventions that could improve living standards in the region. Key questions we asked about poverty in the Andes region are:

- What is known about the levels and distribution of poverty in the Andes basin?
- Why are poor areas poor, and what is the role of water in Andean poverty?
- What are the key exit pathways out of poverty?

4.1. Levels of poverty in the Andes compared with other CPWF basins

A direct comparison of poverty levels across the nine CPWF basins is not possible, because no common methodology was applied across projects (see the methods and findings reported in the annual reports of the nine CPWF basins in Appendix D.1). In spite of the methodological disparities and the heterogeneity of the basins, some common trends in levels of poverty can be observed in the CPWF focal basins. Importantly, no broad-based relationships between poverty and factors related to water conditions or management were found across basins, but in several cases water quality problems were associated with low living standards, especially in Africa. For example, the Volta and Limpopo basins have high incidence of diseases related to poor water quality or management. In some areas in Asia and the Andes irrigation was associated with low poverty, and in others with high poverty. In Africa, the scale of irrigation development is too limited to study its effect on poverty. Furthermore, many of the studies reported indirect linkages between water and poverty.

The Andes region differs from the other CPWF basins in several important respects. Generally, water scarcity is much less a problem than in other CPWF basins, especially in the northern Andes. Soil erosion and sedimentation are key water quality problems in the Andes, whereas the other basins' water quality problems are more likely to be related to health problems such as parasites. Also, the Andes region has greater inequality between the upper reaches of watersheds and the lower valley areas compared to basins with less relief in other parts of the world. The poor in the Andes often lack access to irrigation infrastructure, a condition shared with Africa but less common in Asia. The most important water-related hazards that affect livelihoods in the Andes are droughts and floods related to the El Niño phenomenon, but the severity of droughts in the Andes is probably less than in CPWF basins in Africa and Asia.

4.2. The levels and distribution of poverty in the Andes

Due to the numerous dimensions of poverty, a large number of different methods have been developed to assess poverty. Methods range from globally standardized measures such as the human development index (HDI; Sagara and Najam, 1998), to national-level measures that use poverty indicators that are more relevant in a regional or national context such as Unsatisfied Basic Needs (UBN) approach (Schuschny and Gallopin, 2004). For a more detailed overview of different poverty measures and the variables used for calculating them, see Appendix D.2.

The broad levels and distribution of poverty in the Andes can be assessed and illustrated by mapping its spatial structure. Figure 24 displays the spatial distribution of poverty in the Andes basin using two different approaches. The map on the left shows relative poverty levels in the region from a combination of methods. The maps are not comparable across countries. The Colombia values for poverty levels are displayed using the UBN approach – the method most commonly used in Latin America for assessing poverty. Ecuador and Bolivia data represent the percentage of the population below the official national poverty line. The Peruvian data use childhood stunting as the poverty indicator. The maps shows general patterns for the Andean countries, with higher poverty in the Andean region compared to the coastal and Amazon regions. The exception to this pattern is Colombia, where poverty is lower in the Andean region.

However, these 'choropleth' maps of administrative areas can be improved upon to discover important patterns of poverty. The use of point data (rather than polygons) makes some spatial statistics more easy to calculate and visualize, such as spatial dependency and spatial autocorrelation. On the right, we illustrate the degree of spatial autocorrelation of poverty levels using the LISA (Local Indicators of Spatial Autocorrelation) approach (see detailed description in Appendix D.3). LISA calculates the extent to which the values of any variable are more or less similar to near neighbours as opposed to places further away, using central points or 'centroids' based on the weight of the population in administrative units (Fotheringham et al., 2002). The spatial autocorrelation of poverty levels is displayed for each of the four BFP Andes countries using national-level poverty indicators (Figure 25), and at the Andes basin scale (Figure 25, right). As expected (see Moran's I in Appendix D.3), poverty is generally highly clustered, and there are very few locations with high-low or low-high poverty characteristics.

In **Colombia**, poverty levels (based on infant mortality) are lower in the Andes than in the lowland and coastal regions (

, top left). Clusters of low poverty levels are grouped around the most important urban centers (Bogotá, Cali, Medellín, Bucaramanga, and Cucuta), all of which are located in the Andes region. High poverty clusters are evident along the Pacific coast, in the south close to the border with Ecuador, and in eastern Amazonia. These patterns may be linked to the access to medical staff rather than household poverty *per se*. This could be confirmed or refuted by regression analysis where access to services is one of the explanatory variables.

Ecuador has the lowest global spatial autocorrelation value of the four Andean countries, nonetheless its poverty pattern (based on food consumption) is still more clustered than dispersed (Figure 25, top right). Clusters of high poverty are concentrated along the central Andes, with the exception of a low poverty cluster around the capital city Quito. Other areas of low poverty are found on the fringes of the Amazon region, in southern Ecuador on the border with Peru, and around the country's second largest urban center, Guayaquil. The Pacific coast is generally characterized by clusters of low poverty, with the exception of a high poverty hotspot in the province of Esmeraldas, in the northern coastal region.

In **Peru** the contrast in the poverty pattern (based on undernutrition) between the coast and the central Andes is even more prominent, as illustrated in the spatial autocorrelation map (Figure 25, bottom left). Low poverty clusters extend along the whole coast and inland, as far as Arequipa. Two other low poverty hotspots can be found on the northern fringes of the Amazonian region, in Rodríguez de Mendoza and San Martín. In contrast, along the entire length of the central Andes clusters of high poverty stretch from the border with Ecuador down to as far south as Lake Titicaca.

Compared to the other three countries, **Bolivia** has relatively fewer data points and relatively low levels of spatial autocorrelation (i.e., few clusters of high or low poverty; Figure 25, bottom right). A small cluster of low poverty (based on consumption) is found around the city of Cochabamba, with a crescent of high poverty to the west, south and east, stretching into northern Potosí department. All clusters of high poverty are located in the Andes or altiplano, with local hotspots in western Oruro and western Chuquisaca.

The analysis also shows that the poverty/nutrition/mortality variable is spatially dependent and should be taken into account in regression modelling. The observed

patterns correspond to the expected distribution, with higher levels of poverty in the central Andes of Peru and Bolivia, and to a lesser extent in Ecuador, whereas in Colombia (and northern Ecuador) the most marginal areas are those on the periphery - the Pacific coast, Amazon and the Medio Magdalena. The influence of urban areas in the Andes seems to be significant and is notable in Bolivia, Ecuador, and Colombia, but less so in Peru. We mentioned earlier (section [1.1](#)) that water availability in the Andes is reduced while going south in the region, which is also reflected in agricultural productivity (section [2.1](#)). Mining and other economic activities are also more common in the south (section [2.2.3](#)). These patterns could eventually be linked with poverty.

4.3. The nature of poverty in the Andes

Generally, health, education, land pressure, and land degradation issues have been shown to exacerbate poverty in the Andes region (Zimmerer, 1993; Swinton and Quiroz, 2003), whereas dairy (Holman et al., 2003), high-value crops such as flowers, and coffee (Rushton and Viscarra, 2006), rural non-farm income and rural non-farm employment (Berdegue et al., 2001; Deininger and Olinto, 2001; Dirven 2004; Escobal, 2001; Reardon and Berdegue, 2001) have proven to be poverty exit pathways in many cases. The influence of urban areas seems to be significant and is notable in Bolivia, Ecuador, and Colombia, but less so in Peru. In many cases, labor-migration (particularly male) from upstream communities causes labor scarcity which is the proximate cause of a series of problems, including (i) inadequate attention to agriculture leading to environmental degradation; (ii) deleterious effects on the cultural and social organizations that sustain agriculture; (iii) poverty of agricultural innovation or a stagnant agricultural base; and (iv) an overburdening of those who remain (usually women) with labor, interfering with the performance of all necessary agricultural tasks (Jokisch, 2002).

4.3.1. Factors influencing poverty at country level

To better understand the nature of poverty in the Andes, we used Ecuador and Bolivia as examples and developed a database that included information on poverty and other factors that might have a bearing on poverty. A regression analysis framework was applied to this dataset to study the relationship between poverty, water, and other variables that might be important in the poverty dynamic (for methodological details and the list of variables included see Appendix D.4). No single variable could explain poverty patterns throughout Ecuador or Bolivia, but different variables showed locally significant relationships with poverty.

For **Ecuador** a picture emerges where poverty hotspots in southern Chimborazo, Cañar, Azuay, and Guayas provinces are negatively associated with vegetation vigor (NDVI), whereas in eastern Guayas irrigation seems to be the dominant factor affecting poverty levels (positive association, probably due to plantation farming systems). Failed seasons – or droughts probability – explained high levels of poverty in northern Ecuador (especially in the Andean region north of Quito) and in the provinces of Loja and El Oro in southwestern Ecuador, whereas in several other districts in the Andean region poverty was positively associated with a lack of access to piped water. Key variables that explained local patterns of poverty in Ecuador thus included irrigation, NDVI (Normalized Difference Vegetation Index), failed seasons, and % of households without piped water access.

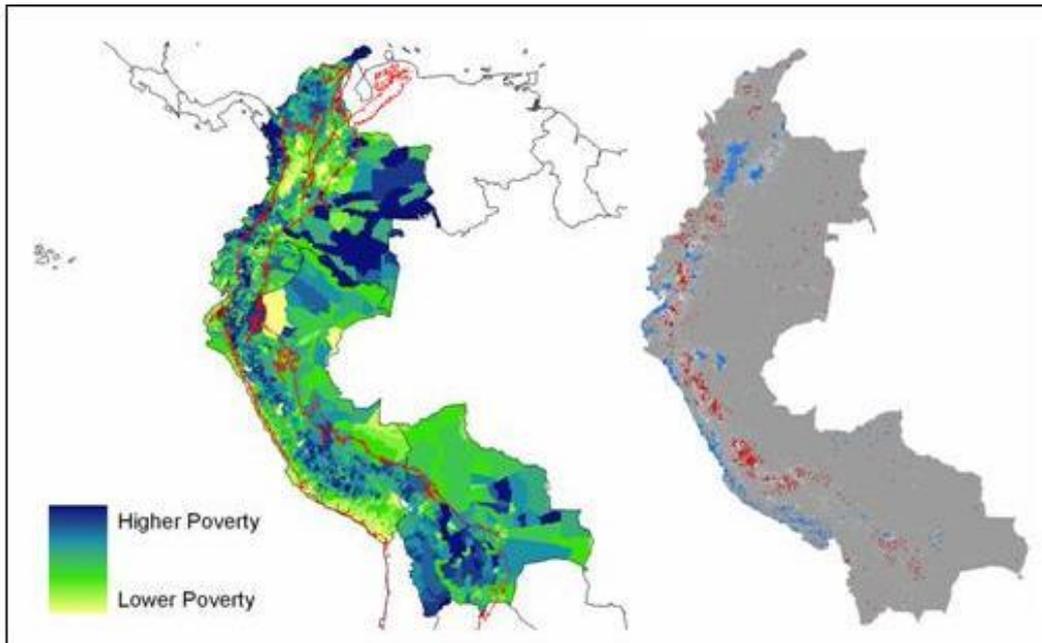


Figure 24. Spatial distribution of poverty in the Andes basin using the 'choropleth' approach (left) and Local Indicators of Spatial Autocorrelation (LISA) (right)

In **Bolivia**, poverty levels were stronger linked with fertility rate and education (number of schools per capita, % of rural population). In the East of the Bolivian Andes high poverty areas have substantially higher rates of illiteracy and fertility (number of children per woman). However, in the southeastern part the failed seasons variable was significant – as in the case of Ecuador.

These results show that in some locations there are possibilities for interventions in water management and provision. For example, interventions designed to alleviate drought might be targeted in southern Bolivia and northern Ecuador, where high levels of poverty concur with a high incidence of failed seasons. However, potential interventions should first be validated in catchment level studies.

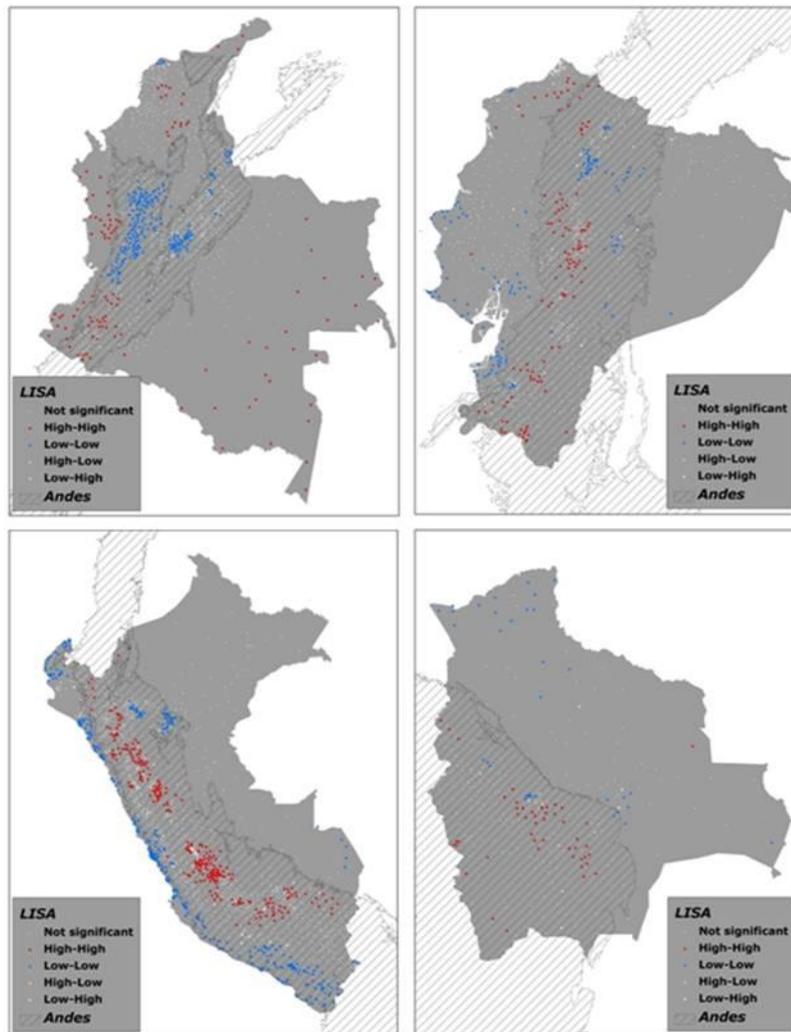


Figure 25. Local Indicators of Spatial Autocorrelation (LISA) for national poverty indicators of the four BFP Andes countries (top left: Colombia, top right: Ecuador, bottom left: Peru, bottom right: Bolivia)

4.3.2. Factors influencing poverty at the watershed scale

Several studies have been carried out in the Andes BFP focus sub-basins to understand the key factors that drive poverty in each basin (Johnson et al. 2009; Chapalbay et al., 2007, Gomez et al, 2005). We analysed these data – collected mainly from household surveys – to illustrate poverty dynamics in these basins (Appendix D.5).

Results show that the three focus sub-basins share several common factors related to poverty. For example, rural non-farm income and employment are important in all basins, and diversified economic activities, ownership of livestock, and market-oriented agriculture all tended to be associated with higher levels of wellbeing (Table 8). A key activity in these basins is dairy operations, an activity increasingly common throughout the Andes. Other activities include artisanal goods, textiles and high-value crops.

Linkages between poverty and water are relatively weak, and water related problems were not found to be dominant issues in any of the basins. However,

households with access to local irrigation systems tended to fare better than those without, suggesting scope for further study into the possibility of interventions that improve household access to irrigation. Furthermore, all three basins have strong upstream / downstream interactions with land management decisions upstream affecting water quantity and quality downstream.

The interaction and contrast between upstream and downstream areas is a consequence of the highly heterogeneous relief in the Andes. Therefore, land management actions in the upstream portions of watersheds affect the environmental conditions throughout the lower sections. The other key element of this dynamic is a difference in livelihood conditions between upstream and downstream parts of the watershed. Figure 33 in Appendix D.5 shows higher levels of poverty in the upstream parts of two watersheds. This pattern also holds for other watersheds throughout the Andean region. For example in the Jequetepeque basin in Peru, poverty levels are twice as high in the upstream parts of watersheds, as they are in the downstream parts, according to unmet basic needs indicators. Downstream irrigation depends on water services supplied by the upper basin. The less-poor lower basin thus benefits from water services supplied by the poorer upper basin. But residents of the upper basin receive no compensation for land use practices that support water resources.

These discrepancies between upstream and downstream use of water suggest an opportunity to establish PES schemes. Such schemes could be important for poverty alleviation because poverty is usually higher in upper parts of the basins compared to the lower sections. For example, the upstream portions of all three basins described in Table 8 are the source areas for water in downstream hydroelectric reservoirs. Programs to reduce soil erosion and land degradation can provide cleaner water for these downstream reservoirs, an environmental service that should be compensated. In general, hydroelectric reservoirs are funded by taxpayers throughout the country. But the benefits such as energy supply and downstream irrigation services are realized by relatively small populations in the lower portions of these watersheds. Payment for Environmental service (PES) schemes could provide a more equitable distribution of these benefits by compensating the service providers in upstream watersheds (see also [5.3.2](#)).

Table 8. Key factors related to poverty and poverty-water linkages in the three Andes BFP sub-basins

Basin	Key Factors	Poverty-Water Linkages
Fúquene, Colombia	Rural non-farm income (RNFI) and employment (RNFE), livelihood diversification	Indirect linkages: Activities that reduce poverty create environmental problems; upstream/downstream interactions
Ambato, Ecuador	RNFI/RNFE, ownership of animals, education	The greater amount of land under irrigation, the lower the poverty; upstream/downstream interactions
Jequetepeque, Peru	RNFI/RNFE, market orientation, land tenure, education	Households with irrigation are more likely to escape poverty; upstream/downstream interactions

We then carried out Bayesian network modeling (see Appendix D.5 for methodological details) for two of the focus sub-basins (Ambato and Jequetepeque), to (a) compare the method with a similar analysis carried out for the CPWF Volta basin, and (b) simulate different scenarios, altering the values of factors that could be viewed as interventions, to observe the effect on poverty variables. Bayesian networks model the probabilistic relationships between variables. The nodes in the network represent indicators that are conditioned by the variables that are linked to them (father-son).

For the Ambato basin, the Bayesian analysis showed a significant relationship between poverty and irrigation, but other factors related to education were more important. This result that does not agree with other studies that showed a greater importance of irrigation and biophysical factors. For the Jequetepeque basin, on the other hand, results did show a strong (direct and significant) relationship with irrigation, where access to irrigation infrastructure correlates well with lower levels of poverty. This is in agreement with Gomez et al. (2005) as well as with our field visits to the basin. Education is a strong predictor of poverty outcomes in both basins, while irrigation may be important in certain niches, such as in the lower Jequetepeque basin. In Jequetepeque, however, the fact must be taken into account that large-scale irrigation schemes have already been developed in places with the highest potential (lower parts of the basin). Those areas most affected by poverty are also the ones that are only poorly suited for large-scale irrigation development, thus here small-scale irrigation schemes would need to be developed that are adapted to local conditions.

4.3.3. The effect of natural hazards

Recent climate change has highly increased the variability of climate in the region, there have been more frequent torrential rainfalls and more frequent and stronger occurrences of the El Niño and La Niña phenomena that have caused flooding and droughts (Lavell, 2008). As a consequence, countries in the Andean region have experienced a disproportionate number of disasters in recent years (Figure 26), with considerable negative social and economic impacts on humans and their livelihoods. Even greater losses are to be expected as climate change and extremes increase in the future.

Anecdotal evidence exists for the long and medium-term impacts of the 1997-98 El Niño event (one of the most severe) and assessments have been carried out at national, sectoral and provincial levels (Comunidad Andina, 2004). In particular, increasing economic losses have been associated with such hydro-meteorological events. A study of the health sector in Ecuador showed, for instance, that the cost of rehabilitating health facilities would amount to US\$3 million (MSP, 1999). Areas affected by El Niño experienced greater deterioration in household welfare and higher poverty headcount ratios than other regions of Ecuador, due to the severe reduction or total loss of crop yields caused by the increased incidence of droughts (Farrow et al., unpublished; Figure 6). Although not much scientific information is available, press accounts suggest significant and widespread effects and impacts of natural hazards on livelihoods in the Andes, including severe harvest losses (e.g., more than 65% fruit harvest loss in Ecuador due to reductions in irrigation water because of the 2002-03 drought; *El Comercio*, 2003a), and reductions in milk production (up to 50% in 2001/2002, and 20% in 2003 in Ecuador; *El Comercio*, 2003b,c).

Nevertheless, the greater part of the risks that are posed to communities could be attributed to vulnerabilities created by economic development models and demographic change in Andean countries. Where these factors have resulted in rural poverty, poverty contributes to the growth of disaster risk conditions by environmental degradation, occupation of unsafe sites, and the development or maintenance of environmentally inadequate or non-resilient livelihood options. Particularly the effect of unsustainable upstream development may have severe consequences for the whole basin. For example, upstream agricultural development leading to intensification leaves less land in fallow and contributes to soil erosion (Swinton and Quiroz, 2003). Upland soil erosion in turn is highly linked to siltation and increased flooding and threatens to degrade watersheds - including major lowland basins. The growth in off-farm employment has in some cases led to a decrease in labor-intensive soil conservation practices (Zimmerer, 1993).

Therefore, the impacts of natural hazards are multiplied when they are met by increased vulnerability of populations to these hazards.

4.4. Conclusions

In the Andean region, poverty is higher in the highlands compared to the coastal regions, and poverty levels are higher in the dry Bolivian and Peruvian Andes than in the humid Ecuadorian and Colombian Andes. Few general factors influencing poverty levels at a broad scale were identified for the Andes. The key ones in this regard are related to education - factors such as literacy, educational infrastructure, and attendance and completion rates in school. Generally, poverty seems to not be linked directly with water (although in Jequetepeque irrigation is a critical factor). The nature of poverty in the Andes is rather multi-faceted and associated with different variables, depending on the local geographical (biophysical), socio-economic, and political context. Education, lack of market access, land pressure, and land degradation issues have been shown to exacerbate poverty in the Andes region, whereas dairy, high-value crops (flowers, coffee, etc.), rural non-farm income and rural non-farm employment have proven to be poverty exit pathways in many cases.

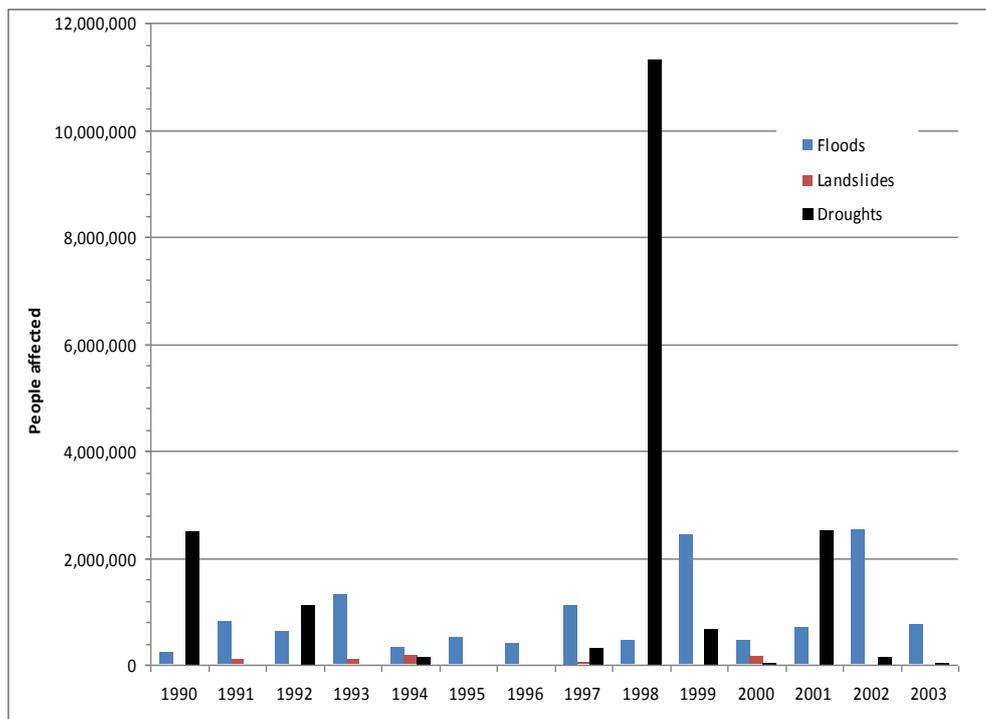


Figure 26. People affected by floods, landslides and droughts in the Latin American region from 1990 to 2003

The following key findings can be drawn from the case studies:

- 1) Relative to other places in the world, water scarcity is comparatively less of a problem in the rural Andes. There are areas where water scarcity does pose a problem (1.1.6), but these regions tend to be less populated.
- 2) Natural hazards (droughts and floods) are a major issue, especially in downstream valleys. Evidence for this condition comes from a growing literature on the effects of El Niño and La Niña in the region, which are increasing in frequency and intensity due to climate change.

- 3) Water access and (lack of) infrastructure are an issue in many regions of the Andes
- 4) Water productivity is an issue in upstream regions of watersheds. The combination of topographic conditions and lack of economic resources limits the opportunities for upstream populations to make more productive use of water. On the one hand, topographic conditions do not allow access to large-scale irrigation schemes such as those developed in conjunction with hydroelectric reservoirs in downstream areas. On the other hand, upstream regions are generally poorer and thus have fewer resources for investing in water productivity technologies.

Poverty issues in the Andes are complex and inter-linked, thus there is no “silver bullet” to address them all – solutions need to be multi-faceted, and interventions to address the above-mentioned poverty issues should bear in mind several recommendations.

They should distinguish between broad-scale interventions (education, health) and site-specific interventions such as water access and infrastructure. Education and health problems tend to be more widely dispersed throughout the region, whereas water related problems tend to be more local and regional.

The effect of better water management on poverty may be limited. Development professionals working on water related issues often view water management interventions as the solution to poverty problems. Our review of the literature and analysis of data suggests that water related interventions may have limited effects on poverty. A better approach may be to focus on water related problems in their own right.

Given the weak relationship between poverty and water in general, interventions should include *ex-ante* impact analyses before moving forward to implementation. There is a need to analyze how poverty and its associated factors influence problems related to water management on a case-by-case basis. Interventions should consider not only the effect of water problems on poverty, but also, how poverty exacerbates water problems.

Due to the lower living standards in the upstream portion of Andean basins, payment for environmental services (PES) schemes may have potential for improving water (and other natural resources) management. See section [5.2.2](#) (*Schemes for managing environmental services*) below for more details on the opportunities and limitations of this type of intervention.

5. Interventions

In this section we analyse potential interventions to address water, food and poverty issues in the Andean region.

- First, a review of previous interventions and lessons learnt on their impacts, opportunities, and limitations are presented.
- Second, we identify and characterize the most relevant technical and institutional interventions for the Andes region, based on our research and stakeholder consultations during this project.
- In the final conclusions and recommendations, we present key interventions for each of the four activity sectors in the Andean region, detailing why they are important for each sector, what is needed for their effective implementation, and where they should be targeted geographically.

5.1 Previous interventions in the region

We conducted an exhaustive assessment of significant interventions for water resource management in the Andean region over the past 10 years. The most relevant interventions in the three Andes BFP focus basins were analyzed qualitatively to (a) assess their impact on water productivity, poverty and the environment, (b) identify the most important factors of success or failure, and (c) develop recommendations for improvements of future interventions.

The resulting interventions database (see Appendix E.1) contains detailed descriptions of 55 water-related interventions, covering areas between 300,000 and 500,000 ha each. All projects address environmental issues related to water quality and quantity, with the general objective of improving the livelihoods of their direct beneficiaries – families and rural communities dedicated to agriculture. A subset of 11 projects (2 regional initiatives, and 3 projects in each of the three Andes BFP focus basins) that aimed specifically at improving water productivity and reducing poverty was selected for more detailed qualitative analysis. See Appendix E.1 for a list of the 11 selected projects and methodological details of the Community Capitals Framework (CCF; Flora and Flora, 2008) that was applied for impact evaluation.

Analysis of the 11 projects allowed us to identify (1) the biophysical, socio-economic and institutional context of the selected interventions, (2) key intervention strategies, and (3) impacts of the interventions on water productivity, poverty levels and the environment.

5.1.1. Intervention context

Project activities in the frame of these interventions were carried out at a variety of different (spatial) levels, from watershed to catchment, to community, and household level. Biophysical characteristics (natural capital) such as precipitation, hours of radiation, and soil fertility varied considerably between the three basins. For example, in Fúquene and Ambato the water and soil conditions are very favorable for crop and livestock production. In Jequetepeque in contrast, soil fertility is low and annual rainfall is far below the precipitation levels of the other two basins (500 to 1000 mm/yr in the upstream watershed and less than 200 mm/yr downstream). However environmental issues were a common feature in all three basins, the most significant ones being the degradation of water-providing mountain ecosystems (e.g., páramos), contamination of water courses with solid and liquid wastes, and overstocking of pastures leading to sedimentation and erosion problems.

Furthermore, we identified common patterns related to the interactions between different types of capital: a strong presence of interest groups (cultural capital) who take advantage of cultural and financial factors to promote the implementation and adoption of alternative production practices, favoring their own private interests. This pattern applied for example to the case of the rice mills owners in Jequetepeque (Peru), the potato producers in Fúquene (Colombia), and the indigenous people in Ambato (Ecuador).

5.1.2. Intervention strategies

We identified three principal groups of intervention strategies (Table 9). In those cases where strategies focused on the promotion and implementation of *institutional* or *technological* innovations, major efforts were directed towards strengthening capacities of the local beneficiaries, i.e. investments were made in social capital. In contrast in those cases where interventions prioritized *infrastructure investments* in physical (built) capital, no positive improvements of social capital were observed – even though projects had explicitly mentioned the

strengthening of local capacities as one of their main objectives. The majority of the interventions analysed promoted institutional or technological innovations. They had positive environmental and social impacts and contributed (indirectly) to reducing soil and water degradation and increased water availability, as well as (directly) to reducing poverty through increases in income.

5.1.3. Intervention impacts

The examples from the Fúquene and Ambato sub-basins showed that increases in natural capital stocks (e.g., water availability) can be achieved when continuity in intervention strategies is given, with projects and programs investing in social, cultural, political and human capitals – leading to positive long-term impacts in economic welfare of local beneficiaries.

In general, successful interventions require an appropriate planning process for defining the optimal implementation strategy. Consequently, for a positive intervention to be successfully replicated elsewhere, a careful analysis of and adaptation to local conditions is mandatory prior to implementation. The main factors that limited positive impacts on water productivity and poverty reduction in the three BFP Andes focus basins were a lack of institutional capacity to start or adapt to processes of innovation, low levels of education, and lack of trust among the different actors affected by interventions.

Table 9. Different intervention strategies identified in the three Andes BFP focus basins

Intervention type	Strategy
Technological innovations	Crops varieties
	Transfer of Irrigations and/or water harvesting Techniques
	Soil Management Techniques (Min tillage, conservation agriculture, Slope management)
Institutional innovations	Benefit Sharing mechanisms (e.g. PES, water and land allocation)
	Coordination mechanisms
Infrastructure investments	Natural resources management
	Hydropower
	Water storage/distribution
	Water treatment plants

Investments in technology and infrastructure therefore also need to consider strengthening of local capacities and adapting technologies or infrastructure to local conditions, otherwise there is a high risk that such interventions may fail to achieve their goals. For example, the PEJEZA project and the construction of the dam “Gallita Ciego” in Peru had positive impacts on agricultural production and hence income generation for farmers in the downstream Jequetepeque watershed. However, the projects did not result in increased agricultural water productivity

(kg/m³) nor reduced environmental degradation, even though these were explicitly formulated project goals.

5.2 Potential strategic interventions in the region

In addition to the insights derived from the literature review and data management, various key knowledge sharing activities helped guide the selection of potential strategic interventions. At the Andes BFP inception meeting in Lima, a group exercise was held with 20 stakeholders, who were asked to list three interventions that they considered to be a priority for reducing poverty and improving water productivity. The following six main issues emerged:

- Technology
- Education
- Inter-institutional coordination and institutional strengthening
- Changes in norms and policies
- Planning and community organization
- Information analysis and research

Additionally, a questionnaire was developed and sent to 80 regional stakeholders, concerning the scope and content of our Policy Support System to provide a clearer picture of the current needs and perspectives of actors working in and researching key sectors that are related to development processes within the Andes. This questionnaire also provided key information on the level of importance given to various issues such as the effects of soil erosion and access to water resources in watershed management by policy makers. One of the agreed main priorities in Andean watersheds was environmental degradation particularly soil erosion, with 44% saying that the effects of soil erosion on agricultural livelihoods should be considered more in the policy making process and 55% agreed that indeed this is a high priority for policy maker.

5.2.1. Technical interventions

Irrigation

One key area of public goods is infrastructure which includes rural roads, electrification, and water allocation and distribution systems for domestic use and irrigation. These serve the purpose of diversification and intensification activities in many areas. However, infrastructure provision must occur in the context of growth opportunities if it is to be effective. The availability of functioning irrigation infrastructure plays a fundamental role in increasing agricultural production and facilitating the process of diversification in Andean basins (Cremers et al., 2005). Primarily – despite declining terms of trade – there is still a significant number of producers engaged in smallholder agriculture and local demand for the crops they produce. Interventions that address the management and availability of irrigation would improve both food security at household level and supply to local and national markets (Gilot et al., 1997). Additionally, the prospects of income diversification into high-value crops requires appropriate irrigation infrastructure. Properly managed irrigation systems also reduce vulnerability to climatic risks such as droughts by increasing the availability of water. Poorly managed and inefficient irrigation systems play a major role in soil salinization and water erosion as well as agricultural runoff including chemicals from fertilizers and pesticides (Gilot et al., 1997). Badly managed irrigation systems can often be attributed to inadequate and poorly funded institutions, but another important factor is lack of education among communities with the sense of water being an abundant and cheap resource and an unwillingness to meet the high upfront costs for improved irrigation techniques.

Managing Risk

Institutional reforms are needed to improve the effectiveness of existing institutional initiatives for reducing disaster risks. There are a variety of development, educational, land use planning, and legal instruments that emphasise in different combinations (i) prevention and mitigation, (ii) preparedness and response, or (iii) resilience and recovery (Lavell, 2008).

In addition to institutional reforms that address institutional weaknesses, the private sector also has a potential role to play in small-scale community disaster risk reduction, for example in the creation of insurance and reinsurance markets, in education, and public information. Civil society also has not been sufficiently involved in the development of institutions for disaster prevention and relief and in reconstruction processes – despite the fact that it has been shown that the success of these processes requires the active participation of the communities in orientation, management, and control of the programs (Swinton and Quiroz, 2003).

Diversification and access to markets

There is a strong argument to suggest that an effective rural poverty alleviation strategy is to further facilitate and encourage rural populations to decrease production within smallholder agriculture in favor of higher-value agricultural commodities. Increasing production within this sector can lead to more availability of off-farm wage work in agriculture and eventually wage work in non-farm activities. Interventions of this nature also help to control the process of rural-urban migration, thus preventing excessive urban poverty (Rigg, 2006).

In order to facilitate the process of diversification it is necessary to invest in human, financial, and productive capital to ensure that the quality of processing, storage, distribution, and marketing of agricultural commodities are overhauled with appropriate technology in order to be able to compete with other regional producers. The establishment of technical and educational institutes in Andean rural areas would be instrumental in the development of a highly skilled labor force needed to adopt competitive modern production techniques (Rigg, 2006).

Undoubtedly uplands smallholders engaged in higher-value commodities such as dairy products are affected by lower profitability levels compared to coastal regions due to a lack of capital and technical know-how. A higher demand for milk could substantially improve the situation of upland regions when market access is granted. Since milk is a product with high market value – particularly when processed – milk production is a suitable economic strategy for upland regions to offset the negative marginalization effects of current globalization processes. The prospects for such a strategy are particularly good since global demand for livestock products is continuously growing, fueled by population growth and changes in consumer behavior – particularly in low income countries where raising incomes translate to growth of demand for livestock products. However, care has to be taken if slope lands and fragile hillsides are used for livestock systems. Relatively low labor and production costs of agricultural commodities such as dairy products and cut flowers in highland Andean regions produce ideal conditions for attracting investment alongside government development agency funds. Local processors are important partners as they have a strong interest in increasing production, market access, and competitiveness in their own region (Bernet et al., 2001).

5.2.2. Institutional interventions

There is particular need of developing a better understanding of the conflicting issues derived from the co-existence of local informal institutions (traditions, local agreements, etc.) with more formal and generalised institutions as expressed by national laws and local environmental regulations ([3.4.3](#)). The conciliation of these

two types of institutions will only be possible if accompanied by changes in structural conditions imposed by current status of international debts, land tenure, import and export market balance, and social unrest.

Macro-economic reforms

As mentioned above, the causes of poverty are often linked with global policies and economies that influence policy decisions at national levels. Specific macroeconomic policies – in particular unequal terms of trade, limited credit, and extreme inequalities in land tenure – are found to have fuel rural-urban migration and environmental problems (see introductory section).

Capacity building as a requirement for the integration between local government, academic sector, private sector, and NGOs

General institutional trends in Andean countries regarding agricultural water management have increasingly leaned towards the rhetoric of participation, decentralization and transferring management to local governments. A prerequisite for achieving this is to train human resources at different levels and instances (Boelens, 2002; Boelens et al., 2005). Only qualified people will successfully integrate themselves into participation and dialogue. Technical agencies should rely on well-trained people. Improving the capacity of personnel, technologies, and data is another area in which NGOs and the academic sector can make a major contribution in terms of financial capital and training. This will not only have a positive impact on water resource management, but also in disaster reductions. Well-informed people take better decisions.

As mentioned before, the participatory rhetoric is not easy to translate in concrete actions allowing stakeholders views to be inclusive or actionable. For this reason, more than participatory *per se*, we believe that the empowerment of different actors – in particular the marginalized – would serve as a way to facilitate or promote integration with better informed sectors. The developmental impacts of improving participatory mechanisms are significant. In terms of improving human development indicators affected by water access and water quality, local governments take action to solve the problems only if there is a group of well-organized people that exert political pressure. Since petitions backed by an organization stand a better chance of being heard by the local authorities, skilled water user associations are crucial to solve problems of this nature.

We recognize that municipalities in remote areas are often weak and may require strengthening of their financial, political, and administrative capacities to perform their role as promoters of development. The biggest hurdle here lies in reinforcing the financial capacities of municipalities, which are still dependant on contributions from external sources – especially the Central Governments, the Mining Canon, and multi- and bi-lateral donors. Unfortunately, local contributions are minimal when compared to external ones, which means that the quality of municipal financial capital is often relatively low and restricted.

Improving the administrative and bureaucratic capacities of small municipalities requires that different parties be involved, not solely state and official actors. In general, local financial infrastructure is best generated and strengthened alongside small-scale interventions such as the irrigation schemes suggested above. It has been found that smallscale producers are willing to invest in agricultural interventions where results look highly probable (see section [9](#)). Additionally, transfer of resources between sectors should be considered as an option of enhancing the local organizational capacity of governance institutions.

Transfer of resources between sectors

Financing interventions requires consideration of investment between sectors, particularly the private sector. Initiatives such as increasing access to irrigation, managing disaster risks, and facilitating the process of income diversification in Andean watersheds work most effectively when combined with small-scale private sector investment approaches. At the scale of Andean watersheds the term 'private sector' could include micro, small, and medium enterprises, technology manufacturers, dealers, distributors, and retailers, as well as non-governmental organizations, and parastatal and private sector entities that promote rural development in various ways (De Vries et al., 2005). An often overlooked aspect of the private sector are farmers in irrigated agriculture using their own financial resources. As IWMI observes "It is often not recognized that many poor smallholder farmers do have access to funds and are willing to invest in their agricultural enterprises if conditions are promising" (De Vries et al., 2005). Public sector actors such as government agencies and donors, also have an important role to play with respect to private sector investments. Primarily, the initial capital to establish the logistic mechanisms of private sector investment is needed. Additionally, there is a need to facilitate the investment process in a way that farmers and micro enterprises are encouraged to proceed. Facilitation includes training, demonstration, information centers, adequate legislation, setting up institutions to empower farmers and micro enterprises, quality control of agricultural inputs and produce, transfer of management of irrigation schemes to empowered farmers, arranging for credit schemes, etc.

Participatory and controlling mechanisms

Reforms are required to ensure more accountability, better integration with civil society, and independence of government structures. State interventions generally neglect the democratic involvement of user organizations. The reasons for this include a lack of adequate participatory methods and methodologies; vertical training of technical experts and social organizers; a need for short-term, tangible results; rigid institutional and budgetary planning by donors; and in some cases reluctance of local government authorities to relinquish control over water institutions (Boelens, 2002; Boelens et al., 2005). Corruption is a prevalent problem at all levels in official organizations.

Research and ongoing training programs for local and national policy making bodies would be effective in integrating cultural and gender considerations into participatory water resource management programs. While efforts have been made, it seems that not enough recognition is given to the fact that communities in highland villages often maintain a distinct culture from the more westernized town dwellers. Indigenous languages such as Quechua are often the main form of communication, with Spanish being spoken only by the younger educated men. This has traditionally led to a lack of opportunity to participate in civil and political spheres at a regional and national level (Jokisch, 2002). Techniques for technical and governance training should be constructed in a way that is not necessarily formal and written.

Schemes for managing environmental services

Compensation schemes for environmental services can provide inputs for specific eco-agricultural practices, especially in upstream areas of major dams thus avoiding downstream impacts of poor management. Such schemes have in theory three potential advantages: (a) access to finance sources not available otherwise for environmental management, (b) they may be sustainable if incentives are compatible with providers and service users, and (c) they are efficient if benefits

exceed the cost to service providers (World Bank, 2008). A particular case of the range of payments for environmental services (PES) schemes is represented by compensation for watershed services (CWS) (see [5.3.2](#)). Such schemes are expected to increase significantly due to growing water and energy demands.

Greater control over private sector water users in regards to water quality/access

In this context we define private sector water users as companies that supply demand from large urban centers, large agricultural producers, and the industrial, mining, and energy sectors. Inefficient disposal of domestic and human wastes, residues from mining operations, industrial wastes, chemicals used in agriculture, and wastes generated by livestock breeding have become important barriers to development in many Andean river basins.

While we acknowledge the difficulties that the need for foreign investment creates over control of the private sector, we also propose that it is possible to create alliances between private sector actors and local populations to increase corporate responsibility.

5.3 Conclusions and recommendations: Key interventions by activity sector

The literature review, data management, and a variety of stakeholder knowledge sharing activities helped guide the selection of the following key strategic interventions for each of the four activity sectors in the Andean region. They reflect the wide variety of causal factors of poverty in the Andes. Our recommendations point towards controlling the process of excessive rural-urban migration by improving farming conditions, employment opportunities, and access to water in remote rural areas.

The team recognizes that there are structural causes of poverty that can lead to site-specific conditions of water use and access, and serious attempts to reduce poverty need to address these. Interventions directed towards structural causes are challenging in the sense that they usually require political and economic changes, but could be tackled by means of institutional changes. In contrast, interventions addressing indirect causes are generally easier to implement, but their impact on poverty reduction may be constrained due to associated structural causes. These are useful considerations to keep in mind when putting regulatory frameworks and legislation in individual countries into perspective.

5.3.1. Broad-scale interventions

The key factors that drive development and are related to poverty throughout the Andes region are aspects related to education (e.g., sections 3.2.4, 3.3.2, and 4.4), and markets and policies (section Introduction 4.4). There are broad-scale issues that need to be addressed on national level by putting in place policy and institutional structures and mechanisms, including investment in rural areas and macro-economic reforms.

Another key regard for interventions around water management to have development impact is policy support. To tackle the complex issues around water management in a spatially detailed and spatially relevant way, we have developed the AguAAndes Policy Support System (PSS). The PSS looks at impacts on water supply and demand under different climate and land use changes, and allows users to examine the impacts of particular interventions on either alleviating or worsening the long-term water-production-poverty situation in a locally relevant way with few requirements for local capacity in order to achieve this. The PSS is described in detail in section [3.4.2](#).

5.3.2. High-value and low-productivity smallholder farming

The following key interventions were identified as relevant for both conventional – usually low-productivity – smallholder farming (mostly in upstream watersheds) and high-value agriculture (mostly downstream):

Matching crops to landscapes

The Andes are characterised by geographical, topographic and elevational heterogeneity. In the face of such variability land use and land management need to be tuned to local conditions. Thus, matching crop types more carefully to local conditions is an important component of achieving greater crop per drop. This is not always possible where market forces provide better incomes for unsustainable practices and high value export crops that may not suit local environmental conditions but do suit market access and labor conditions. In such cases, technological interventions (irrigation, dams, etc.) are often used to overcome environmental limitations, but in the long term such schemes can be environmentally or hydrologically unsustainable and susceptible to changing market conditions

Small-scale irrigation

The availability of functioning irrigation infrastructure plays a fundamental role in increasing agricultural production and facilitating the process of diversification in Andean basins. Properly managed irrigation systems adapted to local conditions have great potential to improve not only food security at household level and supply to local and national markets, but also to reduce vulnerability to climatic risks such as droughts by increasing the availability of water. However, in many cases where irrigation schemes are managed by local organizations or an alliance of grassroots organizations such as in Bolivia and Peru, administrative and financial problems often arise with unclear budgeting practices bringing the financial sustainability of these alliances into question and ambiguous roles between the institutions themselves (Lajaunie, 2008).

Provision of technical training to community organizations that manage irrigation schemes (such as the Comisiones de Regantes) would aid in their successful integration into local government structures. More investment in identifying effective participatory techniques is therefore needed when building irrigation systems. In addition, to avoid technical problems during implementation, it is critical to incorporate hydrological, topographical, and social information when designing such irrigation schemes.

Properly designed and managed small-scale irrigation schemes are especially promising in the Andean highlands, but also in southern Peru and Bolivia, where we identified a lack of quality irrigation infrastructure coupled with inappropriate institutional mechanisms to manage community irrigation systems.

Diversification and access to markets

Agricultural and income diversification plays a significant role in fighting poverty and environmental degradation, since alternative production opportunities help take pressure off of scarce and degraded agricultural inputs and natural resources.

To accelerate and intensify the scale of production of high-value agricultural commodities at local and regional level, an integrated approach is needed to increase small farm competitiveness, especially in the Andean uplands. Currently, the key limiting factors are a lack of infrastructure, lack of marketing and enterprise-development skills, and lack of access to information. To develop both

farm and non-farm wage work in Andean basins, the following components of an integrated market chain approach are instrumental (Bernet et al., 2001):

- Training of farmer groups in commercial management and administration techniques;
- Improved technologies for high value production;
- Reduced entry barriers for small enterprises, as well as the strengthening of enterprise associations;
- Facilitation or part financing of the development of rural market-related infrastructure such as rural road systems, communications services, and market facilities;
- Provision of incentives for relocation of agro-processing and other enterprises to rural areas – including training of personnel, establishment of effective saving systems and lending institutions, infrastructure provision, and technical support to contracted producers.

All Andean countries are currently undergoing a process of increasing income diversification. Therefore, interventions that increase the competitiveness of these sectors will be effective in all basins, particularly in the highland areas. Ecuador, Colombia, and Peru in particular have optimal conditions for the expansion of dairy production for domestic and international markets due to already developed dairy sectors and rapid urbanization that leads to increased demand.

CWS and other PES schemes for land management

Compensation schemes for the provision of ecosystem services can provide incentives for better agriculture and land use practices. The Andean region has much to offer in terms of environmental services thanks to its diversity and heterogeneity. A variety of payments for ecosystem services (PES) schemes are already being implemented in Andean countries and compensate land stewards for environmental services and functions such as carbon sequestration, biodiversity, or watershed services. The latter (also called CWS – compensation for watershed services – schemes) are especially relevant in the context of the BFP Andes since they can provide incentives for upstream land managers to facilitate careful land use and management with positive impacts on downstream water quantity, quality, and regulation – especially in areas facing water scarcity or growing water demands. They have the potential to reduce negative environmental impacts of unsustainable land management practices, while at the same time contributing to poverty alleviation because poverty in the Andes is usually higher in upstream watersheds than downstream. However, CWS schemes can only be developed where hydrological knowledge is good so that upstream providers of services to downstream consumers can be reliably identified and consumers see the value of rewarding upstream managers for careful land and water management.

In order for CWS (and other PES) schemes to achieve both positive environmental impacts and poverty alleviation goals, more research and improved science is required for the quantification of any potential watershed/ecosystem service benefits from better land management. Hydrological analyses should be integrated more closely with integrated water resource management assessments to support policy making processes, e.g. a more systemic analysis of water resources at the local level so that all existing water interventions – such as water diversions and polluting points – are accounted for in analysis. To legitimize this type of schemes and achieve sustainability, it is necessary to improve and clarify the information on property rights, reduce potential excessive transaction costs, and increase political will.

CWS schemes have most potential in tropical mountains that enjoy large extents of cloud forest and paramo, such as the Andes. They are particularly promising in

watersheds with dam operations, since agreements between local authorities and dam projects can use already established structures of dam projects for collecting payments, e.g. water utilities and energy companies (Sáenz and Mulligan, 2009). For instance, the three Andes BFP focus basins all are source areas for water in downstream hydroelectric reservoirs (see [4.3.2](#)). In essence, CWS schemes should be implemented where there is a lot to gain in dam performance improvements (e.g., where watershed management could mitigate sediment inputs that would otherwise threaten the operational life of the project), or where the supply of watershed services to the dams is most at risk (e.g., from land use or climate change). Champions of such schemes (in the Andes the big international conservation NGOs) need to be empowered with accurate, reliable and easy to manage tools that provide the best available information and science for defining robust and sustainable PES schemes.

5.3.3. Large-scale (irrigated) commercial agriculture

Large-scale agricultural production systems dedicated to commercial crops such as sugarcane, oil palm, soy, and rice are an important contributor to rural livelihoods, both in terms of employment opportunities and accessible prices of specific products. They are currently expanding in response to demand from increased population and rural-urban migration. However, they are also a heavy user of natural resources and mostly environmentally unsustainable.

Irrigation

Poorly managed and inefficient irrigation systems play a major role in soil salinization and water erosion, as well as agricultural runoff including chemicals from fertilizers and pesticides (particularly in rice production). As mentioned above, inadequate and poorly funded institutions are one of the principal reasons for badly managed irrigation systems. At present, institutional mechanisms managing irrigation infrastructures often act as a barrier to efficient and functioning systems, and irrigation management at a public sector governance level is often out-of-touch with the producers (Tinsley, 2004). Top-down construction and management styles of irrigation schemes frequently see irrigation engineers disregarding farmer inputs and ideas. For example in Peru, the creation of Autonomous Water Basin Authorities (IPOGRA) was either not implemented at all in many localities, or remained vertically-led without the capacity to participate with other sectors (Boelens et al., 2005).

To avoid these problems, well-defined legal frameworks defining sectoral policy regarding public investment in private irrigation systems are crucial, especially determining responsibility of operation and maintenance of public funded irrigation infrastructure. Furthermore – as above in the case of small-scale irrigation schemes – the incorporation of social, hydrological, and topographical information at the design-level of irrigation schemes would help prevent technical problems during implementation.

5.3.4. Urban centers, industry and mining

The following key interventions were identified as most promising for the urban and industrial sectors:

Regulation of emissions from mining and agriculture

Sharing the benefits of water is as much about regulating and reducing dis-benefits as about finding mechanisms to reward those upstream suppliers who manage resources well for the benefit of downstream users. A single upstream mining or agricultural operation can have considerable impacts on the water quantity, and

especially quality, for millions of downstream users. Since water at its points of consumption is the integral of all land management activities from the entire upstream area, careful regulation of single upstream activities that may influence downstream water quality significantly is critical.

Investment in water treatment capacity

As identified above ([2.2.3](#)), in the densely populated northern Andes the issue of water quality and human footprint on water quality may be more significant than water quantity (which is generally plentiful in the northern Andes). Threats to water quality originate mainly from human interventions in the upstream areas of watersheds, be they unsustainable agricultural practices or industry and mining activities. As laid out earlier, PES and CWS schemes have the potential to incentivise better land use practices and reduce negative downstream impacts. In addition to emission regulations and compensation schemes, investments in water treatment capacity are a key complementary intervention to mitigate any remaining impacts.

Risk and disaster management

The countries in the Andean sub-region are prone to disasters and natural hazards, and the frequency and intensity of these events are predicted to increase in the future (see sections [1.3.1](#) and [4.3.3](#)).

Methods to reduce community vulnerability to disaster risks are closely linked to other selected strategic interventions discussed above (e.g., [5.2.1](#)). For example, compensation schemes for environmental services provision are able to address issues of environmental degradation caused by poor land management practices, thus reducing disaster risks ([5.3.2](#)). This will particularly have a positive impact in the downstream areas of basins where there are no reservoirs upstream.

References

- Ahmad, M. and Giordano, M. 2008. *CPWF Project Report: Karkheh Basin Focal Project*. International Water Management Institute. 59.
- Anonymous. 2000. *Habr  escasez de agua potable*. Econom a Colombiana y Coyuntura Pol tica 208: 78-84.
- Arias, A., Almeida, M.A., and Segarra, P. 2005. *Mapeo participativo con las comunidades de Llangahua, Tambal , Castillo, Pucaucho y Estancia en la cuenca alta del r o Ambato*. Consorcio para el Desarrollo Sostenible de la Ecoregi n Andina (CONDESAN) - Red de Instituciones Vinculadas a la Capacitaci n en Econom a y Pol ticas Agr colas en Am rica Latina y el Caribe (REDCAPA) and Gesellschaft f r Technische Zusammenarbeit (GTZ). Quito, Ecuador.
- Bastidas, E.P. 1999. *Gender issues and women's participation in irrigated agriculture: The case of two private irrigation canals in Carchi, Ecuador*. Research Report 31. Colombo, Sri Lanka: International Water Management Institute.
- Bebbington, A. 2001. *Globalized Andes? Livelihoods, landscapes and development*. *Ecumene: A Journal of Cultural Geography* 8(4): 414-436.
- Beccar, L., Boelens, R., and Hoogendam, P. 2002. *Water rights and collective action in community irrigation*. In: *Water Rights and Empowerment*, R. Boelens and P. Hoogendam (eds), pp. 1-21. Assen: Van Gorcum.
- Berdegue, J., Ramirez, E., and Reardon, T. 2001. *Rural non-farm employment and incomes in Chile*. *World Development* 29(3): 411-425.
- Bernet, T., Staal, S., and Walker, T. 2001. *Changing Milk Production Trends in Peru: Small-Scale Highland Farming Versus Coastal Agrobusiness*. *Mountain Research and Development* 21(3): 268-275.
- BFP (Basin Focal Project). 2008. *BASIN FOCAL PROJECT: Yellow River Annual Report*: 1-20.
- Boelens, R. 2002. *Water rights and participatory irrigation development: the case of Licto, Ecuador*. *Wageningen University*. Paper based on the author's article in: *Law and Anthropology*, forthcoming in 2005; and chapter 7 of the book: *Water Rights and Empowerment*. 2002. R. Boelens and P. Hoogendam, Van Gorcum, Assen, The Netherlands.
- Boelens, R. and Zwarteveen, M. 2002. *Gender dimension of water control in Andean irrigation*. In: *Water Rights and Empowerment*, R. Boelens and P. Hoogendam (eds), pp. 75-109. Van Gorcum, Assen.
- Boelens, R. and Zwarteveen, M. 2003. *The politics of Andean water policy reforms. Local indigenous rights in the context of privatization policies*. *Journal f r Entwicklungspolitik* 19(4):56-75.
- Boelens, R., Dourojeanni, A., and Hoogendam, P. 2005. *Improving water allocation for user communities and platforms in the Andes*. In: *Water Rights Reform*: Bruns, B., Ringler, C., and Meinzen-Dick, R. (eds.). International Food Policy Research Institute (IFPRI). Washington, DC.

Bruns, B., Ringle, C., and Meinzen-Dick, R. 2005. *Water Rights Reform: Lessons for Institutional Design*. International Food Policy Research Institute (IFPRI). Washington, DC.

Candelo, C. 2005. *Fortalecimiento de Capacidades: Oportunidad para el Cambio Social. La experiencia de las piangueras en Nariño (Colombia)*. Presented at the International Seminar: "Enfoques y Perspectivas de la Enseñanza del Desarrollo Rural, Maestría en Desarrollo Rural 25 Años". Pontificia Universidad Javeriana, Bogotá, August 31 to September 02, 2005. Bogotá, Colombia.

Cantillo, L. and González, J. 2008. *Sistematización del conversatorio de acción ciudadana (CAC) de la cuenca de la laguna de Fúquene. Cundinamarca y Boyacá, Colombia*. Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN). Lima, Peru.

CAR (Corporación Autónoma Regional de Cundinamarca). 2006. *Diagnóstico prospectiva y formulación de la cuenca hidrográfica de los ríos Ubaté y Suárez. Plan de Ordenamiento de la Cuenca de los Ríos Ubaté y Suárez*. Bogotá D.C.

Chapalbay, W., Cordero, D., Gómez, L.I., and Ravnborg, H.M. 2007. *Pobreza, agua y tierra en Ambato, Ecuador: perfil de pobreza y el acceso y manejo de agua y tierra en la cuenca de Ambato, Ecuador*. Copenhagen, Denmark, Danish Institute for International Studies: 1-46.

Chomitz, K.M., Buys, P., and Thomas, T.S. 2005. *Quantifying the rural-urban gradient in Latin America and the Caribbean*. World Bank Policy Research Working Paper 3634. 36.

CIESIN (Center for International Earth Science Information Network). 2002. *Country-level GDP and Downscaled Projections based on the A1, A2, B1, and B2 Marker Scenarios, 1990-2100, [digital version]*. CIESIN, Columbia University. Palisades, NY. Available at: www.ciesin.columbia.edu/datasets/downscaled.

CIESIN (Center for International Earth Science Information Network), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT), 2004. *Gridded Population of the World (GPW), Version 3*. Palisades, NY: Columbia University. Available at <http://beta.sedac.ciesin.columbia.edu/gpw>.

CIESIN (Center for International Earth Science Information Network). 2005. *Gridded Population of the World Version 3 (GPWv3): Population Density Grids*. CIESIN, Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). Socioeconomic Data and Applications Center (SEDAC), Columbia University. Palisades, NY. Available at: <http://sedac.ciesin.columbia.edu/gpw>.

CIESIN (Center for International Earth Science Information Network). 2008. *Global Rural-Urban Mapping Project (GRUMP), Alpha Version: Urban Extents*. CIESIN, Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, NY. Available at: <http://sedac.ciesin.columbia.edu/gpw>.

CIP (Centro Internacional de la Papa). 2007. *Gestión Integral de Cuencas. La experiencia del Proyecto Regional Cuencas Andinas*. Lima, Perú.

Clanet, J. and Ogilvie A. 2008. *Basin Focal Project NIGER: Annual Report 2008*.

- CONELEC (Consejo Nacional de Electricidad del Ecuador). 2009. *Estadísticas [Online]*. Available at: www.conelec.gov.ec/
- Comunidad Andina 2004. *Andean Strategy for Disaster Prevention and Relief*. Presentation given by the Andean Council of Ministers of Foreign Affairs. Quito, Ecuador.
- COVENPRE (Comité Venezolano de Grandes Presas). 2009. *Grandes Presas de Venezuela*. Comité Venezolano de Grandes Presas, Caracas Venezuela.
- Cremers, L., Ooijevaar, M., and Boelens, R. 2005. *Institutional reform in the Andean irrigation sector: Enabling policies for strengthening local rights and water management*. United Nations. Blackwell Publishing. Malden, MA, USA. Available at: www.iwe.wur.nl/NR/rdonlyres/99C9EEC8-2FF6-4117-8837-FC2C1095AC78/87647/18NatResFrCremersOoijevaarBoelens2006.pdf
- De Vries, F., Hilmy, S., and Inocencio, A. 2005. *Opportunities for private sector participation in agricultural water development and management*. IWMI Working Paper No. H038088. International Water Management Institute (IWMI). Colombia, Sri Lanka.
- Deininger, K. and Olinto, P. 2001. *Rural non-farm employment and income diversification in Colombia*. World Development 29(3): 455-465.
- Dirven, M. 2004. *Rural non-farm employment and rural diversity in Latin America*. Comisión Económica para América Latina y el Caribe (CEPAL). Review 83:47-66.
- Dourojeanni, A., Jouravlev, A., Chávez, G. 2002. *Gestión del agua a nivel de cuencas: teoría y práctica*. Serie Recursos Naturales e Infraestructura. Series 48. Santiago de Chile. Comisión Económica para América Latina y el Caribe (CEPAL). United Nations.
- Echavarría, M. 2002. *Water user associations in the Cauca Valley, Colombia: A voluntary mechanism to promote upstream-downstream cooperation in the protection of rural watersheds*. Land-Water Linkages in Rural Watersheds Case Study Series, Food and Agriculture Organization of the United Nations (FAO). Rome, Italy.
- Eggertsson, T. 1996. *A note on the economics of institutions*. In: Alston, L.J., Eggertsson, T., North, D.C. (eds.). *Empirical Studies in Institutional Change*, Cambridge, MA. 6-21.
- El Comercio. 2003a. *En la Sierra centro cae la producción de frutas*. [Fruit production falls in the Central Sierra]. Periódico El Comercio. Quito, Ecuador.
- El Comercio. 2003b. *Los ganaderos afectados en la producción láctea*. [Ranchers affected by milk production]. Periódico El Comercio. Quito, Ecuador.
- El Comercio. 2003c. *150,000 ha de pastizales se dañaron en tres cantones* [150,000 ha of pastures damaged in three cantons]. Periódico El Comercio. Quito, Ecuador.
- Escobal, J. 2001. *The determinants of non-farm income diversification in rural Peru*. World Development 29(3): 497-508.
- Falkenmark, M. and Widstrand, C. 1992. *Population and water resources: A delicate balance*. Population Bulletin 47(3): 1-36.

FAO (Food and Agriculture Organization of the United Nations). 2003. *Aquaculture: Key terms and concepts*. Rome, Italy. FAO. Available at: www.fao.org/english/newsroom/focus/2003/aquaculture-defs.htm.

Farrow, A., Larrea, C., Hyman, G., and Lema, G. 2005. *Exploring the spatial variation of food poverty in Ecuador*. Available at: <http://gisweb.ciat.cgiar.org/povertymapping/download/Ecuador.pdf>

FONAFIFO (Fondo Nacional de Financiamiento Forestal) 2004. *Pago de Servicios Ambientales, Costa Rica [Online]*. Available at: www.fonafifo.com/paginas_espanol/servicios_ambientales/servicios_ambientales.htm

Fotheringham, A.S., Brunson, C., and Charlton, M. 2002. *Geographically Weighted Regression: The analysis of spatially varying relationships*. John Wiley & Sons. Chichester, UK.

Fotheringham, A.S., Brunson, C., and Charlton, M. 2004. *GWR 3: Software for geographically weighted regression*. University of Newcastle-upon-Tyne.

Fraser, B. 2009. *Glaciers go, leaving drought, conflict and tension in Andes*. The Daily Climate. Charlottesville, VA. Posted May 20, 2009. Available at: www.dailyclimate.org/tdc-newsroom/2009/05/glaciers-go-leaving-drought-conflict-and-tension

Ghosh, M. and Rao, J.N.K. 1994. *Small area estimation: an appraisal*. Statistical Science 9: 55-93.

Girón, E. 2003. *Andes Basin Profile: Jequetepeque River Basin*. Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN). Lima, Peru.

Gilot, L., Calvez, R., Le Goulven, P. and Thierry, R. 1997. *Evaluating water delivery in tertiary units Part 2: A case study, Urcuqui, a farmer-managed irrigation system in the Andes*. Agricultural Water Management 32: 163-179.

Gleick, P. 1996. *Basic water requirements for human activities: Meeting basic needs*. Water International 21(2): 83-92.

Gómez, L.I., Raben, K., Ravnborg, H.M., and Rodríguez, D. 2005. *Pobreza, agua y tierra en Jequetepeque, Perú: Perfil de pobreza y el acceso y manejo del agua y de la tierra en la parte alta de la cuenca de Jequetepeque, Perú*. Danish Institute for International Studies (DIIS) Working Paper (14): 1-50.

Guaman, C., Galárraga, R., Cruz, A., Abraham, E., Salomón, M. 2005. *Indicadores de uso del agua en una zona seca de los andes centrales del Ecuador. Estudio de la cuenca del río Ambato*. V Foro Centroamericano y del Caribe de Cuenas Hidrográficas. "Desarrollo de Cuenas Hidrográficas". Available at: www.asicprimerazona.com.ar/asic/publicaciones/indic_uso_agua_zona_seca_ecuador_rio_ambato.pdf

Hardin, G. 1968. *The tragedy of the commons*. Science 162: 1243-1248.

Hearn, P.Jr., Hare, T., Schruben, P., Sherrill, D., LaMar, C., and Tsushima, P. 2003. *Global GIS - Global Coverage*. 1st edition. DVD.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. 2005. *Very high resolution interpolated climate surfaces for global land areas*. *International Journal of Climatology* 25: 1965-1978.

Hodgson, G.M. 2006. *What are institutions?* *Journal of Economics Issues* 40(1): 1-25.

Holman, F., Rivas, L., Carulla, J., Rivera, B., Giraldo, L.A., Guzman, S., Martinez, M., Medina, A., and Farrow, A. 2003. *Evolution of milk production systems in tropical Latin America and its interrelationship with markets: An analysis of the Colombian case*. *Livestock Research for Rural Development* 15(9). Available at: www.lrrd.org/lrrd15/9/holm159.htm.

Ibañez A.M. and Querubin, P. 2004. *Desplazamiento forzoso, conflicto armado, acceso a tierras, deseo de retorno y migración*. Documento CEDE 2004-23, Universidad de Los Andes. Bogotá, Colombia. 114.

ICOLD (International Commission on Large Dams). 2003. *World Register of Dams*. Paris, France. 340.

INEI (Instituto Nacional de Estadística e Informática). 2007. *XI Censo de población y VI de vivienda*. Available at: www.inei.gob.pe/.

INGETEC (Ingenieros Consultores Civiles y Eléctricos S.A.). 2004. *Hydropower projects [Online]*. Available at: www.ingetec.com.co/experiencia-ingles/textos-proyectos-ingles/proyecto-hidroelectricos-ingles/guavio-ingles.htm

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Pachauri, R.K. and Reisinger, A. (Eds.). Geneva, Switzerland. IPCC.

Jadán, S 1999. *Experiencias en la cuenca hidrográfica del río Ambato*. Seminario Taller Internacional sobre Desarrollo Sostenible en Zonas de Montaña en América Latina. México D.F. Textos de las ponencias de países miembros de la Red Latinoamericana de Cooperación Técnica en manejo de cuencas de Cuencas Hidrográficas (REDLACH). Querétaro, México.

Johnson, N., García, J., Rubiano, J., Quintero, M., Estrada, R., Mwangi, E., Moreno, A., Peralta, A., and Granados, S. 2009. *Watershed management and poverty alleviation in the Colombian Andes*. *Water Alternatives* 2(1): 34-52.

Jokisch, B. 2002. *Migration and agricultural change: The case of smallholder agriculture in Highland Ecuador*. *Human Ecology* 30(4): 523-550.

Katz, E. 2003. *Is there a feminization of agriculture?* In: *Current and Emerging Issues for Economic Analysis and Policy Research*. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy.

Kirby, M., Krittasudthacheewa, C., Mainuddin, M., Kemp-Benedict, E., Swartz, C., and de la Rosa, E. 2008. *Mekong Basin Focal Project: Draft Final Report*. Australian Commonwealth Scientific and Research Organization (CSIRO). Canberra, Australia.

Lajaunie. 2008. *Appraisal document of Peru Sierra Irrigation Modernization Project, Peru*. World Bank. Washington, DC.

LandScan™ Global Population Database. 2002. Oak Ridge National Laboratory. Oak Ridge, TN, USA. Available at: www.ornl.gov/landscan/

LandScan™ Global Population Database. 2007. Oak Ridge National Laboratory. Oak Ridge, TN, USA. Available at: www.ornl.gov/landscan/

Lavell, A. 2008. *Relationships between Local and Community Disaster Risk Management & Poverty Reduction: A Preliminary Exploration*. A Contribution to the 2009 International Strategy for Disaster Reduction (ISDR) Global Assessment Report on Disaster Risk Reduction.

Lehner, B., Verdin, K., Jarvis, A. 2008. *New global hydrography derived from spaceborne elevation data*. Transactions, AGU, 89(10): 93-94.

Lemoalle, J. 2008. *CPWF Project Report: Basin Focal Project Volta*. Institut de Recherche pour le Developement (IRD). Montpellier, France. 65.

López, F. and Girón, E. 2007. *E. Pago por servicios ambientales para generar una nueva dinámica de desarrollo rural en los Andes*. Análisis biofísico (Modelo SWAT). Parte 1. Cajamarca, Perú.

Maldonado, R. and Kosmus, M. 2003. *El Pago por Servicios Ambientales (PSA): Una alternativa para disponer de agua en cantidad y calidad*. Tungurahua, Ecuador. III Congreso Latinoamericano de Manejo de Cuencas Hidrográficas. Arequipa, Perú.

MAVDT (Ministerio de Ambiente, Vivienda y Desarrollo Territorial). 2006. *Estrategia para el manejo ambiental de la cuenca Ubaté – Suarez*. Ministerio de Agricultura y Desarrollo Rural (MADR); Ministerio del Interior y Justicia, Dirección de Prevención y Atención de Desastres; Ministerio de Minas y Energía (MME); Corporación Autónoma Regional de Cundinamarca (CAR); and Departamento Nacional de Planeación (DDUPA, DDRS, DIES). Documento CONPES 3451. Available at: www.dnp.gov.co/archivos/documentos/Subdireccion_Conpes/3451.pdf

MEM (Ministerio de Energía y Minas del Perú). 2008. *Anuario Estadístico de Electricidad [Online]*. Available at: www.minem.gob.pe/minem/archivos/file/Electricidad/promocion%20electrica/anuarios%20estadisticos/anuario2008/Presentaci%C3%B3n.pdf

MHE (Ministerio de Hidrocarburos y Energía de Bolivia). 2007. *Balance energético nacional [Online]*. Available at: http://hidrocarburos.gov.bo/sitio/index.php?option=com_docman&Itemid=72

Milligan, G.W. and Cooper, M.C. 1984. *An examination of procedures for determining the number of clusters in a dataset*. Psychometrika 50: 159-179.

Molligan, P. 2003. *On the Waterfront – Water distribution, technology and agrarian change in South Indian canal irrigation systems*. Oriented Longman Private. New Delhi.

Mulligan, M. 2006a. *Global Gridded 1 km TRMM Rainfall Climatology and Derivatives. Version 1.0*. Database 2006a.: www.ambiotek.com/1kmrainfall

Mulligan, M. 2006b. *MODIS MOD35 pan-tropical cloud climatology. Version 1*. September 2006. www.ambiotek.com/clouds

- Mulligan, M. 2009. *SimTerra: A consistent tiled database of global coverage environmental raster datasets for environmental modeling* www.ambiotek.com/simterra
- Mulligan, M. and Burke, S.M. 2005. *FIESTA: Fog Interception for the Enhancement of Streamflow in Tropical Areas*, 174 pp.) www.ambiotek.com/fiesta
- NMFS (National Marine Fisheries Service). 2002. *National Marine Fisheries Service. (Online)*. Available at: www.st.nmfs.noaa.gov/st1/fus/current/09_percapita2002.pdf
- North, D.C. 1990. *Institutions, institutional change, and economic performance*. Cambridge University Press, Cambridge, MA.
- Olivera, O. 2004. *iCochabamba!: Water war in Bolivia*. In collaboration with Tom Lewis. South End Press. Cambridge, MA.
- Oré, M.T., Castillo, P. 2009. *¿Quién es Quién en el Agua? Directorio de instituciones de Bolivia, Ecuador y Perú*. Oxfam and IEP, Lima, Peru.
- Otero, W. and Quintero, M. 2006. *Mecanismo de financiación para promover agricultura de conservación con pequeños productores de la cuenca de la laguna de Fúquene. Su diseño, aplicación y beneficios*. Proyecto Regional Cuencas Andinas, CIP/ GTZ. Lima, Perú.
- Poats, S. 2006. *Report on the Latin American Regional Workshop on Compensation for Environmental Services and Poverty Alleviation in Latin America*. World Agroforestry Center (ICRAF). Nairobi, Kenya.
- Proaño, M. and Poats, S. 2000. *Abundancia o Escasez? Concesiones, conflictos y políticas en el manejo del agua en la cuenca del Río El Angel, Carchi-Ecuador*. Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN). Lima, Peru.
- Raben, K. 2007. *Access to water and payment for environmental services, Jequetepeque watershed, Perú*. Danish Institute for International Studies (DIIS) Working Paper No. 10. 27.
- Radcliffe, S. 1990. *Between Hearth and Labor Market: The Recruitment of Peasant Women in the Andes*. *International Migration Review* 24(2): 229-249.
- Ramankutty, N.A., Evan, T., Monfreda, C., Foley, J.A. 2008. *Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000*. *Global Biogeochemical Cycles* 22: 1-19.
- Reardon, T. and Berdegue, J. 2001. *Rural non-farm employment and incomes in Latin America: Overview and policy implications*. *World Development* 29(3): 395-409.
- Restrepo, C. and Vermillion, D. 1998. *Impacts of Colombia's current irrigation management transfer program*. International Irrigation Management Institute (IIMI). Canada.
- Rigg, J. 2006. *Land, farming, livelihoods, and poverty: rethinking the links in the rural South*. *World Development* 34(1): 180-202.

Rodríguez, J. and Busso, G. 2009. *Migración interna y desarrollo en América Latina entre 1980 y 2005. Un estudio comparativo con perspectiva regional basado en siete países*. Comisión Económica para América Latina y el Caribe (CEPAL). Available at: www.eclac.org/cgi-bin/getProd.asp?xml=/publicaciones/xml/6/36526/P36526.xml&xsl=/celade/tpl/p9f.xsl&base=/celade/tpl/top-bottom_minterna.xslt

Rodríguez, F., Southgate, D., and Haab, T. 2009. *Is better drinking water valued in the Latin American countryside? Some evidence from Cotacachi, Ecuador*. *Water International* 34(3): 325-334.

Rushton, J. and Viscarra, R. 2006. *Productive strategies for poor rural households to participate successfully in global economic processes: Country Report for Bolivia, Central Andes*. Overseas Development Institute (ODI). London, UK. 53.

Sáenz, L. 2009. *Understanding the impact of conservation of cloudforests on water inputs to dams in the tropics*. PhD Thesis – Upgrade report. King's College, London, UK.

Sáenz, L.L. and Mulligan, M. 2009. *Development and validation of a georeferenced tropics-wide database of dams*. Submitted to Water Resources Research.

Sagara, A.D. and Najam, A. 1998. *The human development index: A critical review*. *Ecological Economics* 25(3): 249-264.

Saleth, R.M. and Dinar, A. 2004. *The institutional economics of water: A cross-country analysis of institutions and performance*. World Bank, Washington, DC, and Edward Elgar, Cheltenham, UK, Northampton, MA.

Schuschny, A.R. and Gallopin, G. 2004. *La distribución espacial de la pobreza en relación a los sistemas de ambientales en América Latina*. Comisión Económica para América Latina y el Caribe (CEPAL). Serie Medio Ambiente y Desarrollo No. 87. United Nations. Santiago de Chile, Chile.

Sharma, B. 2008. *Basin Focal Project, Indo-Gangetic Basin: Annual Report 2008*. International Water Management Institute: 1-24.

Siebert, S., Döll, P., Feick, S., Frenken, K., and Hoogeveen, J. 2007. *Global map of irrigation areas version 4.0.1*. University of Frankfurt (Main), Germany, and FAO, Rome, Italy.

SIEL (Sistema de Información Eléctrica Colombiana). 2009. [Online] Available at: www.siel.gov.co/

Swinton, S. and Quiroz, R. 2003. *Is poverty to blame for soil, pasture and forest degradation in Peru's Altiplano?* *World Development* 31(1): 903-1919.

Tinsley, R. 2004. *Developing smallholder agriculture: A global perspective*. AgBé Publishing. Brussels, Belgium.

UN (United Nations). 2007. *Panorama de la Población Mundial, revisión 2006*. Edición en CD-ROM - Base de datos en formatos Excel y ASCII (Publicaciones de Naciones Unidas, ST/ESA/SER.A/266).

UNIVALLE 2005. *Una visión a la problemática del distrito de riego Roldadillo - La Unión - Toro: RUT (Documento Preliminar)*. Instituto UNESCO IHE-ASORUT. Cali, Colombia.

Urrutia N. 2006. *Sustainable management after irrigation system transfer: Experiences in Colombia: The RUT irrigation district*. PhD Thesis. UNESCO-IHE Institute for Water Education, The Netherlands.

USAID (United States Agency for International Development). and ARD, Inc. 2008. *Global Land Tenure Master Database*. 2007

WDPA (World Database on Protected Areas) Consortium. 2007. *Annual Release 2007 (web download version)*. Copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Center (UNEP-WCMC). Source for this dataset was the Global Land Cover Facility.

WHO (World Health Organization). 2008. *Progress in Drinking Water and Sanitation: Special Focus on Sanitation*. World Health Organization and United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation (WHO/UNICEF-JMP). UNICEF, New York and WHO, Geneva.

Whitaker, M.D. 1992. *El rol de la agricultura en el desarrollo económico del Ecuador*. IDEA. Quito, Ecuador.

World Bank. 2007. *World Development Report 2008: Agriculture for Development*. The World Bank. Washington, DC.

Zimmerer, K. 1993. *Soil erosion and labor shortages in the Andes with special reference to Bolivia, 1953-9 1: Implications for "Conservation-With-Development"* World Development 21(10): 1659-1675.