Climate Change Adaptation and Integrated Water Resource Management in La Ceiba, Honduras

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Acronyms

BC	Boundary Conditions *Condiciones frontera*
CESAMOS	Centro de Salud Médico Odontológico *Medical and Dental Health Center*
CESAR	Centro de Salud Rural *Rural Health Center*
CODEL	Comité de Emergencia Local *Local Emergency Committee*
CODEM	Comité de Emergencia Municipal *Municipal Emergency Committee*
COPECO	Comisión Permanente de Contingencias *Permanent Contingency Commission*
CN	Curve Number *Número de curva*
CREDIA	Centro Regional de Documentación e Interpretación Ambiental *Regional Center for Environmental Education and Learning Repository*
DEM	Digital Elevation Model *Modelo de Elevación Digital*
ERM	Environmental Resources Management
GEMSS	Generalized Environmental Modeling System for Surfacewaters *Sistema Generalizado de Modelado Ambiental para Aguas Superficiales*
GHG	Greenhouse gases *Gases de efecto invernadero*
GIS	Geographic Information System *Sistema de Información Geográfica*
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System *Centro de Ingeniería Hidrológica – Sistema de Modelado Hidrológico*
HEC-RAS	Hydrologic Engineering Center – River Analysis System *Centro de Ingeniería Hidrológica – Sistema de Modelado Hidrológico*

IDB	Inter-American Development Bank *Banco Interamericano de Desarrollo*
NGO	Non-Government Organizations *Organizaciones no gubernamentales*
ENSO	El Niño-Southern Oscillation *Oscilación del Sur El Niño*
IDF	Intensidad-Duración-Frecuencia *Intensity-Duration-Frequency*
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change *Modelo para la evaluación de cambio climático inducido por gases de efecto invernadero*
NASA	National Aeronautics and Space Administration *Administración Aeronáutica y Espacial de Estados Unidos*
NDF	Nordic Development Fund *Fondo Nórdico de Desarrollo*
NOAA	National Oceanographic and Atmospheric Administration *Administración Nacional Oceanográfica y Atmosférica de Estados Unidos*
OMASAN	Oficina Municipal de Agua y Saneamiento (Municipalidad de La Ceiba) *Municipal Water and Sanitation Department*
SANAA	Servicio Autónomo Nacional de Acueductos y Alcantarillados *National Aqueduct and Sewer Autonomous Service*
SCENGEN	Spatial Climate-Change Scenario GENerator *Generador Espacial de Escenarios de Cambio Climático*
SERNA	Secretaría de Recursos Naturales y Ambiente *Ministry of Environment and Natural Resources*
SINIT	Sistema Nacional de Información Territorial *Land Information National System*
USGS	United States Geological Survey *Servicio Geológico de Estados Unidos*
WSA	Water and Sanitation Sector *Sector Agua y Saneamiento*

Preface

The Inter-American Development Bank (IDB) has recognized that its activities in the countries of the Latin America and Caribbean 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 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.

Honduras is currently considered one of the most vulnerable countries to climate change in Latin America given its high exposure to extreme meteorological events. Six of the twelve strongest hurricanes of the 20th century have impacted Honduras, including Hurricane Mitch in 1998, which has been the most severe storm known to have hit the region. The storm brought about flash floods and landslides, which caused an estimated 10,000 deaths, destroyed 70% of the country's road infrastructure and drinking water supply network, and led to extensive crop losses.

Forecasts of climate change for Central America suggest an increase in the frequency and intensity of tropical storms and intense-rainfall events. In addition, climate projections also suggest that sea level may rise up to 60 cm by 2050, putting further pressure on already vulnerable coastal areas. These natural hazards are a particular concern in the coastal city of La Ceiba, Honduras.

This case study exemplifies a potential approach to addressing adaptation and vulnerability reduction in a developing coastal city. This adaptation experience has resulted in a stakeholder-focused adaptation strategy in the WSA sector that combines infrastructure and policy-based measures to reduce vulnerability to a range of natural risks, from sea level rise to river and coastal flooding to the contamination of drinking water sources.

Lessons learned in La Ceiba are likely to be applicable to other efforts in the region where addressing coastal sensitivity to climate change 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 selected by the Inter-American Development Bank (IDB) to perform an analysis of the potential impacts that climate change could have on the water resources and infrastructure of the City of La Ceiba and to identify potential adaptation measures. This process focused on:

- Understanding the potential effects that changes in climate change induced variables (e.g., sea level rise, rainfall frequency and intensity) may have on the local water cycle, including the extent and recurrence of coastal and riverine flooding;
- Assessing the extent of salt water intrusion and the effect it may have on surface and groundwater sources of drinking water;
- Characterizing and mapping, to the extent possible, the vulnerability of the population, economy and infrastructure to climate-driven impacts; 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.

La Ceiba is an example of a city in Latin America faced with the challenge of adapting to sea level rise and flooding caused by storms of increasing frequency and intensity. It is expected that this adaptation experience can support local policy-makers in understanding and responding to both future and present risks.

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 La Ceiba, Honduras.

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 that met the following objectives:

- Evaluate the impacts that climate change may have on communities, their livelihoods, and the assets and resources in the WSA sector, especially those that can result from flooding and salt water intrusion;
- 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, and acceptance by the community, among others, and;
- Promote knowledge transfer by actively engaging local government and civil society stakeholders (via two workshops in La Ceiba).

1.2 Scope of the Adaptation Process

The adaptation process carried out in La Ceiba focused on designing an adaptation strategy, comprising infrastructure works, policies, and measures, to ensure resilience in the water and sanitation sector in the face of climate change, including variability. The focus on water and sanitation assets and resources defined the boundary of the priority system under study, and therefore, the scope of this project.

La Ceiba is characterized by high vulnerability to different climate hazards, not only in terms of key infrastructure at risk, but also in terms of the population's ability to cope and adapt to climate change. As an initial step, project staff from ERM and the IDB visited La Ceiba to meet with local stakeholders, receiving inputs that further helped focus the project on the following issues:

- Urban flooding caused by the overflow of the Cangrejal River and deficiencies in the stormwater drainage system;
- Coastal flooding resulting from extreme meteorological events (e.g., tropical storms, cold fronts) and associated storm surge;
- Contamination of groundwater sources of drinking water caused by saltwater intrusion in the aquifer; and,
- Coastal erosion due to natural morphologic processes, which can be influenced by sea level rise and storm surges, as well as by human activities, such as construction of structures along the coast and mining of the Cangrejal riverbed.

The initial site visit yielded a better understanding of the main stakeholder priorities. The Mayoralty of La Ceiba, a key stakeholder in the adaptation process, was particularly concerned about impacts to potable water sources as well as flooding from extreme meteorological events. A diverse group of stakeholders – from the public sector to academia – also raised concerns about urban flooding and the continuing erosion of nearby coastal urban and urbanizing areas.

1.3 Stakeholder Engagement

Stakeholder involvement throughout the project has been a key component to ensure a shared understanding of the issues and to create adaptations that are implementable in the local context. In line with this objective, the project established a stakeholder engagement process comprised of an initial scoping visit, a meeting with an expert panel on land use, and two formal day-long workshops with a broad set of stakeholders.

The scoping visit was held on February 6-8, 2013 and included a number of separate meetings with key local stakeholders. These meetings aided in the identification of key stakeholders, who in turn helped shape the scope of the project. The visit was also instrumental in gaining a first-hand understanding of the study region and gathering initial data for the project baseline. During this visit, the Mayoralty of La Ceiba was established as the main beneficiary of the adaptation study, while SANAA was identified as a potential implementing partner given its technical oversight role in the water and sanitation sector.

In December 2013, a half-day workshop was convened with local experts to discuss land use and urbanization trends in the Cangrejal River watershed. Understanding how these trends may shape land use in the future and how those changes would affect hydrologic behavior of the river were important inputs for the analysis. The meeting, which was attended by 16 local experts, focused on the discussion and validation of the assumptions that underpinned the preliminary 2050 land use scenario that ERM developed in collaboration with CREDIA. The results of this meeting and validated projections are documented in **Annex A**.

In February 2014, a broader stakeholder engagement and knowledge transfer workshop was convened. The workshop aimed to build local capacity by illustrating the extent of existing natural hazards, raising awareness of the potential evolution of these risks in the future due to climate change, and discussing the potential options for adaptation and vulnerability reduction. Inputs gained during this workshop, both in terms of an enhanced understanding of vulnerability in La Ceiba and brainstorming of potential adaptation options, are documented throughout this case study.

In August 2014, ERM conducted the final scheduled workshop, which served to present the main findings of the case study and provide our recommendation for potential mitigation and adaptions actions that can be undertaken in response to the assessed risks. The main objective of this workshop focused on eliciting the input of local experts and decision-makers on aspects related to the feasibility and implementation of the proposed measures. Overall, the workshops held during this process also served the purpose of creating a community of local stakeholders who are vested in the adaptation process and shared a vision of long-term sustainability for the city.

1.4 Organization of This Report

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

Chapter 2 **Methodological Approach:** presents the methodology by which ERM has developed and coordinated this risk-based adaptation experience in La Ceiba.

Chapter 3 **Hazard Profile:** characterizes at a high level the frequency, magnitude and extent of the climate-related natural hazards facing La Ceiba, informed by a literature review and input by local residents and experts.

Chapter 4 **Vulnerability Assessment:** provides an overview of the factors believed to drive vulnerability in the local context and identifies the areas prone to the natural hazards under study.

Chapter 5 **Assessment of Future Climate Change Impacts:** presents the results of the technical analyses carried out by ERM to examine how climate change may exacerbate the natural risks that currently threaten La Ceiba. The chapter also evaluates options to reduce the risk of flooding in areas adjacent to the Cangrejal River.

Chapter 6 **Main Recommendations:** documents our final analysis and preliminary recommendations to most effectively address current and future vulnerabilities in the WSA sector in La Ceiba. Aspects such as cost, benefits and other considerations are discussed.

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

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

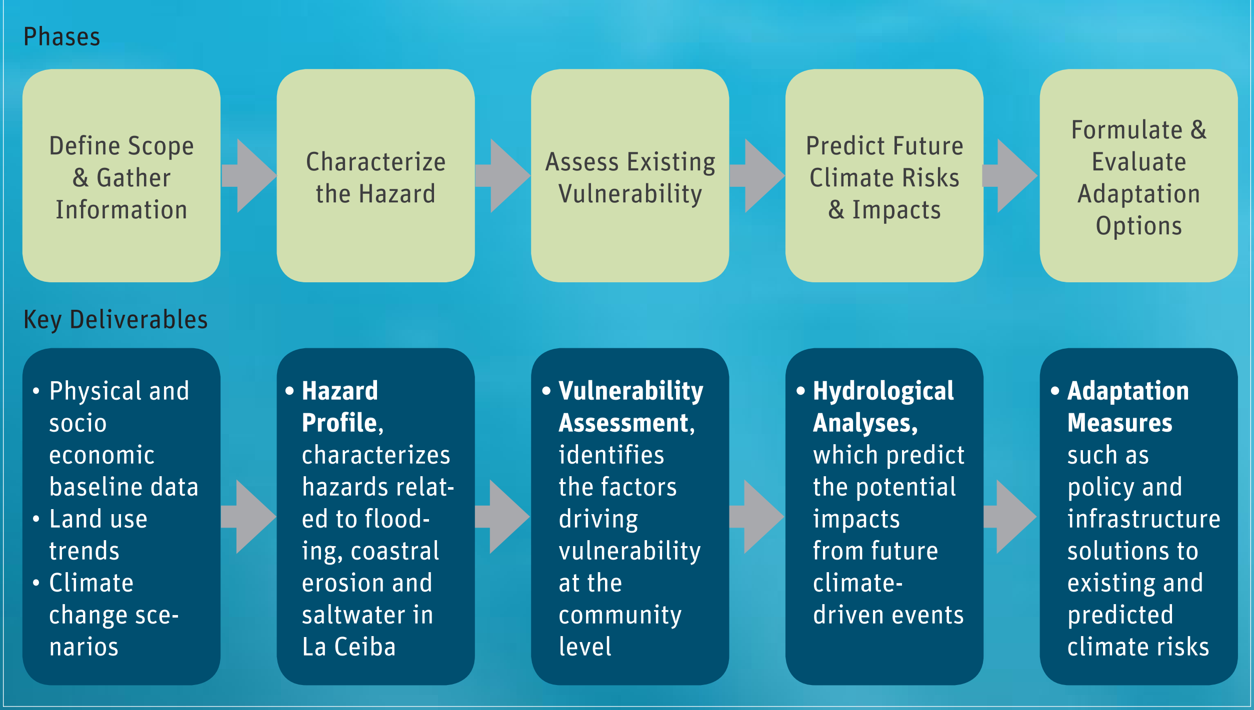
Annex B **Climate Change Scenario for 2050**

2. Methodological Approach

In keeping with the objectives stated in *Chapter 1*, ERM developed a methodology that would enable the identification of planned, proactive and preventative adaptation responses to existing and future climate change risks. This methodology uses a risk-based approach to predict 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.

Figure 2-1: Adaptation Process Approach



Source: ERM, 2014.

As illustrated above, the methodology accounts for the following steps:

Define Scope & Gather Information. At an initial stage, the ERM and IDB teams met with several local stakeholders, mainly from local governmental agencies and NGOs that play a role in the city's development planning, the management of water resources, or in the prevention or response to natural disasters. 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 of the Cangrejal River watershed. 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 provided information related to the physical characteristics of the study area (e.g., geology, topography, land use/land cover, soil infiltration capacity, climate, and hydrology), as well as socioeconomic data (e.g., demographics, economic activities, public infrastructure). This data has been incorporated in several places of this report, for example, as assumptions of the hydrological model (*Chapter 5*), and contextual factors that supported the characterization of hazards (*Chapter 3*) and vulnerability (*Chapter 4*);
- **Future Land Use Scenario** to establish rate of impervious surface increase over time in the Cangrejal River watershed. ERM performed an analysis of satellite imagery to derive land use change rates and set up a statistical, geospatial model to project land use change for the 2050 horizon (refer to **Annex A**); and,
- **Selection of Climate Change Scenario,** which provided the climate variables (e.g., temperature, precipitation frequency and intensity) and sea level projections that together comprise a possible scenario of climate in 2050. ERM reviewed available reports and data regarding climate change scenarios for Honduras, resulting in the selection of projections recognized by local authorities (refer to **Annex B**).

Characterize the Hazards. ERM carried out a literature review and interviews with key informants to characterize the risk associated with climate-driven natural hazards, the rate at which these have taken place in recent years, and the effects these have had on the population, the city's economy and infrastructure. The key deliverable in this step was:

- **Hazard Profile** *(Chapter 3)* that characterizes the effects of urban, riverine and coastal 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 also documents secondary research on the existing risk linked to salt water intrusion. Coastal erosion is discussed insofar as it relates to flooding from storm surge and sea level rise.

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 in La Ceiba. Understanding vulnerability is important to formulate appropriate adaptation options, and provide a baseline against which to evaluate progress on vulnerability reduction. The key output from this step was:

- **Vulnerability Assessment** *(Chapter 4)* that considers the likelihood of exposure and sensitivity of the population to the hazards described in *Chapter 3*. The assessment focuses on four specific neighborhoods, known to be vulnerable to different hazards and for distinct reasons.

Predict Future Climate Risks & Impacts. Based on the modeling of storms of higher intensity and precipitation on local hydrology, this chapter addresses the potential effect climate change would have on the Cangrejal River, mapping the potential areas at risk of flooding under various scenarios. The risk of coastal flooding was analyzed by comparing the extent of low-lying areas with predicted swell associated with storm surge (before and after accounting for a pessimistic scenario of sea level rise: 0.6 meters).

ERM also modeled the extent of the salt water wedge that would intrude upstream along the Cangrejal River. The results helped to qualitatively describe the contribution of sea level rise to existing saltwater intrusion issues. The key output related to this technical analysis phase included:

- **Hydrological Analyses** *(Chapter 5)* which characterizes the possible extent of flooding associated with the rainfall from large storms, i.e., those with a 1:20, 1:50, or 1:100 probability of occurring on any given year. The results were expressed in terms of peak flows (for the Cangrejal River) and spatial visualization of urban areas at risk of flooding. The analysis considered a range of scenarios to assess the relative contribution of land use and climate change to future flood risk.

Formulate and Evaluate Adaptation Options. ERM facilitated a workshop, held in February 2014, to present the results of the hydrological analysis and identify with local stakeholders potential adaptations. Leveraging the models that had been setup in the previous step, ERM also evaluated four stakeholder-proposed options for reducing the risk of flooding in the Cangrejal River (*Section 5.4)*. Based on the results, and analysis of other hazards, *Chapter 6* documents the recommendations of ERM with regard to the issues under study.

3. Hazard Profile: Climate Change Impacts in La Ceiba

Extreme meteorological events, such as droughts, heat waves, hurricanes, and tropical storms, frequently affect Honduras[2], making it one of the most vulnerable countries in Latin America. The coastal city of La Ceiba, on the Atlantic coast, is particularly vulnerable to tropical storms and gradual sea-level rise. This chapter describes the magnitude and frequency of the effects caused by climate-induced phenomena, as context to understanding key vulnerabilities and formulating appropriate adaptive responses.

Due to its geography and climate, La Ceiba is particularly susceptible to flood-related hazards. The city is located in the alluvial floodplain of the Cangrejal River, nestled in a relatively narrow area between the Caribbean Sea and the Nombre de Dios mountain range. The proximity of the mountains to the ocean not only creates the conditions that favor heavy rainfall, but also increases the risk of flooding downstream.

The Cangrejal River frequently overflows during heavy rainfall events. One reason is the large runoff volume that accumulates across the 560 km^2 watershed. This significant volume flows down rapidly due to the steep change in elevation. Another reason is the fact that several of the river's natural outlets to sea have been filled in by development. In addition, the embankments that protect the city are not high enough when the river grows significantly.

La Ceiba is also particularly susceptible to coastal flooding due to storms, which can cause the sea level to temporarily rise, inundating low-lying areas along the coast. In these cases, the combined effect of storm surge and high river flow can increase the extent of flooding-related impacts, along the banks of the river, the estuary, and the coast.

In addition to river and coastal flooding, a third type of flooding in La Ceiba can be linked to the deficient stormwater drainage system. Oftentimes, large volumes of rain can fall in a matter of hours (or over many days saturating the soil), overwhelming the ability of the existing drainage infrastructure to remove stormwater effectively. This causes localized flooding in specific urban areas.

The gradual rise in sea level also increases the vulnerability of coastal areas. Sea level rise can accelerate natural processes such as coastal erosion, and increase the extent of flooding along the coast (due to the increasing height of storm-related surge). Sea level rise also increases the risk of salt water contamination of surface and groundwater drinking sources.

The rest of this section is organized as follows: *Section 3.1* describes the effects associated with flood-related hazards, including the threat of coastal erosion. Salt water intrusion is described in Section 3.2. Section 3.3 summarizes the main adverse effects suffered by the population as a consequence of these hazards.

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2. SERNA (2010) *Estrategia Nacional de Cambio Climático.* Dirección de Cambio Climático

3.1 Flooding-Related Hazards

La Ceiba is highly vulnerable to flooding due to its geographic location and exposure to frequent storms (e.g., cold fronts, tropical storms). Moreover, the city lacks the infrastructure that would otherwise provide adequate protection. In addition, some its poorest residents do not possess the socioeconomic resources necessary to protect and recover from the impacts of current hazards, nor to adapt to a changing climate.

This section discusses the three main types of flooding that occur in La Ceiba:

- Flooding caused by the Cangrejal River, when its waters rise rapidly during intense rainfall events breaching the existing containment structures built to protect the urban area;
- Less frequent but more damaging flooding associated with tropical cyclones, which produce storm surges and affect coastal areas and resources; and,
- Flooding of streets within the urban core due to the lack of sufficient stormwater drainage structures.

The description of the flood-related hazards included in the following sections is based on:

- Review of available literature and data from academic and professional institutions, as cited throughout;
- Semi-structured interviews held with local experts affiliated with local governmental and NGO organizations; and,
- Focus groups held in communities located in known high-exposure areas.

3.1.1 River Flooding

The risk of major flooding due to the overflow of the Cangrejal River has become a genuine concern for the residents and authorities in La Ceiba. According to local experts, the river does not overflow frequently[3], but when it does, the extent of flooding can be significant.

Several factors contribute to the city's present exposure to this risk. First, the city was built on the alluvial plain of the Cangrejal River and development has increased rapidly along its banks, without an appropriate setback zone to account for its floodplain. In fact, annual population growth has averaged 4.7% in the period 1988 to 2001[4]. According to local experts, this growth has been unplanned and uncontrolled[5], evidenced by the appearance of informal settlements in very vulnerable areas along the river banks.

Second, the city lacks adequate natural and artificial defenses to prevent or mitigate the extent of flooding. For example, the wetlands and natural channels that provided the river with additional outlets to the ocean have been filled in by urban development, increasing the propensity for flooding[6]. In addition, the levees that were intended to protect the urban area against flooding have been reported insufficient, particularly during intense precipitation events or tropical storms, such as Hurricane Mitch in 1998[7].

3. Boves, L. (October, 2013). Semi-structured interview with Red Cross representative.

4. CREDIA (2013). *Descripción de las condiciones existentes y escenario tendencial de cobertura vegetal y uso del suelo para el horizonte 2050.*

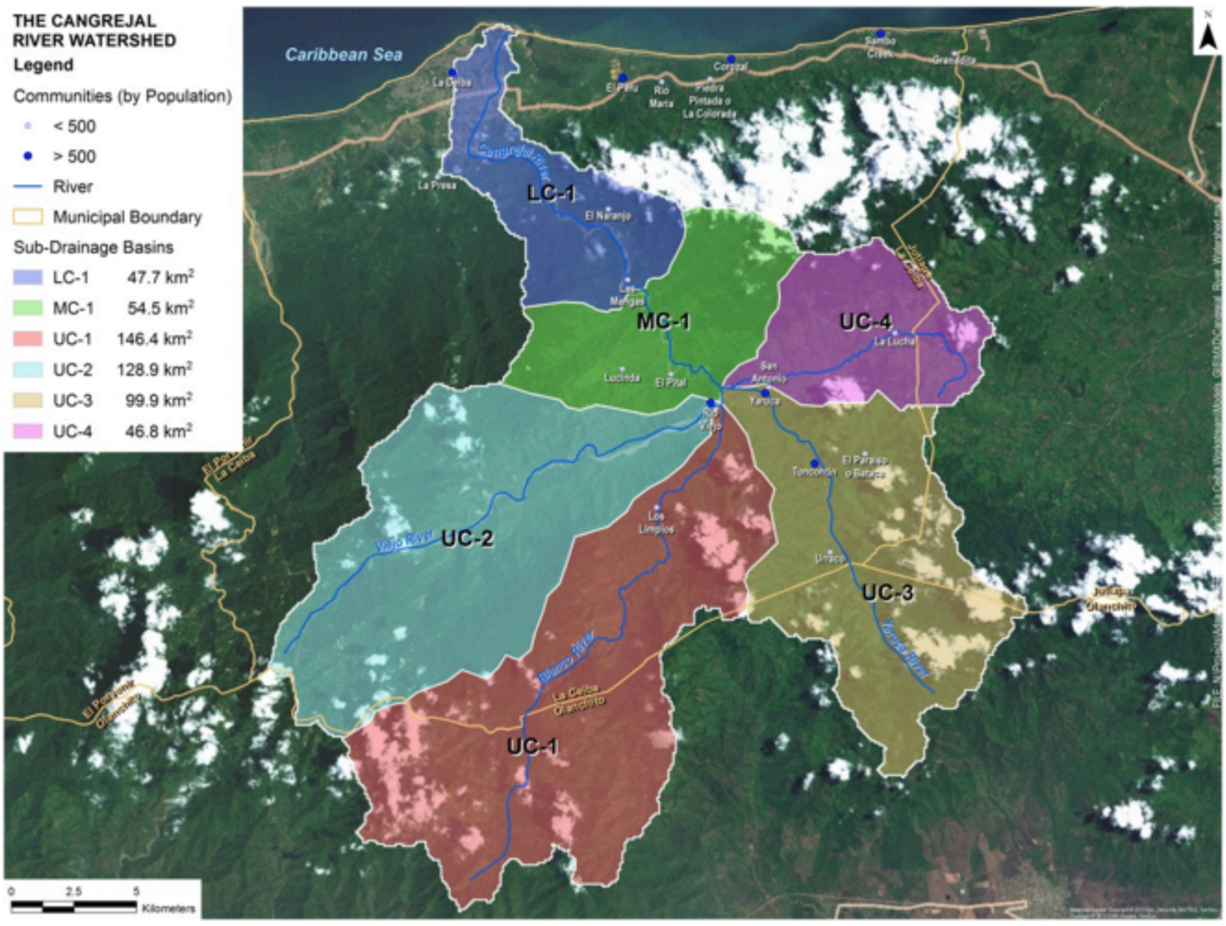
5. Castillo, O. (October, 2013). Semi-structured interview.

6. Smith et.al (2011)

7. Smith et.al (2011)

Third, the Cangrejal River is highly responsive to precipitation and its waters can rise by several meters in a matter of hours. This is due to the large volume of runoff that accumulates across the Cangrejal watershed, which covers an area of 560 km^2. As illustrated in Figure 3-1, the Cangrejal River is comprised by several tributaries located in the mountainous region of the Nombre de Dios range. These tributaries converge to form the Cangrejal River, which runs through La Ceiba at a high flow rate due to the steep change in elevation.

Figure 3-1: The Cangrejal River and Tributaries (Watershed View)



Source: Map by ERM, 2014.

The risk of river flooding increases in the rainy season, particularly due to weather caused by cold fronts from the north. Cold fronts affect the northern coast of Honduras on a yearly basis and are typically associated with heavy rains, high winds, and decrease in temperatures. Cold fronts are more typical in the months of November through January, but have been reported to occur as late as April[8].

The frequency of cold fronts is influenced by the climatic variability associated with fluctuating ocean water temperatures in the Pacific Ocean, also known as the El Niño-Southern Oscillation (ENSO). According to a 2010 study[9] conducted by SERNA, in general, warm ENSO episodes (El Niño years) result in the overall decrease of rainfall, but favors the entrance of cold fronts during the months of November through January. Cool ENSO episodes (La Niña years) creates favorable conditions for the entrance of cold fronts in December.

Tropical storms and hurricanes are also increasingly frequent. In the 1998-2013 period, cyclonic activity led to one particularly exceptional catastrophe, Hurricane Mitch in 1998, but it has also led to smaller scale disasters in at least six of the last 14 years. The frequency and intensity of these storms is expected to increase due to climate change and variability[10].

Precipitation records measured at the meteorological station in La Ceiba (Golosón) suggest the highest 24-hour rainfall values corresponded not to hurricanes or tropical storms, but to heavy rainfall events during the rainy season, some which are likely to have been produced by cold fronts.

In summary, the above discussion highlights the role of geography, urban development, infrastructure investment and climate as factors that determine the possibility and magnitude of river flooding. The evolution of these factors in the future will directly influence the risk profile of the city. For instance, human activity and further development in the upper parts of the watershed can have consequences for residents downstream. Also, continued urbanization of highly exposed areas along the river, including informal settlements on its floodplain, will also magnify the effects of these storms.

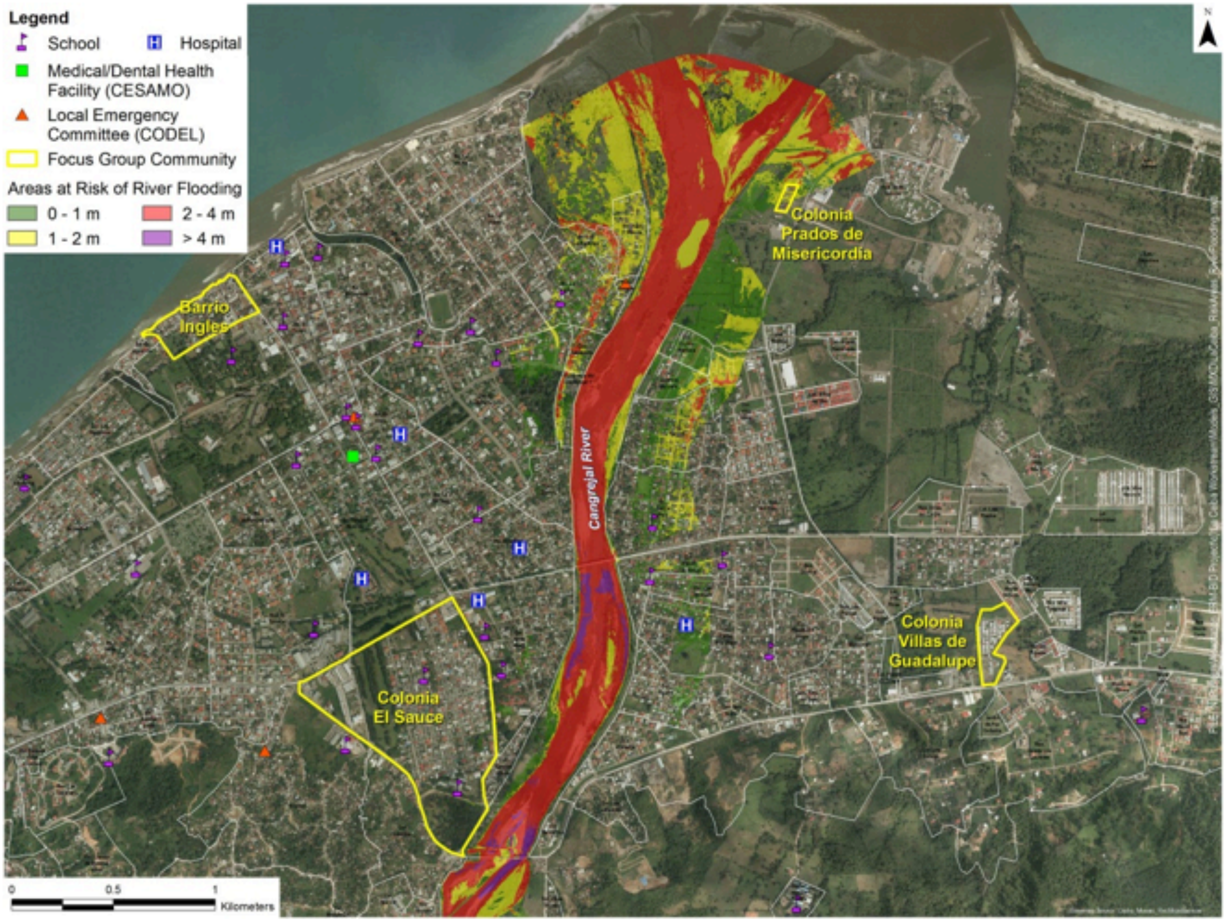
Figure 3-2 illustrates the extent of flooding under existing conditions, assuming a storm event with a 1 in 20-year probability of occurrence. The image is an output from the hydrological and hydraulic analyses, taking into account observed climatic conditions and the 2010 snapshot of land use across the Cangrejal River watershed. The methodology and outputs for storms of greater magnitude are documented in *Chapter 5*.

8. Boves, L. (October, 2013). Entrevista con el Coordinador Regional de Gestión de Riesgos de la Cruz Roja.

9. SERNA (2010). Estrategia Nacional de Cambio Climático.

10 SERNA (2010). Estrategia Nacional de Cambio Climático

Figure 3-2: Predicted extent of flooding under existing conditions (20-Year Return Period)



Source: ERM, 2014

With climate change, more frequent and intense flooding can be expected, leading to more damaging storms. As the magnitude of disasters increases, the chances of correlated negative outcomes, such as loss of life, deteriorated public health and economic losses, also increases[11]. Specific to the Cangrejal River, one study suggests its water flow could increase by one-third from more intense hurricanes in the future[12].

11. Kuhl, L. (2011) *From a culture of disaster to a cultures of adaptation*. Master's Thesis.

12. Smith et al. (2011).

3.1.2 Coastal Flooding

La Ceiba is particularly susceptible to the storm surge caused by tropical storms and hurricanes, and, to a lesser extent, cold fronts. Storm surge[13] is often the greatest threat to life and property from these extreme weather events[14]. According to a recent study[15], more than 12,000 hectares, which account for 10.67% of the municipal area, is under the threat of coastal flooding.

The incidence of storm surge is directly linked to the occurrence of storms with the ability to produce significant wave action. In La Ceiba, cold fronts have produced waves of up to 5 meters in height, while Hurricane Mitch in 1998 produced waves that exceeded 6.5 meters[16]. Anecdotal evidence also suggests Hurricane Fifi in 1974 produced a storm surge of about 5 meters.

Storms do not have to make landfall to produce storm surge. In 2004, Hurricane Ivan generated waves that exceeded 9 meters during its passage through the Caribbean. The storm caused an estimated storm surge between 1.5 and 2 m in La Ceiba, flooding the coastal urban area despite it did not make landfall in Honduras[17].

Three interrelated factors may influence the frequency and extent of coastal flooding in the future: stronger cyclones, sea-level rise, and coastal erosion. First, observed trends in cyclonic activity suggest more intense storms in the future. This is believed to be associated with increasing average surface water temperatures in the Caribbean, which is a factor that determines the strength of tropical cyclones in the Atlantic.

As illustrated in Figure 3-3, over the past 30 years, the percentage of Category 4 and 5 hurricanes that have affected the Caribbean coast of Belize, Guatemala, and Honduras, has increased relative to Category 1-3 storms[18]. This is consistent with predictions regarding the increasing strength of these phenomena.

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13. Storm surge is defined as the abnormal rise of water generated by a storm, over and above the normal astronomical tide, expressed in terms of height above predicted or expected tide levels.

14. NOAA (August 6, 2013) *Defining Storm Surge, Storm Tide and Inundation*

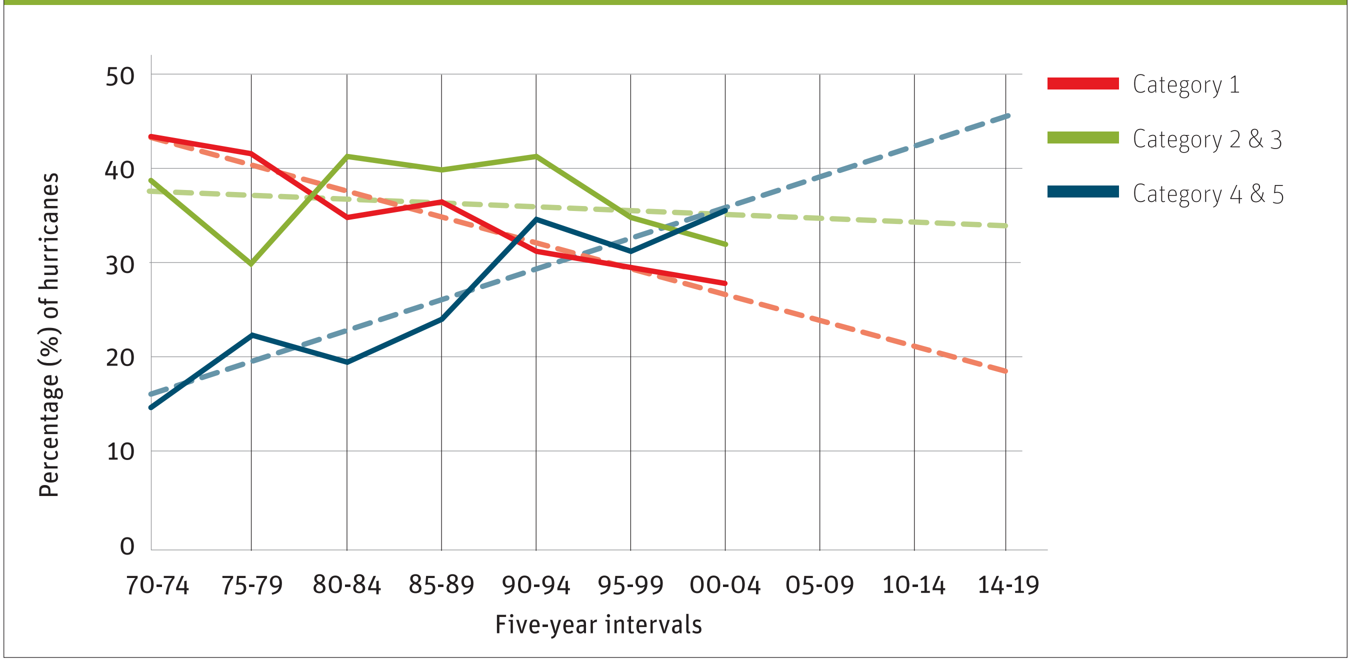
15. Inypsa-Procorredor (2011). *Planes de Desarrollo y Ordenamiento Territorial de la Region IV Valle de Lean: Municipio de La Ceiba*

16. Cardini, Richards and Nichols (2005). *Presentation. Coastal Resource Analysis.* USAID-MIRA.

17. Cardini et. Al. (2005)

18. CATIE-TNC (2012) *Análisis de Vulnerabilidad al Cambio Climático del Caribe de Belice, Guatemala y Honduras.* Developed for the United States Agency for International Aid (USAID)

Figure 3-3: Hurricane incidence by storm category (1970-2004)



Source: CATIE-TNC, 2012

Whether tropical storms and hurricanes will become more frequent events is uncertain[19]. Climate variability is expected to play a role, including ocean water temperatures in the Pacific Ocean linked to the ENSO. Therefore, the frequency and periodicity of these storms will continue to be the focus of climate forecasting efforts.

Sea level rise, which is also a climate-driven factor, will add to the height of storm surge events and likely extend flooding further inland. There is a high degree of confidence regarding the upward trend in sea level rise, though projections for specific locations are more uncertain. Specific to La Ceiba, a study by Smith et al (2011) estimated sea level rise may range between 6 and 60 cm by 2050 relative to 1990 levels (with a middle estimate of 20 cm).

Coastal erosion is the third, and potentially most influential, short-term factor in determining the risk of coastal flooding. In La Ceiba, coastal erosion is the result of natural morphologic processes, which can be influenced by sea level rise and storm surges, as well as by human activities, such as the construction of structures along the coast and mining of the Cangrejal riverbed.

In November 2013, a storm surge event caused damage to at least nine homes in the Miramar neighborhood of La Ceiba[20]. When interviewed, an affected resident, whose home was battered by the waves, said, "there used to be at least 40 meters [between the ocean and her home] and plenty of beach." This anecdote exemplifies the opinion of local experts, which point to the erosion of the shoreline and encroachment of residential and commercial buildings as a major concern[21].

19. Smith and Wigley (2005). *Presentation: Climate Change Scenarios.* USAID-MIRA.

20. Proceso Digital. November 15, 2013. *Marejada daña nueve viviendas en La Ceiba.*
Retrieved online at: www.proceso.hn/2013/11/15/Ciencia+y+Tecnolog%C3%ADa/Marejada.da.C/78080.html

21. Boves, L. (October, 2013). Interview with Red Cross representative.

Figure 3-4 shows a recent photograph illustrating the proximity of the tide with development, east of the historic downtown area.

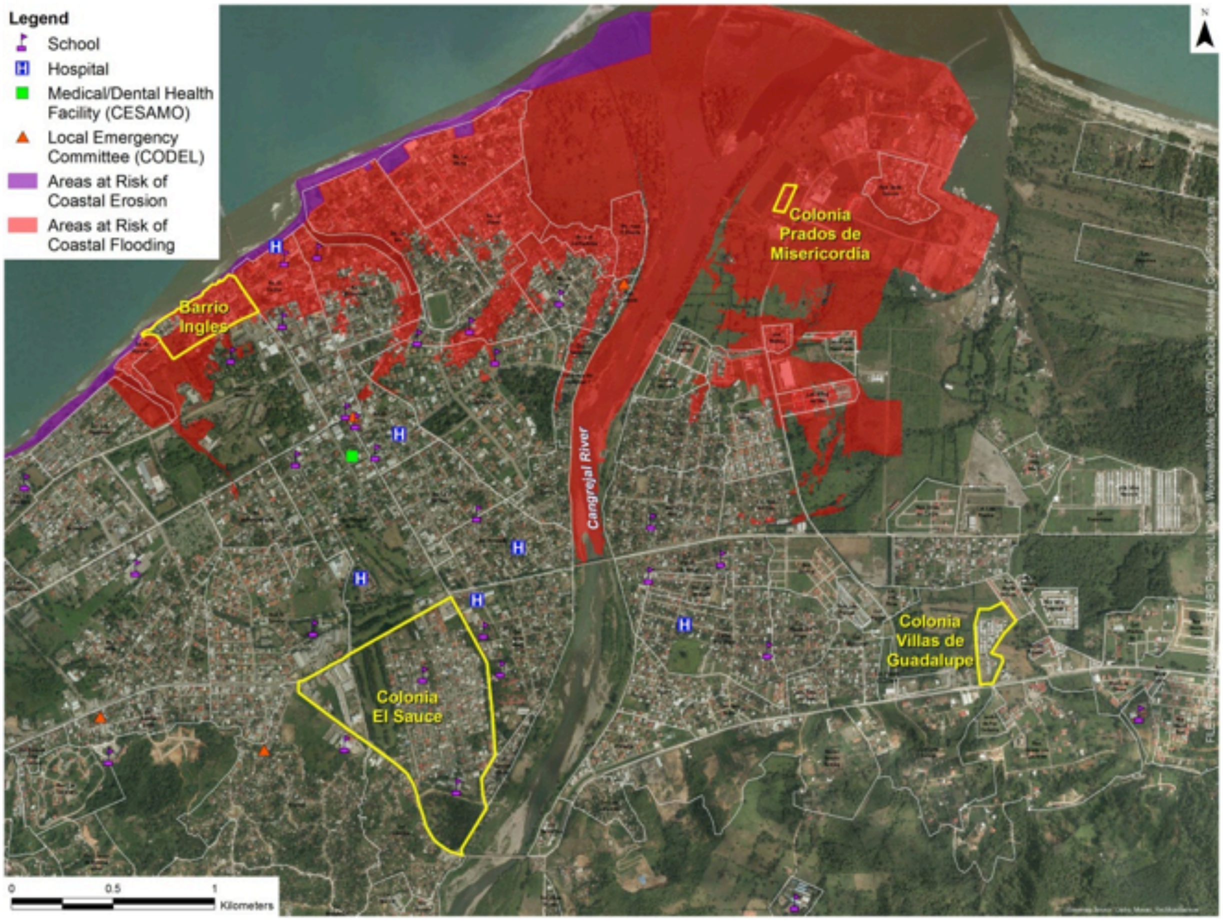
Figure 3-4: Exposed development along the coast in La Ceiba

Source: ERM, 2014

The above figure illustrates the sensitivity of La Ceiba's coastline to the effects of coastal erosion, sea level rise and increased storm intensity. There is significant development along this coast, including established communities, cultural points of interest, public buildings, and businesses, some which are linked to tourism. The areas west of downtown, between the Danto and Bonito Rivers, are also highly vulnerable. Although these are relatively less developed, rapid development is expected in the coming years.

Figure 3-5 shows the areas at highest risk of coastal erosion and a storm surge event of 3 meters, which represents a severe, but likely event associated with an intense cold front or tropical cyclone.

Figure 3-5: Areas at risk of coastal erosion and a 3-meter storm surge event



Source: ERM, 2014

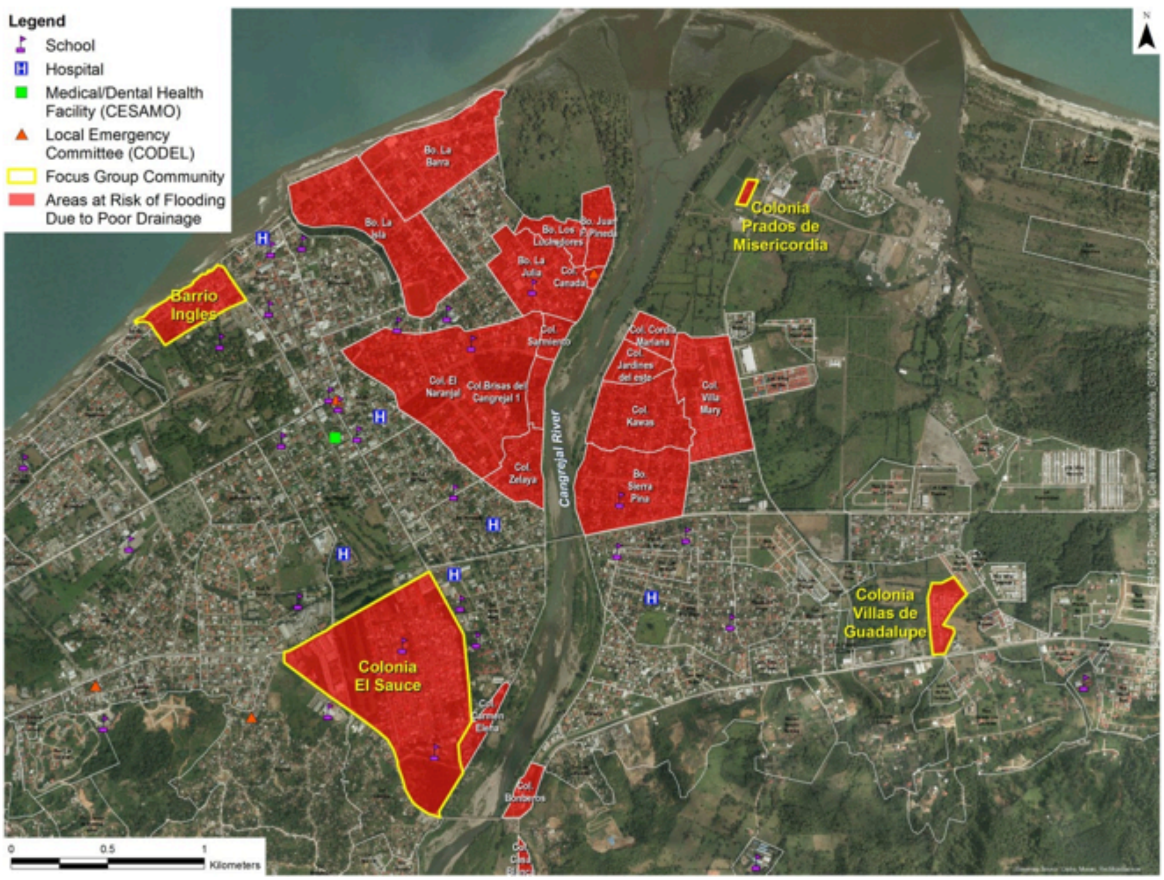
3.1.3 Urban Flooding

Urban flooding is one of the most salient challenges facing La Ceiba, and its high rate of recurrence was a common concern raised by stakeholders during interviews, focus groups and workshops. While other natural hazards pose a greater threat of disaster, the frequent and widespread urban drainage issues take center stage in the local discourse. When considered along with the predicted increase in rainfall intensity due to climate change and variability, adaptation planning becomes a key priority.

According to the director for the local water and sanitation department (OMASAN), "[the frequency of flooding] has been increasing. In just half an hour, rain can flood the city, especially in the months of October, November and December. During the rest of the year, storms also cause damage to the city.[22]" This point of view was seconded by a local climate change specialist, "[floods are] definitely more frequent... it is hard to say by how much because there are no records, but yes, the city is much more vulnerable because even after a light shower it floods.[23]"

As illustrated in Figure 3-6, the risk of urban flooding is widespread throughout the city, but seems to concentrate near the Cangrejal River's floodplain. The effects of this hazard on communities range from mild nuisances to daily life (e.g., traffic delays) to serious risks to human life (e.g., injury, disease) and livelihoods (e.g., destruction of property, disruption of business activity).

Figure 3-6: Areas at risk of flooding caused by the deficient or non-existent drainage



Source: ERM, 2014

Note: The affected communities on this map were identified by local residents during a workshop held on February 2014. This is an illustrative, but not exhaustive, sample of the communities thought to be under frequent threat of flooding due to deficient stormwater drainage.

22. Cruz, P. (October, 2013). Interview with Director, Water and Sanitation Department (OMASAN).

23. Castillo, O. (October, 2013). Interview with climate change coordinator at CREDIA.

The main cause of urban flooding in La Ceiba revolves around the failure of the existing drainage system to efficiently convey stormwater runoff away from low-lying areas where it tends to accumulate and cause flooding.

Local experts point to the uncontrolled growth of the city as one of the main reasons the drainage system is not effective[24]. The lack of urban planning has resulted in a patchwork of residential developments, most which do not connect to a planned drainage system. In some of these cases, new residential developments block the drainage achieved by prior developments; in other cases, residential subdivisions simply gather stormwater and drain it onto the street.

One of the most critical flooding hotspots in the city is the downtown area, where an outdated sewer system is also used for stormwater drainage. This causes the system to collapse with almost every rain shower lasting over 15 minutes. Because the sewage and stormwater systems are combined, flooding typically causes raw sewage to back up onto streets, affecting homes and commercial establishments.

The improper disposal of solid waste and wastewater in these areas can cause increased sedimentation and blockage of the drainage system, thereby reducing their capacity and increasing flood risk. In addition, infrequent maintenance and accumulation of trash and debris substantially reduces the system's overall effectiveness. Unless mitigated, uncontrolled urban development may further overburden the existing drainage infrastructure, exacerbating existing urban flooding issues and public safety concerns.

3.2 Saltwater Intrusion

The intrusion of seawater in the coastal aquifer has been an increasing concern in La Ceiba in recent years. Saltwater intrusion has the potential to diminish the availability of freshwater supply, rendering some areas unsuitable for human development[25] or for continued agriculture. The causes that lead to salinization of drinking water sources are linked in some respects to the changes in climate expected for the region, and are discussed here.

In La Ceiba, groundwater is the main source of freshwater. Over 360 groundwater wells have been accounted for throughout the city, many more are believed to be operating clandestinely. Most of these groundwater wells meet the demand for residential and commercial water uses[26] currently not being serviced directly by SANAA.

According to SANAA, there is confidence that the local water demand can be met into the future. The agency supplies water to about 45% of the urban population, sourced from seven groundwater wells and water withdrawal from the Danto River[27]. Although the Cangrejal River is not a viable drinking water source, due to contamination from agriculture and cattle ranching upstream, other rivers such as the Rio Piedras and Juana Leandra are viable options.

Existing concerns revolves around issues with water quality, including salinization in areas near the coast. The closure of groundwater wells near the ocean is well documented[28]. A technical report developed by SANAA recommends drilling wells no deeper than 20 meters near the coast and 30 meters in other areas to avoid salinization risk[29].

24. Castillo, O. (2013).

25. Anecdotal reports claim that well water has caused allergies and skin irritation among residents of the community of Los Angeles in La Ceiba.

26. Permits for the use of water for agriculture uses are issued by SERNA.

27. Espinal, A. (February, 2013). Interview with Regional Director, SANAA.

28. SANAA (March 2012). *Análisis de Posibilidad de Aguas Subterráneas en el Municipio de la Ceiba.* Division de Investigación y Análisis Técnico (DIAT). Documento No. 827.

29. SANAA (March 2012).

Though many factors can increase salinization risk, saltwater intrusion is typically associated with groundwater overdraft (overpumping), reduction of groundwater recharge, and potential sea level rise[30]. These factors could potentially be at play in La Ceiba, of which the latter two can be directly exacerbated by climate change.

Continued population growth and economic development in La Ceiba will continue to put stress on groundwater resources[31]. Given the utilization of groundwater is not managed, there is the likelihood that in some locations, groundwater overdraft has caused the natural groundwater gradient to reverse and has allowed seawater to intrude coastal aquifers that historically contained only fresh water.

The declining rate at which the groundwater aquifer is recharged may also be a factor, given the continued replacement of natural soils with impermeable surfaces due to development. This is a factor that has not been studied fully. It is however plausible that the combination of continued overpumping and drier-than-average years can lead to a decline in the water table.

Finally, sea level rise can cause tides and storm surges to encroach coastal areas and further inland along the rivers, where it may infiltrate the underlying aquifer. *Section 5.3.3* analyzes the potential effects of a hypothetical rise in sea levels of 0.6 meters and indicates the potential extent of seawater intrusion inland along the Cangrejal River.

3.3 Community Effects due to Natural Hazards

To gain an understanding of the first-hand effects of flooding, ERM conducted focus groups in four La Ceiba neighborhoods, known for being prone to coastal or river flooding or for being located in areas with existing stormwater drainage issues. In varying degree, these neighborhoods also lack the resources and capacity to cope with, recover from, and adjust to the negative effects caused by flooding.

Focus group participants from the four 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 four neighborhoods included Colonia El Sauce (pop: 4,185), Barrio Inglés (pop: 2,398), Colonia Prados de Misericordia (pop: 280), and Villa Guadalupe (pop: 423). These communities are further described in *Chapter 4*. The following are most salient effects identified 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. For example, Hurricane Mitch in 1998 caused 6,500 deaths in Honduras, mostly as a result of flooding and mudslides[32]. While Mitch was an extraordinary event, hurricanes in recent years have also resulted in deaths and significant displacement of communities:

30. Tamayo, C., Fuentes H. (2013). Abstract: Modeling Seawater Intrusion and Sea Level Rise Effects on the Coastal Aquifer of Northern Honduras.

31. Ibid.

32. 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

- 1998: Hurricane Mitch affected 1.5 million people in Honduras, resulting in approximately 6,000 killed, 12,000 injured and 8,000 missing. Close to 285,000 homes damaged or destroyed, while 70% of crops were destroyed. Damages were valued at $3.8 billion[33].
- 2001: Hurricanes Beta caused four rivers to overflow, leaving 11,000 people homeless, damaging 41 bridges and destroying 3,000 hectares of agricultural land. Hurricane Michelle also caused severe flooding, resulting in six deaths and 14 missing[34].
- 2005: Hurricane Stan and Tropical Storm Gamma collectively resulted in 53 fatalities[35].
- 2008: Hurricane Paloma and Tropical Storm Alma displaced thousands of people.
- 2010: During the active 2010 hurricane season, Hurricanes Alex, Karl, Matthew, Paula and Richard, as well as Tropical Storm Agatha, resulted in the evacuation of nearly 45,000 and damaged an estimated 15,370 homes, displacing more than 26,000 residents.

As the above event chronology exemplifies, residents in Honduras are constantly under the threat of harm or displacement due to these climate-driven hazards. At the local level, residents that participated in the focus groups expressed concern about the rapid onset of flooding after heavy rains ensue. In La Ceiba, residents qualified flooding as occurring "without warning", leaving residents with "little time to prepare."

Local residents further noted that once the areas has inundated, flooding typically persists up to 24 hours. Moreover, flooding has become more unpredictable. Residents noted that in the past, rainy seasons were well demarcated, but heavy rains now occur at unexpected times of the year[36], making planning and preparation more difficult.

Property Loss and Damage

Focus group respondents reported that roofs, doors, electrical systems, pipes and paint on homes are frequently damaged during disasters, as well as cars, furniture, and appliances[37]. Table 3-1 presents the estimated costs residents incurred for repairs following three recent flood events.

Table 3-1: Estimated Average Cost of Structural Household Property Damage (US$)

Neighborhood (Hazard Type)	Flood Event (Low Range)	Flood Event (Medium Range)	Flood Event (High Range)
Barrio Inglés (Drainage and Storm Surge)	97 -194	194 – 243	388 – 583
Colonia Prados de Misericordia (River flooding)	243 – 486	N/A	729 – 1,215
Villas Guadalupe (Drainage flooding)	972 – 1,458	N/A	2,431 – 3,403
Colonia El Sauce (Drainage flooding)	97 – 194	97.24 – 243.11	388 – 583

Source: ERM, 2013

33. FAO (n.d.) En Tierra Segura: *Desastres Naturales y Tenencia de la Tierra.*

34. FAO (n.d.).

35. International Institute for Sustainable Development (2013). *Climate Risk Management for Smallholder Agriculture in Honduras.* New York.

36. Interview with Luis Boves, Red Cross Honduras, 2013.

37. ERM sub-contractor, 2013. Community focus groups.

The most affected neighborhoods are characterized by high levels of poverty. In these communities, homes are generally not made with durable materials or features to protect from flooding or extreme weather, such as high winds. Therefore, these structures withstand more damages and are more expensive to repair, worsening the net impact to residents who have the least economic means to incur these costs. Figure 3-4 illustrates the rudimentary construction in an informal settlement along the Cangrejal River, one of the poorest and more vulnerable areas in La Ceiba.

Figure 3-7: Homes in an informal settlement along the Cangrejal River

Source: ERM, 2013

Where homes are also not properly built, residents are often reluctant to evacuate or abandon their homes during emergency conditions. In the community of Villa Guadalupe, respondents reported that thieves often use disaster events as an opportunity to loot homes.

According to respondents in Barrio Inglés, residences and businesses have recently withstood damages due to storm surge. Local sources suggest the entire coastline from the Danto River to the Cangrejal River has eroded between 50 and 80 meters in recent decades; the tide now reaches the urban area at the Nueva York sector in Barrio Inglés[38].

38. Interview with Luis Boves, Red Cross Honduras, 2013.

Loss of Income and Livelihoods

Respondents reported that it is common for them to miss days of work due to flooding, particularly those who work outdoors, such as construction workers, farmers, gardeners, fishermen, or in the informal sector (e.g., street vendors)[39]. In addition, when schools close due to flooding or following the issuance of a warning by COPECO, parents must sometimes miss work to stay home with the children.

Local businesses also miss revenues during blackouts produced by storms or because potential customers do not go about their regular activities under emergency conditions[40]. In the coastal area, several businesses are sometimes affected directly. Commercial establishments along the coastal strip known as the "Zona Viva", which includes hotels, shops and restaurants, have been completely flooded by storm surge in the past[41].

Disruption of Schooling

Participants from focus groups in all four study communities reported that children frequently miss school during flood events or flood warnings[42]. This is particularly the case in neighborhoods that do not have their own schools and therefore transport is required. Parents not only find that transportation is scarce, but also that it is hard to predict whether serious flooding will occur. Even for neighborhoods with schools in closer proximity, parents do not send their children during heavy rains because they fear their children will get sick from unsanitary conditions caused by flooding inside and outside of school buildings.

Additional Monetary and Time Costs

In addition to repair and replacement costs related to property damage, focus group participants also reported additional monetary costs for activities related to preparing and coping with an event. This includes the purchase of rechargeable batteries, flashlights, candles, and taxi fares. Respondents from all four neighborhoods reported additional costs for bottled water, due to disruptions in potable water service during floods.

Recovery efforts also imply additional costs and time investment on behalf of residents. Where public assistance is scarce, communities must take on clean up duties and repair damages to streets and homes. Focus group participants estimated this time investment, which ranged from half a day to pick up debris from the streets (Colonia El Sauce) to twelve days (Villa Guadalupe) to fix damage to houses.

Sanitation and Public Health Risks

In some areas of the city, such as Barrio Inglés, stormwater drainage has been combined with the sewage system. In these areas, flooding causes raw sewage to contaminate the urban environment[43], leading to favorable conditions for the rapid spread of infectious diseases that are transmitted through floodwater. Vermin such as rats and snakes are also reported to be a concern after flood events[44].

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39. ERM sub-contractor, 2013. Community focus groups.

40. ERM, 2013. Focus group in Colonia El Sauce.

41. Boves, L. (October, 2013). Semi-structured interview with Red Cross representative.

42. When COPECO issues warnings, children cannot attend classes at school. From 2013 to 2013, COPECO issued 23 warnings due to cold fronts, heavy rainfall, thunderstorms and earthquakes.

43. ERM, 2013. Focus group in Barrio Inglés.

44. ERM sub-contractor, 2013. Interview with Chamber of Tourism

Pools of standing water after flooding events also provide breeding grounds for mosquitoes, which can transmit diseases such as the dengue fever. As illustrated in Figure 3-5, trash accumulations are common and widespread in certain areas of the city, most notably along the Cangrejal River, which has become an illegal dumping site. Among the causes of this problem, local residents point to an under-resourced solid waste collection system and a culture in which littering is acceptable[45]. Litter is also a factor that exacerbates flooding by clogging drainage systems or natural channels, particularly in areas where trash accumulates.

Figure 3-8: Litter along the Cangrejal River

Source: ERM, 2013

In the informal settlements located along the Cangrejal River, households are not serviced by the sanitary sewer system. Instead, as illustrated in Figure 3-6, residents in these communities rely on latrines that empty into the river, causing environmental contamination and increasing the risk for enteric disease transmission. Direct contact with sewage-contaminated floodwaters can also cause health problems such as wound infections, dermatitis, and eye, nose and throat infections[46].

45. Cruz, P. (October, 2013). Semi-structured interview with OMASAN representative.

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

Figure 3-9: Household latrine in an informal settlement along the Cangrejal River

Source: ERM, 2013

Focus group participants reported having experienced symptoms such as skin irritation, coughing, and diarrhea following a flood event[47]. This suggests the possible incidence of intestinal diseases, such as rotavirus, and other respiratory ailments. Respondents from Colonia El Sauce indicated that parents often keep their children home during floods to prevent them from getting sick.

47. ERM, 2013. Community focus groups.

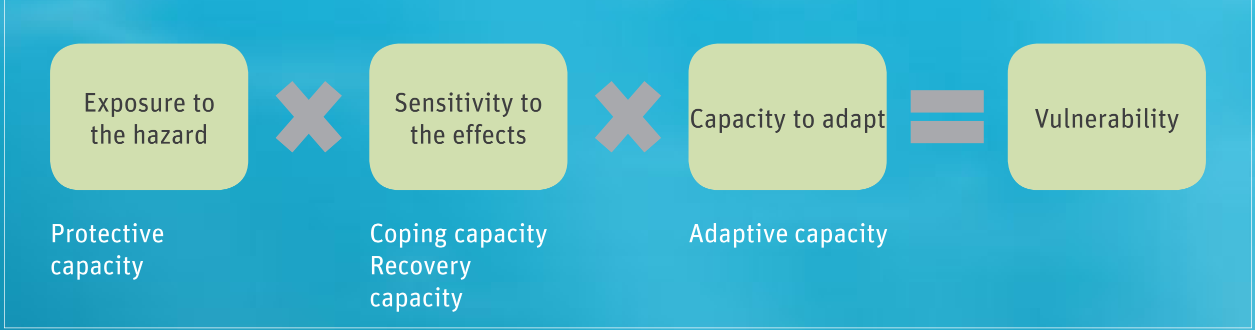
4. Vulnerability Assessment

Vulnerability can be generally defined as "any condition of susceptibility to external shocks that could threaten people's lives and livelihoods, natural resources, properties and infrastructure, economic productivity, and a region's prosperity"[48].

The concept can be further understood as a function of three factors: i) the physical exposure to a hazard, ii) the sensitivity to the impacts, and iii) the capacity to adapt, by reducing the risk of adverse effects or taking advantage of beneficial effects[49].

Figure 4-1 illustrates the approach taken here to assess vulnerability, viewed through the lens of four capacities – protective, coping, recovery, and adaptive. These capacities make up the framework under which vulnerability can be understood at the community level.

Figure 4-1: Factors and Capacities that determine Vulnerability



Source: Adapted from Mertz et al. (2009)[50]

48. Uribe A., et al. (May 1999). *Reducing Vulnerability to Natural Hazards: Lessons Learned from Hurricane Mitch A Strategy Paper on Environmental Management.* Inter-American Development Bank.

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

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

What makes vulnerability a useful concept for adaptation planning is the fact that it not only reflects the physical exposure to the hazard, but it also accounts for the underlying socio-economic factors that can enable or hinder the ability of communities to prepare, cope, recover, and adapt.

Understanding the physical, socio-economic, and ecological conditions that determine vulnerability enables decision-makers to select appropriate interventions based on criteria that consider long-term trends and the needs of specific communities.

Following this conceptual framework, ERM conducted focus groups in four communities of La Ceiba, using a structured questionnaire that elicited respondents to characterize recent natural hazards; describe the damage these events caused; identify the impacts perceived on their health and finances; and suggest ways these impacts could be avoided or lessened.

The findings from this field-based work helped characterize the ability of these communities to prepare, cope, recover and adapt from the climate-driven natural hazards described in *Chapter 3*. It also provided illustrative data on the costs borne by residents due to floods, as well as, the governmental assets and services that are available to them.

Community Assessment Methodology

Vulnerability is highly contextual, either because it can vary significantly among neighboring communities that possess different demographic and socio-economic characteristics, or because the degree to which a community is vulnerable depends on the natural hazard in question.

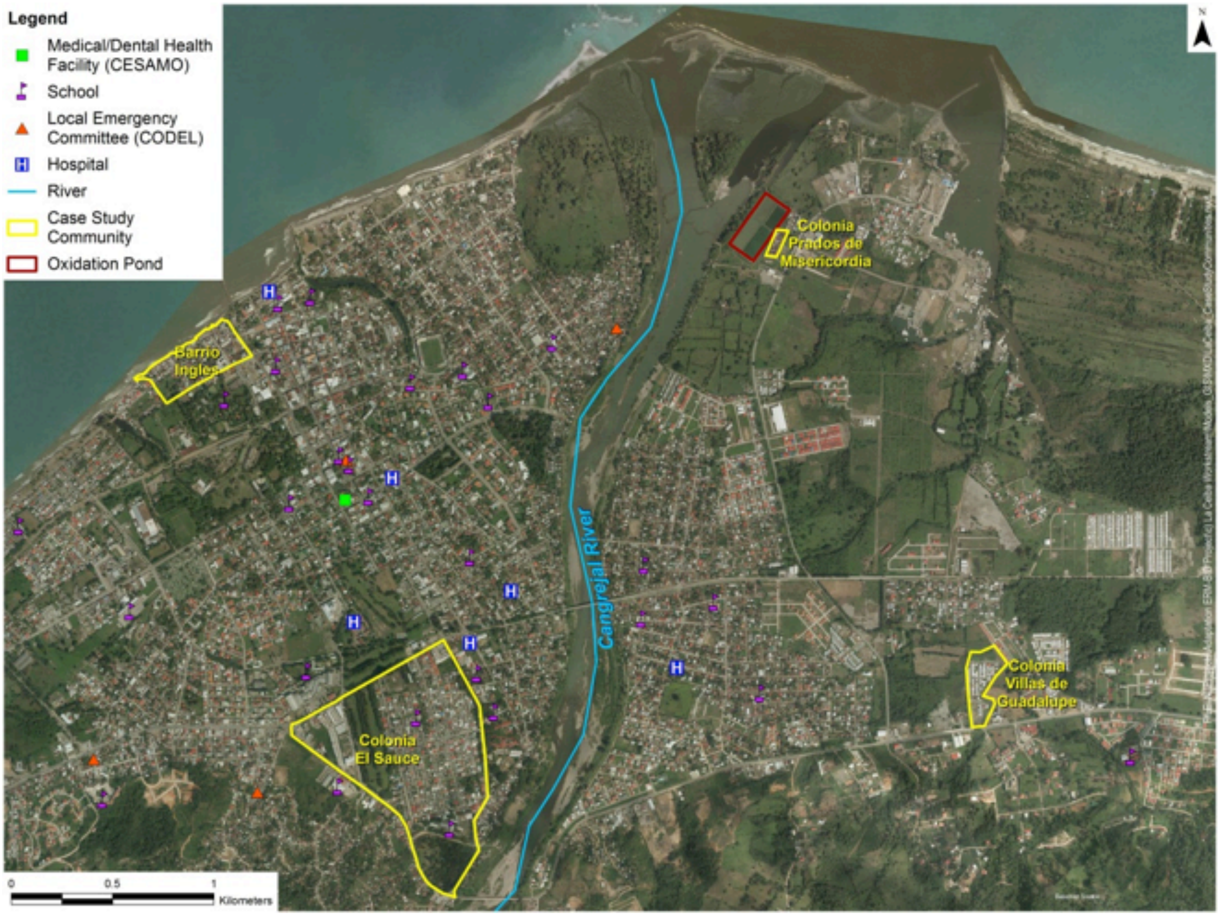
Therefore, this vulnerability assessment focuses on communities that reflect a diverse range of socio-economic conditions and are vulnerable to natural risks, such as flooding. The team selected four communities. These did not include areas where there may be safety concerns, such as the informal settlements along the Cangrejal River.

The selected communities include:

- Colonia El Sauce, a relatively higher income residential neighborhood, prone to flooding due to its proximity to the Cangrejal River;
- Barrio Inglés, which comprises part of what is considered the historic downtown district along the coast, is under threat from coastal retreat and flooding due to its low elevation. Residents include artisanal fishermen and other low-income groups;
- Villa Guadalupe is a low-lying neighborhood where frequent flooding is caused by the inadequate drainage system. The socio-economic status of its residents is very low due to its large proportion of unemployed and dependent individuals; and,
- Colonia Prados de la Misericordia, a low-income neighborhood located adjacent to the wastewater treatment plant. It is at risk of flooding due to its proximity to the Cangrejal River.

Figure 4-2 illustrates the location of these communities relative to the areas identified as prone to flooding and coastal erosion.

Figure 4-2: Location of the communities included in the vulnerability assessment



Source: ERM, 2013

As mentioned earlier, vulnerability is function of the degree of exposure to a hazard, the sensitivity to its effects, and the capacity to adapt in the short- and long-term. Although this definition suggests a high degree of certainty (simply multiply the three components and calculate the risk), it is important to recognize that risk is inherently a subjective concept[51].

Socio-economic conditions can contribute significantly to vulnerability, and vulnerability and poverty are closely linked[52]. For example, families with very low incomes may not have the resources to move away from high-risk areas, nor possess the residual income required to protect their homes from flooding. In general, socio-economic factors play a large role in shaping a community's protective, coping, recovery, and adaptive capacities.

[51] Kuhl, L. (2011).

[52] McGray H, Hammill A, Bradley R. (2007). *Weathering the Storm: Options for Framing Adaptation and Development.* World Research Institute (WRI) Report.

Table 4-1 further explains the four concepts that make up the analytical approach used to assess vulnerability in La Ceiba.

Table 4-1 Capacities that determine vulnerability

Capacity	Explanation
Protective Capacity	Reflects a community's level of exposure to the effects caused by flooding or coastal erosion. The analysis considers factors such as proximity to the Cangrejal River, which can overflow during heavy rainfall; whether the area is prone to flooding due to insufficient drainage; and proximity to the coastline, including elevation. Other secondary factors include quality of home construction or infrastructure in place to protect communities from natural hazards.
Coping Capacity	Represents the ability of communities and people to cope with the adverse effects of flooding, coastal erosion and saline intrusion, 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 return to normal conditions as quickly as possible following the occurrence of a natural hazard. Factors that make up recovery capacity include, for example, the availability of local government – whether through 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 and access to 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 firmly adopted as a factor in development planning.

The rest of this chapter presents the findings of the focus group sessions, complemented by information gathered via interviews with local experts, to provide a snapshot of vulnerability, expressed in terms of the four capacities – protective, coping, recovery, and adaptive.

4.1 Protective Capacity

Protective capacity refers to situations, resources, or measures available to individuals, households, or a community to evade or lessen the effects caused by a natural hazard. This section discusses protective capacity in terms of the following factors:

- Geographic location;
- Flood prevention infrastructure;
- Baseline level of sanitation.

These factors are discussed below.

Geographic Location

The analysis confirmed the fact that the communities along the coast (Barrio Inglés) and close to the Cangrejal River (Colonia El Sauce) were prone to frequent flooding. In Barrio Inglés, residents recalled three recent events in 2013, when the neighborhood flooded by waters of one foot[53] to one meter in height. Residents in Colonia Prados de la Misericordia cited two tropical storms, in 2005 and 2008, which produced flooding of up to two meters when the Cangrejal River overflowed.

53. The foot is an informal term of measurement that corresponds roughly to a third of a meter.

When prompted to mention three recent flooding events, it might have been expected that residents in Barrio Inglés would refer to flooding caused by storm surge. However, respondents attributed the frequent flooding in the community to poor drainage during heavy rains. The following comment illustrates this point, "the houses begin to flood when the water flows back from the drainage pipes, carrying back feces and contaminating homes and the surrounding environment."

Flood Prevention Infrastructure

At the city level, limited infrastructure is in place to protect communities from flooding and coastal erosion. For example, the levee system is considered insufficient to avoid the Cangrejal River from overflowing, while the urban drainage system is considered obsolete, according to an urban planning specialist[54].

The urban drainage system is seen as a primary cause of flooding throughout the city. According to a municipal official, the drainage system was not designed to manage both stormwater and wastewater[55]. During the rainy season, the system frequent collapses due to the volume of both effluents.

The intentional littering of trash, which ends up clogging the drainage system, is generally acknowledged as a problem by residents and public officials. This problem was observed throughout the city, less so in established neighborhoods like Colonia El Sauce, and more so near informal settlements.

According to the director at the municipal water and sanitation department (OMASAN), it is the combined effect of more frequent rains and the trash, which renders the drainage network ineffective, that leads to flooding. Residents expressed the need for better maintenance of drainage channels, including dredging and removal of debris.

At the neighborhood level, residents have developed ways to protect their property against flooding. In Colonia El Sauce, most homes feature concrete walls, built along the perimeter of each property, to contain the flooding. In Barrio Inglés, residents have self-organized to clean up the drainage channels. In Villa Guadalupe, the municipality and CODEM collaborated in dredging a nearby channel.

Baseline Level of Sanitation

Baseline sanitary conditions determine the level of risk to public health in case of flooding. As mentioned earlier, because the drainage system combines sewage and stormwater, flooding typically causes raw sewage to back up onto streets and even homes (confirmed by respondents from Barrio Inglés and Villa Guadalupe, but not Colonia El Sauce, which is a planned residential development). Moreover, respondents in Prados de la Misericordia and Barrio Inglés described their surroundings as particularly unsanitary and reported the presence of flies, rodents and bad odors.

Litter also exacerbates flooding by creating blockages in drainage channels. Residents blame cultural practices and city officials for failing to clean the drainage ditches or provide trash services[56]. Visual observations confirmed the large extent of the problem, particularly around informal settlements, which are not covered by municipal services. Respondents in Colonia El Sauce said that their community is clean because the neighborhood hires a cleaning service for the removal of trash from streets and public spaces.

54. Ulloa, J. (October, 2013). Interview with Urban Planning Dept., Municipality of La Ceiba.

55. Cruz, P. (October, 2013). Interview with Director, Water and Sanitation Department (OMASAN).

56. Kuhl, L. (2011).

4.2 Coping Capacity

Coping capacity is generally described as "the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.[57]" Seen from the neighborhood perspective, coping capacity is the degree to which a community organizes to respond to a natural hazard in the short-term. This section discusses coping capacity in terms of the following factors:

- Socio-economic conditions;
- Demographics;
- Emergency preparedness and response capacity.

These factors are discussed below.

Socio-Economic Conditions

Coping capacity is closely linked to socio-economic conditions because it determines the level of preparations that households are able to make. In general, households with higher income levels can invest more to prepare and therefore are better equipped to cope when a disaster occurs.

Most of the coping strategies employed by residents are adequate for floods that occur with sufficient warning, which allows time for preparations, such as stowing away belongings, and for evacuation as well (despite there is a natural reluctance to abandon homes). The risk of loss of life is lower in this scenario.

In the case of stronger storms, such as hurricanes, the required response is likely beyond the local coping range. These are the events that are central to adaptation planning, given the high risk involved and the prospect of more frequent storms in the future.

Income level determines the ability of residents to cope with flood events due to additional time and money costs involved in procuring bottled water and foodstuffs, transportation (e.g., taxi rides), batteries, and other essential items. In addition to these costs, local residents reported having missed work due to flooding in their communities. Their children also missed school for the same reason. In these cases, transport – due to its scarcity or cost – is a limiting factor.

The poorest are among the least able to cope with disasters, and therefore, some of the most vulnerable. Although, the field team did not directly survey any residents in some of the poorest neighborhoods, visual observations confirmed the poor state of housing and the informal character of the families that have settled on the margins of the Cangrejal River. According to public officials, given that these settlements are not legally recognized, there are implications in terms of disaster response since rescue organizations are required to provide assistance to legally recognized communities first.

Demographics

In terms of demographics, the number of dependents (e.g., children, elderly, and disabled) in a household is an important factor in assessing coping capacity. For example, the presence of disabled residents, who may have mobility issues, would make evacuation or rescue more difficult. Children and the elderly are also more susceptible to injury or health problems during flooding events.

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57. UNISDR (2009). *Definition: Coping Capacity*. Terminology section, UNISDR Web site. Retrieved at: http://www.preventionweb.net/english/professional/terminology/v.php?id=472

Although no data is available to determine the percentage of households with dependents for specific neighborhoods, the focus groups conducted by ERM suggested there is a particularly high percentage of households with dependents in Prados de la Misericordia (>90%) and a relatively low proportion in Villa Guadalupe (40%). Focus group participants in both Barrio Inglés and Colonia El Sauce estimated dependent populations at 60%.

Emergency Preparedness and Response

Much of the infrastructure and services in La Ceiba are sub-optimal for dealing with extreme meteorological events. During storms, potable water systems in some neighborhoods often become clogged with debris and must be shut down for safety reasons. In addition, others have electric treatment pumps, which shut down when electricity service is out. During Hurricane Mitch, communities in La Ceiba went without water and electricity for two weeks following the disaster.

According to the Municipal Risk Management Plan for La Ceiba, 63.2% of the road network is unpaved (252.3 km). In addition, 30.4% of the road network in La Ceiba (12.6% unpaved and 17.8% paved) is considered to lie in areas prone to flooding. Focus group respondents described difficulties traveling to work, school or other locations such as health centers when streets become flooded. Moreover, the cost of transportation increases while the frequency of public transportation (e.g., buses, taxis) diminishes.

The risk management plan also identified areas in which community assets (e.g., health centers, shopping centers) and public infrastructure is at high risk of flooding. This includes four waste disposal facilities and one commercial shopping center. In addition, 5% of the potable water network and 7.4% of the sanitation network are in areas of high flood risk[58].

There are four emergency shelters throughout La Ceiba, with a collective capacity of 900 people. In an interview[59], a representative of the Red Cross considered conditions at the largest shelter, the José Simón Azcona gymnasium, which holds 500 people, to be inadequate. A number of organizations and agencies in La Ceiba are tasked with emergency response, but they are considered to have limitations in terms of capacity, organization and resources.

4.4 Recovery Capacity

Once a disaster is declared, a relatively short period of time exists to plan and initiate recovery operations. In La Ceiba, there are mainly two organizations in charge of recovery operations: COPECO and the Honduras Red Cross. Additionally the municipality, through its Urban Planning Department and Environmental Unit, is also in charge of coordinating recovery efforts. Multiple NGOs reportedly assist in the response and recovery following these events.

COPECO is the institution in charge of coordinating risk management efforts at the regional level. It has a regional office in La Ceiba with a total of five employees who have to coordinate with all the Municipal and Local Emergency Committees (CODEM and CODEL respectively). The Honduras Red Cross has a Risk Management office that works in community education, preparation, response, and rehabilitation. They are focused on developing local emergency plans through school awareness programs. After a disaster, they are typically in charge of distributing humanitarian aid.

According to the interviews conducted by ERM, most of the limitations in risk management and response capacity in La Ceiba are mainly caused by limited financial and human resources[60].

58. Comisión Permanente de Contingencias (COPECO), 2010. *Plan Municipal de Gestión de Riesgos, Municipalidad de La Ceiba.*

59. Boves, L. (2013).

60. Castillo, O. (2013). Interview with climate change coordinator at CREDIA.

Access to Health Services

Respondents from the four different neighborhoods reported instances when residents have suffered respiratory problems, digestive diseases (e.g., rotavirus) and fungal infections following a flooding event. Therefore, restoring sanitary and orderly conditions as quickly as possible following a disaster is a key factor in enabling access to health services and mitigating further impacts to public health[61].

Access to health services is also a major factor that determines the ability of residents to recover from a natural disaster. There are approximately 219 health centers (private and public), 6 Health Municipality Centers (or CESAMOS), and 16 Rural Health Centers (or CESAR) in the Municipality of La Ceiba[62]. As illustrated in Figure 4-2, all study neighborhoods are within 2 km of a health center or hospital. The closest hospitals are the public Atlántida Hospital and the private D'Antoni. However, most residents are unable to afford the services provided at private health facilities.

Community-level organization of clean-up efforts

Despite budget limitations, the municipal Urban Planning Department and the Environmental Unit continue developing response and clean up capacity at the community level. Respondents in Colonia El Sauce and Barrio Inglés reported having participated in campaigns focused cleaning up drainage channels in collaboration with CODEM.

Where urban flooding is regular and fairly foreseeable (e.g., heavy rains or storms), communities commonly make preparations. Community networks within neighborhoods are associated with speedy and more satisfactory recovery outcomes[63]. The Municipal Emergency Plan for La Ceiba identifies the role of these networks as critical. However, during the interviews, respondents expressed they were not organized to respond after an event. Only in Villa Guadalupe did interviewees relate some of the evacuation procedures they follow.

Support networks and recovery programs are driven by CODEM and COPECO with the support of NGOs such as The Red Cross. Typically, their services include providing shelter or food distribution during the aftermath to an event. Long-term assistance programs, focused on rebuilding and financial relief, were recognized as necessary by focus group respondents, but reportedly, the above cited institutions lack the resources or mandate to offer them.

4.4 Adaptive Capacity

Adaptive capacity refers to the ability to adjust to changing and uncertain conditions, and therefore community-level organization and planning can be an indication of capacity.

Observations in the selected neighborhoods suggest that some, although limited, organized flood prevention and mitigation activity is occurring at the neighborhood level. The state of the channels in some of the neighborhoods (unmaintained and full of trash in Prados de la Misericordia) also indicates a lack of community-level action.

An emergency response plan published by the COPECO identifies insufficient capacity of local governments and lack of inter-municipal coordination as key risks for the Municipality of La Ceiba[64].

61. Once the floods subside, the focus group members indicated that a minimum of one week is generally needed in order to clean up the streets and to restore the general order and normalcy.

62. Plan Municipal de Ordenamiento Territorial Caracterización y Planificación Regional. Iberinsa and ESA consultores, July 2010.

63. Nakagawa, Y. Shaw, R. (March 2004). *Social Capital: A Missing Link to Disaster Recovery*. United Nations Center for Regional Development. International Journal of Mass Emergencies and Disasters, Vol. 22, No. 1, pp. 5-34

64. COPECO, 2010. *Plan Municipal de Gestión de Riesgos.* Comisión Permanente de Contingencias (COPECO). Proyecto de Mitigación y Desastres Naturales (PMDN). Municipalidad de Ceiba. Departamento de Atlántida. Sep., 2010. Ibérica de Estudios e Ingeniería, S.A.

Several institutions in La Ceiba (e.g., CREDIA, Tourism Chamber, Municipality) have produced several plans that document critical areas requiring repair of drainage infrastructure in order to prevent flooding, as well as other infrastructure projects needed to mitigate negative effects of unplanned urban growth (e.g. construction of buffer areas around the Cangrejal River, coastal boardwalk).

During the interviews conducted, residents of the selected neighborhoods listed an array of actions that they considered critical in order to promote adaptation to climate change. The list below captures them by order of importance:

- Improving the drainage system;
- Dredging rivers and creeks;
- Improving solid waste management;
- Building or repairing sewer lines in communities;
- Avoiding filling of areas where small winter creeks exist;
- Improving the river banks;
- Not extending construction permits on the river banks;
- Avoiding concession of natural resources;
- Controlling deforestation; and,
- Building public infrastructure that can be climate change resistant.

Municipal Planning Capacity

The municipality lacks the assets (institutional capacity and budget) to effectively implement and enforce development plans that could help to prevent the worsening of climate change hazards[65].

La Ceiba has several planning instruments including the following: Municipal Emergency Plan of La Ceiba, Municipal Plan for Risk Management, Development and Land Planning, Plan of Region IV Lean Valley, and City Plan. Although these plans exist, they are not always effectively implemented due to capacity limitations which undermine risk management efforts. For example, a key recommendation in the Municipal Plan for Risk management is to conduct an assessment of municipal capacity in different units and departments that have a role in risk management; however, this step has not been conducted to date.

Similarly, planning for urban growth in La Ceiba is currently limited. Development controls are rarely enforced when already in place, such as setbacks for development near riverbanks). This ongoing unplanned development in La Ceiba seriously compromises the ability to mitigate and adapt to future climate change risks.

Support from International Aid Community

Due both to its vulnerable location and in part to its potential for tourism, La Ceiba has been a key focus area for the United States Agency for International Aid (USAID), which provides donations and encourages lending from other international financial institutions for a range of development projects related to climate change adaptation. The European Union has also invested in key projects in La Ceiba, such as in founding CREDIA, a regional center focused on facilitating the sharing of environmental and sustainability data and promoting environmental awareness. In all, these investments help promote the capacity of local institutions and individuals to adapt to changing environmental circumstances.

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65. Emergency Response Plan La Ceiba, COPECO. Iberinsa and ESA Consultores, 2010

5. Assessment of Future Climate Change Impacts

Honduras is highly vulnerable to natural disasters, not only because the country is exposed to frequent climate-driven hazards (see *Chapter 3*) but also because these events can significantly impact human populations, infrastructure, and the economy[66]. The severity of those impacts largely depends on factors related to geography, culture, governance, and socio-economic development. These factors determine vulnerability, which is the ability of communities to prepare, cope and recover from a disaster.

The focus of climate adaptation is to address this underlying vulnerability by taking into account how those natural threats will evolve in the future. This chapter examines how climate change may exacerbate the natural risks currently experienced in La Ceiba. Considering a future scenario of climate change, ERM performed a technical analysis aimed at:

- Predicting the extent of flooding due to the overflow of the Cangrejal River by modeling the watershed response to storm events of increasing intensity;
- Assessing the coastal area at risk of flooding given projections of sea level rise and considering the additional effect of storm surge caused by tropical cyclones and cold fronts; and,
- Characterizing the potential adverse effects on drinking water sources due to saltwater intrusion into surface and groundwater.

The rest of this section is organized as follows:

Section 5.1 documents the analysis methodology, by indicating the specific modeling packages employed, the scenarios that were modeled, and the main inputs incorporated in the models.

Section 5.2 presents the projections assumed in the analysis of future climate impacts, and the process by which the land use scenario and climate projections were selected.

66. Harmeling, S. (2009). *Global Climate Risk Index 2010: Who is Most Vulnerable?; Weather-related Loss Events Since 1990 and how Copenhagen Needs to Respond.* GermanWatch Briefing Paper.

Section 5.3 summarizes the technical results for the risks related to river flooding, coastal flooding, and saline intrusion.

Section 5.4 includes a model-based analysis of various stakeholder-proposed options to mitigate the risk of flooding linked to the Cangrejal River.

Section 5.5 concludes the section with a summary of the findings and insights generated during the technical analyses conducted by ERM.

5.1 Methodology

This section documents the methodology followed by ERM to model and evaluate existing and future impacts in La Ceiba as a consequence of riverine or coastal flooding as well as the possible extent of saltwater intrusion along the Cangrejal River. A distinct modeling approach was used for each natural hazard under analysis.

5.1.1 Cangrejal River Flooding

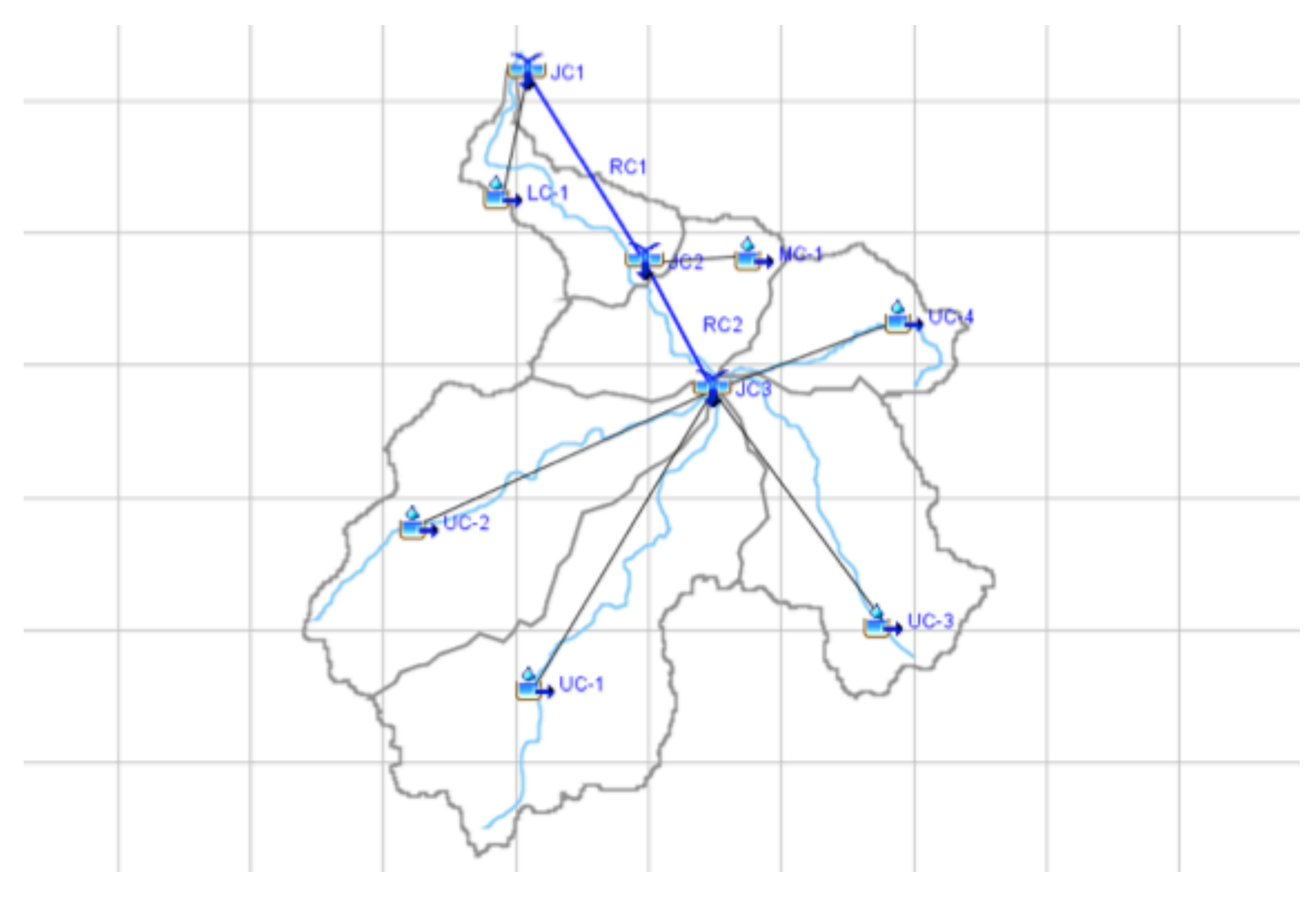
ERM used a hydrological model, a hydraulic model, and topographic and mapping software to assess the extent of river flooding in La Ceiba. The models were selected on the basis of professional judgment, considering the availability of input data and the level of analysis required. In addition, the hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models are publicly available, and they have a history of acceptance in a variety of applications such as this one.

Hydrological Model

ERM set up a hydrologic model (HEC-HMS) to predict the response of the Cangrejal River watershed under different land use and precipitation scenarios. By considering specific land use and soil types in the catchment areas, the hydrologic model quantifies the volume of stormwater runoff that results from precipitation. The model outputs are expressed as peak flows.

HEC-HMS allows the assignment of distinct hydrological characteristics to different watershed areas. As illustrated in Figure 5-1, the Cangrejal River watershed was divided into six catchment areas (subwatersheds).

Figure 5-1: HEC-HMS Model for the Cangrejal River Watershed



Source: ERM, 2013

A time of concentration (Tc) value was calculated for each catchment area based on the morphology of each subwatershed and the runoff curve number (CN). Time of concentration is the total travel time that runoff takes from the farthest point in the watershed to a point of interest[67]. The runoff curve number (CN) is a unit-less hydrological parameter that represents the percentage of precipitation that does not infiltrate into the soil and therefore becomes runoff. The CN is a function of cumulative precipitation, soil type, land use, and antecedent moisture[68].

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67. USDA, 1986. Urban Hydrology for Small Watersheds. TR-55.

68. Wanielsita, M., Kersten, R., and Eaglin, R. 1997. *Hydrology: Water Quantity and Quality Control.* Second Edition. John Wiley and Sons, Inc. Pg. 567.

ERM consulted reference material published by SERNA, SINIT, and the Hydrology Reference Manual for Honduras[69] to calculate and assign a composite CN value for each subwatershed within the Cangrejal River watershed. The information obtained from Honduran agencies included soil types, land use classification, and reference CN values for different soil types and land use.

Table 5-1 summarizes the hydrological characteristics assigned to each catchment area within the Cangrejal River watershed.

Table 5-1 Hydrological Characteristics of the Cangrejal River Watershed

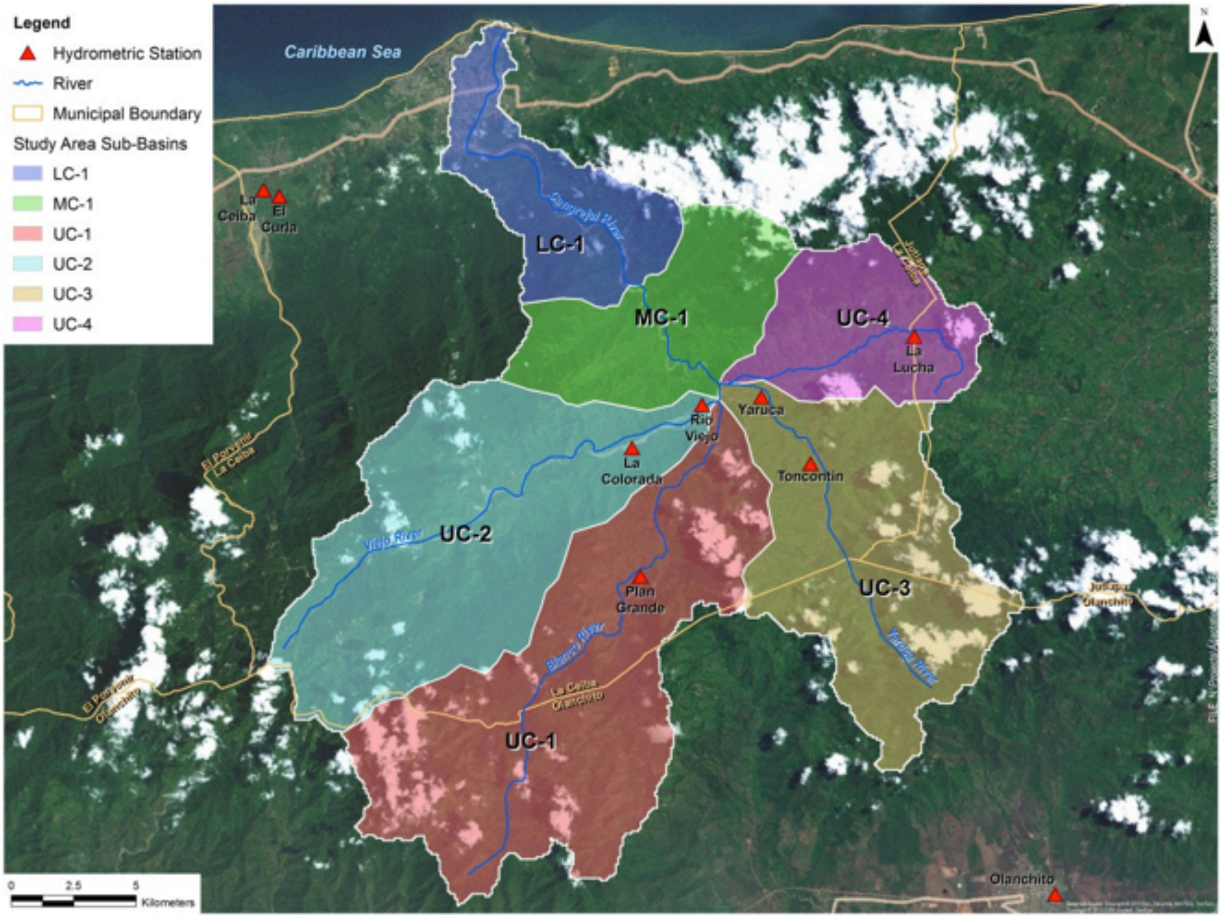
Sub-Watershed	River	Area (Km^2)	CN*	Tc (Hours)
UC-1	Rio Blanco	146.35	54	20.05
UC-2	Rio Viejo	128.91	55	13.84
UC-3	Rio Yaruca	98.38	54	15.80
UC-4	Tributaries	46.75	53	15.11
MC-1	Cangrejal	54.46	64	11.58
LC-1	Cangrejal	47.58	66	18.90

Note: The composite CN was estimated based on soil and land use data, as well as, reference values found in the Hydrology Reference Manual developed by INTEMAS.

In addition to soil type and land use data, precipitation is the other major input that determines the output of the hydrological model. ERM used precipitation data derived from the intensity-duration-frequency (IDF) curves for 20- and 50-year storm events. The IDF curves were constructed by INTEMAS based on historical precipitation data from five hydrometric stations, four of which are located inside the Cangrejal River watershed and one is located at the Golosón International Airport in La Ceiba. Figure 5-2 below shows the location of these stations in the vicinity of La Ceiba.

69. INTEMAS. Manual de Referencias Hidrológicas para el Diseño de Obras de Drenaje Menor. INTEMAS y el Fondo Hondureño de Inversión Social. Dirección de Medio Ambiente.

Figure 5-2: Location of Hydrometric Stations



Source: INTEMAS, 2013.

Given the limited historical data, the IDF curves found in the INTEMAS study did not provide precipitation estimates for a storm event with a 1:100 probability of occurrence. ERM predicted these precipitation values for each of the five stations based on available historical data (1965-2009) from La Ceiba (Golosón) station and mathematical correlations with the other stations.

Table 5-2 presents the volume (in millimeters) associated with 24-hour precipitation events for 20-year, 50-year, and 100-year storm events, also known as return periods (Tr).

Table 52: Precipitation Estimates for Three Return Periods

Sub-Watershed	Hydrometric Station	Precipitation (mm) in 24 hours		
		Tr=20	Tr=50	Tr= 100
UC-1	Plan Grande	272.9	324.4	355.5
UC-2	Rio Viejo	295.3	349.9	383.5
UC-3	Yaruca	409.1	488.7	535.6
UC-4	La Lucha	283.7	327.3	358.7
MC-1	Golosón	528.9	620.5	680.0
LC-1	Golosón	528.9	620.5	680.0

Source: Adapted from the intensity-duration-frequency curves prepared by INTEMAS

Hydraulic Model

While the hydrologic model (HEC-HMS) predicts the peak flows at specific points in the watershed, the hydraulic model (HEC-RAS) simulates the conveyance of these water flows along the river channel and its banks. The hydraulic model permits the identification of areas along the river that are at risk of flooding by comparing peak flows at pre-determined points (cross-sections) against the river channel dimensions and adjacent topography.

A detailed HEC-RAS model was built for the river's course through urban La Ceiba. ERM used cross-section data compiled by the United States Geologic Survey (USGS) for a 2002 flood mapping study[70]. The data was based on a digital elevation model scaled at a 1.5-meter cell resolution.

Modeled Scenarios

ERM simulated 20-year, 50-year, and 100-year storm events under different land use and climate change scenarios. Comparison of model results for the different scenarios provides information on the relative contribution of land use and climate change as factors in driving flooding risk. An understanding of these factors can inform the development of targeted interventions to alleviate existing and projected flooding risks.

Table 5-3 explains the scenarios considered in the hydrological and hydraulic analysis and indicates the nomenclature used in referring to these scenarios through the remainder of this report.

70. Kresch, D.L., Mastin, M.C., and Olsen, T.D. 2002. Fifty-Year Flood-Inundation Maps for La Ceiba, Honduras. U.S. Geological Survey Open-File Report 02-254. U.S. Department of the Interior-U.S. Geological Survey

Table 5-3: Scenarios considered in the hydrological and hydraulic 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

The final step in the analysis of risks associated with Cangrejal River flooding was to overlay water surface elevation (i.e., HEC-RAS output) on the existing topography to create flooding maps. This last step involved the use of the HEC-GeoRAS software, a digital elevation model (DEM) for La Ceiba, and mapping software to generate geo-referenced maps (ArcGIS).

Overlaying model outputs on maps showing communities and infrastructure is a powerful way to quickly characterize the extent of flooding and identify critical points of human vulnerability and economic assets at risk. It also allows the user to visualize the location and extent of additional flooding that may occur as a result of future conditions (2050) due to the incremental effect of changing climate and land use trends.

5.1.2 Coastal Flooding

Floods produced by storm surge and increased sea levels projected for La Ceiba were evaluated using available topographical data (two digital elevation models) and geographic information system (GIS) tools. This approach is a simple but conservative way to evaluate floods in coastal areas.

Analysis and Modeled Scenarios

ERM plotted each DEM in GIS and assigned different ranges of elevation (in 1-meter increments). The assigned ranges of elevations display what areas of La Ceiba could present potential flooding risk due to storm surge and sea level rise. Two scenarios, consisting of existing sea levels, represented by an elevation of 3 meters in the DEMs, and projected sea levels, represented by an elevation of 3.6 meters in the DEMs, were used to evaluate coastal flooding for the city of La Ceiba and its coastal floodplain (refer to Table 5-4).

The first DEM with 1.5-meter cell size, obtained from USGS, was used to evaluate coastal flooding for the urban area of La Ceiba. The second DEM with 30-meter cell size, downloaded from NASA, was used to evaluate the risk of flooding along the coast.

Table 5-4: Scenarios Considered for the Coastal Flooding Analysis

Scenario	Explanation
Existing Conditions (EC)	This baseline scenario reflects a snapshot of the existing conditions based on current storm surges of 3.0 m at the Caribbean Sea.
Future Conditions (FC)	Represents a future storm surge of 3.6 m. The 3.6 m considers the existing conditions plus the projected sea level rise (+0.6 m).

Interpretation of Model Outputs

The final step in the analysis of risks associated with coastal flooding was to evaluate potential areas at La Ceiba that could be impacted by current and future storm surges. This last step involved production of elevation maps for La Ceiba using ArcGIS.

5.1.3 Saline Intrusion

ERM used a two-dimensional hydrodynamic and water quality model (CE-QUAL-W2) to evaluate saltwater intrusion along the Cangrejal River. The model was selected on the basis of professional judgment, considering the availability of input data, morphology of the studied water body, and the level of analysis required. Also, the hydrodynamic and water quality model (CE-QUAL-W2) is publicly available and has a history of acceptance and application in the analysis of saltwater intrusion in water bodies.

Hydrodynamic and Water Quality Model

ERM constructed a CE-QUAL-W2 model for the Cangrejal River based on available topography, climatological, stream flow, salinity, and water temperature data. Climatological data, including air temperature, dew point temperature, wind speed and direction, and cloud cover were obtained from the NOAA website, which compiles data obtained from the meteorological station at the Golosón International Airport[71] in La Ceiba.

The model also required setting boundary conditions at upstream and downstream locations relative to the area of study. In this case, the upstream boundary condition is the Las Mangas gauging station, which is located approximately 3.5 km from the mouth of the Cangrejal River. As per the 2004 to 2009 records shown in Table 5-5, ERM used the lowest stream flow value available (4.88 m^3/s) at Las Mangas as the upstream condition.

71. NOAA, 2014. La Ceiba Airport (15.733º lat; and -86.867º Lon).

Table 5-5: Historical Stream Flow Data from Las Mangas Gauging Station

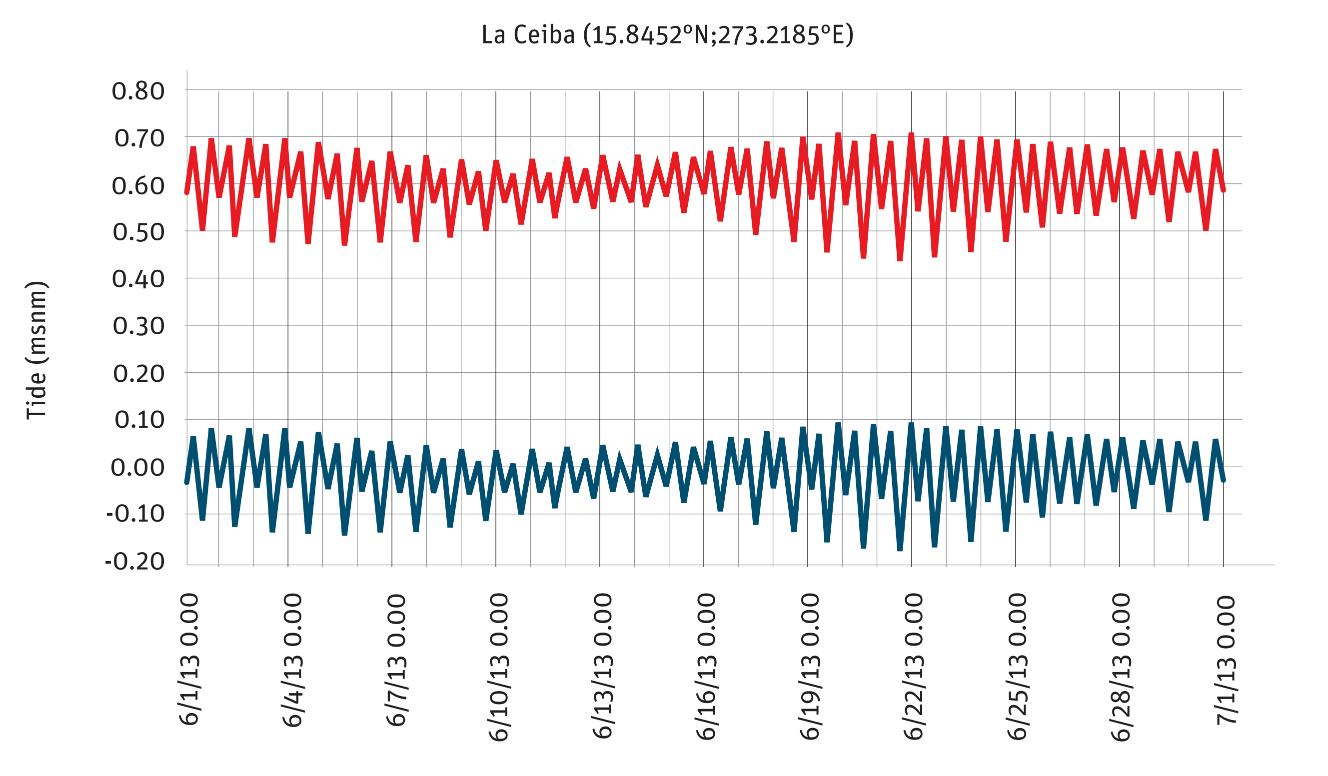
Date	Stream Flow (Q) (m^3/s)	Date	Stream Flow (Q) (m^3/s)
10-Sep-04	14.86	05-Aug-09	13.59
24-Nov-04	11.12	23-Apr-10	7.91
3-Mar-05	8.55	23-May-10	13.90
27-Jun-05	13.25	09-Apr-11	5.29
7-Nov-06	8.19	19-Jun-11	6.10
5-Aug-07	6.70	27-Aug-11	6.83
12-Dec-07	14.44	15-Feb-12	22.26
21-Jun-08	4.88	20-May-12	21.58
19-Feb-09	16.03	27-Aug-12	8.59
20-May-09	10.56	21-Feb-13	13.72

Source: Empresa Nacional de Energía (ENEE)

The downstream boundary was determined by tide values at a location within the Caribbean Sea close to the coast of La Ceiba[72]. As illustrated in Figure 5-3, continuous tide data from the TPX08-Atlas for 2013 was used to construct a tidal cycle model.

72. http://volkov.oce.orst.edu/tides/tpx08_atlas.html

Figure 5-3: Tidal Cycle Model for La Ceiba

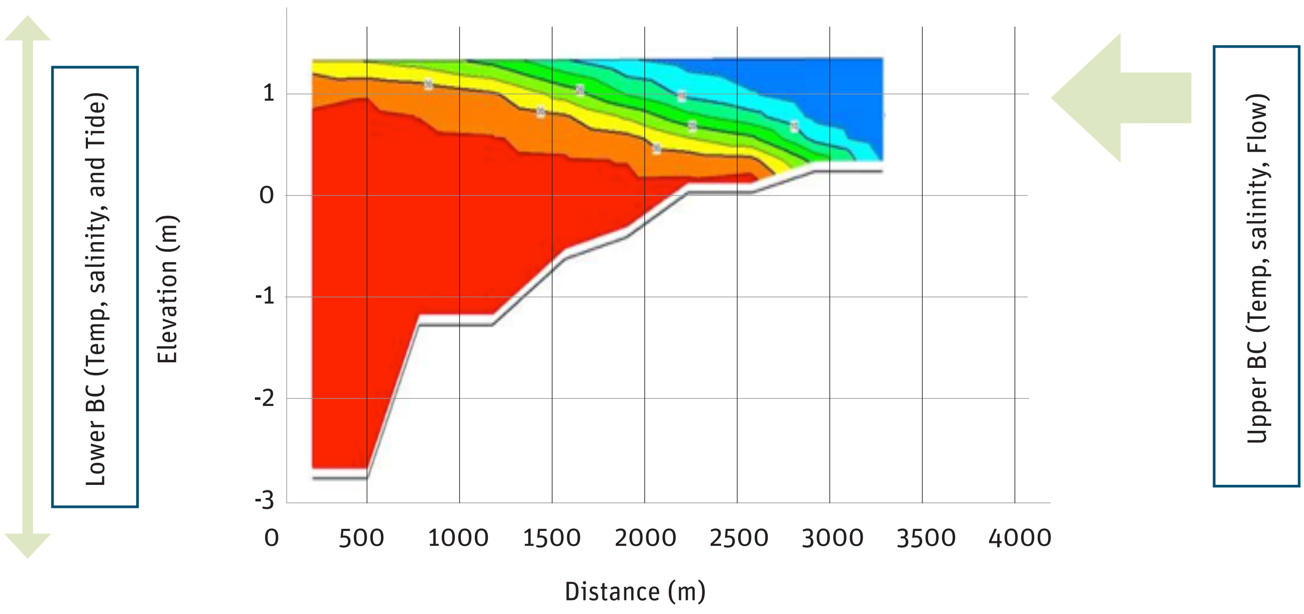


Source: TPX08-Atlas

Other boundary parameters such as freshwater and ocean temperatures and salinity were obtained from literature[73]. Freshwater salinity at the upstream boundary of the Cangrejal estuary was assumed to be zero. Figure 5-4 shows the locations of boundary conditions (BC) assumed in the hydrodynamic and water quality model.

73. http://www.nodc.noaa.gov/cgi-bin/OC5/SELECT/woaselect.pl?parameter=2

Figure 5-4: Boundary Conditions for the 2-D Hydrodynamic Model of the Cangrejal River



Source: ERM, 2014

Modeled Scenarios

ERM simulated two scenarios reflecting different sea level conditions. The results for both scenarios were compared to analyze the relative contribution of climate change, particularly sea level rise, as a factor in driving saltwater intrusion risk along the Cangrejal River. Table 5-6 explains the scenarios considered in the hydrodynamic analysis.

Table 5-6: Scenarios Considered in Hydrodynamic Analysis

Scenario	Explanation
Existing Conditions (EC)	This baseline scenario reflects a snapshot of the existing conditions based on current fluctuation of tides at the Caribbean Sea; and the lowest freshwater flow recorded at Las Mangas, which is 4.88 m^3/s.
Future Conditions (FC)	Represents a conservative assumption of sea level rise for 2050 (+0.6 m); and the lowest freshwater flow at Las Mangas of 4.88 m^3/s.

Interpretation of Model Outputs

The final step in the analysis of risks associated with saltwater intrusion along the Cangrejal River was to estimate the location of the salt wedge, particularly during high tide conditions, under existing and future sea level scenarios. An output grid was created using the 1.5-meter DEM obtained from the USGS and the software GEMSS (Generalized Environmental Modeling System for Surface waters). The GEMSS is proprietary software developed by ERM to model time- and space-varying hydrodynamics for non-steady state analyses.

It is important to note that the surface-water hydrodynamic model cannot be used to directly evaluate salt-water intrusion in groundwater. As a result, ERM recommends a different approach in future studies involving the monitoring of water wells and sampling of water quality. These data can provide the inputs necessary to construct 2-D or 3-D groundwater models.

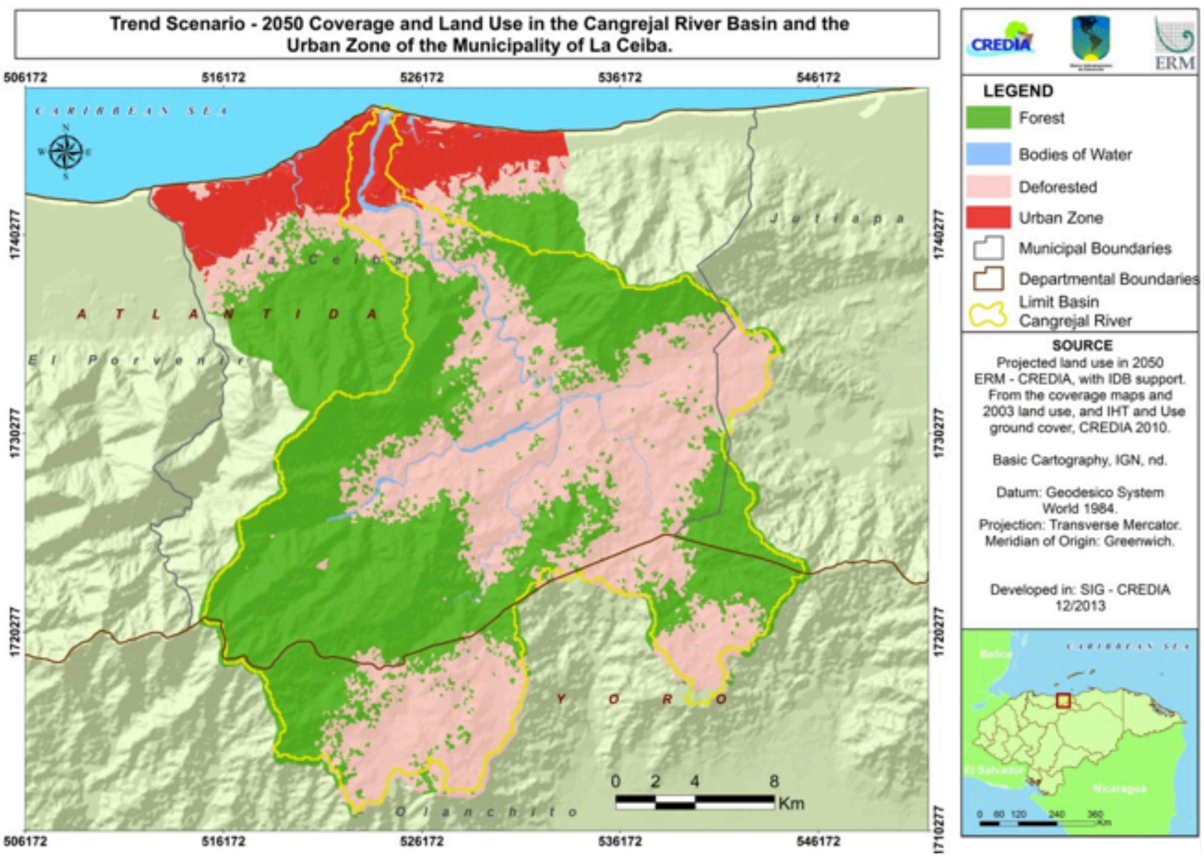
5.2 Land Use and Climate Change Projections

The forward-looking scenarios considered in this study were constructed on the basis of projections of land use and climate for the 2050 planning horizon.

5.2.1 Land Use

Land use projections for 2050 were generated based on historical trends of land use change, derived with the use of statistical software, and calibrated based on feedback from local experts during a half-day workshop held in La Ceiba in December 2013. **Annex B** documents the methodology used in constructing the projected land use scenario. Figure 5-5 shows the resulting land use map for 2050 after stakeholder input.

Figure 5-5: Projected Land Use under the 2050 Scenario



Source: CREDIA, 2013

Table 5-7 compares the land use under existing conditions and the projected scenario of land use.

Table 5-7: Existing and Projected Land Use for the Cangrejal River Watershed

Scenario	Forest	Water bodies	Deforested	Urban Zone
Existing Conditions (2010)	57.9%	1.4%	39.5%	1.2%
Future Scenario (2050)	50.4%	1.4%	46.5%	1.7%

Source: CREDIA, 2013

5.2.2 Climate Projections

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.

In 2010, the Honduran Ministry of Energy, Natural Resources and Environment[74] (SERNA) published the country's National Strategy on Climate Change. This document provides climate projections for the 2050 planning horizon under two greenhouse gas (GHG) emissions scenarios. A study[75] by Argeñal (2010) documents the use of the MAGICC/SCENGEN V5.3 climate model to generate these projections.

The government-endorsed projections partially fulfilled the information needs for the technical analysis, which also required projections for change in precipitation intensity and change in sea level rise. These additional variables are key inputs to the hydrological model undertaken for the study of the Cangrejal River watershed. ERM also conducted additional research to identify forecasts specific to the La Ceiba region and to compile data relevant to conditions associated with storm-related weather events in the future such as hurricanes.

As a result of the literature review, the study by Smith et al. (2011) emerged as a key source of information on projections corresponding to sea level rise and storm-related variables (e.g., precipitation intensity). Smith et al. also relied on the MAGICC/SCENGEN model to generate global mean temperature change projections, which were then downscaled to yield estimated changes in monthly temperature and precipitation at the regional level.

Table 5-8 below summarizes the selected value and source for the two climatic variables used in this study.

Table 5-8: Selected Climate Change Variables

Parameter	Projection	Source
Precipitation Intensity	13% Increase	Smith et al. concludes an increase in rainfall intensity for short-term events such as hurricanes.
Sea Level	0.60 m Increase	Conservative value estimated by Cardini and Richards (2005), as cited in Smith et al., 2011.

74. Secretaría de Energía, Recursos Naturales, Ambiente y Minas (SERNA)

75. Argeñal, F. (2010). *Variabilidad Climática y Cambio Climático en Honduras.* SERNA. PNUD.

5.3 Technical Results

This section presents the results of the analysis conducted by ERM to evaluate the areas at risk due to river and coastal flooding, as well as the results of the model predicting the extent of salt-water intrusion along the Cangrejal River.

5.3.1 Cangrejal River Flooding

As discussed in *Section 5.1.1*, the hydrological model was set up to estimate the peak stormwater flow at several pre-determined points within the Cangrejal River watershed. ERM calculated peak stormwater flow values for four different scenarios and three different return periods (20, 50, and 100 years). Peak flow estimates represent the maximum volume of water passing through a given point as a result of a precipitation event. Table 5-9 presents the peak flows, in cubic meters per second (m^3/s), which were estimated at the point most relevant to analyze flooding risk in urban La Ceiba.

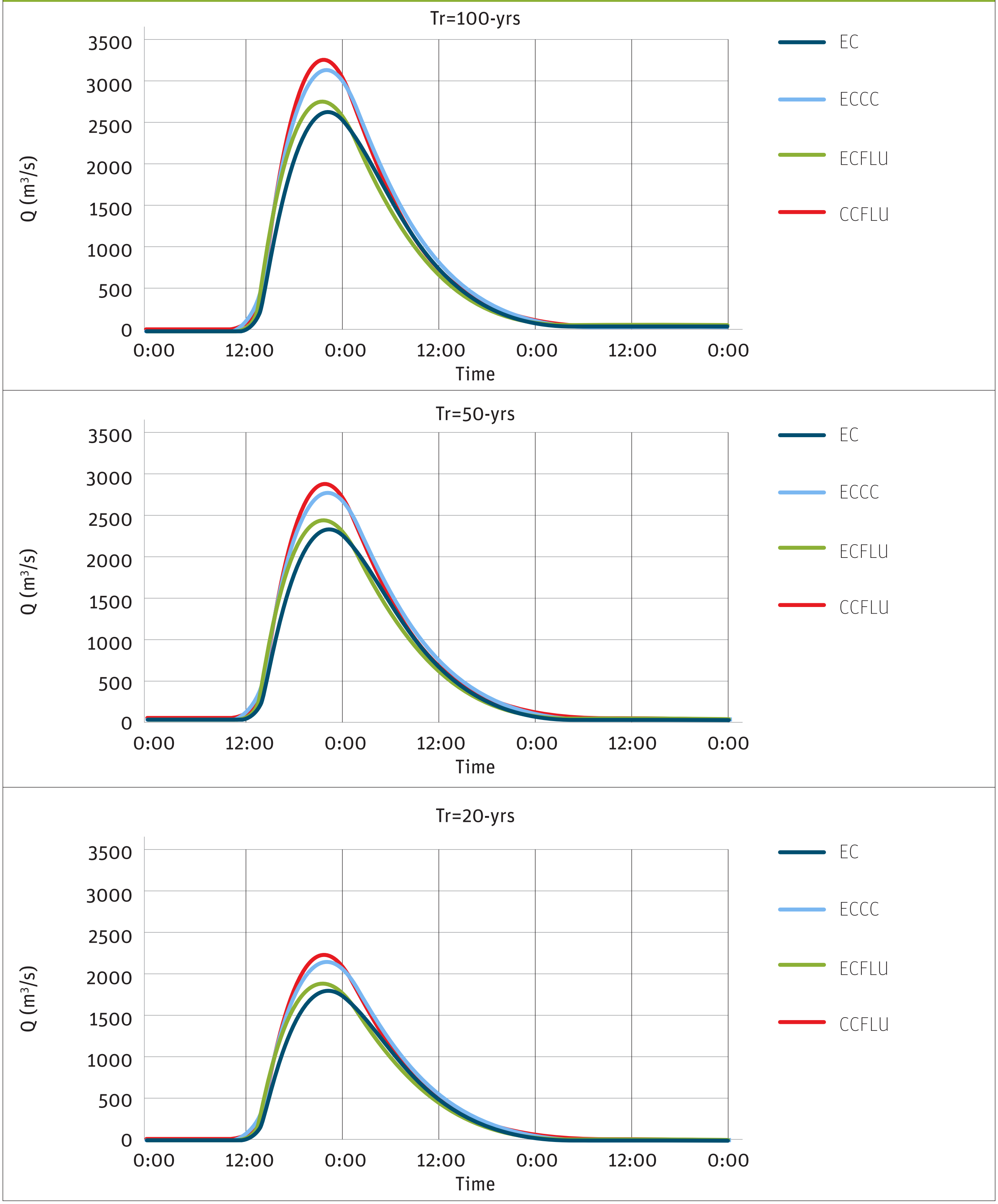
Table 5-9: Peak Flow Estimates for the Cangrejal River

Location	Return Period	Peak Flows Modeled for Each Scenario (m^3/s)			
		CA	CC	FUS	CC + FUS
Downstream La Ceiba	20	1814	2178	1888	2263
	50	2327	2772	2413	2869
	100	2654	3149	2749	3256

Source: HEC-HMS model output, 2013.
Note: 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 5-6 shows the peak flows generated from the hydrological HEC-HMS model for the four different scenarios.

Figure 5-6: Hydrographs Generated at a Downstream Point for Three Return Periods



Source: ERM, 2014.
Note: Water flow is expressed in cubic meters per seconds (m3/s). The abbreviations correspond to the following scenarios:
EC: Existing Conditions / ECCC: Climate Change Only Scenario
ECFLU: Land Use Changes Only Scenario / CCFLU: Climate Change and Future Land Use Scenario

Once the peak flow values were estimated with the hydrological model, the hydraulic model (HEC-RAS) was used to predict the elevation of the water flow along the river channel. This hydraulic simulation enabled the creation of inundation maps for the four different scenarios and three return periods. Table 5-10 and 5-11 present the maximum water depths and estimated flood areas, respectively.

Table 5-10: Water Depth Estimates as per HEC-RAS

Scenario	Tr=20		Tr=50		Tr=100	
	Max Depth (m)	%D Depth	Max Depth (m)	%D Depth	Max Depth (m)	%D Depth
CA	5.03	0%	5.7	0%	5.92	0%
CC	5.44	8%	6.03	6%	6.37	8%
FUS	5.13	2%	5.82	2%	6.01	1%
CC+FUS	5.54	10%	6.13	8%	6.46	9%

Source: ERM, 2014

Table 5-11: Flood Areas as per HEC-GeoRAS

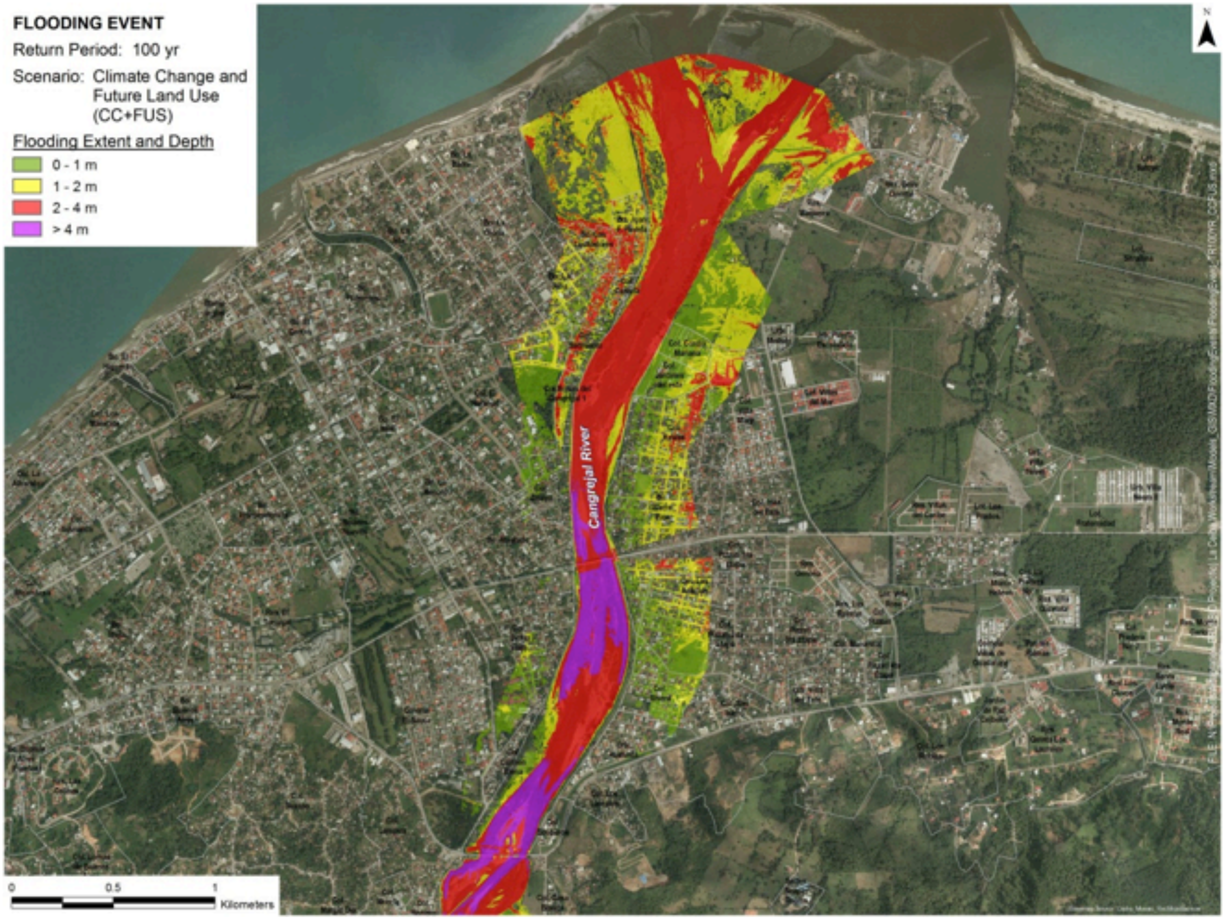
Scenario	Tr=20		Tr=50		Tr=100	
	Flood Area (km^2)	%D Area	Flood Area (km^2)	%D Area	Flood Area (km^2)	%D Area
EC	2.57	0%	2.80	0%	2.95	0%
EC+CC	2.77	8%	3.02	8%	3.16	7%
EC+FLU	2.59	1%	2.83	1%	2.99	1%
CC+FLU	2.74	7%	3.06	9%	3.19	8%

Source: ERM, 2014
Note: 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

The results show that potential changes in climate, leading to rain episodes of greater volume and intensity, had the greatest effect on peak flows and area under risk of flooding. Conversely, the changes in land use predicted for 2050 did not seem to cause a significant increase in predicted peak flows, consistent with a view that degradation in the Cangrejal watershed will be limited by ongoing conservation efforts.

Figure 5-7 shows the inundation map corresponding to the predicted conditions during most extreme projected scenario for La Ceiba due to riverine flooding.

Figure 5-7: Flood map depicting the areas under risk for a 100-year storm event



Source: ERM, 2014

Considering the hazard classification established by COPECO[76] as a basis for analysis, the results of the river flooding modeling predicts a number of areas in urban La Ceiba that could be classified as high risk. The classification used by COPECO is as follows:

- **Low:** Water depth between 0 and 1 m;
- **Medium:** water depth between 1 and 2 m; and
- **High:** water depth greater than 2 m.

76. COPECO, 2010. *Plan Municipal de Gestión de Riesgos.* Comisión Permanente de Contingencias (COPECO). Proyecto de Mitigación y Desastres Naturales (PMDN). Municipalidad de Ceiba. Departamento de Atlántida. Sep., 2010. Ibérica de Estudios e Ingeniería, S.A.

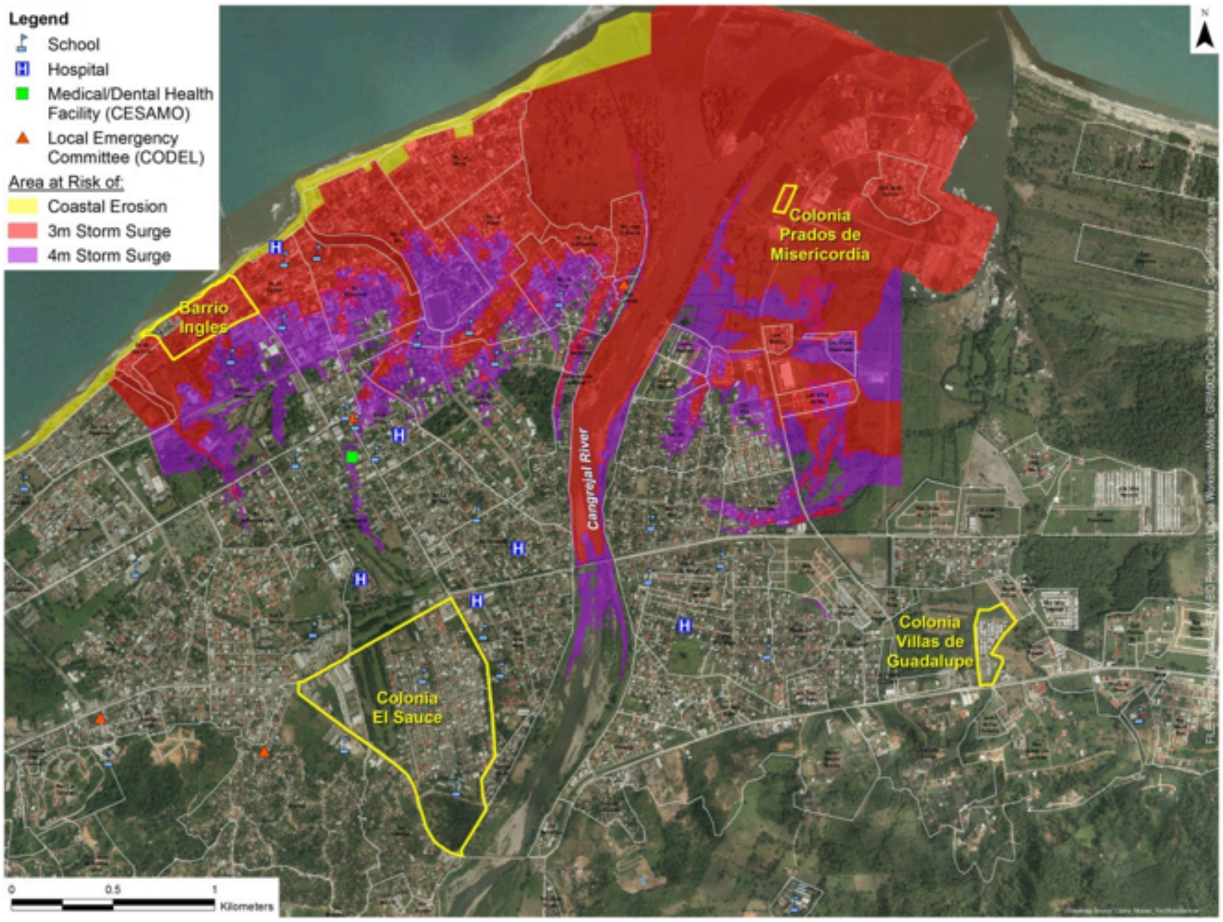
5.3.2 Coastal Flooding

ERM assessed the potential for flooding along the coast by comparing the depth associated with a 3-meter storm surge event and the detailed digital elevation map (DEM) available for a partial section of La Ceiba's coastline. Maps were built upon a DEM with 1.5-m resolution using visualization software (ArcGIS).

A 3-meter storm surge event was selected given the relative frequency with which it occurs based on historical records. To illustrate the additional effect associated with the potential rise in sea levels, assumed here to be 60 cm, a storm surge event of 4 meters was also depicted on a coastline elevation map.

Figure 5-8 shows the areas under risk of flooding relative to the two storm surge events described above.

Figure 5-8: Areas under risk of flooding due to storm surge



Source: ERM, 2014

5.3.3 Saline Intrusion

The hydrodynamic model (CE-QUAL-W2) results indicated that the salt wedge can extend up to 2.8 km upstream from the mouth of Cangrejal River, as illustrated in Figure 5-9. This figure also shows the salt wedge reaching up to 3.2 km inland when factoring in a 60 cm rise in mean sea level and low stream flow conditions (4.88 m^3/s).

Figure 5-9: Maximum salinity levels along the Cangrejal River (21 June 2013, dry season)

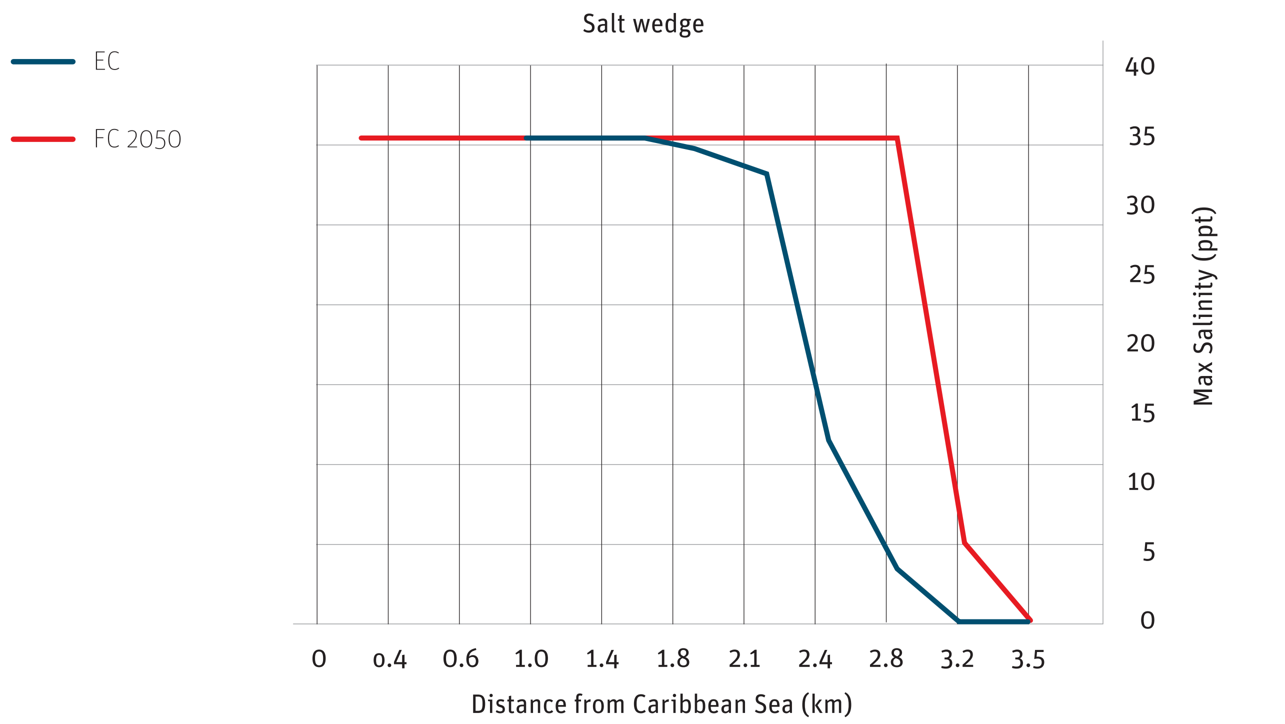
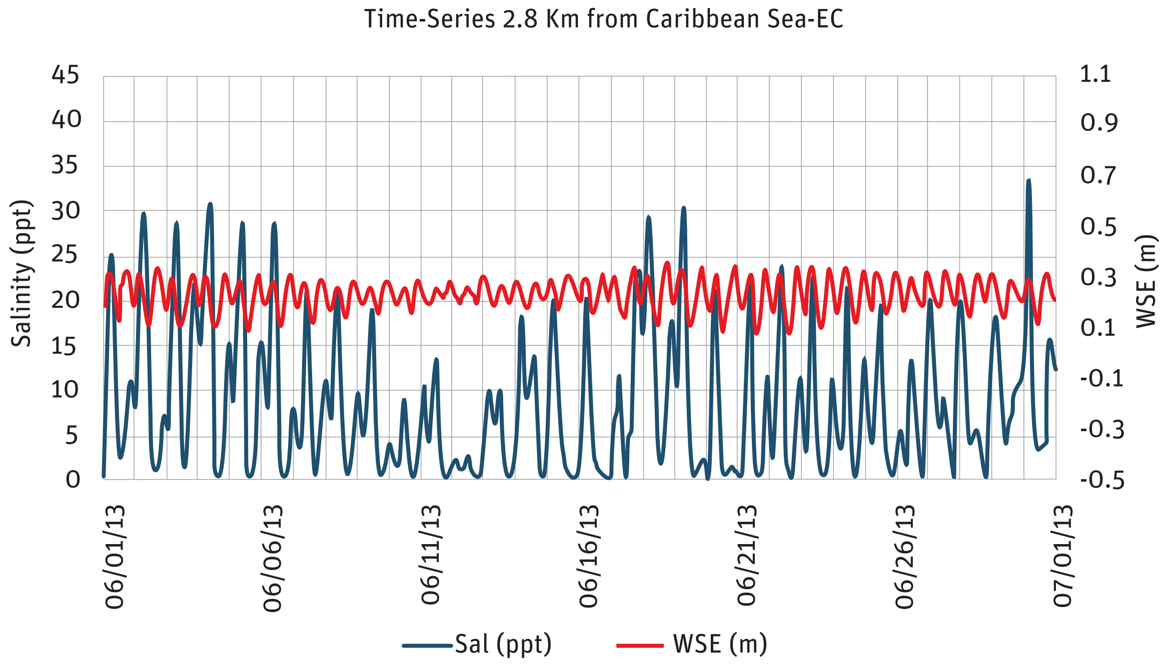


Figure 5-10 shows the salinity and water surface elevation (WSE) time-series for the segment No. 4 (located approximately 0.37 km downstream of the Muelle de Cabotaje Highway Bridge) from 1 June 2013 to 1 July 2013. This period represents dry conditions at La Ceiba. As expected, the salinity-WSE time series also shows that high salinity levels are related with high tide.

Figure 5-10 also shows salinity levels become considerably higher under future sea level conditions in the same location and period of the year (dry season). The maximum salinity levels shown in represent the maximum salinity at each of the ten segments analyzed by the CE-QUAL-W2 grid. These maximum values were observed at the bottom of each segment shown in Figure 5-11.

Figure 5-10: Salinity-WSE time series for existing and future conditions



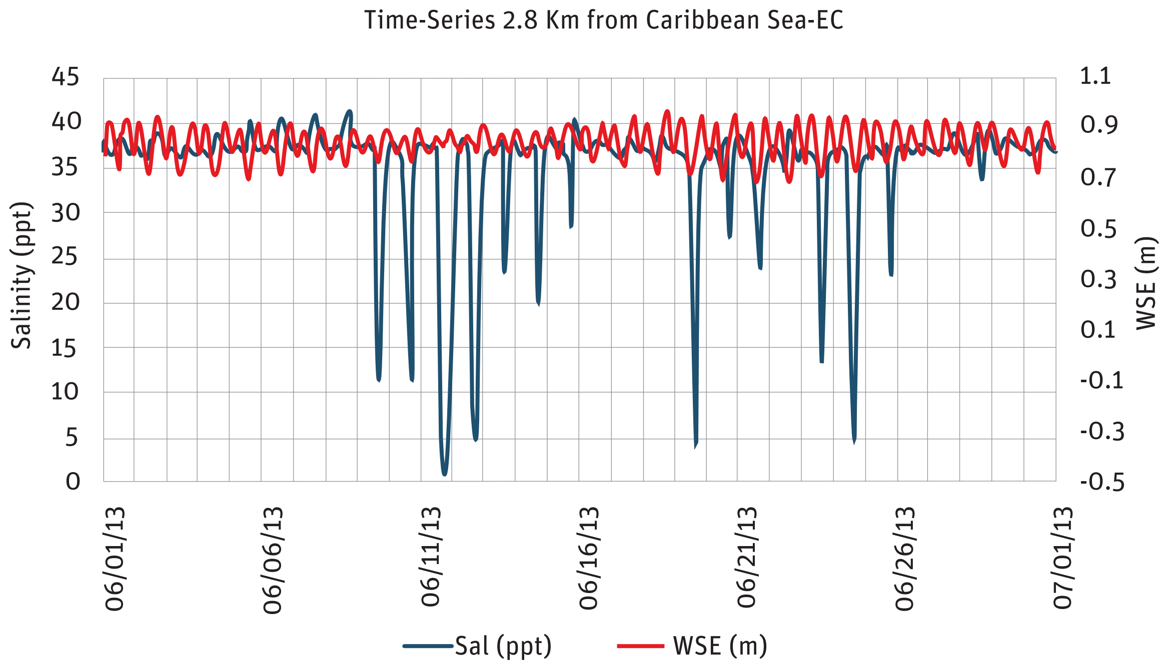
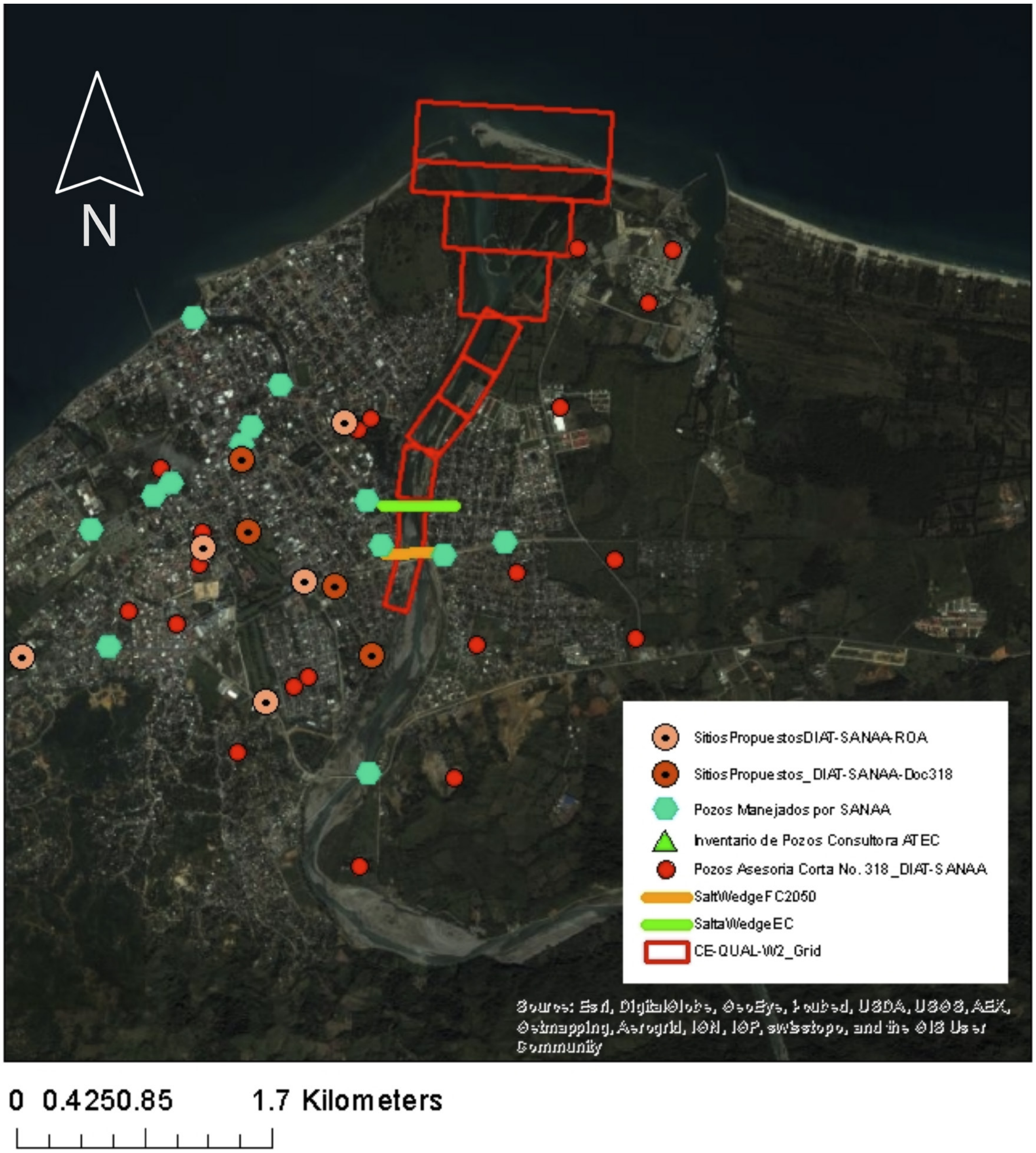


Figure 5-11 shows the extent of the salt wedge as predicted by the hydrodynamic model, including the location of a subset of existing and planned wells obtained from SANAA[77]. Under future conditions, the salt wedge extends approximately 0.4 km further inland. Movement of the salt line in the groundwater aquifer is expected to be of a similar magnitude.

Figure 5-11: Predicted extent of saltwater wedge relative to known water well locations



77. SANAA-DIAT, 2012. *Análisis de posibilidad de aguas subterráneas en el municipio de La Ceiba.* Servicio Autónomo Nacional de Acueductos y Alcantarillados (SANAA) y La Division de Investigación y Análisis Técnico (DIAT). March 2012.

Potential Effects on Groundwater (Qualitative Analysis)

As described in *Section 3.2*, La Ceiba faces salinity intrusion problems in groundwater wells used as drinking water sources. In places where groundwater is pumped from aquifers that are hydraulically connected to the sea, the induced gradients may cause the migration of saltwater from the sea toward wells on land.

In 2010, a study[78] by Mr. Carlos Tamayo set out to assess current and future seawater intrusion in the coastal aquifer of La Ceiba, which supplies water for residential and agro-industrial uses in the nearby region. The study built on two prior site assessments, one performed by Tom Culhane in 2006 and the other by Dr. Hector R. Fuentes in 2007. Together, these three studies combine recent efforts to understand the extent and evolution of the saline intrusion problem in La Ceiba.

The study applied an analytical model to estimate under steady state conditions the saltwater-seawater interface zone for various scenarios. However, given the lack of field data, a number of assumptions were made, including: "selection of adequate hydraulic conductivity values for the site, percentage of recharge from infiltration, location of groundwater divide, well production rates, frequency of pumping, and the applicability of U.S. data in this region".

Despite the data limitations, the study draws some conclusions relevant for water resource managers and future studies. Primarily, it confirms that the "hydraulic gradient within [the urban area between the Danto and Cangrejal rivers] is considerable, and the coarse materials contained in the soil provide an idea of its high level of transmissivity, which additionally implies that the groundwater is prone to contamination at points of shallow depths".

As expected, another important conclusion underlines the importance of the groundwater recharge rate for preventing issues arising from the intrusion of saline water underground. Based on the analysis of various recharge and sea level rise scenarios with the Ghyben-Herzberg model, "the high pumping scenario with low recharge and sea level rise is that in which the advancement of the halocline is more prominent."

The increasing risk of saltwater contamination due to the influence of low recharge and groundwater overdraft has implications for the management of water resources. It has already been documented through interviews with SANAA that the siting of drinking water wells now takes into account distance to the shoreline and drilling depth to reduce the risk of wells becoming contaminated. A longer-term approach, however, would require SANAA and the Municipality of La Ceiba to regulate the extraction of groundwater. City planners may also want to consider the rate and distribution of urbanization, which may further decrease groundwater recharge rates.

ERM recommends that the saltwater intrusion analysis conducted here is considered as qualitative and preliminary. Conclusions based on model results should be evaluated with caution because saltwater intrusion in groundwater can present a different trend than that exhibited by saline intrusion onto surface water bodies. Based on this analysis, ERM recommends a more extensive saltwater intrusion groundwater study that includes field work (to confirm assumptions made in previous studies) and the application of a groundwater model that leverages a full inventory of water resource users in the city.

78. Tamayo, C. 2010. *Modeling Seawater Intrusion in the Coastal Groundwater Aquifer of La Ceiba, Honduras – Central America.* Master's Thesis. Florida International University. Reviewed by Dr. Fang Zhao, Dr. Fernando Miralles-Wilhem, and Dr. Hector R. Fuentes (Chair).

5.4 Assessment of Stakeholder-Proposed Options

This section includes a technical analysis of various stakeholder-proposed options to mitigate the risks of flooding associated with the overflowing of the Cangrejal River. These structural interventions were based on ideas provided by key stakeholders during the workshop conducted in February 2014. ERM further defined these ideas to the extent these could be ran through the hydrological and hydraulic models to test their effectiveness.

As in the baseline analysis, ERM simulated four scenarios of climate change and land use for precipitation events of 1 in 20, 1 in 50, and 1 in 100-year probability of occurrence. The objective of this analysis was to establish what structures would provide greater protection to La Ceiba against river-related flooding.

5.4.1 Adaptation No. 1: Raise levees along the Cangrejal River

This structural measure includes installing and raising levees along lower and urban sections of the Cangrejal River. The length and elevation of these structures were defined based on hydraulic model outputs that show critical points where the Cangrejal River overflows. Figure 5-12 shows the location of the additional levees, as simulated for this intervention.

As per the results shown in Table 5-12, the installation of levees had a positive effect on the total inundated area, achieving a reduction of approximately 35% while the maximum water depth showed a small increase of 5%.

The levees, as simulated, would contain the river's excess flow during extreme climatological events. However, the existing levees today are not high enough to contain the excess flow; in some areas, these show signs of natural and manmade erosion. According to previous estimates, the cost of installing and raising the levees between 0.8 and 2.0 meters would range between $1,000,000 and $2,000,000, depending on the design and material type.

5.4.2 Adaptation No. 2: Restore a natural channel to the ocean

Several natural channels of the Cangrejal River have been filled in by the unplanned and rapid urban development of La Ceiba. ERM tested the effect of restoring one of these natural outlets, by simulating a channel running from the west bank of the river to the estuary by the stadium, as shown in Figure 5-13.

ERM evaluated the efficiency of this adaptation by assuming the river's excess flow could be conveyed through this open channel. The analysis indicated that this adaptation was not technically favorable. It would require a channel width of approximately 80 meters to remove the excess flow and thus prevent flooding arising from large precipitation events. Such endeavor would not only be economically unfeasible, but it was also evident there is no available land in urban La Ceiba to provide for such open channel.

Figure 5-12: Adaptation No. 1: Additional levees along the Cangrejal River

Figure 5-13: Adaptation No. 2: Channel from Cangrejal River to Caribbean Sea

5.4.3 Adaptation No. 3: Flow control reservoir

This adaptation consists of evaluating the construction of a flow control dam at a point upstream to regulate such flow during extreme precipitation events. As illustrated in Figure 5-14, ERM assumed this reservoir could be located at Las Mangas at the confluence of four of the main rivers that traverse the Cangrejal River watershed.

The capacity of this dam was based on the design proposed by the Cangrejal hydropower project, specifically, 9.3 million cubic meters. ERM also modeled a second reservoir design with a bigger storage capacity based on knowledge of other flood control structures. The second reservoir would have a storage capacity of 13.3 million cubic meters.

ERM considered the four climate change and land use scenarios for the three return periods. As per the hydrological and hydraulic model results, the dam – regardless of the modeled capacity – was not satisfactory as a flow control measure during large precipitation events.

5.4.4 Adaptation No. 4: Deviation of excess flow through an artificial tunnel

This intervention would require the construction of a tunnel, which acting as a channel could remove the excess flow from the river, redirecting it to the estuary near the Muelle de Cabotaje. Figure 5-15 illustrates this concept.

The model results showed that the capacity provided by one tunnel would not produce a significant reduction on excess volumes. To achieve a satisfactory reduction in peak flows would require the construction of a large number of tunnels, which would be infeasible due to technical and economic limitations. Therefore, the construction of artificial tunnels was discarded as an option due to technical and cost concerns.

Figure 5-14: Adaptation No. 3: Location of flow control dam

Figure 5-15: Adaptation No. 4: Location of artificial tunnel

Table 5-12 summarizes the model results for the tested interventions.

Table 5-12: Effectiveness of proposed interventions for a 100-year storm event

Scenario/Adaptation	Max Depth (m)	% D Depth compare to CA Scenario	Total inundated area (km^2)	% D Total Area
CA	5.92	0%	2.95	0%
No. 1 (Levees)	6.12	3%	2.03	-31%
No. 2 (Open channel)	4.82	-19%	2.50	-15%
No.3 (Reservoir)	5.91	0%	2.94	0%
No. 3B (Reservoir 2)	5.82	-2%	2.90	-2%
No.4 (Artificial tunnel Q=500 m^3/s)	5.48	-8%	2.72	-8%
No.4B (Artificial tunnel Q=750 m^3/s)	5.15	-13%	2.61	-12%
CA+CC	6.37	8%	3.16	7%
No. 1 (Levees)	6.69	5%	2.08	-34%
No. 2 (Open channel)	5.44	-15%	2.76	-13%
No.3 (Reservoir)	6.36	0%	3.15	0%
No. 3B (Reservoir 2)	6.33	-1%	3.14	-1%
No.4 (Artificial tunnel Q=500 m^3/s)	5.92	-7%	2.97	-6%
No.4B (Artificial tunnel Q=750 m^3/s)	5.81	-9%	2.86	-9%
CA+FUS	6.01	1%	2.99	1%
No. 1 (Levees)	6.23	4%	2.04	-32%
No. 2 (Open channel)	4.95	-18%	2.54	-15%
No.3 (Reservoir)	5.99	0%	2.98	0%
No. 3B (Reservoir 2)	5.85	-3%	2.91	-3%
No.4 (Artificial tunnel Q=500 m^3/s)	5.52	-8%	2.77	-7%
No.4B (Artificial tunnel Q=750 m^3/s)	5.27	-12%	2.65	-11%
CC+FUS	6.46	9%	3.19	8%
No. 1 (Levees)	6.81	5%	2.08	-35%
No. 2 (Open channel)	5.53	-14%	2.81	-12%
No.3 (Reservoir)	6.45	0%	3.18	0%
No. 3B (Reservoir 2)	6.39	-1%	3.16	-1%
No.4 (Artificial tunnel Q=500 m^3/s)	6.02	-7%	3.01	-6%
No.4B (Artificial tunnel Q=750 m^3/s)	5.78	-11%	2.91	-9%

5.5 Conclusions

Based on the technical analyses presented above, the following points summarize our findings with respect to the results, limitations and areas for further study:

Cangrejal River Flooding Analysis

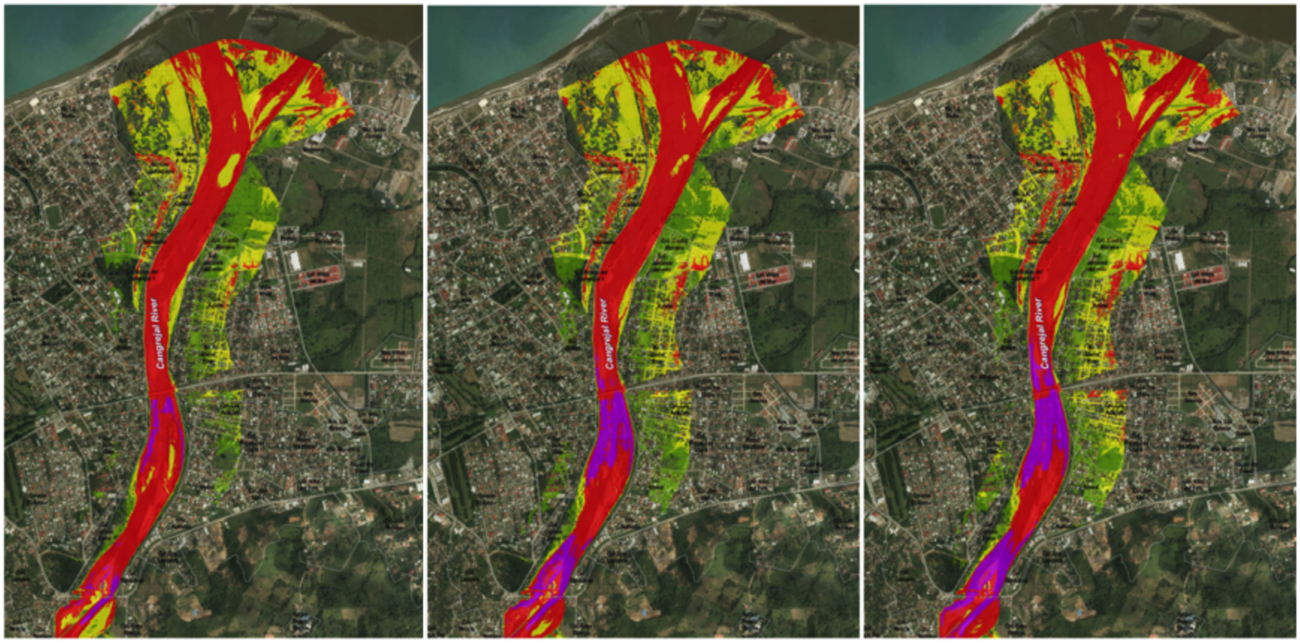
- ERM set up a hydrological model to predict the behavior of the watershed in response to precipitation and land use. A hydraulic model was used to simulate the conveyance of the river flow through La Ceiba and visualize the potential extent of flooding. It is important to note the hydrological and hydraulic models were not calibrated on the basis of historical data. Rather, model outputs were compared with results from previous studies[79, 80].
- The peak flow calculated with the hydrological model for a 50-year event under existing climate and land use (CA) conditions was 44% higher than the peak flow reported by the 2002 USGS study (1030 m^3/s). However, the peak flows estimated by our models were similar to those reported by the 2011 study by Smith et al.
- The model results for the three 24-hour precipitation events assumed in our analysis showed similar spatial distribution, as illustrated in Figure 5-16. The flooding footprint is significant, but it is important to note flooding can extend farther than shown, given that the visualization is constrained by the contour for which detailed topographical data was availabl

79. Kresch, D.L., Mastin, M.C., and Olsen, T.D. 2002. Fifty-Year Flood-Inundation Maps for La Ceiba, Honduras. U.S. Geological Survey Open-File Report 02-254. U.S. Department of the Interior-U.S. Geological Survey

80. Smith, J.B., Strzepek, K.M., Cardini, J., Castaneda, M., Holland, J., Quiroz, C., Wigley, T.M.L., Herrero, J., and Hearne, J. F. 2011. Coping with Climate Variability and Climate Change in La Ceiba, Honduras. Climatic Change. 108:457-470. DOI 10.1007/s10584-011-0161-2.

Figure 5-16: Flood Maps for Three Return Periods

Tr=20 Tr=50



Note: Green indicates water depth of 0-1 m, yellow 1-2 m, red 2-4 m, purple >4 m.

- As described in *Section 5.4,* ERM tested the hypothetical effectiveness of four stakeholder proposed structural interventions to mitigate the risk of flooding. Our analysis indicated that rebuilding the levee system would decrease in about 35% the areal extent of flooding for a 100-year storm, assuming climate change and projected changes in land use (i.e., worst case scenario). Logically, such system would fare better with less intense events, and likely eliminate the risk of flooding for events associated with more frequent storms.
- The running of four scenarios of land use and climate change allowed the identification of climate change, or rather, an increase in precipitation intensity, as the main driver of increased risk in the future. The future scenario of land use developed in collaboration with local stakeholders resulted in a snapshot of future land use that would not lead to marked changes in runoff, and therefore, river flow.

Coastal Flooding Analysis

- The simple spatial analysis conducted for assessing the effects of storm surge along the coastline made clear a large section of the city is exposed to such events. The area closest to the ocean is the most vulnerable, as it is home to a large number of commercial (e.g., hotels, restaurants) and public assets (e.g., city jail, parks, pier), as well as places of cultural importance for the city, including the newly designated *Casa de la Cultura* at the old customs house. Projections of climate change for the region suggest more frequent tropical storms, which would increase the overall risk along the coast.

Saline Intrusion Analysis

- The hydrodynamic model chosen for this analysis (i.e., CE-QUAL-W2) allowed for the evaluation of saline intrusion along the Cangrejal River, but not in groundwater. Further study is required to evaluate the risk of saltwater intrusion into the groundwater aquifer, and therefore, the drinking water supply, which is primarily drawn from wells located throughout the city.
- Previous studies, such as Tamayo (2010), have attempted to characterize the groundwater salinity issue. However, these have come short of a hydrogeological and groundwater modeling study. Such effort would provide the technical basis for a long-term water resource planning effort.
- It is also important to note the model used for this analysis was not calibrated due to the lack of water quality data for the Cangrejal River. The historical stream flow data from the gauging station at Las Mangas was also insufficient to calibrate the model properly. However, the lowest flow record observed at Las Mangas was used as a boundary condition in order to ensure model results were conservative.

6. Main Recommendations & Conclusion

This case study exemplifies the range and potential extent of the challenges faced by coastal cities in Central America, specifically with regard to the sustainability of water resources and the vulnerability to climate-induced natural hazards. Though some of these challenges, such as providing basic sanitation and stormwater drainage, are shared by other developing nations around the globe, the climate variability that characterizes the tropics makes this region susceptible to sudden climatic changes, bringing about drought or intense rains depending on the prevailing ocean temperatures in the Pacific and the Atlantic Oceans.

Due to its location on the coast, La Ceiba is particularly susceptible to the storm surge caused by tropical storms and hurricanes, and, to a lesser extent, cold fronts. Storm surge is a significant risk along the coastline. Moreover, three interrelated factors may influence the frequency and extent of coastal flooding in the future: stronger cyclones, sea-level rise, and coastal erosion. The first two trends are expected to continue given the current trajectory of greenhouse gas concentrations in the atmosphere. Coastal erosion is also expected to continue reshaping La Ceiba's coastline unless targeted interventions are implemented.

La Ceiba is also located on the alluvial plain of the Cangrejal River and development has increased rapidly along its banks, without an appropriate setback zone to account for its floodplain. Though the river does not overflow frequently, when it does, the extent of flooding can be significant. This risk would become higher if precipitation intensity increases as forecasted by experts on climate change. If appropriate measures are not taken to protect the city when the river's waters rise, the impacted area could be significant and thousands of residents as well as key public infrastructure, such as bridges and the wastewater treatment plant, would be affected.

In addition to the threat of coastal and river flooding, the city's deficient drainage is a nuisance to residents and a drag on economic activity year after year. Urban flooding in La Ceiba is linked to the failure of the existing drainage system to efficiently convey stormwater runoff away from low-lying areas where it tends to accumulate and cause flooding. In some areas, flooding causes raw sewage and thrash to back up onto streets, creating unsanitary conditions. Unless mitigated, uncontrolled urban development may further overburden the existing drainage infrastructure, exacerbating existing urban flooding issues and public safety concerns.

The risk of saltwater intrusion into the coastal aquifer rounds out the list of potential problems that threaten the city's water resources and the population that depends on these. Though many factors can increase salinization risk, saltwater intrusion is typically associated with groundwater overdraft (overpumping), reduction of groundwater recharge, and potential sea level rise – all factors that may be present in La Ceiba. This calls for action by local officials in order to regulate the extraction of groundwater according to a technical basis, which could be provided by a field-based hydrogeological study.

6.1 Main Recommendations

In line with the objectives set out by the Inter-American Development Bank, ERM has conducted a technical evaluation to analyze the risk and vulnerability to the natural hazards and infrastructure challenges mentioned above. This evaluation was carried out as a climate change adaptation experience, which endowed the process with a long-term focus appropriate not only for designing adaptive actions but also for planning short-term mitigation interventions.

To reduce the current level of risk and vulnerability in La Ceiba, a comprehensive strategy would have to address the following priorities:

i. Mitigate the risk of coastal, riverine, and urban flooding;

ii. Reduce the critical vulnerability to disasters, such as populations settled in high-risk areas;

iii. Provide the technical basis for the regulation of groundwater use, ensuring sustainability of drinking water in the future;

iv. Expand the stormwater drainage infrastructure as well as ensure appropriate coverage of the sewer system and wastewater treatment capacity; and

v. Strengthen the technical and project execution capacities of the institutions responsible for urban planning and management of water resources.

Based on the above priorities, our main recommendations are organized around three strategic lines of action:

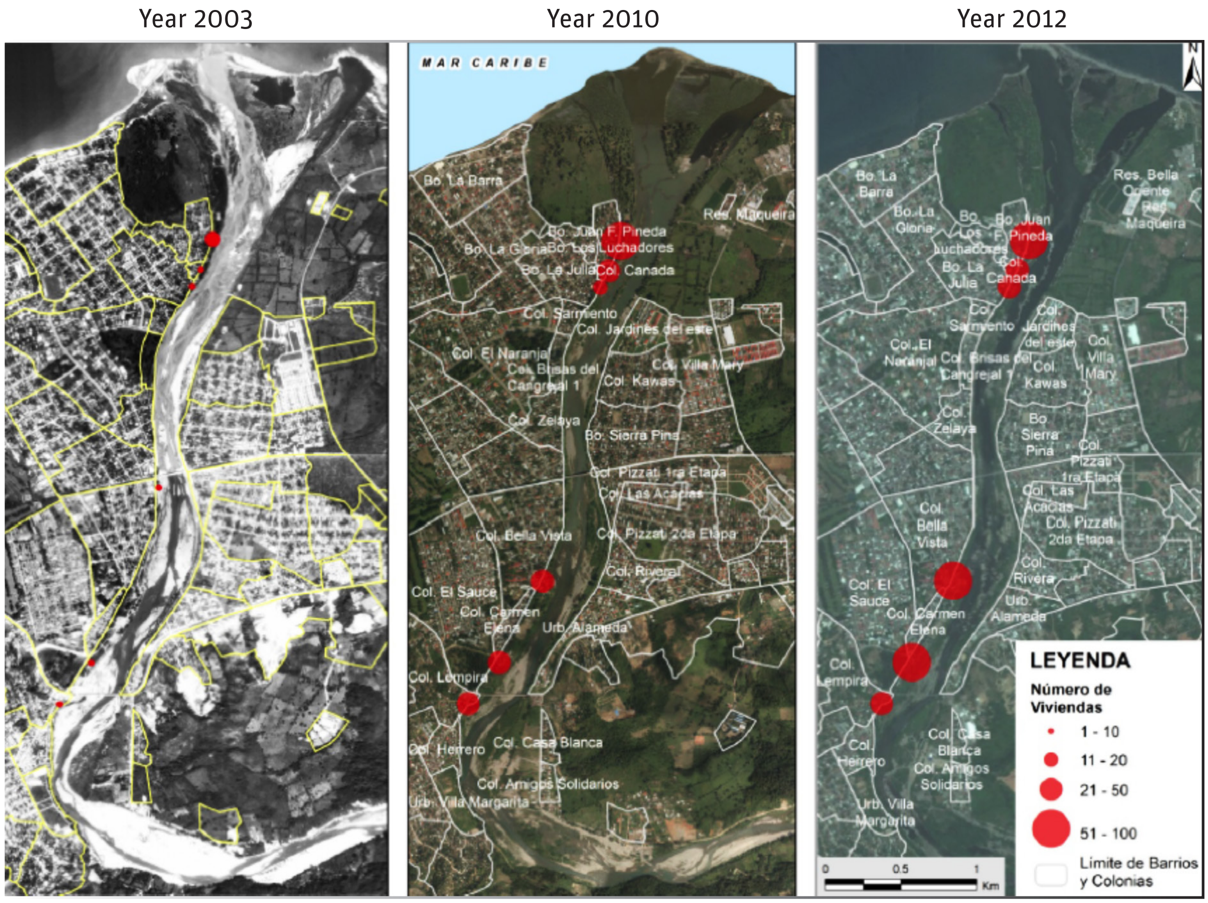
- Integrated Flood Risk Management;
- Water Resource Conservation; and,
- Institutional Strengthening.

6.1.1 Integrated Flood Risk Management

An integrated approach to flood risk management – coastal, riverine, and urban flooding – would comprise the implementation of measures that seek to reduce the risk of exposure to flooding events or lower the vulnerability of affected populations. For instance, in the case of the Cangrejal River, it is necessary to prevent the flooding to take place, while at the same time addressing the areas of critical vulnerability identified by this case study.

As per the results documented in *Section 5.4*, the reconstruction of the levee system along the river was the only structural measure that showed favorable results. The construction of additional levees would be key to prevent overflowing events and mitigate their impact to adjacent populations. However, it is also important to acknowledge that the gradual settlement of communities on the river's floodplain is an urgent area of focus. Thus, it is also recommended that the estimated 450 families in high risk areas are relocated. Figure 6-1 shows the location and estimated size of these vulnerable communities.

Figure 6-1: Location and estimated size of settlements along the Cangrejal River



Source: CREDIA, 2014

The Cangrejal River has become not only a magnet for hundreds of marginalized, low-income families, but has also become an illegal trash dumping site. Consistent with an approach that intertwines risk reduction with sustainable development outcomes, there is an opportunity to harness the river's natural and economic potential by making it the focus of a public-private initiative aimed at establishing a recreational and tourism-oriented park along its west bank. The expected benefits would include: discouraging further illegal settlements along the river, providing recreational opportunities for local residents, and increasing the attractiveness of the city as a hub for tourism. Reshaping the city's relationship with its main river would improve quality of life and boost the local economy.

In addressing the risk posed by storm surge and coastal flooding, one of our main recommendations is to prioritize actions to protect the shoreline against further erosion. One such action comprises the construction of groins to halt the existing erosive processes along the shoreline, including a beach nourishment program.

However, it is also important to address the underlying cause of coastal erosion, which is likely caused by the apparent reduction in sediment deposited by the Cangrejal River along the shoreline. This may be caused by several factors, including a decrease in river flow or the excess removal of fine sediments from the riverbed by authorized extraction companies. It is thus recommended that a sediment transport and geomorphological study be conducted to provide the technical basis for further actions, including the design and installation of the aforementioned groins as well as a reevaluation of the extractive activity in the Cangrejal River. Considering the importance of the construction material extractive activity, it is also recommended that a strategic sector analysis be conducted to identify alternative sites where these materials can be safely extracted from.

With respect to urban flooding, ERM recommends the preparation of a Master Stormwater Drainage Plan to identify, scope, and prioritize the short-term and long-term infrastructure investments required to manage stormwater for existing and future development. It is also important the plan considers the current sanitary sewer system and finds ways to separate the drainage and sewer systems.

6.1.2 Water Resource Conservation

As discussed in *Section 5.3.3*, La Ceiba faces the risk of salinization of its groundwater aquifer, which is used as the primary source of drinking water. To the extent the proliferation of unauthorized wells continues, resulting in the decrease of the water table, the risk of salinization and contamination will become higher. In light of this issue, it is necessary to regulate the extraction of groundwater to ensure its sustainability. Such regulation would need to take into account the existing conditions of the groundwater aquifer and the current and projected rate of water extraction. A hydrogeological and groundwater modeling study, combined with a comprehensive inventory of the groundwater wells in the city, could provide the technical basis upon which water utilization guidelines could be issued to public and private parties.

6.1.3 Institutional Strengthening

The priorities outlined in this chapter, such as reducing La Ceiba's vulnerability to natural disasters or developing adequate water and sanitation infrastructure, requires local institutions with strong governance and project execution competencies. The successful execution of projects, such as the ones introduced above, requires implementing entities with satisfactory capabilities in terms of planning, contracting, financial management, supervision, among other skills. Therefore, it is necessary to strengthen the operational and institutional capacity of the agencies responsible for promoting the sustainable development of the city of La Ceiba, reducing the risk and vulnerability of populations to natural disasters, and managing the sustainable use of water resources.

6.2 Cost-Benefit Analysis

With approximately 192,000 residents[81], La Ceiba is the third largest city in Honduras and its most important tourism hub, with convenient access to several recreational and eco-tourist destinations such as Roatán and the Bay Islands, and the Pico Bonito National Park. Agricultural production, such as pineapples by the Standard Fruit Company, is also a main driver of economic activity.

In contrast, the city is also highly vulnerable to natural disasters and still lacks adequate coverage of some basic services (e.g., sanitation, drainage, and potable water), limiting its socioeconomic development. When assessing the benefits of potential actions aimed at eliminating or mitigating the risks addressed in this case study, the focus is on estimating the following parameters:

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81. Comisión Económica para América Latina (CEPAL). 2013. *"Honduras. Estimaciones y Proyecciones de Población a Largo Plazo 1950-2100."*

- Direct costs to individuals for replacing property or household goods damaged by natural hazards such as floods;
- Direct cost related to the number of additional hours spent commuting due to closure of flooded streets;
- Losses in productivity equivalent to the amount of working hours lost due to storm-related business closures (foregone income);
- Incidence of infant mortality (<5 years) linked to water or environmental contamination;
- Differences in property values relative to assets in flood-prone areas; and,
- Potential increase in economic activity (e.g., tourism, trade) linked to better quality of urban life.

This approach to quantifying benefits derived from disaster risk reduction interventions is consistent with that used previously for environmental management and climate risks projects in Honduras[82]. The quantification of benefits followed here is based on the *damage cost avoided* method. The calculation of damages is complemented by the value of the improvements that would not have occurred without the presence of the improvement project.

Climate risk management is a long-term effort, especially when local institutions must also be strengthened and adapted to new circumstances. Therefore, it has been assumed here that benefits would accrue for 20 years. The intent here is not to evaluate the cost effectiveness of a single measure or intervention, but rather to show, as indicated in Table 6-1, the magnitude of the expected benefits from addressing several of the risks present in La Ceiba.

Table 6-1: Net Present Value of Estimated Benefits from Disaster Risk Reduction

Concept	Affected Households (%)	Number of Households	Cost per Household	Estimated Yearly Losses	NPV, 20 years ($US)
Direct Benefits					
Cangrejal River Flooding	5	1,700	300	510,000	6,038,590
Coastal Flooding	15	5,100	2,200	11,220,000	40,853,644
Coastal Erosion	0.5	170	15,000	2,550,000	2,550,000
Urban Flooding	30	10,200	700	7,140,000	80,242,117
Indirect Benefits					
Foregone Income	25	8,500	63	2,016,000	17,163,344
Foregone Schooling	25	8,500	63	535,500	4,559,013
Improvement in Public Health					5,129,425
Real Estate Appreciation					15,130,000
Economic Growth					21,264,178
Total Benefits					$192,930,312

82. World Bank. 2012. *"Honduras. Disaster Risk Management Project."* Project Appraisal Report No. 73042HN. Washington, D.C.: World Bank.

As shown above, reducing the risks posed by natural hazards to the greatest extent possible would produce benefits, in present-day dollars, of approximately $192 million. This analysis is simply an assessment of the benefits that would accrue if all risks are addressed. As such, it implies the following:

- the monetary value of avoided damages to people, property and assets and public services (road infrastructure, water systems);
- the dollar value of savings in commuting time, as well as time spent bringing children to school (when public transport is unavailable) and caring for children that could not attend school due to flooding;
- the increase in the value of properties once no longer under the risk of flooding or coastal erosion;
- the monetary value of increased labor productivity as workers no longer become sick or otherwise unable to attend due to flooding; and
- higher investment and economic activity resulting from key infrastructure investments, reduced natural disaster risk, and better quality of life.

Addressing the risks and challenges discussed here will require a significant investment. However, this analysis shows there is ample margin for investments to be cost effective in the long-run, assuming a 10% discount rate. Table 6-2 shows the potential internal rate of return for three investment amounts.

Table 6-2: Internal Rate of Return according to Investment Amount

Total Benefits	Potential Investment Amount (in millions of US dollars)	Internal Rate of Return (10% discount rate)
$193 MM	30	43%
	90	18%
	120	14%

6.3 Environmental and Social Issues

In general, it is expected that pursuing the recommendation included here will not have significant negative environmental impacts that could put at risk the surrounding natural environment. However, it is recommended environmental assessments are conducted prior to undertaking any type of civil works to ensure appropriate management plans are put in place.

Special emphasis should be placed on the impact to surrounding communities. For example, rebuilding the levee system is likely to result only in localized, short-term impacts of the sort expected from civil construction works, however, nearby communities may be affected by noise and pollution (e.g., dust) and those impacts should be managed accordingly.

Another salient aspect concerns those communities in high-risk areas, which may be subject to resettlement. In this sense, and considering such measure would likely raise anxiety and expectations among the targeted communities, it is required that a robust resettlement plan is carefully designed and executed, in collaboration with local authorities, and in line with the Bank's Involuntary Resettlement Policy (OP-710).

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Annex A:

Projected Land Use Scenario for La Ceiba

Climate Change Adaptation and Integrated Water Resource Management in La Ceiba, Honduras

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A.0 Introduction

The risk of flooding due to the overflow of the Cangrejal River has become a genuine concern for the residents and authorities in La Ceiba. To assess the risk posed by this natural hazard, ERM has conducted a technical evaluation to predict the possible extent of flooding as a result of extreme precipitation events. The evaluation looked not only at the risk of flooding under current conditions, but it also considered how changing climate and land use patterns would influence that risk in the future.

ERM used a hydrological model, a hydraulic model, and topographic and mapping software to assess the extent of river flooding in La Ceiba. The models were selected on the basis of professional judgment, considering the availability of input data and the level of analysis required. In addition, the hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models are publicly available, and they have a history of acceptance in a variety of applications.

Land use is a key input in modeling the response of the watershed to precipitation. While present land use can be determined on the basis of recent satellite imagery or remote sensing data, to predict what would be the predominant land use across the Cangrejal River's watershed requires a combination of statistical analysis and expert input.

The land use projections presented here were generated based on historical trends of land use change, derived with the use of statistical software, and calibrated based on feedback from local experts during a half-day workshop held in La Ceiba in December 2013. This annex documents the methodology used in constructing the projected land use scenario.

The CREDIA foundation led the statistical analysis described in this annex, supported by ERM staff. CREDIA also facilitated the workshop, which focused on validating the anthropogenic factors and physical characteristics of the terrain that determine the future scenario for land use.

A.1 Objective

The objective of the future land use scenario is to predict the potential distribution of land use across the Cangrejal River watershed for the 2050 planning horizon. The distribution of land use in 2050 is a key input to the flooding risk assessment ERM is to conduct for the City of La Ceiba.

A.2 Study area

The study area comprises the 560 square kilometers belonging to the Cangrejal River watershed. The large extent of this study area necessitated a dual analysis: a close look at urbanization patterns in the urban section of La Ceiba and a high-level analysis of anthropogenic and natural factors across the Cangrejal River basin.

A.3 Methodology

A.3.1 Selection of the Modeling Software

DYNAMICS is a software package that allows the user to build different types of models: static, complex or dynamic; local and regional; and with or without dynamic feedback (Soares Filho, et al, 2009). For modeling of land use patterns, DYNAMICS was used to build a model that simulate changes based on rates of change, derived by comparing current and historic conditions. It also allowed the assignment of weights to the variables associated with these changes.

To build the model, it was necessary to properly geo-reference all the required data and store it in raster format. Maps showing historical land use and current land use were designed with the main purpose of standardizing the land use classes or categories. For each variable thought to determine land use change, a map was also built. These variables included human settlements, rivers, roads, slope and others conditions that may restrict the use of the land, such as protected areas, declared watershed or wetland protection areas, or other zoning and land use policies.

A.3.2 Calibration of the Model

A.3.1.1 Rates of change

Rates of change were determined by comparing the land use distribution across historical maps (1986, 1994, 2002 and 2003) and more recent maps (2009, 2010 and 2012).

A.3.1.2 Weights of evidence

Using the geo-statistical method of weights of evidence determines the influence that the values of a variable have on making change happen. The result of this analysis is a probability of change map, where the probability is given by the local characteristics based on historical rates of change and explanatory variables.

Weights of evidence can be modified according to the opinion of experts, defining how influential a variable can be, to a lesser or greater extent.

A.3.1.3 Correlation between variables

The unique event of the weights of evidence is that all the variables are spatially independent, and statistical tests are applied to verify this such as: test Chi-Square of independence, test of Crammers, contingency test, test of entropy, and test of joint uncertainty information. If two variables are not independent of each other, one of them should be deleted or merged (Soares Filho, et al, 2009).

A.3.1.4 Evaluation

From arrays weights of evidence, maps of the driving variables and historical use, a projection of land use is made to the current situation. Then this map (of simulated current land use) must be spatially compared with the existing land use map. This comparison must focus on the changes, because usually a simulated map has many similarities to its observed pair due to the areas that did not change (Paegelow and Camacho Olmedo 2005).

A.3.1.5 Projection of the trajectories of use changes

Once the model has been properly calibrated it is processed to simulate the land use for the future scenario taking the current situation as a point of departure.

A.4 Application of the methodology

A.4.1 Collection and Generation of Data Base Cartographic

All mapping products that could be useful for the construction of the model, particularly land use maps, were identified at this stage (see Table B-1).

Table A-1: Soil use maps and orthophotos

Maps	Source	Spatial Resolution
Honduras 1984 land use	COHDEFOR	30 x 30 m
Honduras 1994 land use	COHDEFOR	30 x 30 m
Vegan cover of Honduras 2002	Rainforest Alliance	30 x 30 m
Honduras 2003 land use	IHT	30 x 30 m
Honduras 2009 land use	ESNACIFOR	500 x 500 m
PROCORREDOR 2010 land use	PROCORREDOR	15x 15 m
La Ceiba 2010 land use	COPECO	30 x 30 m
PROCORREDOR 2012 land use	PROCORREDOR	15 x 15 m
Orthofotos PROCORREDOR 2010	PROCORREDOR	0.3 x 0.3 m
The urban area of La Ceiba 2003 orthophoto	Unknown	0.5 x 0.5 m

The team analyzed the spatial coincidence of maps of historical use (1986, 1994, 2002 and 2003) with maps of current use (2009, 2010 and 2012), concluding there was not enough coincidence between the maps to be compared, since different methodologies were used for the production of these maps. Also overlaid the maps on the orthophotos of PROCORREDOR, 2010, noting that historical maps which had a higher level of detail and corresponded more to what was observed in the orthophotos, is the 2003 map (IHT), at least for the area under study, therefore this was selected as historical land use map.

A.4.1.1 Map correction of historical use – 2003

The 2003 map presented 10 categories of land use for the area under study. It did not show sufficient reliability to discriminate between types of forest or grassland, scrub, and agricultural uses, but it did differentiate between forests and deforested areas, so categories were grouped as shown in the following table.

Table A-2: Categories of historical land use

Categories	Grouping of categories
Dense coniferous forest	Forest
Sparse coniferous forest	
Lush hardwood forest	
Mixed forest	
Water surfaces	River channels
Erial S.A. to pasture	Stripped
S.A. Pastizales, paddocks	
Urban areas.	Urban area
Localized infrastructure	
Infrastructure roads and others	

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[83]. This satellite and the wave band configuration are specifically designed for the regional land cover mapping being undertaken by this study.

- A detailed correction for the urban area was made with what was observed in the 2003 orthophoto.
- Category of "infrastructure roads and others" was merged with the neighboring land use.
- Note: A limitation in the study was to find cartographic data that could be compared across different years and exhibit a good level of detail.

A.4.1.4 Current Use Map - 2010

A map of current land use was developed from the orthophotos, PROCORREDOR, 2010. Every patch of territory was scanned where they could be. Due to the high level of details of the orthophotos, it was possible to digitize every patch of territory where use of another, you could differentiate using a minimum size of patches of 500 m^2. The land use categories identified, as well as the final group, are shown in the following table.

83. 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.

Table A-3: Categories of current land use

Categories	Grouping of categories
Forest	Forest
Bodies of water	River Channels
Sand banks	
Traditional agriculture	No Forest
Permanent crops	
Shrub lands and grasslands	
Bare soil	
Urban area	Urban area
Institutional	

A.4.1.4 Maps of explanatory variables

A map for each of the variables was obtained, but some needed to be completed. The following table shows a listing of each map.

Table A-4: Listing of Explanatory Variables maps

Map	Source	Update
Population centers (villages, communities, neighborhoods)	IGN, INE	1988 (partial). Completed with 2010 orthophoto.
Road network	--	2010 orthophoto.
Water channels	IGN	1970
Elevation contour	IGN	1970
Areas under forest management plans	ICF	2013
Declared watershed	ICF	2013
Protected areas	ICF	2013

A.4.1.4 Intermediate Cartographic Products

All maps were rasterized with a cell size of 15 x 15 m. For some explanatory variables, it was necessary to calculate a map that is derived from the first, as shown in the following table.

Table A-5: List of intermediate maps

Initial Map	Intermediate Map
Population centers	Distance to population centers
Road network	Distance to roads
Road network	Distance to main roads
Water channels	Distance to drainage channels
Contour	Slope

Besides the maps mentioned above, the distance to the forest, deforested areas, and to urban areas, were calculated for each model iteration and for each year because these distances are changing the dynamics of land use.

A.4.2 Validation Workshop

A short workshop was conducted to validate the projections of land use and to obtain inputs to improve the calibration of the land use model simulation results. The workshop was attended by 16 local experts including representatives of the municipality of La Ceiba (GAM CODEMs, UTM), SEPLAN, CREDIA, SANAA, USAID, DIGTA-SAG, CURLA, SERNA, CICH, UNICAH and UPNFM, besides participation by the IDB representative.

During the workshop the methodology used in the study and the preliminary results were presented; then four groups were organized and given printed maps of current land use and projected to 2050, a map with the driving variables, and other instructional materials that could be used to indicate changes on the map. The groups were asked to test the validity of the projected land use, and suggest changes that could apply to specific areas, new variables to consider, or varying the potential influence of some variables on driving changes to the land use pattern.

Figure A-1: Short Validation Workshop

A.5 Preliminary results

A.5.1 Rates of change of land use

The rates of change in land use are those that define the percentage of cells in use "X" to be transformed into a use "Y" for next year. Three major transitions were identified as shown in the following table.

Table A-6: Rates of change of land use

Transition		Rate (%)
From	**To**	
Forest	Deforested	4.69
Deforested	Forest	5.89
Deforested	Urban area	0.35

Rates of change are always affected by the level of detail and the lack of spatial correspondence. Comparison of land use maps tends to overestimate rates; since the comparison of change cell to cell is made (in this case cells are 15 x 15 m). However, when all of the cells are considered the overestimation of change rate "from X to Y ', is to some extent compensated by the overestimation of the rate of change " from Y to X".

A.5.2 Independence of variables

Only a couple of variables found were correlated with each other, for the three transitions, "Distance to main roads / Distance to urban areas", so the variable "distance to major roads" was removed for transitions "of forest deforested "and" deforested forest "and the variable "distance to urban areas" was eliminated from the transition" from deforested to urban area".

A.5.3 Evaluation Model

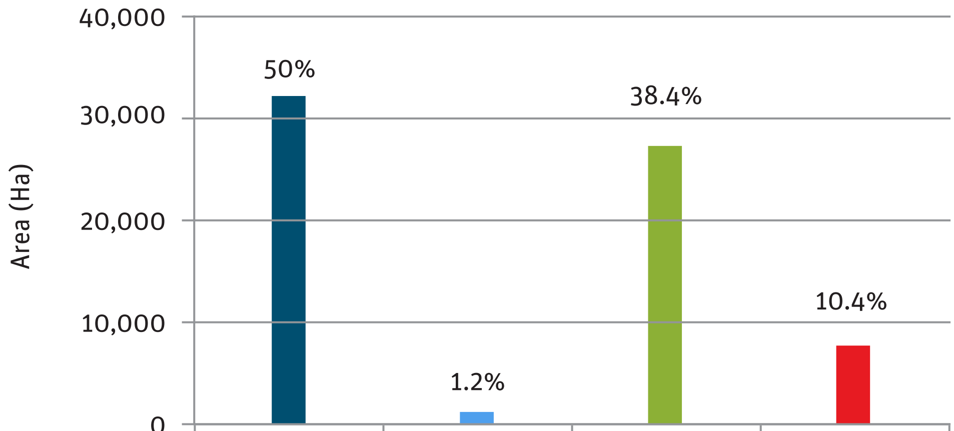
Land use for 2010 was projected from the land use map of 2003. Land use changes between the simulated map and the observed map for 2010 were evaluated using scene windows ranging from one cell to 15 x 15 cells, as sometimes the changes do not occur in a given cell, but they may occur in neighboring cells. The correspondence increased from 43.8% when scenes of one cell were used, to 70.1% when scenes of 15 x 15 cells.

A.5.4 Projection to 2050 land use

The result of the land use projection, prior to the workshop, is presented in the following graphs and map.

Figure A-2: Preliminary Land Use Distribution for 2050, Urban and River Areas

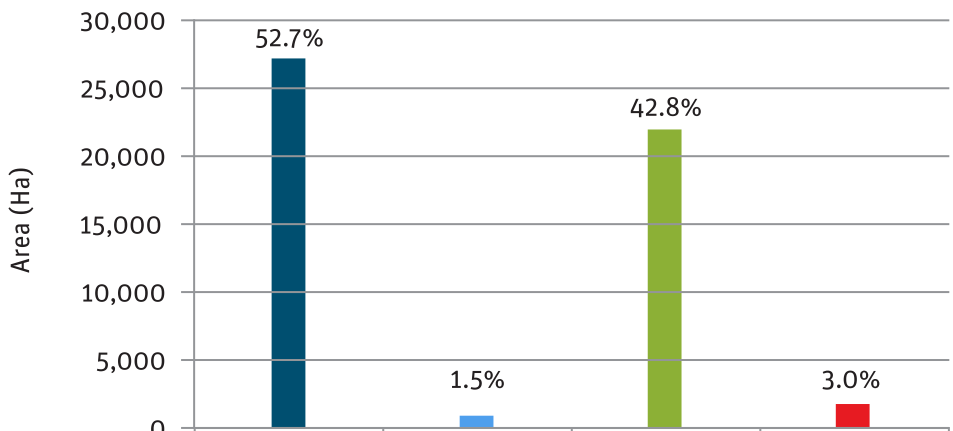
2050 Land Use in Urban Area city of La Ceiba and Cangrejal River Basin



	Forest	Bodies of water and bare soil	Deforested	Urban zone
Area (Ha)	34,943	857	26,885	7,261

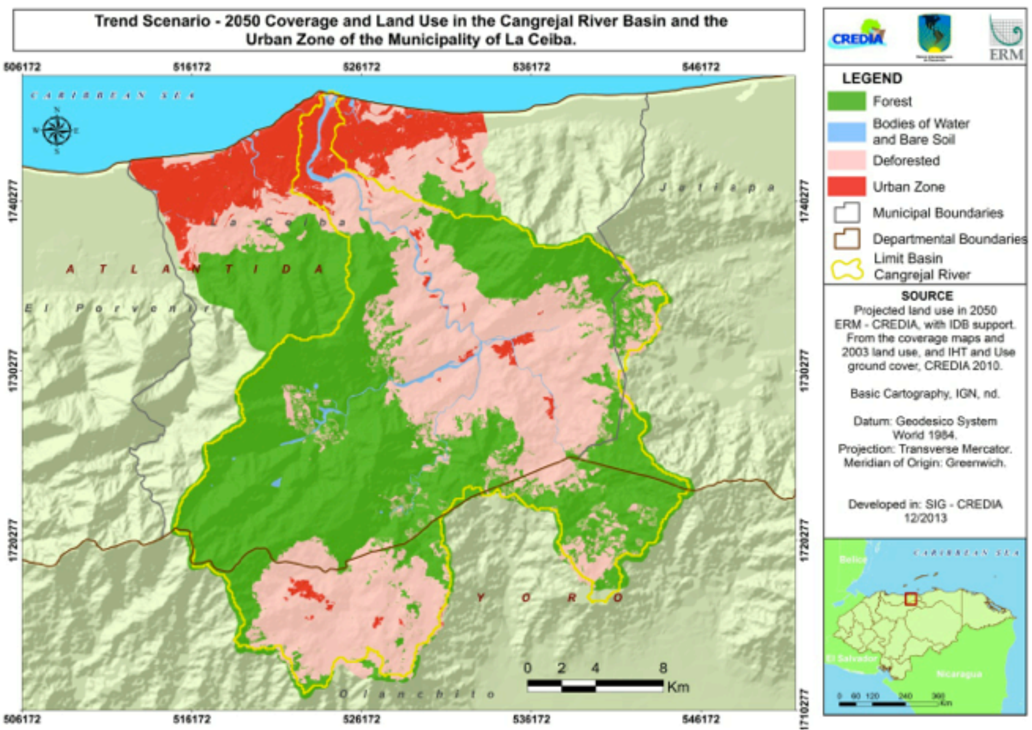
Figure A-3: Preliminary Land Use Distribution for 2050, Cangrejal River Basin

Land Use 2050, Cangrejal River Basin



	Forest	Bodies of water and bare soil	Deforested	Urban zone
Area (Ha)	27,546	771	22,358	1,569

Map A-1: Preliminary Land Use 2050 Scenario



A.6 Results of the workshop

Generally speaking, the preliminary land use scenario for 2050 was well received. Local experts expressed the results were in line with their expectations, but offered the following additional insights:

- Some stakeholders stated that if no action is taken then the deforestation trend could increase even more, while another group with a more optimistic view thought that perhaps deforestation trends would decrease as a result of all the work being done in the upper watershed, including reforestation and protection of forested areas.
- Additional variables were suggested, including accounting for insecurity or violence in some neighborhoods located west of the Cangrejal River. This factor is expected to slow down urban growth in those areas. A security map was therefore developed and integrated into the model with other variables.
- It was also suggested that the potential influence of the "Calle Ocho" project about to be built needed to be considered. This project consists of paving a street that runs from downtown to the west parallel to Main Street CA13. This road segment was integrated into the variable "Distance to Main Roads".
- Considering aspects related to permitting was also suggested as an additional variable. For example, there are no approved zoning ordinances or definition of what constitutes an acceptable use for a parcel of land. Permits are given mainly for construction and for verifying land tenure, restrictions and risk zones. These are verified and determined in the field or by direct knowledge of the technicians in charge. So it becomes difficult to include this aspect.

- Finally, stakeholders also noted agriculture in the upper area of the Cangrejal River basin is shifting from subsistence farming to monoculture, such as the oil palm. Although this will substantially improve the household economy it implies a drastic change in the ecological balance.

During this study different stakeholders from different sectors were approached and their opinions are different. Some say there are government initiatives that are on the table for discussion which are based on encouraging the production of oil palm. Others conclude that this crop is extremely harmful because it increases deforestation. Even others mentioned that there are many restrictions on hillside farming and the palm oil guild (palmeros) is in the process of certifying plantations, which excludes hillside areas from production as a measure to promote forested areas. In spite of all these restrictions, producers introduced these crops in their areas of production in 2010. For this reason we leave this point in the discussion table, therefore, this analysis does not account for potential trends related to palm oil production.

- The weight given to the protected area Nombre de Dios was increased as per stakeholder input. This would decrease the rate of deforestation.
- Another suggestion was to remove the category "urban area" for all those areas that are distant from downtown La Ceiba. These are likely to correspond to rural population centers and should appear "Deforested".
- Stakeholders also noted some roads were missing in the upper and middle part of the Cangrejal River basin. These roads were added to its respective variable map.

A.7 final results

A.7.1 Adjustments Made to the Model

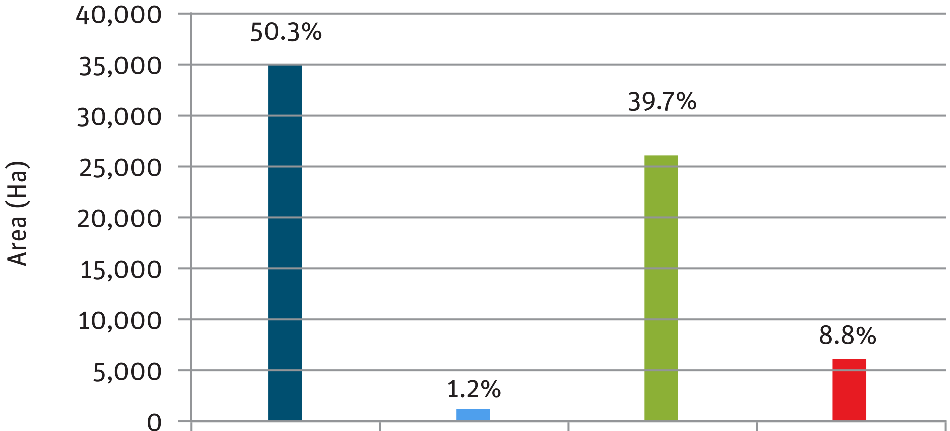
Changes resulting from the workshop were made, and again the evaluation process model was conducted, being able to see an increase in model fit, presenting a setting of 49% for windows of a cell up to 74.6% for windows of 15 x 15 cells. Recall that the evaluation is conducted only for areas that change of use, and not for areas that remain unchanged.

A.7.2 Observed Trends

- The trend of deforestation is evident at the margins of the Cangrejal River, strongly influenced by the road that runs parallel to river and the human settlements that stretch along this road.
- Another important result is that patches of forest that lied among deforested areas disappeared.
- The reappearance of vegetative cover increased within protected areas and areas declared as protected watersheds.
- Development increased toward the east and to a lesser extent to the west, given that the east of the city is safer. It was also noted that some informal settlements appeared to the south, within the buffer zone of the Nombre de Dios and Pico Bonito National Parks.
- The following graphs and map disclose the final results of the baseline scenario of use and land cover 2050.

Figure A-4: Adjusted Land Use Distribution for 2050, Urban and River Areas

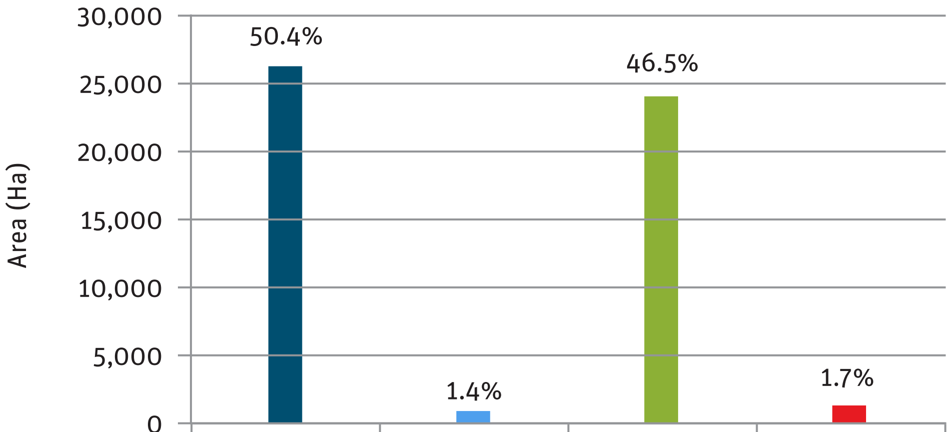
2050 Land Use in Urban Area of the City of La Ceiba and Cangrejal River Basin



	Forest	Bodies of Water	Deforested	Urban Zone
Area (Ha)	35,201	809	22,796	6,140

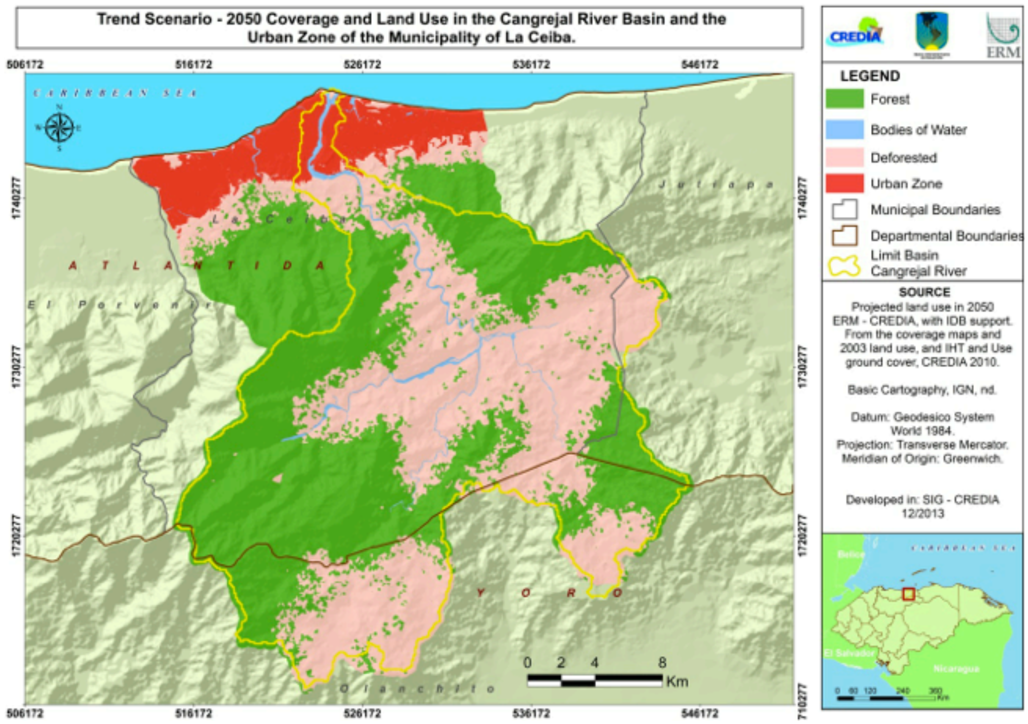
Figure A-5: Adjusted Land Use Distribution for 2050, Cangrejal River Basin

Land use 2050 Cangrejal River Basin



	Forest	Bodies of Water	Deforested	Urban Zone
Area (Ha)	26,355	728	24,277	884

Map A-2: Adjusted Land Use Map for 2050



Annex B:

Selection of Future Climate Change Scenario

Climate Change Adaptation and Integrated Water Resource Management in La Ceiba, Honduras

B.0 Selection of the Climate Change Scenario for La Ceiba

The approach and scope of the adaptation process was determined largely by the projections of future climate and anticipated 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. This section describes the method used to select the climate variables that make up the future climate change scenario assumed in this case study.

In 2010, the Honduran Ministry of Energy, Natural Resources and Environment[84] (SERNA) published the country's National Strategy on Climate Change. This document provides climate projections for the 2050 planning horizon under two greenhouse gas (GHG) emissions scenarios. A study[85] by Argeñal (2010) documents the use of the MAGICC/SCENGEN[86] V5.3 climate model to generate these projections.

MAGICC is a one-dimensional climate model that allows the forecasting of changes in global mean temperature and changes in sea level in response to changes in the concentration of GHGs in the atmosphere. The SCENGEN module takes the output of the MAGICC model, along with a set of global circulation models[87], to forecast rainfall, temperature and atmospheric pressure at a 250-km spatial resolution. The model PRECIS[88] was then used to downscale the MAGICC/SCENGEN projections to a 50-km resolution grid.

The projections generated by MAGICC and the chosen global circulation models were based on historic data compiled from eight (8) meteorological stations across Honduras, spanning the 1961-1990 period. One of these stations is located in the airport at La Ceiba. Data gathered by the National Electric Energy Company (ENEE) for annual temperature and precipitation complemented the station data.

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[89] (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 the National Strategy on Climate Change, SERNA recognized the 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. In this sense, the A2 scenario depicts a higher trend of GHG emissions relative to B2, and thus represents the conservative scenario.

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84. Secretaría de Energía, Recursos Naturales, Ambiente y Minas (SERNA)

85. Argeñal, F. (2010). Variabilidad Climática y Cambio Climático en Honduras. SERNA. PNUD.

86. Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC). Spatial Climate-Change Scenario GENerator (SCENGEN).

87. Twenty global circulation models were evaluated and a subset was selected based on the best fit with observed data. The models that generated the best temperature predictions were: CCC1TR, CSI2TR, ECH4TR, GISSTR, HAD2TR, while those that best reflect precipitation data were: CSI2TR, ECH3TR, ECH4TR, HAD2TR, and HAD3TR.

88. Providing Regional Climates for Impact Studies

89. The Special Report on Emissions Scenarios was developed by the Intergovernmental Panel on Climate Change (IPCC) in 2001.

Based on the analysis of the MAGICC/SCENGEN model results and subsequent downscaling with PRECIS, the following can be highlighted with regard to the projections for the 2050 time horizon:

- Average annual temperature is projected to increase up to 2 degrees Celsius (°C) in the eastern and southern regions of Honduras, with more moderate values along the northern coast, ranging from 1.4 to 1.6°C for the La Ceiba region;
- The months with the largest increase in predicted temperature were June, July and August;
- Difference in temperature projections between the A2 and B2 scenarios was 0.2°C;
- Annual average rainfall is predicted to decrease across the country. Along the northern coast, the decrease in average annual rainfall could range between 10% and 25% by 2050, with the largest drops corresponding to the months of June, July, and August.

The government-endorsed projections partially fulfilled the information needs for the Project, which also required projections for change in precipitation intensity and change in sea level rise. These additional variables are key inputs to the hydrological model undertaken for the study of the Cangrejal River watershed. ERM also conducted additional research to identify forecasts specific to the La Ceiba region, and compile data relevant to conditions associated with storm-related weather events in the future such as hurricanes.

As a result of the literature review, the study[90] by Smith et al. (2011) emerged as a key source of information on projections corresponding to sea level rise and storm-related variables (e.g., precipitation intensity). Smith et al. also relied on the MAGICC/SCENGEN model to generate global mean temperature change projections, which were then downscaled to yield estimated changes in monthly temperature and precipitation at the regional level.

The temperature projections for 2050 ranged between 1 and 2°C, with a mean increase of 1.5°C, consistent with the results in the Argeñal study. Given this projected rise in temperatures for 2050, the increase in total precipitation during intense rain events would range between 6% and 13% according to an analysis based on information from two earlier published peer-reviewed studies[91]. A 6 to 8% increase in maximum wind speed in hurricanes and a 17 to 25% increase in precipitation (within 100 km of center) from hurricanes is also expected by 2050.

Sea level rise projections selected for this case study were based on Cardini and Richards (2005) as cited by Smith et al. (2011): "Sea level rise projections show a rise in the region of 5 to 20 cm by 2025 and up to 60 cm by 2050 (with middle estimates of 12 cm by 2025 and 20 cm by 2050."

Taken together, the studies by Argeñal (2010), Smith et al. (2011), Cardini and Richards (2005), and the National Strategy on Climate Change (SERNA, 2010), served as the basis for the projections of climate change used in this case study. Table B-1 below summarizes the selected value and source for each climate change variable.

90. Smith et al., 2011.

91. K. E. Trenberth et al. (2003). *The Changing Character of Precipitation.* Bulleting of the American Meteorological Society. Issue 84, 1205; and Knutson TR, Tuleya RE (2004). *Impact of CO2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. Journal of Climate,* Vol. 17, Number 18, Pages 3477–3495.

Table B1: Selected Climate Change Projections

Parameter	Projection	Source
Temperature	1.5 °C Increase	Consisted with the mean projections by Argeñal (1.4-1.6°C) and Smith et al (1-2°C).
Total Precipitation (Storm-related events only)	14% Increase	Argeñal indicates an overall decline in precipitation. Smith et al. concludes an increase in precipitation associated with storm events.
Precipitation Intensity	13% Increase	Smith et al. concludes an increase in rainfall intensity for short-term events such as hurricanes.
Wind Velocity	8% Increase	Smith et al., 2011.
Sea Level	0.60 m Increase	Projection reflects most conservative value estimated by Cardini and Richards (2005), as cited in Smith et al., 2011.

Note: Projections are relative to 1990.

IDB
Inter-American Development Bank

NDF
Nordic Development Fund