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OCCASIONAL PAPER SERIES

Climate Change Impacts on Water Resources and Adaptation in the Rural Water Supply and Sanitation Sector in Nicaragua

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The Environment and Water Resources Occasional Paper Series was developed under the direction of Karin Kemper, Sector Manager for Environment and Water Resources in the Latin America and Caribbean Region (LCSEN) of the World Bank. The publications in this Series were designed and produced by GRC Direct under the supervision of Emilia Battaglini and Rachel Pasternack (LCSEN).

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Environment and Water Resources LCSEN Occasional Paper Series

Foreword

The Latin America and Caribbean (LAC) region has a unique mix of qualities and challenges when it comes to the environment. It is exceptionally endowed with natural assets, with globally significant biodiversity and valuable crops, and also harbors the world's greatest carbon sink in the Amazon. At the same time, however, the region registers the highest rates of urbanization in the developing world with pollution, overuse of its water and natural resources and detrimental impacts on the health of people, especially the poor, and the environment.

Over the past twenty years, the LAC region has made impressive gains in tackling these issues. It leads the developing world in biodiversity conservation and natural resource management and is at the forefront in reducing urban pollution. The World Bank has often been the partner of choice for those countries in the region that have had the initiative to pioneer innovative policies for environmental protection and natural resource management, strengthen institutions responsible for environmental management, enhance environmental sustainability, and introduce new approaches to water resources management. Such initiatives include fuel and air quality standards in Peru, carbon emission reduction in Mexico, payment for ecosystem services in Costa Rica, participatory and integrated water resources management in Brazil, and new approaches to irrigation management in Mexico.

The *Environment & Water Resources Occasional Paper Series*, is a publication of the Environment and Water Resources Unit (LCSEN) of the Sustainable Development Department in the World Bank's Latin America and the Caribbean Region. The purpose of the series is to contribute to the global knowledge exchange on innovation in environmental and water resources management and the pursuit of greener and more inclusive growth. The papers seek to bring to a broader public – decision makers, development practitioners, academics and other partners - lessons learned from World Bank-financed projects, technical assistance and other knowledge activities jointly undertaken with our partners. The series addresses issues relevant to the region's environmental sustainability agenda from water resources management to environmental health, natural resource management, biodiversity conservation, environmental policy, pollution management, environmental institutions and governance, ecosystem services, environmental financing, irrigation and climate change and their linkages to development and growth.

In this particular paper, we present to you the case of climate change adaptation in the water supply and sanitation sector in Nicaragua, and a broader analysis of the past trends and future projections of climate impacts on water resources. The paper highlights the expected significant effect on the water balance as an outcome of the expected changes in temperatures, precipitation, and the hydrological variables, broadly consistent with the historic trends in Nicaragua. Many options to reduce the resulting climate vulnerability in domestic water supply and sanitation sector are "no regrets" measures, such as improving the efficiency of water distribution systems and

institutional strengthening at the national and local levels, while others might only be justified in the climate change scenario. Most of the conclusions from this analysis in the case of Nicaragua are applicable to other Latin American & Caribbean countries with similarly high levels of vulnerability to climate change and natural disasters.

We hope that this paper, just as the entire series, will make a contribution to knowledge sharing within the LAC Region and globally.

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Acronyms, Abbreviations and Symbols

ºC: Degree Celsius

BCM: Billion cubic meters

BNPP: Bank-Netherlands Partnership Program

C$: Cordoba (local currency)

CAP: Water and Sanitation Committee (for its acronym in Spanish – *Comité de Agua y Saneamiento*)

CCAD: *Comisión Centroamericana de Ambiente y Desarrollo*

ECLAC: Economic Commission for Latin America and the Caribbean

ENSO: El Nino Southern Oscillation

ESMAP: Energy Sector Management Assistance Program

GCM: Global Circulation Model

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GNI: Gross National Income

INETER: Nicaraguan Institute of Territorial Studies (for its acronym in Spanish - *Instituto Nicaragüense de Estudios Territoriales*)

INIDE: National Institute of Information for Development (for its acronym in Spanish – *Instituto Nacional de Información para el Desarrollo*)

IPCC: Intergovernmental Panel on Climate Change

Km^2: Kilometer square

m^3/capita/year: Cubic meters per capita per year

MARENA: Ministry of Environment and Natural Resources (for its acronym in Spanish – *Ministerio de Ambiente y Recursos Naturales*)

MW: Mega-watts

NCCS: National Climate Change Strategy

Nuevo FISE: New Emergency Social Investment Fund (for its acronym in Spanish – *Nuevo Fondo de Inversión Social de Emergencia*)

RAAN: Northern Atlantic Autonomous Region (for its acronym in Spanish – *Región Autónoma del Atlántico Norte*)

SICA: Central America Integration System (for its acronym in Spanish - *Sistema de la Integración Centroamericana*)

TWINLATIN: Twinning Europe and Latin America River Basins for Research Enabling Sustainable Water Resources Management Project

UNDP: United Nations Development Program – *Programa de las Naciones Unidas para el Desarrollo*

UNFCCC: United Nations Framework Convention on Climate Change

Climate Change Impacts on Water Resources and Adaptation in the Rural Water Supply and Sanitation Sector in Nicaragua

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The authors wish to thank Roberto Araquistain Vice Minister of Environment, Ministry of Environment and Natural Resources of Nicaragua, Suyen Pérez General Director for Climate Change, Ministry of Environment and Natural Resources of Nicaragua and participants of the June 2012 technical workshop from the Ministry of Environment and Natural Resources, the National Water Authority and the Emergency Social Investment Fund for helpful comments during the discussion of the study's results. The authors would also like to acknowledge the editorial support provided by Janice Molina and the translation services from English into Spanish provided by Camila Sepúlveda Taulis.

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Executive Summary

Climate change is at the top of the development agenda in Central America. This region, together with the Caribbean, is highly vulnerable to the effects of climate change in Latin America. Climate change is manifesting itself through higher average temperatures and more frequent droughts that result in higher water stress, and through the rising frequency of extreme weather events such as tropical storms, hurricanes, floods and landslides, all of which pose significant challenges in the rural water supply and sanitation sector.

The paper starts with a review of the historic data on temperature and precipitation trends in Central America and particularly at the regional level in Nicaragua. The data reveal a clear trend of the growing climate variability, increased water stress for crops, and greater frequency of extreme weather events. The rising intensity and frequency of extreme weather events is among the most critical risks to the region's development agenda, and they translate into high economic losses. A review of the earlier efforts to assess the impact of climate variability and the expected effects of climate change on water resources in Nicaragua, which have identified vulnerable watersheds and shown significant expected reductions in aquifer recharge, run-off and water balance, follows. Then the document lays out the findings of the analysis carried it out in the context of the Climate Change Diagnostic Study undertaken by the World Bank in 2011-2012 in consultation with the Nicaraguan agencies, which has entailed a review of climate change projections from a range of models with field assessment.

The "top-down" component of the Climate Change Diagnostic Study combines a review of projections from 16 Global Circulation Models (GCM) for Nicaragua to select three possible future climate scenarios for the 2050s.It then combines temperature and precipitation projections for the three future scenarios with the hydrological modeling tool AguAAndes and simulates the changes in water availability in different regions of Nicaragua, considering the combined effect of temperature and precipitation changes for the 2040–2060 period compared with the baseline (1950–2000). The results of the simulations show that the net effect of climate change on the water balance of fourteen out of the twenty-one basins in Nicaragua is likely to be negative based on the projections of three future scenarios. According to the simulations of the combined climate and hydrological models, droughts will likely worsen in the already dry areas and will tend to expand from the already dry central region of Nicaragua to the Northwest. Furthermore, current flood-prone areas on Nicaragua's Pacific and Atlantic coasts will likely be exposed to higher

runoff than what they are experiencing today. This means that rural water supplies will come under increasing pressure, especially in the areas that depend on surface water or on groundwater sources with small recharge areas.

The study also includes a "bottom-up" component: an assessment carried out through a rapid diagnostic field study of seven sub-basins that are representative of different hydrological conditions in Nicaragua. This assessment corroborates the vulnerability of water resources and infrastructure to the changing climate. Although the projections of climate models alone are not definitive enough to guide adaptation measures, when combined with the results of field observations they result in a set of clear recommendations to facilitate adaptation to existing climate variability and climate change in the water supply and sanitation sector in rural Nicaragua: strengthening water management institutions at the national, municipal and community levels; enhancing hydro-meteorological monitoring and information systems, environmental and climate change education and incentives to promote the protection and sustainable use of water sources; and improving the resilience of water and sanitation infrastructure to climate variability and change through traditional and innovative technological solutions.

They key conclusion of the study is the expected significant effect on the water balance as an outcome of the projected changes in temperatures, precipitation, and the hydrological variables, broadly consistent with the historic trends. Among the sectors that will bear the brunt of the effects of climate change are agriculture, hydropower and domestic water supply. In the latter sector, particularly in rural areas, climate impacts are likely to have some of the highest social costs, so the study has taken a closer look at the adaptation measures in this sector. Many of the options to reduce vulnerability to climate variability and strengthen the resilience of domestic water supplies are no different in a world with climate change than they are in the baseline scenario without climate change. They include measures to improve the efficiency of water distribution systems, institutional strengthening, and local-level capacity building. On the other hand, other actions might only be justifiable in the climate change scenario, such as retrofitting the existing infrastructure to climate change and altering the existing engineering designs and operational models to better adapt to the effects of climate change. The field work carried as part of this study has revealed a high level of awareness of the changing climate and what it means for water resources and domestic water supplies in rural Nicaragua. It has also helped identify some of the critical constraints to adaptation that projects and national investment programs in the rural water supply sector would need to address.

This paper was prepared as part of the broader Climate Change Diagnostic Study financed by the Trust Fund for Bank-Netherlands Partnership Program (BNPP). The study has informed the preparation of the FY2012 Republic of Nicaragua Adaptation of Water Supplies to Climate Change Project, financed by a US$6 million grant from the Special Climate Change Fund and implemented by the Ministry of Environment and Natural Resources, the Emergency Social Investment Fund responsible for rural water supply projects in Nicaragua, and supported by the National Water Authority. The findings of the diagnostic study, summarized in this paper, have been discussed in Nicaragua during a technical workshop held in Managua in June 2012.

Climate Change Impacts on Water Resources and Adaptation in the Rural Water Supply and Sanitation Sector in Nicaragua

Introduction

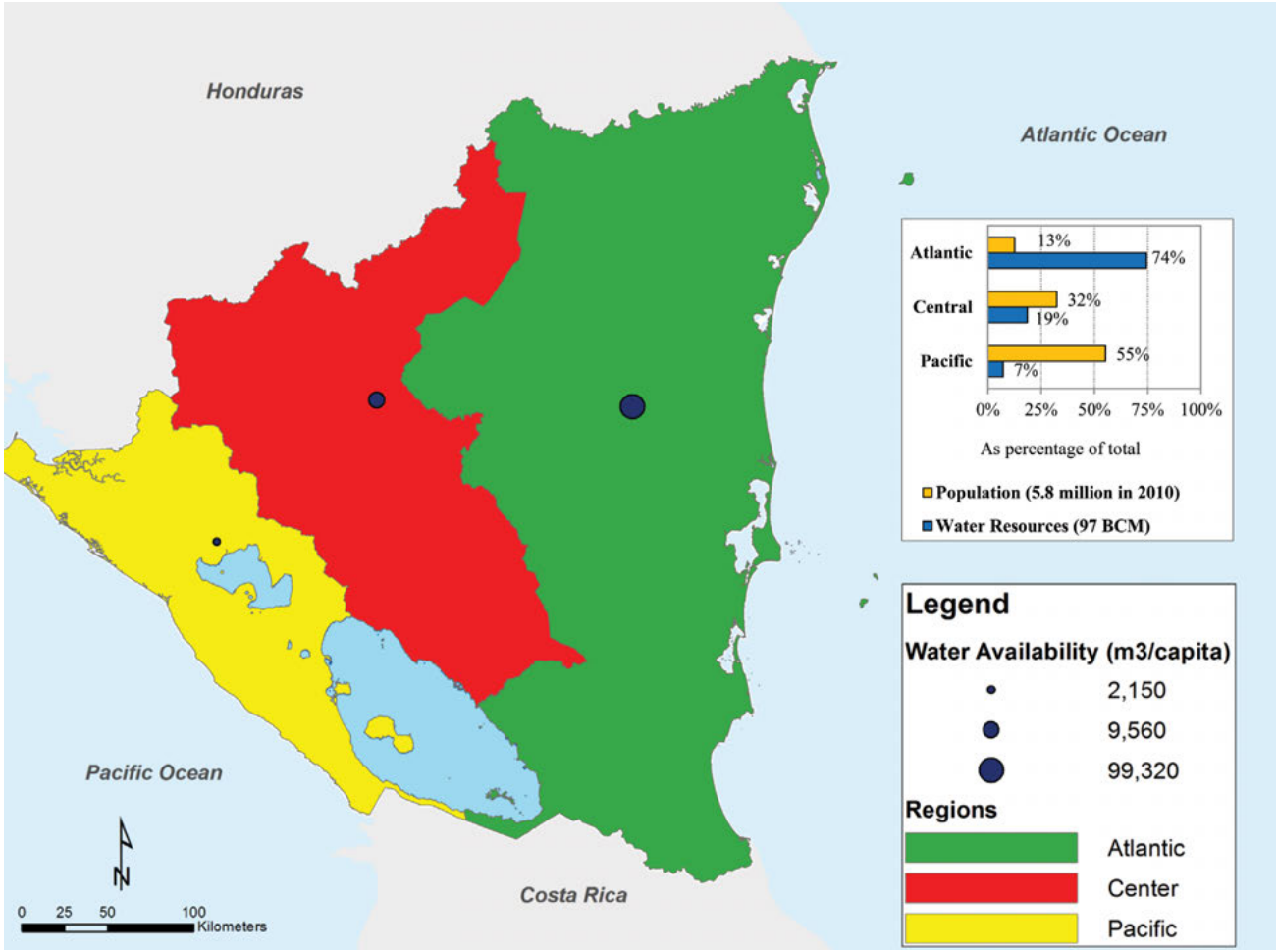
This paper examines the impacts and implications of potential climate change on water resources in Nicaragua and makes key recommendations to integrate climate change and rural water supply and sanitation policies and programs in a way that increase resilience to current and future climate conditions. The paper begins by looking at the current water resources situation in Nicaragua. It then presents the changes in temperature and precipitation that have been observed as a result of current climate variability. This is followed by a review of the projected temperature and precipitation changes from 16 Global Circulation Models (GCM) for Nicaragua, and the results from comprehensive simulations at the country level of three future climate change scenarios on key hydrological variables, both elements of the top-down assessment. The paper then presents the results from the bottom-up assessment of the impacts of climate change on the water supply and sanitation sector, and outlines priority actions and recommendations for Nicaragua's government to improve the resilience of water supply and sanitation sector in the face of increased climate variability and climate change.

Water Resources Situation

Although the Central American region is well-endowed with water resources, the region including Nicaragua faces spatial and seasonal imbalances of its resource base. Regional water availability is estimated to be about 23,000 cubic meters per capita per year (m^3/capita/year) (ECLAC 2010). Seasonal imbalances of water availability are common in the Pacific side of the Central American region, which experiences at least five months a year (from December through April) almost no rain (ECLAC 2010). In the case of Nicaragua, if both surface and groundwater resources are considered, the country has about 16,700 m^3/capita/year[1] (Vammen and Hurtado 2011). However, as shown in Figure 1, this high figure masks an uneven spatial distribution of the resources among the Pacific, Central and Atlantic regions. While about 87 percent

1 This is calculated on the basis of assuming the total population of 5.8 million inhabitants in Nicaragua in 2010.

Figure 1: Regional Contrast between Water Availability and Population



Source: Elaborated by authors using Vammen and Hurtado (2011).

of the population is concentrated in the Pacific and Central regions of the country, about three-quarters of the water resources are located in the Atlantic region Seasonal imbalance of precipitation is also observed in the Pacific region of Nicaragua (Figure 2).

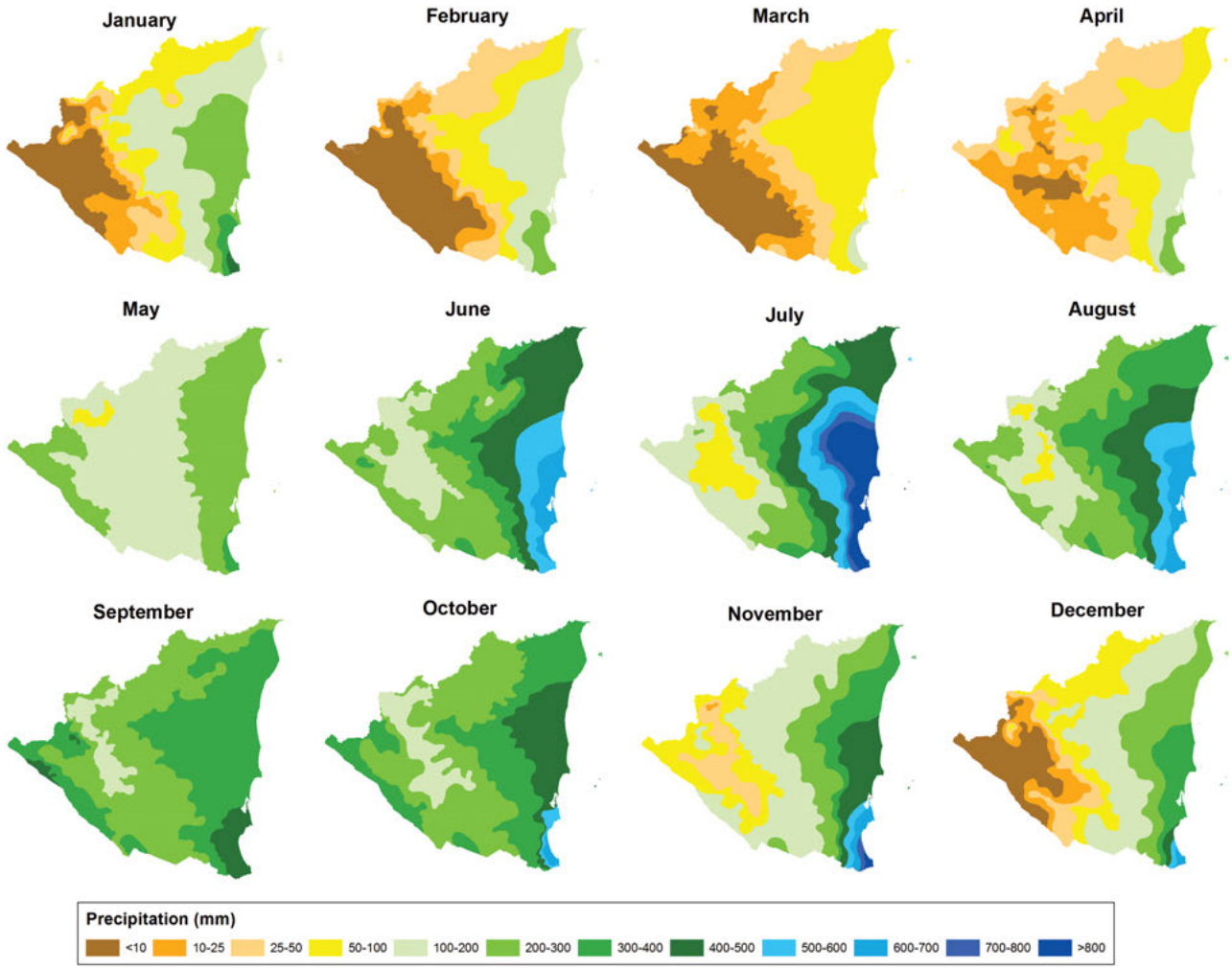
There is a marked difference within the Central American region in terms of water withdrawals and sectoral allocations. In the case of Nicaragua, total water withdrawals are estimated to amount to 1.8 billion cubic meters (BCM) per year or 310 m^3/capita/year, of which agriculture accounts for 83 percent, domestic use for 3 percent and industry for 14 percent (Vammen and Hurtado 2011). Demand for water resources in the most densely populated region of the country outstrips available supplies during dry years.

Water resources make a significant contribution to regional and national socio-economic development. For Nicaragua, water is not only an important environmental asset, but also a key input to agriculture, industry and hydropower generation. Agriculture represents approximately 20 percent of gross domestic product (GDP) and employs more than 30 percent of active population (Vammen and Hurtado 2011). It is estimated that on average only 27 percent of permanent cropped area (about

61,000 ha) is irrigated. During drought years, the water deficit for crop production is high causing significant economic losses in terms of reduced agriculture production. Changes in climate will increase the importance of irrigation in the future. Total technically and economically feasible hydropower potential of Nicaragua is estimated at 751 mega-watts (MW). At present, only 104 MW have been developed, and about 16 percent of electricity is from hydropower, with the remainder made up of thermal (67 percent), geothermal (10 percent) and other sources (7 percent). The electricity demand is expected to grow at 6 percent per year, and hydropower is expected to play a key role in the future electricity generation (ESMAP 2006).

Nicaragua has some of the largest aquifers of Central America, which provide a source of drinking water for approximately half of the country's population. The main source of domestic water supply is groundwater, representing 70 percent of the total, with the remainder coming from surface

Figure 2: Spatial Distribution of Average Annual Precipitation 1971-2000



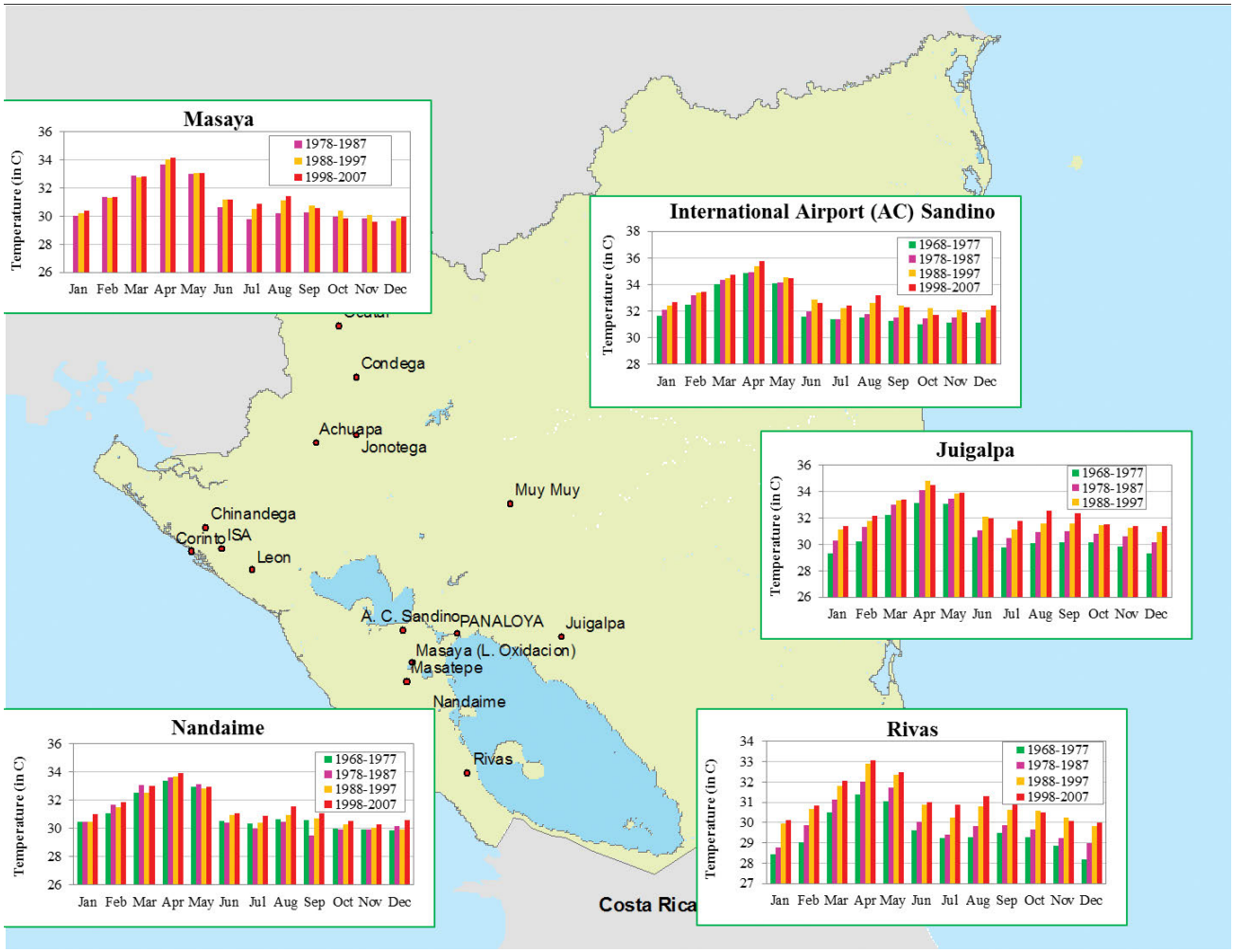
Source: Elaborated by authors with information from the Nicaraguan Institute of Territorial Studies (INETER for its acronym in Spanish - *Instituto Nicaragüense de Estudios Territoriales)* collected by the Twinning European and Latin American River Basins for Research Enabling Sustainable Water Resources Management Project (TWINLATIN) Project.

water and springs (Vammen and Hurtado 2011). Due to seasonal imbalances in water availability and demand, some rivers dry up during the dry season, often leaving rural areas without a reliable source of water supply for half the year. Pollution also limits water availability in urban and rural areas and increases the costs of potable water supply. Many aquifers are currently affected by salinity or pollution from agrochemical runoff, untreated wastewater, and natural contamination by arsenic (World Bank 2009).

Current Climate Variability

Climate in Central America is becoming warmer and rainfall during extreme events is increasing. Over a period of 40 years (1961–2003), the region has experienced increases in maximum and minimum temperatures of 0.2 degree Celsius (°C) and 0.3 °C per decade, respectively, along with an increase in the number of dry days (ECLAC 2010). These changes have increased water stress and resulted in crop losses, as observed during droughts in the Pacific region of Nicaragua and Honduras.

Figure 3: Decadal Averages of Observed Monthly Maximum Temperature



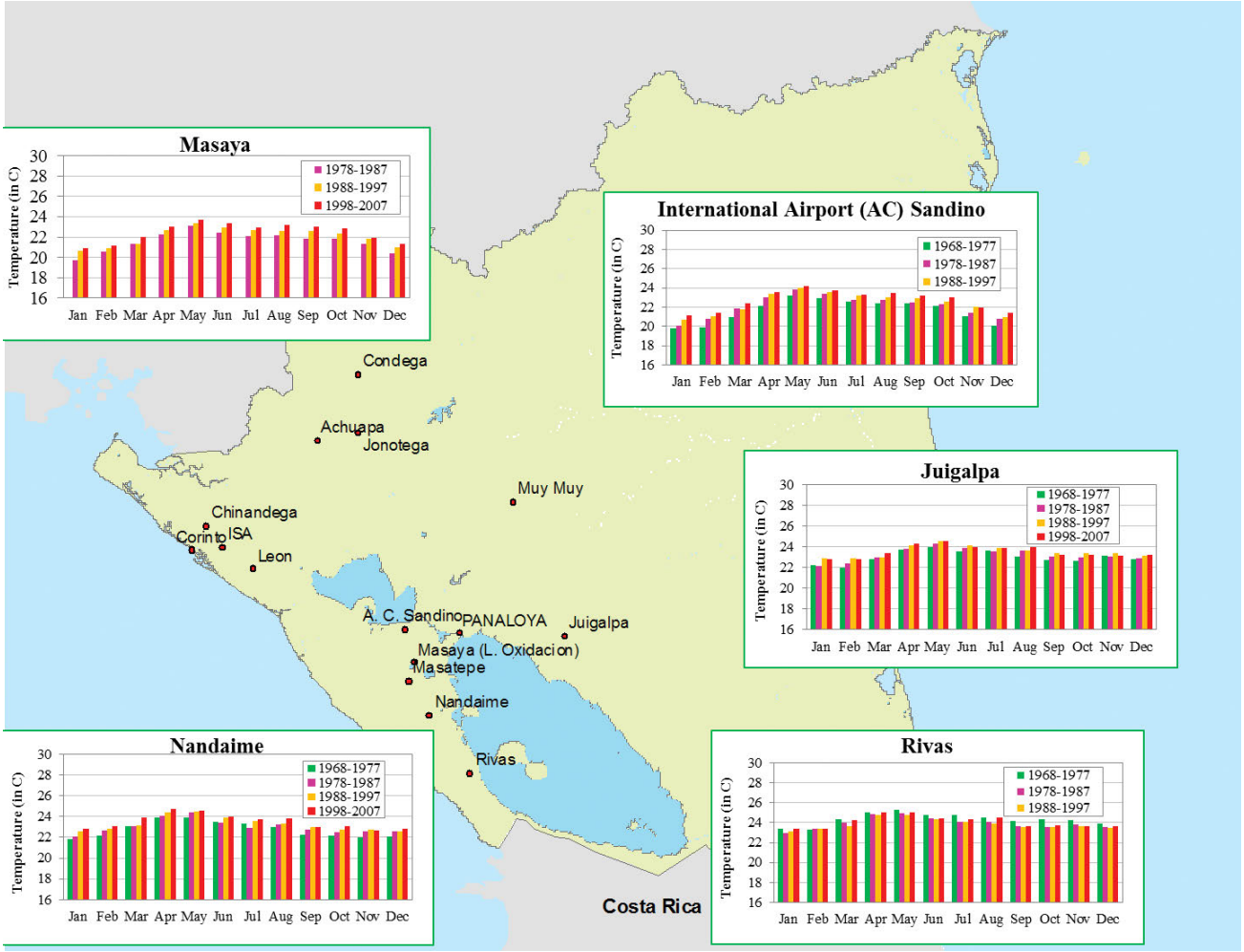
Source: Elaborated by authors with data from meteorological stations collected under the TWINLATIN and the annual statistics report from National Institute of Information for Development (INIDE for its acronym in Spanish – *Instituto Nacional de Información de Desarrollo*).

Similarly, extreme rainfall events have also become more frequent, resulting in higher risks of soil erosion, floods and landslides. Climate change poses a significant threat to the availability of freshwater resources (Vörösmarty et al. 2000 and Kundzewicz et al. 2008).

Warming trends in maximum and minimum average monthly temperatures are observed in Nicaragua. Analysis of temperature records over the period of 1958/1970-2010 for the 10 principal meteorological stations (some stations have registers from 1958 while others have registers from 1970) indicates warming trends in mean monthly minimum and maximum temperature for most of the stations. Increments of temperature of 0.2 °C and 1.6 °C between extreme decades have been observed (Milan 2010). Figures 3 and 4 present decadal averages of the observed monthly maximum and minimum temperature for five stations. They show that warming trends occur during almost all months and for all stations, with the exception of the Rivas station, which shows a cooling trend.

On average, the temperature in Nicaragua has increased by 0.9 °C since 1960. According to the United Nations Development Program (UNDP) Climate Change Country Profile, which compiles a

Figure 4: Decadal Averages of Observed Monthly Minimum Temperature

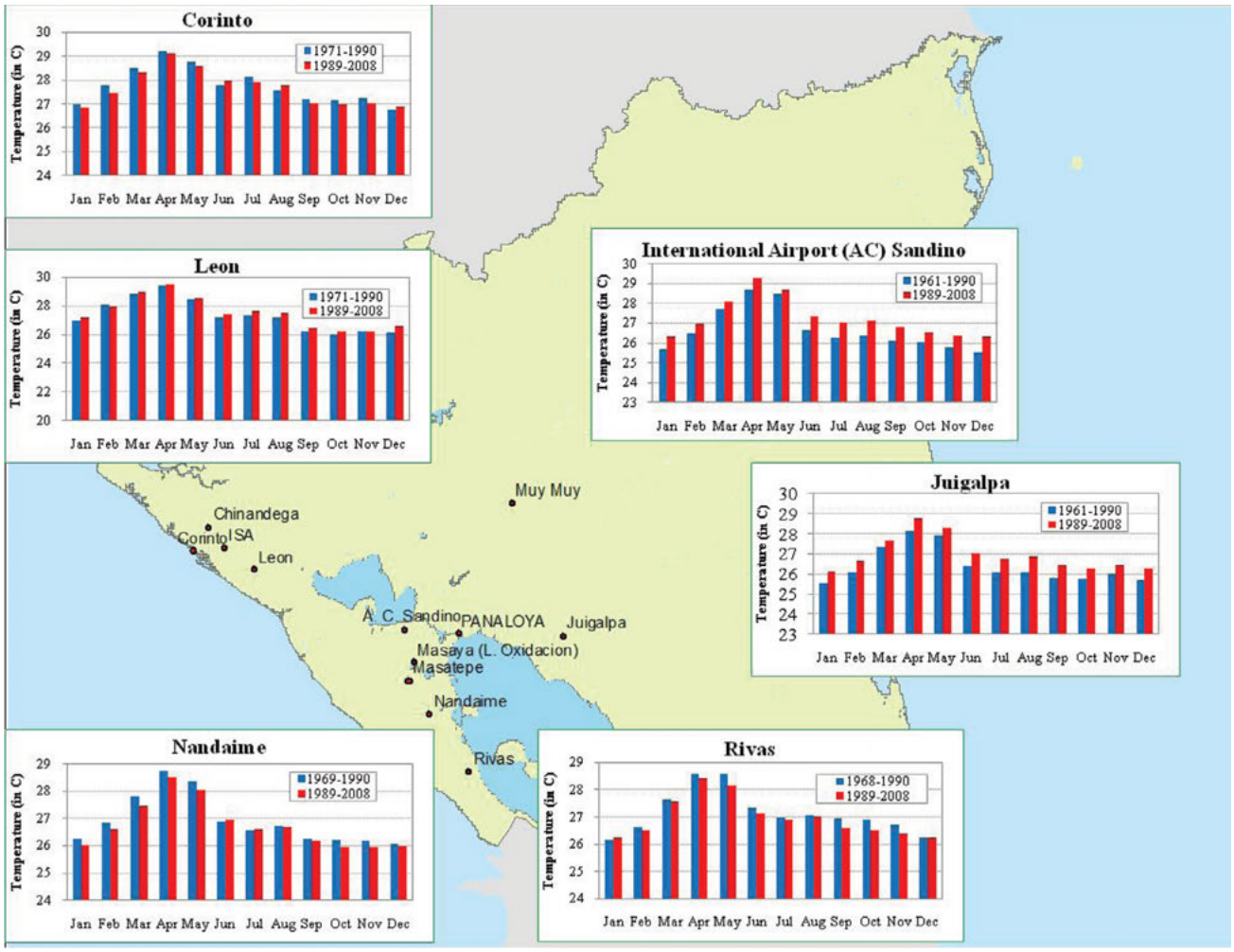


Source: Elaborated by authors with data from meteorological stations analyzed under TWINLATIN and INIDE annual statistics reports.

range of data sources, the average temperature for the whole county has increased by 0.9 °C in all seasons since 1960, and the frequency of hot days and nights has also increased significantly since 1960: the number of hot days has increased by 16.4 percent (an additional 60 hot days) and the number of hot nights by 11.7 percent (an additional 43 hot nights) (McSweeney et al. 2010). As shown in Figure 5, average monthly temperatures do not follow a consistent trend throughout the country. No all of the six stations analyzed have experienced the same trend. Stations in the northwest and center of the country show that those regions are experiencing warming in all months, while stations towards the south show that those areas are not experiencing changes or are becoming cooler.

Annual and seasonal precipitation in Nicaragua is also changing. According to an analysis of precipitation records conducted by INETER for two stations for which data are available since 1895, during the last 30 years mean annual and seasonal precipitation has declined. The overall trend is a decrease of 6-10 percent of precipitation over the analyzed period (Milan 2010). Similar decrease in precipitation is also noted in the UNDP Climate Change Country Profile, which also highlights an increased intensity in rainfall (McSweeney et al. 2010).

Figure 5: Variation of Average Monthly Temperature



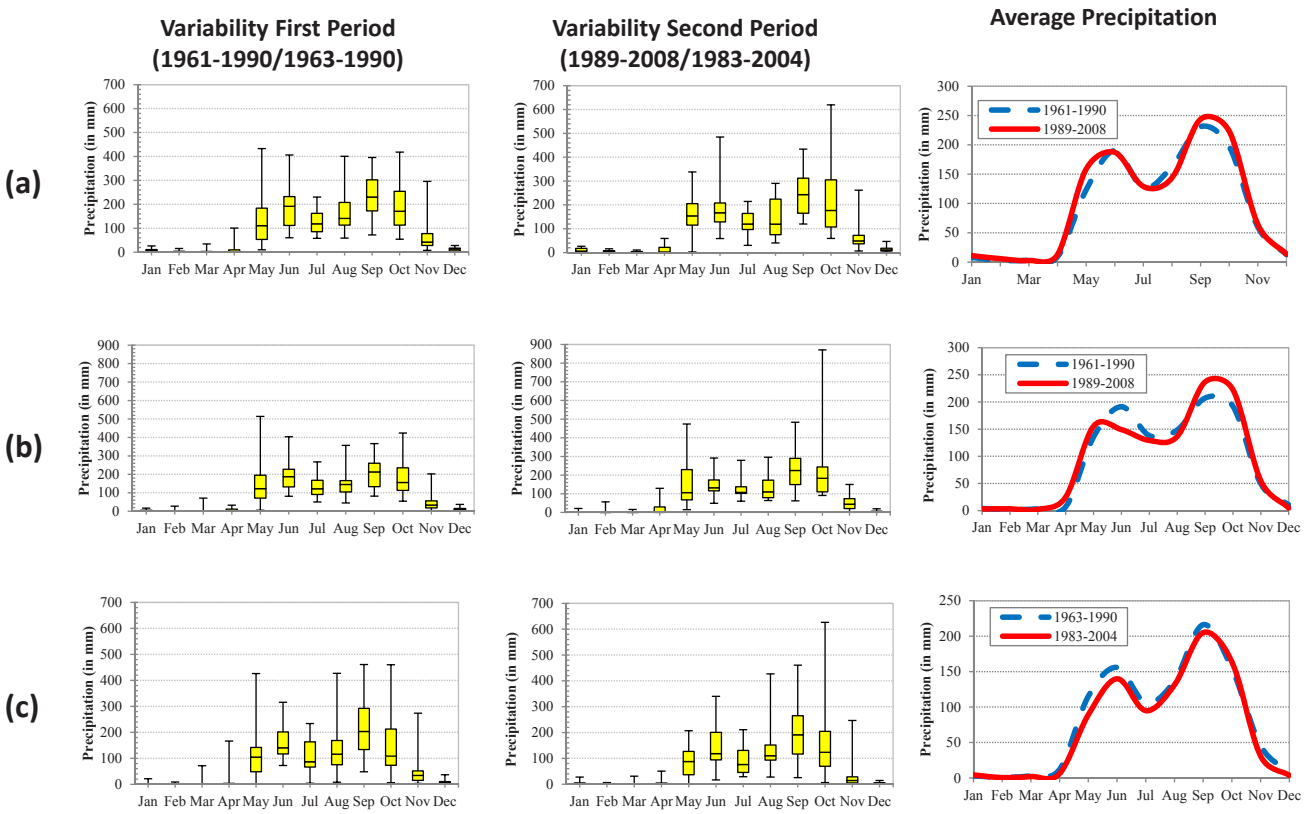
Source: Elaborated by authors with data from meteorological stations analyzed under TWINLATIN and INIDE annual statistics reports.

A 2.2 percent increase per decade on average in the proportion of precipitation that occurs in "heavy" rainfall events since 1960 has been reported.

This assessment does not find evidence of a significant declining trend in overall annual average. However, trends toward increased variability in the late part of the rainy season are observed. Figure 6, which summarizes the results of the analysis of recorded monthly precipitation from three stations, shows that during the second analyzed period monthly average precipitation and variability have changed considerably in relation to the first analyzed period. A high variability is observed during the month of October associated with the end of the rainy season.

The precipitation in Nicaragua presents great variability in time and season, which is associated with El Niño Southern Oscillation (ENSO). According to INETER and the Ministry of Environment and Natural Resources (MARENA for its acronym in Spanish – *Ministerio de Ambiente y Recursos Naturales*), there is a strong correlation between the ENSO events, namely El Niño events, and the lowering of precipitation in the Northern and Central Pacific regions. Large negative anomalies in total annual precipitation are observed during El Nino years. During the period 1971-1998, the dry years of 1972-73, 1976-77, 1982-83, 1986-87, 1990-95 and 1997-98 correspond to the years when El Nino conditions were also present (MARENA 2003). Various studies have shown that the ENSO events have

Figure 6: Trends in Precipitation Variability



Note: Charts in the top row (a) summarize observed precipitation records from Juigalpa station; in the middle row (b) those from the International Airport Sandino station; and in the bottom row (c) those from Panaloya station.

Source: Elaborated by authors with data from TWINLATIN and INIDE annual statistics reports.

Box 1. Earlier Efforts to Estimate Impacts of Climate Change on Water Resources

National-level Study. Within the framework of the First National Communication, MARENA carried out a study to assess the likely impacts of climate change in the energy, forest, agriculture, fishing and acuaqulture, water resourcre and public health sectors. With regard to the impacts of climate change in water resources, the study compared the supply of water and the demand from the various users for three time horizons: 2030, 2050 and 2100. The analysis considered variations in temperature and precipitation of the Hadley Centre Coupled Model 2 (HadCM2) for three emission scenarios – an optimistic, a pessimistic and a most likely scenario for each of the time horizons considered.

For the assessment of future supply of surface water, the analysis made use of the Climate-Runoff Model (CLIRUM), to simulate the behavior of the runoff for future climate conditions in four representative basins in Nicaragua: Basins of the Guanas, Tamarindo, Viejo and Paiwas rivers. The results of this analysis were then extrapolated to the rest of the country based on ecological classification, and reported at the level of the three hydrological regions – Pacific, Central and Atlantic. For the assessment of future groundwater, the analysis made use of the numerical model Visual Modflow, which was applied to the sub-basin of the Chinandega-Leon aquifer.

The most relevant findings of the study were the following:

- At the level of the basins, the study found that the basins of the Tamarindo, Viejo and Guanas rivers are highly vulnerable under all the three scenarios and the 2050 and 2100 time horizons. In the case of the basin of the Paiwas River, it was found that it is vulnerable under the pessimistic and moderate scenarios for the 2100 time horizon, in particular the upstream portion of the basin.
- At the level of the hydrographic regions, the study found that the Pacific region is the most vulnerable to climate change given the notable reduction in run-off, the high concentration of population and large surface area under irrigation. The Central region – particularly the agriculture and hydropower sector– is expected to be impacted by reduction in run-off. In the Atlantic region, the study found that the impacts will be felt in terms of more frequent floods.
- With respect to the aquifer Chinandega-Leon, the study found that from 2050 onwards, the natural recharge of the aquifer would be surpassed by the extraction volume for the three scenarios of climate change considered.

The study also evaluated the vulnerability of water resources to climate change using an index of water scarcity, which was defined as the ratio between the demand and the supply. To determine the supply, the study assumed that water pollution would affect the quantity of available water in the following proportions: 30 percent in the Pacific region, 20 percent in the Central region and 10 percent in the Atlantic region. The study found that the Pacific region is subject to high vulnerability, followed by the Central region with moderate vulnerability and the Atlantic region with low vulnerability.

The analysis done to evaluate the impacts of climate change on energy, namely hydropower, consisted in evaluating the impacts of climate change on average annual run-off at the location of El Carmen hydropower plant in the Rio Grande de Matagalpa. The analysis considered the same climate change scenarios and five time horizons: 2010, 2030, 2050, 2070 and 2100. The study found that by year 2050, it is expected that the run-off will be reduced by 30-36 percent, and by the end of the century, the run-off might experience a reduction ranging between 37- 57 percent.

Basin No. 64 Study. Within the framework of the Second National Communication, MARENA conducted a vulnerability assessment of water resources in the Basin No. 64 between Volcan Cosiguina and Tamarindo River to current climate variability. The study made use of the Water Evaluation and Planning (WEAP) System model and the Visual Modflow model to simulate river flows and aquifer levels for normal years as well as El Niño and La Ninã years. The analysis was done for 2015 and considered two future socio-economic scenarios: one where the area under irrigation for peanuts and sugar cane increases and population grows at an annual rate of 0.5 per cent; and the second scenario similar to the previous one but where efficient irrigation systems and conservation measures are introduced. In this basin, groundwater is the main water source for domestic, agriculture, industry and municipal water needs. The study found that under the first socio-economic scenario and dry climate conditions, there will be areas in the basin under severe water deficit, pumping cost will increase as a result of the lowering of the water table, and artisanal wells will dry up. According to the study, the situation is more manageable under the second socio-economic scenario – where the demand of all water users could be met through 2015.

Sources: MARENA 2001, MARENA 2008a and MARENA 2008b.

had significant changes during the last decades in terms of frequency and intensity.

The increasing intensity of extreme weather events is among the most critical climate risks in the region. Between 1930 and 2009, Central America experienced 259 major extreme weather-related events, of which 85 percent accounted for floods, storms, landslides and mudslides, and 10 percent accounted for droughts (ECLAC 2011b). In the past three decades, the number of disasters has been growing at an estimated annual rate of 5 percent compared to the levels recorded during the 1970s.

Nicaragua and Honduras seem to be the countries in the Central America region most affected by the impacts of weather-related events. According to the Global Climate Risk Index for the period 1991-2010, evaluated by Germanwatch based on the damages and human losses caused by floods, hurricanes, cyclones, droughts, and heat waves, Honduras and Nicaragua rank in the third and fourth place at the global level, respectively, and in the first and second position among the Central American countries (Harmeling, 2011).

Past Efforts to Assess Climate-Related Impacts on Water Resources

At present, only a couple of studies have been conducted to assess the impacts of climate variability and change on water resource in Nicaragua. In the context of formulating its First National Communication to the United Nations Framework Convention on Climate Change (UNFCC), Nicaragua carried out a national-level climate change impact assessment on water resources based on an analysis done at the level of four basins. Another impact assessment of current climate variability on water resources was carried out in the context of the formulation of the Second National Communication to the UNFCC. This second study was done at the level of Basin No. 64 (See Box 1 for a summary of the methodology adopted and the key findings of the national level study and the basin-level study). The lack of baseline information and appropriate hydrological models have been major constraints to conducting impact assessments based on most recent climate change data and research.

Future Climate Scenarios and Potential Impacts on Water Resources

The top-down assessment of this study aims at identifying potential impacts of climate change on the water resources at the level of the basins in Nicaragua making use of latest climate change data and available hydrological modeling tools. The assessment includes: (i) a review of the projected temperature and precipitation changes from several GCMs for Nicaragua; and (ii) comprehensive hydrological simulations for three possible future climate change scenarios.

Projected temperature and precipitation changes from 16 GCMs, each under a medium-high greenhouse gas emission scenario (A2)[2], between the baseline and the middle of the twenty-first century (2050s) were reviewed. All data were obtained from a web-based tool called Climate Wizard.[3] The baseline corresponds to the 1961–1990 time period, while the 2050s are represented by the 2040–2069 time period.

2 The Intergovernmental Panel on Climate Change (IPCC) emission scenarios (from the 4th Assessment Report) are grouped into four scenario families that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting greenhouse gas (GHG) emissions, without including additional climate policies beyond the current ones. A1 assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies; B1 describes a convergent world with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy; B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability; and A2 describes a highly heterogeneous world with high population growth, slow economic development and slow technological change.

3 The Climate Wizard tool is available at http://www.climatewizard.org.

The GCMs agree on an increase in temperature and show unclear trends in precipitation. Projected annual changes in precipitation and temperature for the 16 GCMs are shown in Figures 7 and 8, respectively. Although mean annual temperature changes are projected to be positive, ranging between 1.2 ºC and 2.6 ºC (with a weighted average and median of 1.8 ºC), projected mean annual precipitation changes show broad variation in magnitude and an unclear direction, ranging from -21 percent to +6 percent (with a weighted average and median of -7.0 and -5.0 percent, respectively) (see Figure 9). Similar variation in precipitation changes is observed when the analysis is conducted on a seasonal and monthly basis. However, it is interesting to note that 75 percent of the models show negative trends for annual precipitation, with precipitation falling in the months of March, May, June and July[4] (see Figure 10).

Given the limitation of baseline information, simulations of changes in key hydrological variables, namely, evapo-transpiration, water balance and runoff, were run for three possible future scenarios—warm-dry, moderate, and cool-wet—using a web-based hydrological modeling tool called AguAAndes.[5] For the country as a whole, the UK-MO-HADCM3.1 model was chosen to represent the warm-dry future scenario, the NCAR-PCM1.1 model to represent the cool-wet future scenario, and the ensemble average of the 16 GCMs to represent the moderate future scenario. The overall approach used to assess the hydrological impacts of projected climate change is described in Annex A.

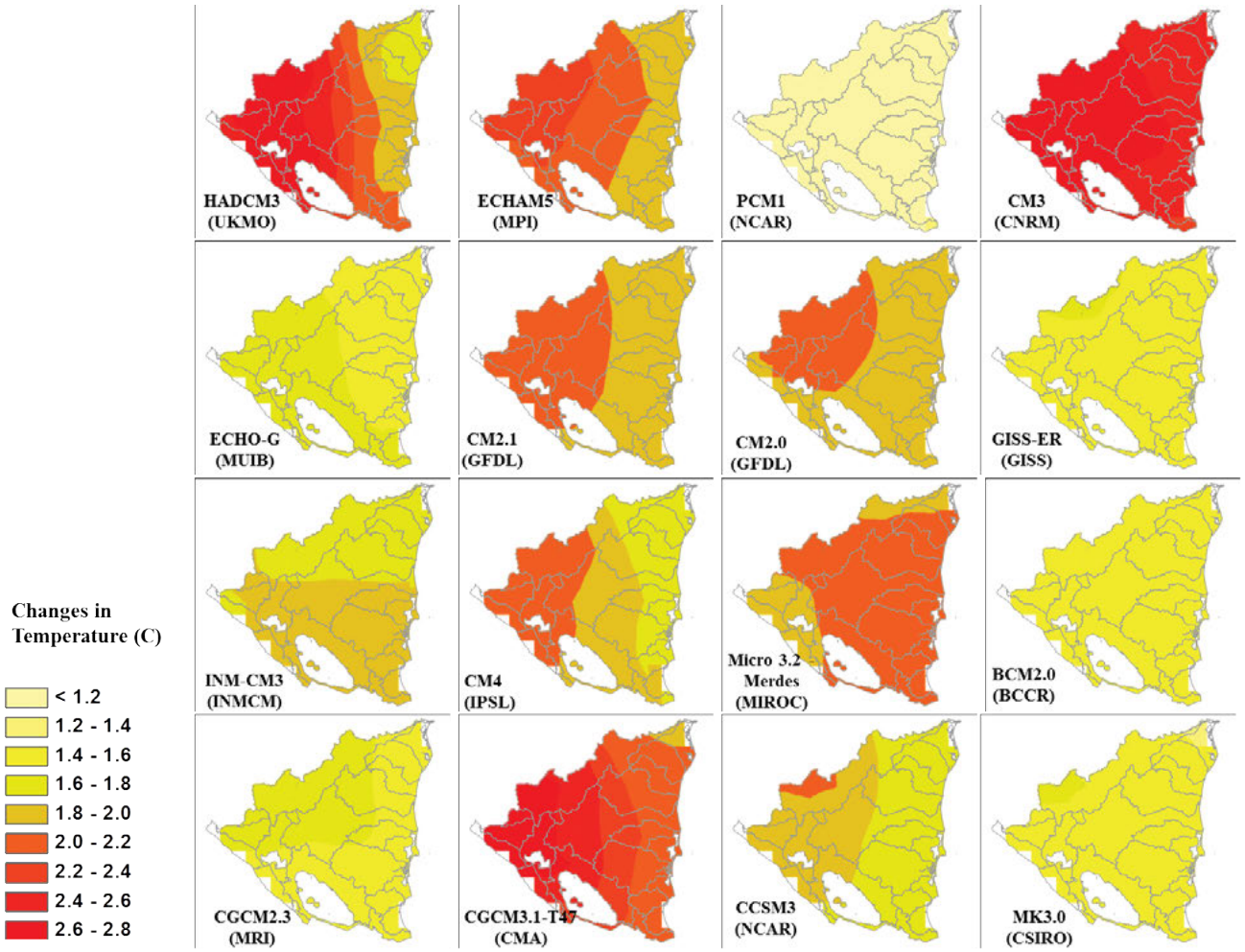
Climate change impact assessment indicates that water availability, as reflected by the projected water balance, will likely decrease in most of Nicaragua's basins. Although the three likely future scenarios considered (warm-dry, moderate and cool-wet) differ in terms of the magnitude of the projected changes in temperature and the magnitude and direction of the projected changes in precipitation, the net effect of climate change on the water balance, which is measured as the difference between precipitation and actual evapo-transpiration, for 14 out of the 21 basins analyzed is negative in each future scenario. As seen in Figure 11, basins draining to the Pacific will experience the highest reduction: Brito River–Sapoa River, Tamarindo River–Brito River, Cosiguina Volcano–Rio Tamarindo River, Brito River and Estero Real River. Under these conditions, water-dependent sectors are under peril because temperature increases could trigger an increase in water demand, while water availability will be subject to the uncertainty of future precipitation trends. Domestic water supply, hydropower, agriculture, health and biodiversity are among the sectors most sensitive to these projections.

Climate variability might become more extreme in the future. Although climate change is expected to have an insignificant effect on the extent and/or frequency of the ENSO events during the next century (Stevenson et al 2011), the warmer and moister atmosphere expected in the future would make these events more extreme because their impacts could worsen unless measures are taken to reduce vulnerabilities. Thus, apart from any change in mean climate expected in the next century, it should be taken into account that the climate variability might become more extreme in the future and the drying patterns observed in Nicaragua during El Niño years could be the norm in the future (Karmalkar et.al 2011).

4 The climate models' ensemble's inter-quartile ranges of precipitation change projections for these months as well as the average year are uniformly negative.

5 The AguAAndes tool is available at http://www.policysupport.org/aguaandes.

Figure 7: Projected Average Changes in Temperature for Nicaragua for the 2050s Relative to Baseline Period, A2 Scenario

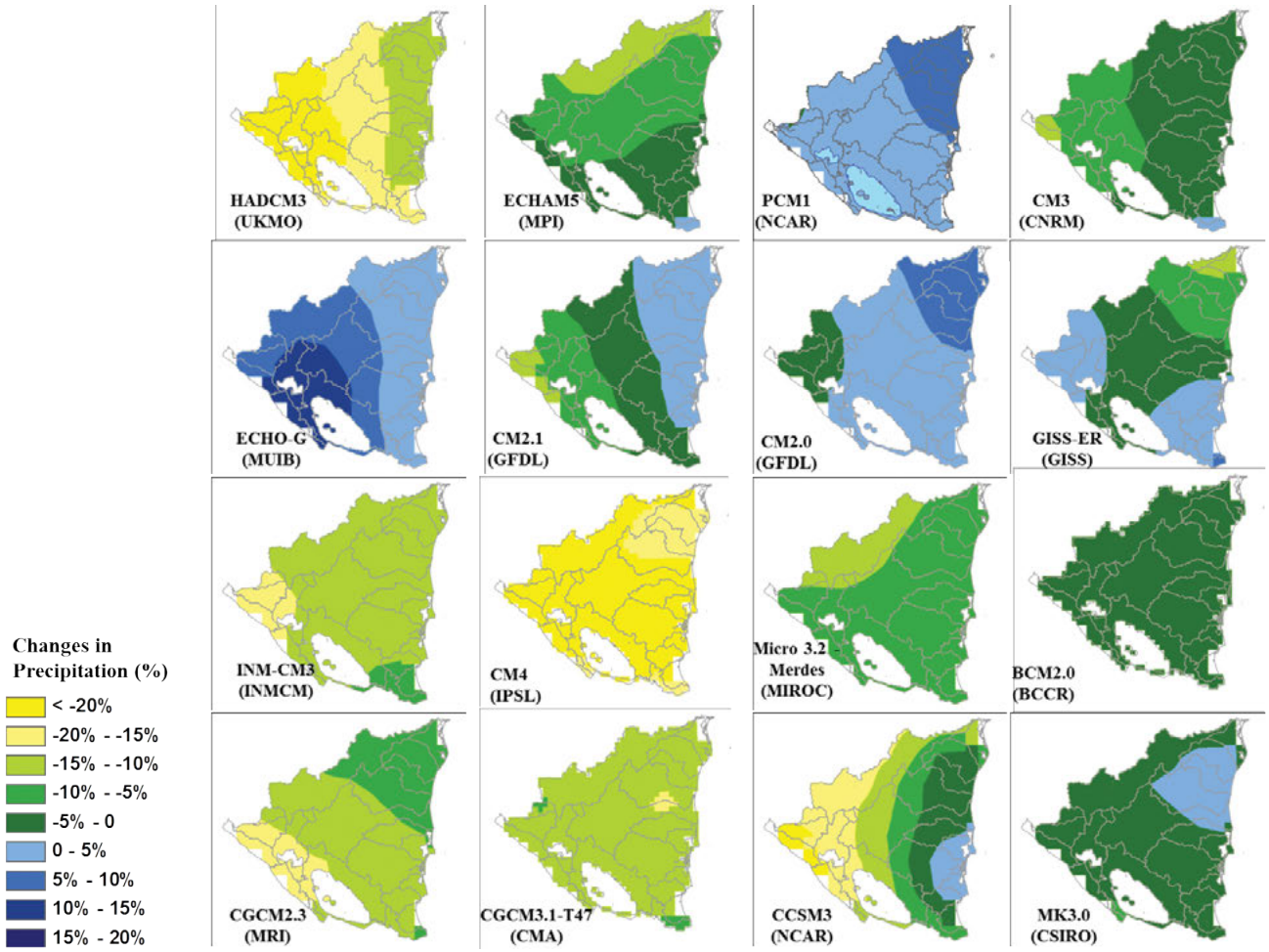


Source: Prepared by the authors with data from Climate Wizard.

Droughts would likely worsen in the already dry areas. The three future scenarios analyzed earlier are in agreement that by 2050 the water balance will be reduced in many areas of the country, particularly in the Dry Corridor[6] zone. This already dry region will face an increasing risk of drier soils and less surface water; droughts will likely worsen and expand to the Northwest. Climate change will also impact areas, particularly those in the Pacific and Central regions, which are highly dependent on groundwater for household and agricultural activities. A reduction in surface water will cause a reduction in groundwater levels and the amount of water available for agriculture, potable water supply and other uses. Groundwater-dependent communities will need to adapt by constructing deeper

6 The Dry Corridor zone *(Corredor Seco)* is characterized by reduced water availability and has been affected by a number of droughts: the most severe droughts occurred in 1983, 1987, 1992 and 1994; moderate droughts in 1986, 1989 and 1997; and less severe droughts in 1991 (MARENA/UNDP 2003).

Figure 8: Projected Average Changes in Precipitation for Nicaragua for the 2050s Relative to Baseline Period, A2 Scenario

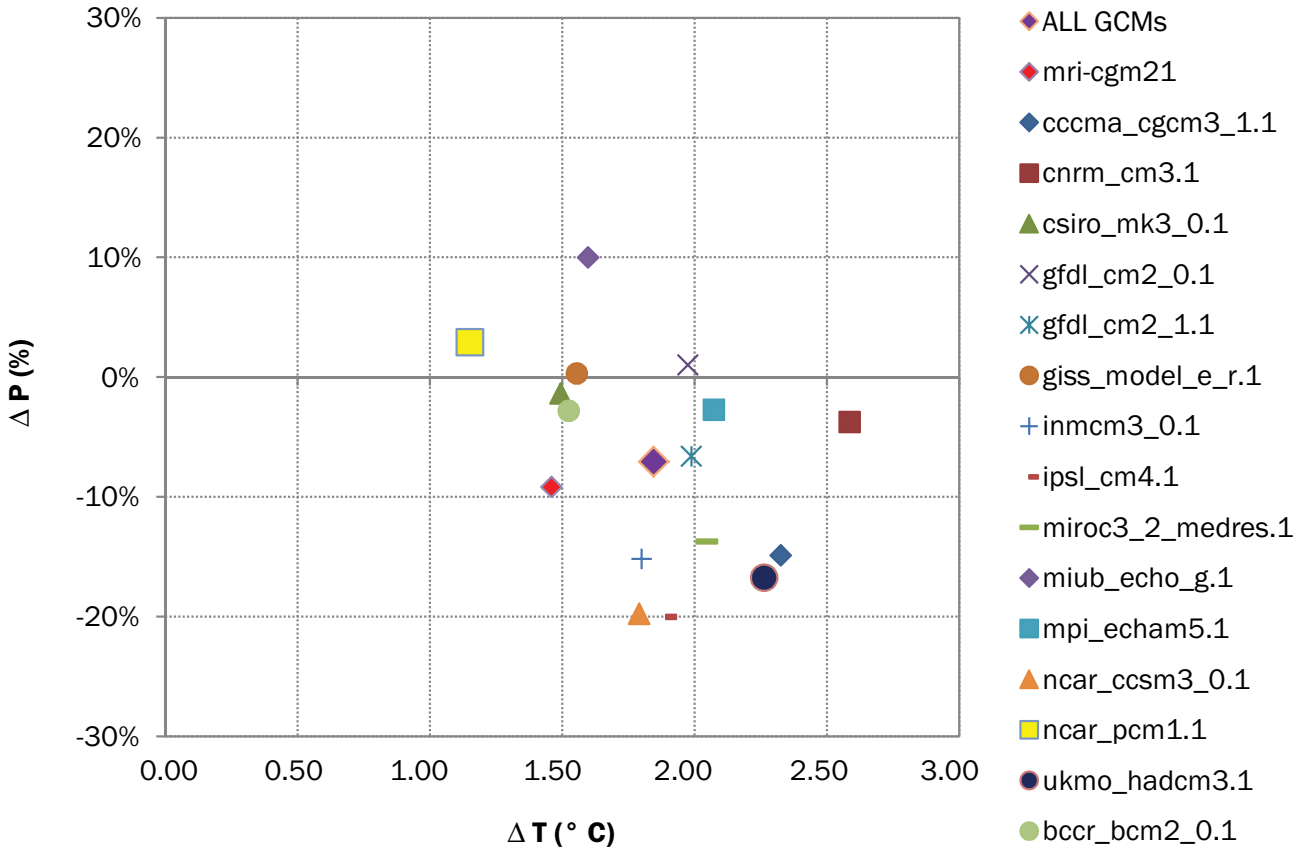


Source: Prepared by the authors with data from Climate Wizard.

wells to reach water tables, and this would increase the costs of water supply.

Current flood-prone areas on Nicaragua's Pacific and Atlantic coasts will likely be exposed to higher runoff than what they are experiencing today. Over the last four decades, Nicaragua's northeast has experienced major climate events such as hurricanes, tropical storms and associated floods. From 1990 to 2008, Nicaragua had the highest incidence of tropical storms and hurricanes among all Central American countries, with 14 major events of this kind. Although there is no clear evidence of an increasing frequency of cyclones and tropical storms that can be attributed to climate change, there is evidence of their greater intensity (IPCC 2007). Higher intensity of extreme drought and rainfall events translates into severe floods that pose higher risks to riverbanks, low-lying areas, and coastal zones. Floods tend to occur in the Caribbean and Atlantic coastal regions, the southwest portion of the Northern Atlantic Autonomous

Figure 9: Projected Average Changes in Temperature versus Precipitation



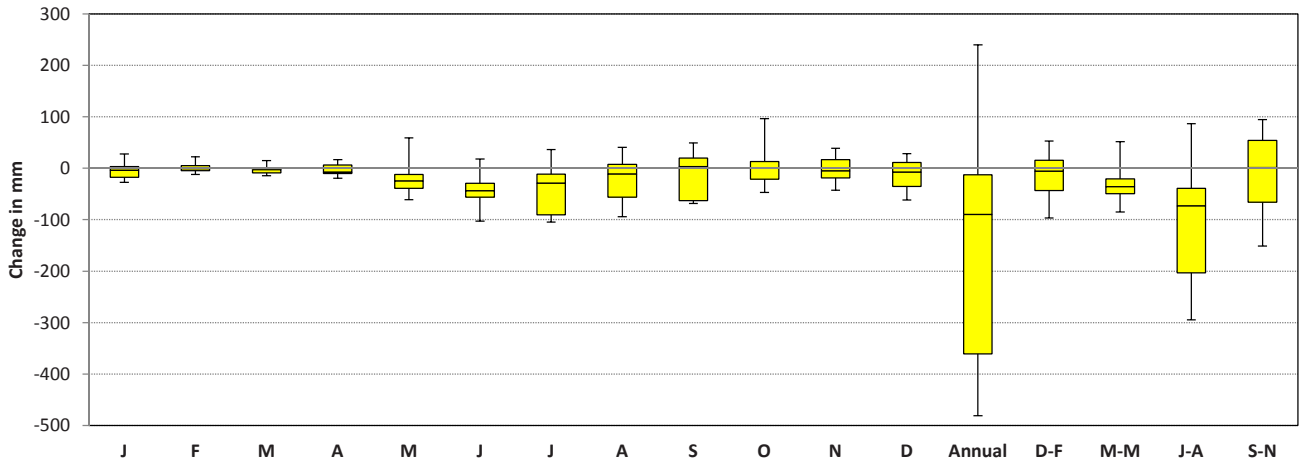
Note: The vertical axis shows the change in average precipitation projected by each of the GCMs included in the analysis and the horizontal axis – the change in temperature.

Source: Prepared by the authors with data from Climate Wizard.

Region (RAAN for its acronym in Spanish - *Región Autónoma del Atlántico Norte*), and Chinandega department. Most of the 16 GCMs under the A2 emission scenario project higher precipitation in Nicaragua's flood-prone areas; therefore, flooding events will likely expand further to the south in Nicaragua. The risk of landslides will likely increase in already vulnerable areas such as the departments of Jinotega, Matagalpa and Chinandega, and the Pacific coast, where deforestation levels are high.

Many sectors will be affected by climate change, notably agriculture and hydropower, and domestic water supply which stands out as a sector where the social costs of the impacts of climate change are likely to be particularly high. The impacts are occurring through the changing availability, distribution of water availability over time, and water quality. The precipitation regime in the Central America region, in Nicaragua in particular, is characterized by the alternating periods of floods and severe drought, which will be exacerbated by climate change. Furthermore, sea level rise threatens the water quality of aquifers in the coastal zones due to saline intrusion. In addition, climate change is likely to degrade drinking water quality (Delpla et al. 2009). Quality and regularity of flow are critical characteristics for drinking water. Regu-

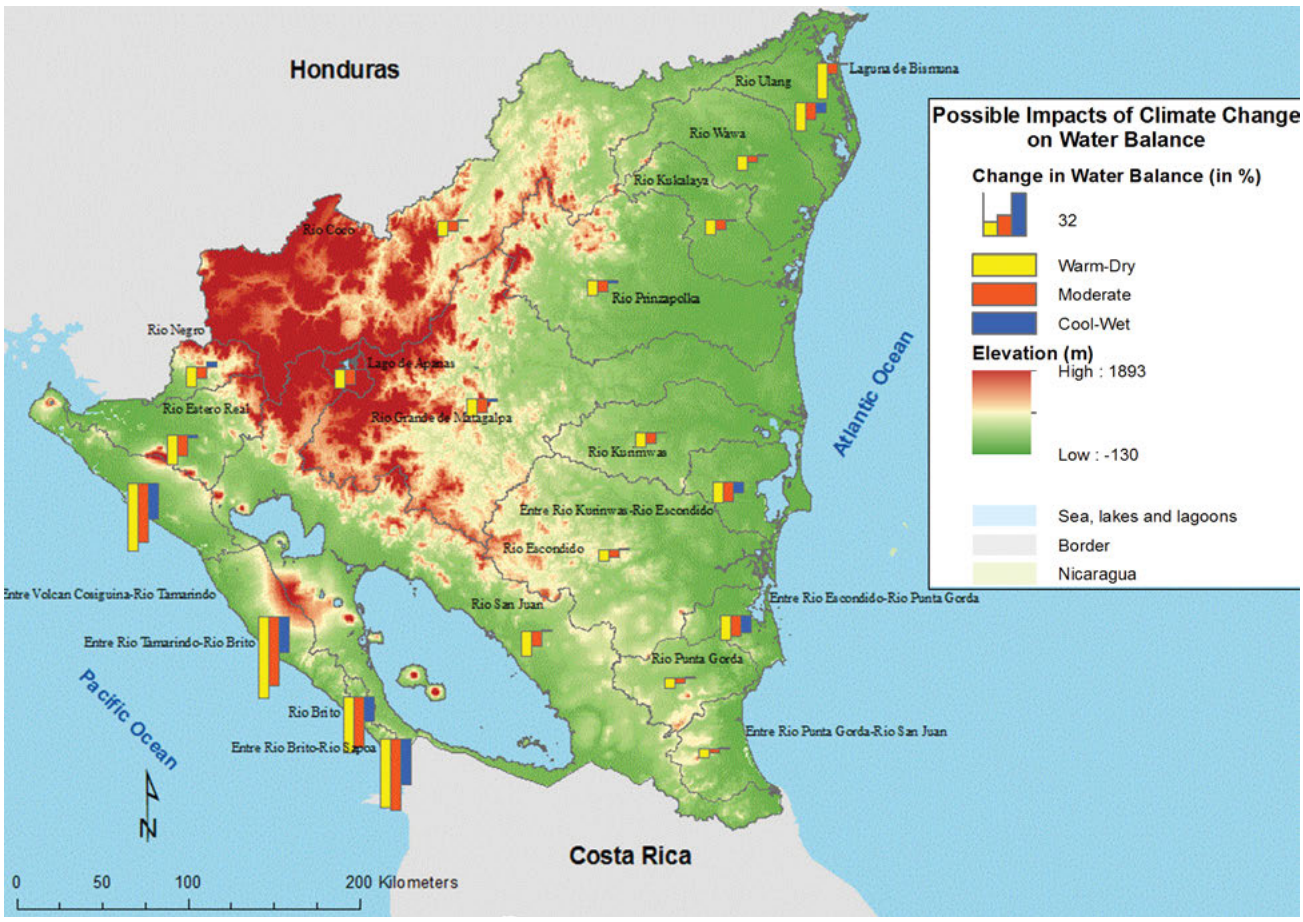
Figure 10. Projected Monthly, Annual and Seasonal Precipitation Changes for Nicaragua



Note: The charts summarize the distribution of projected changes. The horizontal line inside the box represents the median projection, the box the inter-quartile range, and the whiskers extend to the minimum and maximum values.

Source: Prepared by the authors with data from Climate Wizard.

Figure 11. Projected Changes in Water Balance by 2050s (2040–2060) Relative to Baseline Period (1950–2000) by Basin



Source: Prepared by the authors.

larity of flow is expected to be substantially affected by climate change, with increases in inter-annual variability and a higher frequency of intense rainfall events in many areas (IPCC 2007). Assessments of impacts on quality have mostly been limited to developed countries, but are expected to be broadly negative: "an increase in water temperature alters the rate of operation of some key chemical processes in water. Also, changes in intense precipitation events impact the rate at which materials are flushed to rivers and groundwater, and changes in flow volumes affect dilution of loads. Key consequences of declining water quality due to climate change include increasing water withdrawals from low-quality sources; greater pollutant loads from diffuse sources due to heavy precipitation (via higher runoff and infiltration); water infrastructure malfunctioning during floods; and overloading the capacity of water and wastewater treatment plants during extreme rainfall" (IPCC 2007). Flow changes and reduction in water tables would certainly affect the functionality of current water infrastructure, which might need to be retrofitted, adapted or changed to suit the new conditions. However, "it is not the change in flows that is important but the economic consequences associated with those flows" (Rogers 1994, p. 198).

Water demand is rising in tandem with population growth, while climate change reduces water availability. Nicaragua's population reached 5.45 million in 2005, and it is expected to increase to 7.93 million by 2050 (ECLAC 2010). Population growth of this magnitude, coupled with economic growth, could lead to an increase in water demand, which is estimated at 250 percent by 2050 and more than 1,800 percent by 2100 in a baseline scenario without climate change and without improvements in efficiency of water use. In a scenario with climate change, the water demand is expected to increase by 350 percent by 2050 and more than 2,750 by 2100 (ECLAC 2010). Meanwhile, water balance could fall between 36 and 64 percent compared to current levels. Water scarcity or surplus (floods) could result in social instability due to water conflicts and higher vulnerability of rural communities, infrastructure and key water-dependent economic sectors. As Döll (2002) points out, climate change that reduces rainfall will also increase the demand for irrigation water. Emelko et al. (2011) find that the effects of climate change are likely to affect water treatment costs by exacerbating the impact of wildfires and other disturbances. Waterborne diseases, reduced agricultural competitiveness, food insecurity, and compromised hydropower generation are among the gravest consequences for Nicaragua and the Central American region as a whole.

Poverty and environmental degradation exacerbate Nicaragua's vulnerability to the impacts of climate change. Nicaragua is one of the poorest countries in the Latin America region with per capita Gross National Income (GNI) of only $1,510 in 2011. Almost half of the Nicaraguans live below the poverty level, with the poverty rate estimated at 42.5 percent nationally in 2009, and at 26.8 and 63.3 percent in the urban and rural areas, respectively (World Bank 2012). Children are vulnerable to diseases because of limited access to health services and safe drinking water supply and sanitation in rural areas. Only around 56 percent of the rural population of Nicaragua has access to improved drinking water sources and 36 percent have access to improved sanitation in rural areas (WHO/UNICEF 2008). This situation translates into high child mortality. The annual cost of mortality and morbidity due to diarrheal illness—the leading cause of water-borne illnesses, with particularly severe impacts on children under five—was estimated as high as 0.8 to 0.9 percent of GDP (World Bank 2013). Climatic pressures are likely to undermine the reliability and quality of domestic water supplies further, posing further challenges to the attainment of Nicaragua's goals on reducing child

mortality. Land degradation and deforestation are additional factors that accentuate the country's vulnerability. In 2010, annual deforestation was estimated at 70,000 hectares; statistics for 2005–2010 show that the country has lost one tenth of its forest (ECLAC 2011a).

Climate Change Impacts on the Water Supply and Sanitation Sector

In order to assess the potential climate change impacts on the water supply and sanitation sector in this study, the top-down assessment was complemented with a bottom-up assessment, which was carried out through a rapid diagnostic field study of seven sub-basins. The overall approach used in this bottom-up assessment is described in Box 2. The assessment corroborates the vulnerability of water resources and infrastructure to the changing climate in rural Nicaragua. Field observations of the seven sub-basins in Nicaragua's western and central regions, selected to have a good geographic spread and to provide a range of problems in terms of vulnerability to climate change and adaptation responses in the water supply and sanitation sector, have revealed the high extent of watershed degradation and the prevalent unsustainable land-use practices, especially due to deforestation associated with intensive agriculture and livestock raising, and the increasing population density. For more details on the areas covered in the field assessment refer to Table 1 and Figure 12.

Box 2. Approach Followed in the Bottom-Up Assessment

An interdisciplinary team* carried out rapid diagnostic field studies of selected sub-basins located in the western and central regions of Nicaragua. The studies were aimed at identifying and assessing the climate change and water resources-related challenges faced by Nicaragua's rural population, the state of water and sanitation infrastructure, the environmental condition of the watersheds, and people's perceptions of climate change.

The sub-basins were selected with the guidance of MARENA and the New Emergency Social Investment Fund (Nuevo FISE for its acronym in Spanish – *Fondo de Inversion Social para Emergencias*). The selection criteria included: (i) accessibility to community settlements, (ii) population density, (iii) risk of droughts and floods, (iv) presence of water and sanitation infrastructure, (v) existence of Water and Sanitation Committees (CAPS for its acronym in Spanish - *Comités de Agua Potable y Saneamiento*), and (vi) level of local and institutional organization. Selected sub-basins were: Río El Gallo, Río Los Quesos, Alto Río Negro, Río Jicaro, Upa Wabule, Río Calico and Río Mayales. They represent different types of problems in terms of vulnerability to climate change and adaptation responses in the water supply and sanitation sector.

The field assessment includes two components: (i) field visits including field observations and focus group discussions with representatives of the municipalities, members of the community such as CAPS and community boards, the Nuevo FISE and representatives of MARENA; and (ii) the administration of three surveys to evaluate communities' socioeconomic characteristics and climate change perceptions, water management, land-use practices in recharge areas, perceptions of water conflict and conflict-resolution mechanisms, and water and sanitation infrastructure.

For the socioeconomic survey the sample was defined to be 40 families per sub-basin (a total of 280 families). For the water management and water and sanitation surveys, the sample was defined to be five communities per municipality (with a total of 35 communities per survey) where water infrastructure was available. Both the water management and water and sanitation surveys were administered to the CAPS or community boards. The final results of these surveys only showcase a sample of 135 families (socioeconomic survey), 11 communities (water management survey), and 23 communities (water and sanitation survey), all within the municipalities of San Ramón, San Francisco de Cuapa, San Juan de Limay, and Cinco Pinos. The rest of the municipalities (Murra and San Dionisio) did not complete the surveys.

* The interdisciplinary team included Patricia Parera (social development specialist), Pedro Pablo Orozco (institutional and watershed management specialist), Alvaro Orozco (water supply and sanitation engineer), and David Bethune (hydrogeologist). The field visits took place from November 13 to 22, 2011. The questionnaires were administered by the municipal authorities. The sample was not drawn randomly and the results are interpreted as indicative and representative only of the households included in the sample, rather than of the entire population within each sub-basin.

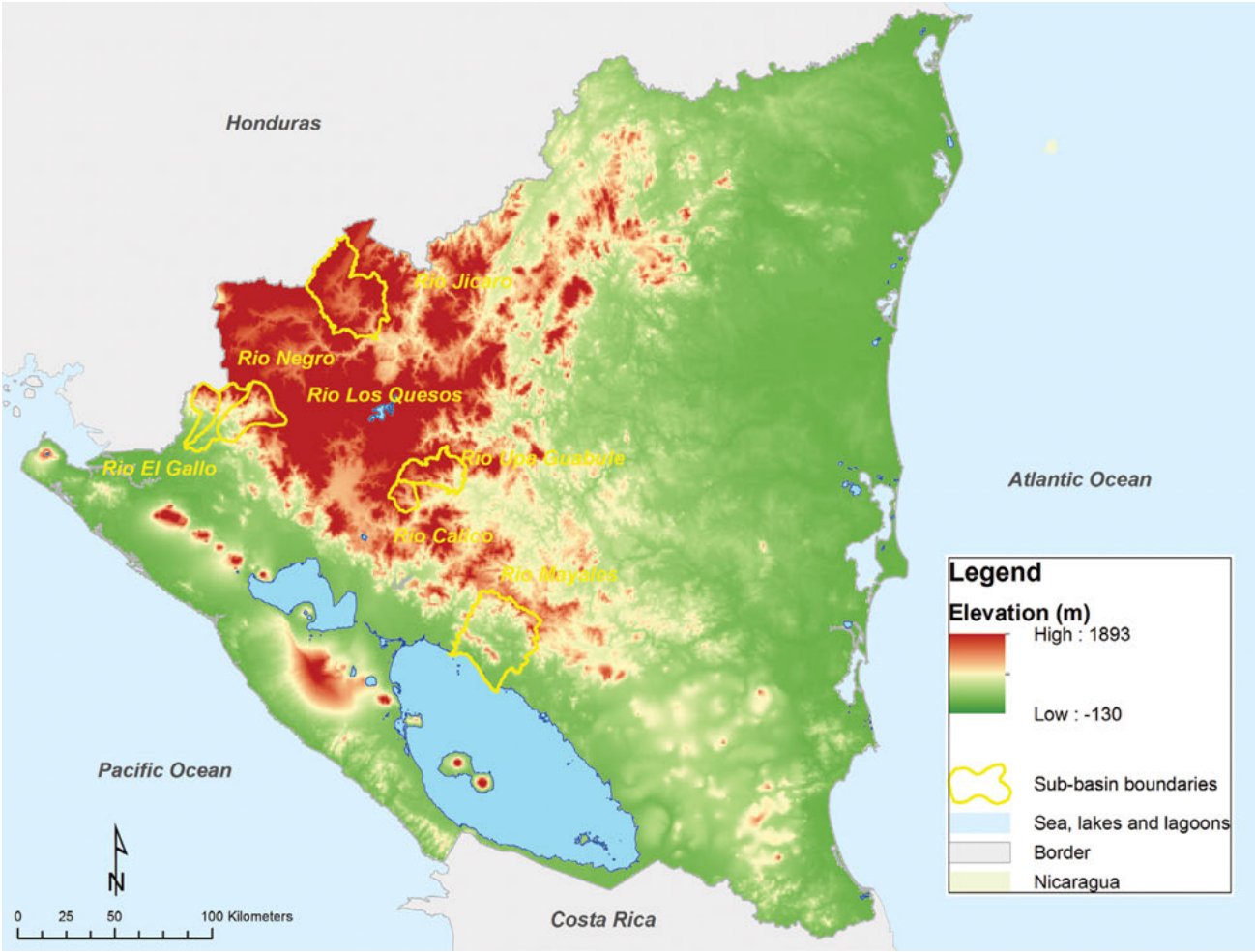
Table 1. Sub-Basins Covered by the Bottom-up Assessment

Sub-basin	Department	Municipality	Micro-basin	Community
Upa Guabule	Matagalpa	San Ramón	Río Yucul, Río Jicaro	San Pablo, Jicaro
Río Los Quesos	Estelí	San Juan de Limay	Comayagua	La Fraternidad
Río El Gallo	Chinandega	Cinco Pinos	Río Las Pozas	Las Pozas
Río Cálico	Matagalpa	San Dionisio *	Jicaro, Susuli	Jicaro, Susuli and Zapote
Río Negro Alto	Madriz	San José de Cusmapa	Río Imire	El Lajero
Río Jicaro	Nueva Segovia	Murra *	Olingo	San Gregorio
Río Mayales	Chontales	Juigalpa and Cuapa	Los Potreros, Mayales Abajo	El Cobano, Las Lajitas, El Melero

Note: *These municipalities were included in the field visit but no questionnaires have been received.

Source: World Bank (2011a).

Figure 12. Location of Sub-Basins Included in the Bottom-up Assessment



Source: Prepared by the authors.

Water sources, types of infrastructure, and pressures from climate change vary across the sub-basins. In the sub-basins surveyed, as elsewhere in the rural areas of Nicaragua, the water infrastructure consists of diverse systems that vary according to the community's location in the basin: manual wells and wells with electric pumps in the lower parts of the sub-basins; and gravity-based micro-aqueducts and micro-aqueducts with pumping systems in the middle and upper parts of the sub-basins. In areas where water infrastructure is unavailable, community members carry water in buckets from either a communal artesian well or nearby surface water sources such as creeks, rivers or springs. According to field observation and expert opinion, current pressures on water resources undermine water security in the areas of the study, and pose a higher risk of increasing water scarcity when coupled with climate change effects (see Box 3).

In a scenario of increasing temperatures, potential drought events, and intense flash floods, water resources of these seven sub-basins are vulnerable in terms of increasing water scarcity and pollution. The following impacts will likely occur: (i) higher frequency and intensity of floods and landslides, triggering more erosion and runoff in the upper part of the sub-basins, and sedimentation and intense runoff downstream; (ii) diminishing groundwater levels with a consequent reduction in spring and aquifer flows, which would tend to worsen during the dry season; and (iii) increasing contamination of water resources such as aquifers and springs due to the transport of pollutants through runoff, overflow of sanitation systems, and soil saturation.

The rapid assessments of the existing water infrastructure in the sub-basins visited also show that some manual wells and even micro-aqueducts are already non-operational due to the drop in water table levels. Systems built over the past 20 years have become obsolete within a few years of operation. Clearly, climate change is posing new environmental conditions and changes to the water balance; thus, the building of new water infrastructure and the retrofitting of existing infrastructure needs to rely on hydrological studies, current climate variability and the expected climate change dynamics.

In the face of climate change, equally important are the location of water infrastructure and its maintenance. There is a high risk of water contamination when wells are surrounded by sanitation works with poor waterproofing and drainage systems, and/or when solid waste and grey-water are disposed in their proximity. Choosing the right location for new wells and building simple live fences around the water source would prevent anthropogenic water contamination. Live fences control the movement of animals and transport of wastes, and act as plant buffer zones to hold sediments and reduce runoff and the transfer of pollutants.

Rural communities are already experiencing the impacts of climate change and are concerned with those impacts. Local consultations with 12 communities within the selected sub-basins, carried out as part of the field assessment, reflect the communities' perceptions and observations regarding the effects of climate change on their livelihoods, as well as their concerns about water availability for household use in the near future. Although communities lack in-depth knowledge about climate change, they perceive that climate risks and uncertainty have increased. They confirm that the occurrence of extreme events, such as floods, droughts, river bank erosion, landslides, storms and heat waves, has increased in recent years (see Box 4).

Box 3. The Hydrology of Nicaragua's Watersheds and the Climate Adaptation Response

Rapid diagnostic field studies of selected sub-basins included rapid hydrological assessments. These were carried out to assess vulnerability to climate change and the adaptation response in the rural water supply and sanitation sector. Based on the results of field studies, it became apparent that the water supply sources in some communities are much more vulnerable to the effects of climate change than in others. The following factors affect the extent of the vulnerability to climate change and the types of required adaptation measures:

- **Rural water supply systems that depend on surface water sources** tend to be the most vulnerable to the effects of climate change. This is the case of the communities of San Pablo, La Fraternidad, El Jícaro, El Jícaro 2 and Susulí. Groundwater-based water supply systems are less vulnerable to the effects of drought and flooding because groundwater aquifers are natural storage reservoirs that can absorb some level of fluctuation in the amount of water available. Within this category, groundwater aquifers with larger recharge areas, such as the aquifers in downstream, flatter regions, are less vulnerable than the aquifers in upstream areas with more mountainous terrain. The water source of the El Cobano belongs to this subcategory.
- **Deforestation and poor land-use management practices in upstream areas** result in erosion and higher runoff during heavy rains and tropical storms. Deforestation leads to a decrease in groundwater recharge and an increase in surface water runoff; this in turn leads to soil erosion and flooding downstream. Soils are easily eroded without deep-rooted vegetation and are less able to infiltrate water downward to the water table. Thus, increasing forest cover in upstream areas is an effective way to enhance water availability in surface and groundwater sources, and to reduce the risk of flooding. Exact types of species and density of vegetation in the recharge areas must be selected to ensure that recharge is maximized, which means that runoff, evaporation and transpiration are minimized. The upper parts of the watershed, where groundwater is recharged, need to be prioritized in terms of land-use management since poor land use in these areas is impacting communities further downstream in the watersheds. In all communities assessed, it was found that more than half of the recharge area was under crop cultivation, cattle raising or both.
- **Water from surface water drainage systems,** which can be mapped and its flow rates measured, needs to be captured and diverted into the ground so that aquifers can be recharged. In addition to increasing storage, water is purified naturally. Artificial diversion and recharge is a well-known engineering practice and includes retention and filtration ponds, trenches or wells. Roads in mountainous areas are notorious for providing a pathway for stormwater runoff and should be constructed in such a way that runoff is captured and filtered into the ground and, if possible, not located in groundwater recharge areas.
- **Water supply systems that depend on shallow groundwater aquifers** are also vulnerable because a small drop in the level of the water table can render the wells dry; the wells are often developed only as deep as the water table in order to save money and effort. As a climate adaptation measure, wells should be developed well below the water table to ensure that they are not vulnerable to drought and are protected from pollution.

  However, because the investment and operating costs of such wells will increase, it is necessary to prioritize the areas where these more costly investments are justified.
- **Poor well maintenance** may also cause disruptions or reductions in water supply. Wells become clogged over time and require periodic cleaning so water can freely enter the well. Community water-supply wells are sometimes not representative of the actual conditions of groundwater because they are sometimes poorly protected from the entry of surface water, are prone to clogging that leads to a reduction in flow, and are often pumped, meaning that the level is not representative of the groundwater. The only way to properly measure water table elevation or groundwater quality is by constructing special, small-scale monitoring wells that are not pumped for water supply. Monitoring wells are needed in order to identify areas where the water table is most vulnerable to changes in recharge and where the additional investment is justified and necessary.
- **Geological conditions** prevailing in rural areas of Nicaragua make the questions of water supply and sanitation inseparable. In the mountains, soils tend to be very thin over fractured rock. Thus, pollution from traditional pit latrines quickly percolates through the soil and into the fractured rock without having enough time to filter and naturally decompose. Polluted water easily and quickly seeps downward through the fractures to the water table. More frequent droughts, anticipated in many areas as a result of climate change, lead to an increase in the vulnerability of groundwater to pollution because there is less dilution with clean rainfall. Thus, the more concentrated pollutant loads from latrines could easily reach water wells or local surface water supplies. It is therefore imperative to continue experimenting with ecological latrines that do not dispose human waste in local soils but instead either treat the waste on site or collect it for transport. Such initiatives have proved challenging because they require behavioral change, but continue piloting these approaches is necessary, especially as the drought conditions become more prevalent in many parts of the country.

Source: Bethune, D. (2012), personal communication.

The findings of the socioeconomic survey further corroborate the concern about the impacts of climate change on the availability and quality of water in rural areas, in addition to the many problems that the rural communities face. Among the sampled households, the average number of family members per household is five; their education level is mainly primary school (84 percent of the sample) and only one percent has reached the university level. The main economic activity (also 84 percent of the sample) is agriculture and 54 percent of the sample receives less than C$1,000 as monthly income and 29 percent receives between C$1,001 and C$2,000. In response to open-ended questions, many households have pointed to the range of solutions that would be needed in order to adapt to climate change, including the strengthening of local institutions (municipalities, potable water and sanitation committees, and other community organizations), environmental education, investment in infrastructure, and protection of water sources (mainly by reducing deforestation, afforestation, and limiting the access of cattle to water sources).

Policy Recommendations and Conclusions

Although the projections of climate models alone are not definitive enough to guide adaptation measures, when combined with the results of field observation they result in a set of clear recommendations to facilitate adaptation to climate variability and change in the water supply and sanitation sector in rural Nicaragua. The three key policy recommendations are: (i) enhancing hydro-meteorological monitoring and baseline information systems, environmental and climate change education and incentives to promote the protection and sustainable use of water sources; (ii) improving the resilience of water and sanitation infrastructure to climate change through traditional and innovative technological solutions; and (iii) strengthening water management institutions at the national, municipal and community levels.

Climate change adaptation requires having in place a comprehensive monitoring and evaluation system. A key characteristic of the system is to make accessible reliable information about current climate variability impacts and potential climate

Box 4. People's Perceptions of their Changing Environment and Climate

An assessment of people's perceptions of climate change impacts was conducted in the seven sub-basins. The perceptions revealed how the communities have been affected by climate changes over the years. According to the community members interviewed, climate risks and hazards are increasing in terms of magnitude, and the frequency and severity of impacts are high compared to past events. The following are literal comments from interviewed community members:

"The climate is hotter compared to 30 years ago, rainfall is more intense, but water flows in creeks, rivers and wells have decreased."

"15 years ago this basin never went dry."

"We have experienced crop losses due to lack of rain and to intense and abundant rainfall."

"During the tropical storm of 2011, we were locked in this place for 15 days, with no means of communication or transportation."

"Water levels of wells have lowered and the wells are no longer operational."

change impacts to decision makers and the public at large. Nicaragua needs to continue making efforts to improve its hydro-meteorological monitoring system and conduct climate change impact analysis and vulnerability assessments based on latest research, data, modeling tools and lessons from experience.

Adaptation to climate variability and climate change impacts in Nicaragua's rural water and sanitation sector needs to be framed at the local level through an integrated, coordinated, multi-sectoral risk management strategy. Adaptation strategies such as low-cost and sustainable water-harvesting technologies and investment in climate-resilient infrastructure will be more effective when combined with long-term planning for climate change adaptation, the strengthening of water resources management institutions, and adoption of incentives to promote sustainable use and protection of water sources.

Potential adaptation options can be categorized as "no regret" and those that are "climate justified". Many of the options to reduce vulnerability to climate variability are no different in a world with climate change than they are in the baseline scenario without climate change. They include demand-management measures to increase water-use efficiency and productivity, such as water-conserving irrigation technologies; wastewater recycling; economic incentives including water pricing; and the encouragement of water markets, where the institutional conditions are right, that move water to high-valued uses. They also include, for example, measures to improve early-warning systems and risk management (e.g., disaster insurance). These are "no regret" options because they would generate net social and/or economic benefits regardless of whether or not climate change occurs. On the other hand, other actions might only be justifiable in the climate change scenario. "Climate-justified" measures may include constructing new infrastructure (dams, water conveyance systems, irrigation systems), retrofitting existing infrastructure, changing rules of operation, tapping new sources of water (e.g., desalination, wastewater reuse), water transfers, joint use of surface and groundwater, and innovative demand management, among others. However, many of these measures may be of the "no regrets" type, depending on the specific circumstances. Whether they belong to one or the other category will have to be determined on a case-by-case basis (Alavian et al. 2009).

Water metering, rain harvesting and storage, construction of new wells and retrofitting of old ones, and watershed protection are among the main interventions to be included in an adaptation program for Nicaragua's rural water supply sector. The field assessment of the seven sub-basins concluded that these demand- and supply-side management measures could address the current and future climate change impacts faced by communities. Adaptation works should also focus on restoring the natural water balance and managing both droughts and intense rainfall. Specific adaptation works may include: (i) rain harvesting on roofs, and underground storage through gravel drains; (ii) runoff harvesting and underground storage through gravel drains, mini-trenches, or filtration ponds; (iii) watershed restoration, especially in the upper parts of basins, using reforestation and organic agricultural programs to limit the load of chemicals in the water; (iv) protection of water sources (springs and wells) from agricultural and latrine pollution; and (v) construction of horizontal wells on hillsides to capture groundwater, thus limiting the use of pumps. The design of these works should nevertheless be based on hydrological studies in order to thoroughly understand the actual state of the water balance. The studies would provide accurate tools

to develop informative, effective and sustainable adaptation solutions.

Demand- and supply-side management measures should be complemented by community-driven development and community-driven disaster risk management. This approach consists of integrating the social dimensions of climate change in the adaptation program for rural Nicaragua's water supply sector in order to strengthen the existing adaptive capacity of communities and local institutions and build long-term resilience. These would help design and implement community-based development and institutional strengthening activities that enhance local people's capacity to adapt to climate variability and volatility. Effective local adaptation requires local institutions that are responsive and adaptive to the uncertainties associated with climate change. Institutions shape adaptive capacity at the local and national levels and are critical in ensuring that the results of adaptation efforts match their intentions. In order to function effectively, they must be transparent and accountable to citizens (World Bank 2011b).

Water infrastructure improvement needs to be implemented in conjunction with water resources protection programs that would increase resilience to climate change. Many sustainable land uses could help reduce the impact of changing precipitation patterns by helping to: (i) increase filtration, (ii) reduce runoff, (iii) reduce erosion, and/or (iv) anchor hillsides to reduce the risk of landslides. Land-use practices that increase filtration, for example, would help reduce the impact of more intense and more variable rainfall by reducing the portion that is lost to runoff. Ensuring that such land uses are adopted or maintained in areas that supply water systems would thus help protect them from the impact of climate change. Among the practices that would help reduce the impact of climate change on water supplies are practices that incorporate considerable tree cover in cropland and pastures (i.e., agroforestry and silvopastoral practices) which are particularly attractive because they are usually profitable for farmers once established, and they provide additional income and reduce costs by requiring lower input levels and by diversifying production. They are also adaptive for farmers, because they can reduce in situ temperatures and because they are less vulnerable to damage from more intensive rainfall. In some cases, agroforestry or silvopastoral practices will be insufficient to provide the necessary level of protection to water sources: for example, where slopes are too steep or where proximity to potable water sources makes the presence of livestock or intensive crop production unacceptable. In such cases, land uses such as reforestation are likely to be necessary to protect water sources from the impact of climate change.

Municipal-level planning in support of climate change adaptation in the sector needs to accompany measures that seek to change local-level water infrastructure, water resources management and land use practices. Effective planning tools to guide municipal-level investment in the water supply and sanitation sector and to guide complementary investments to protect water sources and increase their resilience to climate variability and climate change are urgently needed in vulnerable areas. The methodologies for adaptive planning in the water supply and sanitation sector have been tested elsewhere in the region, but no one-size-fits-all solutions are available. In order to be effective, adaptation planning needs to be informed by technical data on the current and future climatic pressures, other socio-economic and institutional factors that affect the availability and reliability of water supplies, and set clear priorities and an action and investment agenda. In Nicaragua, MARENA has piloted the application of Municipal-Level Climate Change Adaptation Strategies in the water

sector. Jointly with other relevant agencies (the New Emergency Social Investment Fund and the National Water Authority), MARENA is now planning to expand the scope of the strategies and develop them as a tool for guiding the design of investment programs at the municipal level that integrate climate adaptation considerations in the package of infrastructure and watershed protection measures.

The policy recommendations and conclusions resulting from this study are framed within Nicaragua's national context and specifically in accordance with its National Climate Change Strategy (NCCS). The NCCS, developed as a mandate of the National Development Plan, is aimed at strengthening national and local capacities for climate change adaptation and mainstreaming climate change in the country's policy planning, municipal and regional government plans. The NCCS has five strategic pillars: (i) environmental education; (ii) natural resources protection; (iii) water resources conservation and restoration, and water harvesting; (iv) climate change adaptation and mitigation, and risk management; and (v) sustainable land use. The action agenda includes specific projects for each pillar, such as: (i) implementation of forest management programs for ecosystem restoration and water conservation; (ii) implementation of a National Program for Water Harvesting in priority watersheds; (iii) design and implementation of adaptive measures to cope with climate change, including construction of wells and aqueducts, rainwater harvesting and storage, climate-resistant seeds, and crop diversification; (iv) strengthening of climate and meteorology information systems and early warning systems; and (v) implementation of watershed management programs for water quality and flow conservation.

Together with MARENA they taking the lead in bringing together international partners and donors to design and implement adaptation plans in the most vulnerable watersheds and rural communities. In the water supply and sanitation sector, MARENA is engaged in the process of developing the environmental sustainability and climate adaptation pillar of the Master Plan for the Water Supply and Sanitation Sector, currently under preparation in Nicaragua. The policy recommendations and conclusions in this paper are expected to contribute to the design of informative and effective adaptation strategies in the Master Plan and more broadly for the rural water supply and sanitation sector of Nicaragua.

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Annex A. Methodology Used in the Analysis to Assess Hydrological Impacts of Projected Climate Change

Global circulation models (GCMs) are systems that use quantitative methods to enhance the understanding and prediction of future climate change, including calculating as accurately as possible what would happen to surface temperature, precipitation and other climate-related variables. GCMs have mostly been designed to examine mitigation needs and are not well suited to examining adaptation requirements, although their use for this purpose has been growing (Schiermeier 2007; Wilby et al. 2009; Xu et al. 2009; Kundzewicz and Stakhiv 2010; and Wilby 2010). Available GCMs are too coarse and do not necessarily focus on the variables of most interest for adaptation. Because of climate change, previous hydrological patterns provide poor guidance to future water management needs (Milly et al. 2008). Minville and others (2008) find that the predicted effect of climate change on hydrology is strongly dependent on the GCM used; they recommend interpreting with caution any estimates that rely on a single GCM. In many areas, GCMs tend to vary substantially on how precipitation will be affected, and they disagree on the magnitude and even the sign of the change (Nohara et al. 2006; Bates et al. 2008; and Kundzewicz et al. 2008).

In its Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (MARENA 2008b), Nicaragua used the HadCM3 and ECHAM4 GCMs, under emission scenarios A2 and B2, and then used PRECIS to generate more detailed estimates of the impacts of climate change. These models estimate temperature increases of 3°C to 4°C in the 2071–2099 period, with increases being particularly marked in the period between July and October. However, predicted changes in precipitation for the same period varied substantially, ranging from increases of 40 to 60 percent to decreases of 50 to 60 percent.

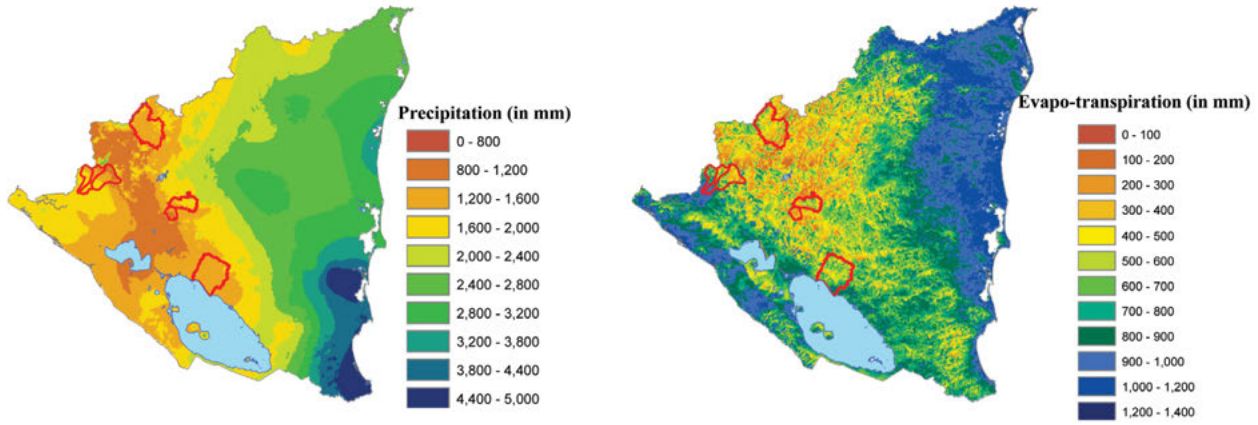
For the assessment of the impacts of climate change on Nicaragua's hydrology, two web-based tools—AguAAndes and Climate Wizard—were used. A brief description of each of these tools is provided below.

- **Climate Wizard** (www.climatewizard.org) is a web-based platform developed by the Nature Conservancy, the University of Washington, and the University of Southern Mississippi. The system provides historic temperature and precipitation data and maps for everywhere in the world and future predictions of the same variables around the globe at a resolution of 12 or 50 square kilometers (km^2). Climate Wizard uses two common approaches to represent climate change data: comparing climate in a given year or time period to a baseline period, and calculating statistical climate trends over a time period of interest using linear trend analysis that accounts for the time-series nature of climate data. This tool allows the selection of the area of interest (the entire country of Nicaragua or any other customized area) and the visualization of the climate change that has occurred to date as well as the climate change that is predicted to occur in the future under the A2, A1B and B1 greenhouse gas emission scenarios.

- **AguAAndes** (www.policysupport.org/aguaandes) is a web-based, free policy support system based on the FIESTA hydrological model and other previous policy support systems. AguAAndes is a test bed for the development and implementation of climate and land-use changes as well as water and land policies and management interventions. It incorporates detailed spatial datasets at 1-km^2 and 1-hectare resolution globally, temporal datasets at monthly resolution, and spatial models for biophysical and socioeconomic processes. It provides scenario tools for climate change and land-use changes, and allows visualization, analysis and download of all output variables. The developers of this tool recommend its use when there is no hydrological baseline or limited local data (as it is the case in Nicaragua). A quick and detailed assessment of the projection of climate changes or deltas is however required. AguAAndes[7] is one of the few tools freely available that allows non-experts to "apply downscaled ensemble climate change and land use change scenario to the hydrological baseline" (Muligan and van Soesbergen 2011).

The first step in the simulations for Nicaragua was to generate the baseline using AguAAndes. This baseline represents the year 2000 in terms of land use and land cover, and the mean of the 1950–2000 period for the climate variables. The area of analysis was defined with a 10-degree tile at 1-km resolution, with boundaries 20° North, 10° South, -90° East, and -80° West. Before running the hydrological model, the required data were prepared. AguAAndes performs this automatically and organizes about 150 files at 1-km spatial scale that correspond to the geographical 10-degree tile containing the area of interest. The baseline climate and

Figure A.1. Precipitation and Evapo-transpiration for the Baseline Period (1950–2000)

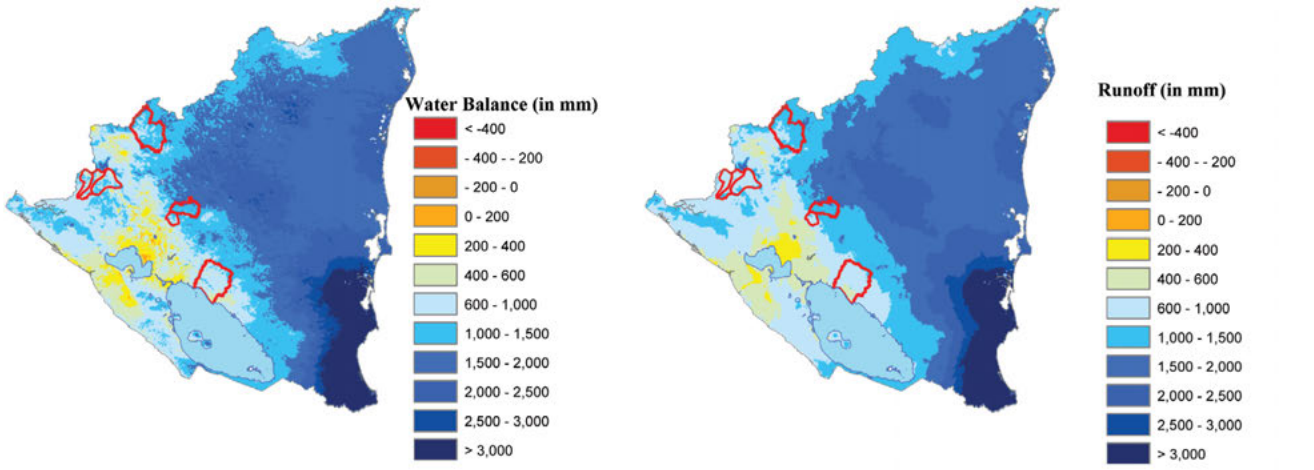


Note: Sub-basins where the bottom-up assessment was conducted are shown with red border.

Source: Prepared by the authors.

7 WaterWorld, the global version of the AguAAndes model, is available at the following address: www.policysupport.org/waterworld.

Figure A.2. Water Balance and Runoff for the Baseline Period (1950-2000)



Note: Sub-basins where the bottom-up assessment was conducted are shown with red border.

Source: Prepared by the authors.

Table A.1. Global Climate Change Models Available in Climate Wizard for Scenario A2

Model	Developer	Country
BCCR-BCM2.0	Bjerknes Centre for Climate Research	Norway
CGCM3.1(T47)	Canadian Centre for Climate Modelling & Analysis	Canada
CNRM-CM3	Météo-France/Centre National de Recherches Météorologiques	France
CSIRO-Mk3.0	CSIRO Atmospheric Research	Australia
GFDL-CM2.0	US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory	USA
GFDL-CM2.1	US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory	USA
GISS-ER	NASA/Goddard Institute for Space Studies	USA
INM-CM3.0	Institute for Numerical Mathematics	Russia
IPSL-CM4	Institut Pierre Simon Laplace	France
MIROC3.2 (medres)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan
ECHO-G	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data Group	Germany/ Korea
ECHAM5/MPI-OM	Max Planck Institute for Meteorology	Germany
MRI-CGCM2.3.2	Meteorological Research Institute	Japan
CCSM3	National Center for Atmospheric Research	USA
PCM	National Center for Atmospheric Research	USA
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research/Met Office	UK

Source: Climate Wizard available from: http://www.climatewizard.org/FAQ.html.

non-climate variables available for analysis included rainfall, water balance, runoff, evapo-transpiration, mean temperature, soil erosion, among others. The data and maps generated by AguAAndes were downloaded in ASCII grid format (see Figures A.1 and A.2).

The second step of the climate change assessment consisted of analyzing the change in temperature and precipitation for various GCMs using data provided by Climate Wizard. The projected changes in temperature and precipitation for Nicaragua were carried out under the A2 emission scenario and used the 16 GCMs available in Climate Wizard (Table A.1).

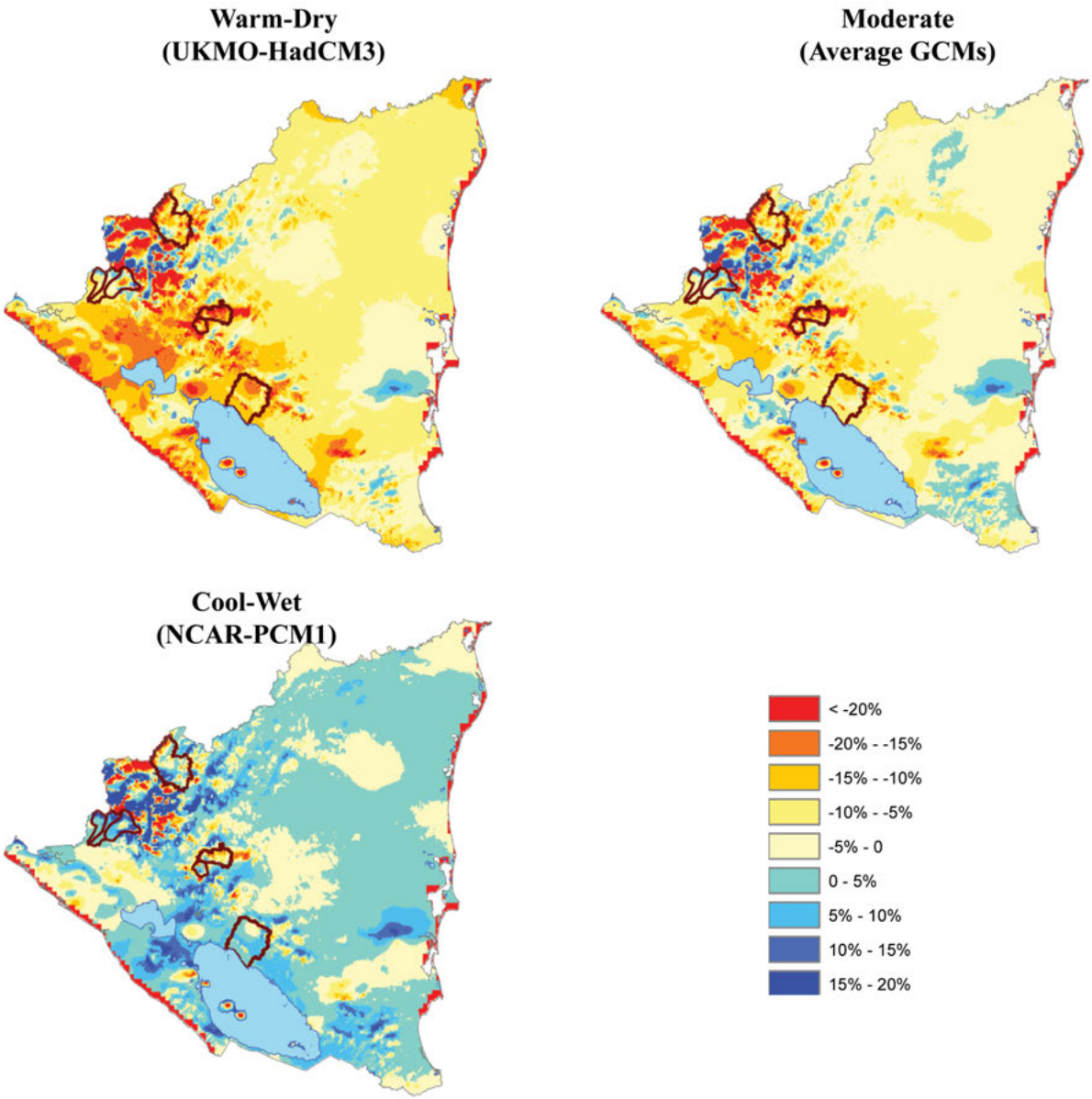
Although the A2 scenario is considered the less conservative one (even though it is not the highest of the IPCC emission scenarios through 2100), according to actual evidence it seems that current greenhouse gas emissions are above the A2 emission projections. Furthermore, differences in the projections issued from various emission scenarios for the same GCM are considered not generally significant from the 2050s time horizon.

For every GCM, maps of temperature change and precipitation change were developed for a total of 32 maps (see Figures 7 and 8 in main text). Each map represents the temperature or precipitation change projected by the specific climate model run under the A2 scenario for 2040–2069 as compared to 1961–1990. The 32 maps were downloaded in .txt format and converted into raster (.img format) using ARC Catalog. The resample function of ARCGIS was used to change the cell size of all raster maps to 0.5 degrees. Each map was then overlapped with a macro-watershed map of Nicaragua to facilitate analysis at the basin level. In order to do that, the coordinate systems of the raster maps were configured in the same coordinate systems of the macro-watershed map.

The next step involved the definition of the three possible future scenarios: a warm-dry future scenario, a cool-wet future scenario, and a moderate future scenario. Making use of the maps showing the changes in temperature and precipitation, two extreme models were selected to represent the warm-dry and cool-wet future scenarios. This was done in order to have a sense of the likely upper and lower bounds on possible effects. For the country as a whole, the UKMO-HADCM3.1 model represents the warm-dry future scenario and the NCAR-PCM1.1 model represents the cool-wet future scenario. The average of the 16 GCMs was used to represent the moderate future scenario.

Once the future scenarios were defined, hydrological simulations were run for each of the scenarios, using AguAAndes. For each of these three future scenarios, changes in hydrological parameters by the 2050s (2040–2060) compared to the baseline period (1950–2000) as well as absolute values for the future scenario and the baseline were obtained: (i) evapo-transpiration, (ii) surface runoff, and (iii) water balance (the difference between precipitation and evapo-transporation). The results of these simulations were downloaded in raster format for each hydrological variable. Results are presented in Figures A.3, A.4, A.5, and A.6.

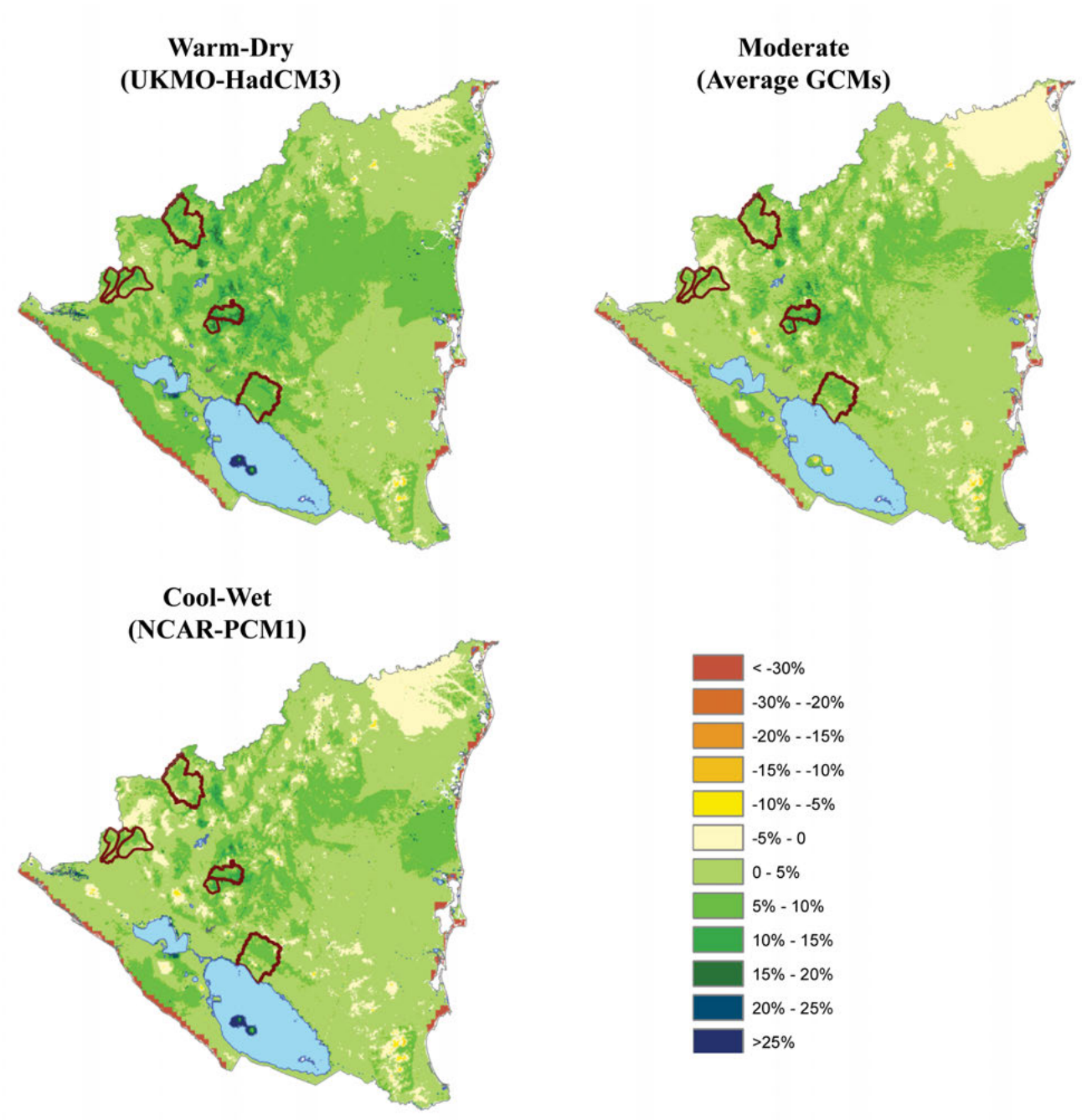
Figure A.3. Expected Changes in Precipitation in the Warm-Dry, Moderate and Cool-Wet Future Scenarios



Note: Sub-basins where the bottom-up assessment was conducted are shown with a brown border.

Source: Prepared by the authors.

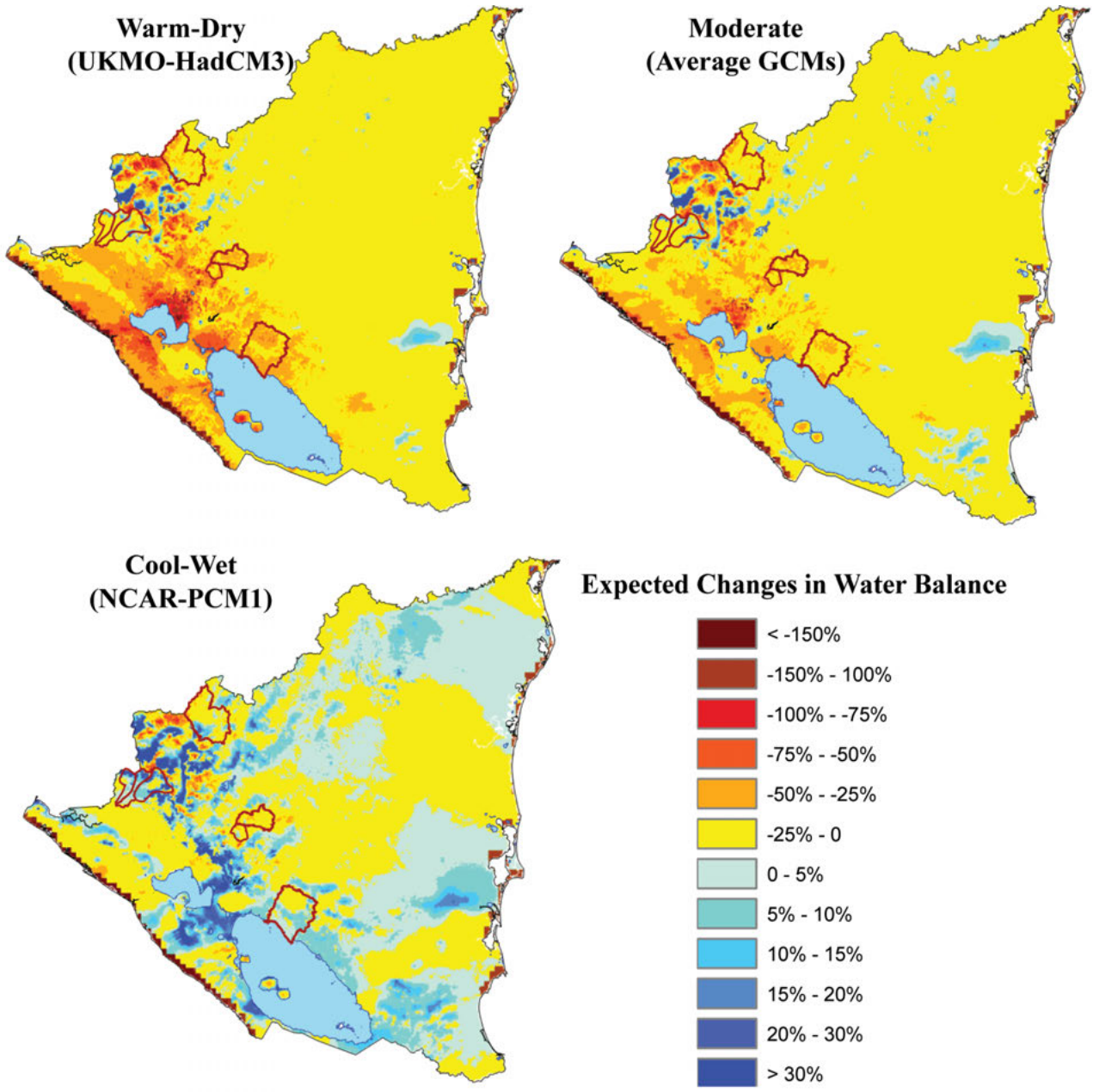
Figure A.4. Expected Changes in Evapo-transpiration in the Warm-Dry, Moderate and Cool-Wet Future Scenarios



Note: Sub-basins where the bottom-up assessment was conducted are shown with a brown border.

Source: Prepared by the authors.

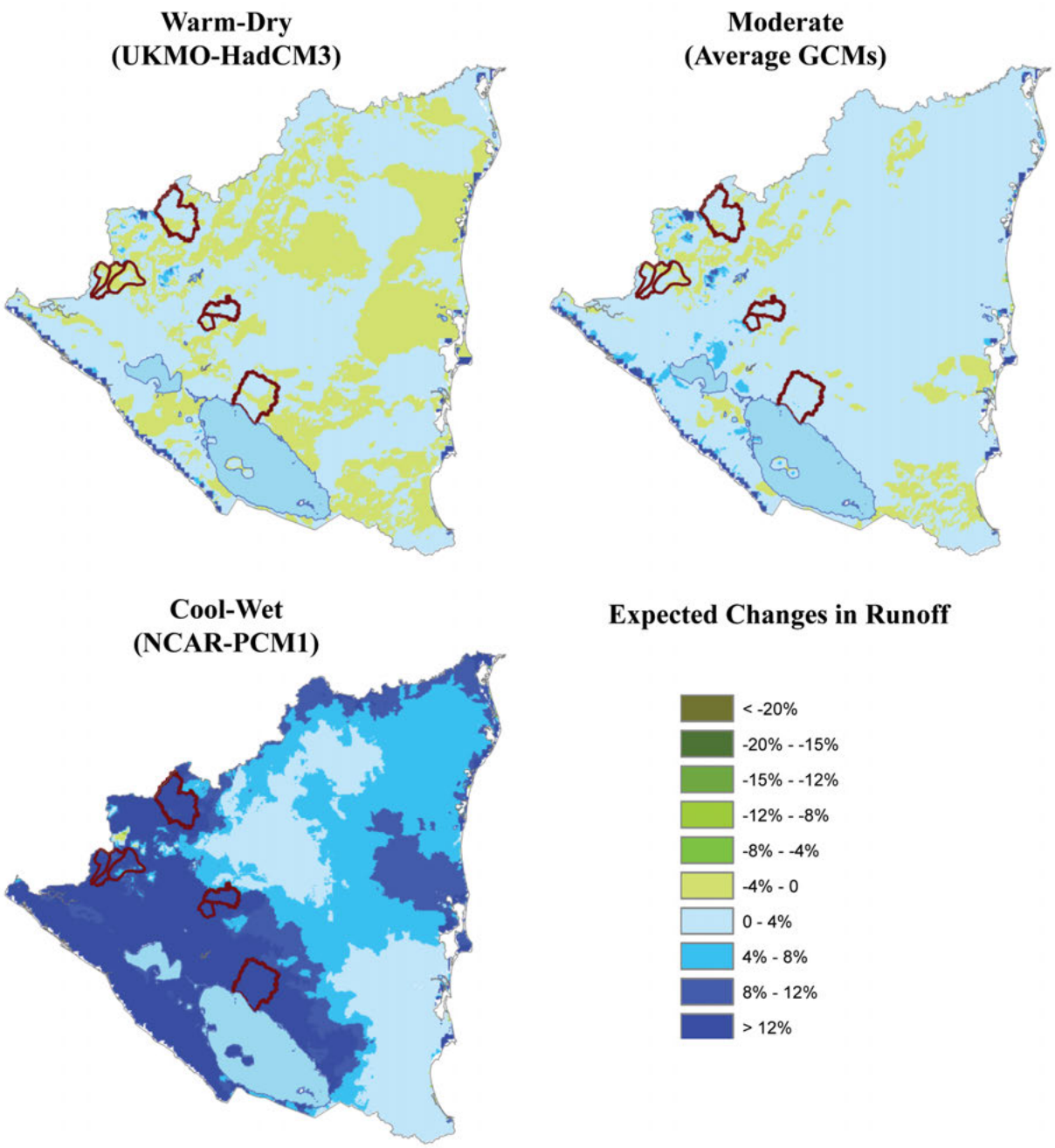
Figure A.5. Expected Changes in Water Balance in the Warm-Dry, Moderate and Cool-Wet Future Scenarios



Note: Sub-basins where the bottom-up assessment was conducted are shown with a brown border.

Source: Prepared by the authors.

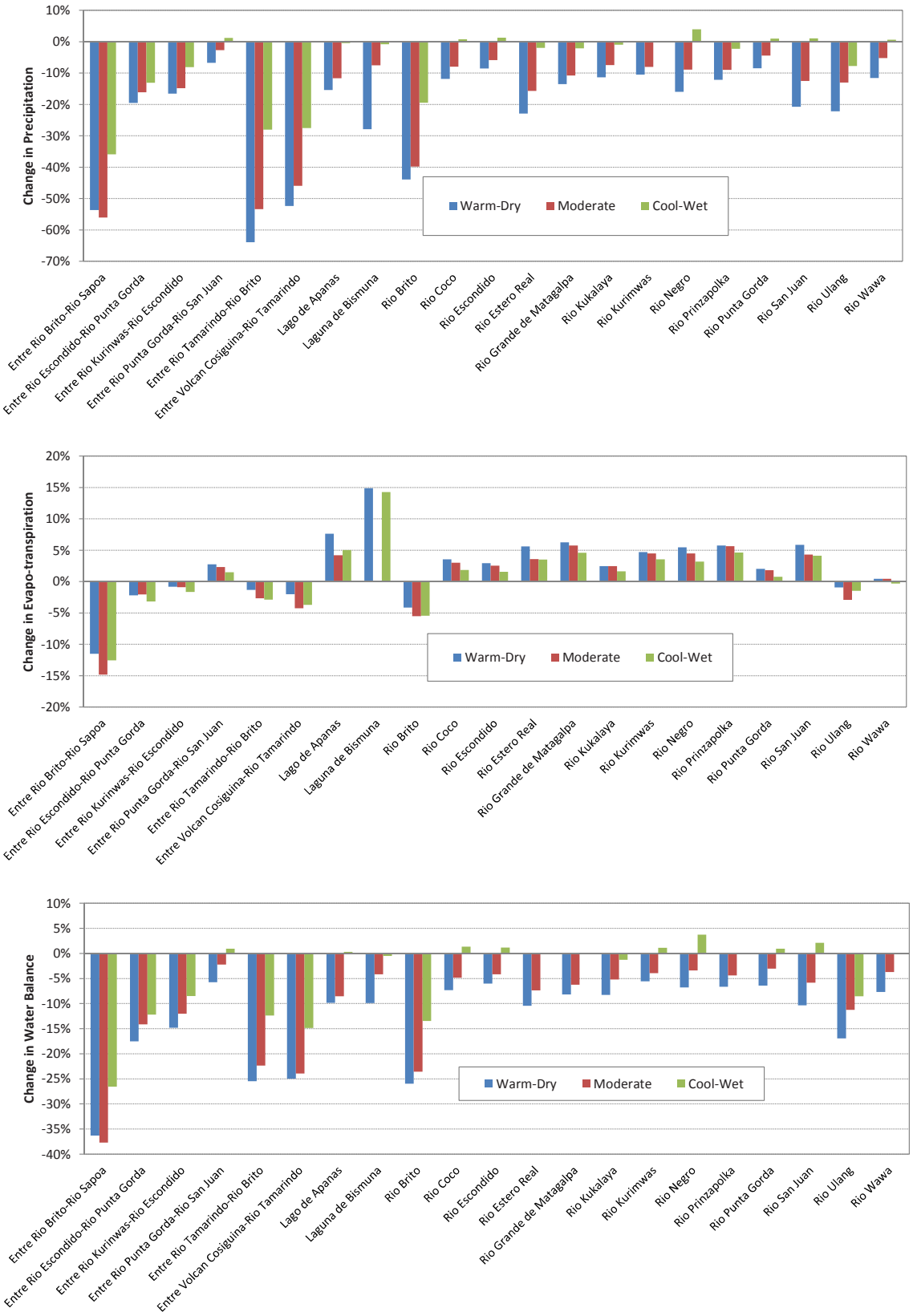
Figure A.6. Expected Changes in Runoff in the Warm-Dry, Moderate and Cool-Wet Future Scenarios



Note: Sub-basins where the bottom-up assessment was conducted are shown with a brown border.

Source: Prepared by the authors.

Figure A.7. Projected Changes in Precipitation, Evapo-transpiration and Water Balance



With the help of Arc Map and the Spatial Analyst extension, projected changes in hydrological variables were calculated for each of the 21 basins (see Figure A.7 and Figure 10 in main text). Although there is no agreement on the direction of projected changes in precipitation across the three scenarios in each of the basins analyzed, the net impact of climate change on the water balance of 14 basins is negative for the three future scenarios considered (Table A.2 and Figure A.8).

Table A.2. Direction of Change of Precipitation, Evapo-transpiration and Water Balance by Basin

Basin	Precipitation	Evapo-transpiration	Water Balance
Between Río Brito–Río Sapoa	↓	↑	↓
Between Río Escondido–Río Punta Gorda	↓	↑	↓
Between Río Kurinwas–Río Escondido	↓	↑	↓
Between Río Punta Gorda–Río San Juan	?	?	?
Between Río Tamarindo–Río Brito	↓	↑	↓
Between Volcan Cosiguina–Río Tamarindo	↓	↑	↓
Lago de Apanas	?	?	↓
Laguna de Bismuna	↓	?	↓
Río Brito	↓	↑	↓
Río Coco	?	?	?
Río Escondido	?	?	?
Río Estero Real	?	?	↓
Río Grande de Matagalpa	↓	?	↓
Río Kukalaya	↓	?	↓
Río Kurimwas	?	?	↓
Río Negro	?	?	?
Río Prinzapolka	↓	?	↓
Río Punta Gorda	?	?	?
Río San Juan	?	?	?
Río Ulang	↓	↑	↓
Río Wawa	↓	?	?

Note: Rows in green are for basins draining into the Pacific Ocean.

Source: Prepared by authors.

Figure A.8: Direction of Change by Basin

Source: Prepared by authors.

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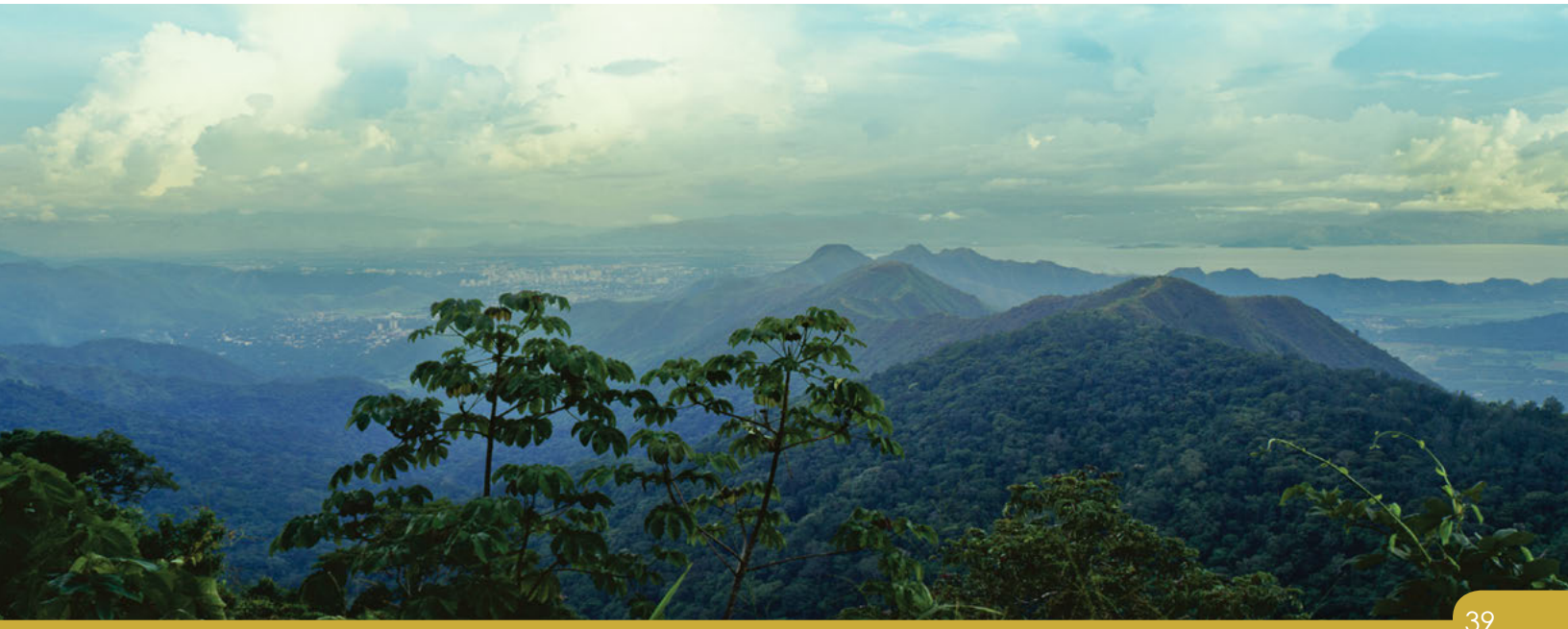

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