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How Forests Enhance Resilience to Climate Change:

THE CASE OF DRINKING WATER SUPPLY IN TEGUCIGALPA, HONDURAS

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PROGRAM ON FORESTS

Acknowledgments

This study on the role of forests in enhancing landscape resilience to climate change is part of a larger multicountry project designed and led by Diji Chandrasekharan Behr (Sr. Natural Resource Management Specialist, World Bank) on the role of forests for enhancing resilience to climate change (www.profor.info/node/2032). The larger project aims to capture the role of forests in enhancing other sectors' resilience to climate change. It examines how sustainable management of forests can contribute to strengthening social and physical resilience of systems in other sectors. Using forest and tree management as part of a broader strategy to enhance resilience to climate change could provide a low-cost option for local landscapes while also helping to balance production, livelihood, adaptation, and mitigation goals.

The field data collection and preparation of the case study was led by Raffaele Vignola, Director of the Latin American Chair of Environmental Decisions at the Tropical Agricultural Research and Higher Education Center (CATIE). Other scientists included Amanda Procter, Angela Díaz Briones also from CATIE,Tim McDaniels from the University of British Columbia in Vancouver, Canada and colleagues at CIFOR—specifically, Serge Rafanoharana, Bruno Locatelli, and Aaron J. M. Russell. The report submitted by the field team was formally reviewed by the Honduras Country Management Unit and comments were provided by Christian Peter (Lead Environmental Specialist). The report was finalized by Diji Chandrasekharan Behr with inputs from Maria Ana de Rijk (World Bank).

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Executive Summary

Climate change has potentially dire effects on livelihoods and human well-being through disruptions to agriculture, food, water, and biomass-based energy supply systems and through changes in disease vector dynamics. It is of particular concern to developing countries, as they have limited resources for large-scale adaptation efforts to buffer people from the impacts.

Honduras is considered one of the most vulnerable countries to climate change in Latin America. It ranks third on a global climate risk index, which uses exposure and vulnerability to extreme events for the period 1991–2010 as a proxy. In addition to extreme events, future climate scenarios forecast an increase in water scarcity in Honduras due to climate change and increased variability in rainfall. A national study on future climate change scenarios suggests a 5 percent decrease in annual rainfall by 2020—particularly along the northwest-southeast corridor. By 2050, a 20–25 percent decrease in precipitation is projected for most parts of the country between June and August, with deficits greater than 30 percent for most areas during July and August, especially in the departments of western Honduras. At the same time, mean temperatures are expected to increase in western and southern regions of the country, aggravating the situation, as the low rainfall period that normally occurs during the rainy season will become longer, hotter, and drier.

Access to water is already a constraint in many parts of Honduras. The expected changes in climate will put crops and water access for human consumption at even greater risk. Ecosystem-based adaptation (EBA) is an approach that seeks to lower the impacts of climate change on human systems by strengthening ecological systems. This type of adaptation attempts to address both past environmental degradation and climate change–induced environmental change to improve outcomes for human systems.

This study examines the potential benefit of using an EBA strategy involving forests as part of a larger strategy for enhancing the climate change resilience of the reservoir systems that provide drinking water to Tegucigalpa, Honduras. This report, one in a series of studies, explores how forests, through the provision of ecosystem services, contribute to other sectors' adaptation to climate change.[1] The case study in Honduras seeks to integrate climate change and ecosystem services modeling at the watershed scale with an economic analysis of the impacts of watershed management policies on water quality and quantity under high and low climate change scenarios. The first objective of the case study is to inform decision makers in government and development organizations of the potential economic benefits of including EBA measures alongside infrastructural investments to enhance the resilience of the water storage system in the watershed, given the projected impacts of climate change.

The second objective, which is tied to the broader set of studies, is to explore an approach of generating the needed evidence, given the challenges of obtaining data that would facilitate optimal decision making. Given the scope of this project, several different research methods were used to generate data on future climate, governance regime, the economic impact of management options, and current and future system vulnerability.

The study area is the Guacerique watershed. The watershed is in a mountainous region with a mean altitude of 1,450m, and over 56 percent of the land area has slopes greater than 15 percent. Steep slopes combined with a shallow soil layer and soil structure, drainage, moisture levels, and rockiness mean the watershed is best suited to forested land uses.

1. For more information on the set of case studies, see www.profor.info/node/2032.

The Guacerique watershed has a current population of 8,853, and the annual growth rate is estimated to be 2.4 percent.[2] The primary livelihoods in the area include subsistence and small-scale commercial agriculture (primarily vegetables), subsistence cattle farming, and forestry. This highlights the close relationship between local livelihoods, forests, and ecosystem services.

The Guacerique watershed is divided between two municipalities. Most of it (166.82 km^2) falls within the boundaries of Tegucigalpa, while 25 km^2 of the watershed is under the jurisdiction of the municipality of Lepaterique. Two of the four streams that come together to form the Guacerique River (Guajire-Mateo and Quiscamote) have their headwaters in Lepaterique, making it an important player in land and resource management in the watershed.

In 1973 the government of Honduras declared the Guacerique watershed a protected public forest. Despite this, the watershed has undergone significant land use changes—deforestation and conversion to agriculture and human settlement. The two main drivers of land use change are small-scale agriculture and human settlement. Small-scale farmers live throughout the watershed, including within the boundaries of the Yerba Buena Biological Reserve.

Drinking water for Tegucigalpa mainly comes from surface waters, and the primary sources are the Guacerique, Grande, Sabacuante, and Tatumbla Rivers, which are part of the upper Choluteca River basin. Additional water is provided to the system from springs in the La Tigra Nature Reserve. Reservoirs are used because the river volumes fluctuate greatly over the course of the year between the wet and dry seasons. Water shortages primarily occur because of insufficient water in the reservoirs. The problem is compounded during the dry season.

There are currently only two reservoirs providing drinking water to Tegucigalpa: the Los Laureles reservoir on the Guacerique River and the Concepción reservoir on the Grande River, providing a total constructed basin volume of about 48 million m^3. Considerable reservoir volume, however, has been lost to sedimentation. Sediment accumulation in the Los Laureles reservoir is estimated to have reduced reservoir capacity by 15 percent. Moreover, water treatment costs at the Los Laureles treatment plant rose considerably after Hurricane Mitch, as the resulting water quality problems required successive investments in infrastructure, including the incorporation of additional water treatment processes, at a total cost of several million dollars. Nonetheless, this reservoir and the associated treatment plant currently supply water to approximately 25 percent of connections in Tegucigalpa, which makes the Guacerique watershed of special importance to national authorities.

Many infrastructure projects have been developed over the years to address water shortages, including the construction of new reservoirs. Looking ahead, the population of Tegucigalpa is expected to reach 1.36 million people by 2015 and 2.13 million people by 2030. Future water consumption in the urban area is projected to be 214,500 cubic meters per day (m^3/day) in 2015 and 336,700 m^3/day in 2030—values that are equivalent to production rates of 3.06 cubic meters per second (m^3/s) and 4.52 m^3/s respectively. The current water production rates are on average 1.99 m^3/s and can be as low as 1.76 m^3/s. Significant investment in drinking water capture, storage, and treatment capacity is required in order to meet current and future demand. There also is the need to reduce loss and leakage in the water supply system. Current infrastructure plans aim to generate the water that Tegucigalpa badly needs.

2. The current population figure does not include 2,245 people estimated to be living at police or military installations in the (lower) watershed.

Climate change and land use change are expected to affect the water supply for Tegucigalpa in several ways. Deforestation decreases water infiltration, which lowers base flow, and increases runoff and thus soil erosion. All watersheds serving Tegucigalpa are undergoing similar processes of land conversion and forest loss. Thus watershed management has been identified as necessary for ensuring the optimal functioning of existing and future drinking water infrastructure. The climate change modeling carried out shows increasing temperatures to 2030 and 2080, with the rate of change increasing in the 2030–80 period. The majority of models predict a reduction in precipitation, and there is a possibility of a shortened rainy season. Related models suggest decreasing runoff resulting from lower precipitation amounts and a landscape transition to a drier ecosystem type.

The resilience strategy explored in this case study is the use of forest cover to enhance water yield and soil retention services. This would help mitigate the impacts of expected changes in precipitation (more erratic precipitation and the impact of intense rainfall events on sediment production) on drinking water supply.

Modeling the combined effects of climate change and land use change on soil erosion demonstrates that erosion can be largely controlled through land use practices. Both reforestation and other soil erosion control methods on nonforested land will bring important gains and buffer systems from the impacts of climate change. While land use practices are important for maintaining soil retention services, climate change will greatly affect agricultural livelihoods in the watershed. Farmers will likely have to adjust to drier growing conditions and more erratic rainfall patterns. Forests can help farmers mitigate these impacts. However, in order for subsistence farmers to participate in forest conservation and reforestation activities, they need to see direct benefits to their livelihoods.

The **vulnerability analysis** shows how human action and climate change put ecosystem service provision at risk and make the watershed, the drinking water infrastructure, and communities more vulnerable to climate change. The **governance analysis** determines that the legal framework has many elements that encourage forest-based approaches to EBA and that key aspects of the existing legislation are being put into practice, but a lack of financial resources, political will, and clear mandates along with barriers to broad-based community participation, among other factors, mean that rule enforcement remains a challenge. Effective EBA can be achieved through generating political will, improving financial resource endowments for resource management initiatives, clarifying stakeholder roles and responsibilities, improving interinstitutional coordination, and working directly with communities.

The **economic analysis** estimates future benefit provision under the combination of the watershed management plan and climate change, using expert judgment. The analysis found the watershed management plan under a 0.5^{0}C increase in temperature and up to a 20 percent decrease in precipitation will bring benefits to the water utility over a 20-year time horizon. Assuming a social discount rate of 3.3 percent, the net economic benefit of the watershed management plan in 2012 to the water utility is approximately $28.6 million under a low climate change scenario and $76.1 million under a high climate change scenario. The analysis also suggests that the watershed management plan may be insufficient to buffer the drinking water infrastructure from more extreme changes in climate (such as increases in precipitation) if the impact of reforestation on water yield estimations fails to materialize. The economic analysis also found a range of ecosystem services provided by the forests and related ecosystems in the Guacerique watershed, such as fiber, soil formation, pollination, and nutrient cycling—all contributing to the agricultural livelihoods of local population.

Given the potential benefits of including EBA in the adaptation strategy, the following recommendations are made:

- Support farmers' adoption of soil and forest conservation practices by making the economic benefits evident and providing needed incentives to promote adoption of soil conservation practices.
- Secure funding for the implementation of watershed management plans in this and other watersheds following clear evidence of government commitment to implement an EBA. It is recommended that dedicated funds for the national water utility's watershed management unit and activities be made available to ensure that legislation regarding management plans is fully implemented.
- Establish a monitoring system for adequate adjustment of EBA responses. Planning and implementing EBA measures have high levels of uncertainty with respect to the impacts of climate change on ecosystems and the effectiveness of certain practices in reducing sedimentation and pollutants. Updated data and information could facilitate optimization of scarce resources and adaptive management, allowing managers to adjust measures through time.
- Achieve effective enforcement of environmental legislation for forest and water resources and commit to bottom-up participatory processes that engender dialogue between communities and the government in order to generate broad-based community support.
- Expand the perspective on the potential benefits of EBA over a broader range of ecosystem services. Forests provide a range of these services, benefiting both local and distant communities. In order to expand the number of stakeholders involved in the successful implementation of the watershed management plan, it is important that the full range of ecosystem services (such as fiber, food, pollination, and nutrient cycling) be accounted for and the benefits adequately communicated to relevant stakeholders.

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Acronyms

AR4	Fourth Assessment Report
CATIE	Tropical Agricultural Research and Higher Education Center (Costa Rica)
EBA	ecosystem-based adaptation
HDI	Human Development Index
ICF	Ministry of Forests and Conservation
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
NPV	net present value
PES	payment for environmental/ecological services
PROFOR	Program on Forests (World Bank)
PRONADERS	National Sustainable Rural Development Program
SANAA	National Autonomous Water Works Services
SERNA	Secretaria de Recursos Naturales y Ambiente
SRES AR4	Special Report on Emissions Scenarios
TroFCCA	Tropical Forests and Climate Change Adaptation
UMA	Unidad de Manejo Ambiental
UNFCCC	United Nations Framework Convention on Climate Change

All dollar amounts are U.S. dollars unless otherwise indicated.

1. Introduction

Human systems around the world are facing the critical challenge of learning to adapt to the combined and related pressures of climate and environmental change. Human activity over the last few hundred years has degraded the natural environment at a global scale, changing the form and function of natural systems in all corners of the globe. Climate change puts further pressure on human systems and the natural systems that ensure human well-being on the planet. It has potentially dire effects on livelihoods and human well-being through disruptions to agriculture, food, water, and biomass-based energy supply systems and through changes in disease vector dynamics. It is of particular concern to developing countries, as they have limited resources for large-scale adaptation efforts to buffer people from the impacts.

Ecosystem-based adaptation (EBA) is one approach to adaptation that seeks to lower the impacts of climate change on human systems by strengthening ecological systems (CBD Secretariat n.d.). This type of adaptation attempts to address both past environmental degradation and climate change–induced environmental change to improve outcomes for human systems (Vignola et al. 2009). This study examines the potential benefit of using an EBA strategy involving forests as part of an effort to enhance the climate change resilience of the reservoir systems that provide water to Tegucigalpa, Honduras.

Honduras is considered one of the most vulnerable countries to climate change in Latin America, and it is third on a global climate risk index that uses exposure and vulnerability to extreme events[3] for the period 1991–2010 as a proxy (Harmeling et al. 2012). The country experienced an average of 56 extreme events during the 1991–2010 period and an annual average of 327 deaths (approximately 5 out of every 100,000 inhabitants) plus annual average losses close to $662 million (PPP dollars) or 2.93 percent of gross domestic product (Harmeling et al. 2012, p. 6). Honduras ranks high on the index due to Hurricane Mitch, which caused 80 percent of all the losses and fatalities recorded for the 20-year period (Harmeling et al. 2012, p. 8).

Another estimate is that in the 30 years from 1981 to 2010, natural disasters caused $4.7 billion in economic losses to Honduras, or 50 percent of all losses in Central America (UNDP 2010). Honduras was affected by 6 of the 12 strongest hurricanes of the twentieth century,[4] including Hurricane Mitch in 1998, which resulted in 10,000 deaths and the destruction of 70 percent of the country's road infrastructure, in addition to extensive damage to drinking water distribution pipes and agricultural crops. Hurricane Mitch damaged forest cover, and many watersheds became highly vulnerable to climatic events of similar or less magnitude (SERNA 2000). Similarly, Tropical Storms Wilma, Beta, and Gamma in 2005 resulted in significant damage to housing, infrastructure, and agriculture. Hurricane Agatha in 2010 caused 18 deaths and the emergency evacuation of 16,000 people.

In the Choluteca River basin, which lies in the hot and dry Pacific Coast of Honduras, 31 percent of households reported damages, and 30 percent of crops were damaged by Hurricane Agatha (UNDP 2010). These types of impacts have led the government of Honduras to identify the Choluteca River basin and the watersheds that provide drinking water to Tegucigalpa—including the Guacerique watershed—as one of the areas most vulnerable to climate change (SERNA 2000).

3. There is no unique definition of climate extreme events (Beniston and Stephenson 2004). Here, the study of Harmeling and colleagues (2012) used the Munich Re GeoRisk definition, which is related more to damages registered in disaster databases than to a climate-based definition.

4. Damages reported have been related mainly to landslides and flooding.

In 2005, Dilley et al (2005) found that Honduras was one of the top 20 countries at risk of suffering significant economic loss from all hazards (the six major hazards considered were drought, earthquakes, floods, landslides, storms, and volcanic eruptions). Many of the extreme events that have struck Honduras have resulted in extensive forest cover loss in many watersheds, increasing their vulnerability to soil erosion.

Future climate scenarios forecast that current levels of water scarcity in Honduras will be exacerbated by climate change and the increasing variability in rainfall. A recent national study on future climate change scenarios (Argeñal 2010, as cited in UNDP 2010) indicates there could be a 5 percent decrease in annual rainfall by 2020—particularly along the northwest-southeast corridor. By 2050, a 20–25 percent decrease in precipitation is projected for most parts of the country between June and August, with deficits exceeding 30 percent for most areas during July and August, especially in the departments of western Honduras. During this time, mean temperatures are also expected to increase in western and southern regions, compounding the situation in these areas, as the period of low rainfall that normally occurs during the rainy season will become longer, hotter, and dryer.

Access to water is a constraint in many parts of Honduras. In the rural areas, only 77 percent of the population has access to water and only 15 percent has access to drinking water (INE 2006, as cited in UNDP 2010). The expected changes in climate will put crops and water access for human consumption at even greater risk.

This case study focuses on the Guacerique watershed in Honduras. This watershed provides water to 25 percent of the water supply connections in Tegucigalpa, a city housing approximately 13 percent of the total population in Honduras (the capital's population amounting to 1.05 million people) (Reyes 2006).[5] Water from the Guacerique River is stored in the Los Laureles reservoir (basin volume of 12 million cubic meters (m^3) and is subsequently treated before being supplied to the city's water distribution system.

1.1 Using forests to enhance resilience to climate change's impact on water availability for drinking water

An environmental vulnerability assessment of the main river basins in Honduras concluded that the river basin with the Guacerique watershed (the Choluteca river basin) is one of the most deforested in the country. Land use change in this watershed over the last 20 years has occurred in an unregulated fashion (despite an existing legal framework), driven primarily by economic factors (mainly subsistence agriculture and industrial and residential development), with negative consequences for the city's drinking water supply (Lee 2000).[6] Urban expansion has already started to penetrate the Guacerique watershed (UNDP 2010). Water managers are currently seeking to combine ecosystem- and infrastructure-based solutions to the water supply challenges they face.

Forests provide a broad range of ecosystem services—such as carbon storage, fuel and fiber provision, water and soil regulation, and habitat for pollinators—that support human well-being in both urban and rural settings. Moreover, forests are a part of the landscape, and factoring in the various elements in a landscape is considered key to successful climate change adaptation (FAO 2010). Forests, therefore, are considered important within the context of EBA to climate change and land use decision making.

5. By Tegucigalpa, the authors are referring to the twin cities of Tegucigalpa and Comayagüela, which are governed by a single municipal government, the Municipality of the Central District.
6. The level of industrial development in the lower watershed is not significant at a national level. Agricultural activity in the watershed, however, is much more important, with water managers reporting that 60 percent of the vegetables sold in Tegucigalpa are produced in this watershed.

Thus forests are relevant not only because of the function of trees in the water cycle but also because they provide a wide range of ecosystem services and economic benefits to society. The links between forests and water at the landscape scale indicate that sustainable water provision is influenced by land use. Recognizing this and managing the landscape for water not only generates benefits from the provisioning of water. It also generates a broad range of additional benefits that humans can derive from forests. Forest-based solutions to water provision bring the opportunity to solve other challenges faced by society at local, regional, and national levels. In this case study, evidence shows that forests contribute to drinking water provision (and therefore urban well-being) and can also support local livelihoods and well-being. Similarly, at the global scale, forests contribute to climate change mitigation. Thus by conserving and expanding forest cover, society can meet the compatible goals of climate change mitigation and adaptation.

1.2 Scope of case study

The case study in Honduras aims to assess how forest management could contribute to adaptation of the drinking water system for Tegucigalpa to the impact of climate change using a 20–50 year time horizon. More specifically, this research project aims to do the following:

- Understand the impact of climate change on existing ecosystems in Honduras, with a specific focus on the Guacerique watershed, and evaluate this in relation to other factors such as expected population growth, changes in land use, and poverty indicators.
- Assess the vulnerability of the coupled human-environmental system in the Guacerique watershed.
- Explore current forest and water governance regimes and their relationship to water-related ecosystem services.
- Explore how forest and agroforestry systems can contribute to existing water and forest conservation measures under climate change, including the economic rationale for enhancing these alternatives.
- Explore a range of adaptation alternatives, compare different scenarios, and describe the governance needed to promote EBA.

The Guacerique watershed provides an ideal case study for analyzing the contribution of forests to enhancing climate change adaptation of another sector for several reasons. First, the relationship between ecosystem services and human well-being is simple and direct: the provision of water yield and erosion control services translates into the production of water with certain quality characteristics that becomes drinking water for a substantial portion of Honduras's largest city. Second, land use change and deforestation over the last 20 years are well documented. Third, extreme climate events in the recent past, most importantly Hurricane Mitch, provide the basis for understanding the vulnerability of different parts of the system. Fourth, there are clear governance challenges, including addressing diverse needs at different scales, limited resources for conservation programs, little effective land use planning, and limited enforcement of environmental law (Lee 2000).

This study, one in a series of studies, explores how forests, through the provision of ecosystem services, contribute to other sectors' adaptation to climate change.[7] The objective of the larger project is to capture the role of forests in enhancing resilience to climate change. It examines how sustainable management of forests can contribute to strengthening the social and physical resilience of systems in other sectors. The audience of the overall project includes decision makers in government and development organizations, and the study aims to help advocate for the use of forests for adaptation and to inform allocations of funding for climate change adaptation and mitigation.

7. For more information on the set of case studies please visit www.profor.info/node/2032.

2. Context

2.1 Location and geography

The Guacerique watershed is located in the province of Francisco Morazán in Honduras (longitude: –87.21; latitude: 14.10), to the northwest of Tegucigalpa. The watershed measures 191.75 km^2 (19,175 ha) and is bounded by the following coordinates: –87.21 and –87.44 longitude and 14.02 and 14.16 latitude (SANAA and ICF 2011). It is a tiny portion of the entire country, which has a total area of 112,492 km^2 (BCH 2012). Figure 1 shows the watershed location in relation to municipal, provincial, and national boundaries.

The Guacerique watershed is a mountainous region with a mean altitude of 1,450m, and over 56 percent of the land area consists of slopes greater than 15 percent (Hernández 2003; SANAA and ICF 2011). Steep slopes combined with a shallow soil layer and soil structure, drainage, moisture levels, and rockiness mean the watershed is best suited to forested land uses (Komives et al. 1986, cited in Maldonado and Pérez 1986).

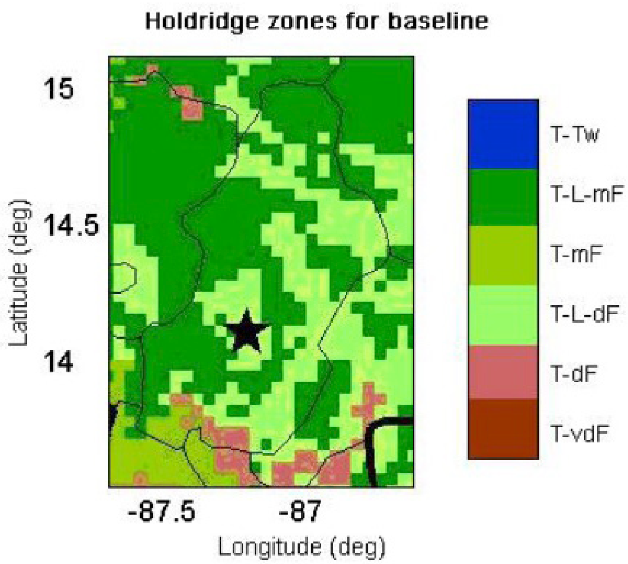
The watershed is composed by five drainages (Guaralalao, Quiscamote, Quiebramontes, Guajire-Mateo, and lower Guacerique). The Guacerique River has been dammed to form the Los Laureles reservoir, which provides drinking water to Tegucigalpa. This watershed is part of the Choluteca River Basin. Downstream from the dam, the Gaucerique River joins the Grande River to form the Choluteca River (which is often mostly dry) that drains into the Gulf of Fonseca in the Pacific Ocean.

Figure 1. Location of the Guacerique watershed

Source: SANAA and ICF 2011.

There are two principal types of forest in the Guacerique watershed: first, seasonal evergreen acicular-leaved lower montane forest located in the mid and upper watershed and composed primarily of *Pinus oocarpa* and *P. pseudostrobus* and, second, seasonal evergreen broadleaf upper montane forest, composed of *Quercus spp* and *Q. oleoides* and also found mainly in the upper regions of the watershed. The vegetation types found in the region are depicted in Figure 2. This figure shows a current Holdridge life zone (Holdridge 1947) distribution of Tropical Lower Montane Moist Forests (57.14 percent) and Tropical Lower Montane Dry Forests (38.50 percent), with small percentages of Tropical Dry Forests (2.18 percent) and Tropical Moist Forests (2.18 percent) in the southern part of the province. Note that the star is located over the center of the Guacerique watershed, suggesting that vegetation in the watershed is generally classified as Tropical Lower Montane Dry Forest.

Figure 2. Current Holdridge life zones in the province of Francisco Morazán, Honduras



Legend:
T-Tw Tropical Thorn Woodland
T-L-mF Tropical Lower Montane Moist Forests
T-mF Tropical Moist Forests
T-L-dF Tropical Lower Montane Dry Forest
T-dF Tropical Dry Forests
T-vdF Tropical Very Dry Forest

2.2 Demographics, economy, and social development

The Guacerique watershed has a current population of 8,853, and the annual growth rate is estimated to be 2.4 percent (SANAA and ICF 2011).[8] The population is 51.3 percent male and 48.7 percent female (TroFCCA 2009). By comparison, the current population of the Capital District is estimated at 1.05 million (urban population only), and the total population for Honduras is approximately 8.22 million (BCH 2012). The national annual population growth rate is about 2.1 percent (BCH 2012).

According to the Tropical Forests and Climate Change Adaptation project (TroFCCA), the primary livelihoods in the Guacerique watershed are subsistence and small-scale commercial agriculture (primarily vegetables), subsistence cattle farming, and forestry (TroFCCA 2009). This highlights the close relationship between local livelihoods, forests, and ecosystem services.

Farming knowledge is transmitted from generation to generation (TroFCCA 2009). Only 43 percent of farmers use soil and water conservation measures, and about 51 percent of farmers have an irrigation system for their fields (TroFCCA 2009). Agricultural activities are generally financed through personal savings, remittances, and sharecropping (TroFCCA

8. The current population figure does not include the 2,245 people estimated in SANAA and ICF (2011) to be living at police or military installations located in the (lower) watershed.

2009).[9] Temporary labor in the service sector (such as watchmen, laundry, and child care) is used to supplement incomes (TroFCCA 2009). Average monthly incomes in the watershed are around $136 (TroFCCA 2009). About 25 percent of women are economically active, whether in agriculture or commerce, and adults have generally completed primary education (TroFCCA 2009).

As recently as the mid-1980s, water or sanitation infrastructure in rural communities in the watershed was almost non-existent; water was obtained from community taps, wells, springs, and even directly from the river and its tributaries. At that time, 96 percent of households did not have latrines, and public garbage collection was also non-existent. Furthermore, rural communities in the watershed had no electricity (Maldonado and Pérez 1986). Today, 76 percent of households are connected to a water distribution grid; however, only 17 percent of households have electricity and 18 percent do not have latrines (TroFCCA 2009). Fuelwood remains the primary energy source, with 96 percent of households using approximately 10 pieces of fuelwood per day (TroFCCA 2009). Only 37 percent of households use high-efficiency wood cookstoves (TroFCCA 2009). Indeed, estimates from 12 years ago regarding national fuelwood consumption indicate that fuelwood provides approximately 70 percent of the energy used for cooking and that 90 percent of timber is cut for this purpose (FAO 2001).

Poverty and extreme poverty rates for the country as a whole have decreased in the last 20 years, from over 80 percent in poverty in 1990 to 66.2 percent in 2010 and from over 60 percent in extreme poverty in 1990 to just over 45 percent in 2010 (Cecchini and Uthoff 2007). Tegucigalpa has the highest Human Development Index (HDI) ranking in the country, measured at 0.759, compared with a national average of 0.664 (UNDP 2006). Lepaterique, the other municipality with jurisdiction over part of the Guacerique watershed, has an HDI of 0.577 (UNDP 2006). Similarly, the Human Poverty Index for Tegucigalpa is 19.4 compared with 42.5 for Lepaterique (UNDP 2006). These indicators allude to the socioeconomic and human development difference between the inhabitants of the mid and upper sections of the Guacerique watershed and inhabitants of the lower watershed and other downstream users.

2.3 Land use designations and land use change

As depicted in Figure 1, the Guacerique watershed is divided between two municipalities. The majority of the watershed (166.82 km^2) falls within the boundaries of Tegucigalpa, while 25 km^2 is under the jurisdiction of Lepaterique. Two of the four streams that come together to form the Guacerique River (Guajire-Mateo and Quiscamote) have their headwaters in Lepaterique, making it an important player in land and resource management in the watershed.

In 1973, under Accord No. 3-1973, the government of Honduras declared the Guacerique watershed to be protected public forest, as allowed for by the relevant legislation enacted in 1971. The text of the accord suggests that the protected status aimed to control logging, which was perceived to be reducing water supply. The upper section of the watershed was subsequently designated as the Yerba Buena Biological Reserve, under Decree 87-1987, which prohibited all human activity in the reserve in perpetuity (Article 5). The decree delegates management responsibility to the Secretaria de Recursos Naturales y Ambiente (SERNA) and the respective municipalities (Article 4). The exact limits of the reserve were to be designated in a separate regulation (Article 11), but the reserve area is roughly from the highest peak down to an altitude of between 1,800 and 2,100 m (Article 5).

The Guacerique watershed has undergone significant changes in land use in recent decades, including deforestation and conversion to agriculture and human settlement (Shlomo et al. 2004). Table 1 shows two different estimations of current land use distribution in the watershed. Note that by these estimates, 60–64 percent of the area remains forested.

9. The local term is *medianía* and under this arrangement, one person provides the land and the labor and another the seeds and other agricultural inputs.

Table 1. Current land use distribution in the Guacerique watershed

Land use	Percent (TroFCCA 2008)	Percent (SANAA and ICF 2011)	Diff. in estimation
Coniferous forest	25.3	22.6	2.7
Broadleaf forest	18.3	23.4	–5.1
Mixed forest	17.4	17.7	–0.3
Agriculture	20.1	15.0	5.1
Pasture	12.3	10.0	2.3
Fallow land	n/a	1.0	1
Brush	2.6	5.0	–2.4
Human settlements	3.9	4.8	–0.9
Water bodies	0.3	0.5	–0.2
Total	100.2	100	

Source: TroFCCA 2008; SANAA and ICF 2011.

Note: Sum for TroFCCA 2008 is greater than 100 due to rounding.

The two main drivers of land use change are small-scale agriculture and human settlement (TroFCCA 2008). The watershed is home to smallholder farmers who practice subsistence agriculture and, more recently, grow vegetables for national and international markets. These farmers live throughout the watershed, including in areas within the boundaries of the Yerba Buena Biological Reserve.

The expansion of the agricultural frontier has led to high rates of deforestation in the watershed. The annual aggregate rate of deforestation for the period 1993–2008 was 1.36 percent (TroFCCA 2008).[10] At the same time, farmers have abandoned some plots, leading to regeneration of secondary forests in lower areas of the watershed (TroFCCA 2008).[11] Forest fires also have a role in deforestation, and agriculture is often subsequently established in areas affected by forest fires. In fact, watershed managers report that inhabitants often start forest fires in order to open new areas to agriculture.

Furthermore, proximity to Tegucigalpa has led to the incursion of residential, commercial, and industrial development in the lower reaches of the watershed (Shlomo et al. 2004). Development is prominent along the Guacerique River and at the edges of the Los Laureles reservoir. In many cases, these developments lack proper water treatment facilities; in some cases, effluents are emitted directly into the river and the reservoir. In addition, many households in the middle and upper reaches of the watershed lack proper sanitation infrastructure. From 1993 to 2008, these drivers led to a conversion of 15 percent of previously forested area to agriculture and human settlement uses and the loss of 7 percent of forest to fallow land or brush (TroFCCA 2008). The scale of land use change in the watershed for this period is depicted in Figure 3.

Various socioeconomic sectors are found in the watershed—ranging from small-scale farmers who depend on land and natural resources for their livelihoods (primarily living in the mid and upper sections) to urban elite in residential developments that have sprung up in the lower sections.

The impact of land use changes on water supply stem from increased levels of soil erosion and sedimentation in waterways and increasing levels of water contamination. The reservoir is estimated to have lost about 15 percent of its full storage capacity in part due to the significant impact of Hurricane Mitch in 1998, which caused significant sedimentation accumulation in the Los Laureles reservoir (Reyes 2006). Moreover, coliform levels are on the rise, and eutrophication is a problem during the

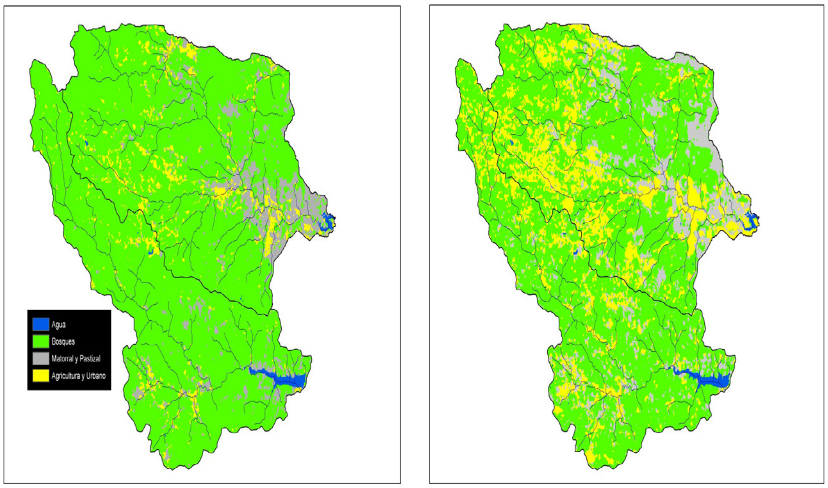
10. However TroFCCA (2008) reports disaggregated rates for mixed and conifer forests for the same period as high as 2.8 percent, which are much higher than the national mean recorded in other studies, such as Rivera (1998).

11. In general, the study found that regeneration was occurring in broadleaf forests in the lower regions of the watershed with poor soils, dominated by *Quercus sp.* adapted to dry conditions.

dry season (Reyes 2006). Furthermore, while Hernández (2003) found no statistically significant trend in precipitation in the Guacerique watershed between 1980, 1991, and 2003, he was able to show a statistically significant increase in average flow during the rainy season and reduction during the dry season (from 0.16 cubic meters per second (m^3/s) in 1980 to 0.06 m^3/s in 2003). This phenomenon was attributed to increased runoff as a product of deforestation.[12]

Figure 3. Land use change in the Guacerique and Grande watersheds, 1993–2008

Source: TroFCCA 2008.



Note: Yellow indicates agriculture or human settlement; grey indicates brush or grasses. The Gaucerique watershed is the upper section of each image. The lower section is the neighboring Grande watershed, which also has important drinking water infrastructure.

Putting forest lost and land conversion in the Guacerique into perspective relative to the rest of the country, 53.2 percent of the national territory was forested in 2004 (FAO 2004), and deforestation rates in the decade 1990–2000 are estimated at 1.1 percent per year (FAO 2001). Thus, while the proportion of the watershed that remains forested is higher than that national average, deforestation rates in the Guacerique watershed are also much higher than the national average.

2.4 Drinking water provision for Tegucigalpa

Provision of drinking water is an ongoing challenge for authorities and inhabitants of Tegucigalpa. Currently, the Tegucigalpa water system operates at a 55 percent deficit. Water managers estimate current citywide demand for water to be 4 m^3/s, while the system only provides around 1.8 m^3/s. This means that water rationing is in effect year-round. In some neighborhoods, the rationing is so severe that people receive water only once a week (SOGREAH Consultants 2004a). Intermittent service is standard across the country in both rural and urban settings, and water rationing was first introduced in Tegucigalpa in the 1980s (PAHO/WHO 2003 and Caballero 1992, in Coello Balthasar 2011). Rapid urban growth in recent decades has outpaced additions to water delivery infrastructure, with neighborhoods not connected to the city's drinking water distribution system. In response, the National Autonomous Water Works Services (SANAA) has organized a cistern truck program providing water to outlying poor neighborhoods that lack public drinking water distribution infrastructure. Leakage from old and degraded water distribution systems and a lack of storm water management infrastructure further aggravate the system.

12. One of the results of the meta-analysis by Locatelli and Vignola (2009) was that reductions in forest cover can increase river flows during both the dry and the rainy season.

The existing water deficit has several implications, including health, hygiene, and equity impacts. Household health and hygiene are compromised when water is scarce, and improper water storage can lead to diarrheal disease and other health problems, with especially negative consequences for infant and child health. A range of private strategies have arisen to meet people's water needs, which have important equity implications. For example, households install water storage tanks and private companies sell water from cistern trucks. However, it is primarily wealthy households who are able to invest in these tanks, despite the fact that water provision is most frequent in wealthy neighborhoods. The sale of water by private cistern trucks also means that some consumers, primarily poorer households, spend a larger portion of their income on meeting this basic need.

Drinking water for Tegucigalpa mainly comes from surface waters, and the primary sources are the Guacerique, Grande, Sabacuante, and Tatumbla Rivers, which are all part of the upper Choluteca River basin (Reyes 2006). Additional water is provided to the system from springs in the La Tigra Nature Reserve (Reyes 2006). Because the system relies on surface water and because river volumes vary greatly over the course of a year between the wet and dry seasons, reservoirs are required. Water shortages primarily occur because of insufficient water in the reservoirs and, as is to be expected, are much worse during the dry season.

There are currently only two reservoirs providing drinking water to Tegucigalpa: the Los Laureles reservoir on the Guacerique River and the Concepción reservoir on the Grande River, providing a total constructed basin volume of about 48 million m^3 (Reyes 2006). However, considerable reservoir volume has been lost to sedimentation. Sediment accumulation in the Los Laureles reservoir is estimated to have reduced reservoir capacity by 15 percent. Moreover, water treatment costs at the Los Laureles treatment plant rose considerably after Hurricane Mitch, as the resulting water quality problems required successive investments in infrastructure, including the incorporation of additional water treatment processes, at a total cost of several million dollars (R. Andrade, personal communication, July 22, 2012). Nonetheless, this reservoir and the associated treatment plant currently supply water to approximately 25 percent of connections in Tegucigalpa, which makes the Guacerique watershed of special importance to national authorities.

Many infrastructure projects have been developed over the years to address water shortages, including the construction of new reservoirs (Guacerique II, Rio del Hombre 6 and 7, and Ojojona) or improvements or connections to existing reservoirs (Tatumbla, Sabacuante, Nacaome, and Jinguare) (CETI S.A. 2011). Multiple studies have identified the Guacerique II reservoir sited upstream from the Los Laureles reservoir in the Guacerique watershed as the most viable project for two reasons: water supply and geographic location (no pumping stations are required from the treatment plant into the distribution network) (CETI S.A. 2011; SOGREAH Consultants 2004a).[13] Financing has yet to be secured for any of the projects just mentioned. However, SANAA is actively seeking partners for its two priority projects: Guacerique II and the Rio del Hombre 7 reservoirs. Researchers were told that the Guacerique II project would reduce the system deficit in the short term to about 35 percent and that the subsequent Rio del Hombre 7 project would be required to reduce water deficit in the medium to long term, meaning that both projects are a priority for the institutions. In addition, the water utility has plans for smaller infrastructure projects also aimed at increasing water capture and distribution capacity. These include the replacement of an existing but currently nonfunctioning inflatable barrier on the Los Laureles reservoir that will add 3 million m^3 to total reservoir volume (approximately one month's water supply under dry-season rationing regimes) and a transfer pipe between the Los Laureles reservoir and the Concepción treatment plant (located in the neighboring Grande River watershed), which will add about another 4 million m^3 to the system annually (as operation will be limited to the rainy season). In order of priority, the inflatable barrier was first and the transfer pipe second, with these expected to be fully operational by 2015.

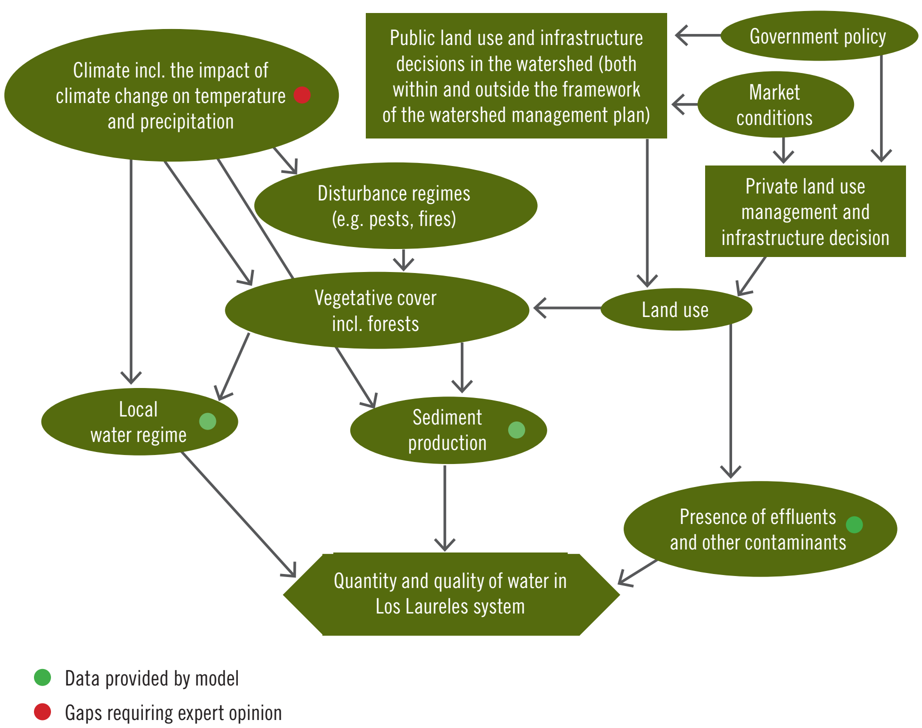
13. Studies for a large reservoir on the Guacerique River were first undertaken in the late 1960s. However, the project's overall cost and especially the high indemnification costs to landowners whose land would be flooded prevented the water utility from implementing this infrastructure project. The Los Laureles reservoir, built between 1974 and 1976, was implemented as an interim measure, given the state's inability to build a larger reservoir.

Looking forward, the population of Tegucigalpa is expected to reach 1.36 million by 2015 and to 2.13 million by 2030 (SOGREAH Consultants 2004a). Future water consumption in the city is projected to be 214,500 m^3/day in 2015 and to reach 336,700 m^3/day in 2030, values that are equivalent to a production rate of 3.06 m^3/s and 4.52 m^3/s respectively (SOGREAH Consultants 2004a). These are well above current water production rates, which on average are 1.99 m^3/s but can be as low as 1.76 m^3/s (SOGREAH Consultants 2004a). Thus significant investment in drinking water capture, storage, and treatment capacity is required in order to meet current and future demand. Climate change is also expected to affect water supply for Tegucigalpa in several ways.

Both water supply and water quality are also affected by land use change. Deforestation decreases water infiltration, which lowers base flow, and it increases runoff and thus soil erosion. All watersheds serving Tegucigalpa are undergoing similar processes of land conversion and forest loss.

Watershed management has therefore been identified as necessary for ensuring the optimal functioning of existing and future drinking water infrastructure (SOGREAH Consultants 2004a). The combined effect of climate change and land management decisions on water provision in the Guacerique watershed is represented in Figure 4.

Figure 4. Factors that affect quality and quantity of drinking water produced by the Guacerique watershed



2.5 Management plan under consideration for the Guacerique watershed

The national water utility (SANAA) and the Honduran Ministry of Forests and Conservation (ICF) have developed a watershed management plan for the Guacerique watershed with the overall objective of ensuring long-term water availability and lowering sediment loads in the Guacerique River in order to maximize the watershed's utility as a source of drinking water for Tegucigalpa.[14]

The management plan spans both environmental and poverty alleviation objectives. It aims to clearly map out landownership, develop an integrated natural resource management program focused on water and forest resources, build economic and management capacity within local communities, monitor environmental indicators, and undertake disaster risk management (SANAA and ICF 2011). Its broad focus responds to the contextual realities of the case study. The water managers understand that broader environmental goals will only be achieved through collaboration with the watershed's inhabitants, especially upstream inhabitants, whose needs and aspirations have to be met.

The watershed management plan contains the following specific forest- and soil-related activities, which are of particular interest to this study:

- Reforest 1,236 ha around springs and creeks.
- Create 100 ha of fuelwood plantations.
- Transition to agroforestry on 161 ha of steeply sloping agricultural land (on slopes of 30 percent or more).
- Concentrate forest fire control on reforested areas.
- Reduce illegal timber extraction on 6,063 ha classified as forest reserve.
- Concentrate pest control on 4,338 ha of existing pine forests.
- Implement soil conservation measures on 2,000 ha of agricultural fields.

It is a six-year plan that received ministerial approval in the last quarter of 2012. SANAA will be in charge of implementation. In accordance with the Law on Forests, Protected Areas and Wildlife, community members will participate in implementation through a watershed council, and inhabitants of the Guacerique watershed recently elected the members of their watershed council in preparation for implementation. Community engagement constitutes SANAA's principal approach to implementation, as it recognizes that success depends on the communities' acceptance and support of the plan and its activities. SANAA is already implementing an agricultural extension project in the watershed, to encourage adoption of soil retention measures by local producers. As will be discussed in the section on governance, water managers also hope to be able to engage communities through payment for environmental services (PES) mechanisms that provide communities with resources for grassroots conservation efforts.

The total approximate cost of the plan expressed in 2012 dollars is $4,216,000 (see Chapter 7). Financing, however, is an unresolved issue at present, as neither institution has identified or designated funds for ensuring implementation, and it is very likely that SANAA will rely on alternative funding sources, primarily development aid, to fund implementation.[15]

14. See SANAA and ICF 2011. As mandated by the Law on Forests, Protected Areas and Wildlife, forest-related management plans, including watershed management plans, are officially the responsibility of ICF. However, the watershed management plan for the Guacerique watershed has been a collaborative effort between SANAA and ICF, and responsibility for implementation has been primarily delegated to SANAA.

15. Currently, the Adaptation Fund project has some funds earmarked for reforestation activities, environmental protection training, and management capacity building in the Guacerique watershed. Further funds will be sought now the plan has become law.

2.6 Current policy framework for climate change

The country's **National Vision (2010–2038) and National Development Plan (2010–2022/2022–2034)** (Republic of Honduras 2010) was drafted in early 2009. The document contains both a long-term vision for the country and a road map (the development plan) for reaching these goals.

Honduras's **National Climate Change Strategy** (SERNA 2010) establishes objectives, strategic directions, and adaptation measures for numerous sectors, including water resources and forests. It was developed by a multisectorial committee that included broad-based representation from numerous sectors, including health, education, universities, the private sector, professional colleges, civil society, and indigenous groups. The strategy was built using expert opinion on possible impacts of climate change on several priority systems, including forests and biodiversity. It has objectives and guidelines for preserving forest function, structure, and composition, for preventing forest loss from fires and pests, and for implementing adequate forest management under scenarios of forest ecosystem change (SERNA 2010).

While the climate change strategy is a requirement under Honduras's obligations under the United Nations Framework Convention on Climate Change (UNFCCC), the strategy is fully integrated into the country's National Vision and National Development Plan, showing political awareness and commitment to addressing climate change. Sections 7, 11, and 23 provide direct links with the National Development Plan in their respective references to regional development, climate change adaptation and mitigation, and disaster risk management.

In relation to forests and biodiversity, the strategy seeks to conserve ecosystem composition, structure, and function over the long term by establishing frameworks for action to ensure the protection and restoration of degraded areas. The principal adaptation measures include strengthening the National Conservation and Reforestation Program (a program led by the ICF), encouraging the development of multipurpose forest plantations through incentives, establishing biological corridors and seed banks, and increasing the use of management plans and physical land use planning.

Beyond the strategy itself, specific legislation on climate change that will formally mandate a multisectorial approach to climate change planning and ensure that climate change is a cross-cutting theme in all government ministries is currently under consideration.

Honduras submitted its first national communication to the UNFCCC in 2000, with support from the Global Environment Facility. The report highlights the importance of its cloud forests, dry tropical forests, and subtropical forests for development (SERNA 2000). This first communication was followed up by a case study in the Aguán watershed by the United Nations Development Programme on vulnerability and adaptation to climate change, in which agroforestry solutions figured prominently (SERNA 2004).

In 2011, Honduras was one of the first countries to receive funding from the Adaptation Fund with a project focused on climate risk to water resources. The project, entitled *Addressing Climate Change Risks on Water Resources in Honduras: Increased Systemic Resilience and Reduced Vulnerability of the Urban Poor (2011–2015)*, aims to encourage the incorporation of climate change concerns into national legislation and regional plans, to develop four early warning systems, and to build capacity at the community level and among specific government institutions. The project focuses on marginalized neighborhoods in the capital city. The Guacerique watershed falls within its geographic scope. This project also aims to create 60,000 ha of protected forest corridors in the upper Choluteca River basin and is thus a stakeholder in forest enhancement in the Guacerique watershed. Studies carried out under the TroFCCA project contributed to the formulation of this project.

3. Framework and Methodological Approach

Water for cities is often sourced from sites where local people live, meaning multiple users in distinct locations use the same water sources and natural resources, such as forests, to ensure the quantity and quality of water. In cases where drinking water infrastructure is fed by surface water sources, as in Tegucigalpa, deforestation, land use change, and climate change induce extremes and irregularities in water availability, changes in overall water availability, and reduction of water quality—putting further stress on urban drinking water systems and affecting the well-being of both rural and urban dwellers. In many cases, the issue of drinking water provision links urban and rural individuals and their diverse livelihoods across spatial scales. Resource managers are faced with the challenge of identifying and implementing mechanisms and encouraging practices that provide the best outcomes for a broad range of needs and goals across these spaces and, as part of that process, facilitating mutual recognition of needs, goals, and benefits at multiple scales.

This case study seeks to integrate modeling of climate change and ecosystem services at the watershed scale with an economic analysis of the impacts of watershed management policies on water quality and quantity under high and low climate change scenarios. It seeks to inform policy makers of economic contributions of forest ecosystem services in the watershed that can be additional to infrastructural development being implemented or considered for future investments in climate change adaptation. Given the scope of this project, several different research methods were used to generate data on climate projections, governance, the economic impact of management options, and current and future system vulnerability.

3.1 Analytical framework

The analytical framework for this study seeks to understand both current and future social and environmental vulnerability and to draw direct connections to planned climate change adaptation. Three key ideas underpin the framework for the case study.

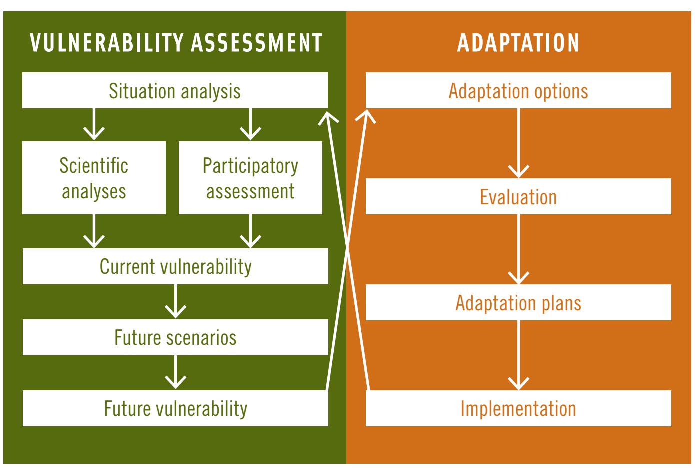
- There is a dual interaction between adaptation actions that support forest ecosystems (adaptation for forests) and adaptation actions that allow forest ecosystems to support human adaptation (forests for adaptation).
- Climate change adaptation refers to the changes to social, political, and economic systems that allow societies to adjust to climate change (Smit et al. 2000; Smit and Wandel 2006). These changes can be anticipatory or reactive and autonomous or planned (Smit et al. 2000). Optimum outcomes are expected from planned, anticipatory adaptation, where actions are designed and implemented in advance after consideration of the potential impacts of future climate change scenarios and a comprehensive evaluation of existing response alternatives.
- Ecosystem-based adaptation refers to adaptation strategies that focus on conservation and management of biodiversity and ecosystem services to buffer the negative effects of climate change on human well-being (CBD Secretariat n.d.). This approach is grounded in the knowledge that human well-being diminishes with the loss of ecosystem services and that the vulnerability of social and ecological systems may increase in the future (Vignola et al. 2009). EBA is particularly challenging, as it requires solutions crossing both spatial and temporal scales and where the costs and benefits are unequally distributed between different groups of stakeholders. In addition, EBA requires effective mechanisms for dialogue between science and policy (so that decision making may be informed by science).

The definition of vulnerability used in this study is from Metzer and Schröter (2006): "Vulnerability is the degree to which an ecosystem service is sensitive to global change plus the degree to which the sector that relies on this service is unable to adapt to the changes." This definition was chosen over others (such as one from the Intergovernmental Panel on Climate Change (IPCC))[16] because, as suggested by Metzer and Schröter (2006), it is easier to apply to a specific analytical case study. It allowed for a focus on sensitivity in relation to the environmental system and on adaptive capacity in relation to the human system. *Sensitivity* refers to how sensitive a specific system is to climatic change. The ability of the system to adapt is equated with *adaptive capacity* or "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (McCarthy et al. 2001, p. 982). Adaptive capacity is understood to be a function of economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al. 2001). It is important to note that skills also include the ability to use resources and achieve the desired change in advance of negative impacts.

Resilience is defined as the "amount of change a system can undergo without changing state" (McCarthy et al. 2001, p. 993). In other words, it is the system's ability to "bounce back." Ecological resilience is conceived in relation to changes or disturbances under climate variability and climate change. Social resilience extends to cultural, technological, economic, and political changes, which also have direct and indirect consequences on ecological systems (Pachauri and Reisinger 2007; Resilience Alliance 2010). It is expected that the impact of climate change will be abrupt and in many cases exceed system resilience, which is why planned adaptation is necessary. As mentioned by Adejuwon et al. (2001), resilience is the inverse of vulnerability.

The analytical framework used for this case study links vulnerability and adaptation (see Figure 5). As mentioned earlier, it seeks to identify current and future social and environmental vulnerabilities and to draw direct connections to planned climate change adaptation. This two-step process allowed the identification of key existing vulnerabilities and the mapping of possible tendencies under climate change. These future scenarios then provide the basis for a discussion and evaluation of adaptation options to respond to future vulnerabilities and needs. Thus the framework fulfills the general purpose of vulnerability assessments, which is to inform stakeholders about adaptation options (Metzger and Schröter 2006).

Figure 5. Analytical framework



Source: CIFOR 2010.

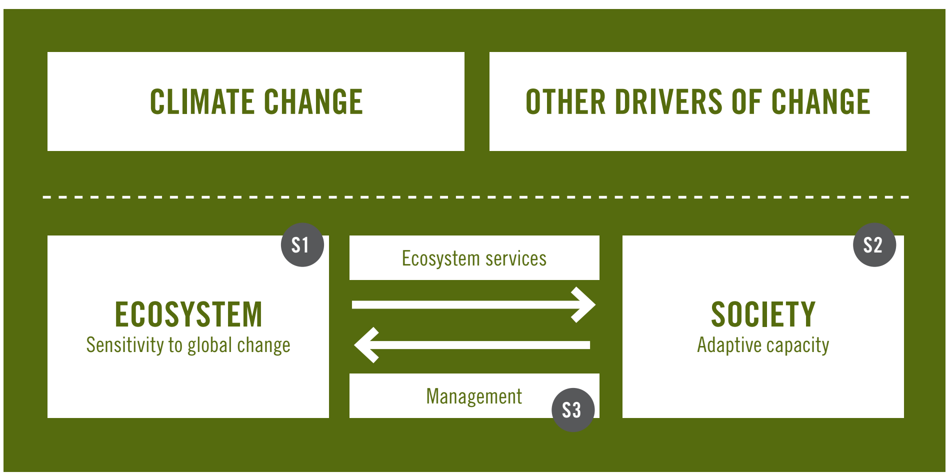
16. "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (McCarthy et al. 2001, p. 995).

3.2 Vulnerability assessment

The vulnerability assessment was carried out using a modified version of the framework developed by researchers at the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica as part of the TroFCCA project, which carried out applied research between 2005 and 2009. The adapted framework is depicted in Figure 6. It is designed to analyze vulnerability on landscapes with both social and ecological components and to integrate climate variability, climate change, and other threats (TroFCCA 2012). It allows for conceptualization of connections between climatic forces and ecological and social systems and for the potential effects of vulnerability in one aspect of the system on other aspects of the system. It also firmly places management options as a mediator between social and ecological systems, which is particularly useful for this study.

The vulnerability assessment involved several steps. It included collecting data on projected climate and land use change as well as on the sensitivity and/or adaptive capacity of the forest ecosystem (S1) and the social system (S2). Information on governance and institutions was collected to assess management (S3). All the previous steps described in this section generated important information for undertaking the vulnerability analysis, and this information was complemented by secondary sources.

Figure 6. Framework for the vulnerability assessment



Source: Adapted from TroFCCA 2012.

3.3 Assessing impact of climate change

We used climate change projections for 2030 and 2080 based on the TYN SC 2.03 (updated February 2004 version) dataset developed by the Climate Research Unit at the University of East Anglia (Mitchell et al. 2003).[17] Even though at present the global mean temperature stands at 0.8°C above preindustrial levels (World Bank 2012b; Jones et al. 2012), scenarios modeling a 0.5°C increase were what was available at the time the analysis for this study took place.[18] The 0.8°C temperature is based on the HadCRUT3v model.[19] In the Fourth IPCC Assessment Report's Special Report on Emissions Scenarios (SRES), temperature changes for Central America in 2020, 2050, and 2080 were projected. In the dry season, expected changes in

17. These data are publicly available at http://www.cru.uea.ac.uk/cru/data/hrg/timm/grid/TYN_SC_2_0.html.
18. As can be seen at http://www.cru.uea.ac.uk/cru/data/hrg/.
19. These data can be accessed at http://www.cru.uea.ac.uk/cru/data/temperature/.

temperature for 2020 are 0.4–1.1°C; for 2050, changes of 1.0–3.0°C; and for 2080, changes of 1.0–5.0°C. In the wet season, the corresponding projections are 0.5–1.7°C for 2020, 1.0–3.0°C for 2050, and an increasing range of 1.3–6.6°C for 2080.

For this study, the dataset used established a global historical baseline of climate variables for the period 1951–2000 and of 16 possible climate change projections resulting from four global climate models[20]—CGCM2, CSIRO2, HadCM3, and PCM—under four different greenhouse gas emissions scenarios—A1F1, A2, B1, and B2. This global dataset has a resolution of 0.5 arc degrees (30 arc minutes). The four emissions scenarios reflect different global development pathways, or "storylines," with unique combinations of predicted economic growth, technological innovation, economic equity, and environmental quality.

We used the Lund-Potsdam-Jena dynamic global vegetation model (Smith et al. 2001; Sitch et al. 2003) to identify the possible impacts of climate change on the net primary production of natural ecosystems, water runoff, and fires. This model explicitly considers key ecosystem processes such as vegetation growth, mortality, carbon allocation, and resource competition. We applied this model to our 16 climate scenarios, in addition to data on soils and carbon dioxide levels.

The study also applied a simple bioclimatic model to analyze how vegetation types (Holdridge 1947) may change in the future under different climate change scenarios. To contemplate the 0.8°C temperature change, according to the country's First National Communication to the climate change convention, the future impacts are increases in overall temperature. It is estimated that the temperature will increase between 0.8°C and 3.3°C in the north and northwest of country, between 0.9°C and 3.7°C in the south and southwest, between 0.8°C and 3.3°C in the east, and between 0.6°C and 2.7°C in the northeast. The highest temperature increases will occur during May and June. There will also be a reduction in rainfall—precipitation will most likely be reduced by 7–30 percent in the north and northwest, by 8–37 percent in the south and southwest, by 8–36 percent in the east, and by 7–28 percent in the northeast. The highest reduction is expected to occur between November and April.[21]

3.4 Historical land cover change

Globcover[22] land cover maps for both 2005 and 2009 were used to derive the historical land cover change in Honduras. Long-term scenarios for the Central American region from the Integrated Model to Assess the Global Environment (IMAGE) 2.2 dynamic integrated assessment model were used (IMAGE 2001). Contrasting land use scenarios produced by the IMAGE 2.2 model were used. The IMAGE 2.2 dataset includes several global socioeconomic and environmental scenarios (representing possible evolutions of, for example, population, economic activities, greenhouse gas emissions, land use, or climate). We used four scenarios (A1F1, A2, B1, and B2), similar to the climate change scenarios used in this work.

Different scenarios were developed to assess the impacts of climate change and land use change on soil erosion in the Guacerique watershed. The analysis examined whether land use and land management could offset the negative impacts of climate change on soil erosion. This was done by applying the Revised Universal Soil Loss Equation Model for estimating soil erosion as a function of rainfall erositivity, soil erodibility, topography, land cover, and land management. The analysis involved combining the 16 climate change scenarios with five land use scenarios for the Guacerique watershed. These land use scenarios include the baseline (no change) and four possible contrasted evolutions of land use, using the most contrasted scenarios from the IMAGE 2.2 dataset (lowest or highest deforestation) and locating the land use changes close to agriculture (mostly upland) or to pastures (mostly lowland).

20. It should be mentioned that there are additional global climate models; however, these four were identified as state of the art by the IPCC in the Third Assessment Working Group 1 Report (McCarthy et al. 2001).

21. According to the World Bank Climate Change Aspects in Agriculture Honduras Country Note (December 2009), available at http://siteresources.worldbank.org/INTLAC/Resources/Climate_HondurasWeb.pdf.

22. Data source: ESA / ESA Globcover Project, led by MEDIAS-France/Postel; see http://postel.mediasfrance.org/en/PROJECTS/Preoperational-GMES/GLOBCOVER/.

3.5 Governance analysis

Data for the governance analysis were collected through primary and secondary sources. The first set of stakeholder workshops, in February 2012, allowed for primary data collection on local conceptions of governance, stakeholder views on governance gaps, and other information related to the current governance context to promote EBA options. This information was supplemented with secondary sources on specific laws, institutional mandates for key stakeholders, and the case study area. The forest governance evaluation framework developed by the United Nations Food and Agriculture Organization (FAO 2011) was used as a guide in developing the analysis.

3.6 Economic Analysis

The economic analysis consisted of estimating the impact of the proposed Guacerique watershed management plan on key ecosystem services and the resulting cost savings to the national water utility under two climate change scenarios. Expert judgment was used to estimate the impact of specific management options on water supply outcomes under climate change. It was used due to the difficulties inherent in estimating future impacts (economic or otherwise) of both climate change and adaptation/management initiatives that arise from the enormous range of uncertainties (of both key impacts and cost processes) involved in these predictions. Expert judgment has been successfully used in the past to address resource management issues under the uncertainty of climate change (Hagerman et al. 2010; McDaniels 1995; McDaniels et al. 2012; Morgan et al. 2001).

Expert responses were elicited in an October 2012 workshop, where experts were asked to respond to questions related to one of two areas of inquiry: the future performance of a set of variables related to the drinking water infrastructure or future general ecosystem service provision within the watershed under a specific management scenario. They were asked to estimate the performance of these variables in 2030 assuming the successful implementation of the management scenario, under a low climate change scenario and high climate change scenario. The climate change scenarios were built using a range of model output data taken from the Regional Analysis Tool (BETA version) developed by the Pacific Climate Impacts Consortium that was ordered to provide 10 and 90 percentile values representing ranges of extremes.[23]

One group of experts on management of the Los Laureles reservoir (sediments, level control, and so on) were asked to judge the impact of the watershed management plan on four variables: reservoir sedimentation rates, turbidity levels in the reservoir, dissolved oxygen levels in the reservoir during the annual dry season (December to May), and the amount of water entering the reservoir during the annual dry season. These variables were developed in response to initial research that showed that water managers' main concerns are the amount of drinking water available for customers and the quality of the water entering the treatment plant. Furthermore, turbidity and dissolved oxygen levels were identified by experts as key quality indicators for the wet and dry season, respectively. The other set of experts on watershed management and ecosystem services in the Guacerique were asked to judge the importance, extent (physical distribution), and substitutability of 10 different ecosystem services as well as to describe the distribution of benefits among beneficiaries. This approach to ecosystem service provision was developed based on the relevant academic literature, including Farber, Costanza, and Wilson (2002), Metzger et al. (2006), and Nelson et al. (2009). Answers were recorded in a workbook (see Annex A1.2), and a three-step estimation protocol for responses (high, low, and best estimate) was used to control for overconfidence in estimation (McDaniels et al. 2012).

23. See Pacific Climate Impacts Consortium n.d. The Regional Analysis Tool (BETA version) developed by the Consortium was used to generate temperature and precipitation data for all SRES AR4 scenarios for the 2020 time horizon (2010–39). The geographic coordinates closest to those of the case study area used by each model were then extracted from each data set. This resulted in 136 data sets for temperature and 133 for precipitation. The data included changes in monthly and annual mean. The tenth and ninetieth percentiles were then calculated for each month and for the annual mean. The tenth percentile value was considered the low climate change scenario (a 1 in 10 chance that the mean would be lower than this value) and the ninetieth percentile value was considered the high climate change scenario (a 1 in 10 chance that the mean would be higher than this value).

Responses to each question were averaged and then multiplied by the associated unit cost and assembled into a net present value (NPV) calculation, providing an overall estimation of the value of benefits in 2012 (expressed in 2012 dollars). This involved a four-step process. First, the annual value of full benefits (that is, the benefit expected in 2030 when maximum benefits are achieved from the watershed management plan) was estimated. This step involved summing benefits accrued in three areas: maintained storage volume, additional water provision, and improved water quality. Second, benefits were distributed over the period 2019–35, with partial benefits beginning in 2019, reaching maximum value in 2030 and retaining that value through to 2035. Third, the implementation costs associated with the watershed management plan were distributed over the implementation period (2013–18). Fourth, the NPV in 2012 of net benefits for the period 2013–35 was calculated using an appropriate discount rate for the country. The chosen time horizon represents benefit provision over a 20-year time horizon, which was one of the parameters in the study.

3.7 Research-policy interface

CATIE researchers contacted SANAA and the Adaptation Fund project team in late 2011. Research efforts were designed within the framework of the objectives and activities of these two entities in the watershed. Staff from these two entities were considered to be key informants throughout the research process and participated in all first-hand data collection activities.

Research results, including the results of the economic analysis, were presented to key national stakeholders at a workshop in November 2012. The purpose of the workshop was to validate results, receive feedback, and engage stakeholders in an assessment of the trade-offs involved in each management option. A matrix approach was used to connect governance options with the climate change scenarios and the future vulnerabilities. This allowed stakeholders to critically analyze the adaptation options through the comparison of outcomes and provided an opportunity for dialogue between key policy makers, resource managers, and researchers as well as the collective exploration of strategies for addressing (future) vulnerability gaps and the collaborative development of adaptation of strategies with key policy makers.

The project took advantage of a monthly electronic newsletter co-produced by SANAA and the Adaptation Fund project to share project activities and findings with a wider audience. In addition, the full technical report was made available in Spanish and English, and a policy brief was produced for key national-level stakeholders and decision makers. Research findings were also disseminated via two important climate change adaptation focused websites: ADAnet (adaptacionyecosistemas.net) and MIA (www.proyectomia.com).

4. Impacts of Climate and Land Use Changes on Water Supply and Ecosystem Services

4.1 Climate scenarios

All the 16 climate change scenarios show a future increase in temperatures in the case study site of between 1.1 and 5.3°C in 2080. Future precipitation trends are uncertain, with a range of relative changes from −34 percent to +9 percent in 2080. Nevertheless, more scenarios show a decrease than an increase (10 scenarios showing a decrease, 4 showing an increase, and 2 with no changes). Another study, using a set of 136 climate change scenarios in Central America, showed that precipitation is very likely to decrease in our study site in 2070–99 under high emission scenarios. Precipitation is also likely to decrease under low and moderate emission scenarios (Imbach et al. 2012). A global analysis of climate change scenarios concluded that Central America is a tropical climate change hotspot (Giorgi 2006).

Uncertainties about future precipitation have major implications for uncertainties about the impacts of climate change on ecosystem services and livelihoods. In the case of Honduras, uncertainties are not as high as in other tropical areas, but given the uncertainties about other drivers of future changes in ecosystem services (particularly land use change and ecosystem degradation from harvesting), impact studies are challenged by the high uncertainties of the results (Kandlikar et al. 2005). This makes it difficult for scientists to communicate results (Patt and Dessai 2005) and for decision makers to use them. However, some decisions may provide adaptation benefits under a wide range of climate scenarios, and flexible and adaptive strategies can be developed that are more likely to be robust to uncertainty (Dessai and Wilby 2011).

4.2 Ecosystem modelling

When using a coupled climate-vegetation-soil-water model with the 16 climate change scenarios, all scenarios predict an increase in the productivity of natural vegetation (range of changes between +16 percent and +62 percent in 2080). The scenario with the highest decrease in precipitation shows the lowest increase in productivity, but the change is still positive. Additional research is needed to understand the reasons of productivity increase in spite of precipitation decrease, perhaps linked to temperature increase. Another global study found limited changes in ecosystem productivity in Central America, much lower than in our study. However, most global studies at a coarse scale cannot reflect the diversity of climate in the narrow strip of Central America. For example, our study shows how productivity varies highly spatially at the scale of Honduras, an area that may be represented by one or two pixels in global studies.

Model results show that water runoff is predicted to decrease in all scenarios, with relative changes ranging from −31 percent to 0 percent by 2080. Similar results were found with a regional study using 136 scenarios and another vegetation model (Imbach et al. 2012): runoff is very likely to decrease in 2070–99. Even though precipitation decrease is not predicted by all scenarios, the certainty of temperature increase makes runoff decrease in all scenarios. This result has major implications for the users of surface water in the study site.

Future trends in fire prevalence are not expected to change much at the 2030 and 2080 horizons in 14 out of the 16 scenarios. Two other scenarios show a decrease in fire prevalence in the future. More research is required to understand what drives these decreases. Results show that fire is of limited concern during average future climates. However, our modeling work does not take into account events such as extremely hot and dry years, during which fires can affect larger areas than in an average year. Several global studies on the impact on climate change on fires show that our study site will experience limited changes in fire probability, frequency, or potential (Alo and Wang 2008; Krawchuk et al. 2009; Liu, Stanturf, and Goodrick 2010; Moritz et al. 2012; Scholze et al. 2006). These studies use different approaches: they combine multiple climate scenarios with empirical fire models (Krawchuk et al. 2009; Moritz et al. 2012), fire indices (Liu, Stanturf, and Goodrick 2010), or dynamic global vegetation models such as in our study (Alo and Wang 2008; Scholze et al. 2006). However, as noted earlier, global studies use a coarse resolution that is not adequate for the study region with high climatic gradients.

Under climate change scenarios, the Holdridge life zones may shift to drier zones (for example, from moist to dry forests). This result has limited implications because of the simplified classification of life zones and only suggests that changes in ecosystem types and biodiversity are possible, but more research is needed on this issue.

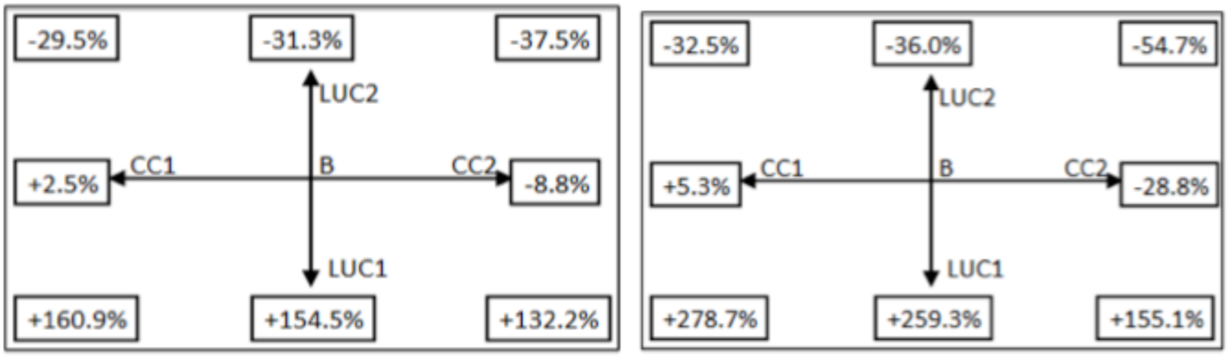
4.3 The case of soil erosion

Climate change will modify the erosivity of rainfall, which is of major concern to water users and to infrastructure affected by sediments (such as reservoirs and drinking water systems). The projected change in rainfall erosivity ranges from –29 percent to +5 percent by 2080. Most scenarios show a decrease in erosion due to decreasing rainfall, but the climate change scenarios consider only changes in mean precipitation, not in extreme events. Erosion may increase due to increasing rainfall intensity or extremely wet years. Even though extreme events are not well represented in the climate change scenarios, one study suggests that the intensity and frequency of extreme precipitation events have been increasing in the last decades (Aguilar et al. 2005).

The major land cover change observed in our study site between 2005 and 2009 was an increase in closed to open forests and a decrease in mosaic croplands, mosaic forests or shrublands, and herbaceous vegetation. One of the four global scenarios of land use change in Central America suggests a strong decrease in areas of natural vegetation by 2080, but the other three show similar or larger areas of natural vegetation by 2080 compared with the baseline.

Using land use and climate change scenarios specifically for the Guacerique watershed, we found that the benefits of lower rainfall erosivity in 2080 (–29 percent) can be lost by inappropriate land use, as the worst land use scenarios (from a point of view of erosion) can lead to a strong increase in erosion (+155 percent) (see Figure 7).

Figure 7. Change in soil erosion compared with the baseline (B) for two contrasting climate scenarios (CC1 – PCM.B2A and CC2 – HAD3.A1FI) and two contrasting land use change scenarios (LUC1 – Scenario A and LUC2 – Scenario D) in 2030 (left) and 2080 (right)



Good land use management can offset the negative impacts of climate change on erosion caused by rainfall: even though erosion caused by rainfall can increase by 5 percent by 2080 in one scenario, it can be decreased by 32 percent with land use management. For all time horizons, land use scenarios induce more variability in erosion than climate change scenarios do.

4.4 Overall discussion

Many projections, including those in this report, show that the area around Tegucigalpa will become drier, with direct implications for the drinking water system reliant on surface water. Furthermore, the more intense rainfall events associated with climate change and the potential concentration of total precipitation into fewer but more-intense rainfall events may mean less water overall captured by reservoirs on an annual basis (as reservoirs overflow and are unable to store the high volume of water for later). In addition, more-intense rainfall means greater erosion, causing sediment to accumulate in reservoirs and affecting water quality. Increased climate variability will also bring more variability in the onset, length, and end of the dry season, in some years increasing the number of months that the system depends entirely on water storage and causing water quality problems when long dry seasons drain reservoirs to low water levels (Republic of Honduras n.d.; TroFFCA 2008; UNDP and SERNA n.d.).

The predictions from the climate change models indicate that forest ecosystems, and thus the current nature of ecosystem services, in the watershed are vulnerable to climate change and are very likely to undergo changes. They also indicate how climate change will affect agricultural livelihoods in the watershed and thus the vulnerability of local communities to climate change.

It is in this context that water managers are seeking to pursue forest-focused EBA to address water issues, namely water availability and water quality. Forest cover will increase upstream sediment retention and influence the water balance (and over the long term, provide some stability to base flow). However, forest and water managers should also expect changes in the predominant forest ecosystem in the watershed, which present a management challenge of understanding how to intervene most appropriately on a landscape undergoing natural processes of change and what impact these natural processes will have on the provision of a wide range of ecosystem services.

5. Vulnerability Assessment for the Guacerique Watershed

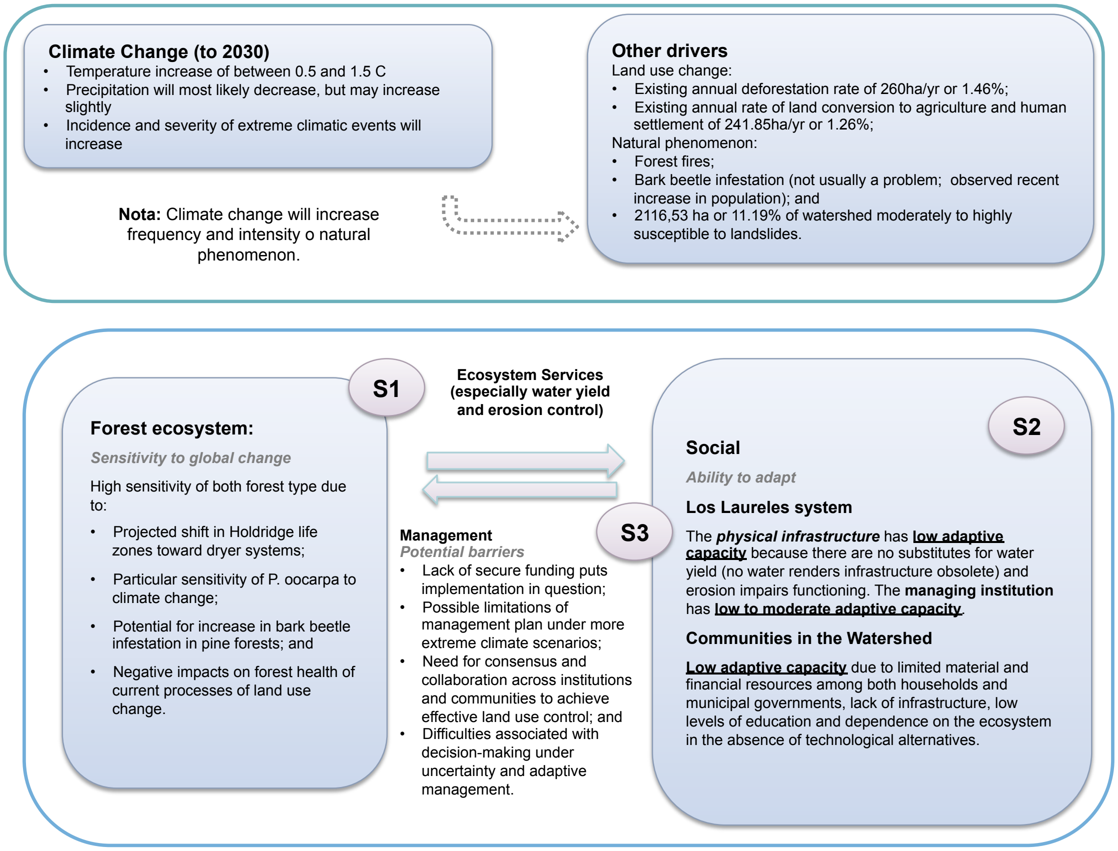
Figure 8 summarizes the results of the vulnerability assessment carried out as part of this research project. The analysis finds that local forests are likely to be moderately to highly sensitive to global change and associated processes, that a range of factors point to a low to moderate adaptive capacity of the managing institution, and that communities situated within the Guacerique watershed are highly sensitive to changes in ecosystem service provision as local livelihoods are intimately linked to the provision of services such as fuel, water, soil formation, nutrient cycling, and pollination. A series of barriers to successful watershed management exist, ranging from funding constraints and the suitability of the management option under some climate futures to a range of constraints on decision making (legal, institutional, and constraints related to human ability to respond to an uncertain future). These findings are discussed in more detail in this section.

5.1 Exposure

Exposure has been described in Chapter 3 and is summarized in the upper left portion of Figure 8. The climatic changes to which social and environmental systems in the Guacerique watershed are expected to be exposed include an increase in temperature of between 0.5 and 1.5°C in the short term (2030) and a strong likelihood for a decrease in precipitation (again to 2030), in addition to an increase in the incidence and severity of extreme events.

Other drivers of change, depicted in the upper right portion of Figure 8, are a recent annual deforestation rate of 260 ha (1.46 percent), a recent annual rate of land conversion to agriculture and human settlement of 241.85 ha (1.26 percent), forest fires (135 ha affecting in 2012), a bark beetle infestation (annual affected area unknown but an increase in populations in 2012 observed by managers), and 11.19 percent of watershed moderately to highly susceptible to landslides.

Figure 8. Vulnerability analysis for the Guacerique watershed



Sources: Framework adapted from TroFCCA 2012; data on other drivers of change from TroFCCA 2008.

5.2 Ecological sensitivity

Tree mortality from physiological stress or from the impacts of pest outbreaks or wildfire resulting from climate change has been identified as an appropriate indicator of forest sensitivity to climate change (Allen et al. 2010). Increases in background mortality of trees in tropical broadleaf forests have already been documented in Costa Rica and Panama (Allen et al. 2010).

Research on *Pinus* and *Quercus* tree species in Mexico shows that sensitivity to climate change is species-specific and also suggests that *P. oocarpa* is one of the more sensitive species of pine (while the sensitivity of *P. pseudostrobus* was half to one quarter of that of the *P. oocarpa*, depending on the scenario) (Gómez-Mendoza and Arriaga 2007). The same study documented significant decreases in range under climate change for those *Quercus* species associated with pine forests, but less sensitivity to climate change for *Quercus* species associated with warmer climates (Gómez-Mendoza and Arriaga 2007). Overall, in that study the geographic distribution of oaks and pines was modeled to decrease 7–48 percent and 0.2–64 percent, respectively, depending on the severity of the climate change scenario (Gómez-Mendoza and Arriaga 2007).

Similar to these results, the modeling carried out under this project in relation to Holdridge life zones shows that the current distribution of life zones is expected to shift toward dryer systems according to almost all climate change scenarios, with a transition toward more dry tropical forest and perhaps even very dry tropical forest (see Figure 9).

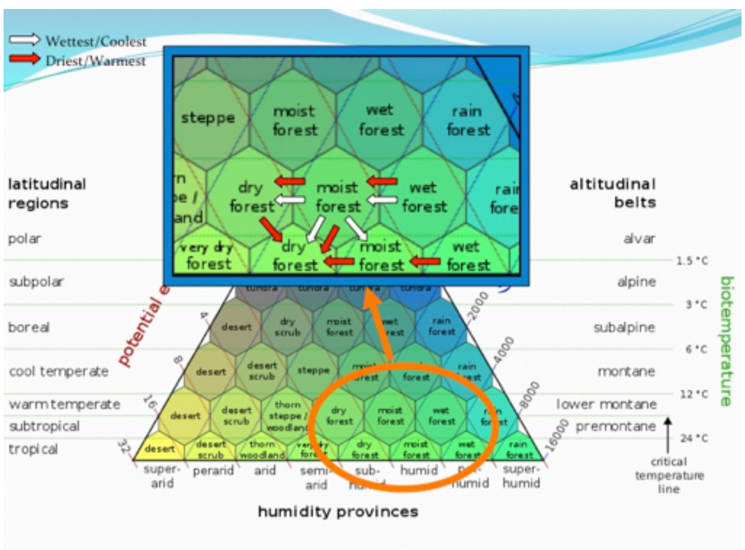
Another study showed a high risk of forest loss in Central America. In this study, up to 40 percent of models showed up to a 10 percent change in forested area, shifting to non-forest vegetation cover, under a scenario of temperature increase of less than 2°C (Scholze et al. 2006).

The study of the impacts of climate change on pine populations in Mexico and Central America indicates certain pine species may be somewhat adaptable, but that land use change and human disturbance pose a significant threat to these forest types (van Zonneveld et al. 2009).

Modeling carried out by Rivera Rojas (2007) suggests that increased temperatures and variations in rain patterns, including a lengthening of the dry season, will increase the propensity for bark beetle infestations. While fire makes Central American pine trees more susceptible to these infestations (Billings et al. 2004), modeling carried out by Palacios (2008) suggests a stable forest fire risk in *Pinus-Quercus* forests in Central America in general and perhaps even a decline in risk for the region of Honduras that contains the case study area.

As mentioned in section 2.3, the deforestation rate in the Guacerique watershed is above the national average and is linked to processes of land use change, both agricultural expansion and urbanization.

Figure 9. Results of modeling of changes to life zones in the province of Francisco Morazán under climate change



This information, as a whole, suggests moderate to high sensitivity of both forest types to global change and associated processes. It is important to note that national-level decision makers consulted during this study associate the increase in temperatures and decreased rainfall with reduced water availability, risks to forest and biodiversity, impacts on human health, and, in general, the need for increased disaster risk management to deal with increased climate variability. This group of stakeholders also demonstrated that it is particularly aware of the role of land use change (urban encroachment, agricultural expansion), forest fire, and pollution from commercial and industrial sources in increasing environmental vulnerability.

5.3 Social vulnerability[24]

The vulnerability analysis for the social component (S2) of this human-environmental system was carried out for two separate but interrelated systems: the drinking water infrastructure belonging to the national water utility (the Los Laureles reservoir) and the communities that live in the watershed and depend on local resources for their livelihoods. The analysis focuses primarily on the vulnerability to changes in ecosystem service provision, namely to changes in water and erosion control for the reservoir and to a broader spectrum of ecosystem services for watershed inhabitants.

5.3.1 Sensitivity and adaptive capacity of the Los Laureles reservoir

The reservoir is highly sensitive to changes in ecosystem service provision: the system is entirely dependent on water yield to function, and erosion reduces system functioning. Hurricane Mitch demonstrated the sensitivity of the Los Laureles reservoir to extreme events. The impact of this climatic event on system functioning continues to be felt to this day in the form of decreased water quality entering the treatment plant, sustained increases in water treatment costs, and the high level of infrastructure investment required during the last 15 years. Water managers are thus already highly aware of the high costs of global climate change to the water utility.

The modeling undertaken for this project shows that climate change is expected to diminish the provision of both water yield and erosion control as ecosystem services in the Guacerique watershed. Modeling of runoff under climate change suggests a reduction of up to 10 percent for both time horizons (2030 and 2080).[25] Experts consulted for the economic analysis felt that more-severe climate change scenarios would increase erosion, overcoming any gains achieved through the watershed management plan. Other stakeholder engagement shows that national decision makers are particularly aware of vulnerabilities with regard to projected decreases in water provision.

Thus the Los Laureles reservoir and associated infrastructure are highly sensitive to processes of global change. The relative importance of this infrastructure to overall water provision in the capital means that there are significant implications for the drinking water system as a whole.

In terms of adaptive capacity, the physical infrastructure can be considered to have very low adaptive capacity for two reasons: there are zero substitutes for water yield (a lack of water renders infrastructure obsolete), and erosion greatly increases operating costs. However, it is more interesting to consider the adaptive capacity of the institution that manages this infrastructure.

In this sense, the experience with Hurricane Mitch shows that the reservoir and the water utility are able to cope with the consequences of global change (the drinking water infrastructure did not collapse during or after Hurricane Mitch, although the institution continues to deal with the consequences 15 years later). Indeed, the development of the watershed management plan and its role in mitigating some of the most significant problems faced by the water utility in this watershed show the utility's ability to act in ways that seek to moderate potential damages.

As noted earlier, economic resources, technology, information and skills, infrastructure, institutions, and equity are considered key determinants of adaptive capacity (Smit et al. 2001). In this sense, adaptive capacity may be limited by the resources available to SANAA to respond to the challenges presented by land use and climate change in the

24. Social vulnerability is assessed using data from 2012/2013. A new administration was elected in 2014, and any changes resulting from this in terms of agencies and ministries has not been accounted for.

25. Experts consulted for the economic analysis are of the opinion that reforestation activities will increase water yield by increasing infiltration and regulating the release of water into base flow under both climate change scenarios.

Guacerique watershed and especially by the few resources available to SANAA's watershed department to effectively implement the watershed management plan. Indeed, the lack of resources put forward by the state to uphold its own environmental legislation in terms of plan development and implementation puts limits on adaptive capacity in general.

The Guacerique is a well-studied watershed, and SANAA has many partnerships that help train its technical staff in environmental modeling and other areas related to water resource protection and drinking water provision. This suggests a good level of information and skills within the organization, although it is important to note that skills also include the ability to use resources in ways that achieve the necessary changes (that is, to effectively implement change). In this respect, the infrastructure deficit is an ongoing issue within SANAA, made most apparent in the 55 percent water deficit within the capital city's drinking water system and the four decades that have passed since the Guacerique II reservoir project was first proposed. This is certainly a limitation on adaptive capacity (Coello Balthasar 2011). On the other hand, institutions are in a time of transition, with the pending process of decentralization of drinking water services from SANAA to a municipal service provider for Tegucigalpa. It will be very important for the future municipal service provider, SANAA, and other institutions to coordinate effectively in relation to resource protection under climate change for this transition not to negatively affect adaptive capacity.

SANAA's ability to implement the watershed management plan and work with other stakeholders (that is, municipal governments) to control land use change in the watershed may be limited by the level of legitimacy that these stakeholders attribute to SANAA (from informal consultations) and thus their willingness to work with it on these goals. Finally, to the extent that both laws and regulations and institutional practices are considered institutions, it may be that SANAA's ability to manage forest and water resources in the watershed under a changing climate are inhibited by existing laws and regulations that define "suitable" management practices in a conservation area and other institutional practices that entrench ways of doing things or inhibit managers from making certain decisions. In essence, the institution in charge of water management should be a recognizable champion and have appropriate funding to effectively implement the plan.

A final consideration is how well a full range of adaptation options have been debated and considered within the institution. The founding premise of the watershed management plan (and related Honduran environmental law) is that reforestation will increase the provision of water resources. However, work by Locatelli and Vignola (2009) demonstrates that this assumption does not hold in all contexts. If the link between forest cover and water availability is not as direct in the Guacerique watershed as assumed by the legislation, then this is potentially a case where laws, as institutions, can act as barriers to adaptation. Given these factors, the managing institution is considered to have low to moderate adaptive capacity.

5.3.2 Sensitivity and adaptive capacity of communities in the watershed

Communities within the Guacerique watershed are highly sensitive to changes in ecosystem service provision, as local livelihoods are intimately linked to services such as fuel, water, soil formation, nutrient cycling, and pollination.

A recent study shows that inhabitants of the watershed are more aware of climate variability than of climate change and that they identify three climatic threats in particular: intense rain storms, delayed rains, and wind storms (Diaz 2009). The respondents in this study linked these climatic threats to negative impacts on natural resources, human health, and household economies. Indeed, household savings are the resources most affected by these types of events, and delayed rains were judged to be the greatest impediment to a farmer's success (Diaz 2009). Finally, this same study showed that communities draw on natural resources (forest, water, and soil resources), material resources (highways and tools), and financial resources (savings and credit), alongside human capital (skills and knowledge), to cope with the impacts of climate variability. The impact of climate variability on these same resources (with the exception of human capital) highlights the extent to which these communities are vulnerable to climate change (Diaz 2009).

In a context of the limited material and financial resources among both households and municipal governments, the lack of infrastructure, the low levels of education, a lack of equity in general in the distribution of these elements, the lack of technological alternatives, and a dependence on degraded ecosystem services, the adaptive capacity of local communities in the Guacerique watershed can be considered low. It is important to mention that the watershed's inhabitants identify limited household incomes, lack of infrastructure (namely health centers and water and sanitation infrastructure, roads, and dignified housing providing sanitary conditions), and lack of education as aspects that increase their vulnerability. Forest fires are seen by locals as a risk to human life as well (Diaz 2009).

5.4 Management for adaptation[26]

Moser and Ekstrom (2010) have developed a framework for diagnosing barriers to climate change adaptation that is useful for discussing the role of environmental management in the context of this vulnerability assessment. They highlight that barriers can be associated with the actors, the context, and the system of focus and can arise during any of the three overarching phases of the adaptation process (understanding, planning, and managing).

Given that water managers are poised to implement the watershed management plan, this discussion will focus on potential barriers to the third phase. However, as Moser and Ekstrom (2010) point out, actions, attitudes, or decisions affecting outcomes in the first two phases can generate barriers in a subsequent phase. Thus it is important to note that there was little community consultation or community participation in the development of the watershed management plan (that is, during the planning phase). As a result, many local inhabitants are misinformed and fearful that plan implementation will affect them negatively (for example, by restricting access to land and thus limiting their livelihoods, or even through evictions from land they do not own) and are reticent to support implementation. More important, the assumed relationship between forest cover and water availability, which may or may not be true, has the potential to generate barriers to successful adaptation down the road for water managers.

In the framework of Moser and Ekstrom (2010), the managing phase begins with the implementation of the chosen adaptation option (in this case, the watershed management plan). Lack of secure funding is an obvious barrier to adaptation in this case study, as without funds, implementation will be piecemeal at best.[27] Logically, lack of funding also puts at risk the subsequent steps of monitoring and evaluating, despite the fact that the watershed management plan makes explicit provision for these steps.

Additional barriers to implementation are likely to arise from the need to identify suitable approaches for providing technical assistance to improve the local capacity at the community and government level. Due to the phasing out of extension services, lack of well-functioning delivery models will be a constraint to implementation, as these services are critical to engender the behavioral change needed to promote the appropriate forms of land management. Another constraint is the need to address land tenure and land conflict, in particular in areas where the person using the land does not have formal access or possess a title.

Another barrier to adaptation is the suitability or robustness of the adaptation option. Expert opinion (solicited as part of the economic analysis) suggests that a watershed management plan will not stem erosion under more-extreme climate change scenarios and will thus not allow water managers to reach their water quality goals.

26. This section is drafted using information from 2012/2013. A new administration was elected in 2014, and any changes resulting from this in terms of agencies and ministries has not been accounted for.

27. It is important to note that the Adaptation Fund project has provided SANAA with some funds to work with local farmers on implementing soil erosion control practices on their fields, and thus at least partial implementation of this one aspect of the watershed management plan is already under way with a handful of producers. The Adaptation Fund has also provided funds for capacity building with communities, including work with local water boards.

Another set of barriers could arise from fact that the achievement of land and resource management goals in the watershed requires coordination across various institutions, including at a minimum two municipalities, two or more departments of SANAA, and ICF. Mutual recognition of legitimacy and authority, strong relationships, consensus on adaptation (land management) objectives, and communication or coordination mechanisms are required for objectives to be achieved. Furthermore, land management objectives will only be achieved with the support and contribution of local inhabitants. In this sense, insufficient attention to watershed community and household needs within the framework of the adaptation option will act as a barrier. Indeed, there are many political barriers to implementation, including the need to successfully negotiate local demands and needs and to overcome resistance and fears. In this sense, the adaptation option must address livelihood and perhaps even municipal government concerns.

There is some collaboration between SANAA and ICF regarding the conservation and management of watersheds in the 11 water and sanitation systems that are under SANAA's administration (though this is not standardized or legally mandated). Other key agencies responsible for implementing the water law and watershed management are the Watershed Councils and the National Resources and Environment Secretariat (SERNA). ICF is providing capacity building for the Watershed Councils. The collaboration between SERNA and SANAA is less evident. Beyond the national agencies, the local government—through municipalities—is the other key level of administration. All the municipalities have an environmental unit, Unidad de Manejo Ambiental (UMA). In the approximately 250 poor municipalities in Honduras, few UMAs are well functioning or have the necessary capacity. These entities are currently being supported (in terms of technical assistance) by the National Association of Municipalities.

A future barrier arises from the uncertainty regarding the continuity of watershed management after the first six-year plan has been completed and the subsequent incorporation of lessons resulting from the evaluation of this first experience. Limited ability to assess and evaluate outcomes and correct management actions is a common problem associated with adaptive management approaches and cannot be considered particular to this case study (Moser and Ekstrom 2010). In this particular context, institutions do little reporting, which further complicates any attempt at adaptive management. On a related angle, the legal nature of the watershed management plan (which is approved by the Minister of Forests) may in itself be a barrier to mid-course corrections deemed worthwhile to managers. Finally, the challenge of decision making under uncertainty is a barrier to managers and stakeholders making management decisions during this and subsequent plans.

In summary, the ecosystem is highly sensitive and the reservoir infrastructure has very limited adaptive capacity. The institution that manages the water supply infrastructure also has a low adaptive capacity, although it is important to point out that many—if not most—institutions find themselves in this position. At the same time, SANAA has shown some resilience in the face of the impacts of climate extremes in the recent past. Communities are also judged to have low adaptive capacity, due primarily to the rates of poverty, lack of education, and the resource-poor municipal government. Nonetheless, communities demonstrate resilience in everyday solutions to household needs and changing conditions, and community capacity to adapt should not be underestimated. Finally, there is a range of barriers to successful watershed management, ranging from funding constraints and the suitability of the management option under some climate futures to various constraints on decision making (legal, institutional, and those related to human ability to respond to an uncertain future).

6. Governance analysis[28]

The governance analysis reviews the relevant legislation for forest and water resources in Honduras and highlights the opportunities and barriers present in the regulatory framework. It also focuses on stakeholder preferences for policy measures and on institutional mechanisms required to ensure water resource protection and forest-based EBA. A complete overview of the relevant legislation is provided in Annex 2, and a summary of the opportunities and barriers is presented in Table 2 at the end of section 6.1.

6.1 Overview of the relevant legislation for EBA

Honduran law establishes an explicit role for forests in a range of sectors, including water provision and biodiversity conservation. This includes the statement included in the country's constitution that reforestation and forest conservation are a matter of "national benefit and collective interest." In this sense, forests are given a central role in maintaining environmental stability and in the resulting benefits to human systems, setting the scene nicely for emphasizing the role of forests in ecosystem-based adaptation initiatives. Furthermore, forest-based responses to water conservation issues are encouraged by the assumption that there is a direct connection between forests and water yield. This assumption appears multiple times throughout the overarching legal and policy framework (although it may be too simplistic to believe that in all landscapes reforestation will necessarily translate into increased base flow in nearby rivers in the short, medium, and/or long term (Locatelli and Vignola 2009)).

Forest policy is generally well situated within broader development policies. For example, the country's **National Vision (2010–2038) and National Development Plan (2010–2022/2022–2034)** (Republic of Honduras 2010) brings sustainable development to the forefront of the country's development plans and promotes the use of integrated natural resource management to ensure sustainable resource use and reduce environmental vulnerability. The plan includes the specific targets of obtaining carbon credits through the restoration of 1 million ha of degraded forestland and the positioning of Honduras somewhere better than 50 on the climate risk index. Climate change and natural resources are two central considerations in the development plan, and a chapter is dedicated to each.

The vulnerabilities of forests and biodiversity to climate change are also explicitly considered in Honduras's **National Climate Change Strategy** (SERNA 2010). The strategy seeks to conserve ecosystem composition, structure, and function over the long term by establishing frameworks for action to ensure the protection and restoration of degraded areas. As noted in Chapter 2, it includes such adaptation measures as a strengthened National Conservation and Reforestation Program, incentives for the development of multipurpose forest plantations, the establishment of biological corridors and seed banks, and more use of management plans and physical land use planning. The combined emphasis on land use planning and reforestation as adaptation measures once again sets the scene nicely for achieving EBA through a focus on forests. The strategy also notes the vulnerability of water resources to climate change and the potential impact on human and ecological systems. The response outlined in the strategy seeks to retain base flow and maintain water quality. It does not, however, explicitly address the vulnerability of drinking water systems to reduced water availability, nor the impact of this on human health and social stability. This is also reflected in the First National Communication to the

28. This section is drafted using information from 2012/2013. New legislation and governance changes since the new administration took office in 2014 have not been reflected in this section.

UNFCCC highlighting that drinking water systems depending on reservoirs such as those of Tegucigalpa will very likely be affected by an increase in sedimentation (SERNA 2000).

Nonetheless, stakeholders involved in water management in Honduras identify a host of barriers to water and forest resource governance. These barriers are related to the frameworks that guide resource management, institutional resource endowments, and institutional approaches to resource management. The outcome is that policy and plans are often not feasible, sustainable, and effective, and many of the activities required by these policies and plans are only partially implemented, if at all. At the same time, these barriers curb the potential positive impact of the many multistakeholder forums on resource management issues that exist.

There are two main pieces of legislation governing water and forest resources: the Law on Forests, Protected Areas and Wildlife (Decree No. 156-2007) and the General Water Law (Decree No. 181-2009). Interestingly, both of these laws were adopted in the last six years. In addition, the national climate change strategy was developed in 2010. Thus, the legislation is recent enough to include provisions for programs such as payment for environmental services and stakeholder consultation/participation in resource management. (Both sets of provisions are discussed in more detail below.)

The **Law on Forests, Protected Areas and Wildlife** provides the primary legal framework for the administration and management of forest resources and protected areas, and it replaces forest-focused legislation from 1971. Under this law, the concept of forests extends to both forested areas and areas that should but do not currently have forest cover (Article 4). Furthermore, the inherent attribute of being "forestland" must be respected in land use planning (Article 93). Article 41 makes reforestation mandatory in areas that produce water, water recharge areas, and along waterways. More important, Article 50 establishes that the ecosystems and forests (and tree-based systems) generate specific ecosystem services, namely biodiversity and soil conservation and recuperation, landslide protection, flood prevention and the prevention of damages to water collection infrastructure and rivers, and water quality improvement. The law also has a whole chapter on water and soil conservation. It establishes that forests with a role in water yield fall under protected areas (Article 5), it prohibits both resource extraction and new settlement in protected areas (Articles 109 and 133), and it states that watersheds that produce water used by humans are to be under special management regimes and are to be reforested (if deforested) (Article 122). This is the legal mandate for watershed management planning in general and for the Guacerique watershed management plan in particular.

The **General Water Law** is the primary framework governing water resources. It sets out principles for water resources management, including water being essential to life and thus a priority for the state, human consumption as the priority, equal access, participatory management, shared responsibility and management shared between government and civil society, and ecosystem services payments for water to be used to finance resource exploitation and conservation (Article 3).

The continuous flux in forest-related laws and regulations (and at times the incompleteness of the legislative framework) and insufficient public education on the changes have left key stakeholders and the general public in the dark to the detriment of forests and is one of the barriers to effective resource governance. For example, the Guacerique watershed first gained protected status under Accord No. 3-1973. Stakeholders point out that an accord, in contrast to a decree, is not a formal law (and that this weakens the watershed's protected status). In their view, the best course of action would be that the protected area declaration for the Guacerique watershed be approved as a legislative decree and that formal regulations would then be drafted and adopted to guide watershed management. Nonetheless, the Law on Forests, Protected Areas and Wildlife establishes that forests with a role in water yield fall under protected areas (Article 5), suggesting that the Guacerique watershed's protected status is upheld by current legislation. (However, Article 122 of that law states that the limits of a management area must be drawn up and the area must be protected, indicating that more explicit protected status is possible). Furthermore, communities are largely misinformed about the legal and institutional structures that govern forest and water resources. Efforts have been undertaken to educate the population on the legislation, especially the Law on Forests, Protected Areas and Wildlife. However, water managers still struggle to engage communities who feel the watershed management plan will jeopardize their livelihoods (through limits on land use, expropriation by the state, or relocation, for example). Clearly, this level of uncertainty among both watershed managers and the general public is a barrier to effective enforcement of legal provisions.

Further to this point—and assuming that the watershed is protected—managers feel that the lack of formal regulations outlining the specific management mandate (meaning there is no clear set of rules regarding the management regime to be used in the watershed) discourages management efforts and allows the state to remain idle. In other words, under the Law on Forests, Protected Areas and Wildlife, the assumed role of the Guacerique forests in producing water for human consumption means that these forests should be under what the law calls a "special management regime" (Articles 122 and 123). This specific management category is not defined by the law or its accompanying regulation (**General Regulations for the Law on Forests, Protected Areas and Wildlife**, Executive Accord No. 031-2010).[29] The management mandate is limited to the statements in Article 123 of the law and Article 160 of the regulations regarding prohibited activities, including the "cutting, damaging, burning or destroying of trees, shrubs and in general forests" and the construction of infrastructure. This level of management guidance does not seem to meet stakeholders' expectations for legal environmental management directives. Indeed, stakeholders feel that unclear roles and responsibilities for initiatives, including PES schemes, are a barrier to forest and water resource management. A key challenge is how to provide stakeholders with the formal management directives they seek and how to prompt effective resource management by the state without mandating actions that prove to be maladaptive in the future.

An additional barrier related to the overall framework is the applicability of relevant legislation given the mismatch between the level of human intervention in the watershed and the levels of human activity allowed by the law. The L**aw on Cloud Forests** prohibits human settlement in the heart of the Yerba Buena Biological Reserve, and, more generally, the **General Law on the Environment** prohibits human settlements in water-producing watersheds. The Law on Forests, Protected Areas and Wildlife limits itself to prohibiting new settlement and new agricultural activities in protected areas and provides the state with the authority to resettle new communities. Despite these restrictions, the watershed has a population of almost 9,000 and exhibits an annual rate of land conversion to agriculture and human settlement of 1.26 percent (approximately 242 ha/yr). This means that actual land use often conflicts with the land use management category defined in the legislation, and thus water managers are faced with the challenge of achieving watershed management goals while respecting the needs of local inhabitants. Water managers understand that success depends on the cooperation, collaboration, and well-being of local inhabitants, and thus they have included significant amounts of local human and economic development activities in the watershed management plan. In a similar vein, the president of the Guacerique watershed council stated that community participation is the key to successful implementation of the watershed management plan and underscored that success would depend on the state's ability to establish true dialogue with the communities in the watershed.

With regard to provisions for PES programs and other incentives for conservation, the Law on Forests, Protected Areas and Wildlife includes a range of incentives to promote reforestation, forest and watershed protection, and forest management, including the provision of free technical assistance and extension by state entities, recognition of forest certification regimes, promotion of agroforestry solutions on forestland currently under agricultural production, and a mandate to provide direct economic benefits for resource protection, including payment for ecosystem service programs (Articles 44, 76, 94, and 149). Likewise, the General Water Law gives payments for ecosystem services a significant role in water resource management. Indeed, Article 25 establishes that communities have the right to receive payments in return for conserving ecosystem services. The law establishes that funds generated by PES regarding water are only to

29. Article 157 of the regulations affirms the statement in the law that these forests can be considered "protected forests."

be used for conservation and protection in the corresponding river basin and that the beneficiaries of water-related ecosystem services must compensate those who conserve the service (Articles 49 and 51).

PES programs provide an opportunity to address this issue of limited resources among institutions, which stakeholders see as an important barrier. Inadequate funding for plans and policies compromises their full implementation and limits capacity, especially at the community and local government levels. (For example, municipalities have limited capacity to carry out environmental management mandates, including controlling land use.) However, stakeholders lament that no concrete PES programs for water conservation have been developed around Tegucigalpa. Even though PES programs can take time to develop, Honduras has several registered carbon sequestration projects (including the World Bank Pico Bonito project) that can provide guidelines on how to set up these types of compensatory systems to reach community beneficiaries.

Additional opportunities for financing water conservation exist, including the Water Fund endowed by the General Water Law with 15 million lempiras to finance conservation projects and programs, including research and the watershed councils (Articles 91 and 93). In addition, the **Law for Sustainable Rural Development** (Decree No. 12-2000) establishes the National Sustainable Rural Development Program (PRONADERS) and includes integrated resource management as one of its objectives (Article 6). In addition to the creation by the law of rural development project fund, Article 6 gives PRONADERS the task of compiling research on best practices for agriculture on hillsides. Both of these provisions could be used to maximize the benefits of the watershed management plan.

A related issue is lack of relevant territorial data and information. The fact that the Guacerique watershed management plan includes an important land use planning component indicates that institutions and governments lack key data and documentation for these types of decisions. This may act as an impediment to land use planning processes. However, the government has identified increased use of management plans and physical land use planning as one of its principal climate change adaptation measures, indicating high-level recognition of this barrier. Increased attention also needs to be placed on data collection, documentation, and reporting to improve the implementation as well as monitoring and evaluation of initiatives, plans, and activities.

With regard to stakeholder consultation and participation in resource management, the General Water Law, for example, explicitly states that the watershed councils are "entities for community empowerment to ensure citizen participation in the enforcement of legislation" (Article 19), and the Law on Forests, Protected Areas and Wildlife creates a framework known as the "Social Forest System" meant to ensure that forest management results in local social and economic development and to ensure community participation in management activities. However, communities have little access to forest management plans developed by the state for public forestland. Furthermore, while Article 21 establishes four levels of Consultative Councils (national, provincial, municipal, and community) to bring communities and other stakeholders to the table and to allow local expertise to contribute to municipal and provincial forest management and watershed planning efforts, Article 121 states that the ICF will coordinate with public and private entities regarding watershed management plans and projects, but it does not explicitly say that the state will consult with communities in these instances. In other words, this law does not ensure broad consultation when it comes to watershed management plan development, and, in general, communities are excluded in various ways from participating in or contributing to management regimes. For example, stakeholders feel there was too little community consultation during development of the Guacerique watershed management plan. This means that there is a certain lack of transparency when it comes to management plans, as the information is primarily in the hands of resource managers. Thus there is limited public involvement in resource management initiatives, despite provisions to promote participation.

Finally, it is important to mention the legal mandates for resource management conferred on other levels of government, which make local governments partners in resource management. The **Law on Municipalities** (Decree No. 134-1990) includes environmental protection among the objectives and responsibilities of municipal government (Articles 13 and 14) and states that municipalities are to enter into agreements with central government and its entities regarding natural resource exploitation, reforestation, environmental protection, and related payments (Article 13). Furthermore, Article 27 of the **Land Use Planning Law** (Decree No. 180-2000) gives municipalities specific authority to use land use planning to regulate settlements for environmental protection purposes and states that these plans must be harmonized with related central government plans (such as plans for special regime areas and protected watersheds). The General Law on the Environment (Decree No. 104-1993) delegates responsibility for water source protection and reforestation to municipalities (Article 29) and also makes them responsible for enforcing the ban on settlements in watersheds (Article 33). It also recognizes the role of municipalities in forest fire and pest outbreak prevention (Article 47). In addition, the Law on Forests, Protected Areas and Wildlife assigns to municipalities the responsibility for monitoring and controlling settlement in protected watersheds. Thus, municipalities' legal obligation to protect local ecology and promote reforestation creates an opportunity for coordinated action between different levels of government on forest- and water-related issues.

With regard to institutional approaches to resource management, stakeholders highlight a range of barriers, including insufficient interinstitutional coordination, especially between local governments who share responsibility for watersheds, and a lack of consensus on common goals between the diverse stakeholders involved in land use and land management, including national authorities, municipal government, civil society, and communities. In fact, local governments do not always recognize SANAA as a legitimate partner in watershed planning, and tensions exists that make collaboration difficult. (One mechanism for overcoming these tensions might be to advance work on PES regimes in return for conservation activities, as provided for in the Law on Forests, Protected Areas and Wildlife.) Furthermore, stakeholders feel that the lack of political will across government is the primary obstacle to effective resource governance, and they lament that multistakeholder resource governance processes are often interrupted by election cycles, which involve significant changes in personnel, meaning processes lose steam or come to a standstill as new people become involved and new working relationships are built. All in all, stakeholders feel private interests often take precedence over public goods. Industrial and residential developments have been built in prime locations with total disregard for watershed function and flow.

In summary, it is clear that the overarching legal framework has many elements that encourage forest-based climate change adaptation and that support effective forest management. Climate change is firmly on the national agenda through the climate change strategy and the National Development Plan, which support future legislative activities for stronger institutional decision making on climate change. Moreover, the legislation emphasizes the role of forests in environmental health and social well-being, and the recent nature of the legislation means it includes important mechanisms for achieving conservation goals, including provisions for PES programs and multistakeholder involvement. Yet lack of resources, political will, and clear mandates plus barriers to broad-based community participation, among other factors, means that rule enforcement remains a challenge. Nonetheless, key aspects of the existing legislation are being put into practice, including the development and implementation of watershed management plans. Water managers will gain important experiences as this process continues. Indeed, lessons learned from the development of the Guacerique watershed management plan are now being applied in processes related to the management plans of other watersheds that produce drinking water for Tegucigalpa.

Table 2. Opportunities for and barriers to forest-based EBA in Honduran legislation

Opportunities	Barriers
• Explicit role for forests in a range of sectors, including water provision and biodiversity conservation, and forests are provided a central role in maintaining environmental stability and in the resulting benefits to human systems. • Forest-based responses to water conservation issues are encouraged by the assumption that there is a direct connection between forests and water yield. • Forest policy is generally well situated within broader development and climate change policies. • Combined emphasis on land use planning and reforestation as adaptation measures further encourages forest-based responses to water conservation • The relevant legislation includes provisions for recognized best practices, such as PES programs and stakeholder consultation and participation in resource management. • Broad definition of "forestland" and the recognition that forests produce ecosystem services in the relevant legislation on forests. • Inclusion of participatory management, shared responsibility, and PES for conservation as governing principles for water resources. • Multiple provisions in law allowing for a range of incentives for conservation, including PES programs and the provision that funds generated through PES for water are only to be used for conservation and protection in the corresponding river basin. • The law identifies local governments as partners in resource management; municipalities' legal obligation to protect local ecology and promote reforestation creates an opportunity for coordinated action between different levels of government on forest- and water-related issues.	• A continuous flux in forest-related laws and regulations, incompleteness of the legislative framework, and insufficient public education. • Gap between management guidance provided in law and stakeholders' expectations for legal environmental management directives. • Applicability of relevant legislation, namely in relation to the mismatch between the level of human intervention in the watershed and the levels of human activity allowed by the law. • Limited resources among institutions. • Inadequate funding for plans and policies, which compromises their full implementation and limits capacity. • Absence of mechanisms to implement the PES provisions in existing legislation for the purposes of water conservation. • Limited public participation in resource management.

6.2 Governance alternative for successful EBA in the Guacerique watershed

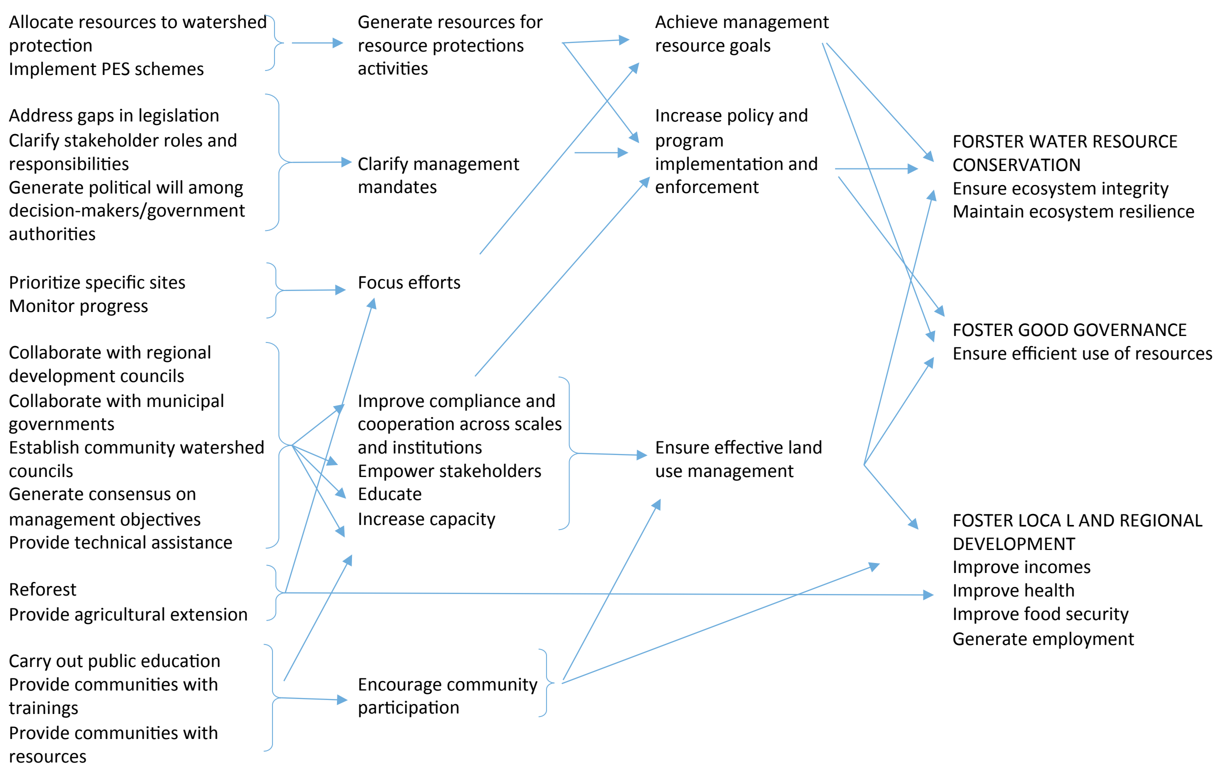
Stakeholders identify multiple pathways for resolving water resource management issues. These pathways are depicted in Figure 10 by using the means-ends objectives approach that has been used to characterize components of governance mechanisms for ecosystem services conservation (Vignola, McDaniels, and Scholz 2012).

Stakeholders identify a set of basic requirements for ensuring water and forest resource governance. First, it is important that adequate resources are made available for plan and policy implementation. Second, given resource constraints, institutions should seek to combine resources. Third, effective communication is required at all levels. Fourth, initiatives need to be strategic, with a well-defined scope. Fifth, initiatives need to include a strong monitoring component. And finally, it is important to identify measures that hold private interests in check in favor of the public good. These components would make initiatives feasible and sustainable, contribute to efficiency and effectiveness, help keep processes on track and moving toward resource management objectives, facilitate coordination between stakeholders, and provide the basis for accountability and transparency for society in general.

It is noteworthy that the stakeholders did not identify the need for a system to mediate and resolve conflicts in an equitable manner. From the evidence it is clear that in a number of cases community members express their "fear to lose access to the land they manage," indicating the need for more than communication and participatory approaches. A mechanism for addressing conflicts is likely to be central in order to facilitate the implementation of any government-led management plan and to ensure that community members become agents for positive change rather than remaining the drivers of land degradation.

Regarding stakeholder preferences for a feasible governance alternative, the actions listed on the left side of Figure 10 can be grouped into five categories: resource generation, government mandates, planning and learning, interinstitutional coordination, and implementation.

Figure 10. Means-ends objectives diagram summarizing stakeholder preferences for successful EBA in the Guacerique watershed



With regard to financial resource generation, stakeholders highlight the need for more resources for conservation in general and PES schemes. Lessons can be drawn from the carbon sequestration projects currently in operation in the country to facilitate the setup of these types of payment schemes. This approach is considered one of the most promising ones for resource generation for watershed management and water conservation initiatives.

In terms of government mandates, stakeholders above all state that it is important to seek ways to generate political will among decision makers and government representatives. Beyond that, it is also important to address gaps in legislation and clearly define the roles and responsibilities for each stakeholder or stakeholder group and improve transparency and accountability. It is important to identify individuals involved in and responsible for the initiative, including decision makers. Equally important is to clearly define the responsibility of support staff and other actors in order to allow the various parties to collaborate effectively.

When it comes to planning and learning, stakeholders suggest that activities and intervention sites be given priority and that programs be accompanied by a strong monitoring component.

The actions listed under interinstitutional coordination and the emphasis on community-focused activities respond to stakeholders' recognition that it is important to carry out activities at multiple scales, from the river basin down through the watershed, municipal level, and community. However, stakeholders highlight the need for technical assistance to improve management capacity, especially at the community and local government levels. Indeed, municipal governments are seen by most stakeholders to be the party with the most control over land use planning and land use change at the landscape level, and they are perceived as not fully exercising power in the Guacerique watershed. Furthermore, given that research shows that controlling land use change is the most important factor in achieving watershed management goals, building effective relationships with municipal governments and encouraging municipal exercise of land use planning faculties are important areas of work. And it is important to generate consensus between stakeholders on the objectives of any particular plan, policy, program, or initiative so that stakeholders agree on the problem and become empowered to act in ways that contribute to achieving collectively set goals.

With regard to implementation, the final category, stakeholders feel that providing communities with training and financial resources is an effective way to increase community participation in watershed management efforts. Also, in this particular case study, stakeholders see agricultural extension as key to improving land use and forest conservation, with important spin-offs for household well-being, including improved incomes and local and regional food security.

7. Economic Analysis

The economic analysis quantifies the potential benefits derived from implementing the Guacerique watershed management plan, which began in late 2012. It estimates the impact of the proposed plan on key ecosystem services and the resulting cost savings through time to the national water utility, SANAA, which has important drinking water infrastructure in the watershed. The study calculated benefits to 2035, providing a 20-year time horizon.

Climate change is expected to put further stress on drinking water resources, and thus benefits were estimated under the influence of two climate change scenarios. Given the nature of the case study, the analysis focused on two specific ecosystem services: water yield and erosion regulation (with the latter ecosystem service included because of its direct relationship to water quality). The study also explored the extent and type of additional benefits that could accrue to various parties from these EBA measures.

The results of the economic analysis are summarized here in terms of experts' judgment of future performance of the drinking water infrastructure with the successful implementation of the watershed management plan, the economic benefits, and experts' judgment of future performance of general ecosystem services provision within the watershed. Additional information is available in Annex 1.

7.1 Future performance of drinking water infrastructure with watershed management

Expert judgment of the future performance of four variables related to drinking water infrastructure with the successful implementation of the watershed management plan under the low climate change scenario indicates that:

- Sedimentation in the reservoir will decrease by 18 percent.
- Dissolved oxygen levels during the annual dry period will increase by 7 percent.
- Turbidity in the reservoir will decrease by 24 percent.
- Water inflow into the reservoir during the annual dry period will increase by 11.3 percent.

Expert judgment of the future performance of the four variables with watershed management under the high climate change scenario indicates that:

- Sedimentation in the reservoir will increase by 13 percent.
- Dissolved oxygen levels during the annual dry period will increase by 23.8 percent.
- Turbidity in the reservoir will increase by 9.8 percent.
- Water inflow into the reservoir during the annual dry period will increase by 29 percent.

7.2 Economic benefit

The overall annual economic benefit of the watershed management plan to the national water utility for the years 2030–35 expressed in undiscounted 2012 dollars is $3.7 million under the low climate change scenario and $9.2 million under the high climate change scenario. Table 3 summarizes the values for each variable and each climate change scenario. Details regarding these calculations are found in Annex 1.

These annual benefits provide the basis for calculated the net present value in 2012 of net benefits from the implementation of watershed management plan for the period 2013–35 (expressed in 2012 dollars).

Table 3. Annual benefits generated by the watershed management plan for 2030–35

Benefit	Low climate change scenario	High climate change scenario
	(2012 dollars)	
Storage volume	$929	–$671
Additional water	$3,575,830	$9,176,908
Water quality	$129,447	–$24,448
Total *(rounded)*	**$3,706,000**	**$9,152,000**

To determine NPV, economic costs and benefits were distributed over the period under evaluation (2013–35). The cost of plan implementation was distributed over the six-year implementation period; benefits were also distributed over the same period. With regards to benefits, it was assumed that some benefits will start to accrue upon implementation of the watershed management plan, while others will take time to materialize. For example, the management scenario assumes 2,000 ha of agricultural fields under soil conservation measures. These benefits will materialize immediately. Conversely, benefits from the reforestation activities (on approximately 1,500 ha) are assumed to materialize more slowly as the forest matures. Thus, it was initially estimated that 60 percent of the benefits will materialize in 2019 and that benefits will increase in a linear fashion up to 100 percent in 2030, when benefit provision will stabilize. This distribution of benefit provision over time reflects the substantial area under soil erosion management compared with the area that will be reforested. Thus the total annual economic benefit was ascribed to the year 2030 and to each subsequent year up to and including 2035; 60 percent of that benefit was ascribed to 2019 and a compound growth rate of 1.0475 was applied to calculate the value for each year from 2020 to 2030. This calculation was carried out for both the high and low climate change scenarios. (See Annex 1.3 for more information on this calculation.)

Table 4 shows overall net economic benefit of the watershed management plan in 2012, expressed in 2012 dollars.

Table 4. NPV of the net economic benefit of the watershed management plan to the national water utility in 2012, by social discount rate and climate change scenario

Social discount rate	Low climate change scenario	High climate change scenario
	(2012 dollars)	
2.1	$34,721,000	$91,518,000
3.3	$28,580,000	$76,135,000
4.5	$23,593,000	$63,616,000

Note: Sixty percent of total benefits are assumed to manifest in 2019 and benefit provision is assumed to increase in a linear fashion, reaching 100 percent in 2030 and remaining at this level through 2035.

7.3 Future performance of general ecosystem services provision within the watershed

The economic analysis also considered the future performance of a broad range of ecosystem services in the watershed. This allowed researchers to highlight the additional benefits that will accrue from the successful implementation of the watershed management plan. Experts were asked to evaluate substitutability of services, distribution of benefits, and the extent and importance of service provision.[30] The ecosystem services considered were freshwater, fiber, fuel, erosion regulation, pest regulation, pollination, natural hazard regulation, soil formation, nutrient cycling, and recreation and ecotourism. These services were identified as the most relevant from the services identified in the Millennium Ecosystem Assessment (MA 2005). Note that in this context the source of both fiber and fuel is wood, and timber is the most common form of fiber extraction. Additional information on the results from this portion of the expert elicitation is available in Annex 1.2.

Turning to substitutability, the ecosystem services relevant to the water utility—namely, freshwater and erosion regulation—were considered nonsubstitutable (freshwater) or partially substitutable (erosion regulation). The substitute for erosion regulation are erosion prevention measures, ranging from cropping practices to civil engineering solutions, but this service is only partially substitutable because of the high costs and lower overall effectiveness of alternatives. In addition, respondents deemed soil formation as not substitutable, as well as pollination and natural hazard regulation. Fiber, fuel, nutrient cycling, pest regulation, and recreation were considered partially substitutable. No ecosystem service was considered completely substitutable. (The most substitutable service among those considered was pest regulation, and substitution of this ecosystem service with agrochemicals is common in Honduras, despite the hidden costs of agrochemical use on human and environmental health.)

It is important to note that substitutability is context-dependent (see related discussion in Farber, Costanza, and Wilson 2002). Thus, it may be that local sources of fiber and fuel (wood, in both cases) are central to local livelihoods and thus relatively nonsubstitutable and that even while gas cookstoves are an alternative to fuelwood, economic or transportation barriers (for example) limit the extent to which fuelwood can be replaced by gas in this particular case. The partial substitutability of nutrient cycling is very likely due to fertilizer substitution, and that of pest regulation is due to chemical pesticides, again only partially substitutable because of cost and associated environmental trade-offs. The substitutability of recreation can be interpreted to mean that watershed inhabitants have limited means with which to reach and engage in outdoor recreation opportunities at sites distant from their home (outside the watershed).

With regard to distribution of benefits, beneficiaries are grouped into five distinct categories: inhabitants of the lower, mid, and upper watershed (three categories); downstream water managers; and other downstream users of watershed resources. The results show that the primary beneficiaries of ecosystem services are watershed inhabitants. These individuals, especially those who live in the mid and upper regions of the watershed, benefit most from the provision of freshwater, fiber, fuel, pest regulation, pollination, soil formation, nutrient cycling, and recreation and ecotourism. The differentiated benefit between watershed sectors can be ascribed to socioeconomic differences (peasant farmers upstream, wealthy elite downstream). Other users, including water managers, benefit from the provision of freshwater, pest regulation, and erosion and natural hazard regulation. These results indicate that maintaining upstream soils mainly benefits downstream beneficiaries, especially the managers of the Guacerique reservoir who are affected by sedimentation. Water managers may benefit from pest regulation because it keeps the pine beetle in check, which keeps upstream forests healthy and promotes soil retention. They may benefit in addition from pollination because of its role in ensuring vegetative ground cover. Water managers and inhabitants of the lower watershed are judged to benefit

30. Substitutability refers to how readily the ecosystem service can be provided to direct beneficiaries through other means, included from sources located in other areas; extent refers to the area of the watershed that provides the ecosystem service; and importance refers to the contribution of the ecosystem service to well-being in the watershed.

most from natural hazard regulation.[31] The medium benefit rating given to inhabitants of the mid and upper watershed contrasts with documented concern for landslide activity in all areas of the watershed (TroFCCA 2008, p. 34), and it may be that respondents confused general natural hazard regulation with a buffering of effects from specific extreme climatic events when answering this question.

Respondents were also asked to mention who would receive adverse consequences from the watershed management plan. Experts mentioned farmers in the mid and upper watershed who might see some farming activities prohibited and, in general, inhabitants of the watershed whose economic development plans are counterproductive to watershed protection and conservation and therefore prohibited by the management plan (such as landowners in the lower watershed who seek to engage in residential development or farmers in the mid and upper watershed who hope to expand their cropping area or seek commercial gain from forests).

With regard to extent of service provision in general, the watershed management plan is expected to increase the area of the watershed that provides the ecosystem services just described, irrespective of the climate outcome. However, additional provision of a service does not necessarily mean increased access for beneficiaries. For example, there will be more wood (fiber) available because of reforestation activities, but access to the resource may be restricted. The extent to which any particular service is present in the watershed is, however, influenced by climate. Thus the best outcomes for the provision of freshwater and for fiber provision and soil formation are considered to occur with the full implementation of the watershed management plan and under the high climate change scenario. Conversely, the best outcomes for erosion, pest and natural hazard regulation, pollination, and recreation are judged to occur with the full implementation of the management plan and under the low climate change scenario. It is logical that benefits of erosion and natural hazard regulation outcomes are reduced under the high climate change scenario compared with the low climate change scenario due to the expected impact of the increased precipitation on these services.

Turning to importance of service provision to human well-being in the watershed, the results show that importance is independent of the climate scenarios. If it is assumed that importance is equal across scenarios, and the responses for each ecosystem service are averaged across all four scenarios and then ordered in a descending fashion, the importance of these ecosystem services is as follows, from most to least: freshwater, nutrient cycling, soil formation, pollination, pest and natural hazard regulation (tie), erosion regulation, fuel, fiber, and recreation. Note that freshwater provision, deemed to be essential to the well-being of inhabitants of the watershed under all scenarios, is also considered not substitutable. No other ecosystem service was deemed as important to well-being as freshwater. The importance of nutrient cycling, soil formation, and pollination is understandable, as they are essential for farming. Fiber and fuel are considered of medium importance (important but not essential) to well-being in the watershed, yet it can be assumed that the provision of both will be restricted under the watershed management plan (more control over timber harvesting). (The watershed management plan does include 100 ha of fuelwood plantations to meet local fuel needs and thus reduce general timber harvesting for use as fuelwood.) The estimated importance of erosion and natural hazard regulation under high climate change is intriguing, as it is lower than under low climate change. The reverse was expected, given the positive relationship between increased precipitation and erosion and natural hazard outcomes. Recreation in last place confirms that recreation is not an important ecosystem service in this context. Freshwater aside, the other ecosystem services given high importance—nutrient cycling, soil formation, pollination, and pest regulation—are key to the livelihoods of upstream inhabitants. The areas with highest risk of landslides within the watershed are also in upstream areas. Downstream users benefit most from erosion regulation. This means that, in general, upstream forest and land management will benefit both upstream and downstream users.

31. This response may reflect perception bias: the respondents were all water managers, and their responses could demonstrate heightened sensitivity to the drinking water infrastructure of which they are stewards.

7.4 Discussion

Expert judgment indicates that the watershed management plan will contribute greatly to improving the performance of the four variables related to drinking water infrastructure under the low climate change scenario. In other words, under conditions where temperature increase over the next 20 years is minimal (approximately 0.5^{0}C) and precipitation decreases are substantial (approximately 20 percent), the watershed management plan can be expected to substantially aid water managers in improving water quantity and quality. However, if climate change is accompanied by a significant increase in precipitation, then these climatic factors overpower gains in erosion regulation from the management plan. In this sense, the plan is "not enough" under more extreme climate change scenarios, and if precipitation were to increase over the next 20 years, the water utility can expect to continue to experience problems with sedimentation and turbidity (namely, loss of overall reservoir volume and quality issues related to turbidity).

Despite this, the watershed management plan is expected to contribute to resolving issues with dissolved oxygen levels (eutrophication problems experienced during the dry season) even under the high climate change scenarios. In fact, outcomes are expected to be better under the high climate change scenario when increased precipitation is combined with decreased sedimentation. In addition, the management plan is also expected to increase the amount of water entering the reservoir during the annual dry season (December to May) under both climate change scenarios. Afforestation is expected to increase base flow (by increasing infiltration), despite the marked decrease in precipitation under the low climate change scenario, with even better outcomes projected under the high climate change scenario, given the increase in precipitation.

Given the expected influence of the watershed management plan on these variables, the net economic benefit expected to accrue from the watershed management plan ranges from $23.6 million to $34.7 million for the low climate change scenario and from $63.6 million to $91.5 million for the high climate change scenario, depending on the social discount rate used. Assuming a moderate economic growth rate in the future, the middle social discount rate becomes applicable and thus the net economic benefit of the watershed management plan is approximately $28.6 million under the low climate change scenario and $76.1 million under the high climate change scenario.

The economic benefit calculation shows that almost 100 percent of the total economic benefit from the watershed management plan comes from increased water provision. Indeed, under the high climate change scenario the total economic benefit of water provision is reduced by costs related to increases in sedimentation and turbidity. This demonstrates that climate change can be expected to burden utilities with additional operating costs and underscores the importance of planned adaptation to managing operating costs over the long run. In addition, the results of sensitivity testing regarding future water yield assumptions show that the total benefit is sensitive to the water yield assumption and that changing the assumption leads to significant changes (increases or decreases) in net economic benefit. Indeed, the net economic benefit possible disappears under the low climate change scenario if additional water does not materialize. On the other hand, if water supply is greater than expected, then overall economic value increases between 55 and 110 percent under high and low climate change, respectively. (See Annex 1.4 for more information.) Indeed, as the majority of benefit accrues from this variable, the price point chosen to value incremental change in the good is also a primary determinant of the result of the benefit calculation. In this sense, further research into consumer willingness-to-pay in this context would help to ensure that the good is not undervalued.

It is important to note here that it is clear that the experts consulted ascribe to the commonly held belief that more tree cover will result in increased stream flow in the Guacerique River. This assumption is also apparent in the watershed management plan. However, work by Locatelli and Vignola (2009) demonstrates that the effect of deforestation and afforestation on stream flow is far from uniform. Further research is required to truly understand the impact of afforestation on base flow in the Guacerique River, as evapotranspiration might play an important role in drying the base flow at least in the initial tree growth stages.

It is also important to put the scale of the projected increases in water volumes during the dry season in perspective. The increased inflow into the reservoir during the annual dry season is projected to be in the 10–30 percent range for the two scenarios, which translates into increases in volume of between 407,000 m^3 and 1.22 million m^3. The larger amount represents still only about 12 percent of current effective reservoir volume.[32] Furthermore, this amount is less than two weeks water supply at dry-season treatment plant processing rates (based on a monthly summer water consumption rate out of the Los Laureles reservoir of 3 million m^3), while the smaller value is less than 4 percent of total reservoir storage volume and less than a week of water supply. Thus, while the impact of increased inflow is important to the water utility given the local context, these volumes are not sufficient to resolve the larger water supply issues faced by the utility.

In this sense, the watershed management plan is clearly not an alternative to drinking water infrastructure projects (nor do water managers see it as an alternative to infrastructure). Informants estimate that the Tegucigalpa water system currently operates at a 55 percent deficit (that is, city-wide demand for water outstrips supply by 55 percent), and thus new infrastructure with greater capacity (storage and treatment) is required to meet the basic needs of the capital's population.

The Guacerique II project, which according to recent studies is the most cost-effective of all possible water provision alternatives for the city, would allow water managers to take advantage of the bountiful water provision ecosystem service that exists in the watershed by greatly increasing overall storage capacity (SOGREAH Consultants 2004a; CETI S.A. 2011). In addition, improved sediment retention resulting from the watershed management plan will contribute to maximizing the utility of future infrastructure investments. Moreover, until such time as new infrastructure becomes a reality, the watershed management plan will have a direct impact on the functioning and operational costs of existing infrastructure and help water managers provide the best and most water to its customers despite current infrastructure-related limitations.

Thus, while a new, large reservoir with adequate watershed management to ensure water supply and sediment retention is the most optimal solution, a more feasible alternative, given ongoing resource constraints, is the combination of the management plan and an inflatable barrier in the Los Laureles reservoir plus the construction of the Los Laureles-Concepción transfer pipe, which would add approximately 7 million m^3 of water to the distribution system annually, at a total implementation cost of approximately \$12.2 million in infrastructure costs (2011 nominal dollars) and \$4.2 million in watershed management costs (2011 nominal dollars). By comparison, the Guacerique II reservoir is estimated to cost \$322.48 million (2012 dollars) (see Annex 1.3.1 for more information).

The results of sensitivity testing of the assumption regarding the proportion of benefit accruing as early as 2019 show that the value increases significantly the sooner the benefits materialize. (See Annex 1.4 for more information.) In this regard, it is in the water utility's best interest to undertake actions that maximize early benefit provision and sustain those benefits through time. For example, the sediment budget concept could perhaps help managers locate sediment sources and sinks and track the influence of land management decisions on reservoir sediment deposition. And while soil erosion measures can be highly effective, past experience highlights the need for innovation in ensuring sustained participation of individuals in landscape-level conservation efforts (Pimentel et al. 1995; Walling and Collins 2008). Further research is thus required to understand how to maximize and sustain benefit provision in the Guacerique watershed.

32. Total volume of the Los Laureles reservoir is 12 million m^3 but 1.5 million m^3 of this is believed to have been lost to sedimentation, reducing effective storage capacity to 10.5 million m^3.

With regards to the estimated impact of the watershed management plan on water quality, international experience indicates that benefits related to water quality stemming from afforestation may be greater than expected. For example, one study of U.S. water utilities found an inverse relationship between forested watershed area and drinking water treatment costs (with treatment costs for utilities with watersheds with 60 percent or more forested area being half those for utilities with watersheds with 30 percent forest cover) (Ernst 2004, cited in Postel and Thompson 2005). Thus the reforestation activities in the Guacerique watershed may decrease water treatment costs to a greater degree than indicated here.

While the projected benefits are significant, the economic calculation does not tell the whole story. The inquiry into additional benefits from general ecosystem service provision demonstrates that the watershed management plan will boost ecosystem service provision under climate change and provide a wide range of benefits to users both inside and outside the watershed. The plan is expected to increase freshwater provision in general and to strengthen services such as pollination, soil formation, and nutrient cycling that support the predominant local livelihood (farming) and contribute to the overall well-being of local inhabitants. The value of these additional benefits—while not calculated here—further increases the overall economic benefits of the watershed management plan.

Interestingly, the exploration of general ecosystem service provision in the watershed resulted in a high rating for water yield and much less importance being placed on erosion regulation, despite recognition that it is an ecosystem service that is only partially substitutable at best. This result certainly reflects that importance of water yield to expected economic benefit for the water utility, but it seems to diminish the negative impacts of sedimentation currently experienced by the water utility, especially its experience in the 15 years since Hurricane Mitch, which is perceived by water managers to have instigated sediment problems in the first place.

Finally, when assessing benefits it is important to address scale and trade-offs. Benefits so far have mostly been considered in relation to the aims and goals of the water utility. While benefits can expect to accrue to the water utility from the implementation of the watershed management plan, watershed inhabitants will face both benefits and trade-offs. SANAA experts indicated that the watershed management plan would restrict livelihoods through increased controls over tree felling and land use, reaching the parcel level and individual decisions. However, the additional ecosystem service provision just described will also bring certain benefits to these same individuals. Thus, specific actions create both benefits and trade-offs at different spatial and temporal scales. Further research is required to understand the economic impact of the watershed management plan on the various stakeholders in the watershed.

In summary, this economic analysis aimed to estimate the impact of the proposed Guacerique watershed management plan on key ecosystem services and the resulting cost savings through time for the national water utility in charge of the drinking water infrastructure in the watershed. This is important in elucidating the potential benefits to human systems associated with carrying out ecosystem-based adaptation in forest settings. Assuming a moderate social discount rate of 3.3 percent, the net economic benefit of the watershed management plan in 2012 is approximately \$28.6 million under the low climate change scenario and \$76.1 million under the high climate change scenario. In addition to these benefits, the plan supports a host of other ecosystem services, which provide a range of benefits to stakeholders inside and outside the watershed.

8. Recommendations on the Contribution of Forest Systems to EBA

The ecosystem-based adaptation explored in this case study considers how specific measures in the Guacerique watershed management plan—the use of forest cover and agricultural conservation practices—can enhance water yields and soil retention services. The following recommendations and institutional changes highlight how forests can be used to adapt to climate change and increase resilience.

SUPPORT FARMERS' ADOPTION OF SOIL AND FOREST CONSERVATION PRACTICES

Climate change is expected to affect agricultural livelihoods in the watershed. Sustainable land use practices play an important role in maintaining soil retention. According to the projected climate change scenarios for the Guacerique watershed, smallholder farmers will likely face longer and drier growing conditions as well as erratic rainfall patterns. In order for subsistence farmers to adopt forest conservation and reforestation activities, they need to comprehend the direct benefits these will have for their livelihoods now and in the future. They need to understand that maintaining forest cover can contribute to controlling soil erosion and landslides and can increase infiltration and evapotranspiration, thereby avoiding floods (Stimson and Losilla Peñón 2004). In addition, farmers will need incentives to adopt soil conservation practices. If they need to make investments to adopt such practices, they also need to have access to credit to make the necessary changes to their plots of land.

The adoption of forest and agricultural soil conservation practices such as terracing, contour cultivation, reduced tillage, live barriers, hillside ditches, and crop rotation is correlated to the availability of technical assistance and agricultural extension by the government and other entities. Adopting agroforestry practices such as intercropping can be another way to increase the soil retention of watershed soils. With the changing climate, it will be necessary to continuously update smallholder farmer knowledge and establish new practices (Vignola, McDaniels, and Scholz 2010).

In addition, the economic analysis of the Guarcerique watershed demonstrates that the overall benefit to the water utility institution increases from a greater quantity and quality of water the sooner effective soil erosion prevention measures are put in place. This provides additional incentives to the government to focus efforts on soil and forest conservation practices in the watershed and surrounding areas.

SECURE FUNDING FOR THE IMPLEMENTATION OF WATERSHED MANAGEMENT PLANS IN PRIORITY WATERSHEDS

For the successful implementation of EBA, political will is needed by the government and institutions. The demonstration of government commitment to effectively implement the Guacerique watershed management plan needs to be accompanied by suitable funding mechanisms. Lack of current funding puts implementation of the plan at risk, jeopardizing land management goals. Through the creation of the watershed management unit, SANAA has defended watershed management as a resource management strategy. Personnel from the various departments recognize the importance of watershed management for the institution. This approach has been upheld in a context where funding for infrastructure projects is scarce, and it can be considered as an alternative course of action that arose as a response to these conditions. At the same time, the watershed management unit receives limited funding, with administrative expenses taking up the large majority of the budget. This reduces the unit's ability to effectively contribute to both infrastructure and environmental management goals.

Thus it is recommended that dedicated funds for SANAA's watershed management unit in general, and for watershed management activities in particular, be made available to ensure that legislation regarding management plans is fully implemented. This would also give managers the capacity to develop solid and responsive management plans for water and forest resources.

ESTABLISH MONITORING SYSTEMS FOR ADEQUATE ADJUSTMENT OF EBA RESPONSES

Forest management schemes that halt or reverse deforestation rates can reduce soil erosion. However, planning and implementing EBA measures is characterized by high levels of uncertainty with respect to the impacts of climate change on ecosystems and the effectiveness of certain practices in reducing sedimentation and pollutants. To optimize scarce resources and implement the watershed management plan, it is important to generate updated data and information, through reporting and monitoring that will allow managers to adjust measures through time. Monitoring should provide data on changes in key areas and variables, track progress on the adoption of forest and soil conservation measures, and measure comparative success in reducing erosion and promoting water infiltration. Successful examples of this from different countries could be considered for Honduras.

ACHIEVE EFFECTIVE ENFORCEMENT OF ENVIRONMENTAL LEGISLATION FOR FOREST AND WATER RESOURCES

While the existing legislation includes many promising elements for ensuring successful resource management, the greatest challenges to water and forest governance in Honduras are related to the implementation and enforcement of existing legislation. Limited human, financial, and technical resources are barriers to the enforcement of environmental laws. Mechanisms that develop trust, dialogue, coordination, collaboration, and consensus—working toward common goals among stakeholders, especially between municipalities and other institutions—are necessary for successful EBA.

A commitment to bottom-up participatory processes that engender dialogue between communities and the state and that allow the former to define the rules and their implementation—accompanied by broad-based community programs of environmental education and awareness raising, systematic reviews of implementation processes, and the documentation and reporting of lessons learned—will lay the groundwork for effective enforcement of environmental legislation.

EXPAND THE PERSPECTIVE ON THE POTENTIAL BENEFITS OF EBA OVER A BROADER RANGE OF ECOSYSTEM SERVICES

This case study shows that forests provide a range of ecosystem services benefiting both local and distant communities. In order to expand the number of stakeholders involved in the successful implementation of the watershed management plan, it is important that the full range of ecosystem services—such as fiber, food, pollination, and nutrient cycling—be accounted for and that the benefits are adequately communicated to the relevant stakeholders. This has the potential to increase consensus on the watershed management plan and to increase the resources available for implementation. In addition, designing and implementing payment for environmental services schemes in the watersheds surrounding the capital can help improve the water supply and livelihoods.

9. Conclusion

This report has explored how a focus on forests in ecosystem-based adaptation can boost social and environmental resilience to climate change in the next 20–50 years by identifying current and future social and environmental vulnerabilities and by drawing direct connections to planned climate change adaptation.

Climate change is likely to involve rising temperatures and decreasing precipitation for the Guacerique watershed, resulting in less runoff and a landscape transition to a drier ecosystem type. In addition, climate change will also bring more frequent extreme rainfall events with high soil erosion potential. The impacts are likely to be less overall availability of surface water for Tegucigalpa's drinking water system and for local inhabitants, who use the same water sources for household and productive activities, and the drier conditions will potentially bring significant changes to the existing forest and related ecosystems. The extreme rainfall events, on the other hand, will potentially periodically deposit large amounts of sediment in the Los Laureles reservoir, lowering already limited storage capacity and permanently affecting water quality. The impacts of climate change will further limit drinking water supply to Tegucigalpa, where strict rationing regimes are already in effect, especially in the dry season, and will affect the livelihood strategies of the largely subsistence farmers who predominate in the watershed. Thus, this human-environmental system presents clear vulnerabilities under climate change, and resource managers are faced with the challenge of identifying and implementing mechanisms and encouraging practices that provide the best outcomes for a broad range of needs and goals across spatial scales—and, as part of that process, facilitating mutual recognition of needs, goals, and benefits at multiple scales.

The adaptation option analyzed in this report is the implementation of a watershed management plan with a significant reforestation and soil erosion control component. The plan also includes land use planning, economic development, and capacity building elements to generate information and successfully engage with local communities. The case study shows how forests not only contribute to drinking water provision (and therefore urban well-being) but also can support local livelihoods and local well-being. Similarly, at the national scale, forests contribute to climate change mitigation. Thus, by conserving and expanding forest cover, society can meet the compatible goals of climate change mitigation and adaptation.

There are significant benefits to human systems associated with EBA in forest settings. Assuming a moderate social discount rate of 3.3 percent, the net economic benefit of the watershed management plan in 2012 is approximately \$28.6 million under the low climate change scenario and \$76.1 million under the high climate change scenario. Economic benefit can be increased somewhat to \$33.1 million under the low climate change scenario and \$89.0 million under the high climate change scenario if benefits such as soil retention materialize sooner rather than later. In addition to these benefits, the watershed management plan supports a host of other ecosystem services, which provide a range of benefits to groups inside and outside the watershed.

Climate change is not always the most significant hazard facing society. When it comes to water provision to Tegucigalpa and the Guacerique watershed, land use outcomes have a significant influence on future soil erosion under climate change. Modeling the combined effects of climate change and land use change on soil erosion demonstrates that, in the mid-term time horizon, adequate land management can decrease erosion potential by 29.5 percent under a scenario in which climate change alone could increase erosion potential by 2.5 percent and, in contrast, that bad land management could lead to a 132.2 percent increase in erosion potential where climate change alone would lead to an 8.8 percent decrease in erosion potential. Thus, erosion can be largely controlled through land use practices (reforestation and other soil erosion control practices), bringing important gains and buffering systems from the impacts of climate change. These results highlight the importance of ensuring effective land use management as a climate change adaptation measure.

While ensuring changes in land use management will be central to delivering climate change resilience benefits from the forest-based EBA, more will be needed to meet growing drinking water demands. The current system of reservoirs does not have the capacity to deliver the needed volume of drinking water. Furthermore, there are weaknesses in the drinking water supply system (the pipes, for example). To build a resilient drinking water system therefore will require examination of the optimal combined investments in different parts of the water storage and drinking water supply system. Investments in EBA will be able to deliver reduced sedimentation and water availability benefits, increasing the likelihood of positive returns on investments in the needed physical infrastructure. Investments in EBA will also help improve the performance of the physical infrastructure.

There are many challenges to a forest-based EBA, as demonstrated by this case study. One of the main challenges is changing the land use practices of a multitude of individual stakeholders (mainly subsistence and small-scale farmers), who collectively are the primary drivers of land use change. Because their basic needs are not necessarily met and because household sustenance depends on their land-based activities, it is difficult to ask them to change for the benefit of downstream users, when the new techniques or approaches are unfamiliar and the immediate benefits uncertain. Thus, it is imperative to prove that reforestation and the other changes in land use will improve livelihoods and well-being. Other challenges include the need to provide security over land to the smallholders who have to change land management practices, provide them with the needed technical assistance, and ensure there are means for mediating any conflicts that should arise. Furthermore, it will also be important to ensure the availability of financial and other resources to systematically implement management plans, the willingness of different institutions to collaborate on achieving land management goals, and the government's capacity to enforce environmental legislation, which may have not been systematically enforced in the past.

In light of these barriers, the key recommendations for implementing EBA as part of a larger approach to build the resilience of the water supply system are to support farmers' adoption of soil and forest conservation practices, secure funding for the implementation of watershed management plans in this and other watersheds, establish monitoring systems for adequate adjustment of EBA responses, achieve effective enforcement of environmental legislation for forest and water resources, and expand the perspective on the potential benefits of EBA over a broader range of ecosystem services. Many of these measures are no-regret or low-regret measures, as they will have broader benefits than those generated through increased water availability in the system.

Annex 1: Details of the Economic Analysis

A1.1 Methods used for economic analysis

The economic analysis consists of estimating the impact of the proposed Guacerique watershed management plan on key ecosystem services and the resulting cost savings to the national water utility under two climate change scenarios. Individual interviews and secondary sources were used to establish the management options and associated unit costs. Subsequently, the impact of specific management options on water supply outcomes under climate change was estimated using expert judgment. Expert elicitation was chosen as an appropriate methodology because it seeks out the knowledge and judgment criteria of the trained individuals who best understand the issue under study and the dynamics of the particular system, while avoiding the high costs of computer-assisted modeling. It has been successfully used in the past to address resource management issues under the uncertainty of climate change (Hagerman et al. 2010; McDaniels 1995; McDaniels et al. 2012; Morgan et al. 2001). Expert responses were elicited in a workshop held in Tegucigalpa in October 2012. Prior to that, individual interviews and secondary sources were used to establish the management options and associated unit costs.

The future climate scenarios for the case study were built using data taken from the Regional Analysis Tool (BETA version) developed by the Pacific Climate Impacts Consortium.[33] The tool was used to generate temperature and precipitation data for all Special Report on Emissions Scenarios from the Fourth Assessment Report for the 2020 time horizon (2010–39). The geographic coordinates closest to the coordinates of the case study area used by each model were then extracted from each data set. This resulted in 136 data sets for temperature and 133 for precipitation. The data included changes in monthly and annual mean. The tenth and ninetieth percentiles were then calculated for each month and for the annual mean. The tenth percentile value was considered the low climate change scenario (a 1 in 10 chance that the mean would be lower than this value) and the ninetieth percentile value was considered the high climate change scenario (a 1 in 10 chance that the mean would be higher than this value). Tables A1 and A2 were presented to experts in the workbook, summarizing the resulting high and low climate change scenarios used in the study.[34]

The management scenario was summarized as the full achievement of the tree- and soil-specific aspects of the watershed management plan over the course of 6 years (2013–18) and the maintenance of these achievements over the subsequent 11 years (2019–29), so that in 2030 the reforestation activities described have led to the establishment of young forest stands, and the benefits resulting from all activities described continue to manifest in and beyond the watershed. In addition, the scenario included the assumption that population growth continued at a rate similar to that observed in the recent past (annual growth rate of 2.4 percent) and that a large residential development that was built in the lower watershed but never opened to habitation continued to remain empty.

33. See Pacific Climate Impacts Consortium n.d.

34. The following statement was also presented alongside these tables in the workbook: "In addition, the IPCC's Fourth Assessment Report [2007] confirms that an increase in frequency and intensity of extreme climatic events will accompany both scenarios."

Table A1: Low climate change scenario to 2030 for the Guacerique watershed

Climate variable	Value	Impact
Change in mean annual temperature	+0.65⁰C	Mean annual temperature reaches 23⁰C
Change in mean annual precipitation	–21.78%	Mean annual precipitation decreases to 894 mm

Table A2: High climate change scenario to 2030 for the Guacerique watershed

Climate variable	Value	Impact
Change in mean annual temperature	+1.51⁰C	Mean annual temperature reaches 23.9⁰C
Change in mean annual precipitation	+5.37%	Mean annual precipitation increases to 1,200 mm

A1.1.1 Identification of experts

Experts were selected from within the National Autonomous Water Works Services (SANAA). Snowballing was used to expand the pool of experts beyond the group identified during the initial phases of the research project. Experts were identified as individuals directly involved in the watershed planning process, in the management of water supply infrastructure in the watershed, or in developing related infrastructure investment plans. A total of 10 experts were identified and participated in the workshop. The group included 6 individuals from the institution's watershed management unit, 3 from infrastructure units, and 1 from the head office. Six of the 10 experts considered the performance of variables related to the drinking water infrastructure and the other 4 considered general ecosystem service provision within the watershed.

A1.1.2 Judgment task

The experts were given a workbook containing both background material and a question section (an electronic version of this is available from the authors of the case study). The background section summarized the geography, economy, and demography of the watershed; two possible future climate scenarios for the watershed; and the management scenario. Participants collectively reviewed and discussed the material in a workshop setting. Participants were given one of two versions of the workbook. In one version, the questions focused on the performance of a set of variables related to the drinking water infrastructure, and in the other version the questions focused on general ecosystem service provision within the watershed (see Annex 1.2). Thus the experts were given only the questions related to their area of work and knowledge. As noted, 6 of the 10 experts considered the performance of variables related to the drinking water infrastructure and the other 4 considered general ecosystem service provision within the watershed. In both cases, experts were asked to estimate the performance of these variables in 2030 assuming the successful implementation of the watershed management plan, under the low climate change scenario and the high climate change scenario.

The experts' answers were recorded in the workbook. Those who estimated the performance of variables related to drinking water infrastructure were asked to provide a high, low, and best estimate of the level of performance of each variable. Three-step estimation was used to control for overconfidence in estimation (McDaniels et al. 2012). The experts judging general ecosystem service provision within the watershed provided single estimation answers.

The questions used to judge future performance of drinking water infrastructure were developed in response to initial research undertaken to elucidate experts' main areas of concern and relevant indicators for these variables. Initial research showed that water managers' main concerns are the amount of drinking water available for customers and the quality of the water entering the treatment plant. Furthermore, turbidity and dissolved oxygen levels were identified as key quality indicators for the wet and dry season respectively. Thus, the experts were asked to judge the impact of the watershed management plan on four variables: reservoir sedimentation rates, turbidity levels in the reservoir, dissolved oxygen levels in the reservoir during the annual dry season (December to May), and the amount of water entering the reservoir during the annual dry season. The specific questions asked of the experts for each of the variables are presented in Table A3.

Table A3: Questions regarding the performance of specific variables related to drinking water infrastructure

H2.1	Under the l**ow climate change scenario**, what effect will the watershed management plan have on sediment accumulation in the reservoir?	H3.1	Under the **high climate change scenario**, what effect will the watershed management plan have on sediment accumulation in the reservoir?
H2.3	Under the **low climate change scenario**, what effect will the watershed management plan have on turbidity levels in the reservoir?	H3.3	Under the **high climate change scenario**, what effect will the watershed management plan have on turbidity levels in the reservoir?
H2.6	Under the **low climate change scenario**, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir *during the annual drying period*?	H3.6	Under the **high climate change scenario**, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir *during the annual drying period*?
H2.9	Under the l**ow climate change scenario**, what effect will the watershed management plan have on water inflow into the reservoir *during the annual drying period*?	H3.9	Under the **high climate change scenario**, what effect will the watershed management plan have on water inflow into the reservoir *during the annual drying period*?

In relation to general ecosystem service provision, watershed experts were asked to judge the importance, extent (physical distribution), and substitutability of 10 different ecosystem services as well as to describe the distribution of benefits among beneficiaries. This approach to ecosystem service provision was developed based on the relevant academic literature, including Farber, Costanza, and Wilson (2002), Metzger et al. (2006), and Nelson et al. (2009). In this case, the experts evaluated provision under four scenarios combining successful completion of the watershed management plan versus a business as usual scenario with the high and low climate change scenarios. The main questions put to this pool of experts are presented in Table A4. The four scenarios used for this judgment task are presented in Table A5.

Table A4: Questions asked in relation to general ecosystem service provision

H5.1	**Please rate, on a scale of 1 to 5, the *substitutability* of each of the following ecosystem services in the Guacerique watershed in 2030.** *Substitutability refers to how readily the ecosystem service can be provided to direct beneficiaries through other means, included from sources located in other areas.*
H5.2	**In your opinion, who benefit most from each of the following ecosystem services provided by the Guacerique watershed? In each case, please order beneficiaries from most (1) to least (5). (Ties are permitted.)**
H5.5	**Please rate, on a scale of 1 to 7, the *extent* of each of the following eco-system services in the Guacerique watershed in 2030?** *Extent refers to the area of the watershed that provides the ecosystem service.*
H5.6	**Please rate, on a scale of 1 to 7, the importance of the following eco-system services in the Guacerique watershed in 2030.** *Importance refers to the contribution of the eco-system service to well-being in the watershed.*

Note: Questions H5.5 and H5.6 were repeated under the four different scenarios considered by this pool of experts.

Table A5: Scenarios used for the judgment task on general ecosystem service provision

Scenario A	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010-2030 have been similar to observed changes in the period 1990-2010. The LOW climate change assumptions have proven correct.
Scenario B	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010-2030 has been similar to observed changes in the period 1990-2010. The LOW climate change assumptions have proven correct.
Scenario C	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010-2030 have been similar to observed changes in the period 1990-2010. The HIGH climate change assumptions have proven correct.
Scenario D	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010-2030 has been similar to observed changes in the period 1990-2010. The HIGH climate change assumptions have proven correct.

A1.1.3 Data analysis

For both sets of questions, expert responses were averaged for each variable, providing an aggregate estimation of performance.

During the data review process, the data set was cleaned. The written explanations of responses provided by experts in the workbook were used to compare logic with responses and ensure consistency. The review process led to some responses being removed from the data set. Table A6 shows the resulting number of responses considered for each question.

Table A6: Number of respondents to each of the questions in the full data set

Q	No. of responses	Q	No. of responses	Q	No. of responses
H2.1	5	H3.1	5		
H2.3	5	H3.3	5	H5.1	
H2.6	4	H3.6	4	-H5.12	4
H2.9	4	H3.9	5		

A1.1.4 Value calculations

The estimates of changes in performance of variables related to drinking water infrastructure under the two scenarios were applied to cost calculations to estimate the economic benefit of the watershed management plan to the national water utility. The value of improvements in water provision (quality and quantity) was calculated in one of three ways. One, the unit cost of specific treatment chemicals was used to value changes in water quality achieved through the watershed management plan. Two, the value of reservoir water storage capacity was equated to unit cost of the proposed Guacerique II reservoir project. This project was deemed to provide a good value measure as it also seeks to achieve similar objectives, including increased water supply and improvement of water quality. Moreover, given the age of the existing Los Laureles reservoir, the Guacerique II project is a good estimate of the current value of storage capacity.[35] Three, water availability was valued using an approximate measure of consumer willingness to pay, as represented by the price per volume presently paid by inhabitants of marginal neighborhoods in Tegucigalpa who purchase water from

35. See Annex 1.3 for details on the calculation of the value of storage capacity.

cistern trucks belonging to either the municipality or private distributors.[36] It is important to recognize that given, among other things, the limited capacity of consumers in marginalized neighborhoods in Tegucigalpa to pay for services, this value can be considered on the lower range of the marginal value.

The initial calculation provided an estimate of the annual value of full benefits expected in 2030 when maximum benefits are achieved from the watershed management plan. However, since some benefits will accrue immediately upon completion of the management plan (that is, the positive impact of soil erosion measures applied to agricultural fields), 60 percent of these benefits were assumed to accrue as early as 2019 and to increase in a linear fashion over the next 11 years, reaching 100 percent in 2030.[37] In the absence of any known rules of thumb to estimate incremental benefits over time, it is believed these assumptions are valid.

On the cost side of the calculation, the projected costs of the watershed management plan were adjusted to 2012 dollars, and transfers (namely, taxes) and other zero opportunity cost items (including local physical labor) were removed from the cost calculation. The result was a cost in 2012 dollars for each of the six years over which the watershed management plan will be implemented (2013–18).[38]

Next, the net present value (NPV) of the net benefits (benefits minus costs) accruing over the period 2013–35 was calculated, using three different discount rates for Honduras, providing an overall estimation of the value of benefits in 2012 expressed in 2012 dollars. The chosen time horizon represents benefit provision over a 20-year time horizon, which was one of the parameters in the study.

As mentioned, the additional ecosystem services identified by the experts as accruing to the watershed under the management plan were not given a dollar value.

A1.1.5 Sensitivity testing

Sensitivity testing was applied to test the influence of a range of assumptions and estimations on the overall outcome. The following aspects of the calculation were tested:

- *Estimation of future water yield under climate change*—considered the most important sensitivity test to have been carried out, as almost 100 percent of the benefits are derived from this variable. The value was tested by using the upper and lower ranges of expert estimates to gauge the influence of this assumption on overall benefit calculation.
- *Assumption of 60 percent of benefits accruing in 2019*—considered the second most important sensitivity test to have been carried out, as overall NPV is affected when benefits occur. The assumption was tested by carrying out the benefit calculation assuming 30 and 90 percent benefit provision in 2019.
- *Estimation of 30 percent of existing sediment in the reservoir attributable to Hurricane Mitch*—the calculation of current sedimentation rates, and thus avoided future sedimentation, was based on this average of estimates provided by the experts. The upper and lower ranges of their estimates (20 and 40 percent) were tested to gauge the influence of this assumption on the overall benefit calculation.

The results of the sensitivity testing are presented in Annex 1.4.

36. See Annex 1.3 for details on the calculation of willingness to pay.
37. A compound growth rate was used to calculate the value of benefits for each year where V_{tn} = benefits in 2030, V_{t0} = value in 2019.
38. See Annex 1.3 for more details on plan implementation costs.

A1.2 Detailed description of results of expert elicitation

A1.2.1 Experts' judgment of future performance of four variables related to drinking water infrastructure with successful implementation of watershed management plan

UNDER THE LOW CLIMATE CHANGE SCENARIO

In relation to **sedimentation rates in the reservoir** under the low climate change scenario, the average of expert best guesses is –1.80, indicating an 18 percent decrease in sedimentation product on the implementation of the watershed management plan.[39] Figure A1 shows relative uniformity across responses, with answers clustered around a decrease in sedimentation of 20 percent (four responses), in addition to one response of a 10 percent decrease in sedimentation. Four of five experts provided a range of potential change of only 10 percent on each side of their central value. One expert had a slightly larger total range of 30 percent, spanning zero change to a 30 percent increase. The average value for the lower end of change is –2.80, or a 28 percent decrease in sedimentation, and the average value for the upper end of change is –0.60, or a 6 percent decrease in sedimentation rates. Four of five experts stated 70–75 percent certainty. One expert stated 50 percent certainty. One comment provided by a participant indicates that, in at least one view, the definitive factor in sediment reduction will be the land use changes achieved under the water management plan. Another comment emphasized the role of individual decisions in land use outcomes and the need to work closely with local inhabitants to achieving land use goals.

In relation to **turbidity levels in the reservoir** under the low climate change scenario, the average of expert best guesses for future turbidity levels was –2.4, meaning a 24 percent reduction in turbidity. Figure A2 shows that respondents agree that there will be a decrease in turbidity under this scenario and that responses are relatively clustered around a 30 percent decrease in turbidity in the reservoir, with two responses at –10 percent and –20 percent. The range of potential change around the central value was again estimated in most cases to be only 20 percent (four cases) and 40 percent in one case. The average value for the lower end of change in this scenario is –3.6, or a 36 percent decrease in turbidity, and the average value for the upper end of change in this scenario is –1.2, or a 12 percent reduction in turbidity levels. Certainty in responses ranged from 60 percent (one response) to 80 percent (three responses), with one respondent stating 70 percent certainty. Experts' comments regarding their answers indicate two factors affecting turbidity in the reservoir: less upstream erosion from land use change and decreased precipitation.

In relation to **dissolved oxygen levels in the reservoir during the annual dry season**, under the low climate change scenario, the average of expert best guesses for this indicator is 0.7, or a 7 percent increase in dissolved oxygen levels in the reservoir during dry months. Figure A3 shows that response to this question can be interpreted as bi-modal. While one expert estimated no change and another had a 10 percent decrease in dissolved oxygen levels, the other two experts estimated an increase in dissolved oxygen levels of 20 percent under this scenario. The range of potential change around the central value was estimated to be as little as 15 percent in one case, 20 percent in two cases, and 30 percent in a fourth case. The average value for the lower end of change in this scenario is –0.5, or a 5 percent decrease in dissolved oxygen levels, and the average value for the upper end of change in this scenario is 1.88, or an 18.8 percent improvement in dissolved oxygen levels. Certainty in responses ranged from 40 percent (one respondent) to 70–75 percent (three respondents). Expert comments regarding their answers indicate that experts believe that sediment deposition in the reservoir is the determinant factor in oxygen levels but that water provision is also important and, thus, the reduced precipitation in this scenario may counteract gains achieved from dissolved oxygen levels from upstream sediment retention.

39. As described in Section 3.6, 100 percent of benefits materialize in 2030.

In relation to water inflow into the reservoir during the annual dry season under the low climate change scenario, the average of expert best guesses for this indicator is 1.13, or an 11.3 percent increase in water inflow to the reservoir during the dry season. Figure A4 shows the responses tend toward an estimate of a 10–25 percent increase water inflow into the reservoir under this scenario, with one outlier response of a 10 percent decrease and are thus again somewhat bi-modal. The range of potential change around the central value was estimated to be 20 percent in one case, 30 percent in two cases, and 40 percent in a fourth case. The average value for the lower end of change in this scenario is –0.5, or a 5 percent reduction in inflow, and the average value for the upper end of change is 2.25, or a 22.5 percent increase in inflow. Experts stated a certainty of responses of 70 percent (two respondents) and 80 percent (three respondents). Expert comments regarding their answers indicate that the experts are divided between those who believe that the determinant factor will be increased base flow resulting from improved infiltration and those who see overall precipitation as the determining factor in water availability.

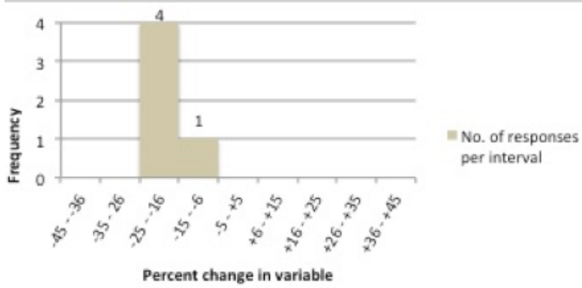
In summary, expert judgment of the future performance of the four variables related to drinking water infrastructure with the successful implementation of the watershed management plan under the low climate change scenario provided the following results:

- Sedimentation in the reservoir will decrease by 18 percent.
- Dissolved oxygen levels during the annual dry period will increase by 7 percent.
- Turbidity in the reservoir will decrease by 24 percent.
- Water inflow into the reservoir during the annual dry period will increase by 11.3 percent.

UNDER THE HIGH CLIMATE CHANGE SCENARIO

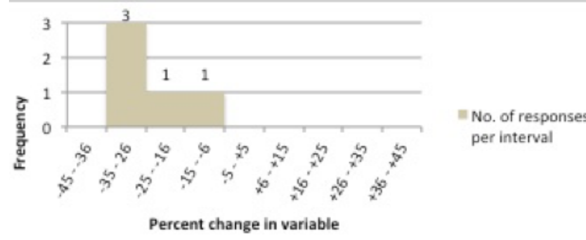
In relation to **sedimentation rates in the reservoir** under the high climate change scenario, the average of expert best guesses for this variable is 1.3, or a 13 percent increase in reservoir sedimentation rates. Figure A5 shows that most respondents agree that there will be an increase in reservoir sedimentation under this scenario, but that there is disagreement over the scale, with best guesses for this variable under this scenario ranging from no change (one respondent) to a 20 percent increase in sedimentation rates (two respondents). The range of potential change around the central value was estimated to be as little as 10 percent in two cases, 15 percent in another case, and 20 percent in the remaining two cases. The average value for the lower end of change in this scenario is a 5 percent increase in sedimentation rates and the average value for the upper end of change is 20 percent increase in sedimentation rates. Experts stated certainty of 70 percent in four cases and 50 percent in one case. Expert comments regarding their answers indicate increased precipitation was the primary variable behind their answers.

Figure A1. Frequency of responses to Question H2.1



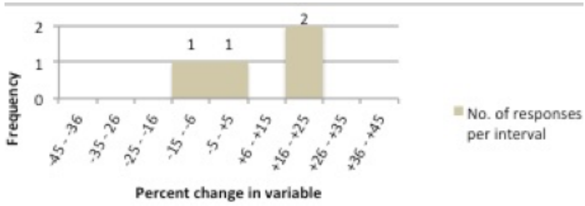
Under the low climate change scenario, what effect will the watershed management plan have on sediment accumulation in the reservoir?

Figure A2. Frequency of responses to Question H2.3



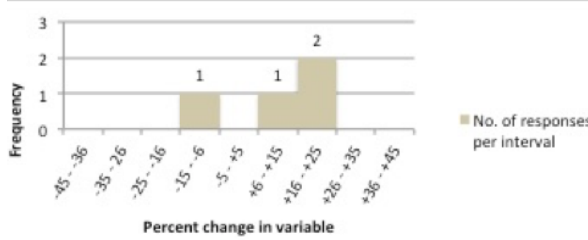
Under the low climate change scenario, what effect will the watershed management plan have on turbidity levels in the reservoir?

Figure A3. Frequency of responses to Question H2.6



Under the low climate change scenario, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir during the annual dry period?

Figure A4. Frequency of responses to Question H2.9



Under the low climate change scenario, what effect will the watershed management plan have on water inflow into the reservoir during the annual dry period?

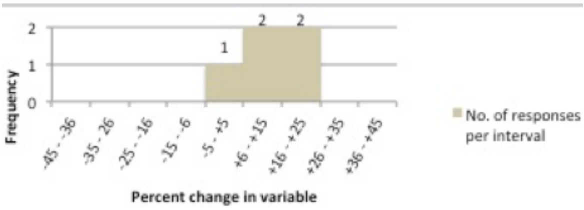
In relation to **turbidity levels in the reservoir** under the high climate change scenario, the average of expert best guesses for this indicator is 0.98, or a 9.8 percent increase in turbidity under this scenario. Figure A6 shows that all respondents agree that there will be an increase in reservoir sedimentation under this scenario, but that once again there is disagreement over scale. The best guesses range from a 5 percent increase (one response) to a 20 percent increase (one response). Other respondents gave figures of 9 and 10 percent increase. The range of potential change around the central value was estimated to be as little as 10 percent in two cases, 15 percent in another case, and 20 percent in the remaining two cases. The average value for the lower end of change in this scenario is 0.2, or a 2 percent increase in turbidity, and the average value for the upper end of change is 1.7, or a 17 percent increase in turbidity. Certainty in responses ranged from 60 percent (one respondent) to 80 percent (one respondent), with three respondents providing a certainty of 70–75 percent.

Expert comments regarding their answers indicate that an increase in precipitation is the driving factor behind turbidity levels, despite upstream soil retention efforts.

In relation to **dissolved oxygen levels in the reservoir during the annual dry season**, under the high climate change scenario, the average of expert best guesses for this indicator is 2.38, or a 23.8 percent increase in dissolved oxygen levels. Figure A7 shows expert responses clustered around a 20–25 percent increase in the variable (three responses), with an additional estimate of a 30 percent increase (one response). The range of potential change around the central value was estimated to be as little as 15 percent in one case and 20 percent in the other three cases. The average value for the lower end of change in this scenario is 1.38, or a 13.8 percent increase, and the average value for the upper end of change is 3.25, or a 32.5 percent increase. Certainty in responses ranged from 60 percent (one respondent) to 80–85 percent (three respondents). Expert comments regarding their answers indicate that this outcome would be the result of the combined effect of increased inflow from increased precipitation and reduced sediment loads from upstream sediment retention.

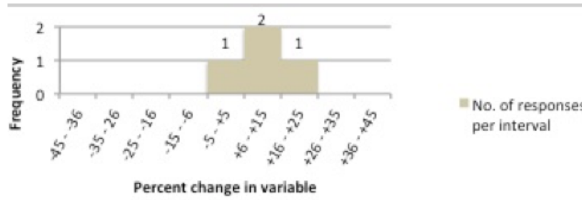
In relation to **water inflow into the reservoir during the annual dry season** under the high climate change scenario, the average of expert best guesses for this indicator is 2.9 percent, or a 29 percent increase in inflow into the reservoir during the drying period. Figure A8 shows that responses tend to be clustered around a significant increase in inflow under this scenario. Experts' best guesses ranged from a 10 percent increase (one respondent) to a 40 percent increase (one respondent). Three respondents provided estimates in the 30–35 percent range. The range of potential change around the central value was estimated to be as little as 15 percent in one case, 20 percent in two cases, 30 percent in another case, and 40 percent in the remaining case. The average value for the lower end of change in this scenario is 1.60, or a 16 percent increase and the average value for the upper end of change is 4.40, or a 44 percent increase. Certainty in responses ranged from 60 percent (one respondent) to 80–85 percent (three respondent). One respondent stated 70 percent certainty. Expert comments regarding their answers indicate that improved infiltration is the primary factor behind base flow. One expert clearly stated this would increase base flow despite increased evapotranspiration under higher temperatures. Another expert highlighted the negative influence of anthropogenic water withdrawals upstream from the dam on water inflow rates.

Figure A5. Frequency of responses to Question H3.1



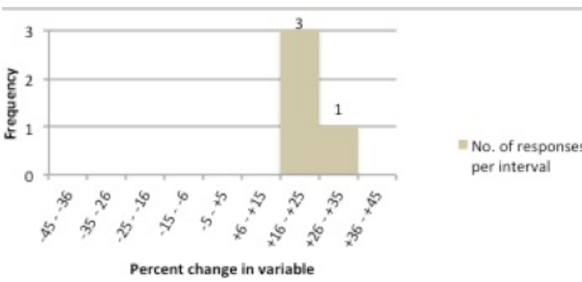
Under the high climate change scenario, what effect will the watershed management plan have on sediment accumulation in the reservoir?

Figure A6. Frequency of responses to Question H3.3



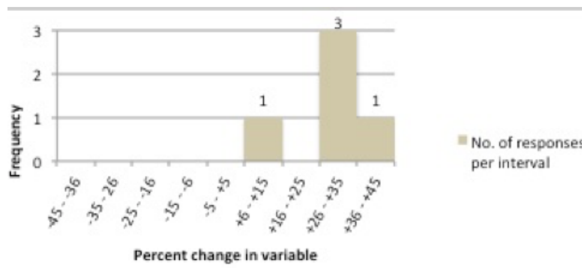
Under the high climate change scenario, what effect will the watershed management plan have on turbidity levels in the reservoir?

Figure A7. Frequency of responses to Question H3.6



Under the high climate change scenario, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir during the annual dry period?

Figure A8. Frequency of responses to Question H3.9



Under the high climate change scenario, what effect will the watershed management plan have on water inflow into the reservoir during the annual dryperiod?

In summary, expert judgment of the future performance of the four variables related to drinking water infrastructure with the successful implementation of the watershed management plan under the high climate change scenario provided the following results:

- Sedimentation in the reservoir will increase by 13 percent.
- Dissolved oxygen levels during the annual dry period will increase by 23.8 percent.
- Turbidity in the reservoir will increase by 9.8 percent.
- Water inflow into the reservoir during the annual dry period will increase by 29 percent.

A1.2.2 Experts' judgment of future performance of general ecosystem service provision within the watershed

As mentioned in the methods section, the second version of the workbook was oriented to ecosystem provision, and four experts were given this judgment task. The four scenarios used here are described in Annex 1.1.2.

The ecosystem services considered in this section are: freshwater, fiber, fuel, erosion regulation, pest regulation, pollination, natural hazard regulation, soil formation, nutrient cycling, and recreation and ecotourism. These ecosystem services were identified as the most relevant from the services described in the Millennium Ecosystem Assessment (MA 2005). Note that in this context the source of both fiber and fuel is wood, as timber is the most common form of fiber extraction, and most households use wood fuel for cooking.

Results will be discussed under four sub-headings: substitutability, distribution of benefits, and extent and importance of service provision under the four scenarios.

EVALUATION OF SUBSTITUTABILITY

Respondents were asked to rate, on a scale of one to five, the substitutability of each of the ecosystem services in the Guacerique watershed in 2030. Substitutability refers to how readily ecosystem services can be provided to beneficiaries. Responses to this question are summarized in Table A7.

Respondents deem **freshwater** and **soil formation** as not substitutable (value of 1.00). Pollination and natural hazard regulation receive similar values (value of 2.00).

Fiber, fuel, nutrient cycling, erosion regulation, pest regulation, and **recreation** are considered partially substitutable (values between 2.50 and 3.50).

No ecosystem service was considered completely substitutable. (The most substitutable service among those considered is judged to be pest regulation, which received a value of 3.50.)[40]

40. The use of agrochemicals as a substitute for this ecosystem service is common in Honduras, despite the hidden costs of agrochemical use on human health, for example.

Table A7: Responses to question H5.1, averaged over all four respondents

Ecosystem service	Value	Ecosystem service	Value
Freshwater	1.00	Erosion regulation	2.75
Fiber	2.50	Pest regulation	3.50
Fuel	2.75	Pollination	2.00
Soil formation	1.5	Natural hazard regulation	2.00
Nutrient cycling	2.67	Recreation and ecotourism	3.25

Note 1: Substitutability was evaluated on a scale of 1 to 5 where 1 = not at all substitutable, 3 = somewhat substitutable, and 5 = completely substitutable.
Note 2: The colors denote the type of ecosystem service: provisioning, regulation, supporting, or cultural.

It is important to note that substitutability is context-dependent (see related discussion in Farber, Costanza, and Wilson 2002). In this respect, local sources of **fiber** and **fuel** (wood in both cases) are central to local livelihoods and thus relatively non-substitutable. In this sense, while gas cookstoves are an alternative to fuelwood, economic or transportation barriers (for example) limit the extent to which fuelwood can be replaced by gas. The partial substitutability of **nutrient cycling** is very likely due to fertilizer substitution. The substitute for **erosion regulation** can be assumed to be a range of erosion prevention measures, from cropping practices to civil engineering solutions, but partially substitutable because of cost and lower overall effectiveness. The substitute for **pest regulation** can be chemical pesticides, but it is partially substitutable because of cost and environmental trade-offs associated with chemicals. The substitutability of **recreation** can be interpreted to mean that watershed inhabitants have limited means with which to reach and engage in outdoor recreation opportunities at far sites from their home (outside the watershed).

EVALUATION OF THE DISTRIBUTION OF BENEFITS

In a second instance, respondents were asked to rate who benefits most from each of the ecosystem services, where the top beneficiary group was given a value of 1. Beneficiaries are grouped into five distinct categories: inhabitants of the lower, mid, and upper watershed (three categories), downstream water managers, and other downstream users of watershed resources.[41] Responses to this question are displayed in Table A8.

Watershed inhabitants (of the upper, mid, and lower regions) and water managers all benefit equally from the provision of **freshwater** (value of 1.00). In two cases, other downstream users were judged to benefit somewhat less from freshwater (value of 3.00). While water from this watershed is fed directly into the water distribution city for the capital city, this result could be explained by the fact that downstream users have other sources of water. The inhabitants of the mid and upper watershed (those who live closest to the land) benefit most from the provision of fiber (values of 1.00 and 1.25). As might be expected, water managers benefit least, and other downstream users do not benefit much (values of 5.00 and 4.50). This suggests that illegal logging for commercial ends is not a major concern in this watershed, something that has been confirmed in prior conversation with experts on the watershed.

Inhabitants of the mid and upper watershed benefit most from the provision of **fuel** (values of 1.25 and 1.50). Inhabitants of the lower watershed are also seen to benefit (value of 2.25). The differentiated benefit between watershed sectors can be ascribed to socioeconomic differences (peasant farmers upstream, wealthy elite downstream). The little benefit attributed to other downstream users of watershed resources (value of 4.75) does not seem to reflect the fact that experts have stated that trucks laden with illegally harvested fuelwood bound for sale in the capital city regularly leave the watershed under the cover of night.

41. Experts indicated that "other users" included Inhabitants of capital city, inhabitants of other towns farther downstream in Choluteca province and other municipalities and provinces (i.e. Choluteca, Valle, Nacaome).

Water managers and inhabitants of the lower watershed are judged to benefit the most from **erosion regulation** (values of 1.00 and 1.25). Interestingly, inhabitants of the mid watershed and other downstream users are seen to benefit equally from erosion regulation (value of 2.75), with inhabitants of the upper zone benefiting the least (value of 3.75). These results indicate that the benefit of erosion regulation is perceived to accrue most to downstream beneficiaries, and especially to people in the lower watershed who are recipients of unwanted sediment, while the benefit of the maintenance of upstream soils (the onsite provision of erosion regulation benefits) is not a concern in this context.

Table A8: Responses to question H5.2, averaged over all four respondents

Ecosystem service	Inhabitants of the watershed (See note below)			Inhabitants of the mid watershed	Inhabitants of the upper watershed
	Downstream water managers (SANAA)	Other downstream users of watershed resources	Inhabitants of the lower watershed		
Fresh water	1.00	1.00	1.00	1.00	3.00
Fiber	3.00	1.25	1.00	5.00	4.50
Fuel	2.25	1.25	1.50	4.75	4.75
Erosion regulation	1.25	2.75	3.75	1.00	2.75
Pest regulation	3.50	1.75	1.25	1.50	4.00
Pollination	4.25	2.00	1.00	2.75	4.00
Natural hazard regulation	1.25	2.75	2.25	1.00	3.00
Soil formation	2.75	1.00	1.00	2.50	4.00
Nutrient cycling	2.75	1.00	1.00	3.00	4.00
Recreation and ecotourism	3.50	2.25	1.00	4.75	3.00

Note: 1 = benefits most, 5 = benefits least.

The inhabitants of the mid and upper watershed and water managers are judged to benefit most from the provision of **pest regulation** (values between 1.25 and 1.75). The importance of pest regulation to commercial (although perhaps illegal) forestry interests does not seem to be reflected in responses (other users given a value of 4.00), signaling once again that illegal logging for commercial purposes is not considered a major concern in this watershed. Water managers may benefit from this ecosystem service, as pest regulation keeps the pine beetle in check, which keeps upstream forests healthy, promoting soil retention.

Inhabitants of the upper watershed are deemed to benefit most from **pollination** (value of 1.00). The inhabitants of the mid-watershed are second (value of 2.00), despite the fact that farming is the primary livelihood for both groups. Water managers may benefit from pollination because of its role in ensuring vegetative ground cover (value of 2.75).

Water managers and inhabitants of the lower watershed are judged to benefit most from **natural hazard regulation** (values of 1.00 and 1.25). On the one hand, this response perhaps reflects perception bias: the respondents were all water managers, and their responses could show heightened sensitivity to the drinking water infrastructure of which they are stewards. The medium benefit rating given to inhabitants of the mid and upper watershed (values of 2.25 and 2.75) appears contrary to documented concern for landslide activity in all areas of the watershed (TroFCCA 2008, p. 34). (It may be that respondents confused general natural hazard regulation with a buffering of effects from specific extreme climatic events when answering this question.)

The inhabitants of the mid and upper watershed are judged to benefit most from **soil formation** (value of 1.00). Water managers are seen as the next in line beneficiaries (value of 2.50).

The inhabitants of the mid and upper watershed are also judged to benefit most from **nutrient cycling** (value of 1.00).

In relation to **recreation and ecotourism**, in ordering beneficiaries, two respondents started the numbering system at 2 and one at 3. (Note that these responses were modified when data were cleaned.) This perhaps indicates that none of the identified beneficiary groups use the watershed much for recreation purposes or perceive the provision of this potential service. Nonetheless, inhabitants from the upper watershed are judged to benefit most from the provision of this service (value of 1.00), followed by the inhabitants of the mid watershed (value of 2.25) and then other downstream users (value of 3.00). One interpretation of these results is that the primary beneficiaries of the outdoor recreation opportunities provided by the watershed are those who live closest to the reserve, with some benefit accruing to inhabitants of the capital city who might visit the reserve. As would be expected, water managers are not seen to benefit from this service (value of 4.75).

In a follow-up question, respondents were also asked to mention who would receive adverse consequences from the watershed management plan. Experts mentioned farmers in the mid and upper watershed who might see some farming activities prohibited and, in general, inhabitants of the watershed whose economic development plans are counterproductive to watershed protection and conservation and are therefore prohibited by the management plan (such as landowners in the lower watershed who seek to engage in residential development or, again, farmers in the mid and upper watershed who hope to expand their cropping area or seek commercial gain from forests).

EVALUATION OF EXTENT OF ECOSYSTEM SERVICE PROVISION UNDER THE FOUR SCENARIOS

With this question, respondents were asked to rate, on a scale of one to seven, the extent of each of the ecosystem services in the watershed in 2030 under four distinct scenarios. Extent refers to the area of the watershed that provides the ecosystem service. (For reference, the four scenarios are described in Table A5.) Responses to this question are displayed in Table A9.

In general, the watershed management plan is expected to increase the area of the watershed providing all of the ecosystem services described, irrespective of the climate outcome. (Scenarios B and D provide better outcomes than Scenarios A and C.) Note that additional provision of a service does not necessarily mean increased access for beneficiaries. For example, there will be more wood (fiber) available because of reforestation activities, but access to the resource will be restricted.

The extent to which any particular service is present in the watershed is, however, influenced by climate (differences between Scenarios B and D). Thus, the best outcomes for the provision of **freshwater** and **fiber** provision and **soil formation** are considered to occur with the full implementation of the watershed management plan and under the high climate change scenario.

Conversely, the best outcomes for **erosion, pest** and **natural hazard regulation, pollination**, and recreation are judged to occur with the full implementation of the watershed management plan and under the low climate change scenario.

It is logical that **erosion** and **natural hazard regulation** outcomes are reduced under the high climate change scenario compared with the low climate change scenario due to the expected impact of the increased precipitation on these services.

The reasons behind the diminished outcomes under the high climate change scenario for some of the other services (pest regulation and pollination and recreation) are less clear. For example, it may be that a 1.5°C increase in temperature is judged sufficient to negatively affect the ecology behind pest regulation and pollination services. However, the significant decrease in precipitation contemplated in the low climate change scenario (around 20 percent) could also upset these systems.[42]

Finally, the climate change scenarios are not judged to have any effect on nutrient cycling outcomes.

42. It may be that respondents' intuitive understanding of each scenario might have been influenced by the title, where "high," for example, was associated with "more extreme" and thus the outcomes were assumed to be "worse" under this scenario, and answers were formulated in response to this intuitive criteria instead of in response to the specific characteristics of each scenario.

Table A9: Evaluation of extent of ecosystem service provision over all four scenarios

Ecosystem service	Scenario			
	A	B	C	D
Freshwater	4.75	6.25	4	6.5
Fiber	3.75	4	3.5	4.25
Fuel	4.75	3.25	3.75	4.25
Soil formation	4	4.75	3.25	5.25
Nutrient cycling	3.25	5	3	5
Erosion regulation	2.5	5.5	2.25	3
Pest regulation	3.5	5.25	2.25	3.25
Pollination	4	6.25	2.75	4
Natural hazard regulation	2.75	5.5	2.5	3.75
Recreation and ecotourism	2.25	5.75	1.75	4.5

Note: Extent was evaluated on a scale of 1 to 7 where 1 = not present in the watershed, 4 = present on half of the watershed area, and 7 = present over the entire watershed area.

EVALUATION OF IMPORTANCE UNDER THE FOUR SCENARIOS

With this question, respondents were asked to rate, on a scale of one to seven, the importance of the ecosystem services in the Guacerique watershed in 2030 under the same four scenarios. Importance refers to the contribution of the service to well-being in the watershed. Responses to this question are displayed in Table A10.

Generally these results show that importance of the ecosystem service to well-being in the watershed is judged to be independent of the scenarios and is therefore rated similarly across scenarios.

If it is assumed that importance is equal across scenarios, and the responses for each ecosystem service are averaged across all four scenarios and then ordered in a descending fashion, the importance of these ecosystem services is as follows (from most to least): freshwater, nutrient cycling, soil formation, pollination, pest and natural hazard regulation (tie), erosion regulation, fuel, fiber, and recreation.

Table A10: Evaluation of importance of ecosystem service provision over all four scenarios

Ecosystem service	Scenario			
	A	B	C	D
Fresh water	7	7	7	6.75
Fiber	4.25	4.75	5	4.75
Fuel	5	4.5	4.75	4.75
Soil formation	5.75	5.25	5.25	5.25
Nutrient cycling	5.75	5.5	5.5	5.5
Erosion regulation	5	5	4.75	4.75
Pest regulation	5	5	5	5.25
Pollination	6	5.25	4.75	4.75
Natural hazard regulation	5.75	5.5	4.25	4.75
Recreation and ecotourism	4	5.25	2.75	4.75

Note: Importance was evaluated on a scale of 1 to 7 where 1 = not at all important, does not contribute at all to the well-being of the watershed's inhabitants; 4 = medium importance, contributes to the well-being of the watershed's inhabitants but is not essential; and 7 = extremely important; fundamental to the well-being of the watershed's inhabitants.

Note that **freshwater** provision, deemed to be essential to the well-being of inhabitants of the watershed under all scenarios, is also considered not substitutable (question H5.1) No other ecosystem service was deemed as important to well-being as freshwater provision.

The importance of **nutrient cycling, soil formation**, and **pollination** is understandable as they are essential for farming.

Fiber and **fuel** are considered of medium importance (important but not essential) to well-being in the watershed, yet it can be assumed that the provision of both will be restricted under the watershed management plan (more control over timber harvesting). (The plan does include 100 ha of fuelwood plantations to meet local fuel needs and thus reduce general timber harvesting for use as fuelwood.)

The estimated importance of **erosion** and **natural hazard regulation** under high climate change is intriguing, as it is lower than under low climate change. The reverse was expected, given the positive relationship between increased precipitation (part of the high climate change scenario) and erosion and natural hazard outcomes.

Recreation in last place confirms indications from responses to question H5.2 that recreation is not an important ecosystem service in this context.

A1.3: Calculation of Net Present Value

A1.3.1 Calculation of the value of the Guacerique II reservoir project and subsequent value per m^3 of reservoir volume

The construction costs for the Guacerique II reservoir project presented in SOGREAH Consultants (2004b) provided the basis for calculating the value of the Guacerique II reservoir project in 2012 dollars.

Figures were transformed from 2004 dollars to 2012 dollars using an appropriate construction price index for the region. SOGREAH Consultants (2004b) explicitly states that the costs are cited in constant 2004 dollars.

SANAA staff indicated that the estimated total compensation to landowners contained in this report is considered inadequate. SANAA provided a more correct and current estimate of $90 million. Thus, the $19.4 million for compensation included in the 2004 estimates was subtracted from the 2004 total project cost.

Table A11 shows the cost of the project as stated in SOGREAH Consultants (2004b), with the modification mentioned above.

Table A11: Estimated cost of the Guacerique II reservoir project with and without 2004 estimate of compensation to property owners

Line items	SOGREAH Consultants estimate (million 2004 dollars)	Estimate minus compensation to landowners (million 2004 dollars)
Construction	95.7	76.3
Equipment	17.6	17.6
Engineers, supervision	8.1	8.1
Unforeseen expenses	10.7	10.7
Total	**132.1**	**112.7**

Source: SOGREAH Consultants (2004b). Note: Compensation to landowners was included under "Construction" in the original report.

The official construction price index in Costa Rica for buildings was selected to calculate the total project cost in 2012 dollars. No other current construction price index for any other Central American country was identified, with the exception of Honduras, which briefly published its own construction price index for homes between 2006 and 2008, with 2003 as the base year; in this case, the index for 2008 was 170.1. The U.S. construction price index was also considered, and the applicable multiplier would have been 1.045.[43] The magnitude of the briefly published Honduran index, however, indicated that the Costa Rican index is more representative of increases in construction costs in the region in recent years than the U.S. index. Table A12 provides the details on the chosen index and resulting multiplier.

Table A12: Details on the construction price index employed for the calculation of the NPV of the Guacerique II reservoir project

Index title	INEC (n.d.)
Base year	1976
Index for 2004	10,944.54[44]
Index for 2012	22.576.56[45]
Multiplier	2.0628

Thus, the following calculation ensued:

Modified cost of the Guacerique II reservoir project (2004 dollars) x Construction price index multiplier + Current estimate of compensation

Or, in numbers:

$112.7 million (2004 dollars) x 2.0628 + $90 million (2012 dollars)

Thus the value of the Guacerique II reservoir project expressed in 2012 dollars is $322.48 million.

Given that the reservoir proposed in SOGREAH Consultants (2004b) has a total basin volume of 82.5 million m^3 and a total life time of 25 years, the unit value of the Guacerique II project in 2012 dollars expressed in $/$m^3$ is $0.16.

43. See United States Census Bureau (n.d.).
44. The index is a monthly index, thus the 2004 figure is simple average of the amounts listed for the 12 months of 2004.
45. When this report was written, only the first two months of 2012 had been published online. Thus this number is the simple average of the construction price index for the months of January and February 2012.

A1.3.2 Identification of an appropriate measure of consumer willingness-to-pay for potable water in the Tegucigalpa Honduras

There are many ways to value an environmental good such as water, and none are perfect. Consumer willingness-to-pay is one suggested valuation mechanism (Cameron 2011). Pond, Pedley, and Edwards (2011) suggest that social cost benefit analysis and shadow pricing are appropriate ways to value water provision in water-scarce circumstances.

This particular case study addresses a situation with profound water shortages, and there are many ways to measure the benefits if those shortages are overcome. The chosen measure reflects what currently occurs in Tegucigalpa in the face of severe water shortages: water cistern trucks belonging to both SANAA and private commercial enterprises distribute water to marginal neighborhoods. Water from SANAA trucks is distributed freely, while the commercial trucks purchase water from SANAA at a reported rate of 0.05 lempiras/gallon and resell to households. Coello Balthasar (2011) shows up to 800,000 m^3 of water being commercialized in Tegucigalpa by private cistern trucks.

It was decided that either the consumer purchase price or the total cost of the SANAA program would be possible proxies for water value, and that the more expensive of the two values would be more representative of true cost. However, SANAA officials reported to researchers that they have no measure of the cost of their cistern truck water distribution program, and the sale price to private trucks was considered to very likely underrepresent true value, given the utility's interest in getting water to the population. Thus, for lack of other measures, media reports regarding the cost to consumers of water from private cistern trucks were used to estimate consumer willingness-to-pay.

A brief Google search turned up two recent media reports on the price paid by consumers for water from cistern trucks (UTVUNAH 2012; *La Tribuna* 2011). Table A13 shows the reported costs per unit of water and their conversions to \$/m^3 expressed in 2012 dollars.

Table A13: Price of water from private cistern trucks in Tegucigalpa, from media sources

Source	Reported cost	
	Lps./g (2012 Lempiras)	\$/m^3 (2012 dollars)
UTVUNAH (2012)	Lps. 0.7	\$9.34
	Lps. 0.4	\$5.34
	Lps. 0.5	\$6.67
	Lps./barrel (2012 Lempiras)	\$/m^3 (2012 dollars)
"More than 250 thousand Honduras face water scarcity in Tegucigalpa" (2011)	Lps. 26.28	\$5.48
	Lps. 57.81	\$12.05
Average cost (2012 dollars)	--	\$7.78

Note: Prices reported in 2012 were considered 2012 lempiras. Prices quoted in 2011 where considered 2011 lempiras and were converted to 2012 lempiras using the change in the Honduran Consumer Price Index between those two years (1.051). In addition, 2012 Lempiras were converted to 2012 dollars using the exchange rate applied in this study of lps. 19.80. Regarding volumes, units were reported in U.S. gallons. There are 64 gallons to a barrel; 1 barrel equals 0.2423 m^3 and 1 gallon equals 0.0039 m^3.

Thus the value of water as measured by willingness to pay sits between \$5.34/m^3 and \$12.05/m^3. The average of all reported values (\$7.78) was chosen as an appropriate measure of the value of additional water. The upper and lower ranges of reported values could have been used in sensitivity testing, but this was not done. Since almost 100 percent of benefits come from this value, it was clear that a lower value would decrease the overall net benefit and a higher value would increase the overall net benefit.

It is important to recognize that, given the limited capacity of consumers in marginalized neighborhoods in Tegucigalpa to pay for services, this value can be considered the lower range of the marginal value.

A1.3.3 Calculation of the cost of watershed management plan implementation

The budget found in SANAA and ICF (2011) provided the bases for calculating the cost of implementing the watershed management plan, expressed in 2012 dollars. The total cost was taken from the final consolidated budget presented at the end of the document, while annual implementation costs were calculated using figures presented in the budgets for each management program (cross-referencing was used because of inconsistencies between program budgets and the consolidated budget). It is important to note that the costs provided did not include the costs of incentives for changing land management behavior or mediating conflicts or for ways of providing extension services. As the benefits of such efforts would exceed the watershed and water supply benefits captured in the economic analysis, the omission of these costs may not significantly alter the findings. Nevertheless, it is important to note that additional costs may need to be incurred beyond what is in the current plan.

The report spreads expenses over a seven-year implementation period. However, SANAA experts indicated that the implementation period had been shortened to six years. Thus the costs for activities in the seventh year were distributed evenly across the prior six years to calculate an approximate price and annual cost distribution for the six-year plan.

The initial figures from SANAA and ICF (2011) were also modified so that taxes and local labor employment opportunities were not included in the NPV calculation. To do this, program budgets were reviewed and line items that primarily involved purchases, contracting of consultants, or physical labor employment opportunities were identified. Line items involving purchases were reduced by 12 percent to correct for sales tax, line items involving consultants were reduced by 12.5 percent to correct for the tax collected by the state on all consultant fees, and physical labor items were reduced by 100 percent (under the assumption that the opportunity cost of contracting with local inhabitants for physical labor is zero). These cost reductions were generally distributed evenly across implementation years, or in some cases allocated to one single year or divided over two to four years, depending on how expenses were distributed in the original budgets. This procedure reduced the overall cost of the watershed management plan by almost 6 million lempiras.

SANAA and ICF (2011) quotes figures in lempiras. It was assumed that these figures were expressed in 2011 lempiras, given that the report was produced in that year.

Honduras' Consumer Price Index updated to September 2012 (BCH n.d.) was used to translate the figures provided in the report into 2012 lempiras. The document consulted showed that the index had increased 5.1 percent in 2012 over 2011.

The resulting figure was divided by the exchange rate used in this report (lps. 19.8 = 1 USD) and the result was assumed to be figures in 2012 dollars.

The resulting figure was considered to be representative of the full cost of implementation of the watershed management plan in 2012 dollars and was incorporated into the overall NPV calculation of benefits of the watershed management plan.

The actual value produced by this calculation was a total overall implementation cost of $4,215,926 in 2012 dollars.

A1.3.4 Calculation of current sedimentation rates in the Los Laureles reservoir (economic analysis)

There are no exact measurements of reservoir sedimentation rates; thus water managers depend on estimations. Table A14 summarizes current knowledge and estimations about sedimentation in the Los Laureles reservoir.

Table A14: Key information regarding sedimentation patterns in the Los Laureles reservoir

Total current sediment volume (estimated):	1,500,000 m^3
Age of dam:	36 years (1976-2012)
Past dredging:	• 50,000 m^3 of sediment was extracted in 2004. (This is equal to 3.2 percent of estimated existing sediment volume.) • The reservoir is currently equipped with a small dredging system that extracts sediment that settles around the water intake system.
Key events:	• Hurricane Mitch (1998) is thought to have contributed a significant portion of current sediment found in the reservoir.

Source: Individual interviews with SANAA experts.

In addition, the workbook included a series of questions regarding sedimentation in the reservoir, which combined with the information above allowed for current sedimentation rates in the reservoir to be estimated.

The following assumptions were used in estimating current sedimentation rates in the Los Laureles reservoir:

1. There is currently 1.5 million m^3 of sediment in the reservoir, accumulated over 36 years.
2. Experts estimate that 30 percent of this amount, or 450,000 m^3, is attributable to Hurricane Mitch, which occurred in 1998.
3. It is logical to then conclude that regular erosion contributed 1.05 million m^3 of sediment over the last 36 years.
4. Experts estimate that sediment concentrations in the Guacerique River are 20.8 percent higher post-Mitch compared with pre-Mitch. This can be equated to a sedimentation rates 21 percent higher post-Mitch than pre-Mitch. In other words, Rate 1 (pre-Mitch) = X and Rate 2 (post-Mitch) = X*1.21.

$(X*23)+(X*1.21*13)=1050000$ $23X+15.73X=1050000$ $X=1050000/38.73$ $X=27110.77$

$X(23+15.73)=1050000$

In summary, it was concluded that sedimentation rates prior to Hurricane Mitch were approximately 27,020 m^3/year and that sedimentation rates in the 13 subsequent years have been approximately 32,964 m^3/year. The rounded figure of 33,000 m^3/year was used in calculations as the current sedimentation rate for the Los Laureles reservoir.

A1.3.5 Calculation of current water inflow into the Los Laureles reservoir

The 10-year average of volume of water entering the Los Laureles reservoir between December and May of each year was calculated using data provided by SANAA. The data consisted of the results of periodic sampling of water velocity (m^3/s) at a point just above the inflow of the reservoir. These months more or less correspond to the annual dry season, when there is insufficient precipitation to continually replenish the reservoir and when the water utility draws solely on the 10.5 million m^3 of water in the reservoir.

The data set provided by SANAA included data from December 1999 to June 2012. Data for 10 consecutive dry seasons (December 2002–May 2003 to December 2011–May 2012) were selected to calculate the average. The data set provided presented irregular sampling frequency, with most months having one or two data points and other months having 4 or 5 (and in one case, 10) data points.

Average velocity was calculated for each month in the 10-year period. The average value (in m^3/s) was subsequently transformed into an estimated volume for each month using the formula below.

X m^3/s x 60 sec x 60 min x 24 hrs x number of days in corresponding month

The resulting volumes were summed for each December to May period, resulting in an estimated inflow volume for the dry season for each year in the period.

Finally, a simple average of these 10 annual figures was calculated.

There were eight months across these 10 selected periods that had zero data points. In this case, water velocity was imputed by taking the average of the last data point from the preceding month and the first data point for the subsequent month. For example, the initial value for April 2009 was imputed by taking the average of the last data point for March 2009 (March 27) and the first data point for May 2009 (May 7).

A1.3.6 Calculation of annual value of benefits for the years 2030 to 2035, expressed in undiscounted 2012 dollars

The economic benefit of the watershed management plan to the national water utility was calculated through a three-step process. First, the annual value of full benefits—that is, the benefit expected in 2030 when maximum benefits are achieved from the watershed management plan—was estimated. This set involved summing benefits accrued in three areas: maintained storage volume, additional water provision, and improved water quality. Second, benefits were distributed over the period 2019 to 2035, with partial benefits beginning in 2019, reaching maximum value in 2030 and retaining that value through to 2035. Third, the implementation costs associated with the watershed management plan were distributed over the implementation period (2013–18). Fourth, the NPV in 2012 of net benefits for the period 2013–35 was calculated using an appropriate discount rate for the country. Each of these steps is described in this annex.

The values produced by the calculations in this section are all annual benefits for each of the years in the 2030 to 2035 period, when it is assumed that the forest-related activities of the watershed management plan will finally result in full benefit provision. These values are stated in undiscounted 2012 dollars.

ANNUAL BENEFITS RESULTING FROM RETENTION OF STORAGE VOLUME

The amount of storage volume retained in the Los Laureles reservoir through the provision of erosion regulation services in the Guacerique watershed is calculated for both climate change scenarios in the following manner:

Amount of sediment that settles in the reservoir annually[46] x Change in annual sediment deposition product of the watershed management plan under each climate change scenario x Unit value providing new reservoir infrastructure[47]

46. Current sedimentation rates were estimated using existing available data and expert opinion on various factors affecting sedimentation in the Los Laureles reservoir. See Annex 1.3.4 for further details about the calculation of this value.
47. See Annex 1.3.1 for details on the calculation of the value of storage capacity.

The numeric calculation is as follows for the two climate change scenarios:

Low climate change scenario:
33,000 m^3/yr x -0.18 x 0.16 $/$m^3$

High climate change scenario:
33,000 m^3/yr x 0.13 x 0.16 $/$m^3$

The annual benefits for this variable are thus equal to $928.74 in the years 2030–35 under the low climate change scenario and –$670.76 in those years under the high climate change scenario (undiscounted 2012 dollars). (The latter value is negative due to the expected increase in sedimentation rates under this scenario and the consequences for total reservoir volume.)

ANNUAL BENEFITS RESULTING FROM ADDITIONAL WATER YIELD

The amount of additional water provided to the Los Laureles reservoir through the provision of water yield ecosystem services in the Guacerique watershed was calculated for both climate change scenarios in the following manner:

Average total volume of water entering the Los Laureles reservoir in the Dec-May period[48] x Change in volume product of the watershed management plan under each climate change scenario x Unit value of water measured by consumer willingness-to-pay[49]

The numeric calculation was as follows for the two climate change scenarios:

Low climate change scenario:
4,070,000 m^3/yr x 0.113 x 7.78 $/$m^3$

High climate change scenario:
4,070,000 m^3/yr x 0.29 x 7.78 $/$m^3$

The annual benefits for this variable are thus equal to $3.58 million in the years 2030–35 under the low climate change scenario and $9.18 million for those years under the high climate change scenario (undiscounted 2012 dollars).

ANNUAL BENEFITS RESULTING FROM IMPROVED WATER QUALITY

The contribution by erosion regulation services in the Guacerique watershed to water quality and impact in water treatment costs was calculated for both climate change scenarios in the following manner:

(Current amount of chemical used in treatment process in one year[50] x Unit cost of chemical[51] – Percent of current amount of chemical required under new scenario x Current amount of chemical used in treatment process in one year x Unit cost of chemical)

48. Ten-year average was calculated using water velocity data provided by SANAA. See Annex 1.3.5 for more information.
49. See Annex 1.3.2 for the calculation of consumer willingness-to-pay.
50. A five-year average was taken to calculate the amount of each chemical generally used in water treatment in one year, using data on annual chemical input volumes provided by SANAA.
51. SANAA provided the current unit cost of treatment chemicals in lempiras/Kg. An exchange rate of lps.19.80 was used to convert prices to $/Kg. This is the approximate value of lempira in the final quarter of 2012.

This calculation was carried out for three chemicals: activated carbon (used for contaminant removal), Aluminum Sulfate (coagulant), and the coagulant activator/flocculant currently used at the treatment plan. An inverse linear relationship was assumed between dissolved oxygen levels and the amount of activated carbon required in treatment processes, and a positive linear relationship was assumed between turbidity levels and the amount of flocculent and coagulant required in treatment processes.

The numeric calculation was as follows for the two climate change scenarios:

Low climate change scenario:
(39,075 kg/yr x 2.73 $/kg - 0.93 x 39,075 kg/yr x 2.73 $/kg) + (822,336 kg/yr x 0.61 $/kg - 0.76 x 822,336 kg/yr x 0.61 $/kg) + (1,719 kg/yr x 5.76 $/kg - 0.76 x 1,719 kg/yr x 5.76 $/kg)

High climate change scenario:
(39,075 kg/yr x 2.73 $/kg - 0.762 x 39,075 kg/yr x 2.73 $/kg) + (822,336 kg/yr x 0.61 $/kg - 1.098 x 822,336 kg/yr x 0.61 $/kg) + (1,719 kg/yr x 5.76 $/kg - 1.098 x 1,719 kg/yr x 5.76 $/kg)

The annual benefits related to water quality are thus equal to $129,447.03 for the years 2030–35 under the low climate change scenario and –$24,447.99 for those years under the high climate change scenario (undiscounted 2012 dollars). (Again, the latter value is negative due to the expected increase in turbidity levels under this scenario and the consequences for water quality at the intake.)

TOTAL ANNUAL BENEFITS FROM ALL THREE VARIABLES

Thus the overall annual economic benefit of the watershed management plan to the national water utility for the years 2030–35 expressed in undiscounted 2012 dollars is $3.71 million under the low climate change scenario and $9.15 million under the high climate change scenario. Table A15 summarizes the values for each variable and the sum for each climate change scenario.

Table A15: Annual benefits generated by the watershed management plan for 2030–35 in undiscounted 2012 dollars

	Low climate change scenario	High climate change scenario
Storage volume	$929	–$671
Additional water	$3,575,830	$9,176,908
Water quality	$129,447	–$24,448
Totals (rounded)	**$3,706,000**	**$9,152,000**

A1.3.7 Calculation of the NPV in 2012 of net benefits from the implementation of watershed management plan for 2013–35

To determine net present value, economic costs and benefits had to be distributed over the period under evaluation (2013–35). A time horizon for the 2013–35 period was constructed in Excel, with the costs of watershed management plan implementation reflected for the implementation period (2013–18) and the benefits resulting from plan implementation reflected during the subsequent period (2019–35). The NPV was calculated using the net present value function in Excel.

The cost of plan implementation was calculated as described in Annex 1.3.3 and distributed over the six-year implementation period.

In order to distribute benefits over the corresponding period, it was assumed that some benefits will start to accrue upon implementation of the watershed management plan, while others will take time to materialize. For example, the management scenario assumes 2,000 ha of agricultural fields under soil conservation measures. These benefits will materialize immediately. Conversely, benefits from the reforestation activities (on approximately 1,500 ha) are assumed to materialize more slowly as the forest matures. Thus it was initially estimated that 60 percent of the benefits will materialize in 2019 and that benefits will increase in a linear fashion up to 100 percent in 2030, when benefit provision will stabilize. This distribution of benefit provision over time reflects the substantial area under soil erosion management compared with the area that will be reforested. Thus the total annual economic benefit was ascribed to 2030 and to each subsequent year up to and including 2035, and 60 percent of that benefit was ascribed to 2019 and then a compound growth rate of 1.0475 was applied to calculate the value for each year from 2020 to 2030. This calculation was carried out for both the high and low climate change scenarios.

Finally, discount rates for the NPV calculation were taken from López (2008) (see Table A16), and the NPV calculation was carried out for each of these social discount rates for both the high and low climate change scenarios.

Table A16: Social discount rates for Honduras by economic growth scenario*

Scenario	Social discount rate
Low growth scenario	2.1
Moderate growth scenario	3.3
High growth scenario	4.5

* calculated by López 2008.

A1.4 Results of sensitivity testing

Note that for each sensitivity test, the other assumptions were held constant. Only one variable was tested at a time.

A1.4.1 Estimation of future water yield under climate change

This was considered the most important sensitivity test to carry out, as almost 100 percent of the benefits are derived from future water yield. Expert judgment indicated that under the low climate change scenario, change in water yield could range from 5 to 22.5 percent, and that under the high climate change scenario, change in water yield could range from 16 to 44 percent. The impact of these high and low estimates on benefit provision is described in Tables A17 and A18. As expected, the overall benefit derived from the watershed management plan is highly influenced by overall water yield.

Table A17: Impact of high and low estimates of future water yield under the low climate change scenario on total annual benefits and NPV of net benefits

Under the low climate change scenario			
Assumption, change in water yield	Total annual benefits (all three variables) (undiscounted 2012 dollars)	Social discount rate	NPV in 2012 of total benefits for the period 2013–35 (2012 dollars)
–5%	–$1,451,850	2.1	–$19,076,000
		3.3	–$16,465,000
		4.5	–$14,317,000
+22.5%	$7,250,391	2.1	$71,687,000
		3.3	$59,531,000
		4.5	$49,642,000

Table A18: Impact of high and low estimates of future water yield under the high climate change scenario on total annual benefits and NPV of net benefits

Under the high climate change scenario			
Assumption, change in water yield	Total annual benefits (all three variables) (undiscounted 2012 dollars)	Social discount rate	NPV in 2012 of total benefits for the period 2013–35 (2012 dollars)
+16%	$5,038,003	2.1	$37,826,000
		3.3	$30,154,000
		4.5	$23,999,000
+44%	$13,898,466	2.1	$141,025,000
		3.3	$117,587,000
		4.5	$98,503,000

A1.4.2 Assumption of 60 percent of benefits accruing in 2019

Sensitivity testing was carried out on the assumption of 60 percent benefit provision starting in 2019, by instead assuming 30 percent benefit provision in 2019 (increasing to 100 percent in 2030) and 90 percent benefit provision in 2019 (increasing to 100 percent in 2030) for both the high and low climate change scenarios. The results of the sensitivity testing are presented in Table A19. As expected, NPV increases with earlier provision of benefits and it decreases the farther into the future that benefits accrue.

Table A19: Results of sensitivity testing of the impact of the assumed proportion of benefits manifesting in 2019 on the Net Present Value of net benefits in 2012 expressed in 2012 dollars

Social discount rate	Low climate change scenario		High climate change scenario	
	30%	90%	30%	90%
2.1	$27,728,000	$40,612,000	$74,248,000	$106,065,000
3.3	$22,408,000	$33,801,000	$60,896,000	$89,027,000
4.5	$18,133,000	$28,231,000	$50,135,000	$75,068,000

A1.4.3 Estimation of 30 percent of existing sediment in the reservoir attributable to Hurricane Mitch

The calculation of current sedimentation rates, and thus avoided reservoir sedimentation in the future, was based on this average of estimates provided by the experts (30 percent). The upper and lower ranges of expert estimates (20 and 40 percent) were tested to gauge the influence of this assumption the on overall benefit calculation. While the change did affect the post-Mitch sedimentation rate (see Table A20), it had minimal effect on the overall net benefit calculation. Thus, the 30 percent or 33,000m^3/yr estimate was retained as an appropriate value.

Table A20: Estimates of annual sedimentation rates post-Hurricane Mitch resulting from changing the assumption of existing sediment attributable to the hurricane

Percent of existing sediment attributable to Hurricane Mitch	Estimated post-Hurricane Mitch reservoir sedimentation rates	
	Exact figure (m^3/yr)	Rounded figure (m^3/yr)
20%	37,490	37,500
30%	32,804	33,000
40%	28,118	28,000

Annex 2: Overview of Current Legislation Related to the Governance of Forest and Water Resources in Honduras

Legislation	Key elements
Constitution	Article 340 explicitly declares reforestation and forest conservation a matter of "national benefit and collective interest."
General Law on the Environment (Decree 104-1993)	Article 28 establishes that the state is responsible for natural resource management, land use planning, and watershed planning. Article 31 establishes that water for human consumption is the object of protection and special control. Article 33 delegates to municipalities responsibility for enforcing no settlement of watersheds. Article 36 allows the state to establish Protected Nature Areas. Article 37 allows municipalities and "other" entities to participate in the establishment, administration, and development of these Protected Nature Areas. Article 39 allows private landowners and local inhabitants of these Protected Nature Areas to engage in productive activities, but under technical and land use norms established by the founding decree for each area. Article 45 establishes that forest exploitation is to occur under the principles of biodiversity protection, sustainable use, and multiple utility (economic, ecological, social). Article 50 establishes that steep slopes with potential for erosion are to remain under permanent vegetative cover.
Law on Forests, Protected Areas and Wildlife (Decree N° 156-2007)	The primary legal framework for the administration and management of forest resources and protected areas in Honduras. Makes management and conservation plans mandatory for all forests and provides for a range of incentives to promote reforestation, forest and watershed protection, and forest management. Article 4 extends the concept of forests to both forested areas and areas that should but do not currently have forest cover. Article 5 establishes that forests with a role in water yield fall under protected areas. Article 9 establishes the option of forest co-management as a means for community participation in forest resource management. Article 12 establishes the Ministry of Forests (ICF). Article 18 describe ICF's primary obligations in relation to forest management, including the obligation to develop land use plans for public forested areas, to approve management plans developed by other entities, and to collect and store data on forests (plans, maps, inventories, etc.) Article 21 establishes four levels of Consultative Councils (national, provincial, municipal, and community) to bring communities and other stakeholders to the table and to allow local expertise to contribute to municipal and provincial forest and watershed planning efforts. Articles 46 and 47 establish public forests as either under national or municipal government control. Article 48 delegates public forest management responsibilities to either the state or the municipal government, dependent on ownership regimes. Article 59 states that ICF will support beneficiaries of legalization processes related to forestland ownership and resource use the right to allow them to participate in the mandatory forest management regimes. Article 92 defines non-commercial timber use as household use and cutting of trees to clear areas for public works.

Legislation	Key elements
Law on Forests, Protected Areas and Wildlife (Decree N° 156-2007) *continued*	Article 109 prohibits resource extraction in protected areas. Article 120, delegates the state's watershed management and land use planning activities to the ICF. Article 121 makes the ICF responsible for the legislation regarding forestland planning and forest restoration and a participant in sustaining water resources and other actions related to soil erosion and the protection of forest soils. This article also says that the ICF will coordinate with public and private entities regarding watershed management plans and projects. Article 122 establishes that watersheds providing water for human consumption are to be under special management regimes and, if deforested, are to be reforested. Article 129 allows communities to solicit and receive forest management contracts. Article 133 prohibits new settlement in protected areas and gives the state the authority to resettle communities to retain the integrity of protected areas.
General Water Law (Decree N° 181-2009)	Article 1 states that the law's objective is to establish the principles and framework for water resource management. Article 3 provides the guiding principles for water resource management. Article 7 establishes the Secretaria de Recursos Naturales y Ambiente (SERNA) as the responsible entity. Article 8 establishes the National Water Resources Council, with cross-sectorial representation. Article 10 establishes the Water Authority within SERNA as the entity responsible for implementing water policy. Article 11 establishes the National Institute for Water Resources (INRH), a technical entity of the Water Authority. Article 19 states the intent of the watershed councils to empower communities in water resource management. Article 23 establishes use rights for populations that carry out actions that promote ecosystem service provision (including erosion control and water quality regulations) and their right to receive payments for environmental services. Article 25 establishes that water is a public good, that distribution will be equitable, and that communities have the right to receive payments in return for conserving ecosystems services. Articles 25 through 29 establish the areas around waterways and water bodies that are considered public domain. Article 34 authorizes the state to carry out expropriation and implement use restrictions to promote water conservation. Article 40 allows for bans on water resource exploitation if the conditions call for it. Article 41 states that reforestation in areas that produce water, water recharge areas, and along waterways is mandatory. Article 44 prohibits dumping of wastewater in areas near to drinking water capture infrastructure and makes wastewater treatment mandatory. Article 46 prohibits extraction of water 500m both upstream and downstream from dams. Article 49 establishes that funds generated by payment for ecosystem services regarding water are only to be used for conservation and protection in the corresponding drainage basin. Article 50 establishes that ecosystems and forests (and tree-based systems) generate specific ecosystem services, namely biodiversity and soil conservation and recuperation, landslide protection, flood prevention and the prevention of damages to water collection infrastructure and rivers, and water quality improvement. Article 51 establishes that beneficiaries of the ecosystem services must compensate those who conserve the ecosystems. Article 52 establishes that the cost of these payments must be incorporated into water service rates.

Legislation	Key elements
General Water Law (Decree N° 181-2009) *continued*	Article 61 establishes that subsistence users do not need water use permits. Article 67 establishes that municipalities emit water use licenses and permits. Article 81 delegates the responsibility of use planning for water resources to the Water Authority, including inventories, carrying out the national hydrological balance, management plans, maps, and information systems and establishes the drainage basis as the planning unit. Article 84 establishes the water cadastre. Article 85 establishes the public water registry. Article 91 establishes the Water Fund, designating 15 million lempiras to finance conservation projects and programs, including research and the watershed councils (Article 93).
Framework Law for the Drinking Water and Sanitation Sector (Decree 118-2003)	Article 4 establishes that municipalities have priority rights over water sources for the purpose of providing drinking water and discharging sewer.
Law on Municipalities (Decree 134-1990)	Articles 13 and 14 assign environmental protection as one of the objectives and responsibilities of municipal government. Article 18 designates municipalities at the entity responsible for collecting rural and urban cadastral data. Article 65 allows municipalities to request the ICF to give protected status to land providing drinking water. Articles 75 and 80 allow municipalities to exercise a 1 percent tax on the commercial value of timber resources extracted in their territory.
Land Use Planning Law (Decree 180-2000)	Article 27 delegates to municipalities specific authority to use land use planning to regulate settlements for environmental protection purposes.

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