Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Alberto Vega and Roberto Jiménez
Fernando Miralles-Wilhelm and Raúl Muñoz Castillo

Nordic Development Fund

IDB
Inter-American Development Bank

This monography is part of the knowledge products of the Water and Sanitation Division (WSA) of the Inter-American Development Bank (IDB), carried out under the direction of the Division Chief Sergio I. Campos G. This monography is part of a series of case studies of adaptation to climate change directed by Fernando Miralles Wilhelm supported by Raúl Muñoz Castillo and inputs from other members of the Division, especially those of Jorge Ducci. Anamaría Núñez has supported in the editing and publication process.

IDB would like to thank the Nordic Development Fund (NDF) for the financial support provided to this study.

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua / Alberto Vega, Roberto Jiménez, Fernando Miralles-Wilhelm, Raúl Muñoz Castillo.

p. cm. — (IDB Monograph; 360)

Includes bibliographic references

1. Water-supply—Nicaragua. 2. Water resources development—Nicaragua. 3. Climate change mitigation—Nicaragua. 4. Environmental protection—Nicaragua. I. Vega, Alberto. II. Jiménez Roberto. III. Miralles Wilhelm, Fernando. IV. Muñoz Castillo Raúl. V. Inter-American Development Bank. Water and Sanitation Division. VI. Series.

IDB-MG-360

JEL code: Q01; Q25; Q53; Q54; Q56; Q57; F63; F64

Keywords: Sustainable development, water, climate change, adaptation, economic development, IDB, Inter-American Development Bank, environment, Nicaragua, Water resource management, Latin America and the Caribbean, Fondo Nórdico de Desarrollo (NDF)

http://www.iadb.org

Table of contents

Tables

List of figures

Prefase

The Inter-American Development Bank (IDB) has recognized that its activities in the countries of the Latin America and Caribbean (LAC) region have significant potential to be impacted by the effects of climate change. This is particularly the case for projects in the water and sanitation (WSA) sector that are currently in planning and execution stages in the region. Most adaptation experiences in the WSA sector have been developed at a global scale, with limited experience existing at a local level (e.g., at the basin scale). This gap presents the challenge of developing on-the-ground knowledge that deepens the IDB's expertise on adaptation to climate change in the WSA sector and helps to define policies and better practices in adaptation at the regional and country levels. This is specifically applicable to countries in Central America.

The objective of this Technical Cooperation project is to support the process of increasing climate change adaptation capacity in communities in Central America. By taking into consideration the range of possible risks and vulnerabilities, plans for future investments in water and sanitation infrastructure can integrate concepts that reduce vulnerability and increase resilience to climate risks, leading to more sustainable development outcomes.

Forecasts of climate change for Central America suggest increased climate variability in the future, which is expected to translate into more severe droughts in the dry season, and increased frequency and intensity of rainfall events during the rainy season. The latter is a particular issue in Managua, Nicaragua, where recent events highlight the existence of significant stormwater drainage challenges, resulting in impacts to communities and the economy.

This case study exemplifies a potential approach that may be used to understand the impacts that increased precipitation intensity would have in a relatively large populated area, and identify the corresponding infrastructure and policy-based adaptation measures that can be implemented in response.

The outcome of this adaptation experience has yielded useful elements for the definition of an alternative strategy to conventional stormwater management, one that places the focus on reducing runoff rather than managing its conveyance.

Lessons learned in Managua are likely to be applicable to other efforts in the region where addressing flood-prone areas in urban settings is a top priority. Going forward, the results of this Technical Cooperation project will be used to inform the design of local and targeted adaptation measures to address climate change impacts in the WSA sector.

1. Introduction

Environmental Resources Management (ERM) was appointed by the Inter-American Development Bank (IDB) to perform an analysis of the potential impacts that climate change could have on the water resources in and around the City of Managua, and to identify potential adaptation measures. This process focused on:

- Understanding the potential effects that climate change induced changes on variables such as rainfall frequency and intensity may have on the local water cycle, including the extent and recurrence of urban flooding; and,
- Conducting, in consultation with local stakeholders, an analysis and prioritization of the adaptation measures that can be implemented to reduce vulnerability to those impacts.

The IDB approved[1] the development of this case study under a Technical Cooperation aimed at increasing climate change adaptation capacity in communities throughout Central America, with a focus on building resilience through targeted infrastructure investments in the Water and Sanitation (WSA) sector.

Managua is an example of a city in Latin America faced with the challenge of adapting to increasing hydrologic extremes, and the consequences these may have in a densely populated urban setting (e.g., flash floods and inundation events of increasing extent and duration). It is expected that this adaptation experience can support local policy-makers in understanding and responding to both future and present risks.

This case study was developed by ERM in close collaboration with the Mayoralty of the City of Managua[2] (ALMA), the Inter-American Development Bank, and other key local stakeholders. Engagement with the relevant local stakeholders has been critical in identifying adaptation options most suitable in this context.

The adaptation process documented in this study provides key lessons that can be leveraged by adaptation planners and city governments in the region to undertake similar adaptation processes. This study provides key messages around the following areas: i) assessment of climate change vulnerability, ii) prediction of future climate-related hazards, iii) identification and evaluation of viable cost-effective adaptation measures, and iv) prioritization of potential future investments for their implementation.

1. This case study was developed in accordance with the tasks outlined in the Work Plan document that ERM submitted on March 8, 2013, and which was subsequently approved by the IDB. In reference to that Work Plan, this report fulfills the requirements listed in *Task 1: Development and Implementation of Case Study on Adaptation* for the City of Managua, Nicaragua.
2. Alcaldía de Managua, in Spanish. Referenced throughout the document by its Spanish abbreviation, ALMA.

1.1 Purpose of This Case Study

In consultation with a diverse set of local stakeholders, and in coordination with the IDB, ERM set out to undertake a process featuring the following objectives:

- Evaluate the impacts on communities, water and sanitation assets, and resources due to climate change, especially those that can result from urban flooding;
- Characterize the areas of greatest vulnerability considering physical and climatic aspects (e.g., hydrology, flood risk, existing infrastructure) and socioeconomic characteristics (e.g., demographic trends, income);
- Formulate possible adaptation options aimed at reducing assessed risks and/or vulnerabilities;
- Select an adaptation option on the basis of stakeholder feedback and several criteria such as effectiveness, institutional capacity for implementation, acceptance by the community, among others, and;
- Promote knowledge transfer by actively engaging local government and civil society stakeholders (via two workshops in Managua).

1.2 Scope of the Adaptation Process

The adaptation process carried out in Managua focused on building adaptive capacity and resilience in the water and sanitation sector, specifically in response to increased hydrologic extremes in Managua. Based on a general understanding of future climate change, ERM and the IDB proposed initially to examine the potential risks associated with (1) the rise in Lake Managua's water level, and (2) urban flooding.

In the planning stage, both hazards – Lake Managua water level rise and urban flooding – were thought to have a high likelihood of significant impacts to communities in Managua. However, initial consultations yielded a better understanding of key stakeholder priorities. The feedback provided by ALMA, as a primary stakeholder in the adaptation process, was central in defining the scope of the study.

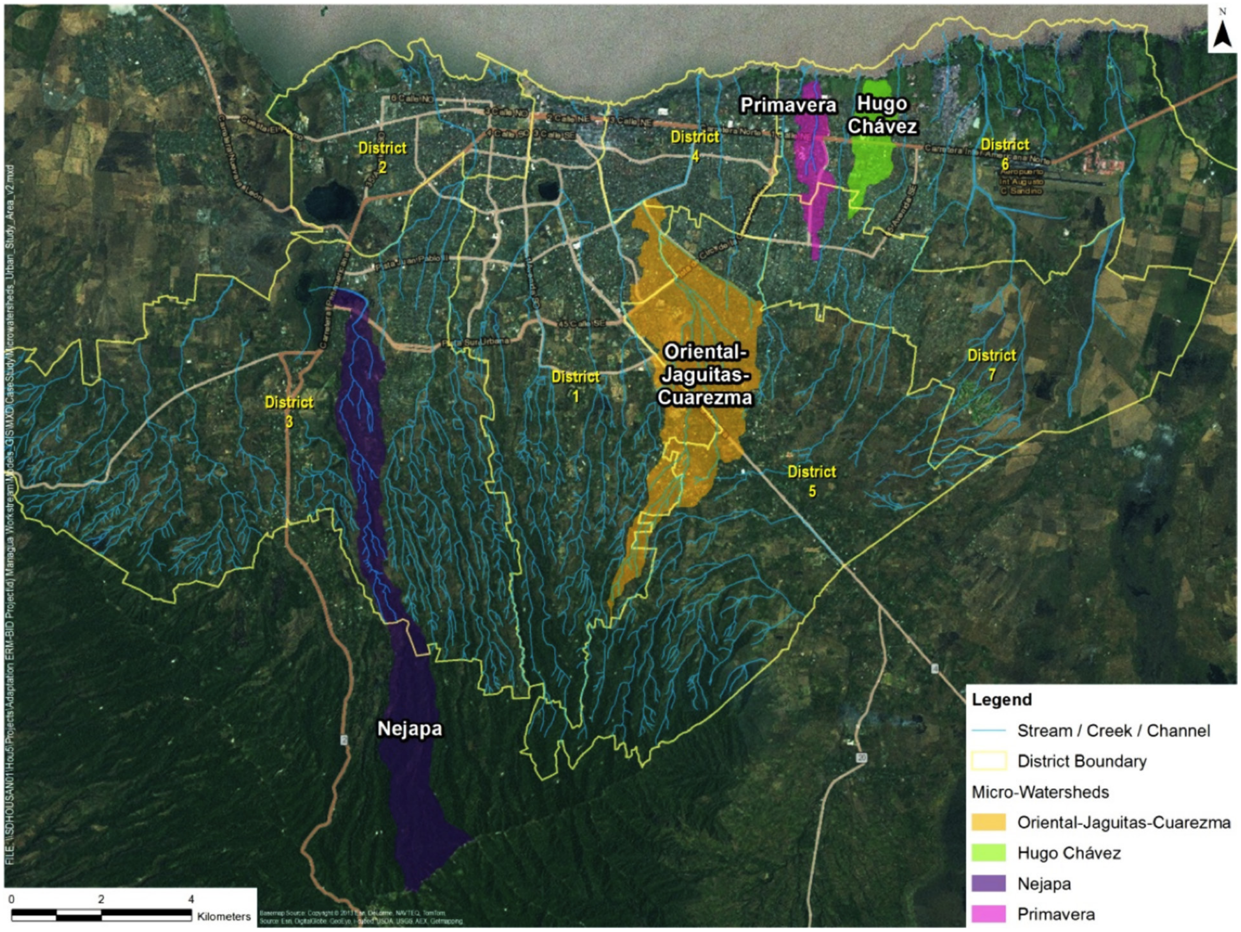
While the risks related to flooding from storm-related rises in the lake's water level were acknowledged, ALMA officials highlighted that addressing the already critical urban drainage challenges in Managua was a top priority. Therefore, there was an agreement to prepare a general water balance of Lake Managua using the monthly averages of relevant climatic variables and existing land use information. This balance is a model in Excel that can be used to forecast the potential changes in lake surface elevation under different scenarios.

Initial engagement with ALMA also yielded clear expectations in terms of adaptation outcomes. The main expectation revolved around the need for the adaptation process to identify investments that could allow the city to pilot approaches for alleviating urban flooding and set the stage for development of an urban drainage master plan at the municipal level.

As the first step in defining the scope of the adaptation process, ERM delineated four study areas based on the location of a number of critical inundation hotspots[3] within the city. These areas were delineated according to the boundaries of the watersheds in which the critical points were located. Specifically, these areas corresponded to small drainage areas, or micro-watersheds, within the greater sub-basin II, which flows into Lake Managua. Figure 1-1 shows the four micro-watersheds proposed for the initial hydrological analyses.

3. ALMA identified these critical locations based on a risk study of a natural disaster that occurred in 2004 and based on ALMA's knowledge of areas presenting high flooding risk.

Figure 1-1: Initial Scope of the Adaptation Process



Source: ERM, 2013.

Following the identification of the four urban micro-watersheds – Primavera, Hugo Chavez, Nejapa, and Oriental-Jagüitas-Cuarezma - ERM proceeded to undertake hydrological analyses on these study areas. The preliminary results were presented to ALMA and other key stakeholders during a workshop held in Managua in July 2013. Following the workshop, ALMA agreed that subsequent analyses would focus only on the Oriental-Jagüitas-Cuarezma (OJC) micro-watershed, since this was viewed as the most dynamic of the four micro-watersheds modeled in terms of its potential future land use change, as well as containing the largest number of current critical flood areas (hot spots). During the modeling and analysis period, ERM and ALMA identified a series of potential adaptation measures and agreed on a handful that would actually be modeled.

1.3 Organization of This Report

In addition to this introduction, this case study includes the following sections:

Section 2 **Methodological Approach:** presents the methodology employed by ERM in developing and coordinating the risk-based adaptation process focused on addressing urban flooding issues in Managua.

Section 3 **Hazard Profile:** documents at a high level the frequency, magnitude and extent of urban flooding in Managua, informed by a chronology of recent events and input by local residents.

Section 4 **Vulnerability Assessment:** provides an overview of the factors believed to drive vulnerability in communities exposed to the effects of urban flooding and reports the results of a comparative analysis of vulnerability in three Managua neighborhoods.

Section 5 **Urban Flooding Risk Assessment:** presents and discusses the outputs of the model-based technical analysis for the Oriental-Jagüitas-Cuarezma (OJC) micro-watershed.

Section 6 **Formulation of Adaptation Options:** describes the methodology and outcome of the process by which adaptation options were identified and assessed as a response to climate-related risks and vulnerabilities.

Section 7 **Main Recommendations:** documents our final analysis and initial conceptualization of the adaptation measures that would most effectively address current and future flooding risks. Aspects such as cost, benefits and other considerations are discussed.

The following addenda provide further detail on the process and deliverables developed as part of this adaptation process:

Annex A **Baseline of Existing Conditions**

Annex B **Future (2050) Land Use Scenario**

Annex C **Detailed Vulnerability Assessment**

Annex D **Detailed Model Results for Four Micro-Watersheds in Managua**

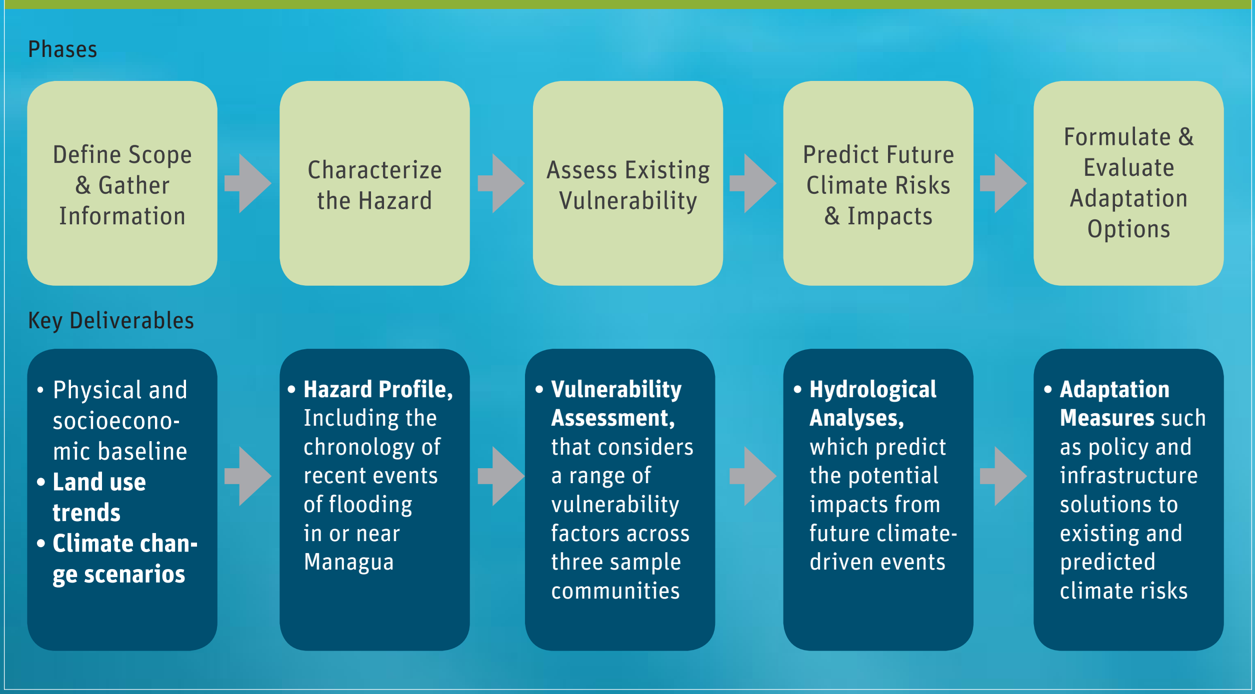
Annex E **Lake Managua Monthly Water Balance Model**

2. Methodological Approach

In keeping with the objectives stated in Section 1-1, ERM developed a methodology that would enable the identification of planned, proactive and preventative adaptation responses to future climate change risks. This methodology employs a risk-based approach to the prediction of potential impacts and considers the input of local stakeholders at all steps in the process. The intended outcome is to increase resilience in the face of a range of possible, but uncertain future scenarios while ensuring that already existing challenges are also addressed.

Figure 2-1 illustrates the steps undertaken during the adaptation process and indicates the key deliverables associated with each sequential step.

Figura 1-2: Enfoque del Proceso de Adaptación –en inglés–



Source: ERM, 2014.

As illustrated above, the methodology employed in this adaptation process is comprised of the following steps and deliverables:

1. **Define Scope & Gather Information.** At an initial stage, the ERM and IDB teams met with ALMA and several local stakeholders, mainly from agencies and ministries that play a role in managing water resources, or in the prevention or response to flooding events. During these meetings, the scope of the adaptation process was defined and key relationships for information sharing were established. ERM then focused data collection efforts in obtaining inputs relevant to the hydrological analysis. Information gathered during the initial baseline phase also included geographical, meteorological, hydrological, demographic, socioeconomic, and land use aspects. The key outputs from this step were:
   - **Baseline of existing conditions** that documented information related to the physical characteristics of the study area (e.g., geology, topography, land use/land cover, soil infiltration capacity, climate, and hydrology); socioeconomic data (e.g., demographics, economic activities, public infrastructure);
   - **Future Land Use Scenario** to establish rate of impervious surface increase overtime. ERM performed a satellite-based historical analysis of land use trends in order to project land use change for the 2050 horizon; and,
   - **Summary of political and institutional context** (e.g., local legislation, regulations and institutions relevant to water resource management and emergency preparedness/response management).
2. **Characterize the Hazard.** Based on key input by ALMA, ERM focused the adaptation process on the already critical urban flooding challenges in Managua. As a result, secondary research was undertaken to understand at a high level the chronology of urban flooding events that have taken place in recent years, and characterize the magnitude and diversity of the effects associated with these events. The key deliverable in this step was:
   - **Hazard Profile** that characterizes the direct effects of urban flooding, which range from mild nuisances to daily life (e.g., slower traffic) to serious risks to human life (e.g., drowning, disease) and livelihoods (e.g., destruction of property, disruption of business activities, lower productivity). The hazard profile provides an understanding of urban flooding, at a level of detail sufficient to support an analysis of the factors that drive the vulnerability of communities exposed to these risks.
3. **Assess Existing Vulnerability.** Based on field-based observations and focus groups held with local residents, ERM developed an analysis focused on identifying the factors that drive vulnerability to the effects of urban flooding, with assessment of a range of vulnerability variables for a sample of communities in Managua. Understanding vulnerability is important to gauge the costs and benefits of different adaptation options. The key output from this step was:
   - **Vulnerability Assessment** that considers the likelihood of exposure and sensitivity of the population to urban flooding. This includes a comparative assessment of vulnerability factors for three sample neighborhoods in Managua. This comparative analysis permits the identification of those context-specific factors believed to heighten the exposure or sensitivity to the hazard.
4. **Predict Future Climate Risks & Impacts.** In order to predict how future climate-driven events (e.g., storms of higher intensity and precipitation) would lead to flooding events, ERM evaluated the behavior of stormwater against the existing drainage infrastructure. ERM employed two separate, but related, modeling packages that, when used in combination, confirm the presence of areas currently at risk of flooding and predict future risks on the basis of changes to land use and climate. The following describes the key inputs and outputs relative to the hydrological and hydraulic modeling:
   - **Future Land Use Projections (Input).** As with any watershed analysis, it is important to understand the infiltration capacity of the soil under study. Given that the consideration of current land use patterns would not provide a realistic output in the long term, ERM used the results of the 2050 land use projections for this assessment.
   - **Climate Change Scenarios (Input)**. Global and regional climate models predict how climate variables (e.g., temperature, precipitation frequency and intensity) will evolve in the future. ERM reviewed available reports and data regarding climate change scenarios and projections for Nicaragua. ERM used climate change projections (based on downscaled regional models) recognized by local authorities.

- **Modeling Results (Output).** Based on the meteorological, drainage channel conveyance capacity, and land use inputs, the models were run to simulate the effect of 25-, 50- and 100-year precipitation events, and the results expressed in terms of peak flows and hydrographs, and the event runoff volume in excess of the channel conveyance capacity. The analysis considered a range of scenarios to assess the relative contribution of land use and climate change to future flood risk.

5. **Formulate and Evaluate Adaptation Options.** As the results from the modeling emerged, ERM identified the suitable types of adaptation measures and tested their effectiveness in the models. Those measures that ranked best in terms of decreasing flooding risk were subject to an evaluation of the potential costs, benefits and risks related to their implementation.

   - **Multi-Criteria Analysis.** In consultation with ALMA, ERM conducted an analysis of the proposed set of adaptation options, focused on evaluating aspects related to the environmental, social and economic feasibility of these alternatives.

   - **Cost-Benefit Analysis**. In view of limited resources made available to infrastructure and adaptation-focused investments, ERM developed a cost-benefit analysis to enable policy-makers to make decisions based on the full range of economic costs and benefits, including those that are not readily quantifiable in monetary terms such as improvements to human well-being.

3. Hazard Profile: Urban Flooding in Managua

A growing body of research continues to raise awareness and understanding of the possible drivers of climate change, the character and magnitude of these changes, and the potential options available to institutions and individuals seeking to cope with them. While forward-looking research helps construct a future vision of climate, an analysis of past trends also points to impacts on environmental resources, production systems, and livelihoods that are likely to be exacerbated by further climate variability.

Nicaragua has a long history of extreme weather and it frequently faces severe impacts related to extreme weather phenomena. Climate variability, especially those associated with El Niño-Southern Oscillation (ENSO) dry and wet episodes. Dry episodes (El Niño years), result in droughts that cause significant losses in the agricultural sector, which provides employment for over 60% of the population and on which the country's food security depends.

During the wet episodes (La Niña years), devastating floods can result in damages to harvests, infrastructure and housing. In a predominantly sub-humid tropical climate characterized by strong inter-annual variability, climate change trends pose a growing threat to continued development and to the wellbeing of poor urban and rural communities in many areas.

Some relatively recent extreme events such as Hurricanes Mitch (1998) and Felix (2007) are still fresh in people's memory. Mitch had an especially tragic impact, leading to 3,800 deaths in Nicaragua alone (2,000 from an enormous mudslide that buried several villages).

In fact, floods and droughts are the main manifestations of extreme climate in Central America, causing close to 85% of all disasters that occurred in the region from 1950 to 2005[4]. In addition, climatic model projections under different scenarios suggest that the current variability is expected to be aggravated by expected climate change.

Climate-driven weather events can lead to more severe impacts in developing countries such as Nicaragua since poverty at the community and household levels result in increased vulnerability due to a range of factors. Furthermore, limited institutional and governance resources in terms of technological capacity and economic wherewithal can lessen the ability of the country to adapt to a changing climate.

When considering the existing and projected impacts from climate variability, the vulnerability of local communities, and the need to strengthen local capacity to cope with those impacts, adaptation planning becomes a key priority.

4. Leary, N. et al. (2007). Assessment of Impacts and Adaptation to Climate Change: Final Report of the AIACC Project. Global Environmental Facility. The International START Secretariat. Washington, DC.

3.1 Selected Climate Change Scenario

The approach and scope of the adaptation process was determined largely by the projections of future climate and corresponding impacts to natural and human systems. Increasingly reliable regional climate projections are now available as well as downscaled projections that permit the forecasting of key climate variables (e.g., temperature, rainfall, storm intensity) at sub-regional scales[5]. In this section, the selection of the climate variables that have been employed in modeling is described along with the watershed response to future precipitation events.

The initial review of background information and literature pointed to the work undertaken by the Nicaraguan government in the development of the Second National Communication on Climate Change as part of the UNFCCC[6] process. In the 2011 report, the Nicaraguan Ministry of Natural Resources and Environment (MARENA) updated its projections of Nicaragua's climate based on the outcome of the regional climate modeling initiative known as PRECIS (Providing Regional Climates for Impact Studies).

PRECIS is a regional climate modeling system designed to downscale the projections made by existing general circulation models, which are designed to predict the evolution of climate at the continental and global scales. The projections recognized by MARENA are based on outputs from the HadCM3 and ECHAM4 general circulation models,[7] as downscaled by the PRECIS-Caribe initiative. MARENA also considered recently developed simulations provided by the Cuban Institute of Meteorology.

Climate model projections are not based on a single outlook of the future, but rather on a number of possible greenhouse gas (GHG) emissions scenarios commonly known as SRES[8] (Special Report on Emission Scenarios). These scenarios consider different trends of global development for the next 100 years and are, in a broad sense, fundamentally based on population and economic growth assumptions. There are four families of SRES scenarios, namely, A1, B1, A2 and B2.

In its analysis, MARENA considered downscaled projections corresponding to the A2 and B2 emissions scenarios. The A2 scenario is constructed on the basis of continuously increasing population growth and regionally oriented economic development, while the B2 scenario assumes continuous, but slower population growth and more fragmented technological change.

The analysis undertaken by MARENA indicated the existence of a range of climate projections for Nicaragua, based on downscaled information from two global models (HadCM3 and ECHAM4) under two emissions scenarios (A2 and B2). To determine the projections that best suited the need to model flooding risks, the ERM team based its decision on the following criteria:

- The availability of downscaled projections for the specific 2050 planning horizon;
- The extent to which the model relied on historical data to increase confidence in the accuracy of future projections; and,
- The need to assume the most conservative emissions scenario.

In the final analysis, ERM decided to employ climate variables based on the projections generated by the ECHAM4 model for the 2041 – 2070 timeframe under the A2 scenario. The deciding factor was the availability of ECHAM4 projections for multiple time periods (i.e., 1991 – 2010, 2011 – 2040, 2041 – 2070, and 2071 – 2099) whereas the HadCM3 model only provided projections for the 2071 – 2099 time period.

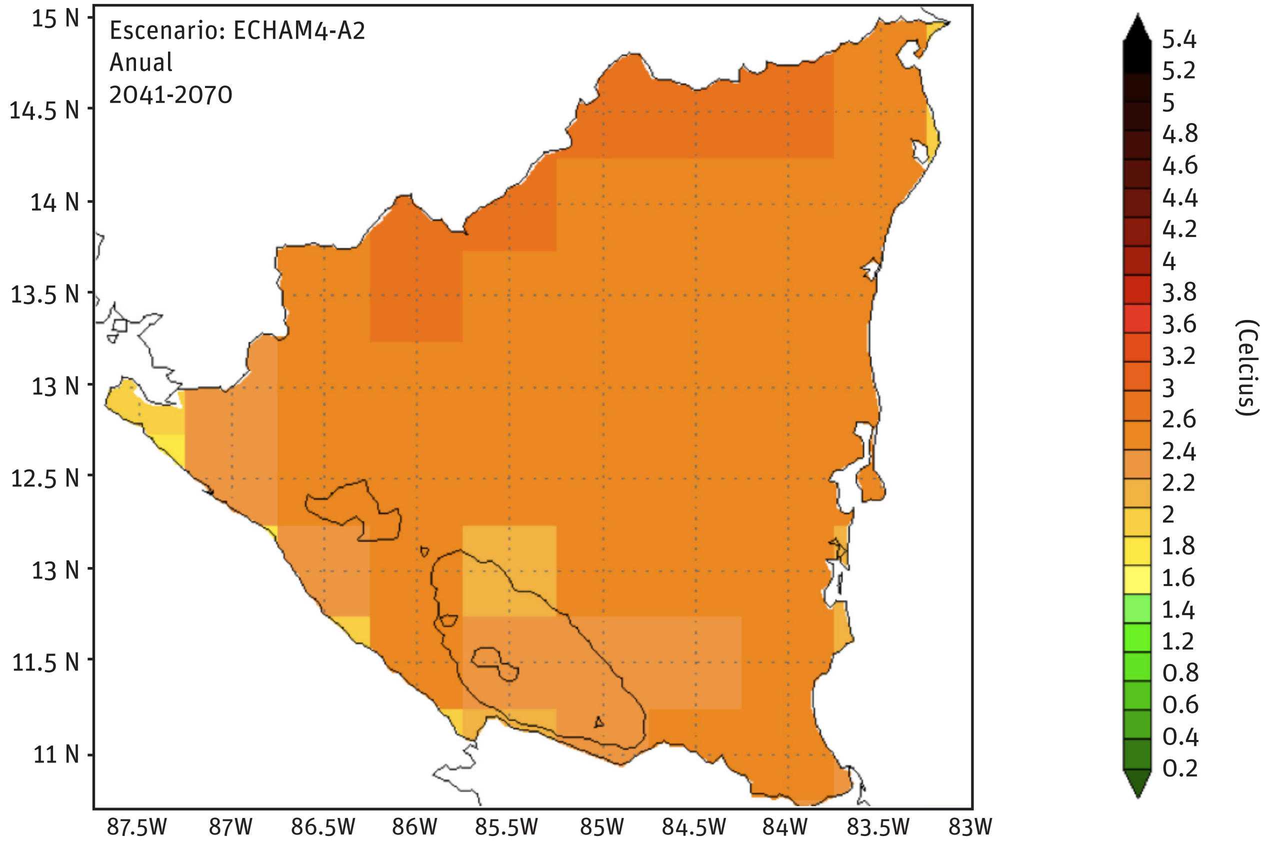
5. Mertz, O. et al. (2009). Adaptation to Climate Change in Developing Countries. Environmental Management. Issue 43, pp 743-752.
6. United Nations Framework Convention for Climate Change
7. HadCM3 was developed by the Hadley Center in the United Kingdom whereas ECHAM4 (currently in version 5) was developed by the Max Planck Institute in Germany.
8. The Special Report on Emissions Scenarios was developed by the Intergovernmental Panel on Climate Change (IPCC) in 2001.

In addition, the downscaled ECHAM4 model was calibrated on the basis of historical data ranging from 1961 to 2010, compared to the HadCM3 model, which used more limited historical data. Both models projected changes to temperature and precipitation, and both provided resolution at the 50-km spatial scale, so these did not become factors in the decision.

In terms of emissions scenarios, the A2 scenario depicted a higher trend of GHG emissions relative to B2, and was thus selected as a measure to embed a conservative assumption in the hydrological analyses.

Figure 3-1 shows the projected changes to average annual temperature under the A2 emissions scenario, as per ECHAM4 model for 2041 – 2070.

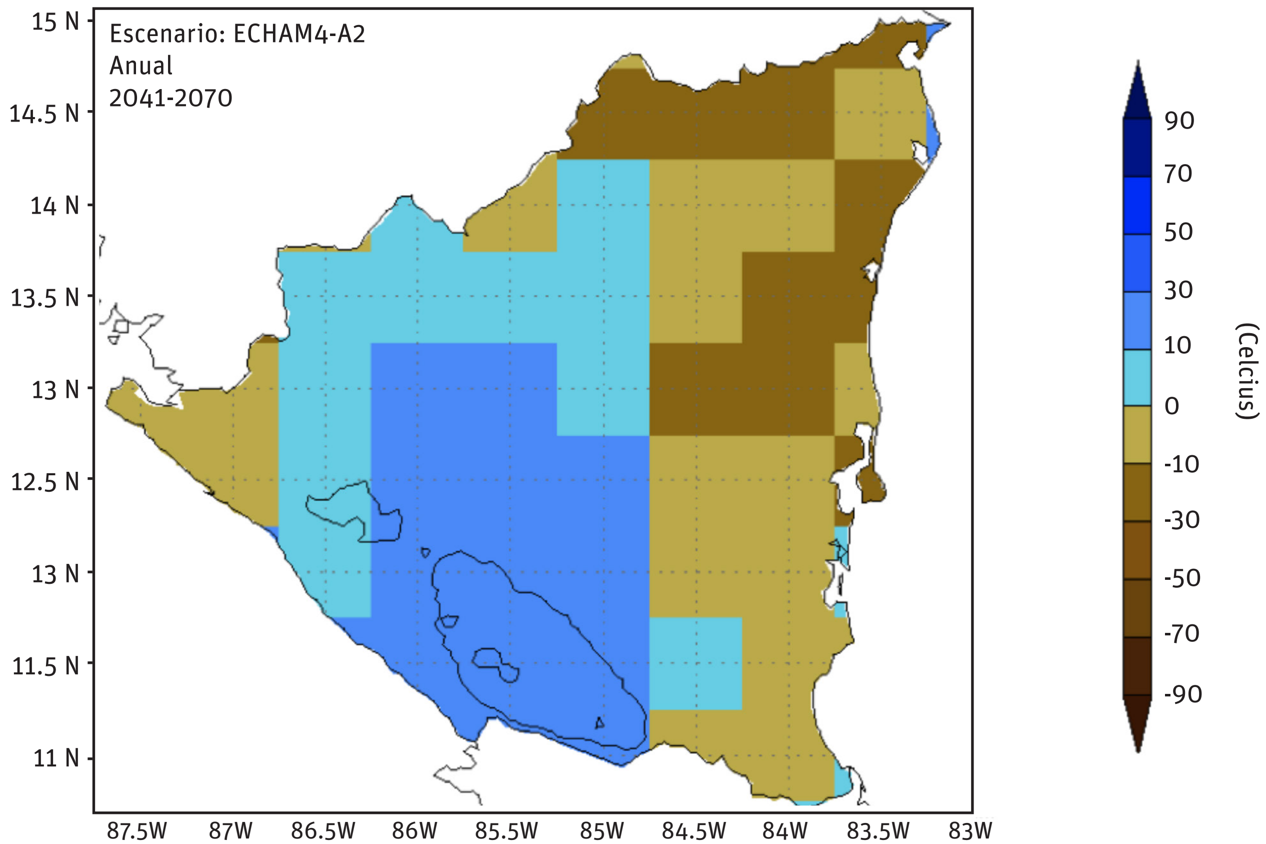
Figure 3-1: Annual Temperature Change Projections for 2041 – 2070 (A2 scenario)



Source: MARENA (2008) based on PRECIS ECHAM4 model projections.

Figure 3-2 shows the projected changes to average annual precipitation projections under the A2 emissions scenario, as per ECHAM4 model for 2041 – 2070.

Figure 3-2: Annual Precipitation Change Projections for 2041 – 2070 (A2 scenario)



Source: MARENA (2008) based on PRECIS ECHAM4 model projections.

The two key climate variables employed by the hydrological models are total precipitation and precipitation intensity. It is important to note that the projections discussed above do not specifically provide a value for precipitation intensity. In the absence of a specific projection, ERM assumed a conservative value of 30% based on the fact that rainfall intensity is not likely to exceed total precipitation increase.

For the analysis focused on predicting Lake Managua's water balance, temperature is a key climate variable due to its influence on lake evaporation rates. Refer to Annex E for the methodology and results of the Lake Managua basin-level analysis.

Table 31 below summarizes the climate change variables employed in this study:

Table 3.1 Selected Climate Change Factors

Parameter	Projection	Source
Temperature	**2.6** °C ***Increase***	Value generated from the PRECIS (ECHAM4) model for the A2 scenario and the 2041-2070 period.
Total Precipitation	**30%** ***Increase***	Value generated from the PRECIS (ECHAM4) model for the A2 scenario and the 2041-2070 period.
Precipitation Intensity	**30%** ***Increase***	Projection derived from the Bárcenas *et al* (2010) study[9].

3.2 Urban Flooding

Urban flooding is a term that refers specifically to flooding that is caused or made worse by human activity. In urban settings like Managua, conversion of land from open fields or woodlands to houses, roads or infrastructure (e.g., buildings, parking lots), results in an increase of impervious surface and it's a reduction of the ability to absorb rainfall. Without the proper measures in place to facilitate infiltration, water accumulates in depressions and low lying terrain or runs off the surface into natural and man-made channels. When the capacity of existing structures to handle runoff water is exceeded, the result is typically urban flooding.

Managua and surrounding municipalities have experienced rapid and uncontrolled urban development, which has resulted in the replacement of permeable soil with impermeable surfaces such as roads, roofs, parking lots and sidewalks. This has accelerated the runoff of storm water into ditches, channels and streams. Throughout the urban landscape, a dense network of ditches, culverts, and "mini dams" has sought to divert surface runoff to a series of man-made channels.

Although the municipality has a network of urban drainage channels, the capacity of the network has fallen behind the accelerated expansion of the city. In addition, infrequent maintenance and accumulation of trash and debris substantially reduce its overall effectiveness. Unless mitigated, uncontrolled urban development may further overburden the existing drainage infrastructure, exacerbating existing urban flooding issues and public safety concerns.

The direct effects of urban flooding range from mild nuisances to daily life (e.g., slower traffic) to serious risks to human life (e.g., injury, drowning) and livelihoods (e.g., destruction of property, disruption of business activity). Urban flooding also has the potential to create public health risks. For example, when storm water and sewage drainage networks are combined, heavy rainfall may cause raw sewage to surface onto the streets. This increases the potential for contamination of drinking water sources, which poses serious risks for outbreaks of diarrheal diseases such as typhoid and cholera. Direct contact with sewage-contaminated floodwaters can also cause health problems such as wound infections, dermatitis, and eye, nose and throat infections[9].

9 World Health Organization (n.d.). Flooding and communicable diseases. Available at: http://who.int/hac/techguidance/ems/flood_cds/en/

3.2.1 Hazard Chronology

Due to various factors (i.e., geographic location, infrastructure conditions), Nicaragua is ranked as the second most vulnerable country in the world to hurricanes and tropical storms[10]. Historically, natural disasters have occurred with relatively high frequency in Nicaragua, and frequency has increased in recent years. In the last 40 years, the country has experienced 53 natural disasters[11], the most catastrophic of which was Hurricane Mitch in 1998. This storm was characterized by NOAA as the deadliest Atlantic hurricane since 1780, with a total reported death toll of 11,000, of which 3,800 were in Nicaragua[12].

The year 1998 appears to have been an inflection point as the frequency of hurricanes affecting Nicaragua increased from that year forward. Five hurricanes – Alma (2002), Isidore (2002), Beta (2005), Felix (2007), and Ida (2009) – have affected Nicaragua in the 14year period from 1998 to 2012. The Disaster Information System (Desinventar) reports 55 flood events between 1992 and 2011 affecting Managua and surrounding municipalities. The most significant events are summarized below[13]:

- April 1996: Intense precipitation caused flooding in the Managua and Tipitapa municipalities, specifically in barrios Tangara, Pantanal, and Pedro Joaquin Chamorro. Approximately 1,100 people were affected.
- October 1998: Several neighborhoods located in the coast of Lake Managua and along the Pan-American Road were affected due to floods caused by Hurricane Mitch. Approximately 9,000 people were affected in the Municipality of Tipitapa. Additionally, 2,750 km of road were damaged and 700,000 USD in losses were reported in the City of Managua.
- October 1999: Several neighborhoods located on the coast of Lake Managua were flooded due to the lake's water-level rise. It was estimated that 1,080 people were affected.
- April 2002: Rainfall caused by Tropical Storm No. 8 resulted in flooding of the Ayapa, Laberinto and Hugo Chavez barrios. Approximately 1,750 people were affected, and 435 were evacuated.
- October 2008: Intense rainfall in the City of Managua caused floods that affected approximately 1,525 people and damaged 305 houses.
- April 2009: Intense rainfall caused by Tropical Wave No. 1 affected the Municipality of Managua, specifically Mercado Oriental, Fernando Vélez Paez, and Batahola Norte. Approximately 2,210 people were affected, and 200 meters of road infrastructure were damaged.
- April 2010: Intense rainfall caused floods in the City of Managua. About a 100 km of road infrastructure, 400 manholes, and 680 m of drainage were damaged. Approximately 144 people were affected and 306 residences were flooded.
- September 2010: Water-level rise in Lake Managua caused floods in Barrio La Bocana in the Municipality of Managua. Seventeen houses were damaged and 85 people affected.
- July 2011: Twenty-four (24) barrios in the City of Managua were affected by floods caused by intense rainfall. About 169 km of the channel were damaged, one house was destroyed, and approximately 885 people were affected. One fatality was reported.

10 "Nicaragua improves ability to respond to natural disasters with IDB support". *IADB News Releases*. November 27, 2013. Available at: http://www.iadb.org/en/news/news-releases/2013-11-27/nicaragua-improves-respond-to-natural-disasters,10676.html

11 Includes geophysical events as well as meteorological.

12 NOAA (2009). *Mitch: The Deadliest Atlantic Hurricane since 1780*. Available at: http://www.ncdc.noaa.gov/oa/reports/mitch/mitch.html

13 Desinventar (2013). Nicaragua – Historical Inventory of Disasters. Available at: http://www.desinventar.org/en/database

- August 2011: Water level rise on Lake Managua affected the Barrio Manchester in the City of Managua. Approximately 700 people were affected, and many of them had to be relocated to shelters.
- May 2013: Intense rainfall resulted in flooding across five municipalities: Managua, Ciudad Sandino, Tipitapa, Ticuantepe and Mateare. Over 53 mm of rainfall were recorded in Managua for a 3-hour period. Over a 100 mm were recorded in Ciudad Sandino during the same period. Over 3,000 residents were affected, out of which 1,415 live in Managua.

3.2.2 Areas Most Susceptible to Flooding

Most urbanized areas of Managua are at high risk for urban flooding due to the replacement of open areas with impervious surfaces. However according to key stakeholder input, the fifth district of the Municipality of Managua is considered particularly vulnerable due to its geographic location, inadequate residential drainage infrastructure, and the presence of approximately 29,689 meters of drainage channels[14] (more than in any other district).

The total population in District V is also slightly higher than in the other districts (refer to the baseline presented in **Annex A**). As a result of these conditions, the estimated population that could be potentially affected by flooding is much larger in District V than in the other Managua districts, as illustrated in Figure 3-3.

Figura 3-3: Total length of channels and population located in high-risk areas

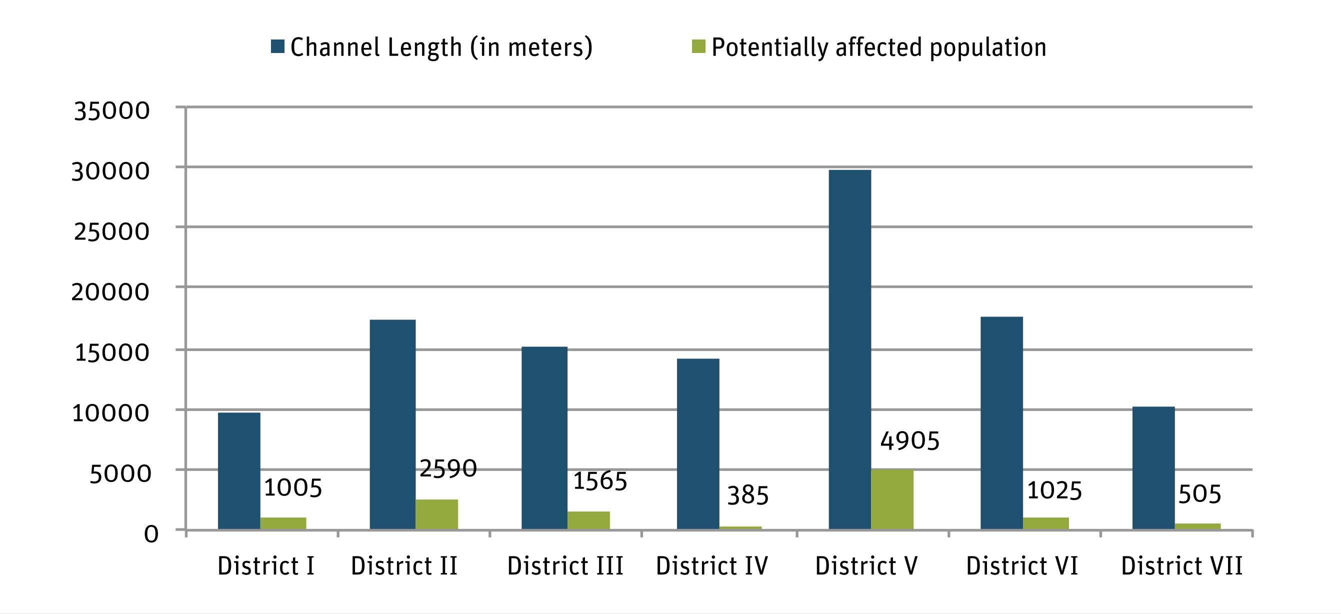


Figure 33 Total length of channels and population located in high-risk areas
Source: Nicaragua Army, 2011.
Note: "Potentially affected population" corresponds to estimates contained in an Emergency Response Plan of the Nicaraguan Army, based on the number of households living adjacent to identified critical flooding points. Specific methodology explaining the identification of critical points and the populations considered to be at risk is not provided in the document, and therefore this figure is provided for illustrative purposes only.

14 Of the drainage channels in District V, 51% are concrete lined, while the remaining 49% are unimproved.

3.2.3 Effects on Communities from Urban Flooding

To gain an understanding of the first-hand effects of urban flooding, information was collected from community focus groups conducted in three Managua neighborhoods[15]. These neighborhoods are considered to represent particularly vulnerable populations, both in terms of exposure to flooding, and in terms of lacking resources and capacity to cope with, recover from, and adjust to the negative effects of urban flooding.

Focus group participants from the three sample neighborhoods reported a range of negative social, economic and health effects that have resulted from prior inundation events. In general, focus groups results confirmed the notion that poverty exacerbated or prolonged these effects. In other words, the lack of economic resources hinders the ability of households and individuals to control the variables that determine vulnerability and capacity to adapt to frequent flooding.

The following headers presents the most salient effects identified by previous vulnerability studies of Managua and confirmed by feedback gathered during the focus groups.

Personal Safety

The most immediate concern associated with flooding is the potential for injury or loss of life during storm events and/or flooding. Hurricane Mitch in 1998 caused 3,800 deaths in Nicaragua, mostly as a result of flooding and mudslides[16], which occurred outside of Managua. Fortunately, more recent storm events have rarely resulted in fatality (as described in Section 3.2.1, an event in 2011 resulted in one death). However, fears and uncertainty over personal safety during storm events cause disruptions to residents' daily lives; for example focus group participants reported that children must be kept indoors at times when floodwaters could potentially rise rapidly and pose a safety threat.

Property Loss and Damage

Focus group participants reported that the most significant personal property losses from flood events during the past three rainy seasons consisted of damaged electrical appliances, at a cost of up to C$15,000 córdobas (approximately $600 US). Other losses included clothing at a cost of approximately C$500 córdobas ($20 US). Due to high levels of poverty, the majority of residents in these neighborhoods do not own valuable private property such as vehicles or bicycles. For the most part, these families do not engage in agricultural activity, so there was no mention of crop losses. In addition, respondents in all three neighborhoods reported that their communities lack public and commercial infrastructure that could be damaged by flooding, such as parks, government buildings or commercial buildings.

Disruptions to Work and Schooling

Focus group respondents reported that despite challenges in traveling to their places of work during flood events, they generally ensure that they do not miss days of work during flood events since it would be deducted from their salary. Because buses and taxis do not enter the barrios' unpaved streets, they generally walk barefoot to a main road to catch the bus, and bring an extra set of clothing to change into when they arrive at work.

Due to the lack of transportation within the study neighborhoods, children usually stay home and miss school during heavy rains. Barrio 18 de Mayo has one small primary school that is reported to be in a poor state of repair, and leaks during rainfall. The other two neighborhoods do not have schools. Respondents estimated that children miss 3-15 days of school during the rainy season due to flooding.

15 Focus groups were organized at the three neighborhoods: Barrio 18 de Mayo, La Finquita, and Los Vanegas-El Cenicero. Approximately 10 to 15 residents attended each focus group.

16 NOAA National Climatic Data Center (2009). Mitch: The Deadliest Atlantic Hurricane since 1780. Available at: http://www.ncdc.noaa.gov/oa/reports/mitch/mitch.html

Additional Monetary and Time Costs

In addition to repair and replacement costs for damaged goods, residents of the study neighborhoods often incur additional costs in preparation to the rainy season. As illustrated in Figure 3-4, the use of sandbags is a common protective measure that costs approximately C$1,500 córdobas ($60 US) every year. Some focus group participants also reported spending money on candles as electricity service can become disrupted (C$15 córdobas per box) due to flooding. Access to health care due to flooding-related ailments was estimated at C$700 córdobas ($28 US), including the cost of transport to health centers and the cost of medications not covered by the public health system.

Estimated time required to clean streets and houses after flooding varied by neighborhood from three days to about a week.

Figura 3-4: Medida de prevención de inundaciones en hogares, barrios 18 de Mayo y La Finquita

Source: ERM, 2013

Sanitation and Public Health

Health effects reported to occur after flooding are dengue fever, respiratory illnesses, flu, cough and fungal infections. Rotavirus and other diarrheal diseases were not mentioned during the focus groups, though generally remain a concern in flood-prone areas, particularly when the sanitation infrastructure is inadequate and drinking water may become contaminated.

Garbage collection occurs once per week in La Finquita and Los Vanegas, and twice per week in Barrio 18 de Mayo. Despite regular service, residents reported litter often accumulates on the streets and in the channels, where garbage accumulation is a serious concern as illustrated in Figure 3-5.

Figure 3-5: Trash in the streets and drainage channels, Barrio 18 de Mayo

Source: ERM, 2013

In addition to reducing the conveyance capacity of the drainage system, garbage accumulation along the channels causes water stagnation (as illustrated in Figure 3-6), creating the conditions for the spread of the mosquito species that transmits dengue fever.

Figure 3.6: Stagnant water observed in Barrio 18 de Mayo and Los Vanegas

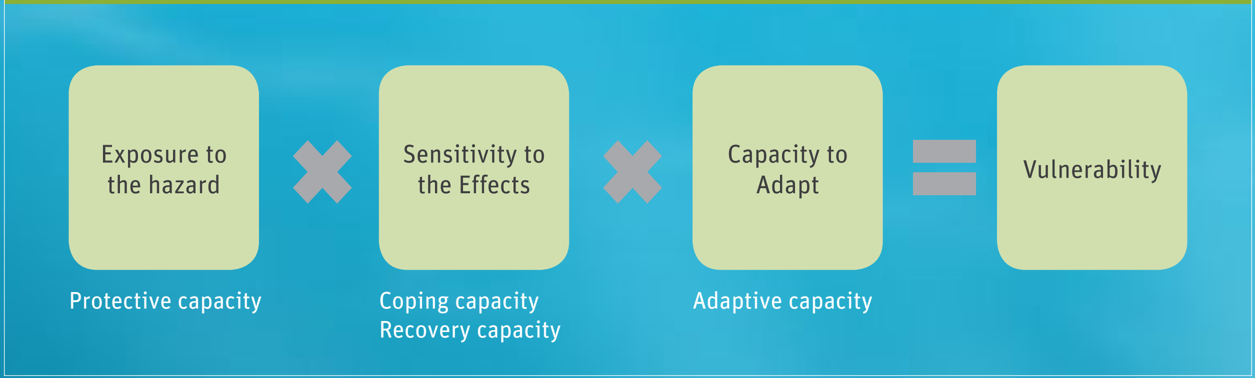
Source: ERM, 2013

4. Vulnerability Assessment

According to the IPCC, vulnerability is a function of the exposure to a hazard, sensitivity of the receptor to the effects resulting from the hazard, and the capacity of the system to adapt by reducing adverse effects or taking advantage of beneficial effects[17].

Vulnerability is highly contextual. As described in *Section 3*, urban flooding in Managua is typically the result of heavy rains, which cause channels to overflow as water flows exceed existing drainage capacity. This flooding hazard then leads to adverse effects in exposed communities ranging from individual economic losses to public health threats. As illustrated in Figure 4-1, the ability of individuals and communities to avoid or mitigate these adverse effects, which can be referred as adaptive capacity, rounds out the definition of vulnerability.

Figure 4-1: General factors and corresponding capacities that determine vulnerability



Source: Adapted from Mertz et al. (2009)[18]

The vulnerability assessment conducted as part of this adaptation exercise focused on understanding the degree to which a community has developed protective, coping, recovery, and adaptive capacities. These capacities make up the framework under which vulnerability can be assessed at the community level. Table 4-1 further explains what these concepts represent within the context of urban flooding.

17 McCarthy, J. et al. (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, New York.
18 Mertz, O., Halsnæs, K., Olesen, J., Rasmussen, R. 2009. *Adaptation to Climate Change in Developing Countries.* Environmental Management 43:743-752.

Table 4-1 Capacities considered by the vulnerability assessment

Capacity	Explanation
Protective Capacity	Reflects the level of exposure among people and places to flooding. Its analysis considers factors such as proximity with channels, adequacy of drainage infrastructure, home construction, and access to potable water and sanitation.
Coping Capacity	Represents the ability of communities and people to cope with the adverse effects of flooding through measures, resources or behaviors that may include emergency evacuation procedures, monetary resources to purchase water and food reserves, and good physical health and mobility to avoid injury.
Recovery Capacity	Corresponds to the ability of people to recover from the adverse effects of flooding and return to normal conditions as quickly as possible. Factors that make up recovery capacity include, for example, the availability of local government assets and/or procedures to support cleanup operations. Access to health services also indicates the ability to recover from flooding-related illnesses or injuries.
Adaptive Capacity	Reflects the availability of resources and assets that enable communities to adapt. This includes measures that raise awareness of the risk facing specific communities, the internal and external resources invested in flood-prevention measures, and the degree to which adaptation has been adopted broadly as a factor in development planning.

Following this conceptual framework, ERM conducted an analysis of three highly vulnerable communities in Managua. The full methodology and results of the community vulnerability assessment are included in **Annex C.**

This section presents the key takeaways of that assessment, emphasizing the factors that in our analysis appeared to drive vulnerability to flooding at the community level. These findings form the basis for gauging the costs and benefits of different adaptation options, and help inform the scope of specific investments in physical assets and institutional capacities aimed at reducing exposure to flooding or mitigating its effects.

4.1 Selection of Sample Communities

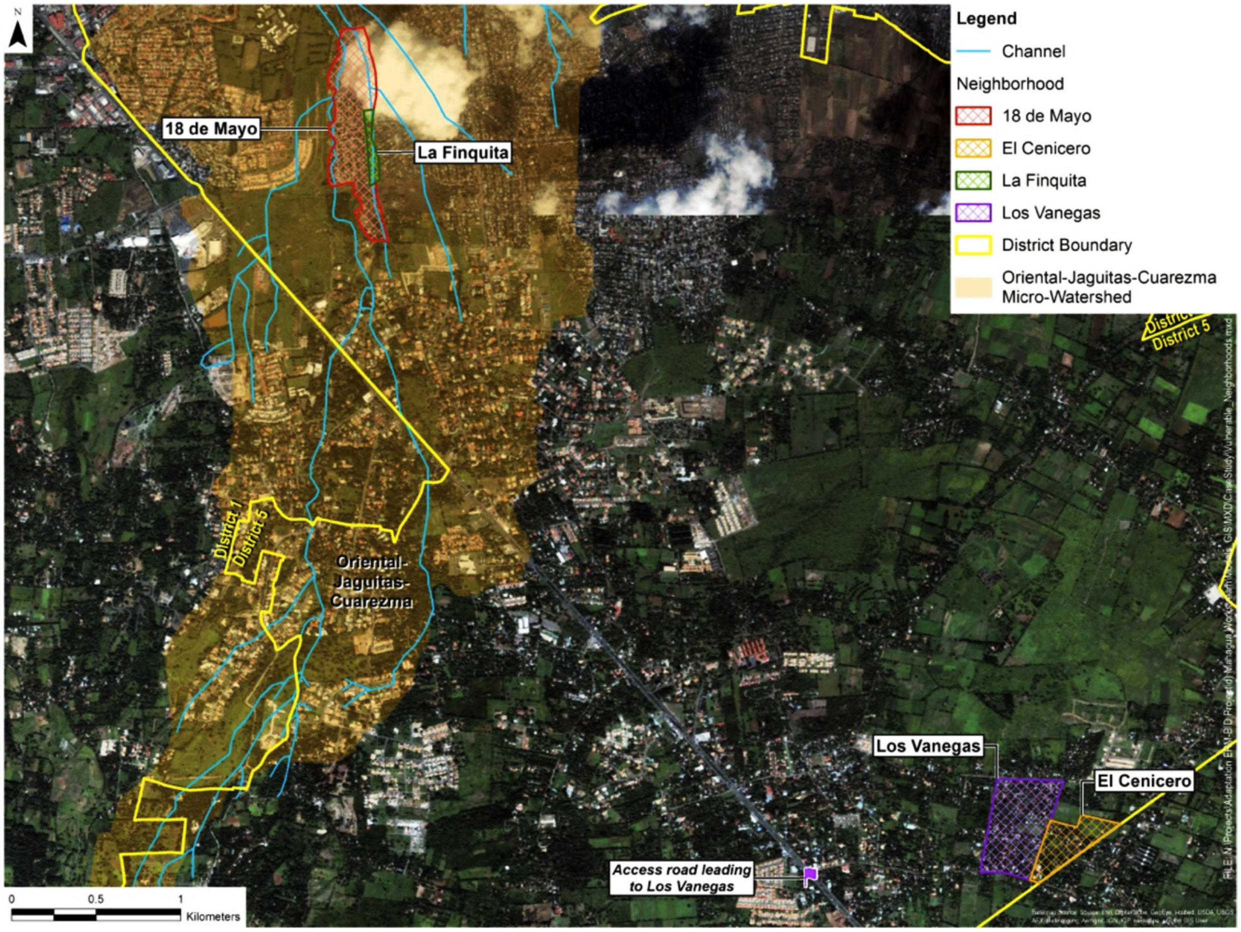
As discussed in *Section 1.2,* in consultation with local stakeholders, it was determined to focus the adaptation experience on the Oriental-Jagüitas-Cuarezma (OJC) watershed, an area that is particularly prone to urban flooding and which comprises a significant undeveloped area apt for urbanization.

ERM consulted with the local District V government to identify specific communities with high exposure to flooding events. Based on this information, and the input of the local subcontractor tasked with conducting the field work, ERM selected the following communities for the vulnerability assessment:

- Barrio 18 de Mayo;
- La Finquita; and
- Los Vanegas/El Cenicero.

Los Vanegas and El Cenicero are considered as a single unit for the analysis, given only one focus group was held here with residents from both communities. Figure 4-2 shows the location of these neighborhoods with respect to the OJC watershed.

Figure 4-2: Neighborhoods included in the vulnerability assessment



Source: ERM, 2013

Given that the three neighborhoods were selected based on a high level of exposure to flooding and that socioeconomic conditions in these communities are low, it is assumed this sample reflects the worst-case end of the spectrum in terms of vulnerability to existing flooding issues, and therefore the greatest sensitivity to changes that may lead to increased pressures on the drainage system, such as adverse land use changes and increases in the intensity of precipitation events.

4.2 Assessment Variables and Criteria

As per the methodology presented in **Annex C**, each capacity – protective, coping, recovery, and adaptive – was further subdivided into indicators and variables for purposes of the numerical scoring assessment. Scoring criteria were defined for each variable based on the information available to characterize each aspect at the neighborhood level. The numerical scoring reflects the qualitative assessment that serves as the basis for comparing vulnerability across the three selected neighborhoods.

The sources of the information used in scoring each variable included data gathered from local respondent interviews and focus groups, data from the most recent national population census (2005), and publicly available information such as municipal plans and studies.

Table 4-2 provides the specific scoring criteria considered for each variable.

Table 4-2 Community Vulnerability Assessment Criteria

Indicator	Variable	Scoring Criteria
Protective Capacity		
Location	Exposure to channels	[0] 0% of neighborhood area [1] 0.1-3% of neighborhood area [2] 3.1-5% of neighborhood area
	Elevation	[0] >300 m [1] 200-299 m [2] <199 m
Infrastructure	Permanent flood prevention infrastructure	[0] Yes [1] No
	Percentage of households living in inadequate dwellings	[0] Less than 10% [1] Between 10% to 49% [2] More than 50%
Sanitation	Percentage of households with potable water	[0] More than 80% [1] Between 50% to 79% [2] Less than 50%
	Connection to drainage system	[0] Yes [1] No
	Unsanitary conditions in neighborhoods (e.g., trash accumulations, stagnant water)	[0] Clean [1] Some litter [2] Lots of litter
Coping Capacity		
Socioeconomic Status	Percentage employed on a permanent, full-time basis	[0] More than 80% [1] Between 79% and 30% [2] Less than 30%
	Percentage of female-headed households	[0] Less than 15% [1] Between 16% and 30% [2] More than 30%
	Percentage of families in extreme poverty	[0] Less than 20% [1] Between 21% and 50% [2] More than 50%

Indicator	Variable	Scoring Criteria
Transportation	Access to own means of transportation (majority)	[0] Yes [1] No
	Paved roads	[0] Yes [1] No
Dependent Populations	Households with disabled members	[0] Less than 2% [1] Between 2 and 5% [2] More than 5%
	Households with children under 15 years of age	[0] Less than 20% [1] Between 21% and 50% [2] More than 50%
Emergency Procedures	Has an emergency evacuation process been communicated within the community?	[0] Yes [1] No
	Is there an emergency shelters available in the vicinity?	[0] Yes [1] No
Recovery Capacity		
Access to Health Service	Distance to nearest health center	[0] Less than 2 km [1] Between 2 and 5 km [2] More than 5 km
Sanitation and Cleanup Capacity	Have cleanup procedures been communicated and implemented within the community?	[0] Yes [1] No
	Sanitation emergency response plan in place to minimize public health consequences in the wake of disasters	[0] Plan in place [1] Plan not in place
Adaptive Capacity		
Institutions, coordination and leadership	Local government capacity and resources	[0] Well-resourced and efficient [1] Lacking in resources and effectiveness
	Inter-institutional and inter-municipal coordination	[0] Highly coordinated [1] Moderately coordinated [2] Lacking coordination
	External cooperation	[0] Good support from international organizations [1] Moderate support [2] Lack of support
Long-term flood prevention planning (municipal)	Community-level flood prevention/mitigation planning	[0] Effective measures in place [1] some measures in place [2] No measures in place
	Municipal-level flood prevention/mitigation planning	[0] Yes [1] No

4.3 Assessment Results

After populating the assessment matrix with variable data, totals for each of the four indices were normalized and summed so that each of the four components (protective capacity, coping capacity, recovery capacity and adaptive capacity) are equally weighted in the overall vulnerability score. A higher score corresponds to a higher level of vulnerability and therefore lower capacity to respond to or cope with urban flooding.

Results of the assessment show a similar level of overall vulnerability in the three study neighborhoods, on a scale of one to four:

Neighborhood	Vulnerability Score
Barrio 18 de Mayo	2.42
La Finquita	2.43
Los Vanegas/El Cenicero	2.24

Although the overall scores are similar, the detailed analysis shows that the scores differed considerably across the three neighborhoods. Specifically, Barrio 18 de Mayo and La Finquita have considerably lower protective and coping capacity relative to Los Vanegas/El Cenicero, mostly due to closer proximity to channels that overflow during heavy rains, and high levels of household poverty that leave residents with limited resources to invest in flood prevention infrastructure and to cope with negative effects of flooding.

On the other hand, Los Vanegas and El Cenicero do not have natural water bodies within the neighborhoods, have lower rates of poverty, and appear to have better household-level flood prevention infrastructure. However, these communities have relatively low recovery and adaptive capacity due to their more remote location outside of the city center. Distances to the nearest hospitals are longer, and municipal investments in infrastructure are less likely to be channeled to these outlying, less populated areas[19].

Results of the assessment indicate that in addition to increased intensity of precipitation events, a number of other systemic factors at municipal and regional levels affect vulnerability to urban flooding for populations in Managua. These context-specific and inter-related factors are discussed below at a high level. The completed vulnerability assessment scoring matrix, along with a more detailed discussion of the ways in which the major factors discussed below emerged in the assessment results for each studied community, are provided in **Annex C.**

Unplanned Urban Growth

Unplanned urban growth has increased Managua's vulnerability to natural disasters. After the earthquake of 1972, Managua has grown in a disorganized manner, with informal settlements like 18 de Mayo and La Finquita emerging in areas that are unfit for residential use due to their low elevations and lack of proper drainage. Risks become even greater for residents of these areas due to a lack of adequate construction materials and practices, reduction of natural flood protection, and in-

19 "Comunidades rurales olvidadas." *La Prensa.* November 25, 2013.

adequate sanitation and transport infrastructure. Residents of these informal settlements tend to be the least prepared to cope with natural disasters since they lack the financial means to build effective or permanent household flood prevention infrastructure, and resort instead to temporary measures such as building barriers with sandbags or old tires. Managua's General Municipal Development Plan highlights continued geographic segregation of different socioeconomic classes as a negative consequence of unplanned urban growth[20].

Stormwater Drainage System

Urban growth in Managua is overloading the stormwater drainage system and affecting the quantity and quality of water replenishing the aquifers[21], putting the city's drinking water supply at risk[22]. Moreover, the sediment and solid waste conveyed in the drainage system exposes the lower watershed areas to flooding in the rainy season, and the absence of basic services in informal settlements causes wastewater to enter the stormwater system. Polluted water subsequently leaks into the aquifer or flows into Lake Managua.

Housing Availability and Cost

Population growth in Managua has greatly increased the demand for housing. During community focus groups, respondents expressed that they would like to move to less flood-prone areas, but that it is not an option since they do not have the economic resources to purchase a home in such an area.

Infrastructure and Public Services

Managua is home to approximately 20% of Nicaragua's population. Rapid population growth in the last decades has created challenges for keeping pace with infrastructure and service needs, such as road maintenance and provision of adequate sewage, potable water, electricity, storm water drainage and solid waste management services to city residents. In all three of the neighborhoods included in this assessment, roads are unpaved and there are no connections to a public drainage system. While the city provides solid waste collection in these areas, residents must bring their trash to the entrance of the barrios for pick-up since large vehicles such as garbage trucks cannot safely access through the unpaved dirt roads.

ALMA has an annual investment plan that lists the flood prevention infrastructure prioritized for upgrade or repair; however, it is evident that the municipality cannot keep pace with needs since key informants and residents of the selected neighborhoods note that drainage systems in many areas of Managua are insufficient. During field visits, infrastructure such as footbridges and sidewalks in and around the studied neighborhoods were observed to be in need of repair (See Figure 4-3).

20 Municipality of Managua. Plan General de Desarrollo Municipal.

21 The aquifer that lies under sub-watershed III provides 60% of Managua's drinking water.

22 Inter-American Development Bank (2009). *New Release: Nicaragua to improve Lake Managua's southern watershed drainage with IDB assistance.* Available at: http://www.iadb.org/en/news/news-releases/2009-12-02/nicaragua-to-improve-lake-managuas-southern-watershed-drainage-with-idb-assistance,6003.html

Figure 4-3: Neighborhood infrastructure in need of repair

Source: ERM, 2013

Sanitation and Public Health Conditions

In two of the selected neighborhoods, rates of extreme poverty are high and as a result high percentages of the population (>40%) live in overcrowded conditions (more than three people per bedroom) or in dwellings that are considered to be inadequate (>30%)[23]. These neighborhoods experience problems related to deficiencies in solid waste removal capacity, evidenced by trash accumulations on streets and drainage channels (see Figure 4-4).

Living in unsanitary and overcrowded conditions poses infectious disease risks. Heavier rains can increase the amount of time that water remains stagnant in streets of residential areas, providing optimal breeding environments for the mosquito species that acts as the primary vector for dengue fever (*Aedes aegypti*)[24]. Molds and fungi also thrive in flooded environments, and can cause skin and respiratory issues[25]. Contact with floodwaters contaminated with sewage can cause skin problems and infections, or outbreaks of diarrheal diseases such as cholera and rotavirus if contamination of potable water sources occurs[26].

23 INIDE (2005). *VIII Population Census and IV Household Census.*
24 Centers for Disease Control and Prevention (2012). Dengue: Entomology and Ecology.
25 National Safety Council (2009). Air Quality Problems Caused by Floods. Available at: http://www.nsc.org/news_resources/Resources/Documents/Air_Quality_Problems_Caused_by_Floods.pdf
26 Occupational Health and Safety Administration. Fact Sheets on Natural Disaster Recovery (n.d.). Available at: https://www.osha.gov/OshDoc/flood-Cleanup.html

Figura 4-4: Fotografías que ilustran las condiciones de vivienda y saneamiento existentes

Source: J. Cisneros, 2013

5. Assessment of Urban Flooding Risk

As discussed in *Section 3*, Managua faces a range of flood risks related to the reduced ability of urban areas to absorb stormwater, the limited capacity of existing drainage infrastructure to convey stormwater runoff, and the prospect of more frequent and intense precipitation events in the future. To assess these risks, ERM performed a hydrological and hydraulic model-based analysis that aimed at:

- Predicting the watershed response to storm events given the physical characteristics of the catchment areas (e.g., topography, permeability) and existing drainage infrastructure in flooding-prone areas of Managua;
- Assessing the sufficiency of existing drainage infrastructure to prevent flooding under storm events reflecting existing patterns as well as projected changes in climatic variables (e.g., precipitation, intensity) and land use (e.g., net loss of permeable areas due to urban development);
- Formulating potential interventions that can be implemented to avoid or mitigate flooding impacts under existing conditions and under scenarios that assume future land use and climatic changes (the latter expressed as storms of greater rainfall volume and intensity).

Section 5.1 documents the methodology of this analysis in terms of the specific modeling packages employed, the scenarios that were modeled, and the main parameters incorporated in the models. The rest of this section presents the analysis results for the Oriental-Jagüitas-Cuarezma (OJC) micro-watershed, since this was viewed by ALMA as a priority in terms of addressing critical drainage needs in a highly vulnerable area. The results for the other micro-watersheds that were studied – Primavera, Nejapa and Hugo Chavez – are included in Annex D.

5.1. Methodology

Selection of Modeling Tools

ERM chose two separate, but related modeling packages: HEC-HMS[27] and HEC-RAS[28]. The hydrologic model (HEC-HMS) component describes the watershed response to precipitation, expressed as peak flows and provides the event hydrographs. The hydraulic model (HEC-RAS) component simulates the conveyance of the instantaneous flows from the hydrographs generated in the previous step through existing or proposed drainage infrastructure. Particular attention is given to the peak flows, which are the periods during each event when maximum flooding may occur.

27 US Army Corps of Engineers. 2010. Hydrologic Engineering Center - Hydrologic Modeling System, HEC-HMS. User's Manual Version 3.5. August 2010. US Army Corps of Engineers. Hydrologic Engineering Center. http://www.hec.usace.army.mil/software/hec-hms/

28 US Army Corps of Engineers. Hydrologic Engineering Center - River Analysis System, HEC-RAS. http://www.hec.usace.army.mil/software/hec-ras/

When used in combination, the hydrologic and hydraulic models help in understanding watershed behavior in response to storm events. By taking into account the specific land use types in the catchment area, the hydrologic model quantifies the volume of stormwater runoff that results from precipitation. The hydraulic model permits the identification of areas along the drainage path that are at risk of flooding, by comparing the peak flows at pre-determined points in the drainage system against the capacity of the channel. When stormwater exceeds the channel capacity, it fills the overbanks or floodplain, and possibly further depending on the topography.

The models employed were selected on the basis of professional judgment, considering the availability of input data and the level of analysis required. In addition, the HEC-HMS and HEC-RAS models are publicly available, and they have a history of acceptance and application to urban watersheds. They are highly compatible with the scope of the urban flooding risk analysis.

Data Collection

At the outset, the ERM and IDB teams met with ALMA and several local stakeholders, mainly from agencies and ministries that play a role in managing water resources, or in the prevention or response to flooding events. During these meetings, the project scope was defined and key relationships for information sharing were established. ERM then focused data collection efforts in obtaining inputs relevant to the hydrological and hydraulic analyses. This information included geographical, meteorological, hydrological, hydraulic, demographic, socioeconomic, land use, and of risk and vulnerability to flooding. ERM compiled data in the form of maps, reports, studies, digital elevation models (DEM), GIS shapefiles, databases, and existing channel dimensions (e.g., cross-section width and depth).

Model Setup

Setting up the hydrological model (HEC-HMS) initially required the watershed to be delineated. The OJC watershed is shown in Figure 5-1. The next step included determining the curve number for each of the eight catchment areas in OJC. The curve number is a measure of the hydrologic response of a catchment based on land use, land cover, soil type, and slope. ERM performed a land cover analysis that provided data for the 2010 baseline year as well as projections for the 2050 planning horizon. **Annex B** documents the land cover analysis, which also included projections for future land use based on historical satellite data.

The next step was to identify the watershed's drainage features and travel time through each watershed and to enter that data into the HEC-HMS model. Coupled with precipitation data, HEC-HMS simulates the precipitation-runoff processes and estimates water volumes flowing into the dendritic channel system.

ERM defined 24-hour precipitation events that reflected 25-, 50-, and 100-year recurrence intervals (also known as return periods) for existing and projected climate conditions. Table 5-1 presents the volume (in millimeters) for the existing and projected 24-hour precipitation events associated with each return period.

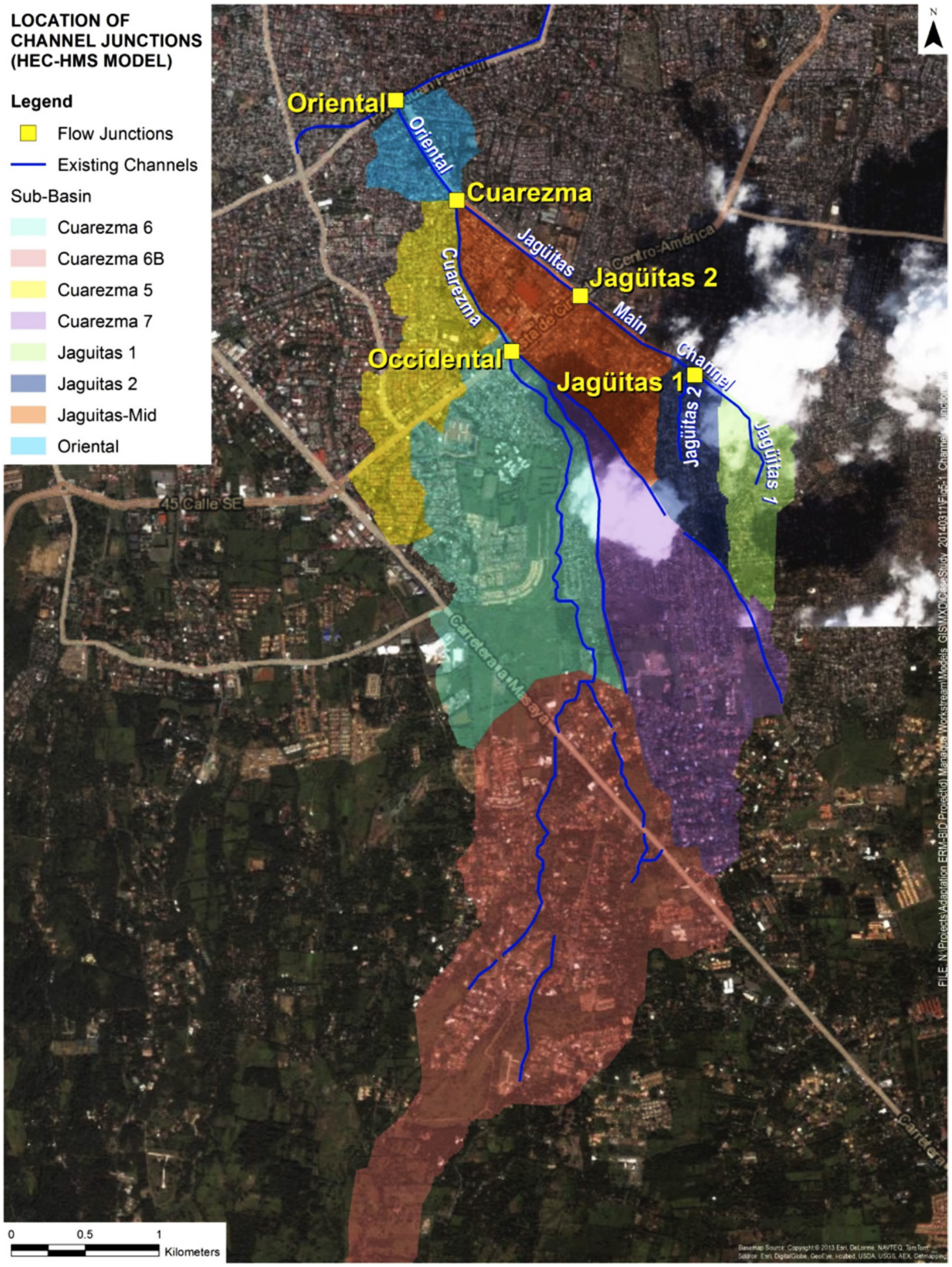
Table 5-1 Existing and projected precipitation for each return period

Return Period	Existing Conditions (Observed)	Future 2050 Conditions (Projected)
25 year	233.5 mm	303.6 mm
50 year	256.5 mm	333.5 mm
100 year	280.7 mm	364.9 mm

Source: Adapted from intensity-duration-frequency curves provided by INETER
Note: Values reflect 24-hour precipitation events

The HEC-HMS model estimates the peak flows associated with each return period at pre-determined points in the watershed. These pre-determined points, or flow junctions, represent places where one or more inflows merge into a single outflow. Figure 5-1 highlights the existing channels and modeled flow junctions that were configured for the OJC watershed. It also illustrates the location and extent of the eight catchment areas, or sub-basins, within OJC.

Figure 5-1: Existing channels and model junctions in the OJC watershed



Source: ERM, 2013

Once an estimate of the peak flows for each return period are obtained, the hydraulic model (HEC-RAS) is then used to simulate the conveyance of this water volume as it is transported through existing stormwater drainage infrastructure (e.g., channels). The HEC-RAS output is expressed in terms of average channel depth and width that would be required to transport the water flows estimated by HEC-HMS. Coupled with an understanding of existing channel capacity, this permits the prediction of areas at risk of flooding.

Modeled Scenarios

For each micro-watershed under study, ERM simulated the 25-, 50- and 100-year stormwater runoff events under different land use and climate change scenarios. Comparison of model results for the different scenarios yields information on the relative contribution of land use and climate change as factors in driving flooding risk. An understanding of these factors informs the development of targeted interventions to alleviate existing and projected flooding risks. Table 5-2 further explains the scenarios considered in the hydrological analysis and indicates the nomenclature used in referring to these scenarios through the remainder of this report.

Table 5-2 Scenarios considered in the hydrological analysis

Scenario	Abbreviation in Spanish	Explanation
Existing Conditions	Condiciones Actuales (CA)	This baseline scenario reflects a snapshot of the existing conditions based on current observed land use patterns and present-day hydrological conditions, constructed on the basis of historical weather information.
Existing Land Use with Climate Change	Uso de Suelo Existente con Cambio Climático (CC)	Represents a static scenario of land use whereas hydrological conditions continue to be influenced by climate change throughout the 2050 horizon. This scenario allows the analysis of the relative contribution of climate change alone to the magnitude of stormwater related events.
Future Land Use Change without Climate Change	Futuro Uso del Suelo sin Cambio Climático (FUS)	This scenario assumes current climate conditions will stay the same in the future, but land use will continue to evolve as a result of demographic and economic drivers. This scenario emphasizes the contribution of land use changes, specifically those that translate to loss of permeable cover, in the increase of stormwater runoff.
Future Scenario with Climate Change and Land Use Change	Futuro Uso del Suelo con Cambio Climático (CC + FUS)	This scenario intends to reflect the combined effects of land use change and climate change on the magnitude and risk related to stormwater events.

Interpretation of Model Outputs

Section 5.2.1 presents the modeling results expressed in terms of peak flows for the three return periods (i.e., 25-, 50-, and 100-year precipitation events). A peak flow is the maximum flowrate of water passing through a given point along a drainage channel, and is indicative of the risk of flooding.

Section 5.2.3 describes the modeling results in terms of runoff volume for the three return periods. Comparison of peak flows and volumes across the different modeled scenarios yields insights related to the incremental effect of climate change and/or land use change on the flood risk profile in 2050.

Formulation of Interventions

The final step in the assessment of urban flooding risk is to identify suitable types of interventions that not only help alleviate existing flooding issues, but also take into account challenges related to projected land use trends and climate change (i.e., those that increase adaptive capacity). By taking into account the expected continued conversion of land to urban uses, which results in increased runoff, it is possible to develop targeted measures to avoid or minimize adverse land use changes.

This analysis also provides an understanding of the likely magnitude and effects of storm events in the future, enabling decision makers to ensure that future infrastructure investments are also resilient to climate change, in terms of effectiveness and long-term suitability.

Section 6 documents the process and results related to the formulation of suitable interventions and adaptation strategies in response to the risks identified in this section.

5.2 Hydrologic Model Results

This section presents the modeling results organized according to the land use and climate change scenarios chosen for the analysis. Results are mainly expressed as peak flows for the pre-determined return periods.

5.2.1 Peak Flow Estimates

As discussed in *Section 5.1*, the hydrological model was set up to estimate the peak stormwater flow at five (5) pre-determined points along drainage channels within the OJC watershed. Figure 5-1 showed the location of these points, termed flow junctions, in relation to the existing drainage system, which includes natural (e.g., streams) and improved waterways (e.g., paved channels).

Peak flow estimates represent the maximum volume of water passing through a given junction as a result of a precipitation event. Table 5-3 presents the peak flows that were estimated at each model junction. Water flows are expressed in cubic meters per second (m^3/s).

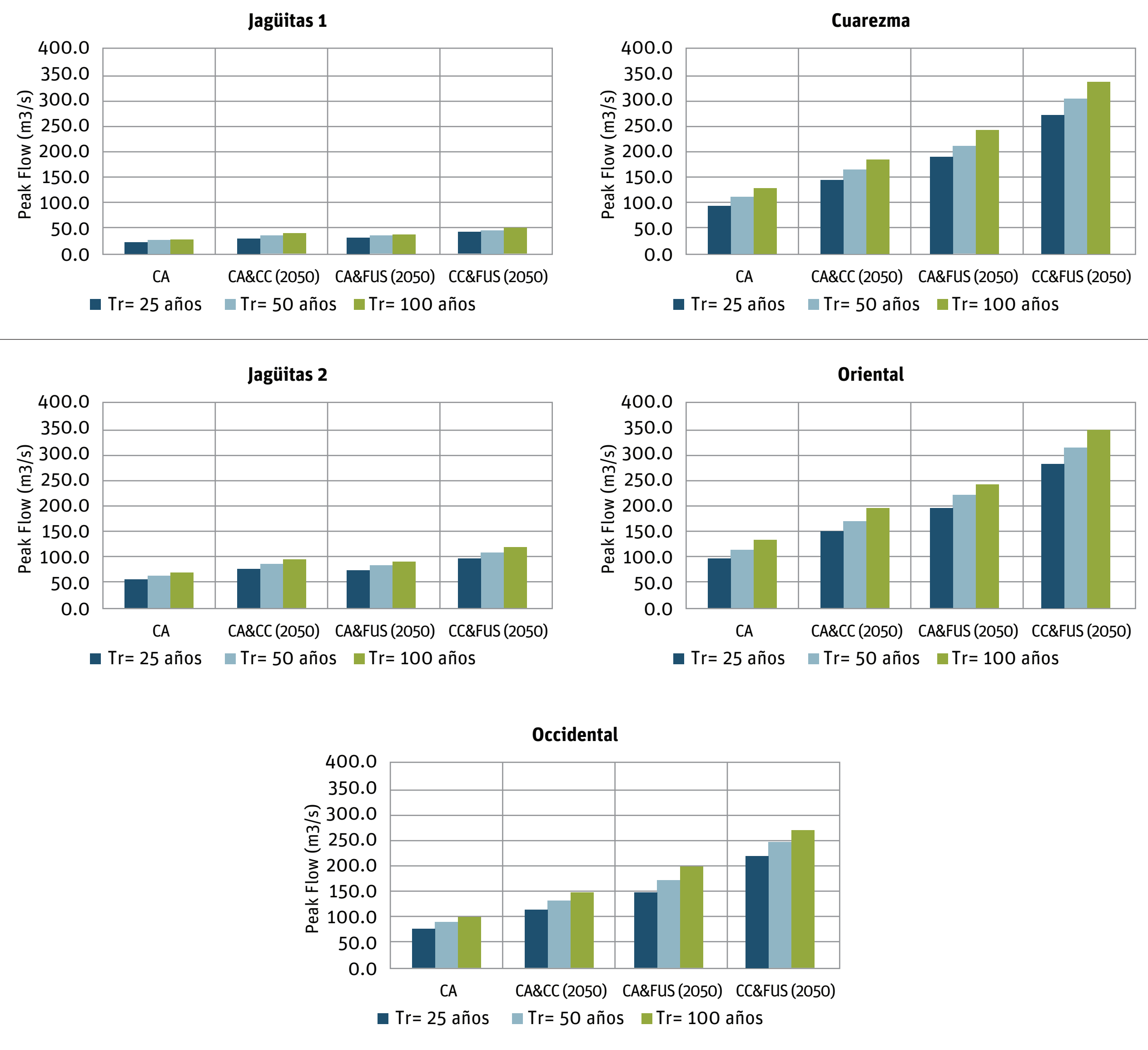
Table 5-3 Peak flow estimates for OJC junctions under the four scenarios

Flow Junction	Return Period	Peak Flows Modeled for Each Scenario (m^3/s)			
		CA	CC	FUS	CC + FUS
Occidental	*25*	78.5	116.4	152.0	222.8
	50	91.2	133.3	175.6	246.7
	100	103.9	150.3	201.7	272.7
Cuarezma	*25*	99.9	151.1	195.1	278.4
	50	117.3	171.6	217.2	312.6
	100	135.0	193.6	249.7	346.7
Oriental	*25*	101.8	154.5	199.8	283.7
	50	119.7	175.7	222.8	319.4
	100	137.9	197.9	254.0	354.9
Jagüitas 2	*25*	55.4	76.7	73.6	98.4
	50	62.4	85.8	81.8	108.9
	100	69.8	95.3	90.3	119.9
Jagüitas 1	*25*	24.8	34.2	33.3	44.4
	50	27.9	38.2	36.9	49.1
	100	31.1	42.4	40.8	54.0

Note: Water flow is expressed in cubic meters per seconds (m3/s). The abbreviations correspond to the following scenarios:
CA: Existing Conditions
CC: Climate Change Only Scenario
FUS: Land Use Changes Only Scenario
CC + FUS: Climate Change and Future Land Use Scenario

Figure 5-2 illustrates the peak flow estimates generated by the HEC-HMS model for the five model junctions within OJC assuming storm events of varying precipitation volume.

Figure 5-2: Peak flow estimates for OJC junctions under four scenarios



Source: ERM, 2013.

Analysis of Peak Flow Estimates

Overall increases in peak flows were evidenced under scenarios that assume changes in land use and future precipitation as individual and complementary factors. The projected changes in land use emerge as the main factor driving the increase in stormwater volumes predicted for this watershed. The average increase in peak flows predicted by the model for the land use change only (FUS) scenario was 67% for all junctions and return periods. This is likely due to the fact that if existing land use conversion trends persist into the future, significant areas within OJC will be urbanized or converted to land uses with inferior infiltration capacity. It is likely that land use changes in the upper watershed would translate to large increases in stormwater runoff conveyed downstream.

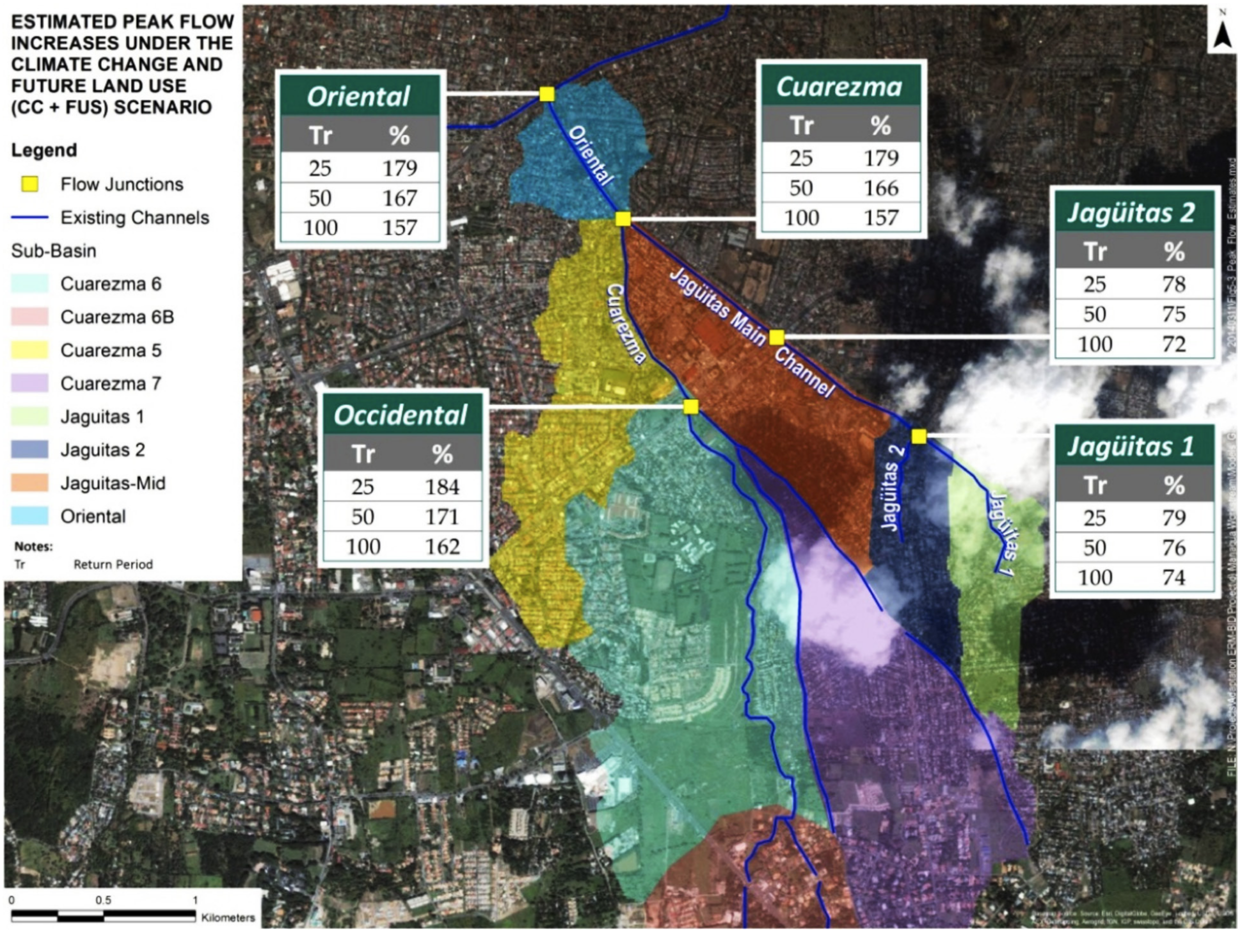
It is important to note that land use change is not a factor driving peak flow increases along the eastern drainage channels (expressed by values for junctions Jagüitas 1 and Jagüitas 2). This is because the catchment areas that contribute stormwater runoff to the eastern channel are already highly urbanized.

Anticipated increases in climate variability, as expressed through 24-hour precipitation events of higher intensity, is also a significant contributing factor to the general increase in peak water flows. On average, peak water flows under the climate change only (CC) scenario are 43% higher than compared to those under existing conditions (CA).

As expected, the model predicts significant increases when the two factors are combined. In this scenario (CC + FUS), increases in peak flow volumes range from 73% to 184%. In other words, the hydrologic model predicts that under the land use conversion and climate change business-as-usual scenario, stormwater events could translate to a doubling and almost trebling of stormwater flow at the modeled junctions.

As illustrated in Figure 5-3, percentage increases in peak flow estimates are higher along the central drainage channel given the large extent of the catchment area and the projected loss of infiltration capacity in the upper watershed. Land use change is a relatively minor contributing factor in the already urbanized areas along the eastern boundary of the watershed.

Figure 5-3: Peak flow estimates expressed as percentage increases for each model junction



Source: ERM, 2013

5.2.2 Predicted Channel Widths and Depths

The hydraulic model (HEC-RAS) simulates the conveyance of the water volume (i.e., peak flows) as it flows through existing stormwater drainage channels. The HEC-RAS model predicted the average channel depth and width that would be required to transport the stormwater flows estimated by HEC-HMS (shown in the preceding section). Coupled with an understanding of existing channel capacity, this permitted the identification of areas at risk of flooding.

Table 5-4 presents the actual channel dimensions for each transect analyzed as well as the corresponding HEC-RAS estimate under the four modeled scenarios. The average channel widths and depths estimated by the HEC-RAS model represent the ideal channel depths and widths necessary for the conveyance of the estimated peak water flows.

Table 5-4 Hydraulic parameters predicted by HEC-RAS under the four scenarios

Channel Transect	Tr	Average Observed Dimensions		Hydraulic Parameters for Each Scenario							
				CA		CC		FUS		CC + FUS	
		W	D	W	D	W	D	W	D	W	D
Oriental	25	7.70	1.96	20.9	2.3	20.2	2.7	21.9	3.0	27.8	3.5
	50			23.3	2.5	20.5	2.8	23.5	3.1	29.1	3.7
	100			22.4	2.6	21.9	3.0	26.4	3.4	30.1	3.8
Cuarezma	25	7.94	1.55	13.4	2.1	16.5	2.6	17.7	3.0	19.2	3.7
	50			14.5	2.3	16.8	2.8	18.3	3.3	19.5	3.9
	100			15.7	2.5	17.6	3.0	18.8	3.5	20.0	4.2
Jagüitas Main Channel	25	5.07	1.12	15.8	2.0	18.3	2.4	18.5	2.4	19.1	2.8
	50			16.8	2.1	18.8	2.5	18.6	2.5	18.9	2.9
	100			17.7	2.3	19.0	2.7	19.0	2.6	19.2	3.1
Jagüitas 1	25	6.77	1.03	21.6	0.9	21.3	1.0	21.8	1.0	23.1	1.1
	50			21.6	0.9	22.8	1.1	22.4	1.0	23.1	1.2
	100			20.6	1.0	23.9	1.1	23.6	1.1	23.7	1.3
Jagüitas 2	25	5.48	1.20	12.5	0.8	13.7	0.9	13.7	0.9	14.3	1.1
	50			13.2	0.8	13.5	1.0	13.3	1.0	15.1	1.1
	100			13.1	0.9	14.0	1.0	13.6	1.0	15.8	1.2

Note: The abbreviations correspond to the following:
W: Channel Width (in meters)
D: Channel Depth (in meters)
Tr: Return Period (in years)
CA: Existing Conditions
CC: Climate Change Only Scenario
FUS: Land Use Changes Only Scenario
CC + FUS: Climate Change and Future Land Use Scenario

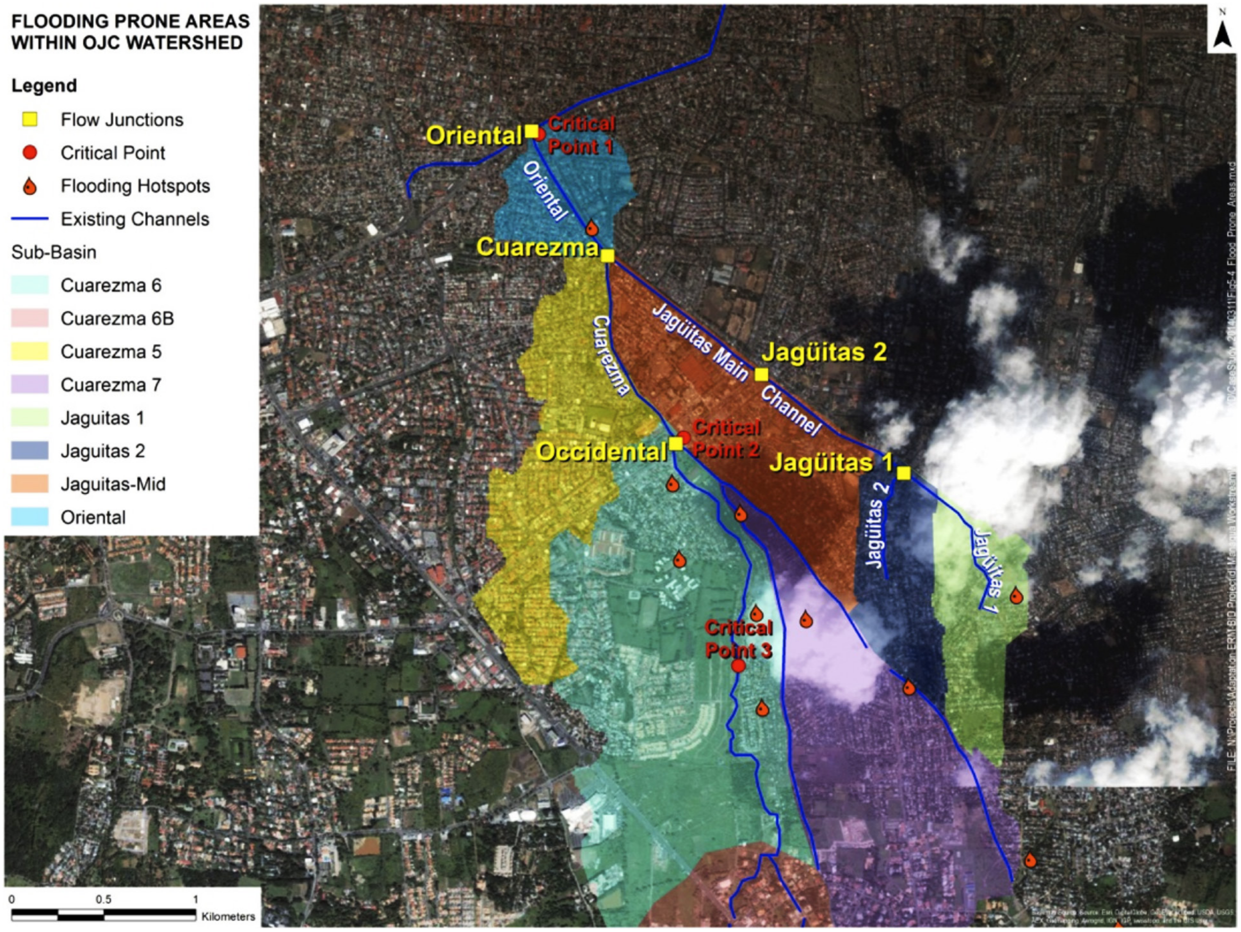
5.3 Urban Flooding Risk Analysis

The hydrological model results indicate significant increases in stormwater peak flows for all return periods. These increases are driven by projected changes in land use and precipitation patterns. The models confirm various points along the urban area within the OJC watershed where stormwater flows may exceed channel capacity and overflow. The sites identified through this analysis are consistent with observations made in previous inundation risk studies focused on Managua[29,30].

It is important to note that ALMA also indicated the presence of three urban locations that were considered critical in terms of propensity to flooding and human and economic assets at risk. Figure 5-4 illustrates the location of inundation hot spots (identified by previous studies) and the three critical points prioritized by ALMA.

29 Consorcio INDES/CABAL/NICATIERRA. Mayo 2004. "Plan Municipal para la Prevención y Mitigación de Desastres Naturales en el Municipio de Managua."
30 Abt Associates Inc., 1995. "Estudio de Factibilidad del Programa de Manejo de la Cuenca del Lago de Managua, Alcaldía de Managua.

Figure 5-4: Location of inundation hot spots and critical points within the OJC watershed



Source: Flooding hotspot locations were sourced from studies developed by the Dirección de Defensa Civil del Ejército Nacional (2003). Critical points were identified by ALMA during July 2013 workshop. Map by ERM, 2013.

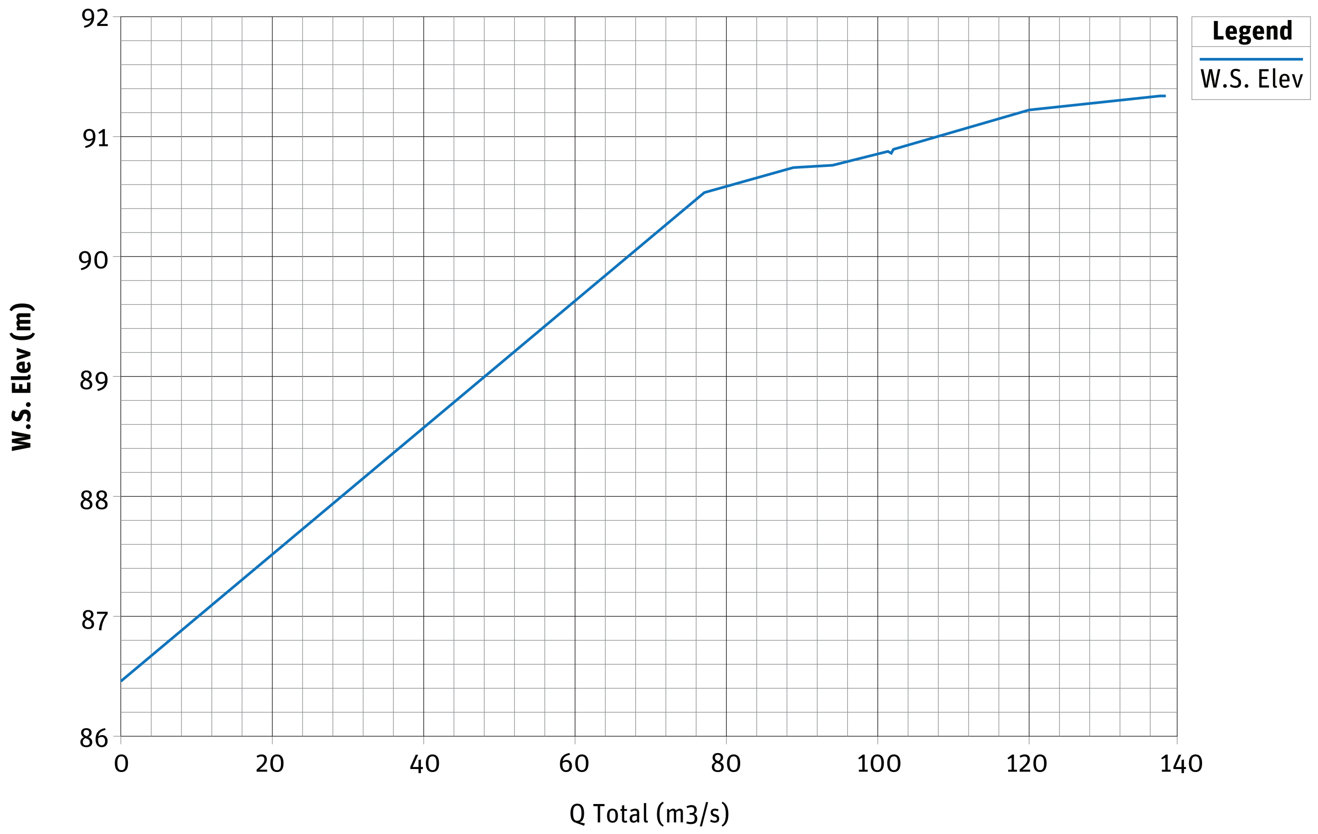
ERM estimated the conveyance capacity of the channels at Critical Points #1 and #2 to calculate the stormwater runoff volume that would result under flooding conditions. The results suggest how flooding risks may evolve in the future in response to precipitation events of increasing intensity while considering potential changes in land use in upper watershed regions.

The availability of peak flow estimates for junctions Oriental and Occidental permitted the analysis of excess stormwater runoff in Critical Points #1 and #2, respectively (refer to Figure 5-4). This analysis did not include Critical Point #3 as it was not possible to obtain precise cross-section data (e.g., width and depth) for this channel transect.

Channel capacity was estimated by calculating the water flow that could be adequately conveyed (i.e., without overflowing) at the lowest bank elevation along the channel. The water flow that corresponds to the lowest bank elevation ($Q_{CHANNEL}$) was calculated for each cross-section using water elevation-flow curves.

Figure 5-5 shows the water elevation-flow curve for Union 3 corresponding to Critical Point #1.

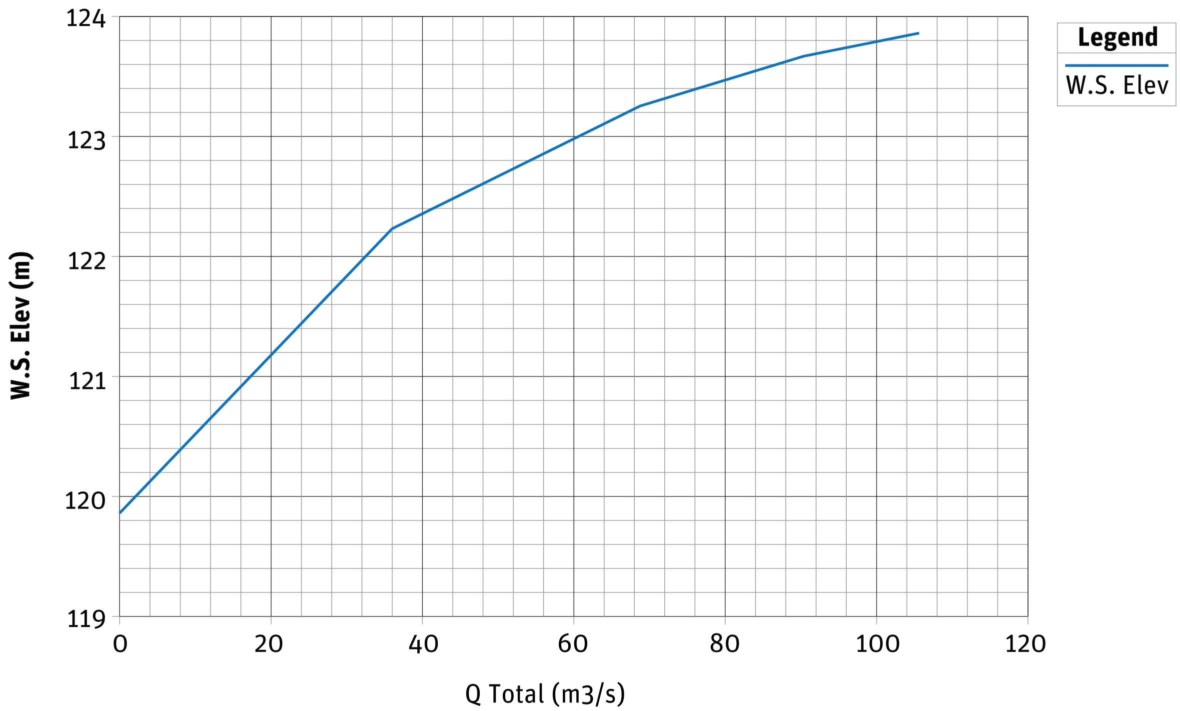
Figure 5-5: Water elevation-flow curve for Union 3 (Critical Point #1)



Source: ERM, 2013.

Figure 5-6 shows the water elevation-flow curve for Union 1 corresponding to Critical Point #2.

Figure 5-6: Water elevation-flow curve for Union 1 (Critical Point #2)



Source: ERM, 2013.

The lowest bank elevations derived from the water elevation-flow curves for the cross-sections at junctions Occidental and Oriental are 122.0 m and 89.7 m, respectively. Maximum conveyable flow ($Q_{CHANNEL}$) values are estimated at 36.1 and 60.2 m^3/s for Occidental and Oriental, or Critical Points #2 and #1, respectively. Water flows estimated above $Q_{CHANNEL}$ values can be considered to be excess flow. Table 5-5 summarizes the above mentioned parameters.

Table 5-5 Lowest bank elevation and $Q_{CHANNEL}$ values

Critical Points (Junctions)	Lowest Bank Elevation	Maximum Conveyable Flow ($Q_{CHANNEL}$)
Critical Point #1 (Oriental)	89.7 m	60.2 m^3/s
Critical Point #2 (Occidental)	122.0 m	36.1 m^3/s

Critical Point #1

Critical Point #1 is located on the intersection of *Pista Juan Pablo II* and *Boulevard Don Bosco*. The area is densely populated and lies along a major commercial thoroughfare. As shown in Figure 5-7, the predicted stormwater peak flows exceed the existing capacity of the channel. This suggests flooding risk will increase significantly in the future, particularly when assuming adverse trends in land use and climate variability. It is also important to note that Critical Point #1 reflects a "bottleneck" situation within the watershed, as runoff from a substantial areal extent converges at this junction.

Figure 5-7: Estimated excess peak flows above channel capacity at Critical Point #1

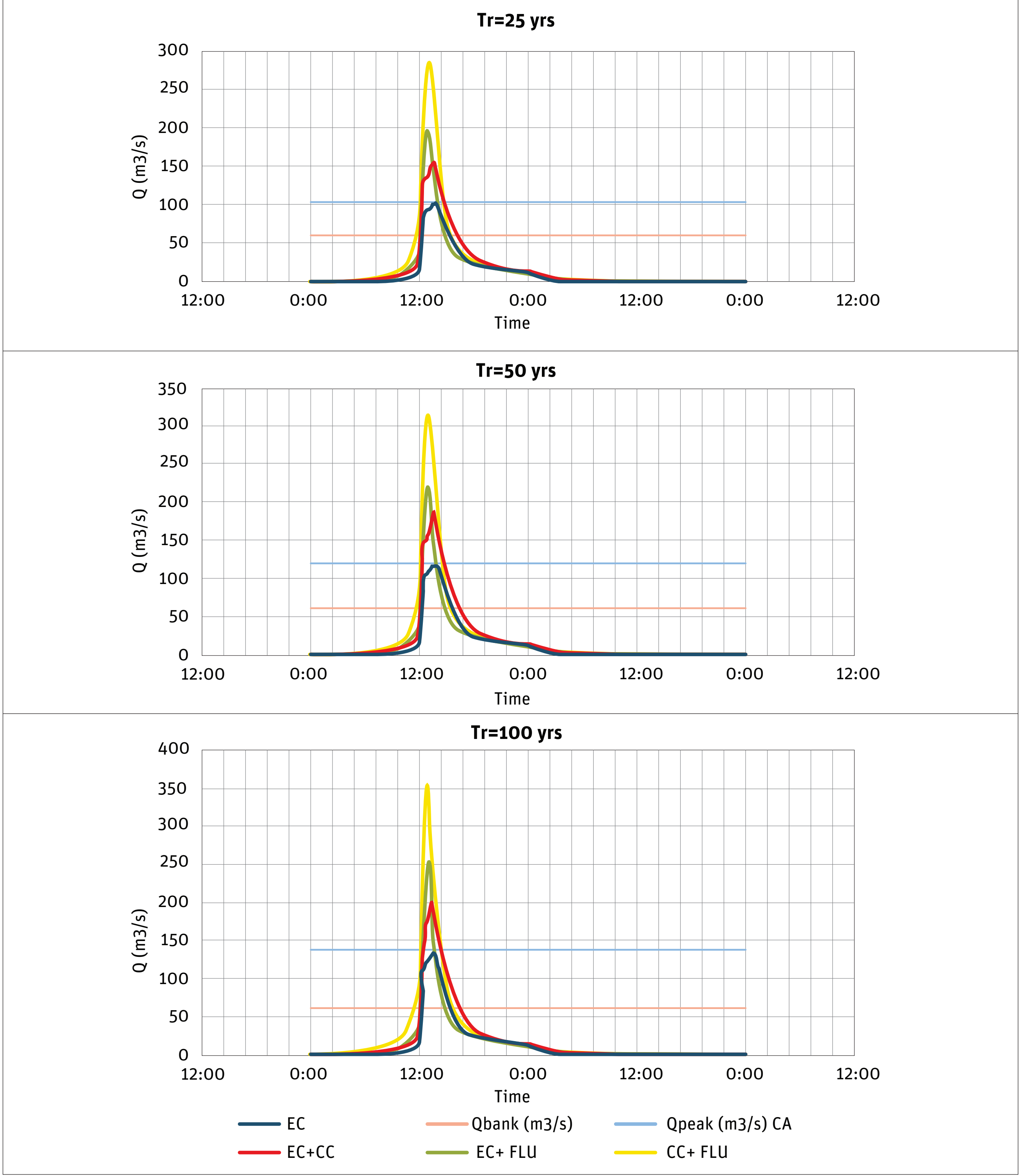
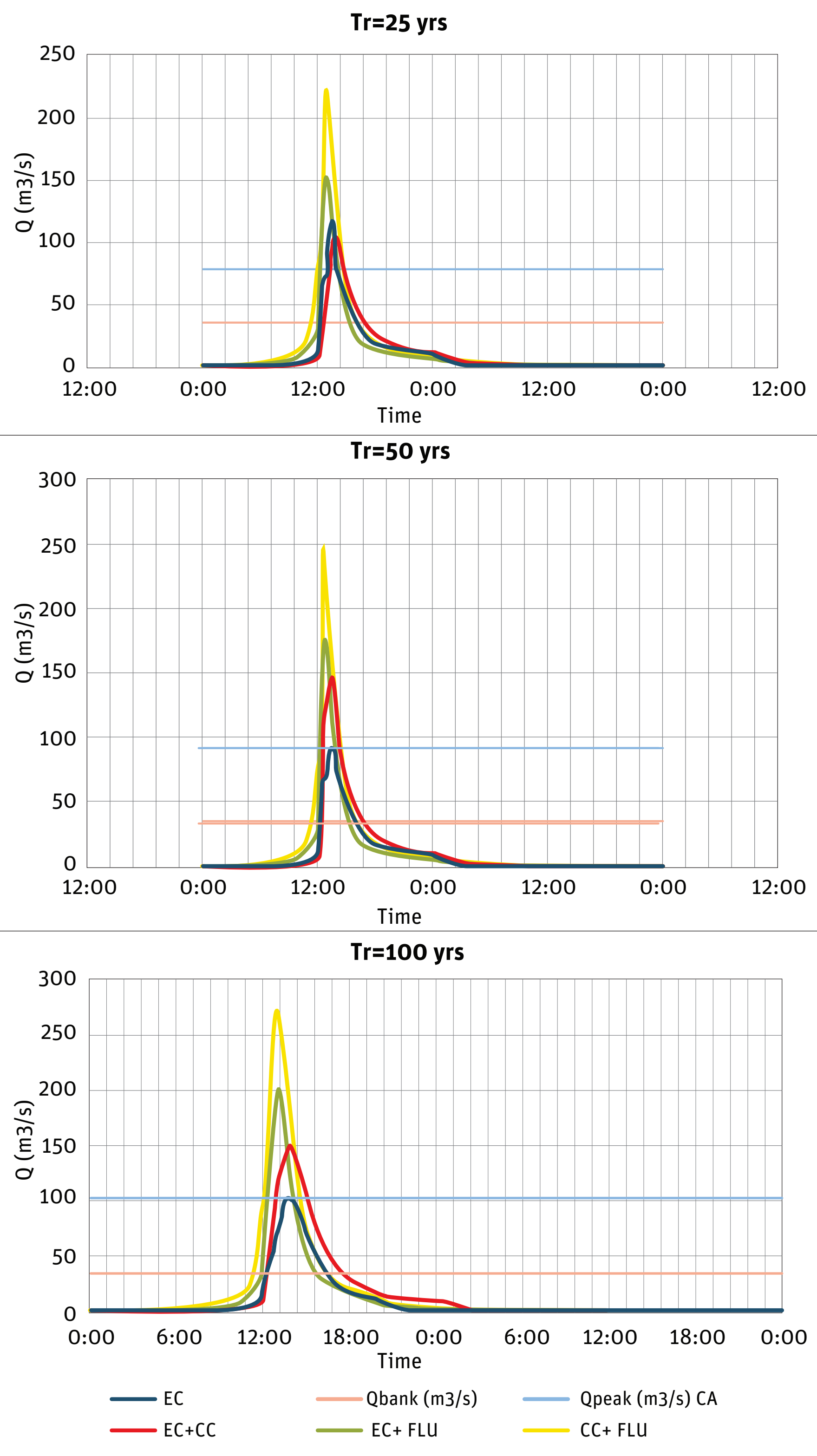


Figure 5-8: Estimated excess peak flows above channel capacity at Critical Point #2



Critical Point #2

Critical Point #2 is located on the intersection of *Pista de La Solidaridad* and *Avenida Isidro Centeno*. The area comprises one of the largest markets in Managua (*Roberto Huembes)*, a specialized healthcare facility (*Hospital Manolo Morales Peralta)*, and various residential neighborhoods. As shown in Figure 5-8, the predicted stormwater peak flows exceed the existing capacity of the channel. This suggests flooding risk will increase significantly in the future, particularly when assuming adverse trends in land use and climate variability.

Table 5-6 shows the estimated excess volumes above the channel capacity at Critical Points #1 and #2. These volumes are indicative of the magnitude of potential flooding that may be associated with a precipitation event corresponding to a 25-, 50-, or 100-year storm.

Table 5-6 Excess stormwater volumes above channel capacity at Critical Point #1 and #2

Critical Point	Return Period	Excess water volumes above channel capacity (m^3)			
		CA	CC	FUS	CC + FUS
Critical Point #1	25	326,730	842,570	859,369	1,408,515
	50	482,871	1,083,584	1,037,066	1,650,975
	100	666,696	1,344,272	1,226,612	1,909,176
Critical Point #2	25	281,305	669,954	703,378	1,120,055
	50	401,849	852,852	838,195	1,304,310
	100	536,730	1,051,735	981,915	1,500,633

Note: Excess water volumes are expressed in cubic meters (m^3). The abbreviations correspond to the following scenarios:
CA: Existing Conditions
CC: Climate Change Only Scenario
FUS: Land Use Changes Only Scenario
CC + FUS: Climate Change and Future Land Use Scenario

6. Analysis of Stakeholder Proposed Adaptation Options

The results showed the volume of stormwater runoff anticipated for the 2050 horizon far exceeds the capacity of the existing drainage infrastructure in OJC. When considering the combined effect of the projected land use changes and a 30% increase in precipitation intensity, the peak flows predicted by the hydrological model exceeded at least four times the capacity of the channels at the two critical inundation hotspots analyzed. This suggests existing urban flooding issues are likely to become worse under the business-as-usual scenario.

A workshop was held on Tuesday, July 16, 2013 at the IDB's office in Managua to present the hydrological analyses, identify the potentially vulnerable populations, and discuss possible adaptations[31]. The majority of the 21 participants at the workshop represented various departments within ALMA; while seven attendees were affiliated with ANA, SINAPRED, INVUR, INETER, ENACAL, and IDB's local office. Following the presentation of the analysis, stakeholders participated in a brainstorming session on potential adaptation measures. Table 6-1 lists each proposed measure according to whether it represents a structural or nonstructural solution.

Table 6-1 Initial set of adaptation measures proposed by stakeholders

Structural Measures	Nonstructural Measures
▪ Concrete-lining (or paving) of channels to accelerate conveyance ▪ Deepening and/or widening of channels ▪ Installation of weirs on specific points along the channel to slow down flows ▪ Construction of retention ponds in the upper and lower sections of OJC ▪ Intubate the channel along *Pista Juan Pablo II* so the road can be widened	▪ Development of a Drainage Master Plan that considers land uses in the upper watershed ▪ Development of an Integrated Watershed Management Plan ▪ Development of an Integrated Municipal Land Use Plan ▪ Enact policy that makes the analysis of flooding risks compulsory for all new private works and residential developments ▪ Implement tax incentives that encourage new works and residential developments to infiltrate stormwater in-situ ▪ Promote land use conservation in undeveloped areas of OJC ▪ Promote environmental awareness campaigns aimed at reducing trash disposals in and along the channels

The structural measures proposed by participants (primarily those who represented ALMA at the workshop) indicated the preference for approaches that improved the conveyance capacity of the urban drainage system. In line with this observation, following the workshop, ALMA requested ERM to examine previous urban drainage and watershed studies to ensure previous proposals were considered and that these helped define the scope of the adaptations that were to be chosen for further analysis. The reviewed documents included:

31 A second knowledge transfer session was held on the morning of Wednesday, July 17 to share the mechanics of the hydrological and hydraulic models with technical staff from ALMA.

- **Lake Managua Watershed Hydrology Report**. Prepared by an engineering consulting consortium[32], and published in November 1999, this report provided a hydrological analysis of the main watersheds in Managua as the design basis for proposed drainage-related civil works.
- **Environmental Impact Report.** Prepared by the same consortium that developed the hydrology analysis, this September 2000 report provided a description of the drainage improvement works proposed to be developed in various parts of Managua.
- **Urban Drainage Improvements Project Profile.** Developed by the project management unit at ALMA, this August 2013 report describes a number of proposed stormwater drainage works aimed at reducing the risk of flooding, erosion and landslides in vulnerable areas of Managua.

Working with engineering staff at ALMA, the ERM team further defined the scope of the adaptation measures whose effectiveness for avoiding or mitigating existing and projected flooding risks was assessed. Table 6-2 presents these measures.

Table 6-2 Adaptation measures assessed with the hydrological models

Measure	Scope
Construction of an Additional Retention Pond	The construction of a retention pond (*Micropresa El Tránsito*) was considered as potential flood control measure to regulate water flow along the Cuarezma channel and mitigate flooding risks downstream (e.g., Critical Point #1 and #2). Design parameters were provided by ALMA based on two existing retention structures in OJC, namely *Micropresa Bariloche* and *Micropresa Las Colinas*.
Channel Lining and Improvement	This measure comprised the simulation of improvements in the drainage network, including the lining of a 600 meter transect and the removal of debris from channel beds. These measures were considered to test the overall increase in flow conveyance efficiency.
Land Use Conservation, Reforestation, and Improvement in Infiltration Capacity	The model results emphasized the importance of improving infiltration capacity and therefore reducing runoff across the watershed. In this sense, stakeholders proposed land use conservation, particularly in areas in the upper OJC watershed that remain undeveloped, as a measure to preserve the regulating capacity of the soil in those areas. Protecting Managua from floods may also require increasing infiltration capacity in urban areas of the watershed as well. The need to the restore natural storage capacity of the soil was evident given the fact that peak flows increased substantially under the future scenario even when assuming land use stayed the same as it is today. Programs that combine both structural (e.g., infiltration trenches) and policy-based measures (e.g., reforestation) may be effective in increasing infiltration capacity in developed areas.
Installation of Weirs	A weir is an obstruction placed across an open channel so that water flows over the weir's top edge or through a well-defined opening in the weir. This causes flow to slow down via a partial dam effect[2]. This adaptation comprises the installation of five weirs along the Cuarezma channel, three along the Jagüitas 1 channel, and three more along the Jagüitas 2 channel. Weirs are a relatively inexpensive intervention, which ALMA has included in recent drainage improvement plans. Therefore, the effectiveness of these hydraulic structures was assessed with the models.

32 This consortium consisted of Abt Associates Inc., CISCONCO Engineering Consulting, and Gomez, Cajiao & Asociados.

6.1 Assessment of Proposed Adaptation Measures

ERM applied the methodology described in *Section 5.1* to analyze the effectiveness of the adaptation measures proposed by stakeholders. We estimated runoff for each of the eight drainage sub-basins that comprise OJC and analyzed the hydraulic implications of peak flows along the existing channel system after the measures were implemented. The models were run for 25-, 50- and 100-year storms (24-hour rainfall values were included in Table 5-1).

Two scenarios were considered in the assessment of adaptation options: existing conditions (CA) and the future scenario that assumes projected land cover and precipitation increases in 2050 (CC+FUS). The hydrologic runoff model for the CA scenario is based on observed land cover (2010) and assumes 25-, 50- and 100-year rainfall events, which were derived from historical precipitation data. The future scenario provided runoff estimates based on the projected land cover for 2050 (refer to **Annex B**) and a 30% increase in precipitation intensity.

Evaluating the effectiveness of the proposed adaptations focused on the analysis of the following hydrologic components:

- Peak flows estimated by the hydrologic runoff model (HEC-HMS) for each of the five flow junctions modeled (i.e., Oriental, Cuarezma, Occidental, Jagüitas 1, and Jagüitas 2); and,
- Estimates provided by the hydraulic model (HEC-RAS) for average top width and elevation of channel flows for each peak discharge from the hydrologic model.

6.1.1 Adaptation #1: Additional Retention Pond in OJC

The team analyzed the construction of a retention basin (*Micropresa El Tránsito)* along the Cuarezma channel. The effectiveness of the retention structure, as a flood control measure, depends on its capacity and location relative to the drainage system. The area is densely urbanized, however, two possible locations were identified based on a flyover of the area performed using Google Earth.

ALMA provided design specifications (e.g., capacity, dimensions) for two existing retention structures in OJC, *Micropresa Bariloche* and *Micropresa Las Colinas* (refer to Figure 6-1). Data provided by ALMA included storage-elevation and discharge-elevation curves[33], which made possible the modeling of these structures.

Table 6-3 tabulates the four different location and capacity combinations that were considered in the analysis. Option 4 represented the best location/design combination (the smaller capacity options produced instability in the hydrologic HEC-HMS model).

33 Information provided by Ing. Freddy Sarria, ALMA

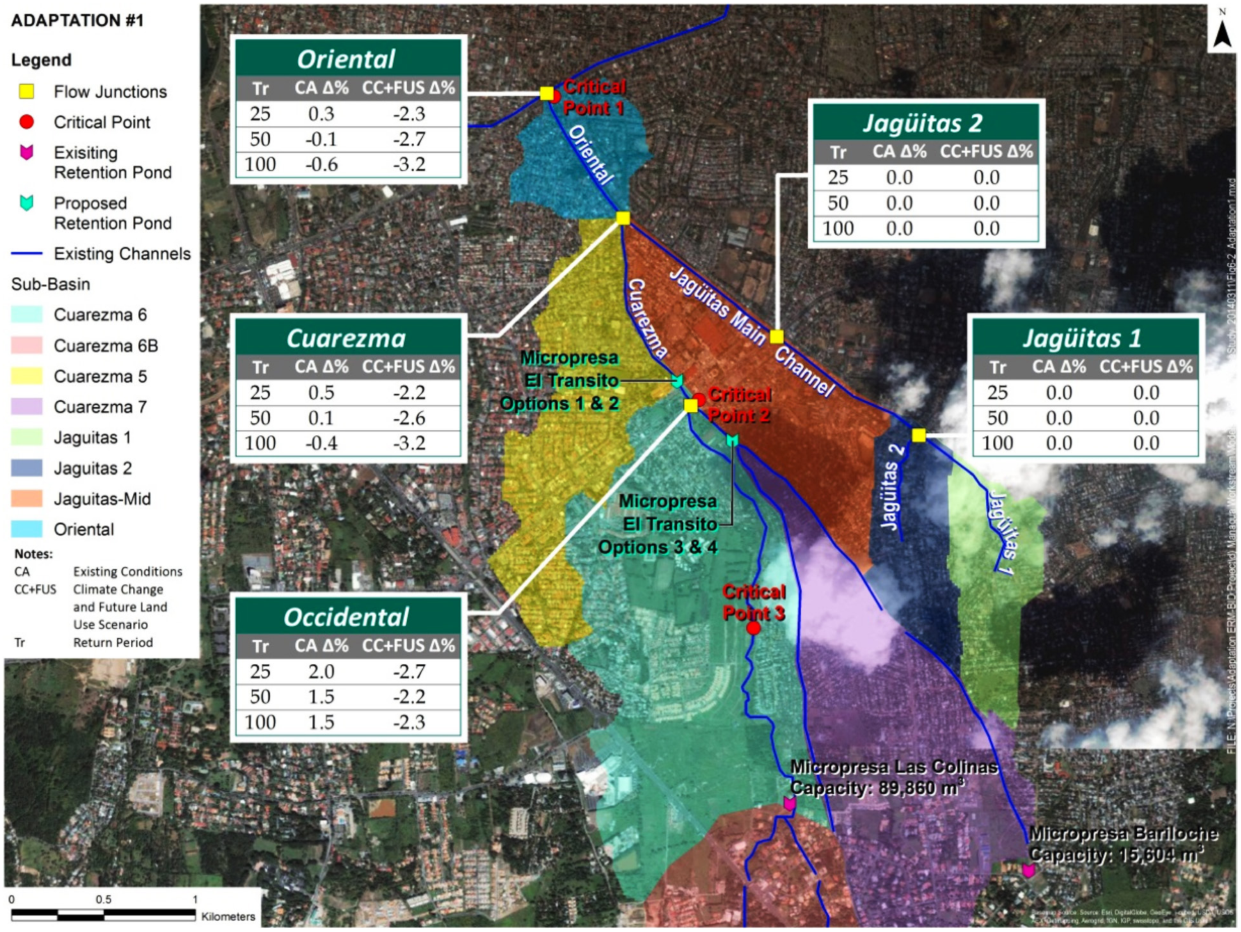
Table 6-3 Location and capacity options for proposed retention structure

Option	Location	Capacity & Dimensions
1	Along the Cuarezma channel, just north of *Pista de La Solidaridad* and west of the *Roberto Huembes Market*	15,604 m^3 based on *Micropresa Bariloche* design
2		89,860m^3 based on *Micropresa Las Colinas* design
3	Confluence of two channels in Cuarezma 7 sub-basin, approximately 300 meters southeast of intersection between *Pista de La Solidaridad* and *Avenida Isidro Centeno*.	15,604 m^3 based on *Micropresa Bariloche* design
4		89,860m^3 based on *Micropresa Las Colinas* design

The results indicated the addition of the retention structure as a flood control measure proved ineffective. The volume of runoff that drains from sub-basins Cuarezma 6 and Cuarezma 7 is too large for the retention structure to drive significant reductions in peak flows. This analysis is true for both the existing and future conditions scenarios and for the three return periods.

Figure 6-1 illustrates the peak flows generated by the hydrologic model for each model junction. Marginal improvements were evidenced along the main Cuarezma and Oriental channels. Given the location of the structure, no changes were perceived at the Jagüitas 1 and 2 junctions (as expected).

Figure 6-1: Results for Adaptation #1 expressed as peak flow percentage changes



Source: ERM, 2013.

6.1.2 Adaptation #2: Channel Lining and Improvement

Some of the drainage problems in Managua are related to the reliance on natural channels for the conveyance of stormwater runoff. In many places, channels are earthen or vegetated, which reduces potential flow capacity and leads to accumulations of trash and stagnant water. This measure modeled the potential effect on hydraulic performance from freeing the channels from debris.

We modeled the hydraulic performance by adjusting the roughness coefficients. The roughness coefficient is an empirical parameter that reflects the drag created by the surface of the channel along which the water flows. It determines in part the velocity of the water flow. Table 6-4 presents the roughness coefficients for the modeled channels before and after improvements.

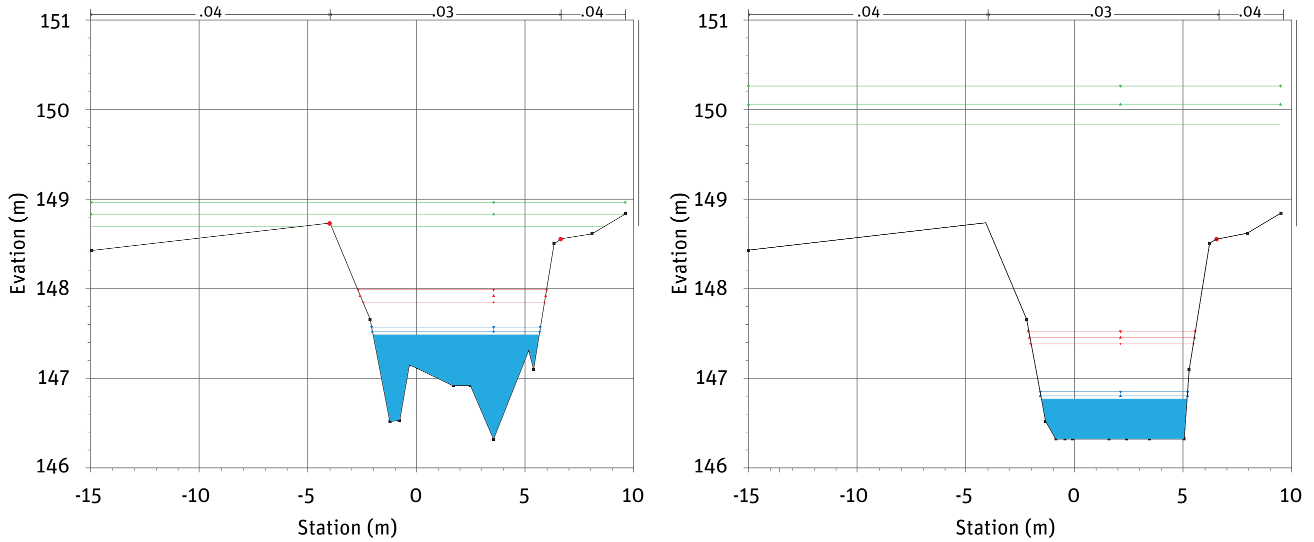
Table 6-4 Roughness coefficients assumed for the main channel and banks

Channel Transect	Before Channel Lining		After Channel Lining	
	Channel	Banks	Channel	Banks
Jagüitas	0.03	0.022-0.04	0.017	0.022-0.04
Oriental	0.03	0.022-0.04	0.017	0.022-0.04
Cuarezma	0.03	0.022-0.04	0.017	0.022-0.04
Jagüitas 1	0.03	0.04	0.017	0.02
Jagüitas 2	0.03	0.04	0.017	0.02

Note: A range is shown for some channel banks because the coefficient varied along the transect

The analysis also included evaluating the effectiveness of lining a channel with concrete. From a hydraulic perspective, lining accelerates the flow along a channel, decreasing the overall depth of the flow. This solution typically involves changing the overall geometry (e.g., depth and width) of the channel. Figure 6-2 illustrates the cross-section before and after the channel improvement simulated for 600-meter Jagüitas 2 channel.

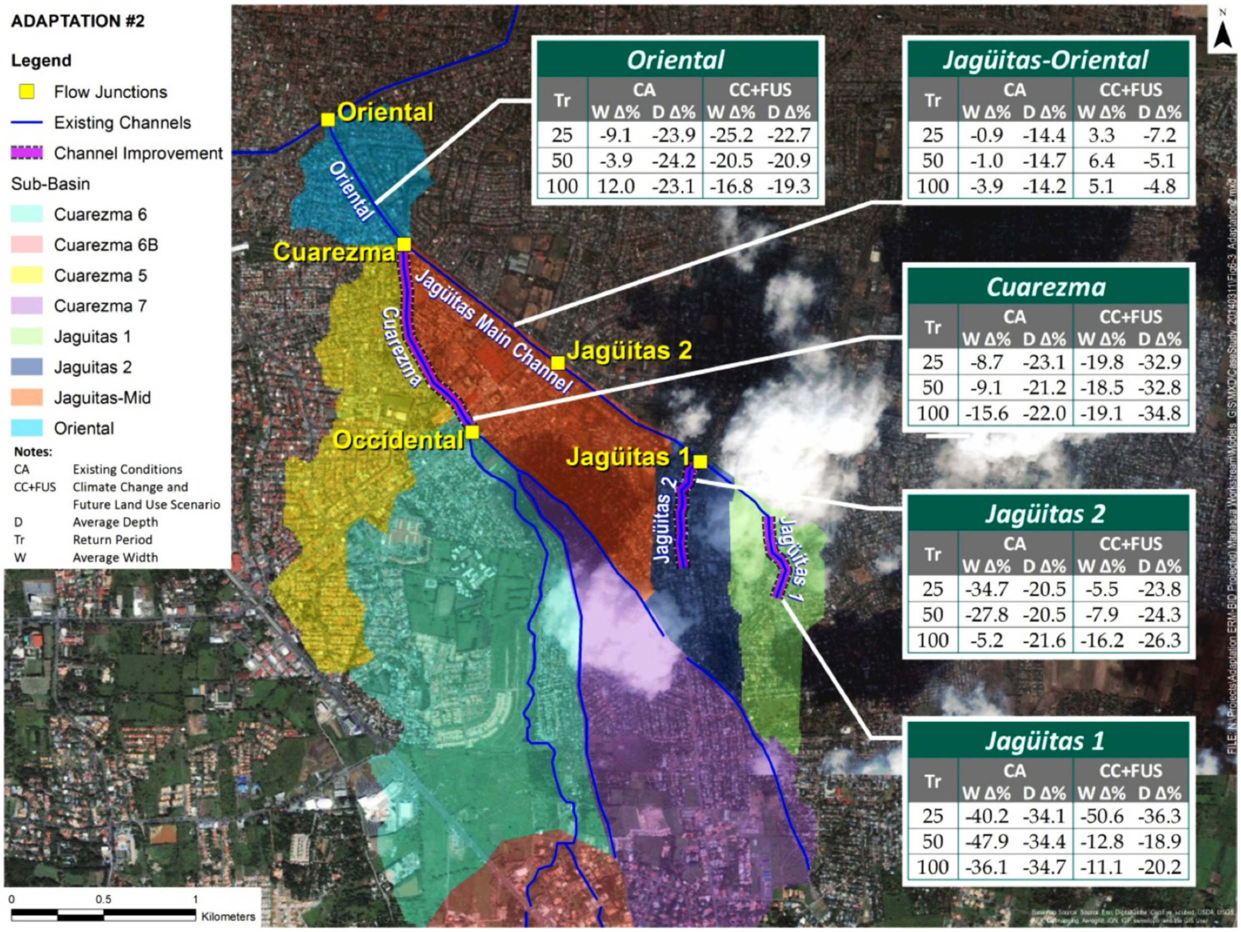
Figurae6-2: Cross-section of channel in Jagüitas 2 before and after channel improvement



Source: ERM, 2013.

The hydraulic behavior of water flows along the lined channels showed significant improvement. Figure 6-3 presents the flow widths and depths predicted by the hydraulic model under the existing conditions scenario. The table shows the corresponding reductions in percentage terms.

Figura 6-3: Adaptación #2 resultados expresados como cambios en los parámetros hidráulicos del canal –en inglés–



Source: ERM, 2013.

6.1.3 Adaptation #3: Increase in Infiltration Capacity and Land Use Conservation

Urban growth in Managua has led to the increase in the amount of impervious surfaces (e.g., roadways, curbs, roofs) and a corresponding increase in the volume of stormwater runoff that must be managed. In view of the inadequate drainage system in Managua, stakeholders recognized the importance of striving to match predevelopment conditions by reversing or compensating for losses in infiltration capacity.

This measure combines two main practices focused on different areas in the watershed:

- In undeveloped areas, the aim would be to promote land use conservation and reforestation as measures to preserve the infiltratable soils that remain in the watershed;

- In developed areas, minimizing stormwater impacts would require a different approach to conventional stormwater management, involving the application of small, cost-effective and distributed techniques that increase infiltration capacity and reduce runoff.

For the purposes of assessing the effectiveness of land use conservation under the future scenario (CC+FUS), we assumed the runoff curve numbers derived from the 2012 land cover analysis (i.e., curve numbers associated with existing conditions). The runoff curve number (CN) is a unit-less hydrological parameter that represents the percentage of rainfall that does not infiltrate into the soil and therefore becomes runoff. To assess the effectiveness of reforestation, we lowered the CN parameter for the Cuarezma 6 and Cuarezma 6B sub-basins[34].

To test the effectiveness of measures aimed at increasing infiltration capacity, the initial rainfall abstractions for each sub-basin were increased from 20% to 50%. The initial rainfall abstraction (Ia) is the amount of water (measured in millimeters) intercepted or stored in vegetation, depressions and pits, prior to rainfall becoming runoff. In other words, *Ia* is the amount of precipitation at the beginning of a storm that is not available for runoff[35], and is a parameter empirically related to the CN[36].

In summary, land use conservation was simulated by holding runoff curve numbers constant under the future scenario. Reforestation in sub-basins Cuarezma 6 and Cuarezma 6B was simulated by lowering the CN relative to existing conditions (from 68 to 62). Increases in infiltration capacity were modeled by increasing the Ia parameter for each sub-basin. Table 6-5 summarizes the hydrological parameter assumptions.

Table 6-5 Hydrological parameters assumed in the modeling of Adaptation #3

Sub-Basin	Assumed Curve Number (CN)	Initial Rainfall Abstraction (Ia) (mm)
Cuarezma 6	62*	77.8
Cuarezma 6B	62*	77.8
Cuarezma 7	77	37.9
Jagüitas-Mid	80	31.8
Jagüitas 1	80	31.8
Jagüitas 2	80	31.8
Cuarezma 5	80	31.8
Oriental	80	31.8

Note: The curve numbers denoted with an asterisk (*) reflect an improvement over existing conditions, the result of reforestation actions.

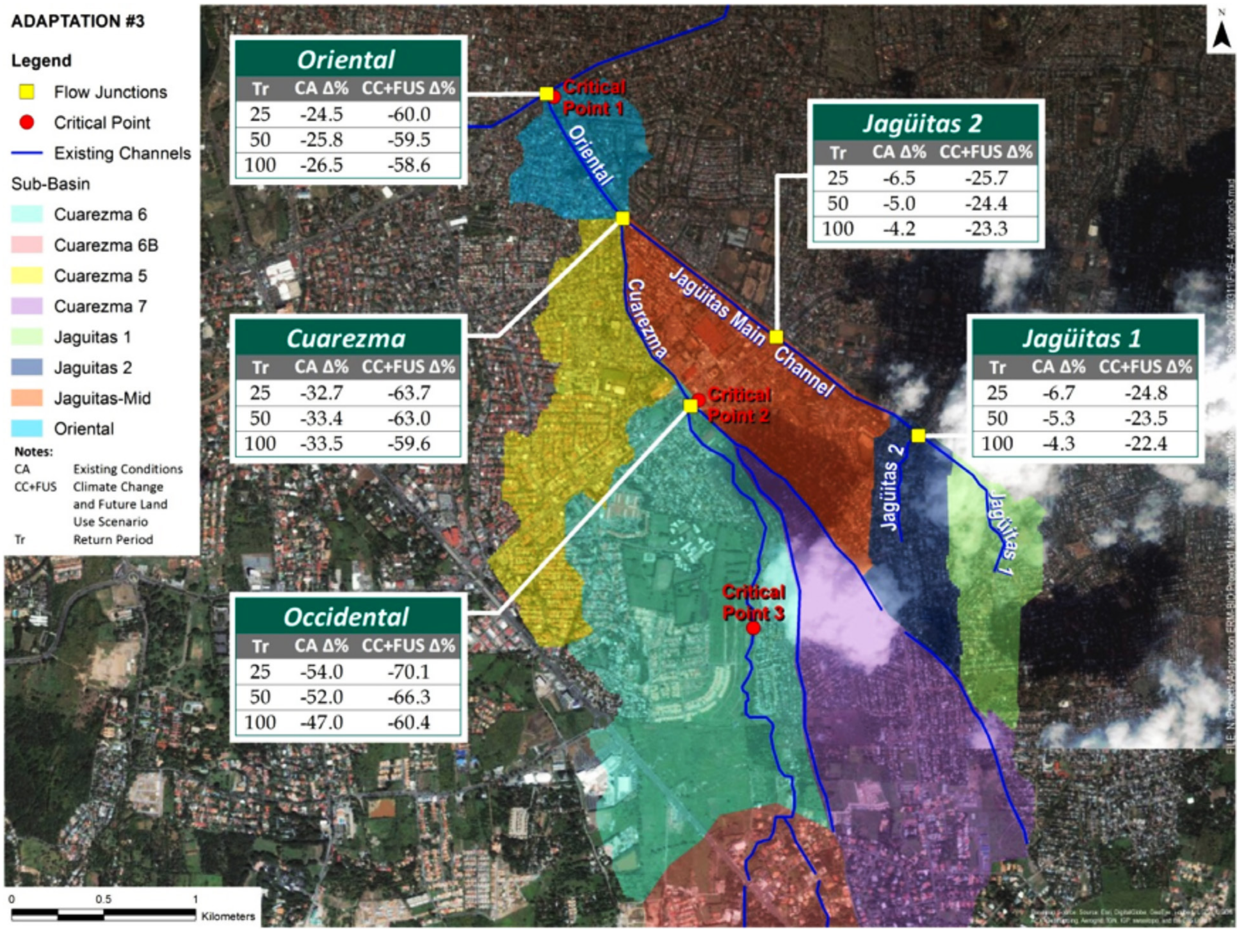
34`Forest cover in the Cuarezma 6 and 6B sub-basins is currently 2.53 km^2 or 35% of their total area of 7.31 km^2. The target forest cover area was set at 3.71 km^2 representing an increase of 16% in forest land cover to be achieved by reforestation.

35 McCuen, R.H. 1989. Hydrologic Analysis and Design. Prentice Hall. ISBN 0-13-447954-8.

36 Wanielista, M., Kersten, R., and Eaglin, R. 1997. Hydrology, Water Quantity and Quality Control. 2nd Edition Jonh Wiley and Sons, Inc.

Figure 6-4 show the peak flows generated by HEC-HMS for each of the five modeled junctions.

Figure 6-4: Results for Adaptation #3 expressed as peak flow percentage changes



Source: ERM, 2013.

The results indicate substantial reductions in the risk of flooding. At Occidental junction, where effects from reforestation would be more evident, peak flows predicted for present-day storms were cut by 50% on average. Increases in infiltration capacity help to mitigate peak flows further downstream.

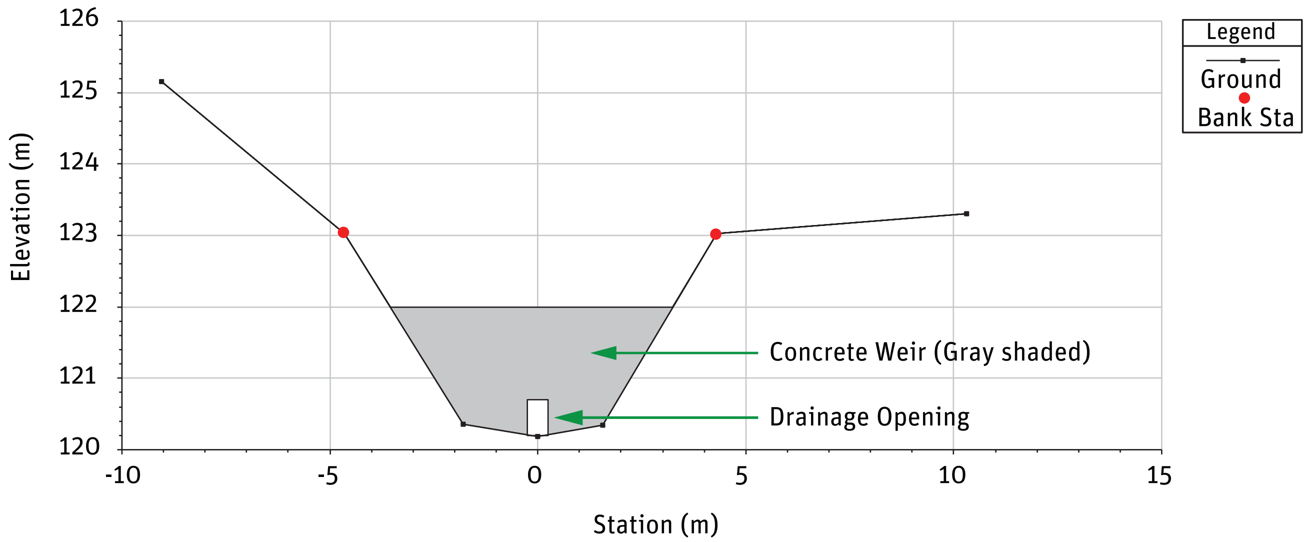
In the Jagüitas sub-basins, peak flows decreased approximately 25% on average under the future scenario. Peak flows decreased less than 10% on average under present-day conditions. Despite more modest results in the eastern sub-basins, their contribution to flow reductions downstream is significant.

Overall, measures that combine efforts to preserve and, to the extent possible, increase infiltration capacity were the most successful of the assessed adaptation alternatives.

6.1.4 Adaptation #4: Inline Channel Structures (weirs)

A weir is an obstruction placed across an open channel so that water flows over the weir's top edge or through a well-defined opening in the weir. The weir backs up water along a channel by creating a partial dam[37]. Figure 6-7 illustrates a weir (gray-shaded area) along the channel as seen on a cross-section diagram.

Figure 6-5: Example of a weir installed along a channel (cross-section view)



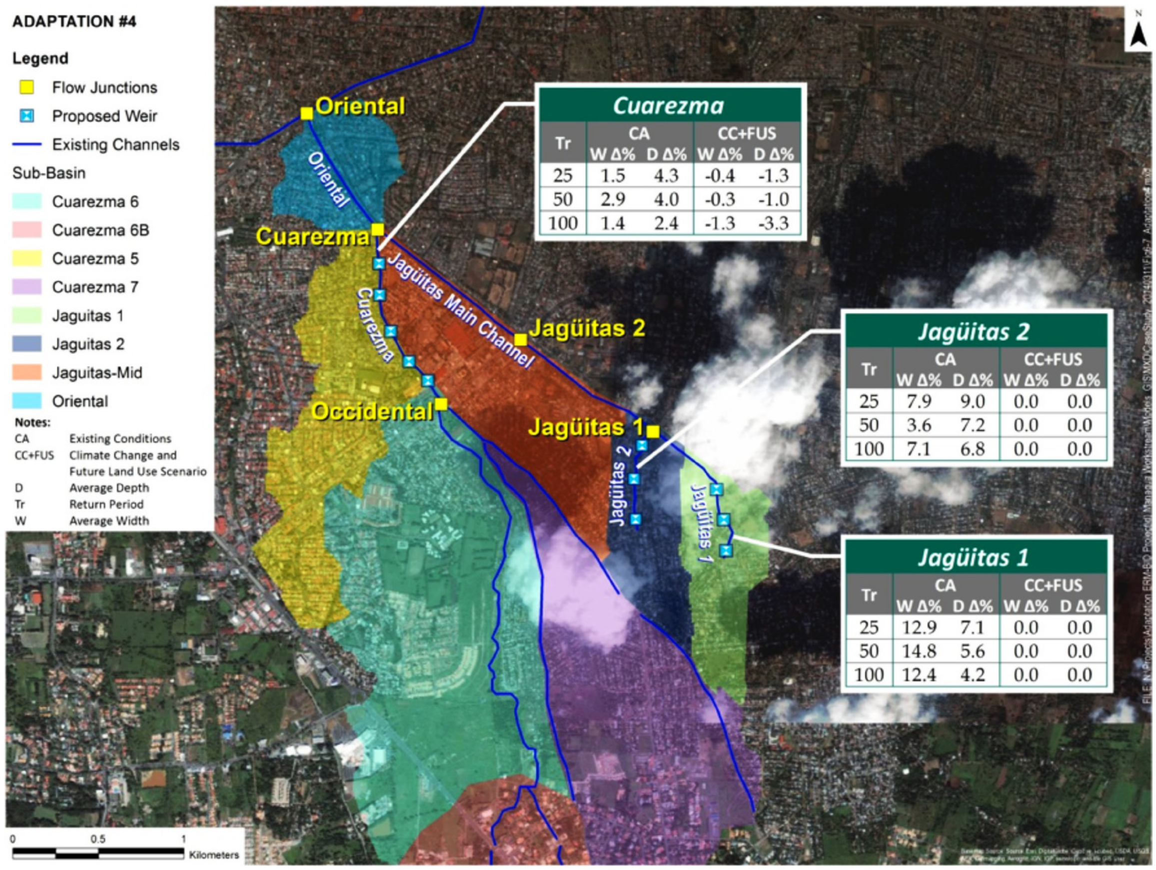
Source: ERM, 2013.

The effectiveness of weirs as flood control mechanisms were evaluated in terms of the hydraulic effects along specific channels. We tested the placement of weirs along three main channels: Cuarezma, Jagüitas 1, and Jagüitas 2. Five weirs were simulated along the Cuarezma channel, three along the Jagüitas 1 channel, and three along the Jagüitas 2 channel.

The results indicate the weirs appear to be inadequate to cope with the water flows resulting from the 25-, 50-, and 100-year design storms under both the CA and CC+FUS scenarios. As shown in Figure 6-6, the changes in flow width and depth were marginal and therefore the installation of weirs does not prove to be an effective flood control measure.

37 ASCE and EPA, 2002. Urban Stormwter BMP Performance Monitoring. A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. GeoSyntec Consultants Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of American Society of Civil Engineers.

Figure 6-6: Results from Adaptation #4 expressed as channel hydraulic parameters



Source: ERM, 2013.

6.2 Results Summary

The adaptations proposed by stakeholders comprised conventional measures designed to manage stormwater runoff (e.g., retention ponds, weirs) as well as measures to reduce runoff by conserving land use and increasing ground infiltration. Following is a summary of our findings for each of the adaptations assessed.

Adaptation #1: Construction of *Micropresa El Tránsito*. This measure showed only marginal improvements in peak flows under all scenarios. The location and capacity of the retention structure were optimized within the parameters given by ALMA, yet the results were unsatisfactory. Though ALMA possesses technical capacity to design and execute this measure, our analysis suggests land and cost may also be constraining factors. The construction of *Micropresa El Tránsito* may cost approximately US$2 million[38], a cost which may not be justified given the unfavorable technical results. In addition, land is likely to be scarce and expensive given the extent of urbanization in areas where flow control is needed most.

Adaptation #2: Channel Lining and Improvement. The results indicated the potential for channel improvements to mitigate drainage-related flooding in specific transects. Larger channel dimensions, smoother channel bed and slope surfaces, and trash-free channels translated to improved hydraulic conveyance. The lining of channels can also provide aesthetic and health benefits (i.e., elimination of stagnant water pools).

When improving channels, bridges and culverts should also be designed to convey surface runoff associated with storms of increasing rainfall volume and intensity (as captured under the CC+FUS scenario). Channel improvements can also combine the use of infiltratable lining materials. Proper cleaning and maintenance of channels should be considered along all existing channels and waterways.

Adaptation #3: Land Use Conservation and Increase in Infiltration Capacity. Increasing infiltration capacity across the watershed was the single most effective solution tested. The implementation of practices designed to reduce or store runoff would have the most effect in reducing flood risk of any of the adaptation measures assessed. These practices can also be implemented at a micro-scale using a distributed approach, and various designs exist for a range of residential and non-residential uses[39].

The results also highlighted the importance of preserving existing infiltratable surfaces. As expected, reforestation also had a positive impact by increasing the time it takes for runoff to flow from the most remote point to the lowest point in the watershed (i.e., concentration time).

Adaptation #4: Installation of Weirs. Based on the model outputs, the installation of weirs along the Cuarezma, Jagüitas 1, and Jagüitas 2 channels appear to be inadequate in controlling flows associated with the 25-, 50-, and 100-year design storms. Over time, weirs would also tend to accumulate sediment, trash and other types of debris, thus altering the hydraulic conditions along the channels[40].

It is important to note that in ALMA's experience[41], the construction of weirs in channels have helped alleviate flooding issues in the past, particularly for lower-intensity precipitation events. While these structures did not fare satisfactorily for the simulated events, this should not discourage their consideration in other applications, particularly given their low cost and ease of installation. Careful regard should be given to their design, ensuring their dimensions and location is optimal for the channel's characteristics (e.g., slope, size, condition). The estimated cost to construct a weir in Managua is approximately US$120,000[42].

38 ALMA, 2013. Obras de Drenaje Pluvial Municipio de Managua. Alcaldía de Managua. Dirección General de Proyectos. August 2013.
39 http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec8INFILTRATION.html
40 ASCE and EPA, 2002. Urban Stormwter BMP Performance Monitoring. A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. GeoSyntec Consultants Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of American Society of Civil Engineers.
41 Personal communication with Ing. Fredy Sarria and Maritza Maradiaga.
42 ALMA, 2013. Obras de Drenaje Pluvial Municipio de Managua. Alcaldía de Managua. Dirección General de Proyectos. August 2013.

7. Main Recommendation & Conclusion

The rapid and widespread urban development in Managua has resulted in the replacement of natural soils and vegetation with impervious surfaces such as roads, buildings, dwellings, and compacted soils; all of which lack the ability to capture and store rainfall (through infiltration), resulting in higher rates of stormwater runoff. Government officials have attempted to manage stormwater runoff by diverting it onto a drainage network of natural and artificial streams and channels, and investing in conventional flow control measures such as ditches, culverts and retention ponds.

Efforts to develop an urban drainage network have not yielded adequate results. Factors such as limited funds for infrastructure investments, lack of adequate maintenance of existing assets, and outdated design standards further limit the efforts to control runoff. Today, a large number of communities, such as those highlighted in this case study, live under the threat of flooding and experience frequent socioeconomic and public health impacts.

The hydrological and hydraulic analyses, undertaken for this study, not only highlight the urgency of actions aimed at preventing flooding associated with large storms, i.e., those with a 1:25, 1:50, or 1:100 probability of occurring on any given year, but also underscores the need to rethink conventional stormwater practices because, in some areas and in some communities, flooding is a hazard that affects residents year after year.

The paradigm that has dominated conventional stormwater management is that "stormwater runoff is undesirable and must be removed from the site as quickly as possible to achieve good drainage."[43] Our technical analysis suggests conventional stormwater management measures, such as retention and flow control devices, ranked lowest in terms of effectiveness. The volume of stormwater runoff generated by the rainfall events of increasing intensity predicted for Managua is simply too large to be managed by the existing urban drainage system, even after testing some potential improvements.

Redesigning and reconstructing a climate-resilient urban drainage system is likely to be too costly and face potentially unsurmountable technical, environmental and social challenges. In addition, flow improvements in one place may lead to bottlenecks elsewhere; therefore an urban drainage overhaul would be a large-scale undertaking.

The most effective adaptations assessed by this study were based on increases in infiltration capacity across the watershed. Adaptation #3 embodies actions aimed at restoring predevelopment hydrologic functions such as interception, storage, and infiltration. We modeled lower runoff curve numbers and higher initial rainfall abstractions as a means to mimic the predevelopment hydrological regime in terms of infiltration capacity and resulting runoff volumes. The results obtained by this method showed the most significant reductions in peak flows at the modeled flow junctions. Coupled with other structural and policy-based measures, this approach offers the best possibilities for significant flood risk reductions in a region prone to climatic variability and tropical cyclones.

43 Prince George County's Department of Environmental Resources, Maryland. June 1999. *Low-Impact Development Design Strategies: an Integrated Design Approach.* Page 4.

Main Recommendation

In order to replicate the predevelopment hydrology in Managua, we propose a shift in stormwater management practices toward a Low-Impact Development (LID) approach that comprises techniques to store, infiltrate, evaporate, and detain runoff at the individual lot or neighborhood level. These techniques focus on managing stormwater at the source in contrast to managing runoff via large and costly drainage and retention facilities.

LID is based on concepts that include "considering the site hydrology as a design focus, minimizing imperviousness, disconnecting impervious surfaces, increasing flow paths, and defining and siting micromanagement controls."[44] In practice, LID techniques can be applied to any residential, commercial, and industrial suburban development. If properly sited, designed and operated, LID practices can have economic and environmental benefits for Managua, and represent cost savings in the range of 15% to 80% when compared to conventional practices[45].

Examples of LID practices include bioretention devices, infiltration wells and trenches, green roofs, pervious pavers, rain barrels and cisterns, tree box filters, preservation of infiltratable soils, and re-vegetation, among others. The choice of technique is highly dependent on the site and the desired hydrological function. Defining a package of suitable options for a specific site, or group of sites, must be preceded by a hydrological evaluation to determine the stormwater management goal and define the measures that can be implemented.

ERM's main recommendation is to develop an investment program aimed at piloting approaches to mainstreaming LID-based techniques in Managua. An investment program to pilot LID-based approaches could have three distinct stages of action:

- **Large and medium-sized residential lots**. Properties of sufficient size would be suitable for the installation of individual rainwater collection devices, such as rain barrels or infiltration wells. Local government would provide the equipment and know-how. The cost of installation would be the responsibility of the owner, partly or wholly subsidized via a tax credit.
- **Small units and low-income housing.** In densely urbanized areas comprised of smaller lots, a possible approach depending on site characteristics is to divert rainwater from individual houses to a central well or infiltration trench. The cost of civil works would likely be borne by local government, but direct assessments could be placed on all benefitted households for specific improvements. Incentives for individual improvements can be provided such as the distribution of environmental bonds.
- **Industrial, commercial and institutional properties.** These properties can be identified during planning and required to collect their own rainwater. Proprietors are given the option to install storage systems (to discharge after storms have passed) or infiltration devices. The cost is borne by owners. Tax credits could be made available to partly or wholly subsidize the improvements.

Cost and Benefit Considerations

The area comprised by the OJC watershed is home to a public and private asset base of relative importance to the commercial and social life of Managua. This infrastructure includes several health facilities (including a specialized care hospital); several sports fields and neighborhood parks; the two largest markets in Managua (*Oriental* and *Roberto Huembes*); over 100 primary and secondary schools; some of the largest and most important shopping centers; several hotels; city landmarks and governmental offices. This watershed is also home to several (planned and unplanned) residential developments representing a range of income levels.

44 Prince George County's Department of Environmental Resources, Maryland. June 1999. *Low-Impact Development Design Strategies: an Integrated Design Approach.* Page 6.

45 http://www.epa.gov/region1/npdes/stormwater/assets/pdfs/AddressingBarrier2LID.pdf

The importance of the asset base in OJC means that when flooding occurs, negative economic impacts can be expected, commensurate to the magnitude of the flooding event. Some economic impacts are explicit, such as those resulting from the loss in retail sales and damages to property and households. Other costs are hidden because they are not readily quantifiable, such as losses in productivity and the opportunity cost associated with depressed real estate values in flood-prone areas.

When assessing the benefits of potential reductions to flooding risk and occurrence, the focus is on estimating the following parameters:

- Direct damages to residential property and household goods;
- Losses in productivity (i.e., foregone personal income);
- Negative impact on housing values; and,
- Lower rate of investment in property (i.e., opportunity cost).

A preliminary cost-benefit analysis was developed to account for these losses as a basis for determining the cost-effectiveness of potential improvements. In general terms, the private and public economic losses avoided by actions aimed at reducing flooding constitute its benefits. As per initial estimates, the total cost of flooding in the OJC watershed ranged from US$152 million to US$221.5 million for a period of 20 years. Based on specific assumptions, flood mitigation improvements with a Present Value of less than US$152 million would be economically viable.

A key aspect of developing and implementing the pilot program is the design of a cost recovery system that is equitable, transparent, and self-sufficient. In terms of equity, costs for certain improvements may be borne by a few but benefits from avoided flooding can be gained by many. Thus, it is important to spread the total cost of the flood mitigation infrastructure across all households, weighted perhaps by an index of relative value of land.

The issue of property rights must also be contemplated by the pilot program. In low-income neighborhoods, and especially among the poorest, it is common to find that homesteads do not yet have a clear title to their land. As a result, there is a reduced incentive for households to make permanent improvements to their dwelling. Therefore, the titling of homesteads to promote home improvements and reduce the cost of flood damage should be taken into consideration.

An orderly regime of land tenure will also facilitate the use of property taxes as a cost recovery mechanism. Credits in lieu of property taxes could be given for improvements that directly benefit the households paying for it. In the case of households with clear title that are already paying property taxes, any increase in taxes tied to flood mitigation must be spent on flood mitigation by the local government.

Institutional Considerations

The process for selection and design of site-specific LID techniques is based on a hydrological evaluation to identify the control goals. Hydrological expertise can be found within ALMA, INETER and other local institutions. However, technology transfer initiatives may be necessary to introduce LID-based applications and institutionalize a procedure for LID-based planning, including site design, hydrological analysis, technique selection and evaluation, project planning and execution, and public outreach.

LID techniques are relatively simple technological interventions. Given ALMA's previous experiences in designing and executing drainage civil works, we expect sufficient capacity to exist within the organization, in addition to resources and expertise in the private sector.

In addition to implementing LID techniques, restoring the watershed's predevelopment hydrological functions will require active efforts to preserve and increase, to the extent possible, vegetative land cover. It is important to note the positive results associated with Adaptation #3 assume undeveloped areas retain their current infiltration capacity, or their conversion presupposes no additional runoff. Specific plans to identify areas suitable for land use preservation and re-vegetation must be developed at the municipal level. Coordination across municipalities and institutions would play a key role in operationalizing and enforcing those plans.

Environmental Considerations

Measures to improve infiltration capacity and increase vegetative cover are also likely to generate environmental benefits. One such benefit is the possibility for groundwater recharge given that a considerable percentage of the rainfall abstraction infiltrates into the soil and may contribute to groundwater recharge. On the other hand, infiltrated water may also carry pollutants that would be undesirable to find in groundwater. Further analysis may be required to assess the suitability of rainwater collected by residences for infiltration, while rainwater collected by industrial sites may carry a risk of contamination that would call for a storage-based solution. This is a consideration that must be included during the formulation of a site control strategy.

Beyond groundwater, environmental concerns associated with distributed, small-scale LID techniques and land use conservation/enhancement are typically associated with construction activities and can include short-term reductions in air quality, noise and vibration, and aesthetics. Given the small scale of infiltration related works, these impacts are likely to be manageable.

Social Considerations

The pilot program is expected to provide several direct and indirect significant positive impacts. The most salient benefits relate to the reduction of the adverse effects caused by flooding such as damages to property and household goods, loss of income and school time, increased risk of disease, and depressed property values. The expected benefits include improved socioeconomic conditions (due to increases in productivity) and improvements in quality of life as flooding ceases to be a recurring worry.

The program would integrate a technology transfer component to build local capacity in the new approach to stormwater management. An environmental education component would also be crucial to the implementation of LID-based strategies and to raise awareness of the alert and response systems in place. The end result is improved adaptive capacity to the anticipated impacts due to climate change.

8. References

ALMA, 2013. Obras de Drenaje Pluvial Municipio de Managua. Alcaldía de Managua. Dirección General de Proyectos. August 2013.

Abt Associates Inc., 1995. "Estudio de Factibilidad del Programa de Manejo de la Cuenca del Lago de Managua, Alcaldía de Managua.

ALMA, 2013. Obras de Drenaje Pluvial Municipio de Managua. Alcaldía de Managua. Dirección General de Proyectos. August 2013.

ASCE and EPA, 2002. Urban Stormwter BMP Performance Monitoring. A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. GeoSyntec Consultants Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of American Society of Civil Engineers.

ASCE and EPA, 2002. Urban Stormwter BMP Performance Monitoring. A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. GeoSyntec Consultants Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of American Society of Civil Engineers.

ASCE and EPA. 2002. *Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements.* GeoSyntec Consultants for the Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers.

Bárcena, A., Prado, A., Beteta, H., Samaniego, J.L., Lennox, J. (2012). The Economics of Climate Change in Central America: Summary 2012. ECLAC, UKAid, CCAD, SICA.

Centers for Disease Control and Prevention (2012). Dengue: Entomology and Ecology.

Consorcio INDES/CABAL/NICATIERRA. Mayo 2004. "Plan Municipal para la Prevención y Mitigación de Desastres Naturales en el Municipio de Managua."

"Comunidades rurales olvidadas." *La Prensa*. November 25, 2013.

Desinventar (2013). Nicaragua – Historical Inventory of Disasters. Available at: http://www.desinventar.org/en/database

http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec8INFILTRATION.html

INIDE (2005). *VIII Population Census and IV Household Census.*

Inter-American Development Bank (2009). *New Release: Nicaragua to improve Lake Managua's southern watershed drainage with IDB assistance*. Available at: http://www.iadb.org/en/news/news-releases/2009-12-02/nicaragua-to-improve-lake-managuas-southern-watershed-drainage-with-idb-assistance,6003.html

Leary, N. et al. (2007). Assessment of Impacts and Adaptation to Climate Change: Final Report of the AIACC Project. Global Environmental Facility. The International START Secretariat. Washington, DC.

McCarthy, J. et al. (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, New York.

McCuen, R.H. 1989. Hydrologic Analysis and Design. Prentice Hall. ISBN 0-13-447954-8.

Mertz, O. et al. (2009). Adaptation to Climate Change in Developing Countries. Environmental Management. Issue 43, pp 743-752.

Mertz, O., Halsnæs, K., Olesen, J., Rasmussen, R. 2009. *Adaptation to Climate Change in Developing Countries.* Environmental Management 43:743-752.

Municipality of Managua. Plan General de Desarrollo Municipal.

National Safety Council (2009). Air Quality Problems Caused by Floods. Available at: http://www.nsc.org/news_resources/Resources/Documents/Air_Quality_Problems_Caused_by_Floods.pdf

"Nicaragua improves ability to respond to natural disasters with IDB support". *IADB News Releases*. November 27, 2013. Available at: http://www.iadb.org/en/news/news-releases/2013-11-27/nicaragua-improves-respond-to-natural-disasters,10676.html

NOAA National Climatic Data Center (2009). Mitch: The Deadliest Atlantic Hurricane since 1780. Available at: http://www.ncdc.noaa.gov/oa/reports/mitch/mitch.html

Occupational Health and Safety Administration. Fact Sheets on Natural Disaster Recovery (n.d.). Available at: https://www.osha.gov/OshDoc/floodCleanup.html

Prince George County's Department of Environmental Resources, Maryland. June 1999. *Low-Impact Development Design Strategies: an Integrated Design Approach.* Page 4.

Prince George County's Department of Environmental Resources, Maryland. June 1999. *Low-Impact Development Design Strategies: an Integrated Design Approach.* Page 6.

United Nations Framework Convention for Climate Change

US Army Corps of Engineers. Hydrologic Engineering Center - River Analysis System, HEC-RAS. http://www.hec.usace.army.mil/software/hec-ras/

US Army Corps of Engineers. 2010. Hydrologic Engineering Center - Hydrologic Modeling System, HEC-HMS. User's Manual Version 3.5. August 2010. US Army Corps of Engineers. Hydrologic Engineering Center. http://www.hec.usace.army.mil/software/hec-hms/

Wanielista, M., Kersten, R., and Eaglin, R. 1997. Hydrology, Water Quantity and Quality Control. 2nd Edition Jonh Wiley and Sons, Inc.

World Health Organization (n.d.). Flooding and communicable diseases. Available at: http://who.int/hac/techguidance/ems/flood_cds/en/

Annex A:

Baseline of Existing Conditions

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Table of contents

List of Tables

List of Figures

A.0 Baseline Characterization of Study Area

This baseline emphasizes aspects that influence the vulnerability of stakeholders to climate change induced hazards such as urban flooding and lake level rise. The physical, hydrologic, environmental and socioeconomic data presented in this section provides the basis for understanding the propensity for climate induced hazards to take place, and assessing resulting impacts and vulnerability at the community level.

This baseline contains three main sub-sections:

- **Physical Characteristics:** provides a high-level overview of aspects related to geology, topography, land use/land cover, soil infiltration capacity, climate, and hydrology. This data provide key inputs for the model-based hydrological analysis.
- **Socioeconomic and Demographic Data:** summarizes census-based data and secondary research on population, population density, educational attainment, socioeconomic status, economic activities, and public infrastructure. This information is presented as context for understanding the factors that drive community vulnerability.
- **Political and Institutional Context**: includes local legislation, regulations and institutions relevant to water resource management and emergency preparedness/response management. This overview serves as context for characterizing local capacity to implement adaptive measures and cope with climate-induced natural hazards.

Where relevant, this baseline documents observed trends in changes to the human and natural environment due to growth patterns, irrespective of climate change. Therefore, this baseline intends to support an understanding of future vulnerability based not on a static snapshot of society, but rather, taking into account key changes in socioeconomic and land-use patterns.

This baseline was developed with public information available online or collected during a three-day field visit ERM conducted in December 2012. ERM also facilitated a capacity building workshop in July 2013, which yielded key stakeholder input relevant to the adaptation process. In October 2013, additional community-level data was obtained via focus groups and semi-structured interviews in three neighborhoods[1]. Results from that field effort have enhanced the contents of this baseline as well.

Data has been compiled at two distinct scales. The first focuses on the Managua Lake Basin, which is comprised of thirteen sub-watersheds. The second focuses on the urban area of Managua. Section 2.1 describes the study areas considered by the Project.

1 On behalf of ERM, a local consulting firm (Jerez & Asociados) conducted site visits to three neighborhoods in Managua, which were selected according to criteria that prioritized those communities considered as particularly vulnerable.

A.1 Study Area

The Technical Cooperation places a priority on building adaptation capacity and resiliency in the water and sanitation sector, which presents both high vulnerability and a high likelihood of significant impacts from climate-induced hazards. These hazards include floods associated with rise in Lake Managua's water level and urban flooding events of increasing extent and duration.

As a result, ERM identified two distinct study areas:

- **Lake Managua Basin Study Area:** includes the thirteen drainage basins flowing into the lake and supports the analysis of the lake's water balance, which is underpinned by a watershed runoff model.
- **Urban Level Study Area:** corresponds to the boundary of the Municipality of Managua and supports the hydrologic and hydraulic model-based evaluation of stormwater flooding in selected sections of the City of Managua. Four micro-watersheds – Primavera, Hugo Chavez, Nejapa, and Oriental-Jagüitas-Cuarezma – were selected for a detailed analysis.

Initial consultations yielded a better sense for key stakeholder priorities. ALMA did not consider tackling lake-water-level flood issues as the most pressing adaptation priority, but rather preferred that the Project focused its resources on evaluating the extent to which climate change will exacerbate already critical urban drainage challenges, and identifying adaptation investments that can allow the city to pilot approaches towards alleviating urban flooding and set the stage for development of an urban drainage master plan at the municipal level. As a result, this baseline and subsequent chapters focus on the urban-level Study Area.

A.1.1 Lake Managua Basin Study Area

The Project considered the entire Lake Managua drainage basin to gauge the potential effects from climate change on the water balance of the lake and resulting fluctuations in lake level.

Table A1 lists the thirteen sub-basins that comprise the Lake Managua watershed, grouped according to their orientation with respect to the lake. The Lake Managua watershed covers an area of approximately 5,334 sq. km.

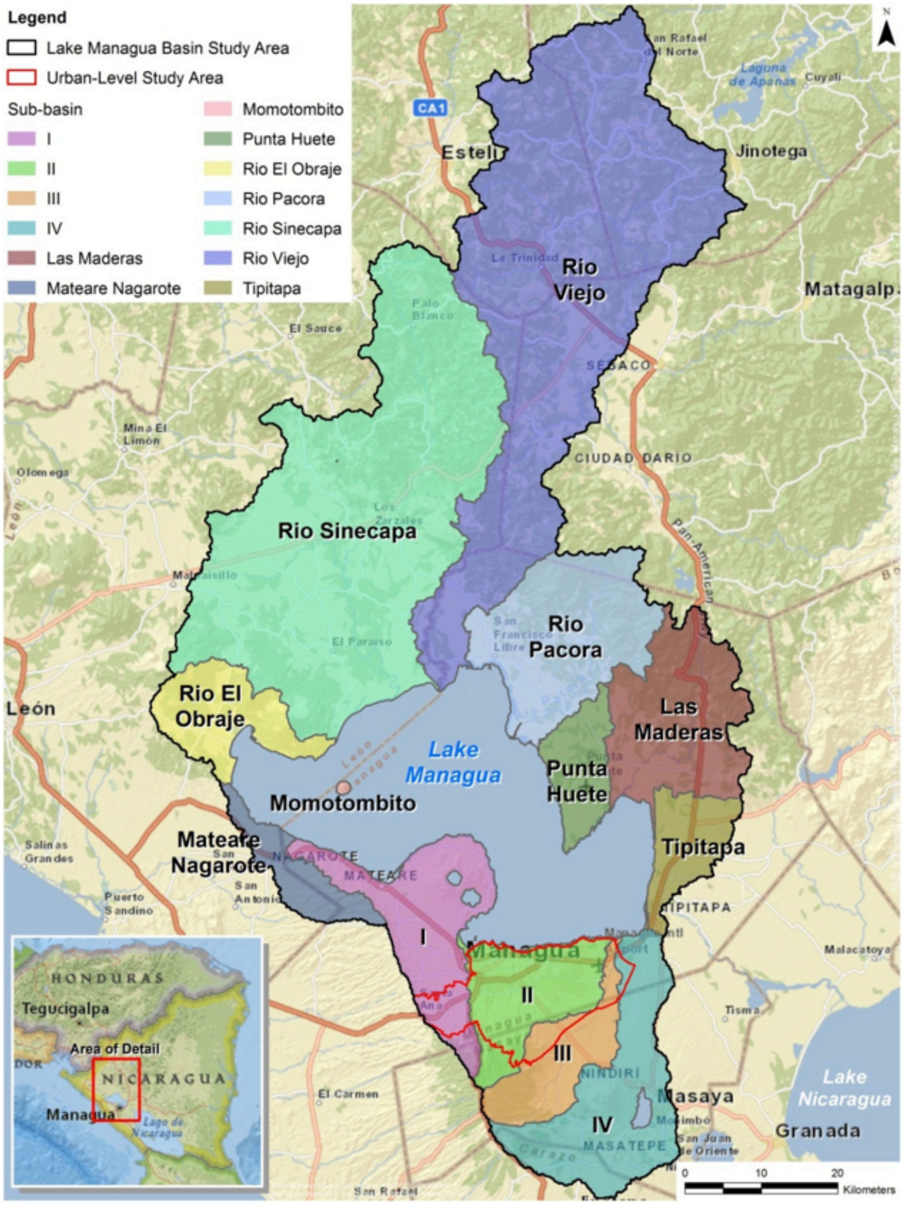
Table A-1: Lake Managua Drainage Basins

Orientation	Sub-Basin	Area (km2)
South	I, II, III and IV	1,057
North	Viejo, Sinecapa, Obraje and Pacora Rivers	3,552
East	Punta Huete, Las Maderas y Tipitapa	610
West	Mateare-Nagarote	110
Island	Momotombito Island	2.57

Source: ERM, 2013.

Figure A1 illustrates the Lake Managua watershed and therefore the Study Area considered by the hydrological analysis.

Figure A-1: Lake Managua Basin Study Area

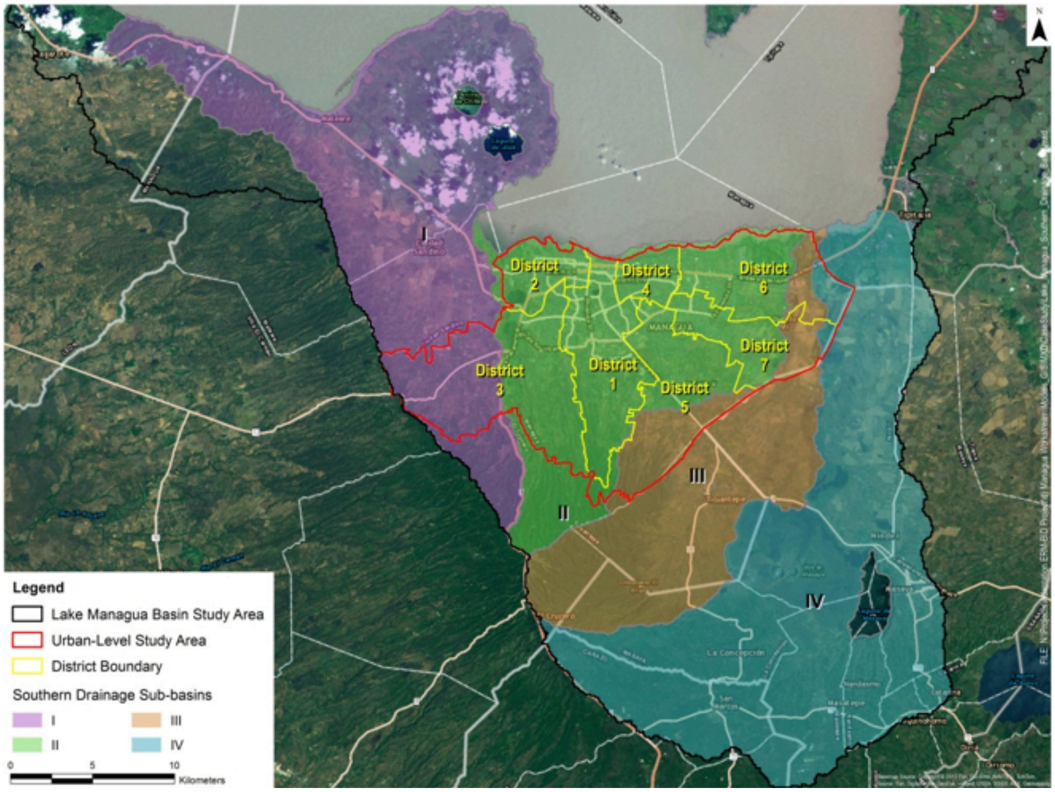


Source: ERM, 2013.

A.1.2 Urban-Level Study Area

As illustrated in Figure A-2, the majority of the urban area of Managua is located within sub-basin II, which covers an area of 217 sq. km. across the municipalities of Managua and Masaya. Sub-basin II is part of the southern Lake Managua drainage basin, which covers an area of 825 sq. km.. Each of the four sub-basins (i.e., I, II, III, and IV) within the southern Lake Managua drainage basin has distinct geomorphological, environmental and urban development features.

Figure A-2: Lake Managua Southern Drainage Basin



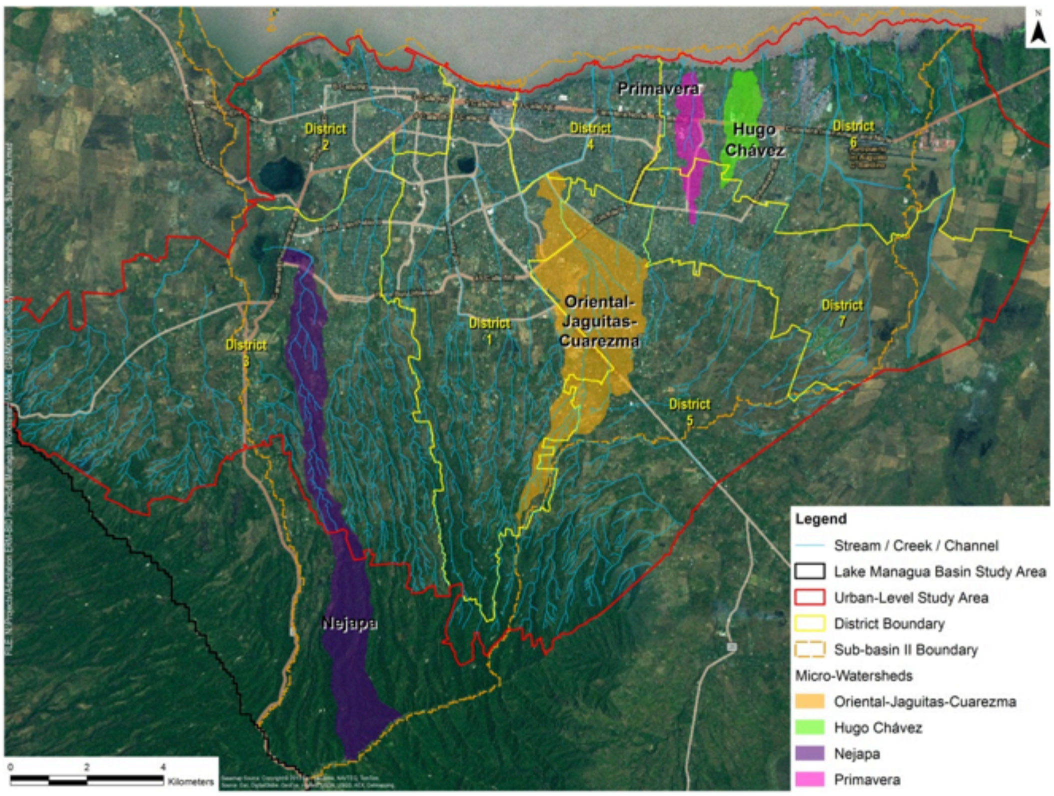
Source: ERM, 2013.

In response to local stakeholder feedback, the Project focused the adaptation process on understanding the causes and potential solutions to the already-pressing urban drainage problems within the core urban area of Managua. In consultation with ALMA, the Project delineated four areas within sub-basin II based on the location of a number of critical inundation hotspots[2] within the city. These areas have been termed micro-watersheds as these correspond to lower-scale, partial drainage areas within sub-basin II. Hydrological analyses were performed for these four micro-watersheds.

In addition to being flood-prone areas, the four micro-watersheds were selected to represent a range of socioeconomic and developmental conditions. For example, these areas include established residential areas, with adequate infrastructure and public services, as well as quickly urbanizing areas where informal settlements are currently present.

For purposes of this baseline, given that available data is readily available at the municipality level, the urban-level Study Area corresponds to the boundary of the Municipality of Managua. Where possible, this baseline presents data at the micro-watershed level. Figure A3 illustrates the boundary of the Municipality of Managua and the four priority micro-watersheds, namely, Primavera, Hugo Chavez, Nejapa and Oriental-Jagüitas-Cuarezma. Together, these areas comprise the urban-level Study Area.

Figura A-3: Cuatro Microcuencas dentro de la Subcuenca II (Área de Estudio del Nivel Urbano) –en inglés–



Source: ERM, 2013.

2 ALMA identified these critical locations based on a risk study of a natural disaster that occurred in 2004 and based on ALMA's knowledge of areas presenting high flooding risk.

A.2 Physical Characteristics

A.2.1 Geology and Topography

In general, the geology[3] of Nicaragua can be characterized by a wide range of geological formations of different age and origin, ranging from Cretaceous and Quaternary sedimentary accumulations to Tertiary volcanic depositions. Volcanic activity continues to shape the geology of the region as indicated by the presence of recent pyroclastic formations near the Momotombo Volcano and Ometepe Island volcanoes.

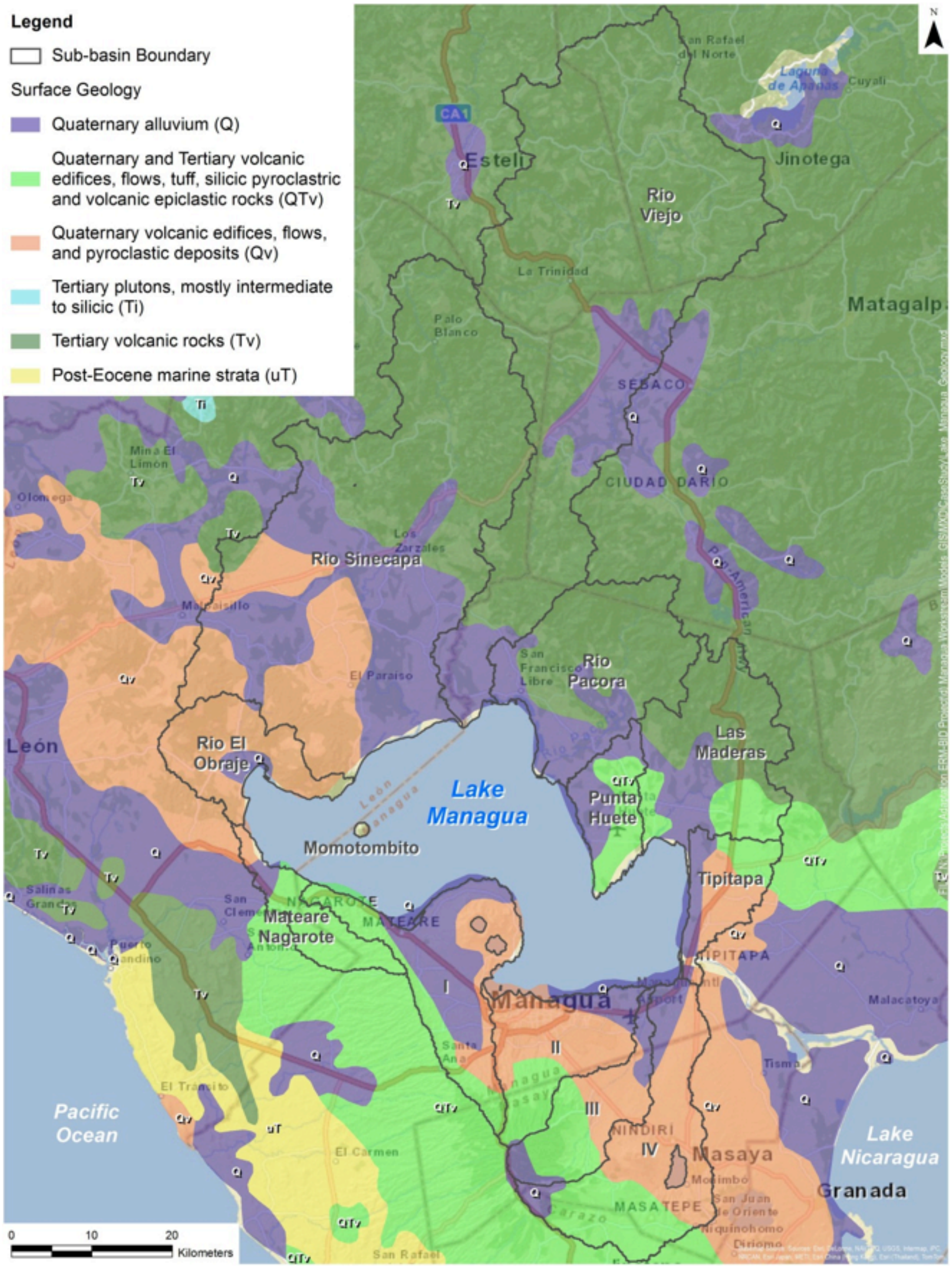
As illustrated in Figure A4, the geology in the area comprised by the Lake Managua basin Study Area is primarily composed by Quaternary and Tertiary age stratigraphic rock structures of volcanic origin. Its lithology is characterized by sediments of clay, silt, sand and gravel. This is the predominant geology for most of the lake-level Study Area, including most of urban Managua.

The lake-level Study Area geology is also influenced by geomorphologic processes associated with the Volcanic Range of Marrabios. This range runs continuously in a northwest-southeast direction from the Gulf of Fonseca, where the Cosigüina Volcano is located, to the Concepción and Maderas volcanoes, which lie on Ometepe Island in Lake Nicaragua. The range also features a number of gaps formed by extinct craters.

The topography of the lake-level Study Area includes slopes greater than 50% near volcanic cones and mountains formed of Tertiary age rocks. Elsewhere in the lake-level Study Area, including urban Managua, the topography is characterized by rolling hills of gentle relief and horizontal plains, particularly on the surrounds of Lake Managua, which in many cases are flooded in rainy periods.

3 This section is based on a 2010 study published by the Ministry of Environmental and Natural Resources (MARENA) titled "Caracterización de la Cuenca No. 69 – Rio San Juan." The information has been complemented with information published by the United States Geological Survey (USGS) in a dataset titled, "Surface Geology of the Caribbean Region."

Figure A-4: Geology and Lithology in the Greater Lake Managua Basin



A.2.2 Soils and Infiltration Capacity

Two soil orders, Entisols and Mollisols, comprise the predominant soil composition in the Lake Managua basin Study Area[4]. Entisols make up a large part of the west and north Lake Managua sub-basins. South of Lake Managua, including urban Managua, the Mollisols become the predominant soil type.

Entisols are soils of recent origin or are located in heavily eroded surfaces. These soils consist of recent pyroclastic ash or have been slightly weathered by the geomorphologic processes into sand, gravel or volcanic silt. These soils are generally not suitable for growing crops but are suitable for reforestation or natural regeneration.

Mollisols are the predominant soil type in southern Lake Managua sub-basin . These soils are typical of grassland ecosystems and are characterized by a thick, dark surface horizon. This fertile surface horizon results from the long-term addition of organic materials derived from plant roots. These soils are suitable for cultivation of sesame, cotton, peanuts, sorghum, rice, sugar cane and pineapple. Good soils and favorable climate contributes to making this region Nicaragua's economic and demographic center.

Inceptisol and Vertisol are the additional soil orders that make up the rest of the Study Area. Figure A5 illustrates the distribution of soil orders across the Lake Managua basin Study Area.

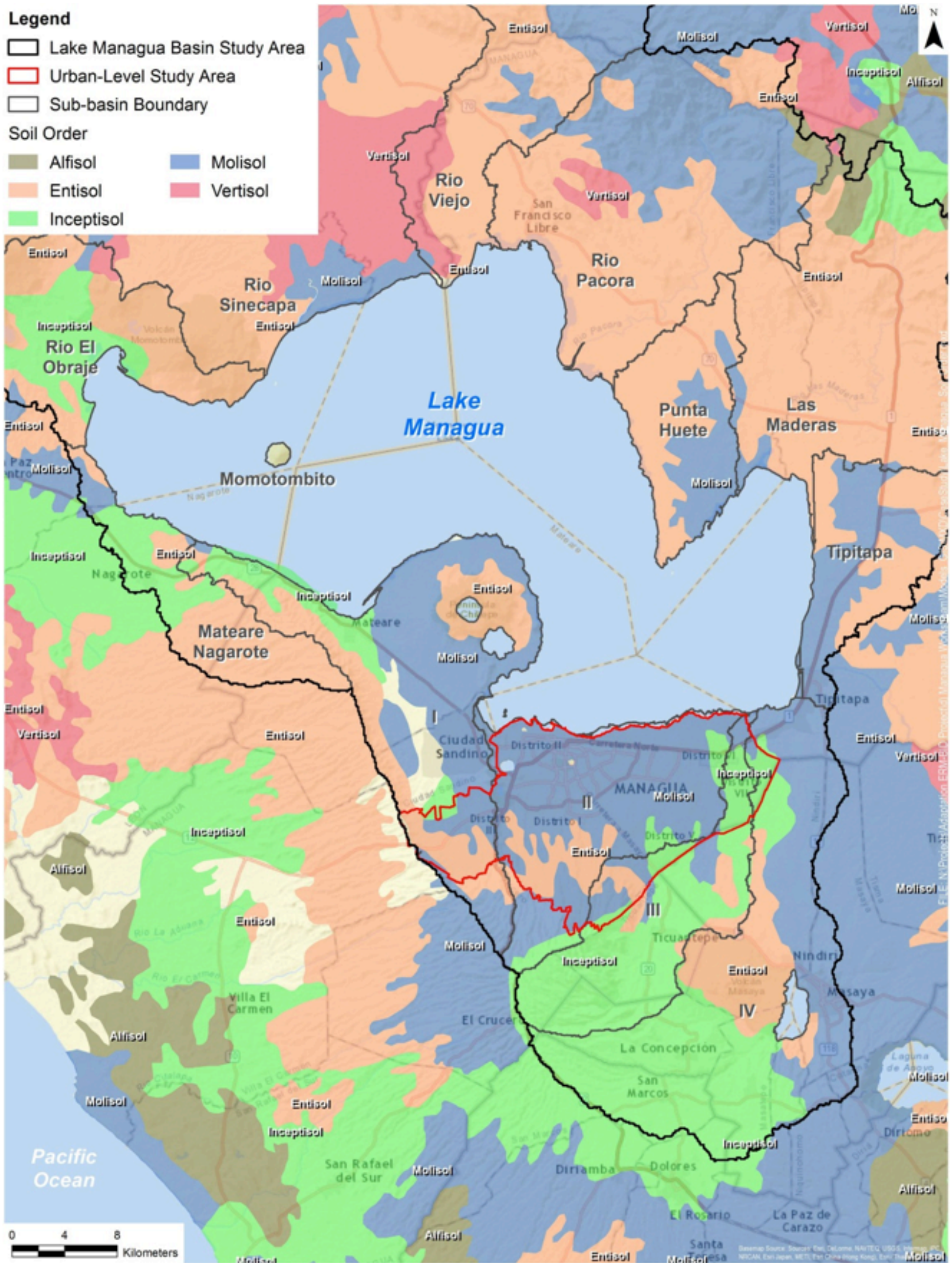
Various factors such as soil texture and structure, vegetation types and cover, , soil moisture and temperature, and rainfall intensity determine infiltration rates and capacity. When precipitation exceeds infiltration capacity, the excess water becomes the pluvial runoff. The infiltration capacity depends on soil physical characteristics and land cover .

In the Lake Managua basin Study Area, areas that have experienced deforestation and soil erosion have lower infiltration rates. Municipalities such as

Santa Rosa del Peñón, El Jicaral and San Francisco Libre, which are located on the northern portion of Lake Managua sub-basin, have been identified as areas prone to desertification due to the impacts of unsustainable agricultural and soil erosion. Precipitation in these areas is likely to result in higher runoff rates. This is also the case in highly urbanized areas where soil permeability is low to null.

4 MARENA, 2010. "Caracterización de la Cuenca No. 69 – Rio San Juan." Managua.

Figura A-5: Distribución de los Tipos de Suelos en la Cuenca del Gran Lago de Managua –en inglés–

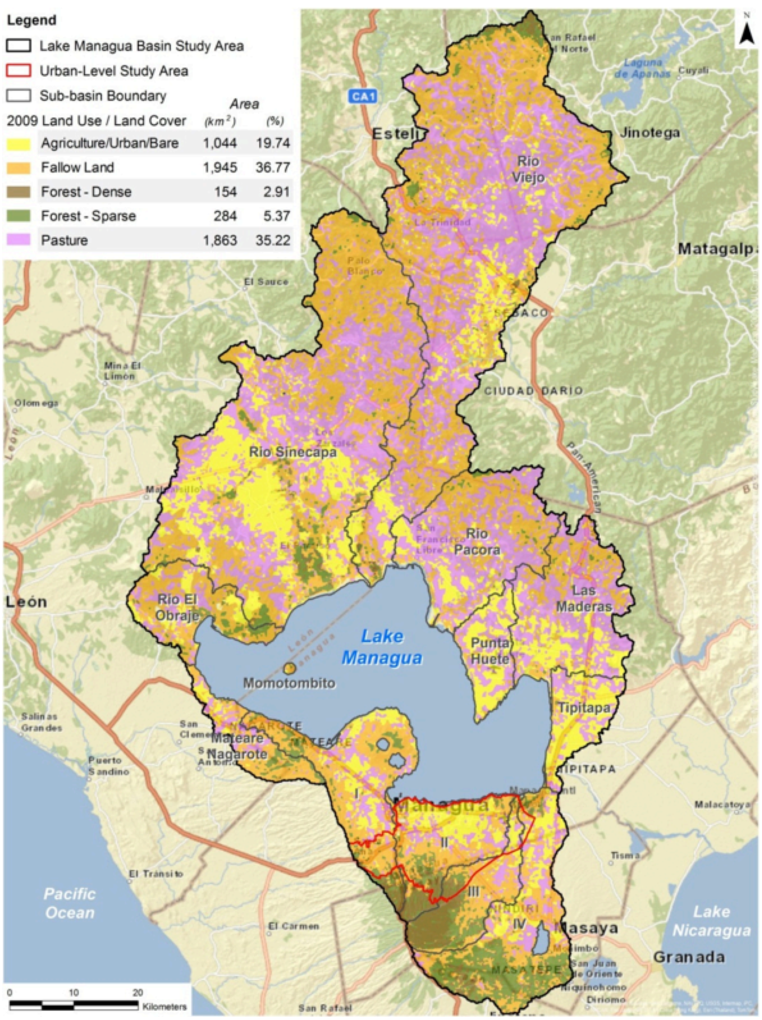


Source: Data published by the United States Geological Survey, 2004. Map by ERM.

A.2.3 Land Cover and Land Use

Land cover types in the Study Area range widely as a result of varying geographical characteristics and land uses across the Lake Managua watershed. As illustrated in Figure A6, land cover is characterized by little forest cover and predominance of grasslands (35.2%) and second growth after agriculture or livestock ranching (36.8%). Land set aside for agriculture along with urban areas accounted for nearly 20% of land cover in 2009.

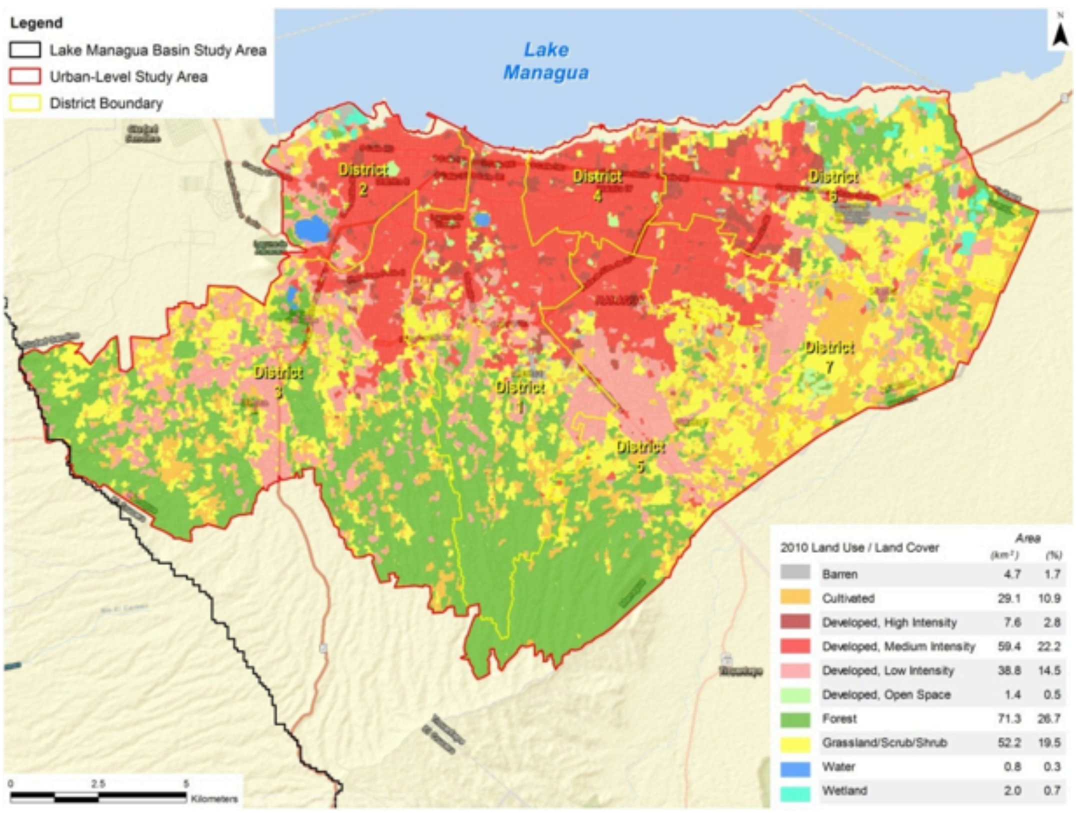
Figure A-6: Land Cover in the Greater Lake Managua Basin (2009)



Source: Land cover 2009 data provided by MAGFOR. Map by ERM.

In the Municipality of Managua (i.e., urban-level Study Area), as illustrated in Figure A7, land cover reflects predominant urban use. According to an analysis of historical satellite data developed by ERM, urban areas of medium and high density have increased significantly in the 1989-2010 period (refer to Table A2). As observed by the analysis, the lack of urban planning and uncontrolled growth of the city has contributed to the decrease in forests and grasslands in favor of agricultural and urban uses.

Figure A-7: Land Cover in the Urban-Level Study Area (2010)



Source: Land cover classification by ERM based on 2010 LANDSAT satellite imagery.

Table A-2: Historical Land Use Distribution in Managua

Land Use Type	Estimated Area in Squared Kilometers (Km^2)			
	1989	1998	2004	2010
Developed, high density	0.77%	1.49%	2.07%	2.83%
Developed, medium density	12.87%	17.25%	19.90%	22.21%
Developed, low density	15.65%	15.96%	14.52%	14.52%
Developed, open space	0.76%	0.57%	0.67%	0.52%
Agriculture	8.85%	11.46%	2.07%	10.88%
Grasslands	34.50%	29.13%	28.69%	19.54%
Forest	24.85%	23.29%	30.92%	26.67%
Wetlands	0.87%	0.12%	0.12%	0.75%
Barren	0.35%	0.09%	0.62%	1.74%
Water	0.53%	0.44%	0.39%	0.30%

Source: Data compiled by ERM based on LANDSAT satellite imagery.

Inadequate agricultural practices and poor solid waste, sewage and storm-water management are also putting pressure on vegetative land cover. For instance, in the upper parts of Lake Managua southern sub-basin, agricultural activities have contributed to rapid deforestation, especially in areas with high to moderate slopes. Moreover, increasing urbanization and changes in land use have led to increase of surface runoff, erosion and the demand for basic infrastructure and services.

A.2.4 Temperature and Precipitation

Average annual temperatures and precipitation estimates vary widely across the Lake Managua watershed due to its large areal extent (5,334 sq. km) and elevation gradient. In general, the Study Area's climate is associated with the physiographic region known as the Pacific lowlands, which extend about 75 kilometers inland from the Pacific coast. Most of the area is flat, except for the volcanic range running between the Gulf of Fonseca and Lake Nicaragua.

The prevalent climate in this region is tropical savanna, characterized by mean monthly temperatures above 18 °C and pronounced dry and wet seasons[5]. Temperatures in the Pacific lowlands remain virtually constant throughout the year, with highs ranging between 29.4 and 32.2 °C.

The dry season extends from November to April, whereas the rainy season begins in May and continues through October. A short dry period (2-3 weeks) locally known as "canícula", typically occurs between the

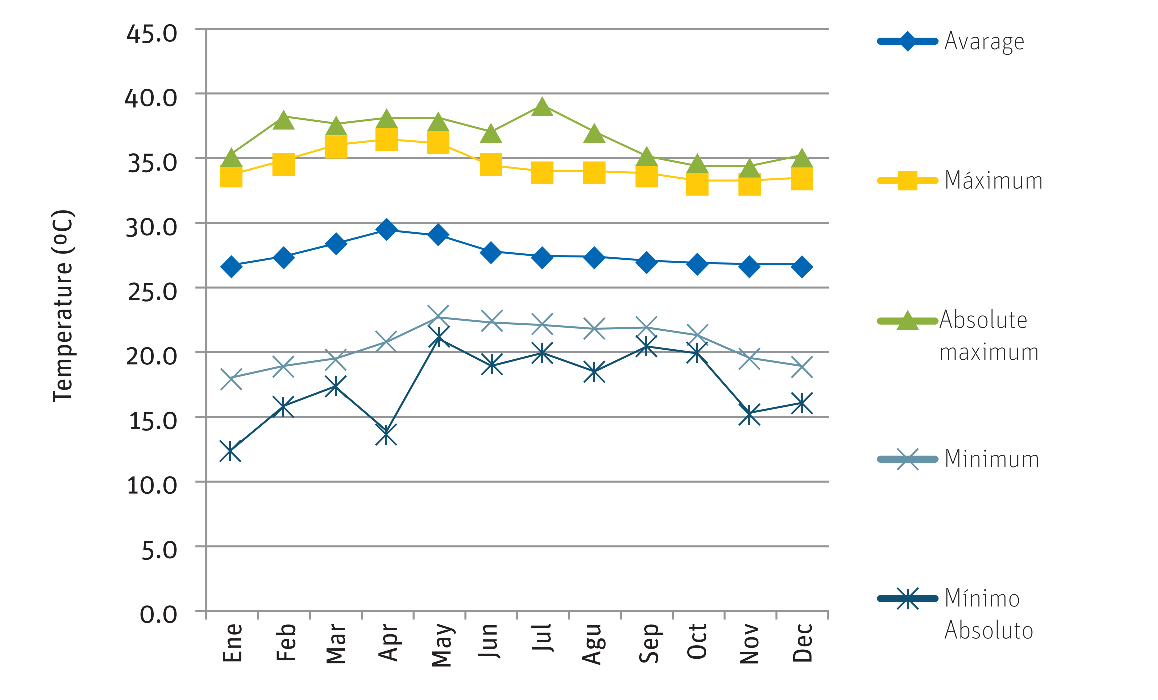
5 Romero, 2007.

months of July and August. According to INETER (2012), in the Pacific lowlands macro-region, where the Study Area is located, rainfall ranges between 700 to 2,500 mm annually.

Managua's climate is also influenced by its proximity with surrounding lakes (Managua and Nicaragua) and its elevation, which reaches up to 1,000 meters above sea level. Data indicates that rainfall is higher in Managua relative to the greater lake-basin Study Area. Rainfall in Managua oscillates between 1,200 and 2,000 mm annually, with a high frequency of high intensity (24-hour precipitation) rainfall events.

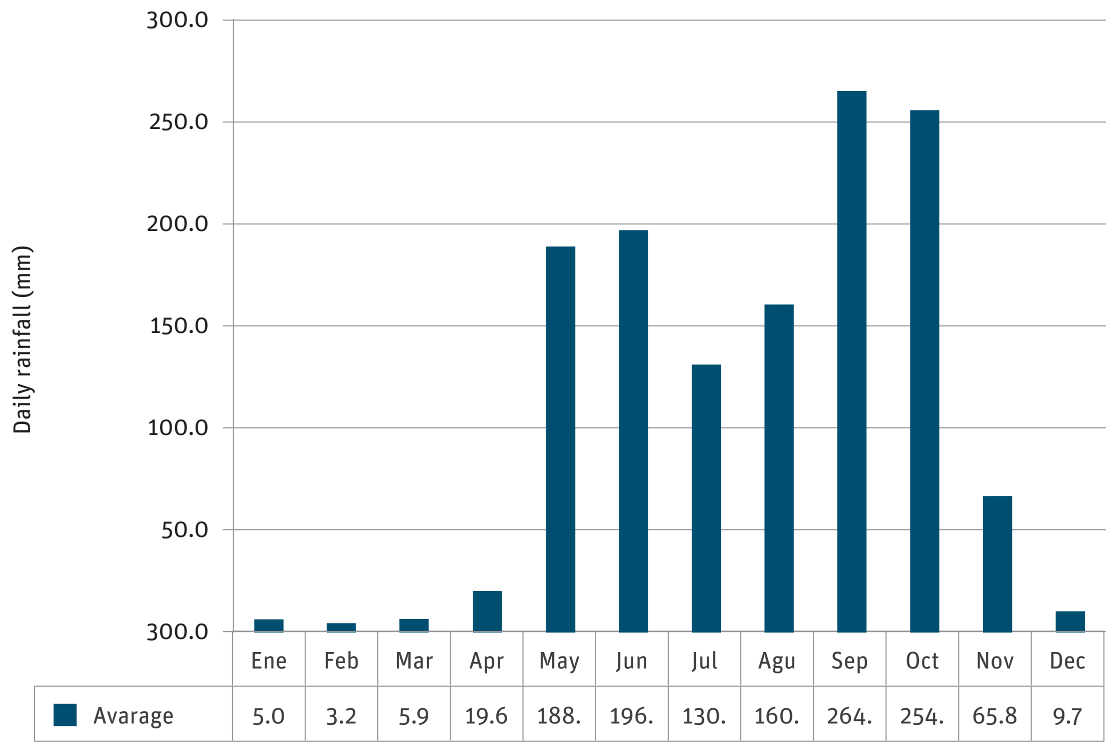
Figure A8 illustrates the mean monthly temperatures recorded at Managua's international airport meteorological station for the period 1980-2010 and Figure A-9 illustrates the mean daily precipitation estimates per month as averaged for the period 1980-2010.

Figure A-8: Monthly Average Temperatures for Managua, 1980-2010



Source: Based on data published by INETER compiled from its Managua Airport meteorological station.

Figure A-9: Monthly Average Precipitation Records for Managua, 1980 -2010



Source: Compiled by ERM based on 2013 data published by INETER.

In recent years, extreme weather events (i.e., weather phenomena that are at the end of the historical range) have increased in frequency and scale of impact. In Nicaragua, damages to infrastructure have been documented as a result of drought, floods, hurricanes, tornadoes, thunderstorms, and other weather-related events[6]. For example, thunderstorms, which occur with greater incidence in the month of September, are linked to an increased in the frequency of tropical cyclones.

6 INETER, 2013.

A.2.5 Water Supply and Sanitation Infrastructure

Given the focus on urban flooding and water resources in general, this sub-section summarizes available information on the water supply and sanitation infrastructure for the urban-level Study Area.

Despite the abundance of surface water sources (as illustrated in Figure A10), groundwater from Lake Managua's southern watershed is the sole source of water supply for the City of Managua. As illustrated in Figure A11, approximately 80 water wells are distributed throughout Managua's metropolitan region.

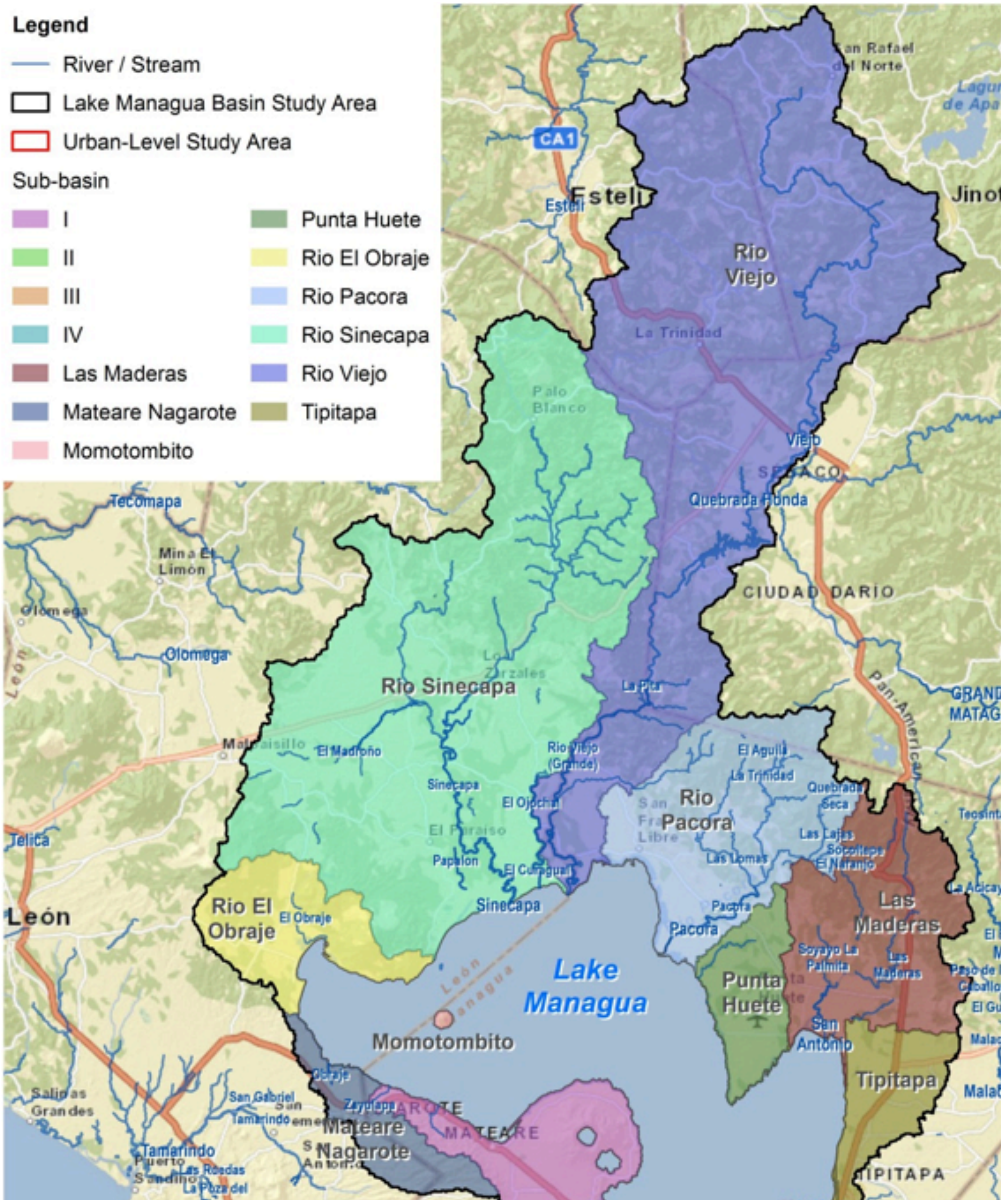
In the past ten years, urban development has further hindered the natural ability of the underground aquifer to recharge. As the soil is further sealed by construction, rainwater is not infiltrated and flows as surface runoff, which increases the risk of erosion, flooding and sedimentation.

According to the National Aqueducts and Sewer Company (ENACAL)[7], coverage of potable water and sanitation services is 85% and 52% respectively, at the national level. In urban areas where ENACAL operates, drinking water coverage varies between 98% and 10% (92% on average) and sanitary sewer services range between zero and 52% (36% on average). According to ENACAL, in Managua, only 60% of the urban population has access to sanitary sewer service. Alternative means of sewage disposal include latrines and septic tanks.

The increase in solid waste generation has also exceeded the local waste management capacity, such as services for collection and safe disposal of solid wastes, therefore creating conditions that may lead to potential environmental and health hazards. The Ministry of Health (MINSA) notes that 70% of all waste in Nicaragua remains untreated. Most municipalities operate open-air landfills, and wastewater is released into rivers and lakes without treatment. These conditions constitute a permanent threat to health, as they can lead to contaminated water sources and provide breeding grounds for vectors.

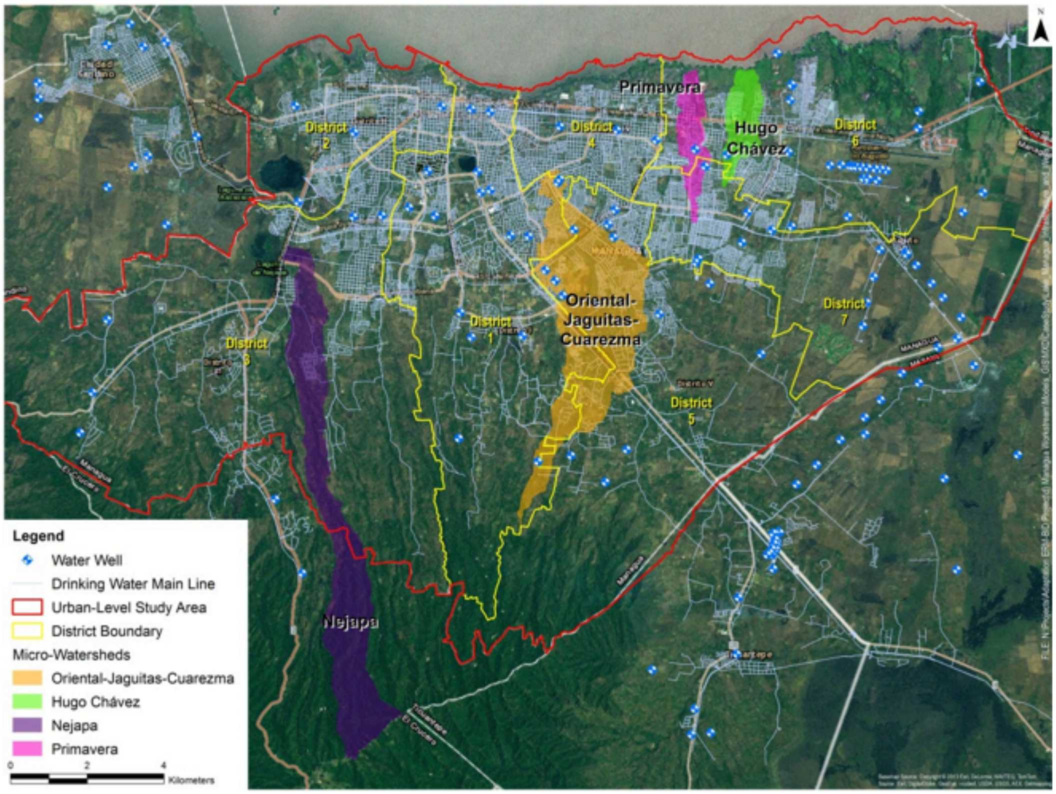
7 Empresa Nacional de Acueductos y Alcantarillados (ENACAL)

Figure A-10: Distribution of Rivers and Streams in the Study Area



Source: River and stream information derived from INETER cartographic datasets, 2002. Map by ERM.

Figure A-11: Water Well Distribution in the City of Managua



Source: Water well information provided by ENACAL. Map by ERM.

A.3 Socioeconomic and Demographic Data

This sub-section presents key demographic and socioeconomic data for the Municipality of Managua. This data provides an understanding of the factors influencing climate-related vulnerability at the community level.

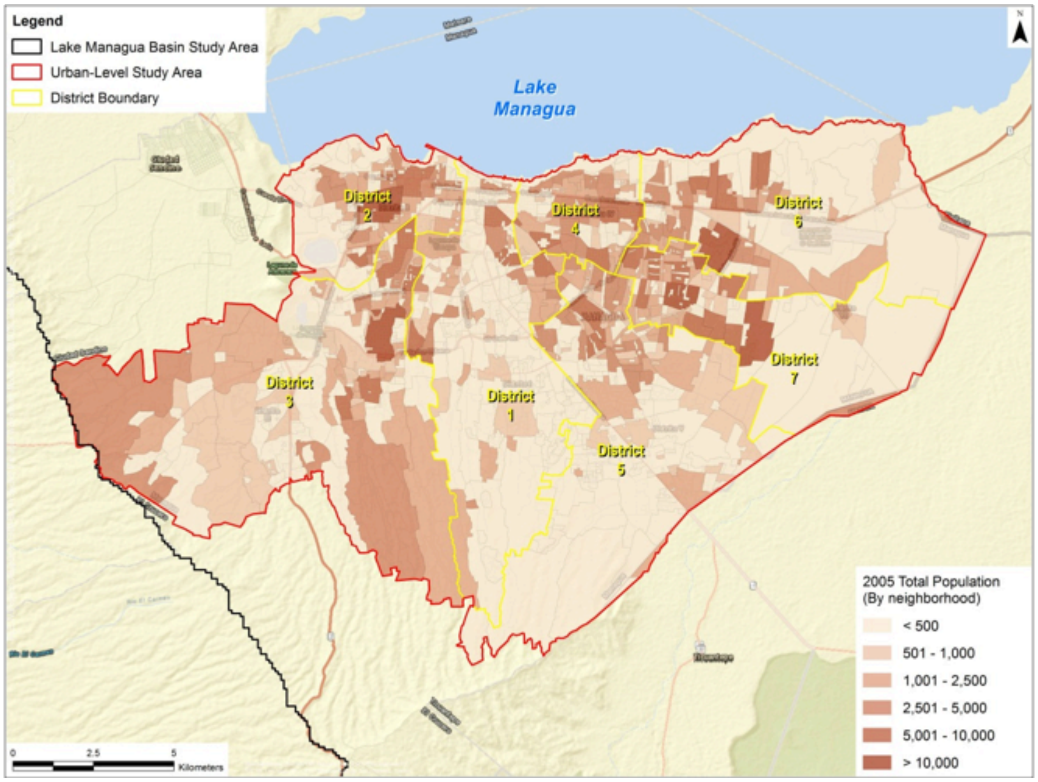
A.3.1 Demographic Characteristics

A.3.1.1 Population and Households

As of the most recent census (2005), the population in the Department of Managua was 1,093,761, with approximately 85% (937,489) residing in the Municipality of Managua[8]. A recent population estimate published by ALMA suggests that the population in the municipality had grown to 1,254,878 by 2011, which is approximately 33% more than the 2005 census estimate an represents a 5% per year growth rate during the 6-year period.

Figure A-12 shows the distribution of population within the municipality.

Figure A-12: Population Distribution by Neighborhood, 2005

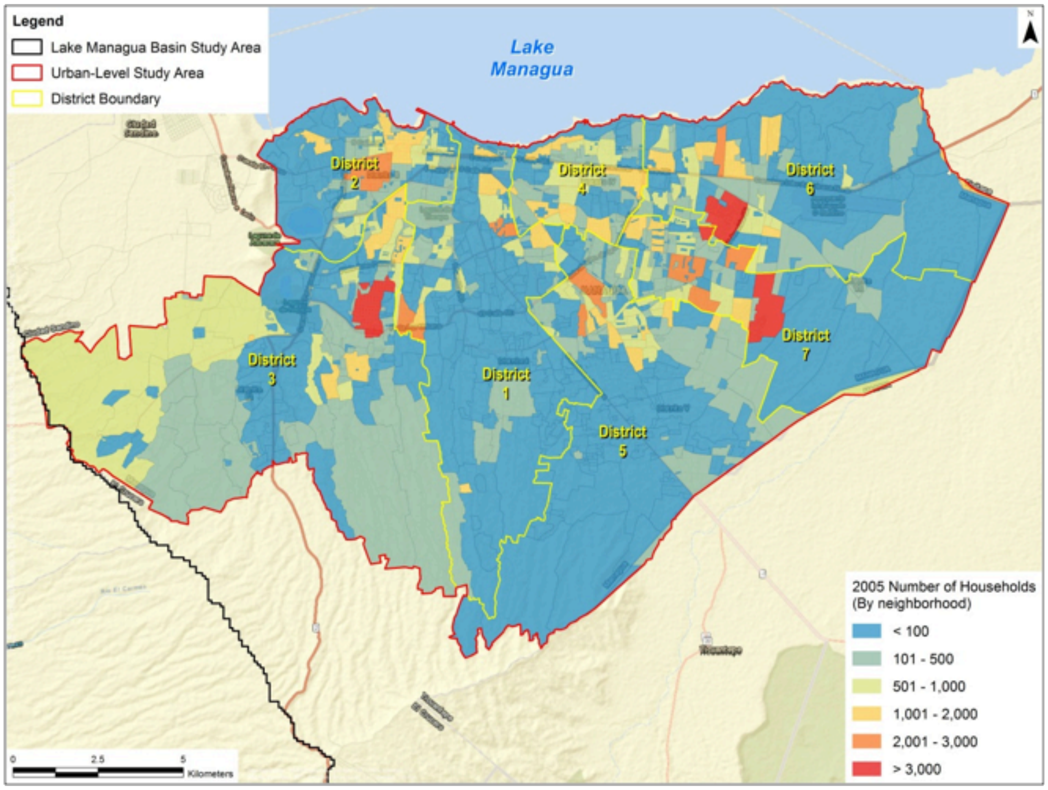


Source: Based on census data provided by INIDE 2005. Map by ERM.

8 INIDE, 2005. *VII Population Census and IV Household Census.*

Figure A13 illustrates the number of households per neighborhood. As expected, the map shows a pattern similar to the population distribution within the municipality.

Figure A-13: Number of Households by Neighborhood, 2005



Source: Based on census data provided by INEC, 2005. Map by ERM.

As Table A3 shows, given that the total population per district is similar across the seven districts, population density is higher in the smaller districts, specifically Districts II, IV and VII.

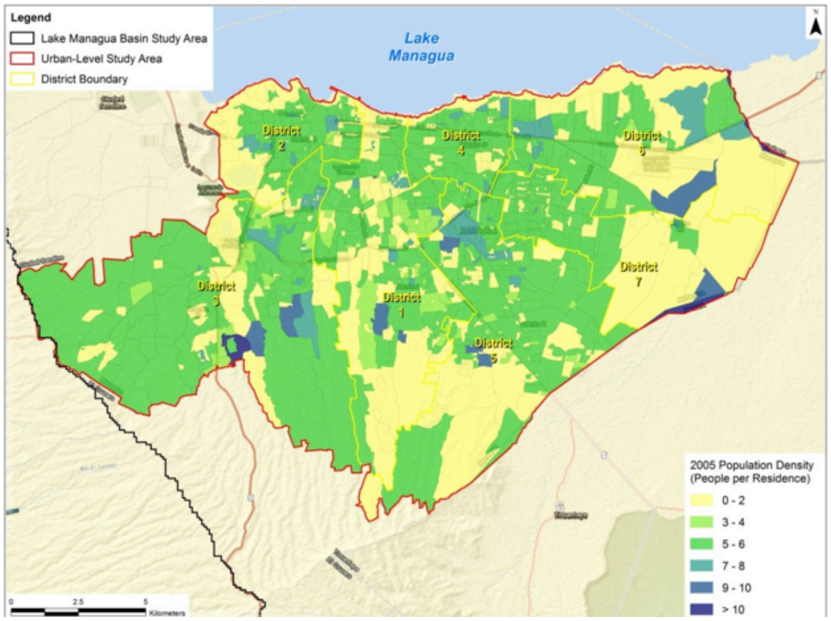
Table A-3: Population Characteristics by District, 2005

District	Area (km²)	Population	Population Density (per km²)	Households	Persons per Household
District I	44.6	109,875	2463.6	21,737	5.1
District II	17.3	124,387	7190.0	23,096	5.4
District III	72.5	131,647	1815.8	24,832	5.3
District IV	11.5	104,806	9113.6	19,242	5.4
District V	51.5	146,069	2836.3	27,081	5.4
District VI	41.8	122,348	2927.0	23,753	5.2
District VII	29.1	122,426	4207.1	29,365	4.2
Municipality of Managua	**268.2**	**937,489**	**3495.4**	**197,332**	**4.7**

Source: INIDE, 2005.

Figure A14 shows the average number of persons per household by neighborhood, and indicates evidence of areas with relatively higher concentrations of high-occupancy dwellings. These areas (shaded in blue) occur in all districts throughout Managua.

Figure A-14: Within-Dwelling Density by Neighborhood, 2005

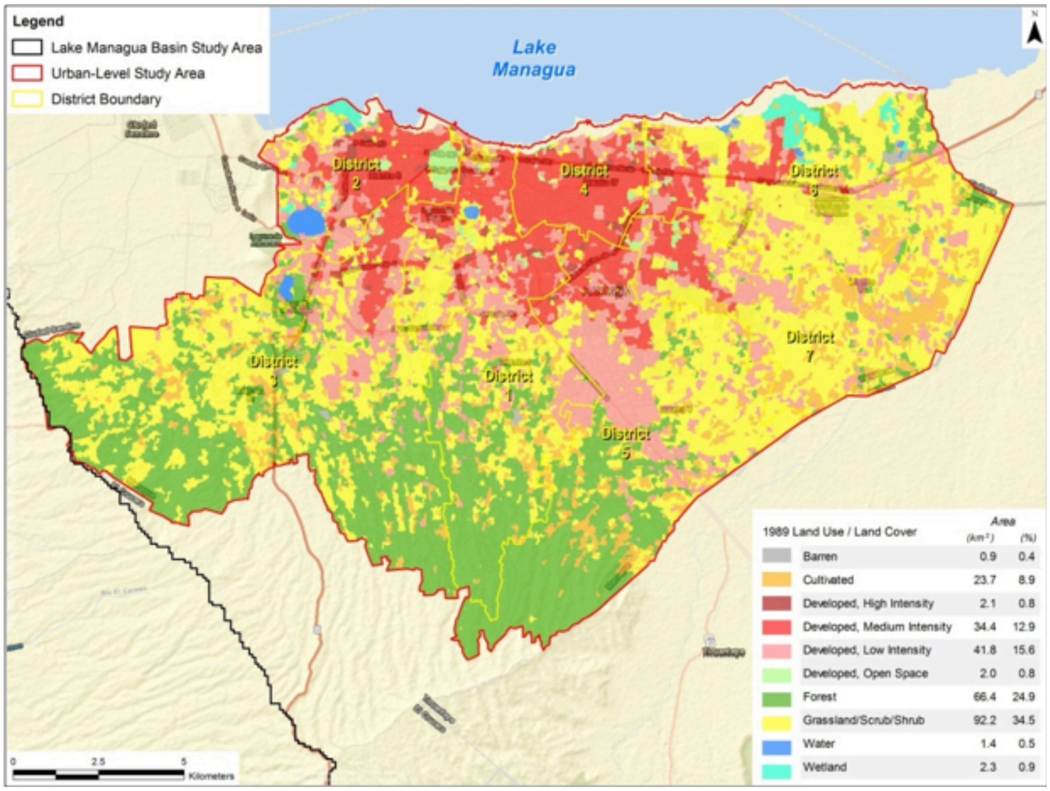


Source: Based on census data provided by INIDE, 2005. Map by ERM.

A.3.1.2 Historical Land Use Distribution in Managua

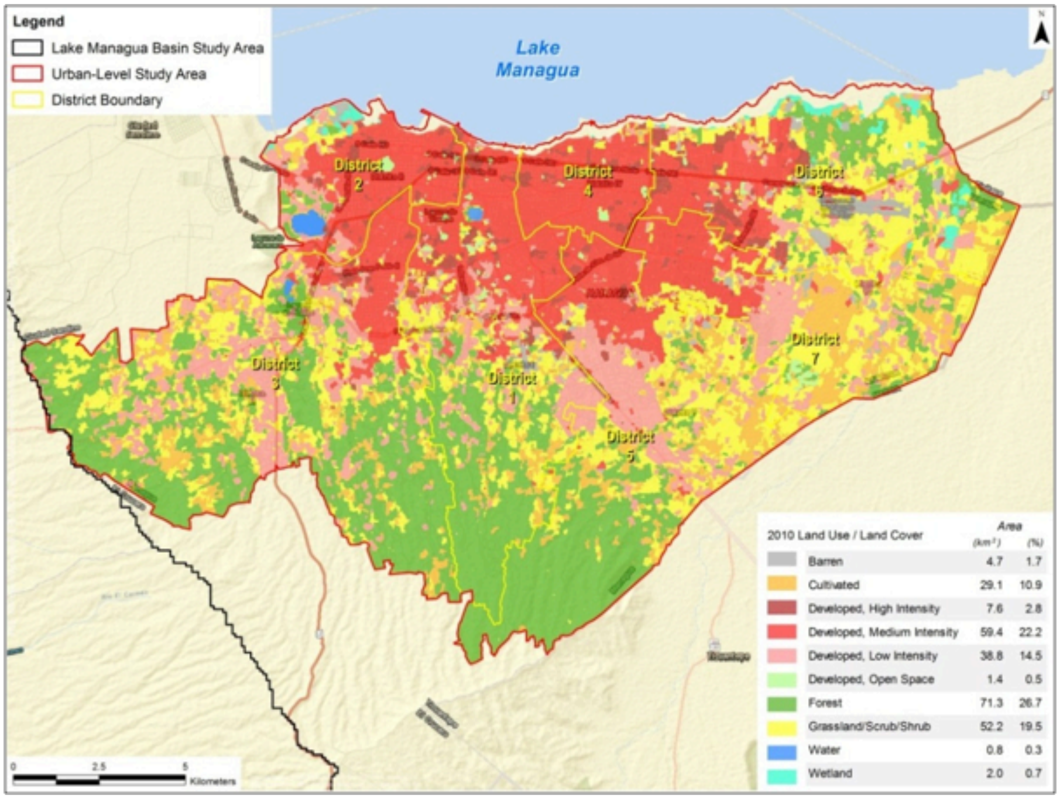
Urbanization typically replaces the vegetation cover with impervious materials. Historical land use data for Managua indicates conversion of permeable surfaces such as grassland and forest to impermeable urban land cover, as well as intensification of development in the urban area. Net loss of wetlands along the coast that act as natural drainage areas is also evident from these maps (Figure A-15andFigure A-16).

Figure A-15: Land Use Patterns in 1989, Municipality of Managua



Source: Based on satellite imagery from LANDSAT. Classification and map by ERM.

Figure A-16: Land Use Patterns in 2010, Municipality of Managua

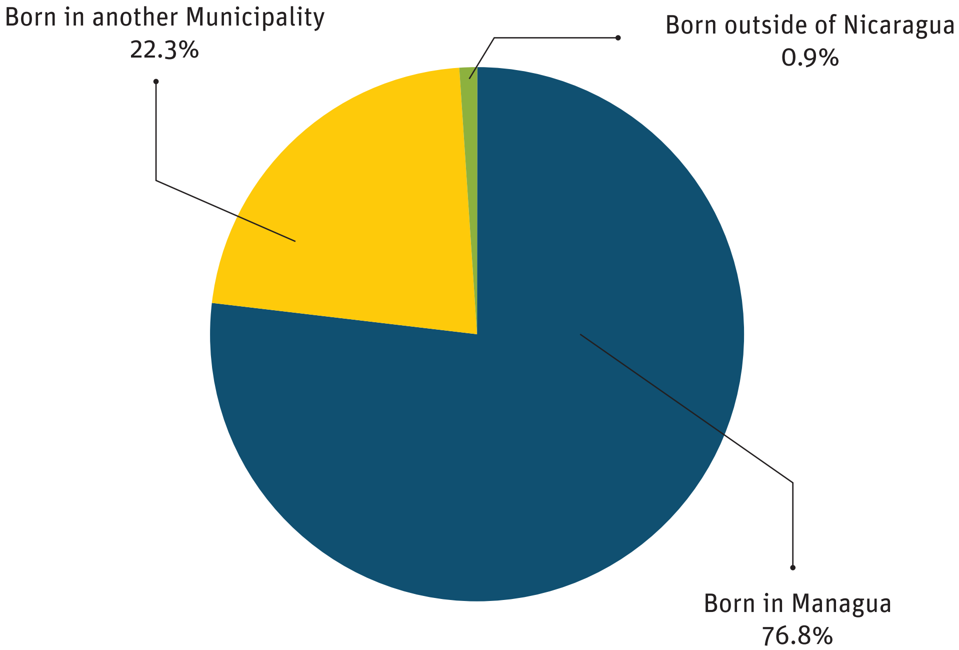


Source: Based on satellite imagery from LANDSAT. Classification and map by ERM.

A.3.1.3 Place of Birth

As shown in Figure A17, census data indicates that the majority of Managua residents were born within the municipality (76.8%); 22.2% were born in other areas of Nicaragua and less than 1% of residents were born outside Nicaragua at the time of the 2005 census.

Figure A-17: Managua Residents' Place of Birth, 2005



Source: Based on census data from INIDE, 2005. Graph by ERM.

A.3.1.4 Gender and Age Distribution

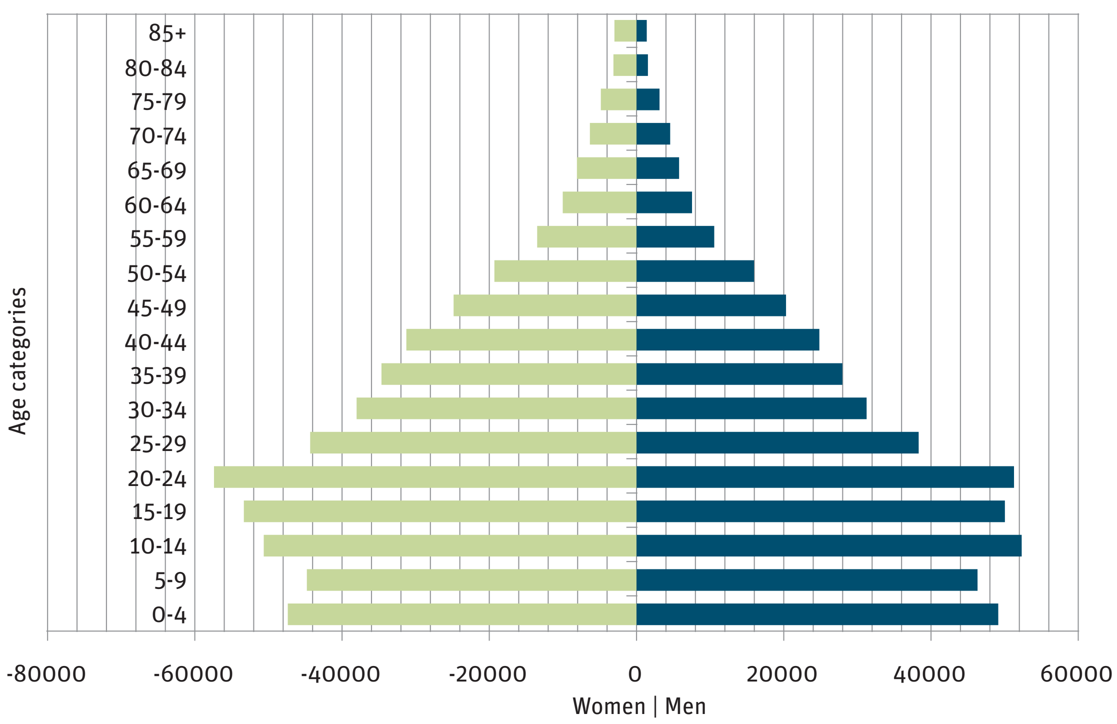
As of the most recent census (2005), the gender ratio in the Municipality of Managua was 0.92 males to every female. Figure A18 illustrates that age cohorts below the age of 24 comprise a significant percentage of the population in Managua. This relatively young population structure is due to the high fertility rate in Nicaragua in the 1990s and early 2000s[9]. However, the fertility rate has gradually declined in recent years to a rate of 2.7 children per woman in 2011[10]. As a result, population pyramids based on more recent population estimates would show a comparatively smaller population in the younger age groups[11].

9 The total fertility rate of a population is the average number of children that would be born to a woman of the specified population over her lifetime.

10 United Nations Population Fund. (2011). *The State of the World's Midwifery*. Available at: http://www.unfpa.org/sowmy/resources/docs/country_info/profile/en_Nicaragua_SoWMy_Profile.pdf

11 Pan American Health Organization (2012). *Health in the Americas.*

Figure A-18: Population Pyramid, Municipality of Managua, 2005



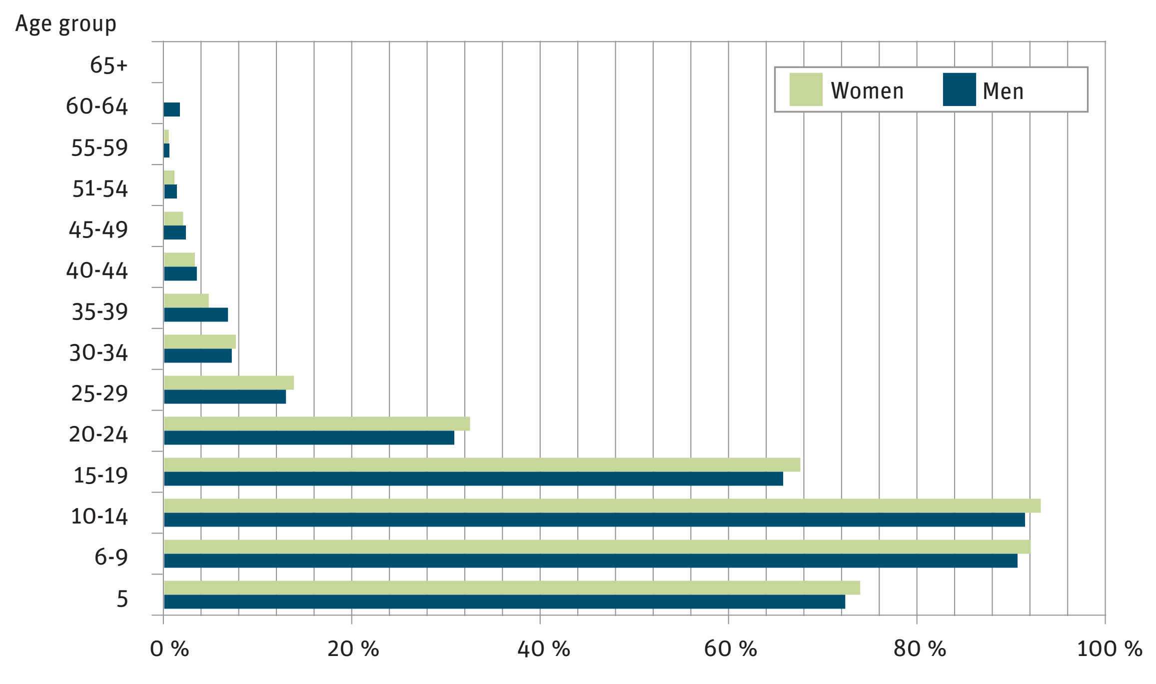
Source: Based on census data from INIDE, 2005. Graph by ERM

A.3.1.5 Education

Education indicators in Nicaragua have improved in recent years, with illiteracy rates falling 3.4% in the period 2008-2010 and primary school enrollment increasing from 86.4% in 2006 to 92.8% in 2010[12]. Figure A19 illustrates the major gains in education, within the Municipality of Managua in recent years, with much larger percentages of younger age groups having attended or currently attending primary school. The data also show a recent reversal in trends for female education, with women of older generations showing lower rates of school attendance relative to men, but females of younger generations showing higher rates than their male counterparts.

12 Pan American Health Organization (2012). *Health in the Americas – Nicaragua Country Profile*. Available at: http://www.paho.org/saludenlasamericas/index.php?id=48&option=com_content&Itemid=0&lang=pt#ref7

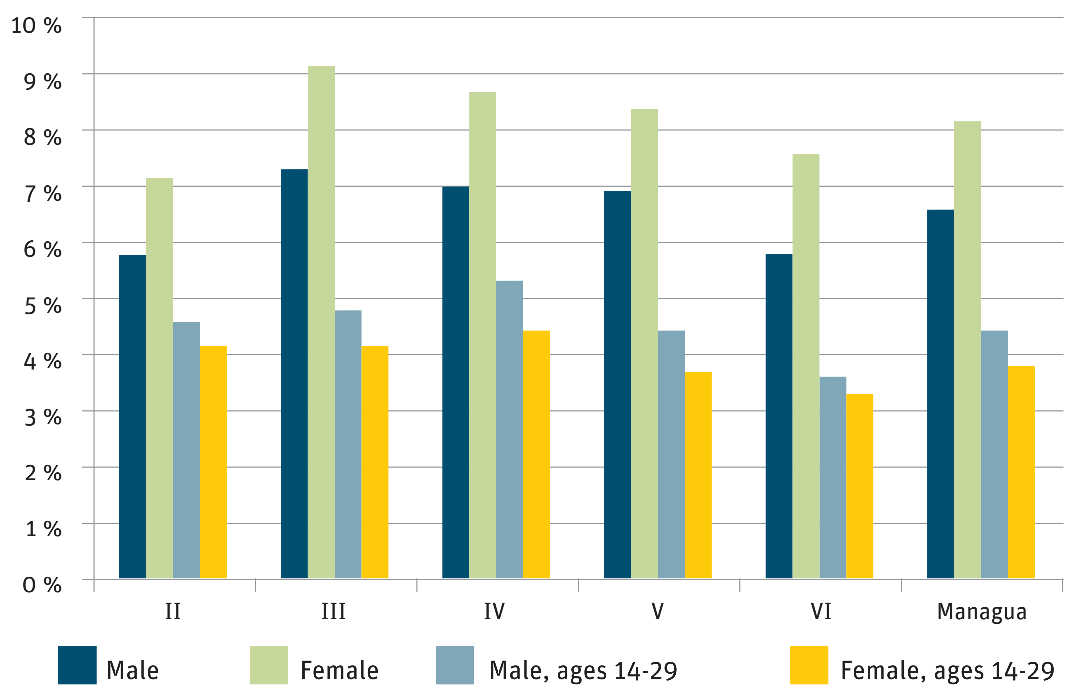
Figure A-19: Primary School Attendance by Age Group, Municipality of Managua, 2005



Source: Based on census data from INIDE, 2005. Graph by ERM.

Figure A20 shows illiteracy rates by district, sex and age group in Managua. Consistent with school attendance trends, the data show that while women in the general population have relatively high rates of illiteracy, women in the age group 14-29 show a higher rate of literacy relative to their male counterparts. The data also suggests that literacy rates are comparable throughout the municipality, with similar trends in each district.

Figure A-20: Illiteracy Rates by District and Sex, Municipality of Managua, 2005



Source: Based on census data from INIDE, 2005. Graph by ERM.
Note: Data for Districts I and VII was not available.

A.3.2 Socioeconomic Characteristics

A.3.2.1 Economic Activities and Livelihoods

Data from the 2005 census indicates that jobs as plant and machinery workers, operators and artisans, as well as service industry jobs make up the majority of employment for men in Managua (refer to Table A4). For women, service industry jobs are most common, followed by professions in the sciences, and personal services. There is little agricultural or fishing activity in the municipality.

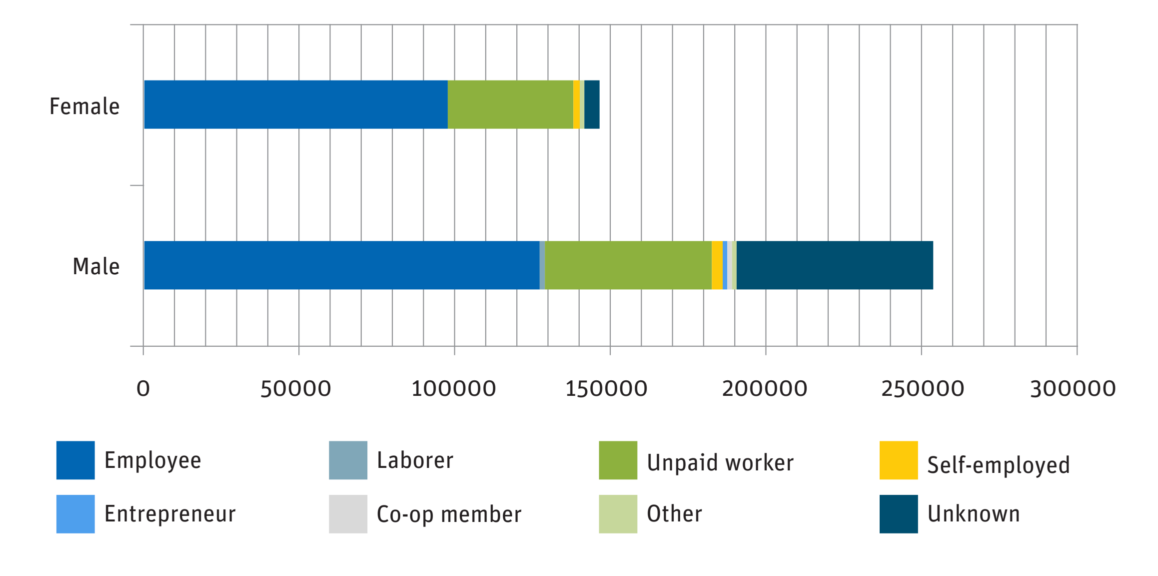
Table A-4: Employment Categories in the Municipality of Managua by Sex, 2005

Employment Category	Male Workers	Female Workers
Public administration professional	7577	6151
Scientific professional	18416	15805
Mid-level technician/professional	15527	14952
Office worker	8758	11557
Service/commercial industry worker	28665	32411
Personal services worker	6679	15246
Agricultural/fishing industry workers	4309	230
Officials, operators and artisans	43208	5612
Plant and machinery operators and assemblers	30650	12188
Unskilled workers	29700	31377
Unspecified work	2188	1592

Source: INIDE, 2005.

As illustrated in Figure A21, the majority of workers are private or public sector employees. There is also a large percentage of unpaid female and male workers

Figure A-21: Worker Types in the Municipality of Managua by Sex, 2005



Source: Based on census data from INIDE, 2005. Graph by ERM.

As the country's capital, there is a relatively large concentration of business establishments in Managua. Table A-5 provides the number of businesses and workers per industry sector or business type in the Municipality of Managua.

Table A-5: Workforce Distribution by Sector or Activity

Business Type	Number of Establishments	Number of Workers
Food	131	5398
Drink	15	2500
Textiles	14	737
Clothing	40	376
Leather and leather products	2	100
Footwear	7	534
Wood and wood products	33	289
Furniture	73	651
Paper and paper products	2	128
Printing and editing services	158	2138
Petroleum products	1	100
Chemical products	36	826
Rubber and plastic	17	743
Non-metallic minerals	83	2073
Metal products	63	851
Machinery and Electrical/non-electrical equipment	41	397
Transportation	51	602
Various industry	20	156
Wholesale commerce	328	7406
Retail commerce	1269	10596
Automotive trade	256	3276
Hotels	128	2414
Restaurants	398	4480
Business services	521	11937
Community services	507	5991
Education	423	9261
Health	393	4486
Vehicle repair/maintenance	236	1655
Transport, storage and communication	41	363
Financial services	43	2354

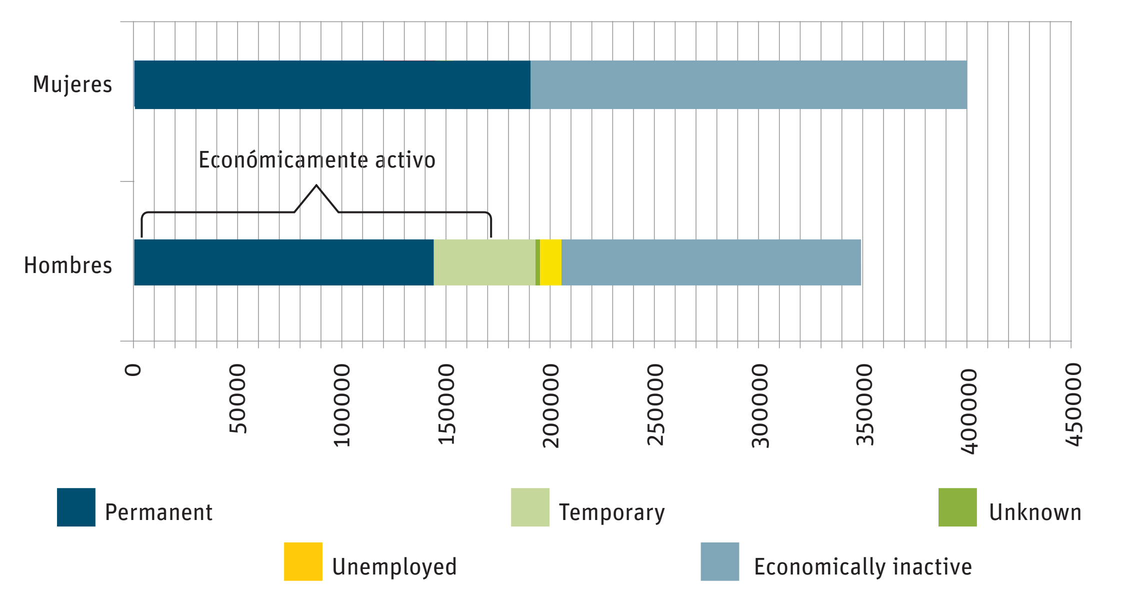
Source: INIDE, 2005

A.3.2.2 Economically Active Population

As per the 2005 census, the total population above age 10 in Managua was 750,250. Of these, 358,818 (47.8%) were considered to be economically active. Those classified as economically inactive include house-wives/husbands, students, retirees, and the permanently disabled.

Figure A22 illustrates the population above age 10 in Managua according to economic activity and employment status. The data shows that more men (59.0%) were economically active than women (38.2%). Also, men (23.8%) were more likely than women (15.9%) to engage in temporary employment.

Figure A-22: Economic Activity and Employment Status of Population Over 10, Municipality of Managua, 2005



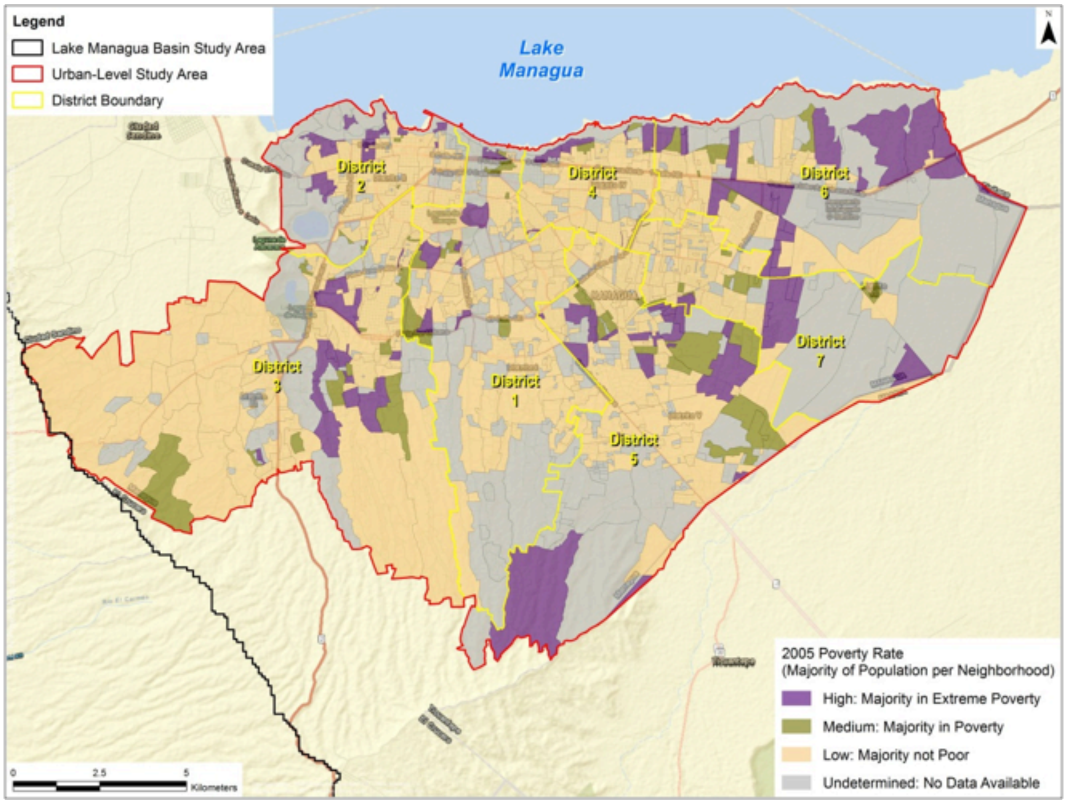
Source: Based on census data from INIDE, 2005. Graph by ERM.

A.3.2.3 Poverty

Nicaragua is among the poorest countries in Latin America. According to a 2011 report published by the World Bank, poverty in Nicaragua tends to concentrate in rural areas, particularly among populations involved in the agricultural sector. As a result, the overall rate of poverty in Managua is considerably lower than the national average.

Nevertheless, there are concentrations of extreme poverty in urban Managua, particularly in informal settlements located in under-serviced areas. Figure A23 indicates Managua neighborhoods where the majority of the population lives in extreme poverty (purple) or poverty (dark brown).

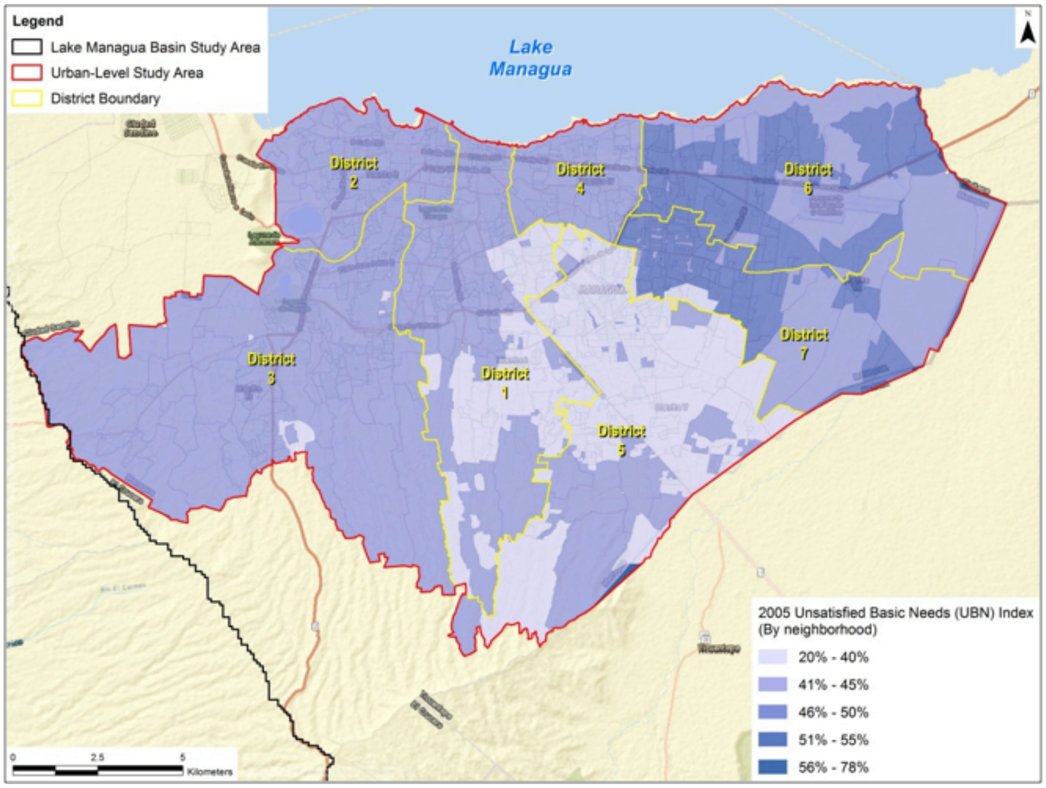
Figure A-23: Distribution of Poverty by Neighborhood, 2005



Source: Based on data from INIDE, 2005. Map by ERM.

Figure A24 shows the average Unsatisfied Basic Needs (NBI, in Spanish) index scores for each neighborhood. The NBI is a composite index developed by the United Nations Development Program that relies on housing, water and sewage, education and income indicators. Data suggest that Districts VI and VII have the highest concentration of neighborhoods where basic needs are not met, while Districts I and V have the lowest concentration.

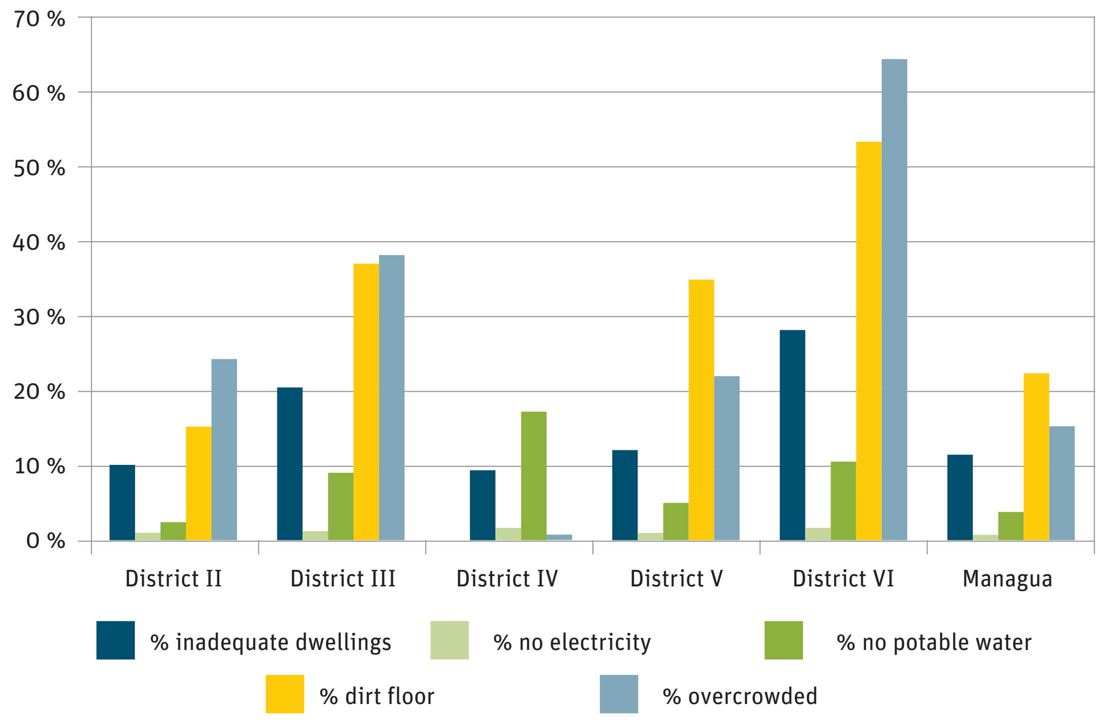
Figure A-24: NBI Rankings by Neighborhood, 2005



Source: Based on data from INIDE, 2005. Map by ERM.

Figure A25 indicates the percentages of dwellings in each district that are considered inadequate or overcrowded, or that lack basic services. The data indicates that very few households in Managua lack electricity service, but that overcrowding and homes with dirt floors are prevalent, particularly in District VI. Approximately 10% of dwellings in Districts III and VI also lack potable water service.

Figure A-25: Dwelling Characteristics by District, Municipality of Managua, 2005



Source: Based on census data from INIDE, 2005. Graph by ERM.
Note: Data for Districts I and IV was not available.

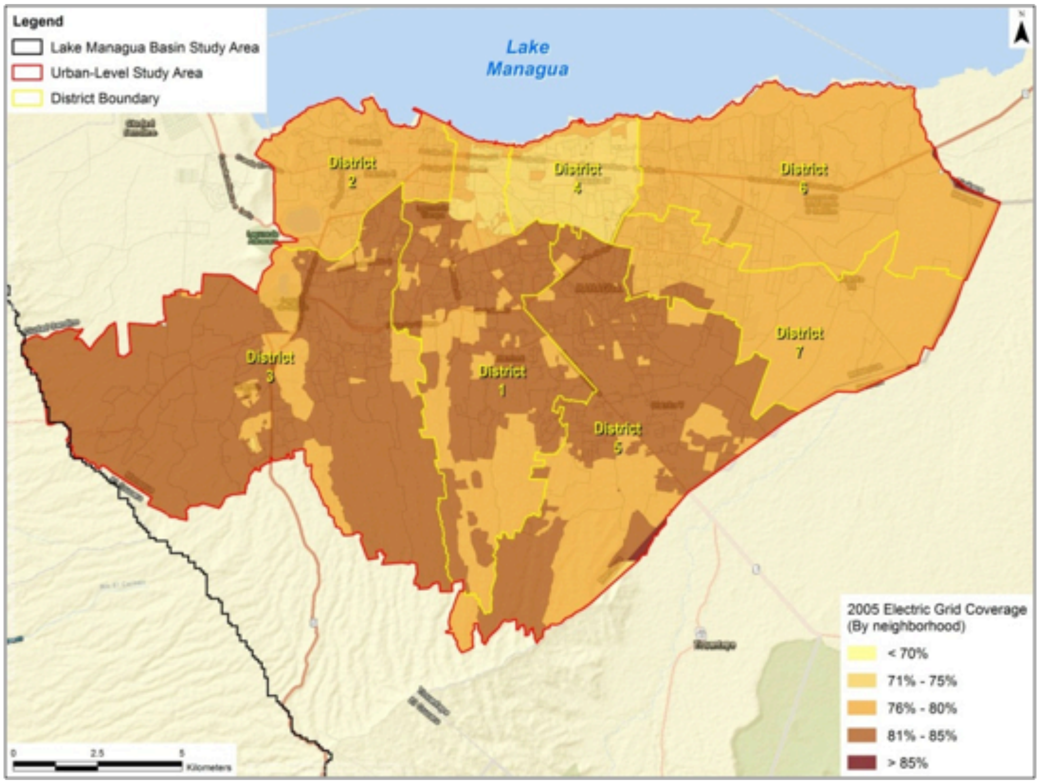
A.3.3 Social Infrastructure

A.3.3.1 Public Utilities

Electricity

According to ALMA, 97% of households in Managua had electricity in 2011. However, this data did not indicate whether the household was connected to the grid or relied on private generation. Figure A26 illustrates the percentage of households in each neighborhood that are connected to the electrical grid, based on 2005 data obtained from INIDE. The data shows that Districts I, III and V have the highest number of households connected to the grid.

Figure A-26: Electrical Grid Coverage by Neighborhood, 2005

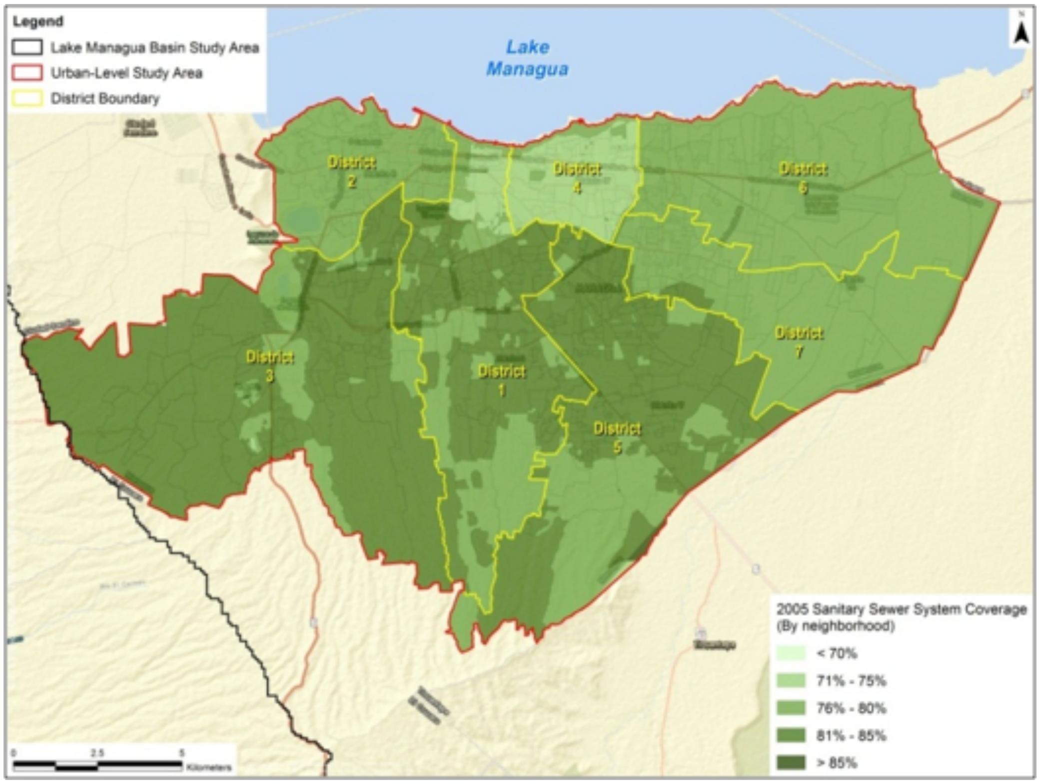


Source: Based on census data from INIDE, 2005. Graph by ERM

Sanitary Sewer System

In 2011, ALMA reported that 62.2% of households in the municipality had access to sanitation infrastructure. As illustrated in Figure A27, this coverage follows a similar distribution pattern than electricity coverage.

Figure A-27: Sanitary Sewer System Coverage by Neighborhood

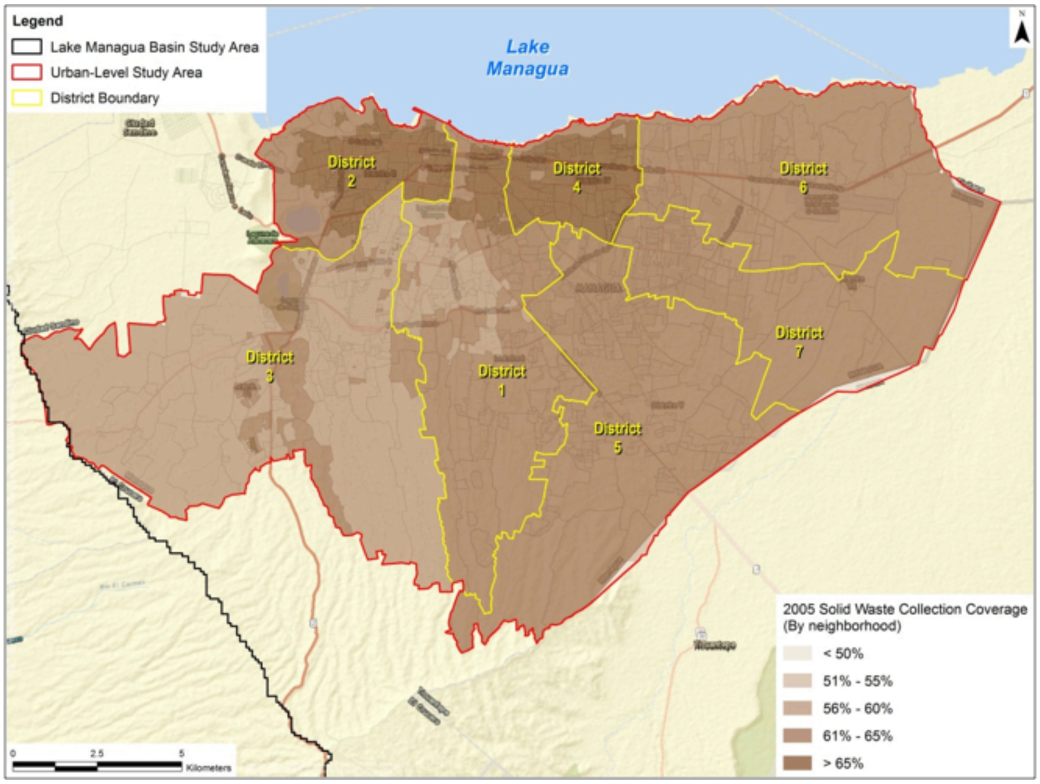


Source: Based on census data from INIDE, 2005. Graph by ERM

Solid Waste Collection

ALMA reported that 79.2% of households in Managua received solid waste collection service in 2011. Figure A28 illustrates the percentage of households serviced in each neighborhood as of 2005 and shows that the northwest portion of the municipality has the highest concentration of households with waste collection service.

Figure A-28: Solid Waste Collection Service Coverage by Neighborhood

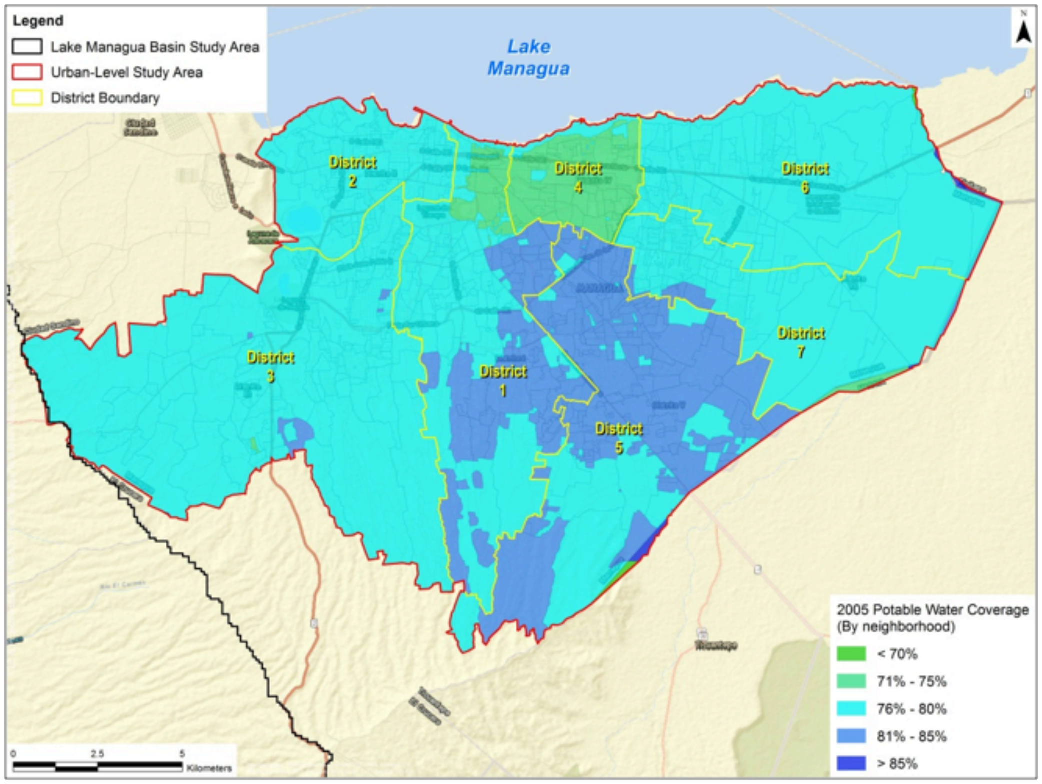


Source: Based on census data from INIDE, 2005. Graph by ERM

Potable Water System

As of 2011, ALMA reported that 73.1% of households in the municipality have access to potable water in their homes. Figure A29 shows percent coverage by neighborhood.

Figure A-29: Potable Water System Coverage by Neighborhood



Source: Based on census data from INIDE, 2005. Graph by ERM

A.3.3.2 Roads

The road network in Managua consists of 1552 kilometers of roadway, of which 54% is asphalt, 21% is paved, 1% is hydraulic concrete, and the remaining 24% are unpaved dirt roads[13].

13 ALMA (2011).

A.3.3.3 Health Services

The health system in Nicaragua is organized into 17 administrative health regions called SILAIS (Sistemas Locales de Atención Integral de Salud). Public health and primary care services are provided through national or departmental hospitals (classified as tertiary or secondary levels of care), and primary care health centers or health posts which are satellites of the health centers (classified as primary level of care). Of the 172 health centers in the country, only 24 have inpatient facilities, and all of the 855 health posts provide outpatient services only.

As the country's capital, Managua has a relatively high concentration of health care facilities. There are 34 health posts, 14 health centers and 16 hospitals, of which seven are public and nine are private. There are also six specialty centers, namely centers for rehabilitation, dermatology, cardiology, psychiatry, radiotherapy and ophthalmology[14]. Table A6 summarizes the distribution of health center types in each of Managua's districts.

Table A-6: Health Facilities by District, Municipality of Managua

District	Primary		Secondary		Tertiary
	Health Posts	Health Centers	Public Hospitals	Private Hospitals	Specialty Centers
District I	-	1	-	5	1
District II	-	2	1	1	3
District III	-	2	3	-	1
District IV	-	2	-	2	-
District V	8	2	2	1	1
District VI	21	3	1	-	-
District VII	5	2	-	-	-
Total	**34**	**14**	**7**	**9**	**6**

Source: ALMA, 2011

A.3.3.4 Education

There are approximately 555 education centers in Managua. This estimate is comprised by 150 preschools, 108 primary schools, 186 secondary schools, 15 technical schools and 31 institutions of higher learning, of which five are public and the other 26 are private[15].

14 ALMA (2011). Caractéristicas Generales de los Distritos de Managua.
15 ALMA (2011). Caractéristicas Generales de los Distritos de Managua.

A.4 Political and Institutional Context

This section provides an overview of the legal framework governing water supply and sanitation activities in Nicaragua. It also briefly describes the country's institutional context for climate change and adaptation planning, and highlights the multilateral agreements related to climate change to which Nicaragua is a signatory (where relevant).

A.4.1 Water Resource Management

The legal framework governing the management of water resources, and the water and sanitation sector in general, is comprised by a number of legislative acts passed by the National Assembly, which is Nicaragua's primary legislative body. These laws are briefly described below.

Law 620 - National Water Act

This law was passed in 2007 creating a legal framework on water resources in Nicaragua, and establishing the institutional and legal regime for the sustainable use of the resource. The law's purpose is to establish institutional jurisdiction over national waters so government can ensure the sustainable use, conservation, and quality of the country's hydrologic resources. The law also established the National Commission of Hydrological Resources (CNRH, in Spanish).

The National Aqueducts and Sewer Company[16] (ENACAL, in Spanish) is the main utility responsible for the provision of potable water and sanitation services throughout urban and rural Nicaragua. Upon passing of Law 620, ENACAL became the main public body responsible for compliance with Article 5, which states that it is the irrevocable obligation and priority of the State to promote, facilitate and regulate adequate water supply in quantity and quality to the Nicaraguan people, at a cost that considers less affluent populations.

Law 297- Act of Drinking Water and Sanitation

Act 297 regulates activities related to the drinking water supply and distribution, as well as, wastewater collection and disposal. This law indicates that the Nicaraguan Institute of Water Supply and Sewer (INAA) is responsible for the "exploration, production and distribution of drinking water and the collection and disposal of sewage." without prejudice to the competences conferred to the Ministries of Health, and Environment and Natural Resources.

Law No. 690 - General Law for Coastal Development

Law No. 690 was promulgated on July 29, 2009 with the aim of regulating coastal access, on the principle that the public interest should be placed before privatize interests. It established the National Commission of Coastal Development (CDZC) to operationalize the main goals of the law, which include: the preservation

16 Empresa Nacional de Acueductos y Alcantarillados (ENACAL)

of historic and prehistoric coastal and submerged resources, the zoning of public and restricted use areas along the coast, and regulation of titles for use along the coast. The CDZC regulates the restricted access to the coast for sanitary, national defense, and natural disaster reasons. The law also states that development along the coast will require coordination at regional, departmental and municipal levels.

Law 722 - Community Water Policy

Law 722, which was passed in 2010, creates the Drinking Water and Sanitation Committees (CAPS, in Spanish) to support community economic and social development, and specifically to help guarantee that the right of Nicaraguan citizens to access drinking water and sanitation services. The organizational structure of these committees is comprised of community leaders, selected from established community organizations, and individuals, selected by the community. CAPS are intended to execute strategies aligned with integrated water management best practices, such as those established by the Global Water Partnership (GWP).

In addition to the above laws, which comprise the main legal framework for management of water resources, additional laws regulate activities related to the water and sanitation sector as listed below:

- Law 276 (1998) establishes the National Aqueducts and Sewer Company (ENACAL), which is responsible for the supply and distribution of drinking water services and sanitation.
- Decree 51 (1998) establishes the National Commission on Potable Water and Sanitation (CONAPAS, in Spanish), which is tasked with governance of INAA and ENACAL, as well as leading strategic planning in the water and sanitation sector.
- Decree 52 (July 1998) outlines additional regulatory requirements related to the provision of potable water and sanitation services by the public sector.
- Decree 45 (August 1998) regulates pricing related to the provision of drinking water services.
- Resolution No. 001 specifies rate limits depending on the type service.
- January 1999 Special Regulation for the Public Registry of Water and Sewerage Concessions of fewer than 500 users and municipal companies.
- Decree 33 (1995), "Provisions for Pollution Control from Domestic, Industrial and Agricultural Wastewater Discharges," defines the functions of the various agencies in the enforcement of crimes related to pollution generated by sewage and wastewater.
- Law 423, "General Health Law," designates the Ministry of Health as the entity in charge of monitoring water quality.
- Law 217 (June 1996), "Environmental and Natural Resources General Law," defines the protection of water and water sources as a fundamental public function, and outlines sanctions against their contamination.
- Law 40 (August 1997), "Municipalities Law," devolves responsibility to municipalities for ensuring access to water and sanitation services, and establishes their role in managing these resources when they are decentralized.
- Law 440 (2003), "Suspension of Concessions Law," indicates that water concessions may not be granted to individuals or facilities by ENACAL until the General Water Law is promulgated.
- Law 559 (2006) outlines a number of crimes against the environment and natural resources.

A.4.2 National Policy and Strategy on Climate Change17

Nicaragua has developed various polices and strategies that address needs in sectors vulnerable to climate change. The national authority in charge of climate change issues is the Ministry for Natural Resources and Environment (MARENA, in Spanish). MARENA is responsible for the implementation of international treaties (e.g., UNFCCC, Kyoto Protocol) and has led the development of national communications under the UNFCCC[18] framework as well as the development of the National Action Plan on Climate Change.

The 2003 National Action Plan on Climate Change contains important steps toward advancing adaptation and building resilience against climate-driven changes, particularly with respect to agriculture and water. In practice, however, the 2003 document seems to not have been fully implemented.

In 2010, the Government of Nicaragua developed the National Strategy and Action Plan on Environment and Climate Change. This document describes the key climate change related environmental challenges facing Nicaragua and sets out an agenda with key actions to be undertaken in the 2010-2015 period. Actions revolve around topics such as the defense and protection of the environment and natural resources, environmental education, conservation, recovery and use of water sources, prevention, mitigation and adaptation to climate change, and sustainable land use. Specific priority adaptation actions noted in this plan are:

- Water – Building water wells and aqueducts; water capture and storage; and watershed adaptation, including riverbank protection.
- Agriculture – Resilient seeds, agricultural diversification, new crops and new economic activities.
- Climate information – Strengthening monitoring and information collection, early warning systems, and response capacity.

The Climate Change Directorate of the Ministry for Environment and Natural Resources (MARENA) is Nicaragua's UNFCCC focal point. MARENA has submitted, on behalf of Nicaragua, two National Communications under the UNFCCC process (i.e., 2001 and 2011).

At the Central American level, a regional climate change strategy has recently been developed under the auspices of the Central American Integration System (SICA, In Spanish), and specifically, its Central American Commission for Environment and Development (CCAD, in Spanish), a committee which fosters collaboration among the environment ministries of SICA member states.

The strategy summarizes climate information and sectorial vulnerabilities, and proposes six strategic areas, one of which is "vulnerability and adaptation to climate variability and change, and risk management." Nine strategic objectives—disaster risk reduction, agriculture and food security, forest ecosystems and biodiversity, water, health, coastal-marine systems, tourism, indigenous people and public infrastructure—

17 Information for this section has been sourced from the Adaptation Learning Mechanism, which is a website repository for various climate change and adaptation related documents and news, developed by the United Nations. http://www.adaptation-learning.net/nicaragua/profile

18 UNFCCC stands for the United Nations Framework Convention on Climate Change, which is an international treaty whose mission is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

with over 150 proposed measures, are mentioned. Other strategic areas are: mitigation; capacity building; education, awareness raising, communication and participation; technology transfer; and international negotiations and management[19] .

A.4.3 National Policy on Disaster Risk Management

In 2000, the National Assembly approved Law 337, which created the National System for Disaster Prevention, Mitigation and Attention (SINAPRED, in Spanish) and established the current framework to manage disasters in the country. This system integrates numerous governmental and non-governmental agencies at the national, regional and local levels.

The mission of SINAPRED is to "reduce vulnerability of people at risk of suffering from disasters caused by natural phenomena and/or generated by human activities that put in danger the lives of citizens, their belongings, ecosystems and the national economy[20]." At the local level, SINAPRED works through municipal, departmental and regional committees, as well as through sectorial work commissions[21].

Nicaragua is also a member of the Regional Coordination Center for the Prevention of Natural Disasters in Central America (CEPREDENAC). CEPREDENAC belongs to the institutional framework set in place by the SICA, and brings together the national emergency commissions of the seven Central American countries to promote international cooperation, knowledge exchange, technical and scientific assistance, and dissemination of information on disaster risks. Its main policy instrument is the "Central American Policy on Integrated Disaster Risk Management," which establishes guidelines, directives and actions that are to be detailed in more specific plans, such as a five-year regional disaster reduction plan[22].

A.4.4 Relevant International Guidance on Climate Change & Adaptation

Nicaragua is party to a number of multilateral environmental agreements (e.g., conventions, treaties, and protocols) that are relevant context for understanding local actions and plans related climate change. These agreements are tabulated below.

19 Centro de Coordinación para la Prevención de los Desastres Naturales en América Central (CEPREDENAC) and Sistema de la Integración Centroamericana (SICA) (2010). Política Centroamericana de Gestión Integral de Riesgo de Desastres (Central American Policy on Integrated Disaster Risk Management). Guatemala City: CEPREDENAC and Ciudad Merliot, El Salvador: SICA.

20 SINAPRED 2013. Available at http://www.sinapred.gob.ni/

21 SINAPRED 2013. Retrieved at http://www.sinapred.gob.ni/

22 Centro de Coordinación para la Prevención de los Desastres Naturales en América Central (CEPREDENAC) and Sistema de la Integración Centroamericana (SICA) (2010). *Política Centroamericana de Gestión Integral de Riesgo de Desastres (Central American Policy on Integrated Disaster Risk Management).* Guatemala City: CEPREDENAC and Ciudad Merliot, El Salvador: SICA.

Table A-7: International Multi-Lateral Agreements Ratified by Nicaragua

Multilateral Environmental Agreement	Description / Project Standards
United Nations Framework Convention on Climate Change (UNFCCC).	The UNFCCC Treaty was signed in 1992 and ratified by Nicaragua on 1995; it entered into force in Nicaragua in January 1996. Its objective is to stabilize greenhouse gas concentrations in the atmosphere.
Kyoto Protocol (1998)	The Kyoto Protocol was signed by Nicaragua in 1998 and ratified in November 1999. It implements the principles laid out by UNFCCC Treaty with a special focus on emissions reduction (Art. 3).
Vienna Agreement for the Protection of the Ozone Layer and the Montreal Protocol. Published on March 22, 1985 in Vienna.	This agreement focuses on protecting the health of the people and the environment from adverse effects resulting from changes and modifications in the ozone layer.
United Nations Convention for Climate Change. Published on May 9, 1992 in New York.	The objective of this convention was to protect the climate for present and future generations and prevent climate changes.
Regional Agreement on Climate Change. Published on October 29, 1993 in Guatemala.	Coordinate actions in the Central American Region in order to create economic growth while confronting the challenges of climate change.
Hyogo Framework for Action	It is 10-year plan adopted by 168 United Nations member states in 2005 to undertake actions aimed at reducing natural disaster risk.

Annex B:

Projected Land Use Scenario for Managua

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Table of contents

List of Tables

List of Figures

B.0 Projected land use scenario for MANAGUA

As discussed in the main document, ERM conducted a hydrological analysis of selected urban watersheds in Managua to model the potential risks associated with stormwater events in the future. As with any watershed analysis, it is important to understand the infiltration capacity of the soil under study, as it plays a large role in determining the extent of runoff that occurs in a given drainage basin.

This section focuses on establishing a future scenario of land use in Managua. Given that infiltration rate is directly associated with the imperviousness of the ground surface, which is linked to its land cover/land use, projecting what such land uses will be are a key input for modeling the watershed behavior in the future.

B.1 Methodology

In order to determine the imperviousness of the Lake Managua basin, ERM studied the land cover across the lake's thirteen sub-watersheds. At the urban level, ERM also analyzed the existing land cover for the four selected micro-watersheds. The analysis was conducted using a phased-approach where distinct parts of the watershed were studied one at a time, beginning with the northern watersheds, moving on to the southern watersheds, and then focusing on the urban-level micro-watersheds. As a result, this analysis is divided in three sections:

- Southern watersheds;
- Northern watersheds; and,
- Urban-level watersheds.

The analysis of each watershed section comprised two steps:

- Historic analysis of land use change, utilizing multi-year satellite data; and,
- Projection of land use changes to 2050 based on the land use change trends derived from the historical analysis.

For the historical analysis, ERM compiled information from two main sources: land cover maps generated by the Ministry of Agriculture and Forestry (MAGFOR), which provided data on the northern Lake Managua sub-watersheds, and from LANDSAT satellite images, which provided data for the southern lake watershed.

The second step of the analysis focused on projecting future land use for the 2050 time horizon. The same methodology was employed for the three watershed units under study. As illustrated in Figure B-1, the projection of the future scenario included:

1. Applying statistical functions to forecast future behavior of each land use category based on the historical data;
2. Selecting one function for each land use category; and,
3. Normalizing data and build the final time series, ensuring the extent of the project land uses remained constant to the total area of each unit of analysis.

Figure B-1: Land use analysis process for the Lake Managua watershed

Lake Xolotlán watersheds Multi-temporal land use analysis and projections			
	Process / Units of analysis	Northern Basin 9 Watersheds	Souther Basin 5 Watersheds 6 Micro-Watersheds 6 polygons* *Polygons within Jagüitas and Cuarezma micro-watersheds
Multi-temporal Analytics	Land Use Maps	Magfor 1998-2000-2009	Landsat 1989-1998-2004-2010
	Areas measured by land use category	5 Categories Cultivate and without vegetation Dense forest Thin forest Rangeland Tacotal* *Young secondary forest	12 Categories Developed high intensity Developed medium intensity Developed low intensity Developed open space Forest Cultivate Rangeland Barren Water Forested wetland Scrub wetland Emergent wetland
Projections 2010-2050	996 possible statistical functions	4 for each land use category Linear Exponential Logartithmical Double logarithmical	
	249 selected statistical functions	1 for each land use category Most suitable: - Non negative. - Behaviour adjusted to the literature and empiric knowledge of the area of study. - Follow the trends found in the historic data. - First figure in the projection series closer to the last figure in the historic data.	
	Final time series: areas by land use category	1998-2050	1989-2050

B.2 Southern Watersheds

The southern basin of Lake Managua, which is also known as Lake Xolotlán, is divided into five watersheds: Mateare-Nagarote, Sub-cuenca I, Sub-cuenca II, Sub-cuenca III y Sub-cuenca IV. For each, ERM analyzed land use maps derived from LANDSAT satellite images based on remote sensing.

The land use study for the southern watershed was conducted in two parts: first, a historic analysis of land use change and second, a projection from the most recent information available to 2050, using the data gathered in the historic analysis to determine land use change trends over time.

B.2.1 Historic analysis with LANDSAT Satellite Images

For the land use historic analysis ERM studied land cover derived from LANDSAT satellite images for the southern basin. ERM selected images from the freely available USGS LANDSAT 5 satellite (Thematic Mapper). LANDSAT 5 was launched March 1, 1984 and offers a 30 meter (m) spatial resolution, which captures visible and infrared land surface reflectance across seven bands[1]. This satellite and the wave band configuration are specifically designed for the regional land cover mapping being undertaken by this study.

The criteria for image selection were:

- Time Period and Frequency: Earliest available image up to present with a minimum of four images at a consistent time interval;
- Cloud Cover: Preferably cloud-free cover and free from other atmospheric effects, or cloud cover limited to non-urban portions of study area; and,
- Season: After initial review of local climate patterns and available imagery, images from the end of November and December were selected, which correspond to the beginning of the dry season.

ERM then selected four time periods for which satellite imagery was available:

- November 27th, 1989;
- December 22th, 1998;
- November 24th, 2004; and,
- December 23th, 2010.

The LANDSAT images were downloaded in raw format to avoid residual errors and create a raw dataset suitable for further multi-temporal analysis[2].

1 1 Blue 0.45 – 0.52 30, 2 Green 0.52 – 0.60 30, 3 Red 0.63 – 0.69 30, 4 Near infrared 0.76 – 0.90 30, 5 Shortwave infrared 1.55 – 1.75 30, 6 Thermal infrared 10.40 – 12.50 120, 7 Shortwave infrared 2.08 – 2.35 30.

2

Processing of LANDSAT Data

The LANDSAT images were preprocessed to Level T1 standard correction, which provides radiometric and geometric error correction to the raw images from the satellite. The Level T1 imagery also removes residual errors in the calibrated data to improve the qualitative appearance of the imagery. Geometric correction removes geometric distortions and projects the image to a standard map projection. This preprocessing does not remove all errors or artifacts in the raw data so ERM conducted additional preprocessing to create a raw dataset suitable for further image analysis.

All wavebands were run through a Principal Components Analysis (PCA), which reprocesses the bands based on reflectance variability across all wavebands to eliminate any residual noise or error, with the exception of band 6 (thermal infra-red) which has limited use for vegetation mapping. In four of the cases, the first three components (out of six) were used and comprised approximately 98.5%of the image variance. The final components, which accounted for less than 1.5% of the variance in the data (and the majority of the errors) were discarded before reassembling the individual images.

Further inspection showed some striping was still present on a few of the principal component bands in the 1998 and 2004 images so a de-striping algorithm was applied to correct this. Finally, digital numbers were converted to radiance values as this additional level of correction adjusts for any remaining temporal distortions between images. To determine land use, ERM ran a series of automated analysis and statistical techniques (unsupervised classification)[3], to highlight variability in the images that may not be easily distinguished simply by manual visual review particularly when considering reflectance of non-visible infrared wavebands. These preliminary analyses served to illustrate the spectrally ambiguous regions (e.g., Cultivated confused with Rangeland) as well as provide insight into general land cover. This process also aided the selection of 'training sites' for the supervised classification.

Land Cover Classification

Taking into account the area of study geography, climate and land use, as well as the industry standards, the land cover categories chosen to be represented in the final report are a combination of the Tier 2 Coastal Change Analysis Program (C-CAP) and the United States National Land Cover Database (NLCD) classification categories.

The final land cover classification color scheme used for the maps and shown in Table B-1 merges these two systems to best illustrate and differentiate between the classes. Due to the spectral, climatological, and data resolution characteristics of the region, the classes Scrub and Grassland had to be combined into one class called Rangeland.

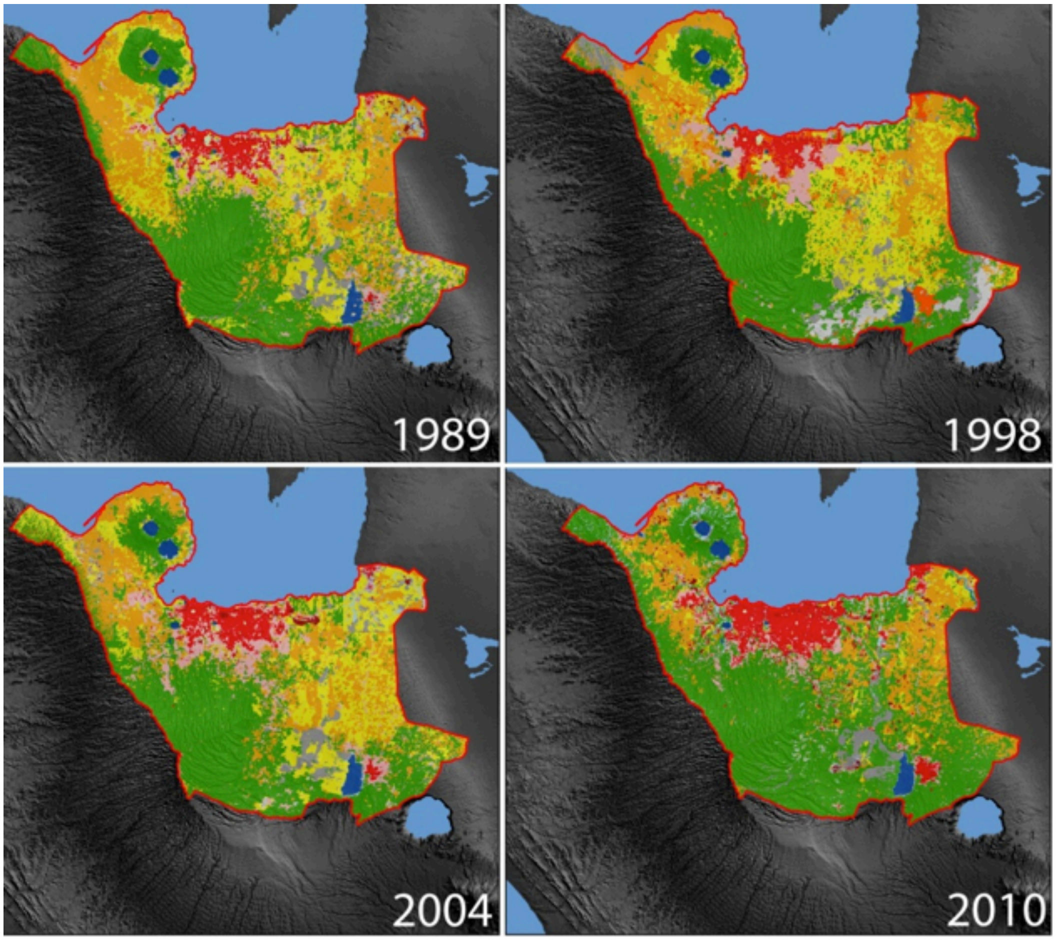
3 ERM ran the following analysis: Parallel Piped; Minimum Distance to Mean; Multi-Layer Perceptron; K- Nearest Neighbors; Bayesian Probabilities; Mahal Typicality; and Fisher (LDA).

Tablae B-1 Land cover classification systems

Tier 1 C-CAP Class	Tier 2 C-CAP Class	Class Used in Study
Unclassified Developed	Unclassified	Unclassified
	Developed, High Intensity	Developed, High Intensity
	Developed, Medium Intensity	Developed, Medium Intensity
	Developed, Low Intensity	Developed, Low Intensity
	Developed, Open Space	Developed, Open Space
Agricultural Land	Agricultural Land	Agricultural Land
Grassland	Grassland/Herbaceous	Grassland/Herbaceous Scrub/ Shrub
Scrub Land	Scrub/ Shrub	
Forest	Forest	Forest
Wetland	Forested Wetland	Forested Wetland
	Scrub/Shrub Wetland	Scrub/Shrub Wetland
	Emergent Wetland (Persistent)	Emergent Wetland (Persistent)
Barren Land	Barren Land	Barren Land
Water/Submerged	Open Water	Open Water

The next step in the categorization process included estimating the areas that corresponded to each land-use category, taking into account trends observed between 1998 and 2009. This multi-temporal analysis was the base for forecasting the distribution of land use in each watershed for the year 2050 based on a 2009 baseline year. The same methodological approach was used for all units of analysis (e.g., Lake Managua watershed, urban micro- watersheds, and polygons within micro-watersheds). Figure B-2 illustrates the land cover maps for the four time periods under study.

Figure B-2: Land use maps for southern watersheds: 1989, 1998, 2004 & 2010



Source: LANDSAT satellite data. Map by ERM, 2013.

B.2.2 Multi-temporal analysis and projections

Once the land use maps were completed, ERM analyzed the evolution of the categories and measured the area occupied by each one of the watersheds. That allowed the team to build a time series to evaluate variations in each unit of analysis and identify land use change trends.

The multi-temporal study 1989-2010[4] was the basis of the projections from 2010 to 2050. Using the statistics software STATA, the team ran four types of projections[5] for each category in each unit of analysis. A total of 240 projections, ran from the historic data gathered, were used to evaluate possible future trends for each land use category in the watersheds of the southern basin.

From the set of statistically possible projections, ERM selected the 60 projections that best suited each land use category. First, negative projections, with values below zero, were discarded. Second, the remaining projections were evaluated against current trends identified by study of secondary sources and against trends found in the historic data. In some cases, when two or more functions complied with the criteria discussed above, the function with the first figure in the projection series closer to the last figure in the historic data was selected, assuming that the less abrupt change will occur in a five year interval. Finally, the best suited projections for each category were evaluated jointly, in each unit of analysis to determine their final distribution.

In the case of the urban areas, the raw figures from the projections were contrasted with demographic analysis used to estimate land use demand. Once the urban areas were calibrated, the raw figures for each projection in rural and natural areas were normalized to fit within the area of analysis, which is constant over time.

The final dataset for each unit of analysis consisted of a matrix displaying the areas occupied by land use categories against time. The matrix included historic data from 1989 to 2010 and projected data from 2010 to 2050, for five-year intervals. Table B-2 illustrates the output for a single unit of study, Sub-cuenca IV.

Table B-2: Sample output for Sub-cuenca IV, Southern Basin

Área en Hectáreas Subcuenca IV	1989	1998	2004	2010	2015	2020	2025	2030	2035	2040	2045	2050
Desarrollado de alta densidad	253	0	23	419	479	484	486	487	487	487	486	484
Desarrolado de media densidad	116	71	288	1,012	1,052	1,205	1,339	1,456	1,558	1,648	1,728	1,797
Desarrolado de baja densidad	1,443	1,267	1,963	1,187	1,326	1,247	1,171	1,100	1,034	973	917	865
Desarrollado espacio abierto	12	10	18	40	47	51	55	58	60	63	65	66
Cultivado	8,384	6,603	6,907	6,426	6,618	5,940	5,327	4,777	4,289	3,855	3,471	3,128
Pastizales	10,078	13,095	11,964	1,718	1,273	850	567	379	253	170	114	77
Bosque	10,877	8,384	10,295	19,999	20,099	21,126	21,977	22,690	23,293	23,809	24,255	24,622
Humedal boscoso	229	40	434	600	682	707	726	742	755	766	775	813
Humedal arbustivo	365	93	76	78	56	37	24	16	10	7	5	3
Humedal emergente	42	58	32	10	11	8	5	4	2	2	1	1
Cuerpo de agua	55	82	25	21	20	14	10	7	5	4	3	2
Estéril	2,457	3,335	3,354	3,234	4,037	4,031	4,012	3,984	3,951	3,916	3,881	3,842
Nubes	394	2,199	213	205	0	0	0	0	0	0	0	0
Sombra	994	461	108	751	0	0	0	0	0	0	0	0
Total	35,699	35,699	35,699	35,699	35,699	35,699	35,699	35,699	35,699	35,699	35,699	35,699

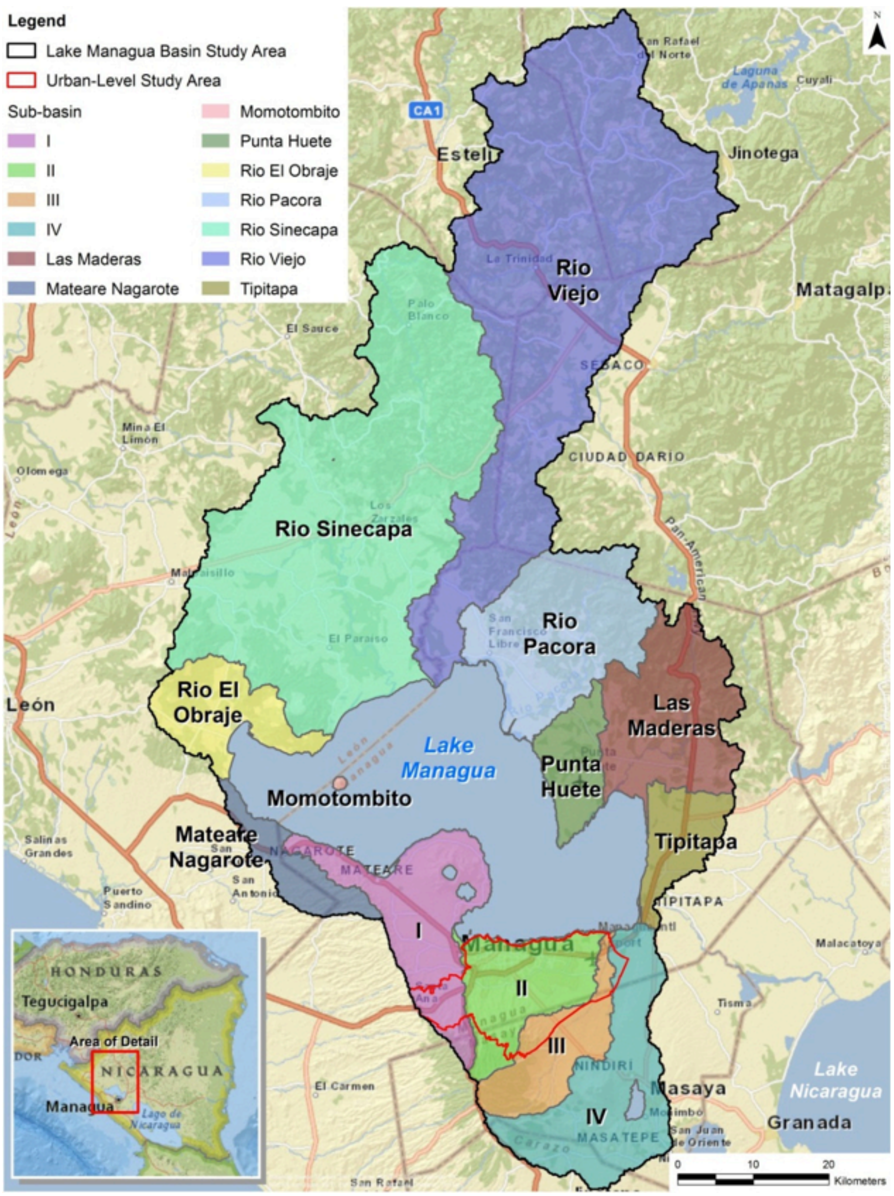
4 1998-2009 for the northern watersheds.

5 Projections programed in STATA: linear, exponential, logarithmical, double logarithmical and constant.

B.3 Northern Watersheds

As illustrated in Figure B-3, the northern basin of Lake Managua is divided into nine watersheds: Las Maderas, Momotombito, Punta Huete, Río Obraje, Río Jinotega, Río Pacora, Río Sinecapa, Río Viejo and Tipitapa.

Figure B-3: The Lake Managua watershed sub-units



Source: ERM, 2013

For these nine watersheds, the best data source available is the official MAGFOR land use maps. The 1998, 2000 and 2009 MAGFOR land use maps were processed to reclassify its original 22 categories into six categories (as shown in Figure B-4), representative of different imperviousness levels. These six categories are:

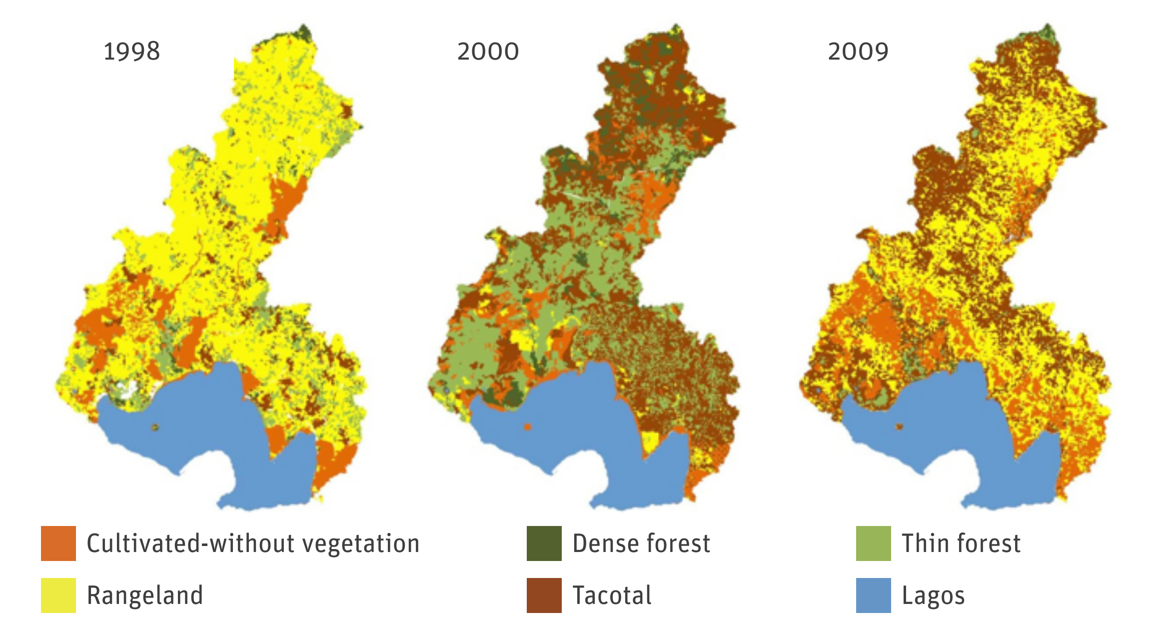
- Cultivated (without vegetation);
- Dense forest;
- Thin forest;
- Rangeland;
- Tacotal[6]; and,
- Water bodies.

The land use analysis for the northern watershed comprised a historic analysis of land use change and the statistical-based formulation of projects to the 2050 time horizon (based on the historical data to determine land use change trends over time). The same process performed for the Lake Managua's southern watershed; however, the main difference is that different source data was used.

B.3.1 Historic analysis with MAGFOR land use maps

Maps showing the distribution of dense forest, thin forest, rangeland, tacotales and areas cultivated or without vegetation were created in order to study the distribution of land use in each of the watersheds. Figure B-4 shows the land cover distribution as maps of the northern watershed for three time periods.

Figure B-4: Land use maps for northern watersheds: 1998, 2000 & 2009



Fuente: MAGFOR. Mapa por ERM, 2013.

6 Tacotal is known as an area characterized by the growth of wild plants and where the predominant types of plants are shrubs and trees no taller 5 meters. In essence, tacotal is a type of young secondary forest, typically regenerated from prior exhaustive use such as cattle grazing.

The technical team measured the areas occupied by each land-use category in the maps and identified land use variation trends between 1998 and 2009. This multi-temporal analysis was the base for forecasting the distribution of land use in each watershed 2009 to 2050.

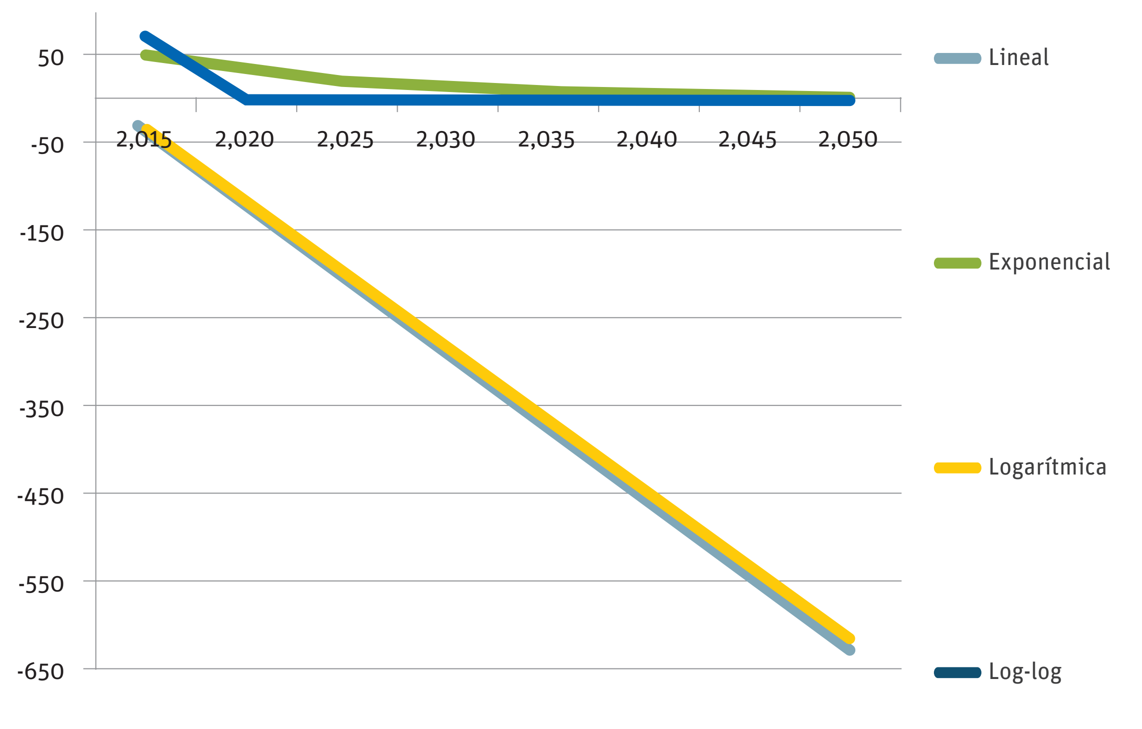
B.3.2 Multi-temporal analysis and projections

The same methodological approach described in Sections B.1 and B.2.1 was used for all units of analysis (i.e., watersheds, micro-watersheds and polygons within micro-watersheds), and therefore for all watersheds in the northern and southern basins of Lake Managua.

The multi-temporal study 1998-2009 was the basis of the projections from 2009 to 2050 in the northern watersheds. Using the statistics software STATA, the team ran four types of projections[7] for each category in each unit of analysis. A total of 240 projections, ran from the historic data gathered, were used to evaluate possible future trends for each land use category in the watersheds of the southern basin.

In summary, ERM ran a total of 180 statistical functions and selected the 45 best suited for each of the northern watersheds. The final time series was built from the selected functions for each of the land uses in a particular watershed. Figure B-5 shows a plot of four of the five statistical projections performed, in this case, for the Dense Forest land use category in the Las Maderas watershed.

Figure B-5: Statistical projections for dense forest in Las Maderas



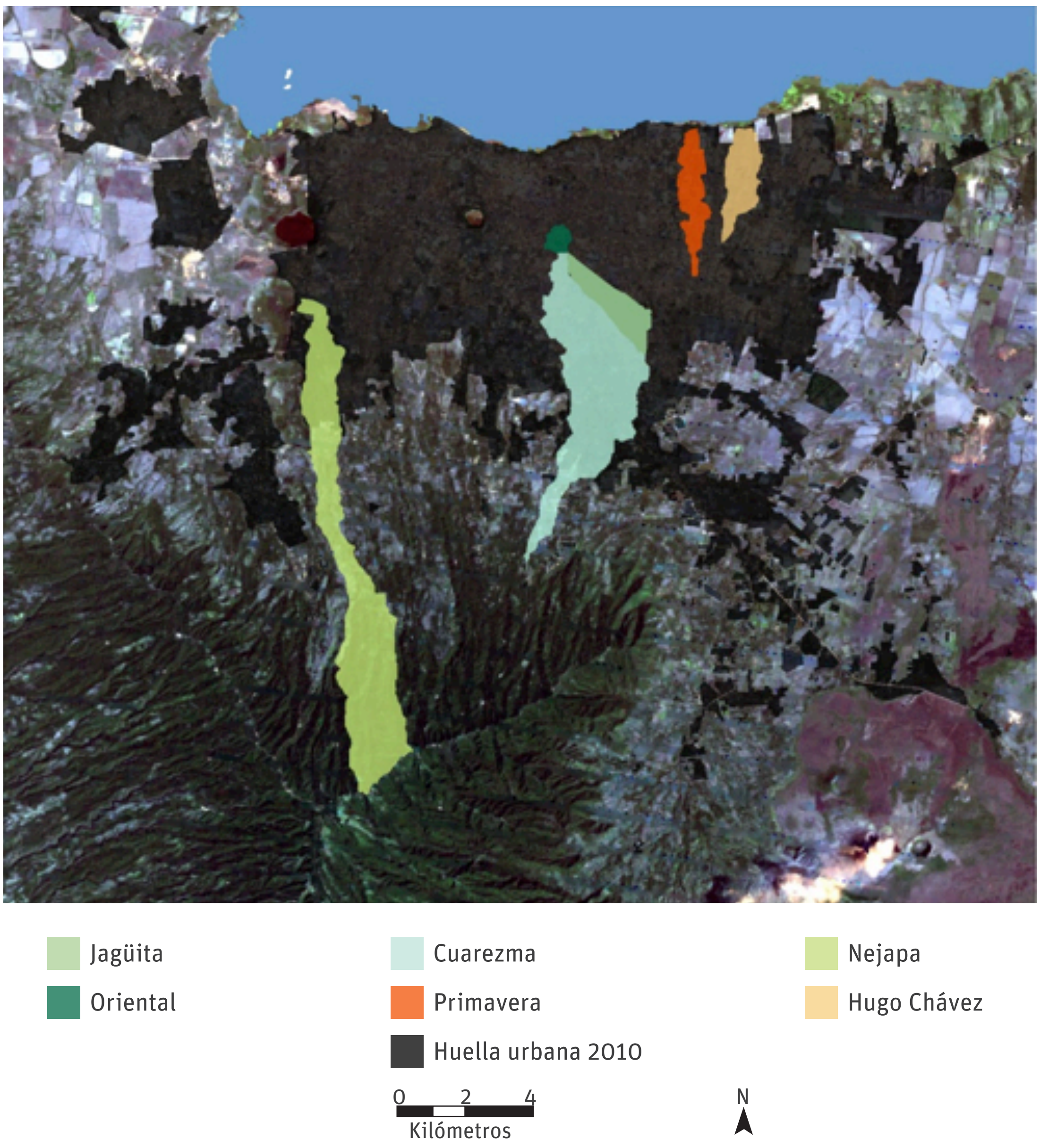
Source: ERM, 2013

7 Projections programed in STATA: linear, exponential, logarithmical, double logarithmical and constant.

B.4 Micro-watersheds

As illustrated in Figure B-6, a total of four micro-watersheds were selected for detailed analysis in the southern basin: Hugo Chávez, Primavera, Oriental-Jagüitas-Cuarezma (OJC), and Nejapa. In addition, six polygons inside the OJC micro-watersheds were analyzed in further detail.

Figure B-6: Four micro-watersheds subject to detailed land use analysis



B.4.1 Historic Analysis LANDSAT Satellite Images

ERM performed a detailed land use analysis of the LADNSAT satellite-based maps. Taking into account the area of study geography, climate and land use, as well as the industry standards, the land cover categories chosen to be represented in the final report are a combination of the Tier 2 Coastal Change Analysis Program (C-CAP[8]) and the United States National Land Cover Database (NLCD[9]) classification categories.

B.4.2 Multi-temporal analysis and projections

The technical team measured the areas occupied by each land-use category in the maps and identified land use variation trends between 1989 and 2010. The multi-temporal study was the basis of the projections from 2010 to 2050 of the land uses in each micro-watershed.

Using the statistics software STATA, the team ran four types of projections[10] for each category in each unit of analysis. A total of 288 projections for the micro watersheds and another 288 for the polygons inside Jagüitas and Cuarezma, were ran from the historic data gathered. These projections were evaluated and the 72 best suited for the micro-watersheds and the 72 best suited for the mentioned polygons were selected to build the final time series for each unit of analysis.

B.5 Imperviousness Cover

Once the land cover was identified for existing conditions (2010) and estimated for the 2050 horizon, ERM used this information to define imperviousness cover for each one of the four micro-watersheds in Managua and the thirteen sub-watersheds surrounding Lake Managua. The imperviousness cover was represented by the runoff curve number (CN) method developed by the United States Soil Conservation Service (SCS). The CN method was initially developed as a design tool to estimate runoff from rainfall events on agricultural fields, but the method is now used for computing peak runoff rates and volumes for urban hydrology. The selection of the CN value that best represents the ground cover type and hydrologic conditions is based on land cover type, hydrologic conditions and soil group which includes different infiltration soil rates[11].

ERM selected and calculated the CNs for the four studied micro-watersheds located within Managua based on soils characteristics and land cover for existing conditions. Table B-3 shows the curve numbers for each study-microwatershed under existing conditions.

8 The C-CAP classification scheme was developed by the United States National Oceanic and Atmospheric Administration (NOAA) as a best practice and as a nationally standardized database of land cover and land change information for the coastal regions of the United States. As the C-CAP is used primarily for coastal regions many of the coast specific classes were not applicable to this study.

9 The older NLCD classification scheme, on which C-CAP is based, was developed by the US Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) with the intention of having a national standard throughout the United States.

10 Projections programed in STATA: linear, exponential, logarithmical, double logarithmical and constant.

11 Wanielista, M., Kersten, R., and Eaglin, R. 1997. Hydrology, Water Quantity and Quality Control. 2nd Edition Jonh Wiley and Sons, Inc.

Table B-3 Composite curve numbers existing land cover at the four micro-watersheds

Micro watershed	Sub-micro watershed	Composite CN
Hugo Chávez	Inferior	76
Hugo Chávez	Superior	76
Primavera	Inferior	77
Primavera	Superior	77
Nejapa	Norte	59
Nejapa	Inferior	63
Nejapa	Media	48
Nejapa	Superior	45
Oriental-Jagüitas-Cuarezma	Cuarezma 7	77
Oriental-Jagüitas-Cuarezma	Cuarezma 6	68
Oriental-Jagüitas-Cuarezma	Cuarezma 5	68
Oriental-Jagüitas-Cuarezma	Jagüitas del Medio	80
Oriental-Jagüitas-Cuarezma	Jagüitas 1	80
Oriental-Jagüitas-Cuarezma	Jagüitas 2	80
Oriental-Jagüitas-Cuarezma	Oriental	80

Table B-4 shows the curve numbers for each study micro-watershed for the 2050 horizon.

Table B-4 Composite curve numbers the 2050 land cover scenario

Micro watershed	Sub-micro watershed	Composite CN
Hugo Chávez	Inferior	84
Hugo Chávez	Superior	84
Primavera	Inferior	85
Primavera	Superior	85
Nejapa	Norte	67
Nejapa	Inferior	73
Nejapa	Media	56
Nejapa	Superior	52
Oriental-Jagüitas-Cuarezma	Cuarezma 7	86
Oriental-Jagüitas-Cuarezma	Cuarezma 6	86
Oriental-Jagüitas-Cuarezma	Cuarezma 5	88
Oriental-Jagüitas-Cuarezma	Jagüitas del Medio	88
Oriental-Jagüitas-Cuarezma	Jagüitas 1	88
Oriental-Jagüitas-Cuarezma	Jagüitas 2	88
Oriental-Jagüitas-Cuarezma	Oriental-Inferior	88

Table B-5 shows the calculated composite curve numbers for the thirteen sub-watersheds of Lake Managua, under existing conditions and projected scenario.

Table B-5 Curve numbers for the Lake Managua watershed sub-units

Sub-watershed	Composite CN Existing Conditions	Composite CN (2050 Horizon)
I	51	56
II	63	69
III	48	53
IV	49	53
Las Maderas	53	58
Mateare-Nagarote	58	64
Punta Huete	60	67
El Obraje	33	36
Pacora	46	50
Sinecapa	39	43
Viejo-Jinotega	36	40
Momotombito	32	35
Tipitapa	58	64

Annex C:

Detailed Vulnerability Assessment

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Table of contents

List of Tables

List of Figures

C.0 Vulnerability Assessment

Since urban flooding in Managua occurs mostly due to the overflow of channels during heavy rains, some areas of the city are more vulnerable than others. This section assesses vulnerability to urban flooding in three highly vulnerable communities in Managua. This section provides an overview of the selected neighborhoods and the criteria by which they were selected, and also describes in detail the conceptual framework, vulnerability criteria and process by which these communities were assessed and compared. Because these specific areas are considered to represent areas of Managua with some of the highest levels of flood hazard exposure and socio-economic disadvantage, the resulting characterization and understanding of current vulnerability in these communities is important to predict worst-case future increases in vulnerability as a result of current urbanization trends and continued changes in climate.

C.1 Scope

During the capacity-building workshop[1] held in Managua on July 16th, 2013, participants identified the micro-watershed of Oriental-Jagüitas-Cuarezma (OJC) as an area that is particularly vulnerable to urban flooding (See Figure C-1 for a map of micro-watersheds and district boundaries in Managua) and that is considered the most dynamic in terms of potential future land use change[2]. Based on this information, a sample of neighborhoods in District V, within the OJC watershed, was selected for the adaptation process' primary data collection efforts and vulnerability assessment. Three neighborhoods were selected based on the following criteria:

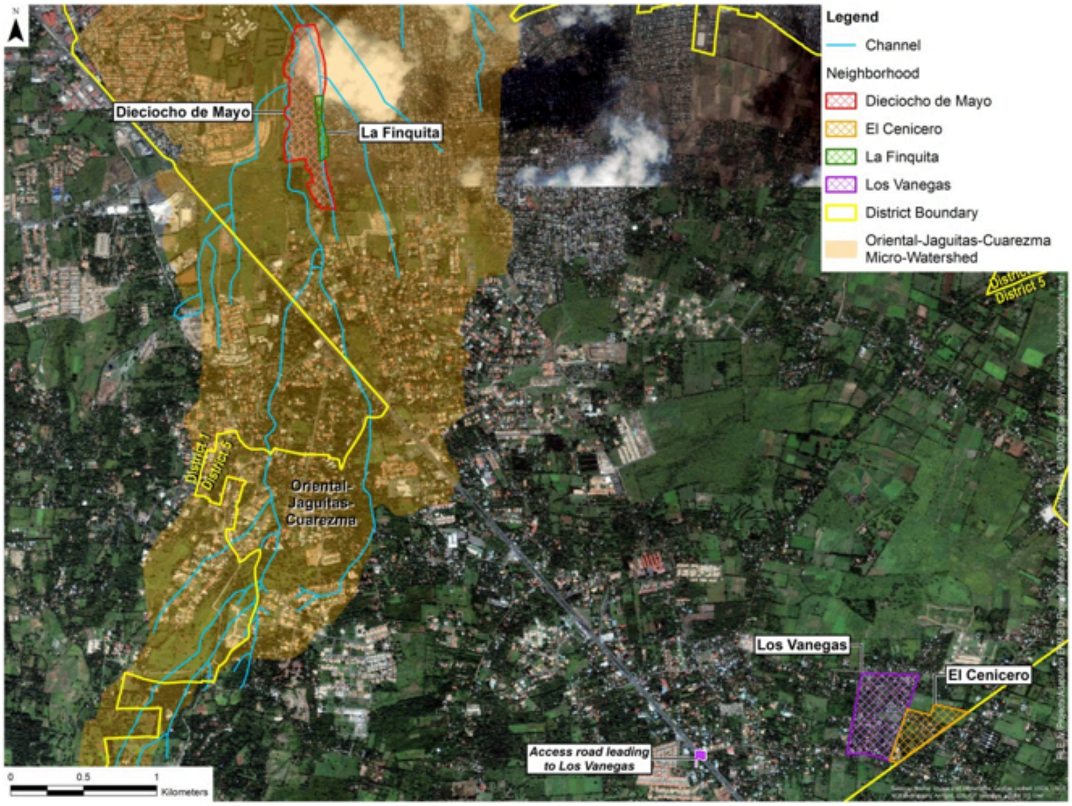
- Representative of different socio-economic classes;
- Located in areas that are considered uniquely vulnerable to the climate change hazard under study (urban flooding); and
- Not located in an area that would present safety concerns for field research teams.

Based on these criteria, the following neighborhoods were selected (see Figure C-1):

1 Participants of the capacity-building workshop included representatives of ALMA, ANA, SINAPRED, INVUR, INETER, ENACAL as well as the IDB.

2 ERM (2013). Memo: First Capacity-Building Workshop Key Outcomes.

Figure C-1: Neighborhoods Included in the Vulnerability Assessment



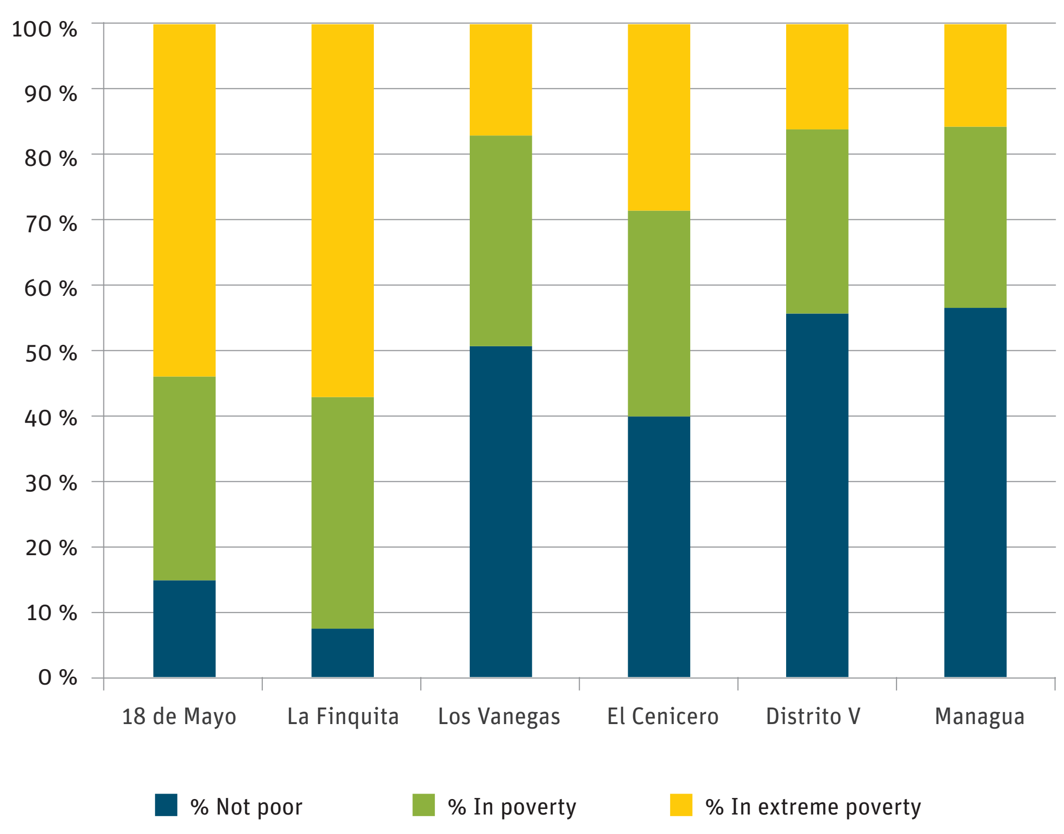
Source: ERM, 2013

- Barrio 18 de Mayo: This community is reported to have been established in 1986 and is classified by ALMA as an informal settlement[3]. As of the 2005 census, the community had 904 households, representing a population of 4,702. It is directly adjacent to the smaller and more recently established community of La Finquita, and shows high rates of poverty, with 54.2 percent of the population considered to be living in extreme poverty at the time of the 2005 census, compared with 16.1 percent in District V and 15.7 percent in Managua as a whole (see Figure C-2).
- La Finquita: This community is also classified as an informal settlement. As of the 2005 census, the neighborhood consisted of 53 households representing a population of 242. The community shows similar patterns of poverty as in the adjacent 18 de Mayo, with 57.1 percent of the population classified as living in extreme poverty.
- Comarcas Los Vanegas and El Cenicero: Although these are classified as distinct neighborhoods, for the purposes of this study these two adjacent semi-rural neighborhoods are assessed as one community.

3 Alcadia de Managua, Dirección de Medio Ambiente y Urbanismo. Datos Poblacionales de Barrios, Distrito 5 (2011).

As of the 2005 census, Los Vanegas and El Cenicero consisted of a combined total of 313 households representing 1,332 people. Poverty levels are lower than in the informal settlements, with 17.3 percent and 28.6 percent, respectively, of Los Vanegas and El Cenicero residents living in extreme poverty. However, rural and semi-rural areas are subject to other vulnerabilities since they are relatively neglected in terms of investments in flood prevention infrastructure[4] and may have poorer geographic access to public services such as health care.

Figure C-2: Percentages of population living in poverty and extreme poverty in the selected neighborhoods



Source: Data from INIDE, 2005. Graphic by ERM.

4 "Comunidades rurales olvidadas". *La Prensa*. November 25, 2013.

To develop an in-depth understanding of the reality experienced by communities at the local level, the social and demographic analysis in this section focuses on indicators at the District V and the neighborhood levels, with less focus on Managua at a broader scale. Given that the three neighborhoods were selected based on a high level of exposure to flood hazards and to high socio-economic vulnerability to the effects of such hazards, it is assumed that conditions in these communities are an accurate representation of the worst-case end of the spectrum of current flooding, future trends and higher climate change risks within Managua.

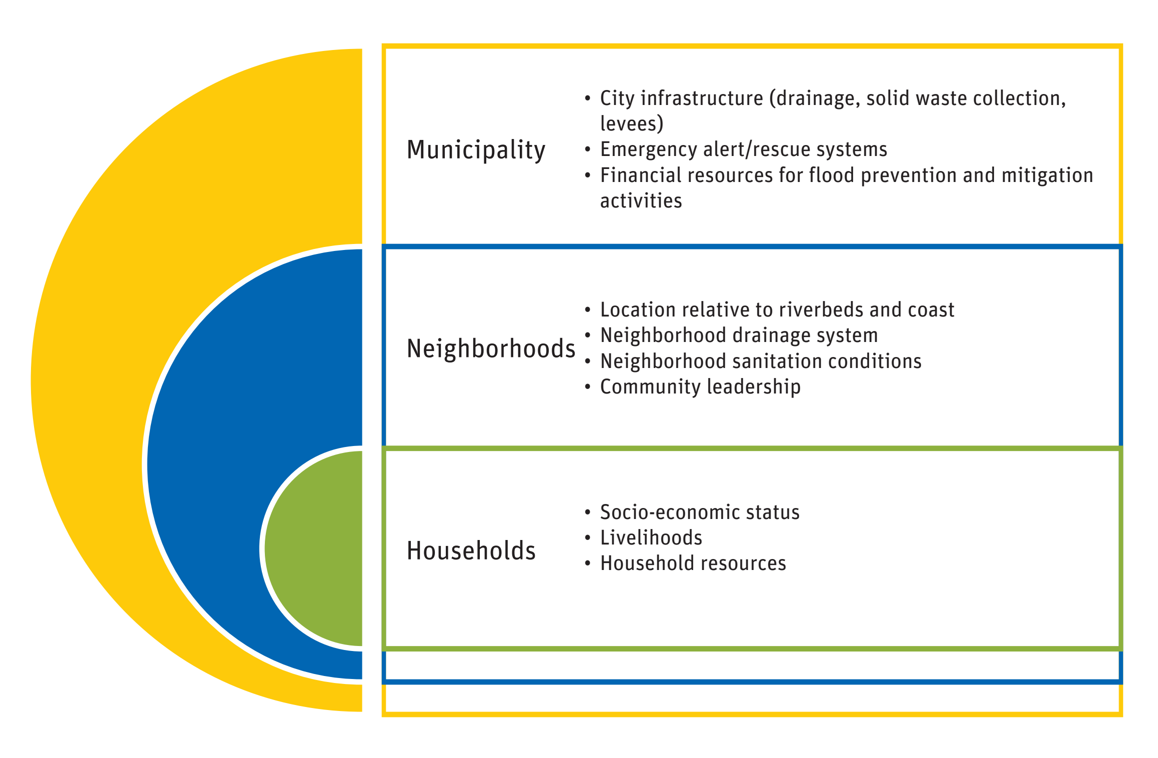
C.2 Factors Contributing to Climate Change Vulnerability in Managua

In addition to the effects of climate change on precipitation patterns, a number of local factors affect vulnerability to urban flooding for populations in Managua. These context-specific factors are discussed below.

C.3 Community-Level Vulnerability Assessment

Indicators of vulnerability to climate change hazards exist at different institutional levels. Figure C-3 illustrates the levels of analysis considered as most relevant in this assessment. Many areas within Managua's footprint are subject to common hydrological vulnerabilities, and most existing flood prevention and mitigation infrastructure and programs are administered at the municipal level. The community and household levels are important since socio-economic conditions play a major role in determining how the population is able to prepare for and respond to hazard events. Although household-level data was not collected as part of this case study methodology, important indicators of household-level conditions such as poverty and overcrowding are rolled up and analyzed at the neighborhood level as part of this assessment.

Figure C-3: Examples of Municipal, Neighborhood and Household-Level Indicators of Vulnerability to Climate Change Hazards



Source: ERM, 2013

C.3.1 Vulnerability Definition and Conceptual Framework

There is no universal definition for vulnerability, but most definitions generally refer to the capacity to be harmed by a source of perturbation or stress[5], and often include consideration for the degree to which the affected receptor or system is able to cope with and recover from the effects of the stressor. Given the absence of a universal definition of vulnerability to climate change hazards, a fit for purpose definition and conceptual framework were developed for the purposes of this case study.

5 Kasperson et al (2005). Vulnerable People and Places. In: Ecosystems and Human Well-Being: Current State and Trends. Millennium Ecosystem Assessment.

In this assessment, vulnerability and capacity are considered to be antithetical concepts that exist on a continuum. An increase in capacity to respond to a hazard or threat is equivalent to a decrease in vulnerability, and vice versa. The overall measure of capacity/vulnerability to climate change hazards in this case study is conceptualized as comprising the following four factors[6]:

1. A receptor's[7] level of exposure to the hazard. Measures or infrastructure in place to reduce exposure (e.g. levees, drainage systems) are referred to as *protective capacity;*
2. The receptor's level of ability to cope with the hazard through measures, resources or abilities such as emergency evacuation procedures, monetary resources to purchase water and food reserves, and good physical health and mobility to avoid injury. This is referred to as *coping capacity*;
3. The ability of the receptor to return to normal conditions as quickly as possible and with as few negative impacts as possible. Measures, resources or abilities that facilitate this include emergency clean-up and sanitation processes, and access to health services. This is referred to as *recovery capacity; and,*

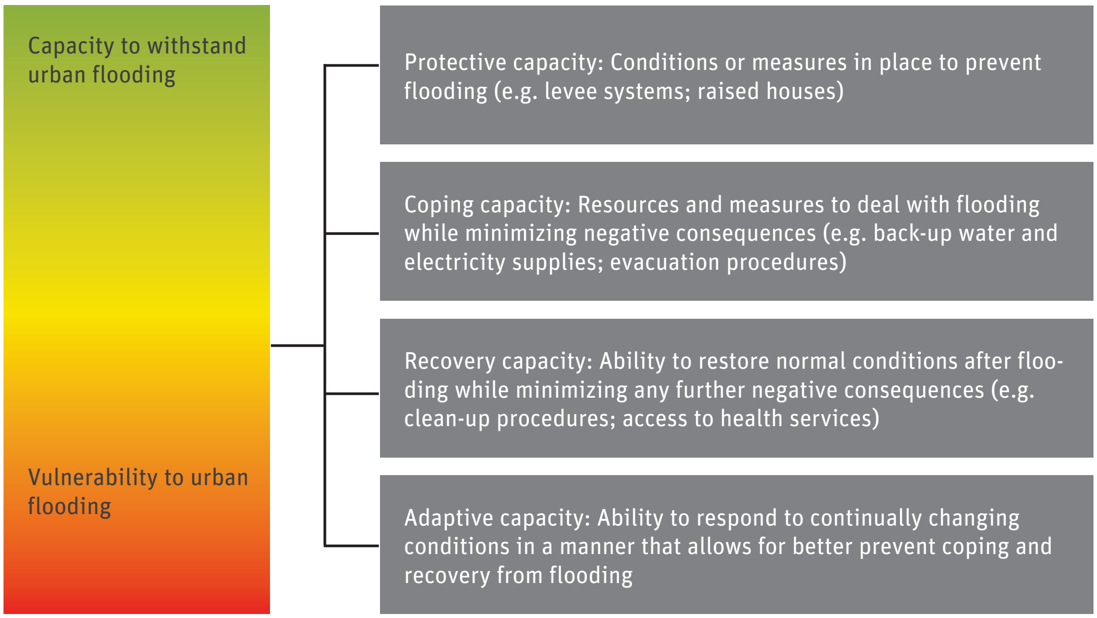
The ability of the receptor to anticipate and reduce harm from uncertain and changing conditions that could bring about new and different scenarios in the future. This is referred to as *adaptive capacity*. Examples of good adaptive capacity include institutional flexibility to mobilize resources and change program priorities rapidly, access to good sources of information for informed decision-making, and diversity in crops and farming methods that will withstand a range of different climatic conditions.

Figure C-4 illustrates the conceptual framework for inland flooding capacity/vulnerability as defined in this study. Any increase in any of the four components contributes to higher overall capacity to the hazard, which is equivalent to a proportional decrease in vulnerability.

6 De Graaf, R.E. (2008). Reducing flood vulnerability of urban lowland areas. *11th International Conference on Urban Drainage.* Edinburgh, Scotland.

7 In this assessment, "receptors" refer to communities, households or individuals exposed to flood risk

Figure C-4: Capacity/Vulnerability Conceptual Framework

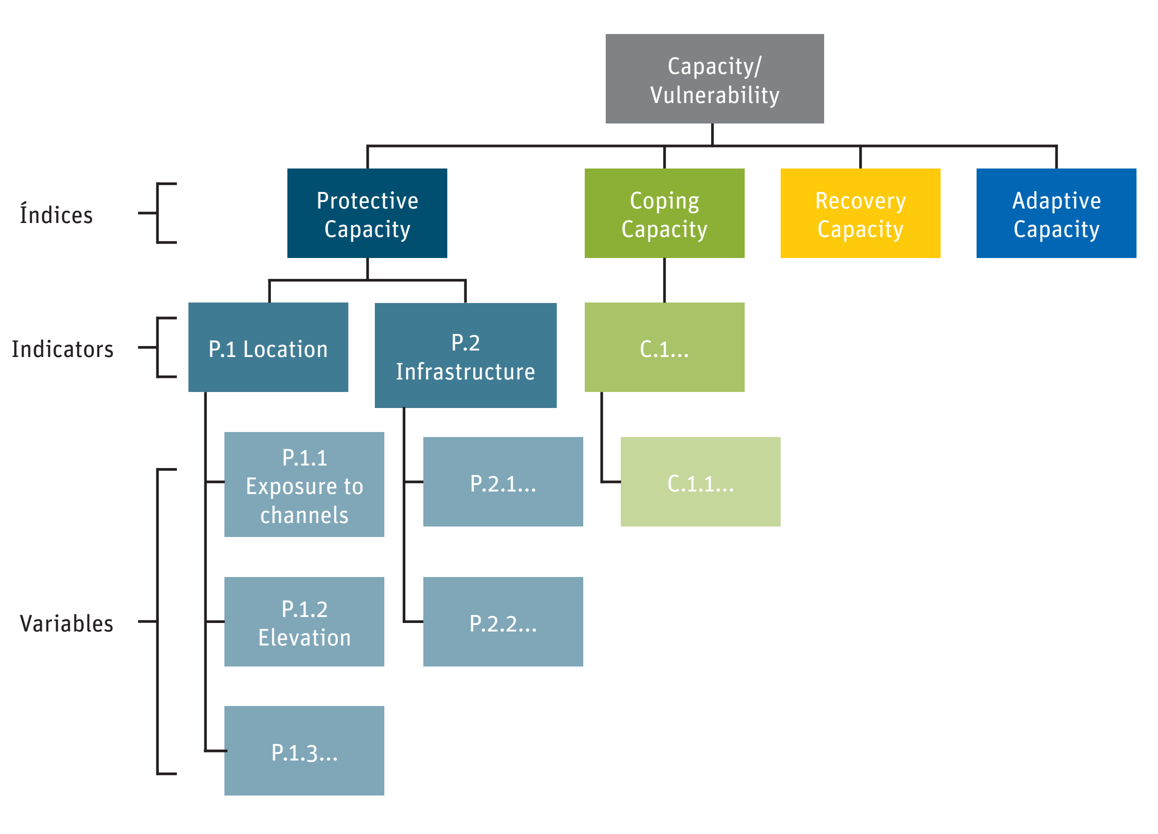


Source: ERM, 2013 adapted from De Graaf, 2008.

C.3.2 Development of Vulnerability Assessment Criteria

To consistently characterize and compare vulnerability among the three selected neighborhoods, we developed a set of standardized criteria used to calculate an overall capacity/vulnerability index for each neighborhood. Sub-indices were developed to characterize protective capacity, coping capacity, recovery capacity and adaptive capacity at the neighborhood level, and scores were then combined to arrive at a composite measure of overall capacity/vulnerability as per the study's working conceptual definition. Each sub-index is composed of indicators that are in turn comprised of variables. Figure C-5 below illustrates the hierarchy and nomenclature used to develop the vulnerability assessment criteria for this case study.

Figure C-5: Hierarchy and Nomenclature Used in Development of Community Capacity/Vulnerability Assessment Criteria



Source: ERM, 2013

The indices, indicators and variables were selected based on a review of climate change literature, other vulnerability assessments and frameworks, and information from key informant interviews and community focus groups. This integration of information sources ensures that the selected assessment criteria represent standard indicators for assessing climate change vulnerability, but are also appropriate and relevant to the context and reality of urban Managua communities. The list of final indicators is presented in Table C-1.

Table C-1: Vulnerability Assessment Criteria

Indicator	Variable	Scoring Criteria
Protective Capacity		
Location	Exposure to channels	[0] 0% of neighborhood area [1] 0.1-3% of neighborhood area [2] 3.1-5% of neighborhood area
	Elevation	[0] >300 m [1] 200-299 m [2] <199 m
Infrastructure	Permanent flood prevention infrastructure	[0] Yes [1] No
	Percentage of households living in inadequate dwellings	[0] Less than 10% [1] Between 10% to 49% [2] More than 50%
Sanitation	Percentage of households with potable water	[0] More than 80% [1] Between 50% to 79% [2] Less than 50%
	Connection to drainage system	[0] Yes [1] No
	Unsanitary conditions in neighborhoods (e.g., trash accumulations, stagnant water)	[0] Clean [1] Some litter [2] Lots of litter
Coping Capacity		
Socioeconomic Status	Percentage employed on a permanent, full-time basis	[0] More than 80% [1] Between 79% and 30% [2] Less than 30%
	Percentage of female-headed households	[0] Less than 15% [1] Between 16% and 30% [2] More than 30%
	Percentage of families in extreme poverty	[0] Less than 20% [1] Between 21% and 50% [2] More than 50%
Transportation	Access to own means of transportation (majority)	[0] Yes [1] No
	Paved roads	[0] Yes [1] No
Dependent Populations	Households with disabled members	[0] Less than 2% [1] Between 2 and 5% [2] More than 5%
	Households with children under 15 years of age	[0] Less than 20% [1] Between 21% and 50% [2] More than 50%
Emergency Procedures	Has an emergency evacuation process been communicated within the community?	[0] Yes [1] No
	Is there an emergency shelters available in the vicinity?	[0] Yes [1] No

Indicator	Variable	Scoring Criteria
Recovery Capacity		
Access to Health Service	Distance to nearest health center	[0] Less than 2 km [1] Between 2 and 5 km [2] More than 5 km
Sanitation and Cleanup Capacity	Have cleanup procedures been communicated and implemented within the community?	[0] Yes [1] No
	Sanitation emergency response plan in place to minimize public health consequences in the wake of disasters	[0] Plan in place [1] Plan not in place
Adaptive Capacity		
Institutions, coordination and leadership	Local government capacity and resources	[0] Well-resourced and efficient [1] Lacking in resources and effectiveness
	Inter-institutional and inter-municipal coordination	[0] Highly coordinated [1] Moderately coordinated [2] Lacking coordination
	External cooperation	[0] Good support from international organizations [1] Moderate support [2] Lack of support
Long-term flood prevention planning (municipal)	Community-level flood prevention/mitigation planning	[0] Effective measures in place [1] some measures in place [2] No measures in place
	Municipal-level flood prevention/mitigation planning	[0] Yes [1] No

Source: ERM, 2013

Data inputs for the assessment matrix were derived from the most recent national population census (2005), from primary data collected during field visits, and from secondary sources such as municipal plans and studies. The majority of this data is at the neighborhood level, but municipal-level data is also incorporated where relevant (for example, in characterizing evacuation and infrastructure planning, which occurs at the municipal level).

C.3.3 Assessment Results

After populating the assessment matrix with variable data, totals for each of the four indices were normalized and summed so that each of the four components (protective capacity, coping capacity, recovery capacity and adaptive capacity) are equally weighted in the overall capacity/vulnerability score. A higher score corresponds to a higher level of vulnerability and therefore lower capacity. Table C-2 summarizes the index and overall capacity/vulnerability scores for the three study neighborhoods.

Table C-2: Completed Vulnerability Assessment Scoring Matrix

Index	*Indicator*	*Variables*	*Barrio 18 de Mayo*	*La Finquita*	*Los Vanegas/ El Cenicero*	*Total Possible Score*
Protective Capacity	P.1. Location	P.1.1 Exposure to channels	1	2	0	**2**
		P.1.3. Elevation	2	2	2	**2**
	P.2. Infrastructure	P.2.1 Permanent flood prevention infrastructure (e.g. walls, elevated homes)	1	1	0	**1**
		P.2.2 Inadequate dwelling	1	1	1	**2**
	P.3. Sanitation	p.3.1 Percent of households with potable water	2	2	0	**2**
		P.3.2 Connection to drainage system	1	1	1	**1**
		P.3.4 Unsanitary conditions in neighborhood (garbage)	2	2	1	**2**
	PROTECTIVE VULNERABILITY		10	11	5	**12**
	NORMALIZED		0.83	0.92	0.42	**1**
Coping Capacity	C.1. Socio-economic status	C.1.1 Permanent employment	2	2	2	**2**
		C.1.2 Female-headed household	2	2	1	**2**
		C.1.3 Extreme poverty	2	2	1	**2**
	C.2 Transportation	C.2.1 Own means of transportation (majority)	1	1	1	**1**
		C.2.2 Paved roads	1	1	1	**1**
	C.3 Dependent populations	C.3.1 Households with disabled members	1	0	1	**2**
		C.3.2 Children <15 years	1	1	1	**2**
	C.4. Emergency Procedures	C.4.1 Evacuation processes in place	0	0	0	**1**
		C.4.2 Sufficient emergency shelters available	0	0	0	**1**
	COPING VULNERABILITY TOTAL		10	9	8	**14**
	NORMALIZED		0.71	0.64	0.57	**1**
Recovery Ca	R.1. Health service accessibility	R.1.1 Distance to nearest hospital	0	0	1	**2**
	R.2. Sanitation and clean-up	R.2.1 Community-level clean-up processes in place	1	1	1	**1**
		R.2.2 Sanitation emergency response plan in place to minimize public health consequences in the wake of disasters	0	0	0	**1**
	RECOVERY VULNERABILITY TOTAL		1	1	2	**4**
	NORMALIZED		0.25	0.25	0.5	**1**
Adaptive Capacity	A.1 Institutions, coordination and leadership	A.1.1 Local government capacity and resources	1	1	1	1
		A.1.2 Inter-institutional and inter-municipal coordination	2	2	2	2
		A.1.3 External cooperation	0	0	0	2
	A.2 Long-term flood prevention planning (municipal)	A.2.1 Community-level flood prevention/mitigation planning	2	2	2	2
		A.2.2 Municipal-level flood prevention/mitigation planning	0	0	1	1
	ADAPTIVE VULNERABILITY TOTAL		5	5	6	**8**
	NORMALIZED		0.625	0.625	0.75	**1**
OVERALL VULNERABILITY SCORE (Scale of 4)			***2.42***	***2.43***	***2.24***	**4**

Source: ERM, 2013

Assessment results indicate that while the overall vulnerability scores do not differ significantly among the three selected neighborhoods (range of 2.24 to 2.43 on a scale of 4.0), there are considerable differences in the contributing factors, most notably the urban barrios of La Finquita and Barrio 18 de Mayo relative to the more rural area of Los Vanegas/El Cenicero. La Finquita and 18 de Mayo have low protective and coping capacity relative to Los Vanegas/ El Cenicero due to their proximity to channels that overflow during heavy rains, and high rates of poverty which leave residents with limited resources and capacity to invest in flood prevention infrastructure and to cope with negative effects of flooding. On the other hand, Los Vanegas and

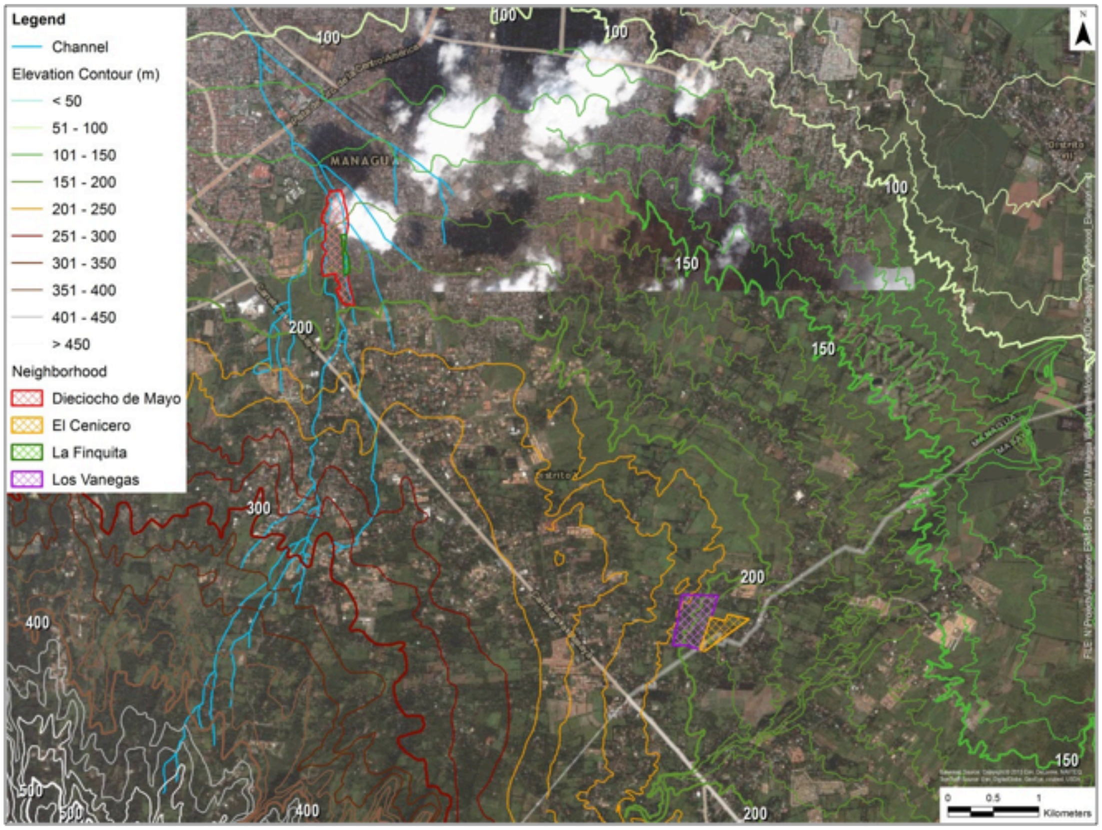
El Cenicero do not have natural water bodies within the neighborhoods, have lower rates of poverty and appear to have better household-level flood prevention infrastructure. However, these communities have relatively low recovery and adaptive capacity due to their more remote location outside of the city center. Distances to the nearest hospitals are longer, and municipal investments in infrastructure are less likely to be channeled to these outlying areas[8].

A qualitative overview of the study communities' vulnerability characteristics is provided below.

Protective Capacity

As expected, the three study neighborhoods have high levels of vulnerability in terms of their exposure to flooding as a result of relatively low elevation (all at less than 200 m – see Figure C-6).

Figure C-6: Elevation of Selected Neighborhoods and Surrounding Areas



Source: ERM, 2013

8 "Comunidades rurales olvidadas". *La Prensa*. November 25, 2013.

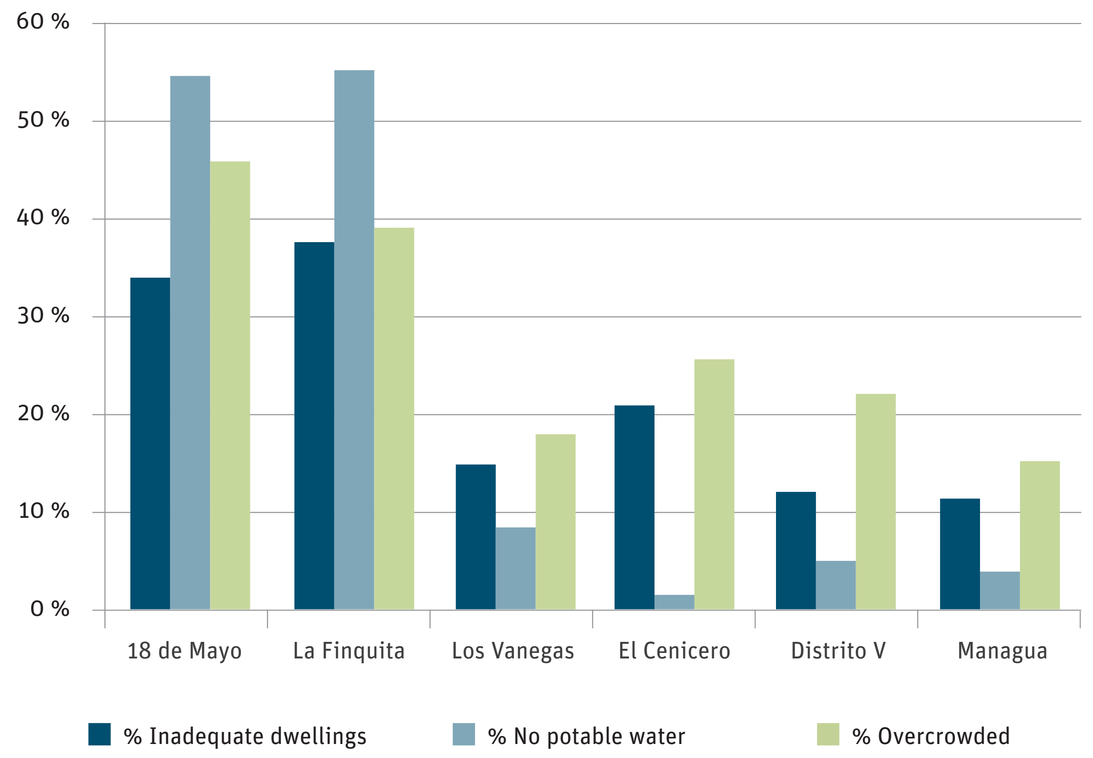
La Finquita and 18 de Mayo are also vulnerable due to their proximity to channels that overflow frequently, and a lack of adequate protective infrastructure at the household level. Residents in these informal settlements are generally only able to afford temporary prevention measures such as piling up dirt around house perimeters or using sandbags, tires or concrete tiles to create low walls or barriers (see Figure C-7, top two and bottom left photos). On the other hand, in Los Vanegas some instances of more costly, long-term solutions like building permanent walls or raising homes above the flood line were observed (Figure C-7, bottom right).

Figure C-7: Flood Prevention Barriers in the Selected Neighborhoods

Source: J. Cisneros, 2013

Census data indicates that relative to overall rates in District V and Managua, the three selected neighborhoods have relatively high percentages of dwellings that are classified as "inadequate", due to lack of access to potable water, and/or are overcrowded[9] (Figure C-8). In all three neighborhoods residents also reported inadequate drainage and unsanitary conditions due to trash in the channels, contributing to a lower protective capacity.

Figure C-8: Selected Housing Characteristics, by Neighborhood



Source: INIDE, 2005

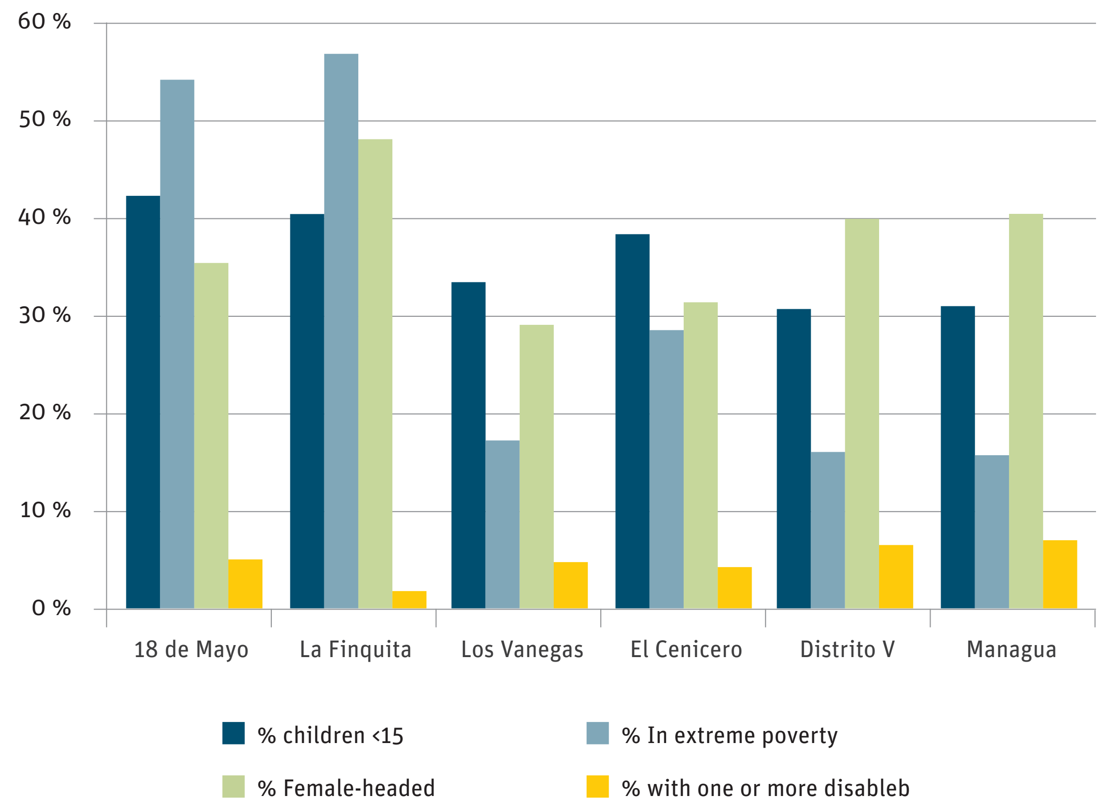
Coping Capacity

Census data indicates high levels of poverty in the study neighborhoods, particularly in the urban informal settlements of Barrio 18 de Mayo and La Finquita (see Figure C-9). Poverty greatly amplifies the negative effects of urban flooding. All of the study neighborhoods also have relatively high percentages of youth below age 15. This is relevant from a socio-economic perspective since youth are likely to be financially dependent on the head of household. This factor is also important because children may have strength and mobility limitations during emergencies requiring evacuation.

9 Defined as households in which three or more people sleep in one room.

Of the selected neighborhoods, only La Finquita has a higher percentage of female-headed households than the overall District or municipal rates, and all three neighborhoods have a lower percentage of households with disabled members than at the District and municipal levels[10].

Figure C-9: Selected Household Socio-Demographic Characteristics, by Neighborhood



Source: INIDE, 2005

Community focus groups and field observations indicate that few residents of the study neighborhoods have access to personal vehicles, and neighborhood roads are unpaved. As a result, mobility is restricted during heavy rains, greatly impacting residents' ability to cope with negative effects.

10 Instituto Nacional de Información de Desarrollo (2005). Principales Indicadores de Población al Menor Nivel de Desagregación Geográfica.

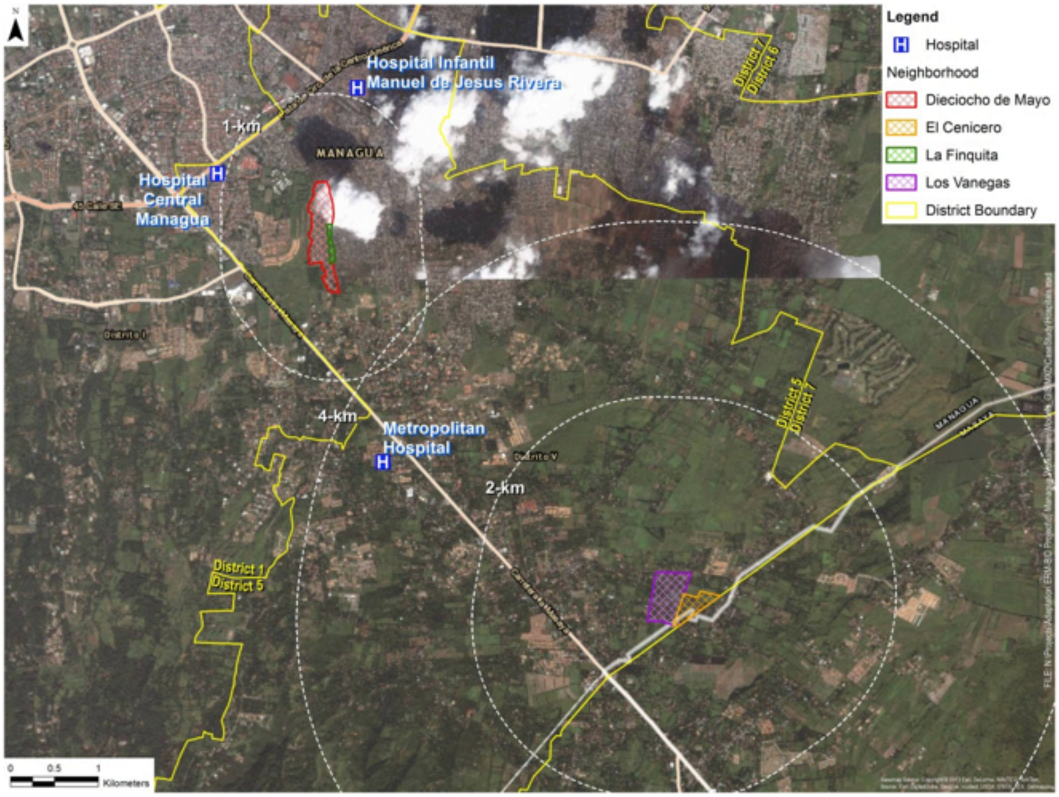
However, coping capacity in terms of evacuation planning is considered to be strong in the municipality as a whole since the national military has formulated an emergency evacuation plan for Managua that identifies households in high-risk areas, resources to be mobilized in the event of an evacuation order, and an adequate level of temporary shelter capacity.

Recovery Capacity

Recovery from flood events without any further adverse effects is often dependent on rapid sanitation response and access to health services.

Relative to other departments in the country, Managua has a high ratio of health facilities and health care workers to population[11]. As the capital city, it is home to the highest concentration of hospitals, including national reference and specialty hospitals. Mapping of distances from the study neighborhoods to the nearest hospital indicates that all study neighborhoods are within 5 km of a hospital (see Figure C-10). This is important since residents report that health issues such as dengue fever sometimes occur after flood events, and the majority of residents do not have their own vehicles.

Figure C-10: Closest Hospitals to the Selected Neighborhoods



Source: ERM, 2013

11 PATH (2011). *The Nicaraguan Health System: An overview of critical challenges and opportunities.*

Managua's Ministry of Health (MINSA) published a Local Emergency Sanitation Plan in 2003, indicating proactive efforts to ensure that disaster events such as flooding to not lead to public health disasters. However, community focus groups and field observations indicate a lack of neighborhood-level organization and planning for post-flood clean up and sanitation.

Adaptive Capacity

Observations in the three selected neighborhoods suggest that little, if any organized flood prevention and mitigation activity is occurring at the neighborhood level. This is evident in the makeshift and temporary nature of the majority of preventative measures employed by barrio residents as depicted above. The state of the channels in the barrios (unmaintained and full of trash) also indicates a lack of community-level action.

The index for adaptive capacity includes municipal-level indicators as well as *barrio*-level, since institutions and resources are most likely to be available at the municipal level for flood prevention and mitigation activities.

A general municipal development plan published by ALMA identifies insufficient empowerment of local governments and lack of inter-municipal coordination as key risks for the municipality[12]. However, external support from international organizations is strong in Managua and contributes significantly to adaptive capacity[13].

ALMA has an annual investment plan that documents critical areas requiring repair of drainage infrastructure in order to prevent flooding, as well as other infrastructure projects needed to mitigate negative effects currently experienced by victims of flooding (e.g. construction of new homes and footbridges to replace structurally unsound ones). However, the majority of projects outlined in the plan are in urban neighborhoods, including several in Barrio 18 de Mayo. The semi-rural areas of Los Vanegas and El Cenicero are not earmarked for improvements, and recent newspaper articles indicate that the lack of attention and resources channeled to these communities has been an ongoing concern[14,15].

C.3.4 Unplanned Urban Growth

Unplanned urban growth has increased Managua's vulnerability to natural disasters. After the earthquake of 1972, Managua has grown in a disorganized manner, with informal settlements emerging in places that are unfit for residential use. Some of the most important challenges are a lack of adequate construction practices, environmental degradation, including destruction of natural drainage and flood protection areas, poor sanitation and transport infrastructure, and a lack of adequate public spaces. Managua's General Municipal Development Plan also highlights continued geographic segregation of different socio-economic classes as a negative consequence of unplanned urban growth[16].

12 Alcadía de Managua (n.d.). Plan General de Desarollo Municipal.
13 Alcadía de Managua (n.d.). Plan General de Desarollo Municipal.
14 "Comunidades rurales olvidadas". *La Prensa*. November 25, 2013.
15 "Los Vanegas, tierra de nadie". *La Prensa*. August 12, 2012.
16 Municipality of Managua. Plan General de Desarollo Municipal.

C.3.5 Stormwater Drainage System

Urban growth in Managua is overloading the stormwater drainage system and affecting the quantity and quality of water feeding the aquifers[17], putting the city's drinking water supply at risk. Moreover, the sediment and solid waste conveyed in the drainage system exposes the lower watershed areas to flooding in the rainy season, and the absence of basic services in informal settlements causes wastewater to enter the stormwater system. Polluted water subsequently leaks into the aquifer or flows into Lake Managua.

C.3.6 Housing Availability and Cost

Population growth in Managua has greatly increased the demand for housing. During community focus groups, respondents expressed that they would like to leave their neighborhoods and move to less flood-prone areas, but that it is not an option since they do not have the economic resources to purchase a home in such an area.

C.3.7 Infrastructure and Public Services

Managua is home to approximately 20% of Nicaragua's population. Rapid population growth in the last decades has created challenges for keeping pace with infrastructure and service needs, such as road maintenance and provision of adequate sewage, potable water, electricity, storm water drainage and solid waste management services to city residents. In all three of the neighborhoods included in the scope of this assessment, roads are unpaved and there are no connections to a public drainage system. While the city provides solid waste collection in these areas, residents must bring their trash to the entrance of the barrios for pick-up since large vehicles such as garbage trucks cannot safely access through the unpaved dirt roads.

ALMA has an annual investment plan that lists flood prevention infrastructure that is considered as a priority for upgrade or repair; however, it is evident that the municipality cannot keep pace with needs since key informants and residents of the selected neighborhoods note that drainage systems in many areas of Managua are insufficient. During field visits, infrastructure such as footbridges and sidewalks in and around study neighborhoods were observed to be in need of repair (See Figure C-11).

17 The 180-square-km Subwatershed III is the principal area for recharging the aquifer that provides 60 percent of Managua's drinking water.

Figure C-11: Neighborhood Infrastructure in Need of Repair in the Study Communities

Source: J. Cisneros, 2013

C.3.8 Sanitation and Public Health

In two of the selected neighborhoods, rates of extreme poverty are high and as a result high percentages of the population (>40%) live in overcrowded conditions (more than three people per bedroom) or in dwellings that are considered to be inadequate (>30%)[18]. The *barrios* were also observed to have problems with both stormwater drainage and solid waste removal, with litter present in the streets and creating blockages in the channels (see Figure C-12).

Living in unsanitary and overcrowded conditions of this nature poses infectious disease risks, which in turn can be amplified as a result of climate change effects. For example, heavier rains can increase the amount of time that water remains pooled around human residences, providing optimal breeding environments for the mosquito species that acts as the primary vector for dengue fever (*Aedes aegypti*)[19]. Molds and fungi also thrive in flooded environments, which can cause skin and respiratory issues[20]. Contact with floodwaters contaminated with sewage can cause skin problems and infections, or outbreaks of diarrheal diseases such as cholera and rotavirus if contamination of potable water sources occurs[21].

18 INIDE (2005). *VIII Population Census and IV Household Census.*
19 Centers for Disease Control and Prevention (2012). Dengue: Entomology and Ecology.
20 National Safety Council (2009). Air Quality Problems Caused by Floods. Available at: http://www.nsc.org/news_resources/Resources/Documents/Air_Quality_Problems_Caused_by_Floods.pdf
21 Occupational Health and Safety Administration. Fact Sheets on Natural Disaster Recovery (n.d.). Available at: https://www.osha.gov/OshDoc/floodCleanup.html

Figure C-12: Housing and Sanitation Conditions in the Study Neighborhoods

Source: J. Cisneros, 2013

Moreover, these pathogens and vectors of infectious disease are likely to thrive as temperatures increase as a result of climate change.

Focus group participants in the study neighborhoods reported experiencing dengue fever, respiratory illnesses, cough, flu, fungal infections and skin irritation after flood events.

Annex D:

Detailed Model Results for Three Micro-Watersheds in Managua

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Table of contents

List of Tables

List of Figures

D.0 Results for Selected Micro-Watersheds in Managua

As discussed in Section 1.2 of the main document, four urban micro-watersheds – Primavera, Hugo Chavez, Nejapa, and Oriental-Jagüitas-Cuarezma – were preliminary selected by stakeholders as the focus of ERM's analysis of urban flooding. Following the presentation of preliminary results during the July 2013 workshop held in Managua, ALMA proposed to focus the subsequent analyses only on the Oriental-Jagüitas-Cuarezma (OJC) micro-watershed, since this was viewed as the most dynamic of the four in terms of its potential for future land use change, as well as for containing the largest number of current critical flooding hot spots.

As a result of this agreement, ERM defined and modeled potential adaptation measures for the OJC watershed only. This annex provides the results of the technical model-based simulations ran for Primavera, Hugo Chavez, and Nejapa, which were presented to stakeholders in the July 2013 workshop.

D.1 Methodology

To evaluate the behavior of stormwater, ERM employed two separate, but related, hydrological modeling packages: HEC-HMS[1] and HEC-RAS[2]. When used in combination, the hydrologic and hydraulic models support the identification of areas currently at risk of flooding and the prediction of future risks on the basis of changes to land use and climate.

The hydrologic model (HEC-HMS) component describes the watershed response to precipitation, expressed as peak flows and hydrographs. The hydraulic model (HEC-RAS) component simulates the peak flows and hydrographs generated in the previous step based on existing drainage infrastructure, such as channels that convey stormwater. Section D.2 provides a brief overview of the models.

In addition to the Oriental-Jagüitas-Cuarezma model, described in the main document, models were set up to study the hydrological behavior of three micro-watersheds in the city: Hugo Chavez, Primavera, and Nejapa[3]. For each, ERM simulated the results of 25-, 50-, and 100-year storm events under four different scenarios, which reflect existing and projected land use and climate conditions.

The methodological steps undertaken by ERM to perform the model-based hydrological analysis are summarized below:

1. **Data Collection.** At an initial stage, the ERM and IDB teams met with ALMA and several local stakeholders, mainly from agencies and ministries that play a role in managing water resources, or in the prevention or response to flooding events. During these meetings, the scope of the Project was defined and key relationships for information sharing were established. ERM then focused data collection efforts in obtaining inputs relevant to the hydrological analysis. This information included geographical, meteorological, hydrological, demographic, socioeconomic, land use, and of risk and vulnerability to flooding.

1 US Army Corps of Engineers. 2010. Hydrologic Modeling System HEC-HMS. User's Manual Version 3.5. August 2010. US Army Corps of Engineers. Hydrologic Engineering Center. http://www.hec.usace.army.mil/software/hec-hms/

2 Water Resources Hydrologic Engineering Center. http://www.hec.usace.army.mil/software/hec-ras/

3 As discussed earlier, these areas were recommended by ALMA on the basis of natural disaster risk study developed by the City of Managua, which had identified these as critical flood locations in 2004.

2. **Prediction of Future (2050) Land Use Scenario**. To predict future hydrological risks, land use projections for the 2050 horizon were made based on historical trends, with the purpose of projecting the change of surface impermeability of the micro-watersheds. **Annex B** describes the methodology developed for determining the future land use scenario for Managua.

3. **Selection of Future (2050) Climate Change Scenario**. ERM compiled and assessed the projections generated by regional climate models and selected key model input parameters (e.g., air temperature, precipitation intensity and total rainfall), which were consistent with projections recognized by the relevant Nicaraguan governmental agencies. **Section 3.1** of the main document provides a brief overview of the regional models that were reviewed and indicates which climatological variables were employed in the hydrological and hydraulic models.

4. **Evaluation of Existing and Future Flooding Risk.** Once the models were set up with the relevant hydrological, meteorological and land use inputs, the next step involved evaluating the effect of 25-, 50- and 100-year precipitation events. To assess the relative contribution of land use and climate change to future flood risk, ERM ran the models under the following scenarios:

Scenario	Abbreviation	Explanation
Existing Conditions (EC)	EC	This baseline scenario reflects a snapshot of the present based on current observed land use patterns and present-day hydrological conditions, constructed on the basis of historical weather information.
Existing Land Use with Climate Change (CC)	CC	Represents a static scenario of land use whereas hydrological conditions continue to be influenced by climate change throughout the 2050 horizon. This scenario allows the analysis of the relative contribution of climate change to the magnitude of stormwater related events.
Future Land Use Change (LUC) without Climate Change	LUC	This scenario assumes current climate conditions will stay the same in the future, but land use will continue to evolve as a result of demographic and economic drivers. This scenario emphasizes the contribution of land use changes, specifically those that translate to loss of permeable cover, in the increase of stormwater runoff.
Future Scenario with Climate Change and Land Use Change	CC & LUC	This scenario intends to reflect the combined effects of land use change and climate change on the magnitude and risk related to stormwater events.

Section D.4 presents the modeling results expressed in terms of peak flows for various return periods (i.e., 25-, 50-, and 100-year precipitation events). A peak flow is the highest volume of water passing through a given point along a drainage channel, and is indicative of the risk of flooding. Comparison of peak flows across the different modeled scenarios yields insights related to the incremental effect of climate change and/or land use change on the flood risk profile in 2050.

5. **Evaluation of Adaptation Strategies**. As the results from the modeling emerge, it becomes clear that existing urban flooding issues are likely to worsen in the business-as-usual scenario (**CC&LUC**). The final step in the assessment of flooding exposure risk is to identify suitable types of mitigation/adaptation measures, and test their effectiveness in the models. As mentioned earlier, this step was not performed for Primavera, Hugo Chavez, and Nejapa. The formulation of adaptation strategies focused only on the Oriental-Jagüitas-Cuarezma micro-watershed as described in **Section 6** of the main document.

D.2 Model Overview

The selection of models was made based on the availability of model input data, the level of analysis required, and the key factors that drive adaptive measure selection. In addition to meeting these criteria, ERM selected HEC-HMS given that it was designed to be applied in small urban watersheds[4], so it was highly compatible with the scope of the urban flooding risk analysis.

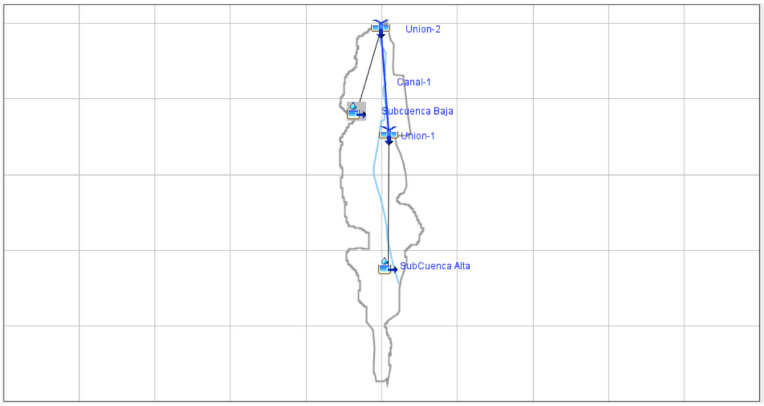
HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. When the hydrological characteristics of a given watershed are programmed into the model, HEC-HMS predicts the watershed response to precipitation. Figure D-1 illustrates the conceptual layout of the modeled micro-watersheds.

HEC-HMS estimates the peak flows associated with pre-determined return periods, i.e., 25-, 50-, and 100-year precipitation events. These peak flows were then routed through the streets and existing stormwater drainage infrastructure using HEC-RAS (Version 3.1) to predict flood depths for each return period. Figure D-2 illustrates a stormwater channel sketch built in HEC-RAS for the main channel in Hugo Chavez.

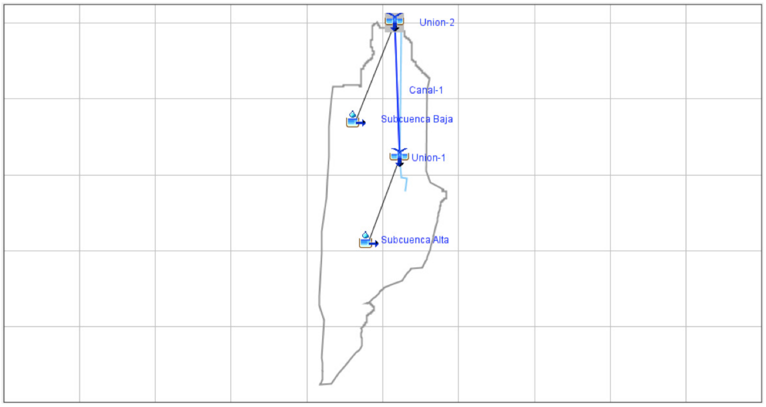
4 Further, HEC-HMS can also be applied to water availability studies, urban drainage analyses, flow monitoring, impact analysis of watershed interventions, flood damage reduction, etc.

Figure D-1: HEC-HMS model layouts for the three micro-watersheds Primavera

Primavera



Hugo Chávez



Nejapa

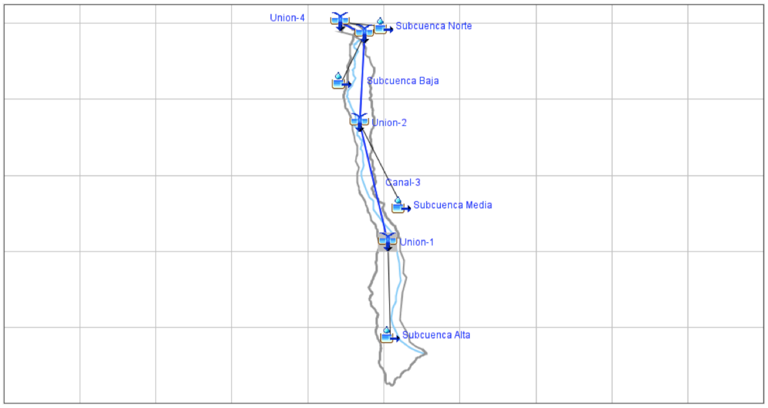
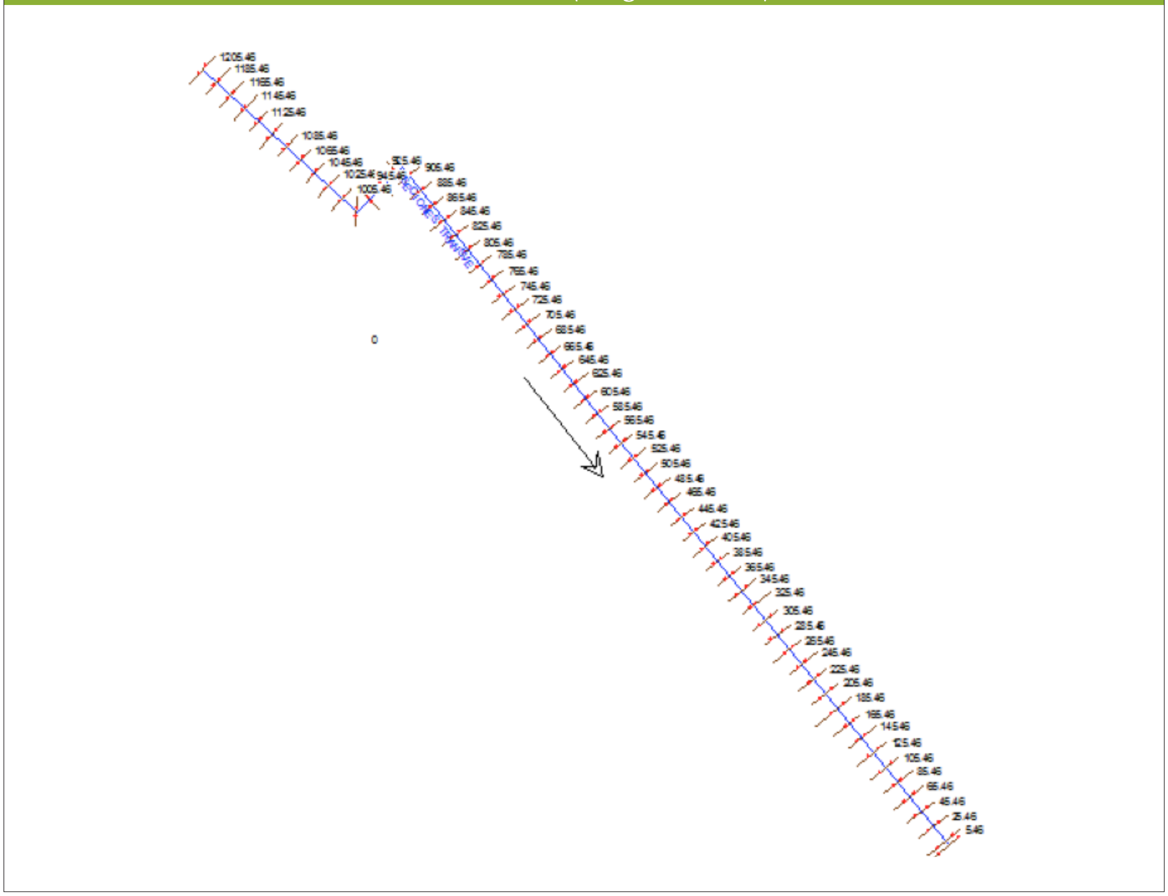


Figura D-2: Ejemplo de un diseño (layout) del canal de drenaje en HEC-RAS (Hugo Chávez)



Source: Adapted from Estudio de Riesgo

D.3 Hydrologic Model Results

This section presents the modeling results for Primavera, Hugo Chavez, and Nejapa, organized according to the land use and climate change scenarios chosen for the analysis. Results are mainly expressed peak flows for the pre-determined return periods.

D.3.1 Scenario 1: Existing Conditions (EC)

The baseline scenario of existing climate conditions and land use characteristics was developed according to historical data mainly obtained from the Nicaraguan Institute of Territorial Studies (INETER), the Ministry of Agriculture and Forestry (MAGFOR), and ALMA.

Table D-1 presents the peak flows for the three micro-watersheds and three return periods under the EC scenario.

Table D-1: Peak Flows under Scenario 1 - Existing Conditions

Micro-watershed	Junction	Return Period (years)	Peak Flow (m^3/s)
Hugo Chávez	Unión-2	25	31.3
Hugo Chávez	Unión-2	50	35.6
Hugo Chávez	Unión-2	100	40.1
Primavera	Unión-2	25	28.9
Primavera	Unión-2	50	32.8
Primavera	Unión-2	100	36.9
Nejapa-Norte	Unión-4	25	29.9
Nejapa-Norte	Unión-4	50	31.6
Nejapa-Norte	Unión-4	100	33.4
Nejapa-Sur (Baja)	Unión-3	25	29.5
Nejapa-Sur (Baja)	Unión-3	50	31.2
Nejapa-Sur (Baja)	Unión-3	100	33.0

Note: Union (junction) is an element with one or more inflows and only one outflow in the HEC-HMS model.

The peak flows presented in Table D-1 were used as input values for the HEC-RAS hydraulic model. Table D-2 presents the hydraulic parameters (total average width and average channel depth) generated by the HEC-RAS hydraulic model. These hydraulic parameters are average values of all cross sections used in the HEC-RAS hydraulic model for different return periods (25-, 50- and 100-year events).

Table D-2: Hydraulic parameters of the channels modeled under Scenario 1

System	Return Period (Years)	Average Total Width (m)	Average Depth of the channel (m)
Hugo Chávez	25	27.7	0.87
Hugo Chávez	50	29.0	0.93
Hugo Chávez	100	30.2	0.99
Primavera	25	46.1	1.36
Primavera	50	46.2	1.42
Primavera	100	46.4	1.48
Nejapa	25	22.6	0.80
Nejapa	50	23.3	0.82
Nejapa	100	24.6	0.84

D.3.2 Scenario 2: Existing Land Use with Climate Change (CC)

This scenario takes into account the climate parameters included in the climate change scenario selected for the analysis (as described in Section 3 from the main document). Under this scenario, the hydrological model assumes an increase of 30% in rainfall intensity by 2050. Table D-3 shows the peak flows generated by the HEC-HMS model while the total average width and average depth of the channels calculated by HEC-RAS are shown in Table D-4.

It is important to note that this scenario was modeled to understand the potential effectiveness that land use management and conservation measures may have on reducing flood risk (assuming climate change will occur as predicted by regional climate models).

Table D-3: Peak flows under Scenario 2 - Existing Land Use with Climate Change

Micro-watershed	Junction	Return Period (Years)	Peak Flow (m^3/s)
Hugo Chávez	Unión-2	25	44.3
Hugo Chávez	Unión-2	50	49.9
Hugo Chávez	Unión-2	100	55.8
Primavera	Unión-2	25	40.8
Primavera	Unión-2	50	45.9
Primavera	Unión-2	100	51.2
Nejapa-Norte	Unión-4	25	51.5
Nejapa-Norte	Unión-4	50	54.1
Nejapa-Norte	Unión-4	100	56.8
Nejapa-Sur (Baja)	Unión-3	25	50.9
Nejapa-Sur (Baja)	Unión-3	50	53.6
Nejapa-Sur (Baja)	Unión-3	100	56.2

Table D-4: Hydraulic parameters of the channels modeled under Scenario 2

Channel	Return Period (Years)	Average Total Width (m)	Average Channel Depth (m)
Hugo Chávez	25	31.2	1.04
Hugo Chávez	50	32.0	1.10
Hugo Chávez	100	32.7	1.16
Primavera	25	50.7	1.53
Primavera	50	51.9	1.59
Primavera	100	53.4	1.64
Nejapa	25	26.3	1.05
Nejapa	50	26.8	1.07
Nejapa	100	27.2	1.09

D.3.3 Scenario 3: Future Land Use Change without Climate Change (LUC)

Appendix B documents the land use composition projected for the 2050 horizon and which serves as basis for the simulation of this future scenario. This scenario also assumes current weather conditions will continue to hold in the future. Current climate parameters are derived from Intensity-Duration-Frequency curves (IDF) generated with historical data from weather stations located across Managua.

Table D-5 shows the peak flows modeled with HEC-HMS while the average total width and average depth of the channels calculated in HEC-RAS are presented in Table D-6.

Table D-5: Peak flows under Scenario 3 - Future Land Use without Climate Change

Micro-watershed	Junction	Return Period (Years)	Peak Flow (m^3/s)
Hugo Chávez	Unión-2	25	42.5
Hugo Chávez	Unión-2	50	47.5
Hugo Chávez	Unión-2	100	52.8
Primavera	Unión-2	25	39.6
Primavera	Unión-2	50	44.3
Primavera	Unión-2	100	49.2
Nejapa-Norte	Unión-4	25	50.1
Nejapa-Norte	Unión-4	50	52.6
Nejapa-Norte	Unión-4	100	55.0
Nejapa-Sur (Baja)	Unión-3	25	49.5
Nejapa-Sur (Baja)	Unión-3	50	52.0
Nejapa-Sur (Baja)	Unión-3	100	54.5

Table D-6: Hydraulic parameters of the channels modeled under Scenario 3

Channel	Return Period (Years)	Average Total Width (m)	Average Depth of the channel (m)
Hugo Chávez	25	30.8	1.02
Hugo Chávez	50	31.7	1.08
Hugo Chávez	100	32.4	1.13
Primavera	25	46.4	1.51
Primavera	50	52.2	1.57
Primavera	100	52.6	1.62
Nejapa	25	25.9	1.03
Nejapa	50	26.5	1.06
Nejapa	100	26.6	1.08

D.3.4 Scenario 4: Future Land Use and Climate Change (CC & LUC)

In this scenario, climate projections, which indicate a 30% increase in the intensity of precipitation, were combined with the future land use projections developed for the 2050 horizon.

Table D7 shows the peak flows modeled with HEC-HMS while the total average width and average depth of the channels calculated in HEC-RAS are presented in Table D8.

Table D-7: Peak flows under Scenario 4 - Future Land Use with Climate Change

Micro-watershed	Junction	Return Period (Years)	Peak Flow (m^3/s)
Hugo Chávez	Unión-2	25	57.8
Hugo Chávez	Unión-2	50	64.3
Hugo Chávez	Unión-2	100	71.1
Primavera	Unión-2	25	53.8
Primavera	Unión-2	50	59.8
Primavera	Unión-2	100	66.1
Nejapa-Norte	Unión-4	25	79.8
Nejapa-Norte	Unión-4	50	83.4
Nejapa-Norte	Unión-4	100	86.9
Nejapa-Sur (Baja)	Unión-3	25	79.1
Nejapa-Sur (Baja)	Unión-3	50	82.6
Nejapa-Sur (Baja)	Unión-3	100	86.1

Table D-8: Hydraulic parameters of the channels modeled under Scenario 4

Channel	Return Period (Years)	Average Total Width (m)	Average Channel Depth (m)
Hugo Chávez	25	32.9	1.18
Hugo Chávez	50	33.3	1.24
Hugo Chávez	100	33.5	1.30
Primavera	25	54.8	1.66
Primavera	50	53.0	1.72
Primavera	100	50.6	1.77
Nejapa	25	26.7	1.28
Nejapa	50	27.1	1.31
Nejapa	100	27.2	1.34

D.4 Summary of results in graphics: modeling of micro watersheds

In this section comparative graphs are presented with the results obtained from the hydrologic and hydraulic models for the four scenarios simulated for the three systems of micro-watersheds (Hugo Chávez, Primavera, and Nejapa system).

D.4.1 Peak Flow

Figure D-3 shows that the peak flows for Hugo Chavez and Primavera micro-watersheds increased in the climate change to 2050 (CC) scenarios and future land use (FUS) both separately and together (CC & FUS) compared with current conditions (CA). The modeled peak flows for the watershed Hugo Chavez for CA & CC scenario show slightly higher values than the CA & FUS scenario because a considerable change in land use within the watershed is not projected. This same trend is observed in the Primavera micro-watershed. This means that more intense precipitation is a more significant driver than changes in land use when considering the relative impact of these factors on flooding risk.

Figure D-3: Peak flows generated by HEC-HMS for two selected micro-watersheds

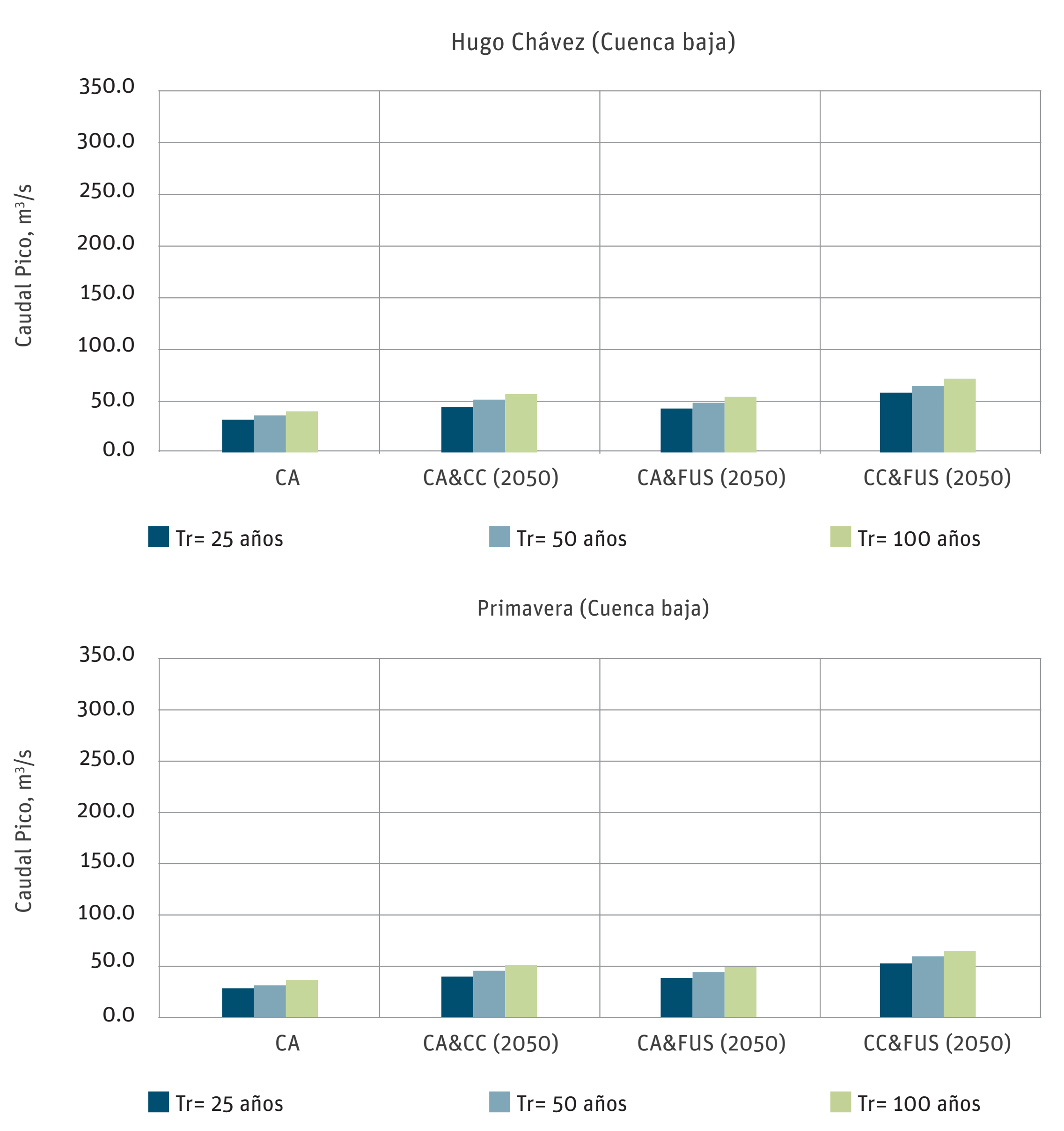
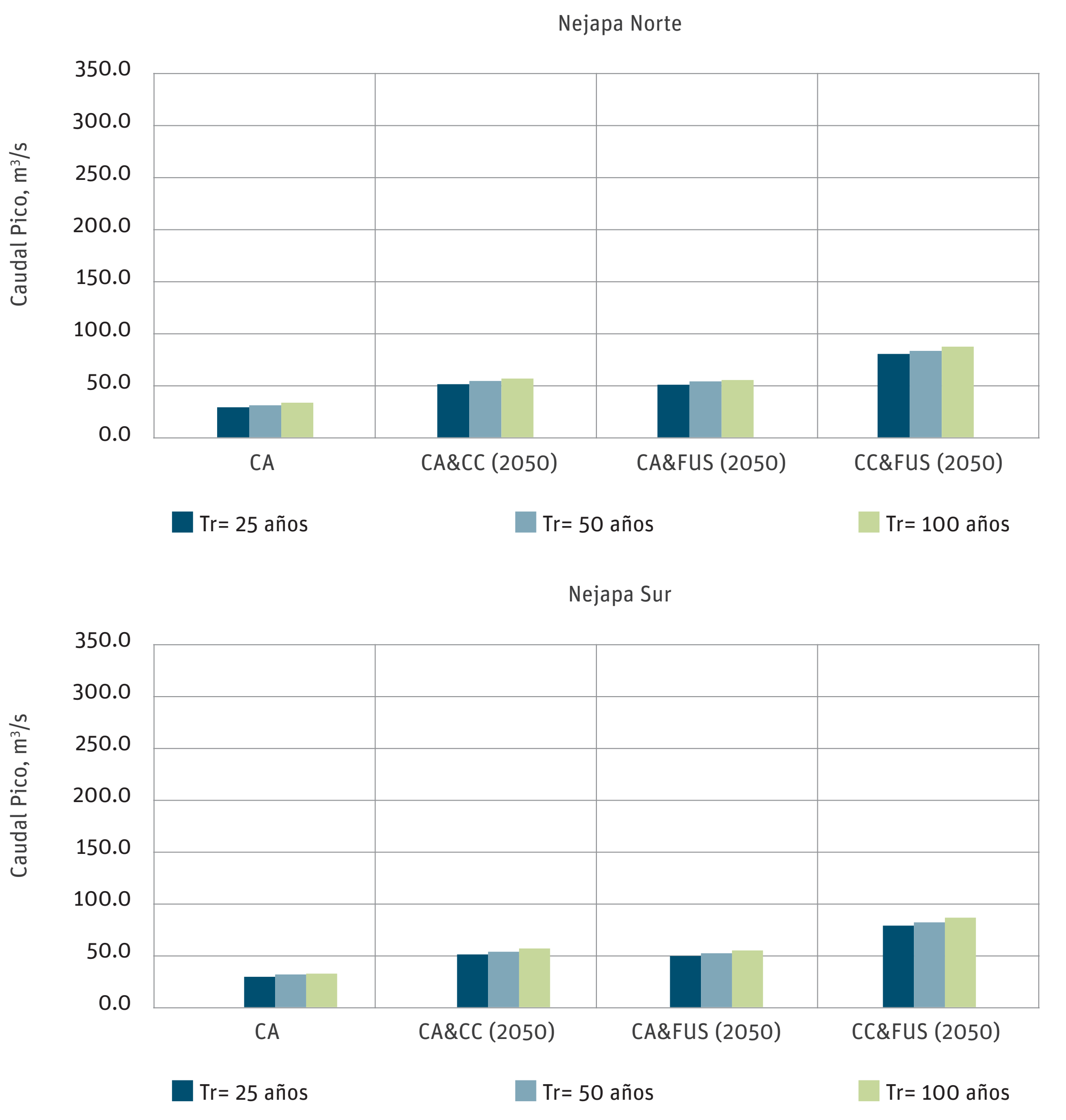


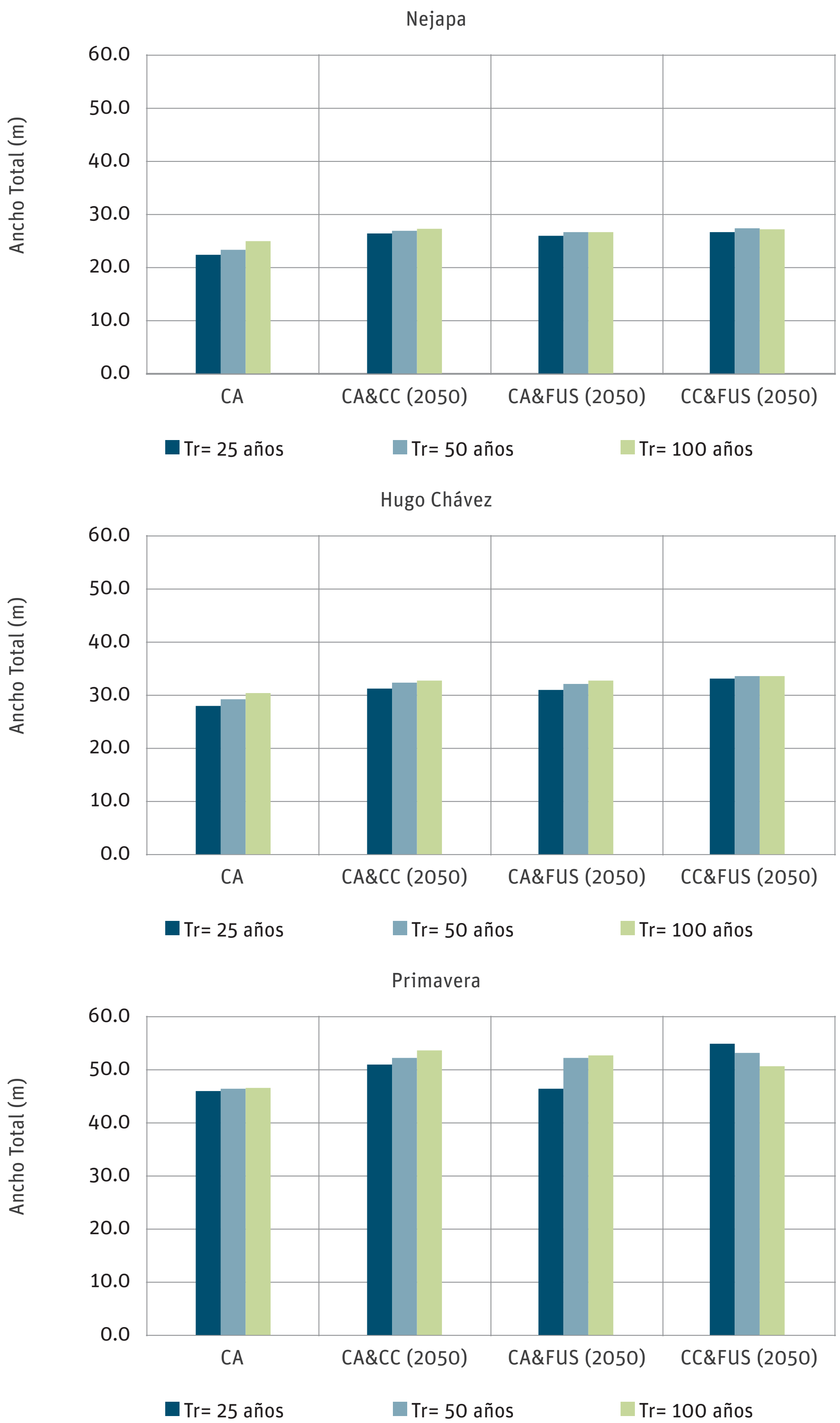
Figure D-4 compares the modeled peak flows for the Nejapa micro-watershed. The analysis for Nejapa was undertaken at two flow junctions in the watershed, e.g., Norte and Sur. The graphs show that the three scenarios with climate and land use projections will generate an increase in peak flows compared to the baseline represented by the scenario of current conditions (CA). The CA & FUS scenario shows a slightly smaller impact on peak flows than the CA & CC scenario because a considerable change of land use in the Nejapa watershed is not projected.

Figure D-4: Peak flows generated by the HEC-HMS model for two Nejapa sections



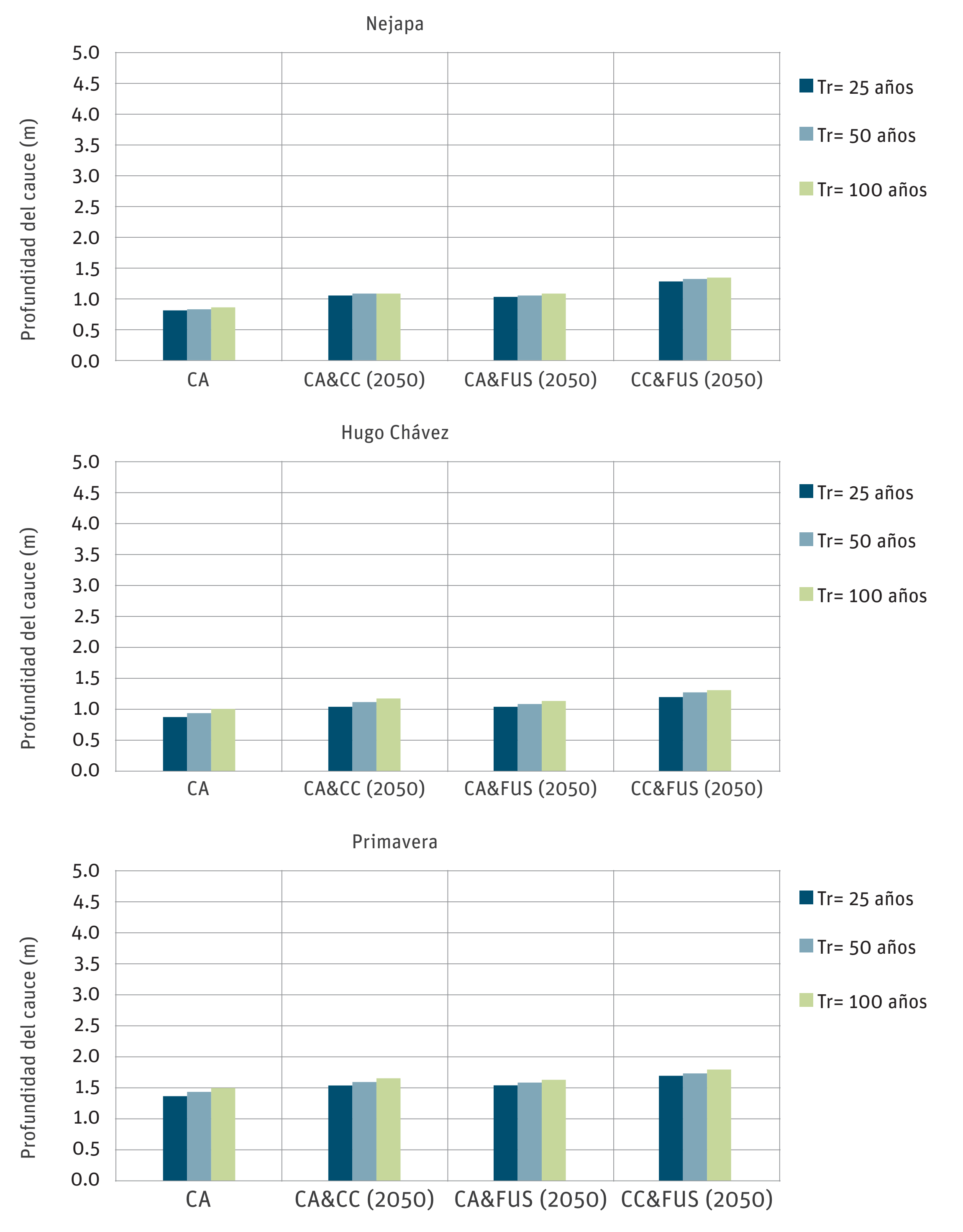
D-5 and Figure D-6 show comparative graphs of the hydraulic characteristics (average channel width and depth) for existing conditions and the three modeled scenarios. As shown in ***Figure D-5***, the average width of the channels (including its banks) has increased slightly for the three modeled scenarios compared to current climate and land use conditions (CA). The scenario that shows a greater change corresponds to the scenario of climate change (CC) and land use (FUS) 2050 presenting the broadest total average width of the four modeled scenarios for different periods of return.

Figure D-5: Average channel width for three watersheds



The average depths of the channels (see Figure D-6) show a similar trend to that observed for peak flows for the three scenarios of climate change and land use. This trend suggests that a combination of climate change and land use projected for the 2050 horizon (CC & FUS scenario) generates deeper water depths if compared to the baseline represented by current conditions (CA).

Figure D-6: Average channel depth for three microwatersheds



Annex E:

Analysis of Lake Managua Water Balance

Climate Change Adaptation and Integrated Water Resource Management in Managua, Nicaragua

Table of contents

List of Tables

List of Figures

E.1 Introduction

It is well documented and known that sudden rises in Lake Managua's water level – due to intense storms and pronounced rainy seasons – has led to flooding along communities on its coast, resulting in damages to personal and private property, as well as to city infrastructure such as the Rubén Dario National Theater. In some cases, the flooding is so recurrent that specific neighborhoods have been declared uninhabitable and many others face high risk[1].

During the course of this adaptation experience, ALMA officials preferred to focus the project's resources on addressing the already critical urban drainage challenges in Managua. Therefore, there was an agreement to address the lake-related issues separately by preparing a general water balance model of Lake Managua. The Lake Managua water balance tool was designed to aid technical specialists and local planners in estimating the likely response of the lake's water level to future changes in land use and climate.

Along this line of thinking, ERM has developed a Lake Managua (LM) water balance model that can be used to forecast the potential changes in lake surface elevation under different scenarios. The model is a relatively simple-to-use, Excel spreadsheet-based tool that considers both the monthly averages of relevant climatic variables and existing land uses across the watershed.

E.1. Organization of this Document

This annex explains aspects related to the configuration and usage of the LM water balance model, including a description of the input data, calibration steps, and model output. Instructions on where to download the spreadsheet and this annex, which serves as user manual, are included at the end of this document. The rest of this document is structured as follows:

Section E.2 **Model Description:** provides an overview of the Excel tool, indicating the purpose of each of the spreadsheet tabs and the procedure by which the model is run.

Section E.3 **Model Inputs:** describes the source and nature of the input data that is required by the model to simulate the lake's water-level response.

Section E.4 **Model Calibration:** describes the adjustments made to the model and underlying equations to improve the veracity of its output.

Section E.5 **Model Results:** presents and discusses the outputs of the model under various scenarios.

Section E.6 **Download Instructions:** provides the address of an FTP site that users can access to download the model and this annex.

1 An article published in La Prensa quoted a government official (Defensa Civil) who indicated that "40 neighborhoods [of Managua] should be evacuated and declared uninhabitable." http://m.laprensa.com.ni/nacionales/28385

E.2 Model description

E.2.1 Setup

The LM water balance spreadsheet is comprised of nine different tabs. Each tab serves a different function, either to input data, make calculations or display data and results. Relevant cells in the spreadsheet are color coded to guide the user.

Table E-1 shows whether each column or cell in the spreadsheet is used to enter new data, change existing conditions, make a calculation, or link to another tab or cell in the LM water balance tool:

Table E-1: ID colors for the LM Water Balance Tool

Entrada	Enter value
No Cambiar	No Change value
Calculado	Calculated Value
Enlace	Linked Value

The nine tabs in the spreadsheet model are further explained below:

- *Master* - In this tab, calculations of all the inflows and outflows to Lake Managua are displayed. Linked values of evaporation and precipitation are also shown in this tab. The user enters initial lake water elevation in this tab.
- *CN* - The average monthly stream flow data for each of the thirteen watersheds that comprise the Lake Managua watershed are calculated in this tab. The user can enter observed stream flow and base flow data. Calculated stream flow values can be compared to observed stream flow data. Note that base flow values should be calculated outside of the LM water balance tool. The user should also enter the total area of each of the watersheds in this tab.
- *Control* - In this tab, the user enters most of the parameters. The user should enter the average monthly precipitation and average monthly air temperatures from the available climatological stations located within the thirteen watersheds. Projected climate and land use changes should also be entered in this tab. For example, increased air temperature of 2.6 °C should be typed in the column titled DTaire(°C). Percentages of land use areas calculated from the *UsodeSuelo* tab should be inserted in this tab. *Section 3.1* documents the variables projected for the 2050 future climate scenario.
- *Uso de Suelo* – This tab has land use areas for each of the thirteen watersheds under existing conditions and the 2050 projected horizon. These areas come from historical land use and statistical calculations as described in *Annex B*. This tab should be only modified if new land use projections are generated for new horizon dates.
- *Evap* – The user can enter historical average monthly evaporation data (optional) to compare it with values calculated in this tab. Evaporation is calculated with the Thornthwaite equation which uses air temperature provided in the *Control* tab.

- *Grafica Nivel Lago*- Calculated and observed Lake Managua water levels are plotted in this tab (Graphical output of the LM water balance tool).
- *Precip+Evap* – Calculated monthly average evaporation and precipitation are plotted (Graphical output of the LM water balance tool)
- *BatimetriaLago* – This tab includes the area-storage-elevation table for Lake Managua.
- *Grafica_BalanceNeto* – The graph displays each monthly component of the water budget and the net volume for Lake Managua (Graphical output of the LM water balance tool).

E.2.2 Operation

To operate the LM water balance tool, the user should enter the data according to the following steps:

Configuring the water balance tool:

1. Select the land use scenario, percentage of area for existing conditions 2009, or future land cover 2050 from the *UsodeSuelo* tab (copy cell highlighted in light green).
2. Copy and Paste the percentages corresponding to the selected land use scenario from the *UsodeSuelo* tab into the *Control* tab (column T to AC).
3. Enter the average monthly precipitation data for each of the nine meteorological stations into the *Control* tab (column I to Q) – minimum or maximum values may also be used.
4. In the *Control* tab, enter the average monthly air temperature under observed conditions (column C); the predicted air temperature change for 2050 (column B); the precipitation change along the lake predicted for 2050 (column E); and precipitation change along the lake's watershed, also for 2050 (column F). For example, if the user wants to evaluate an increase of 2.6 ºC in air temperature and 30% in precipitation, these values should be typed in column B (2.6 ºC) and columns E (1.3) and F (1.3), respectively.
5. Enter the initial water level under observed conditions (Column G) in the *Control* tab. If the runoff curve number[2] needs to be modified, enter a value in column H, also in the *Control* tab. For example, to assume a 10% increase in the curve numbers associated with the lake's watershed, enter 1.10 in column H.
6. Under the *CN* tab, the user can enter the average monthly base flow for each of the thirteen watersheds. Note that base flow should be calculated outside of the LM water balance tool based on observed historical stream flow data. Also, the user can modify the areas of the thirteen watersheds. However, if the areas are modified, the user should check the *UsodeSuelo* tab and make sure that total areas match.
7. Entering monthly evaporation values from the Managua and RURD[3] stations into the *Evap* tab is optional. The evaporation values used for the LM water balance tool are calculated with average monthly air temperature and the Thornthwaite equation. Observed historical evaporation values can be entered to compare with the calculated values.

2 The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess

3 Recinto Universitario Rubén Darío.

Running the LM water balance tool:

- The user can run the LM water balance tool from the *Master* tab, where all of the water balance calculations are performed. This tab summarizes all the inflows and outflows for Lake Managua. In this tab the user can enter observed average monthly Lake Managua water levels (if available) to compare with calculated water levels.

Viewing the results:

- Finally, the user can see outputs from the LM water balance tool in three different plots displayed in tabs *Grafica_Nivel Lago, Precip+Evap,* and *Grafica_BalanceNeto.*

E.3 MODEL INPUTS

The LM water balance tool requires inputs for five main aspects: meteorology, land use, bathymetry, inflows, and outflows. The main inflows for the lake include direct precipitation over the lake and runoff coming from the thirteen watersheds that drain into the lake. It is important to note that groundwater interactions with the lake and its watershed are not considered by the LM water balance tool. The main outflows are evaporation and the lake's discharge onto the Tipitapa River, which connects Lake Managua with Lake Nicaragua. A detailed description of the main five model inputs are described below:

- *Meteorological* - This data includes average air temperature from the Managua Station and precipitation data from nine meteorological stations. Figure E-1 shows the location of these stations, namely, Asosca, RURD, San Isidro, Bay Pass, Managua, Primavera, Los Zarzales, La Zopilota, and San Lorenzo. Average air temperature data was used to calculate monthly evaporation with the Thornthwaite equation[4].
- *Land Use* - This data includes existing land cover and future land cover for 2050 for the thirteen watersheds. Existing land cover data was provided by MAGFOR. ERM has developed a future land cover scenario based on LANSAT satellite images as described in Annex B.
- *Bathymetry* - This data include area-storage-curves for Lake Managua obtained from INETER.
- *Streamflow* - This data were used to estimate base flow and to compare streamflow values calculated by the LM water balance tool.
- *Baseflow*- This data was calculated using available streamflow data and empirical equations for each of the thirteen sub-watersheds. The Viejo de Lima and Pacora gauging stations include the most complete continuous daily streamflow data. Streamflow data for the other sub-watersheds were estimated correlating streamflow from these two gauging stations with individual watersheds areas. Then, daily baseflow for each of the thirteen watersheds was calculated with the recursive digital filter method described by Eckhardt (2004), and average monthly baseflows were estimated for each watershed.

4 Eckhardt, K., 2004. *How to construct recursive digital filters for baseflow separation.* Hydrological Processes. Vol. 19, Issue 2, pgs 507-515.

- *Runoff-* This input was estimated on a monthly basis by adding the baseflow described above and precipitation excess (in m^3/s). Precipitation excess was also calculated in a monthly basis as a function of cumulative precipitation, soil cover, land use and the SCS Curve Number loss model. Average historical observed monthly streamflow for each watershed were compared with calculated streamflow to verify calculated runoff. The total runoff calculated from the thirteen watersheds was then incorporated as an inflow to the LM water balance.

- *Direct Precipitation on Lake:* This inflow was calculated using average monthly precipitation records from nine climatological stations (Asosca, RURD, San Isidro, Bay Pass, Managua, Primavera, Los Zarzales, La Zopilota, and San Lorenzo) located around Lake Managua (refer to Figure E-1). Then, these precipitation values (in mm) were multiplied by the area of the lake at approximately 39.5 meters (1,052 km^2). Note that this area remains the same for each calculated precipitation volume.

- *Evaporation:* Average monthly air temperature data from the Managua meteorological station and Thornthwaite equation[5] was used to calculate monthly potential evaporation rates for the LM water balance tool. The results were compared with average observed evaporation data from two stations (Managua and RURD) to verify the calculated evaporation rates.

Where:

E is evaporation (mm/day); *T* is monthly mean air temperature (°C); *I* is a heat index which is the sum of the twelve months *i* heat indexes calculated based on monthly mean air temperatures. Potential evaporation (*EP*) is calculated by multiplying *E* by 0.4-0.5 for the LM water balance tool. The *EP* was then entered as an outflow to calculate the water balance by multiplying:

and

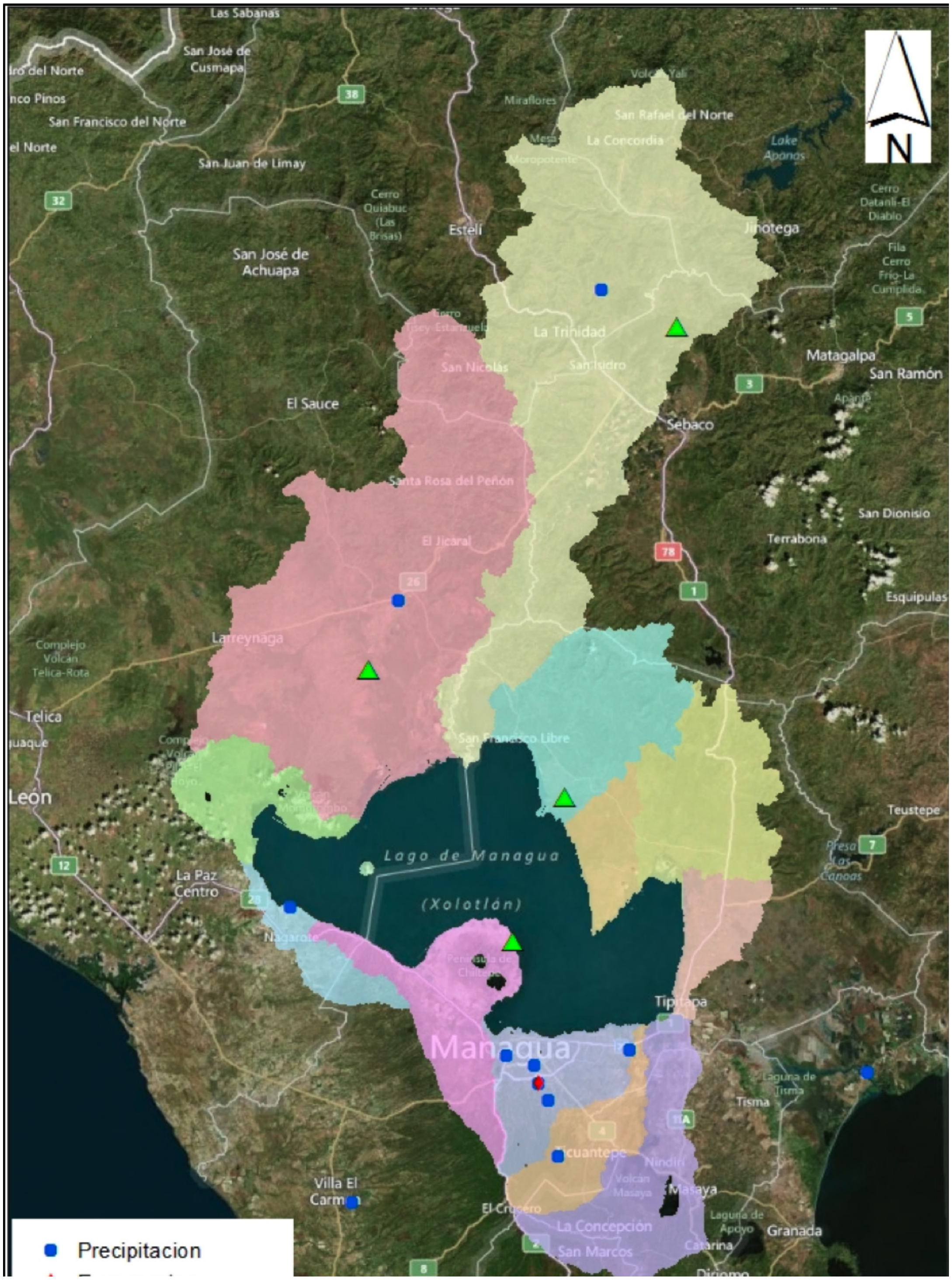
- *Discharge:* The only outlet for Lake Managua is located at Tipitapa. This outlet is controlled by a bridge that crosses the Pan-American Highway. The bridge is approximately 13 m wide and 25 m long, and functions as a weir. Based on this assumption and estimating the maximum water elevation at which the lake starts discharging water (approximately 37.7 m), an empirical discharge equation was estimated. The empirical discharge equation is a modified equation for a rectangular weir with a wider channel than the weir[6]:

where

Q is discharge from the bridge (m^3/s); *L* is channel width (m); and *H* is approach head on the crest of the weir (m).

5 Chow, V.T. 1964. *Handbook of Applied Hydrology: A Compendium of Water-resources Technology.* McGraw-Hill. Pg. 1468.
6 Sturm, T.W. 2001. Open Channel Hydraulics. McGraw-Hill

Figure E-1: Location of weather and river stations used in the study

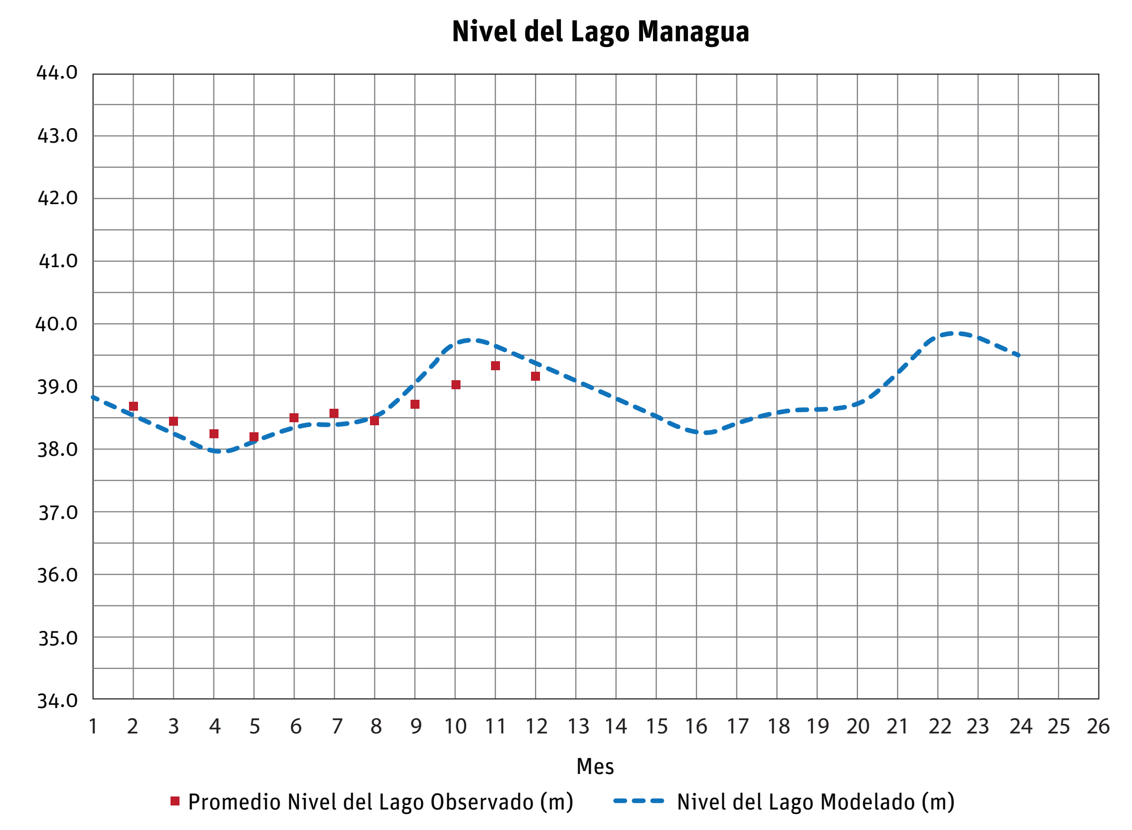


Source: ERM, 2013

E.4 Model calibration

The LM water balance model was calibrated using compiled monthly averages for all of the input data. Initial calibration attempts were showing lower modeled lake levels than the average observed values. It was determined that the cause was an unrealistic calculated discharge. The initial discharge equation did not consider flow contraction at the Pan-American Highway bridge in Tipitapa. The channel becomes significantly constrained at the site of the bridge before regaining its natural width further downstream. Without accounting for this constraint, the modeled discharge is too high resulting in lake levels that are too low. An empirical equation used for calculating discharge across a constrained weir was applied to the model and the coefficient was adjusted until the resulting monthly lake levels were a very close fit to the average observed data.

Figure E-2: Modeled average lake level compared to average observed levels



E.5 MODEL OUTPUTS

Evaluated Scenarios

ERM employed the LM water balance tool under four different scenarios, which are detailed in Table E-2.

Table E-2: The four scenarios evaluated with the LM water balance tool

Scenario	Abbreviation in Spanish	Explanation
Existing Conditions (EC)	*Condiciones Actuales (CA)*	This baseline scenario reflects a snapshot of the present based on current observed land use patterns and present-day hydrological conditions, constructed on the basis of historical weather information.
Existing Land Use with Climate Change (CC)	*Uso de Suelo Existente con Cambio Climático (CC)*	Represents a static scenario of land use whereas hydrological conditions continue to be influenced by climate change throughout the 2050 horizon. This scenario allows the analysis of the relative contribution of climate change to the magnitude of stormwater related events.
Future Land Use Change (LUC) without Climate Change	*Futuro Uso del Suelo sin Cambio Climático (FUS)*	This scenario assumes current climate conditions will stay the same in the future, but land use will continue to evolve as a result of demographic and economic drivers. This scenario emphasizes the contribution of land use changes, specifically those that translate to loss of permeable cover, in the increase of stormwater runoff.
Future Scenario with Climate Change and Land Use Change	*Futuro Uso del Suelo con Cambio Climático (CC + FUS)*	This scenario intends to reflect the combined effects of land use change and climate change on the magnitude and risk related to stormwater events.

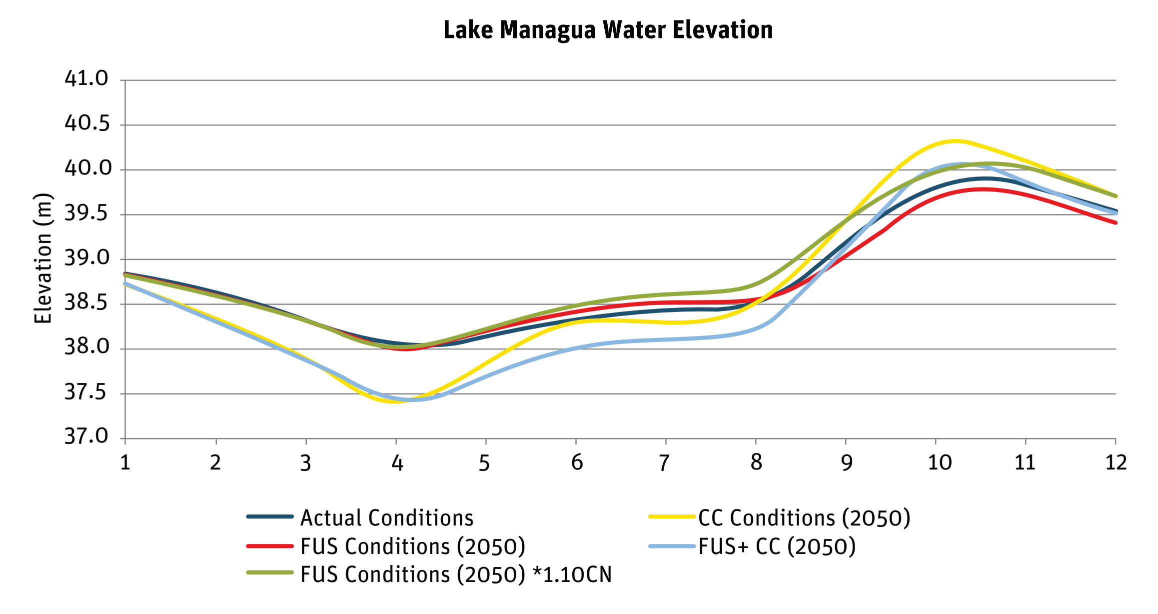
The model incorporated historical rainfall, evaporation, air temperature, and flow rate data documented by various meteorological and hydraulic stations (refer to Figure E-1). The data from these stations was provided by INETER. In addition, ERM considered forecasts of climatic variables (refer *to Section 3.1)* and projections for possible land use (refer to *Annex B)*.

Preliminary results did not show that the projected land use changes for 2050 would generate a significant influence in the lake's surface water elevation. As a result, ERM included an additional scenario, which assumed a 10% increase in the curve number associated with the future land use scenario (FUS). The curve number is a parameter that reflects the percentage of rainfall that is not absorbed by the soil and runs off as a result. A 10% increase in the curve number was set to reflect a more conservative assumption in relation to projected land use changes, which indicated a trend toward the presence of greater impermeable zones across the Lake Managua watershed. The parameter was entered in column H under the *Control* tab. This scenario was termed "FUS + 1.10 CN."

Model Results

The results showed that the future climate change and land use scenario (FUS + CC) generated more significant changes in lake levels as compared to the baseline scenario (CA). As illustrated in Figure E-2, the FUS + CC scenario leads to markedly decreased lake level projections during the dry-season (February – May), and markedly increased lake levels during the months of highest precipitation (August – October). Increases in evaporation (during the hot dry season) and precipitation during the rainy season (driven by climate variability) are the factors driving these projections.

Figure E-3: LM water balance tool results for five evaluated scenarios



It is important to note the results emphasize the greater role that the climatic variables (e.g., precipitation and temperature) play in driving the lake's surface water elevation. As per the results tabulated in Table E-3, it appears that changes in land use, and the related increase in impermeable area, would not significantly increase or decrease the lake's elevation.

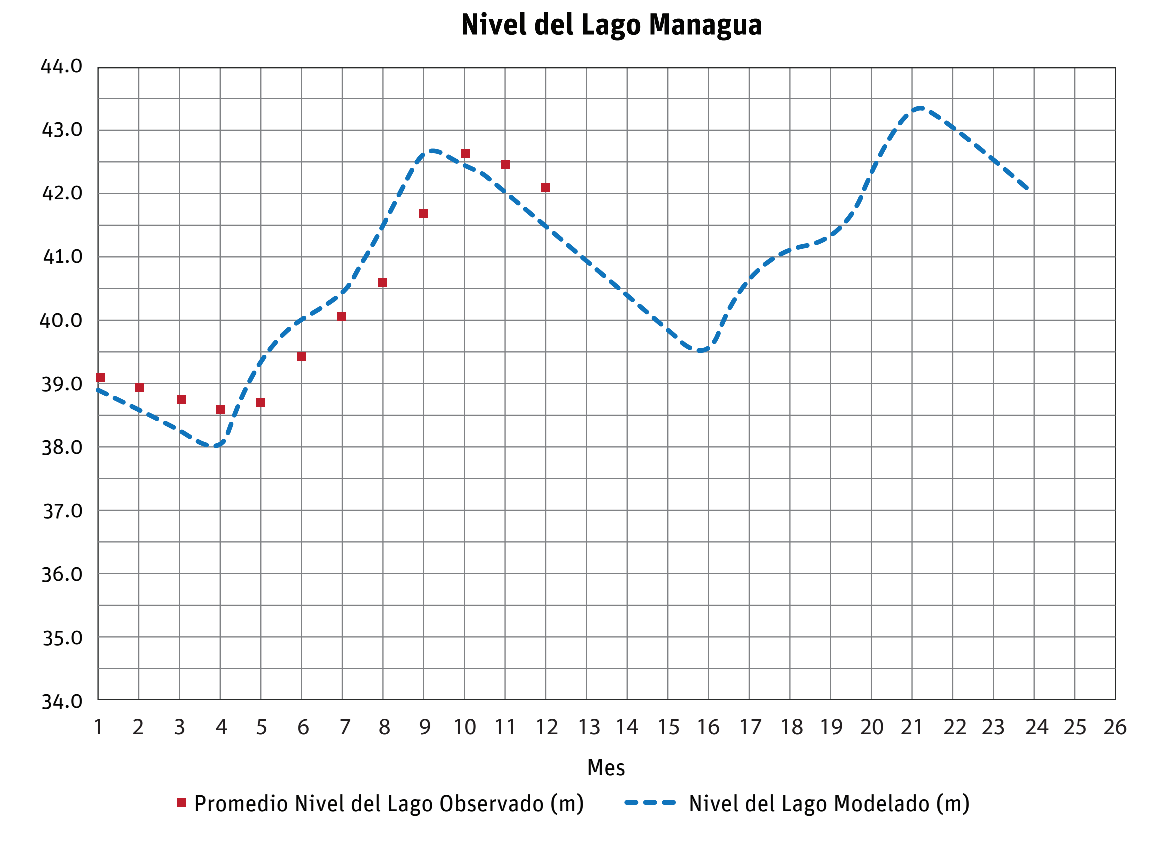
Table E-3: Levels of Lake Managua generated by the water balance

Month	Projected Lake Managua Water Elevations (m)			
	CA	CC	FUS	CC + FUS
January	38.8	38.7	38.8	38.7
February	38.6	38.3	38.6	38.3
March	38.3	37.9	38.3	37.9
April	38.0	37.4	38.0	37.4
May	38.1	37.8	38.2	37.7
June	38.3	38.3	38.4	38.0
July	38.4	38.3	38.5	38.1
August	38.5	38.5	38.5	38.2
September	39.1	39.4	39.0	39.1
October	39.8	40.3	39.7	40.0
November	39.8	40.1	39.7	39.9
December	39.5	39.7	39.4	39.5

Note: Water elevation is expressed in meters (m).

The model was also run using 2010 data, a particularly wet season with above average observed lake levels exceeding 42 meters. Precipitation data was not available for three of the nine rain gauge stations for 2010 so missing data had to be estimated based on a similar station, the Sandino Airport in Managua. The ratio between the average monthly rainfall and 2010 observed monthly rainfall for the Managua station was applied to the average monthly totals for the three missing stations to yield estimated 2010 monthly rainfall totals. As per Figure E-3, the results showed a very good fit to the observed lake levels illustrating that the model could be effective, even in extreme wet seasons.

Figure E-4: LM water balance tool results for 2010



Like any other water balance, the LM water balance tool has strengths and limitations. One of the biggest limitations is the lack of consistent and continuous observed data for calibration. It is also limited by the fact that the data is compiled monthly, leading to coarser model output than what one might expect with daily input data. Even so, the results fit very well to the observed trends in lake level fluctuations. The end product is a water balance tool that can be used to evaluate potential changes in Lake Managua water levels produced by environmental or human activities, given a known starting lake level.

Anticipated El Niño or El Niña years can be evaluated for flood risk based on existing lake levels and expected changes in other climatic variables, such as precipitation and air temperature. Human activities, such as land use changes, can be evaluated with this tool as well in order to estimate their effects on lake levels. The user can change land use in each of the thirteen watersheds to represent population growth or agricultural shifts, and allow the tool to estimate the impacts on Lake Managua water surface elevations. The approximate flood extent can also be mapped based on surrounding topographic contours.

E.6 DOWNLOAD INSTRUCTIONS

To download the LM water balance model spreadsheet, type the following address into a browser, ftp://onyx.erm.com, and enter the following login information.

Username = SW-0181353

Password = 9F2282hb

A copy of the spreadsheet model and this annex will be available for download until April 2015.

IDB
Inter-American
Development Bank

NDF
Nordic Development Fund